NONRESIDENT TRAINING COURSE

September 2013

Engineman (EN)

NAVEDTRA 14075A

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PREFACE

By obtaining this rate training manual, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this manual is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

THE MANUAL: This manual is organized into subject matter areas, each containing learning objectives to help you determine what you should learn, along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards that are listed in the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards,* NAVPERS 18068(series).

THE QUESTIONS: The questions that appear in this manual are designed to help you understand the material in the text. The answers for the end of chapter questions are located in the appendixes.

THE EVALUATION: The end of book evaluation is available on Navy Knowledge Online. The evaluation serves as proof of your knowledge of the entire contents of this NRTC. When you achieve a passing score of 70 percent, your electronic training jacket will automatically be updated.

THE INTERACTIVITY: This manual contains interactive animations and graphics. They are available throughout the course and provide additional insight to the operation of equipment and processes. For the clearest view of the images, animations, and videos embedded in this interactive rate training manual, adjust your monitor to its maximum resolution setting.

VALUE: In completing this manual, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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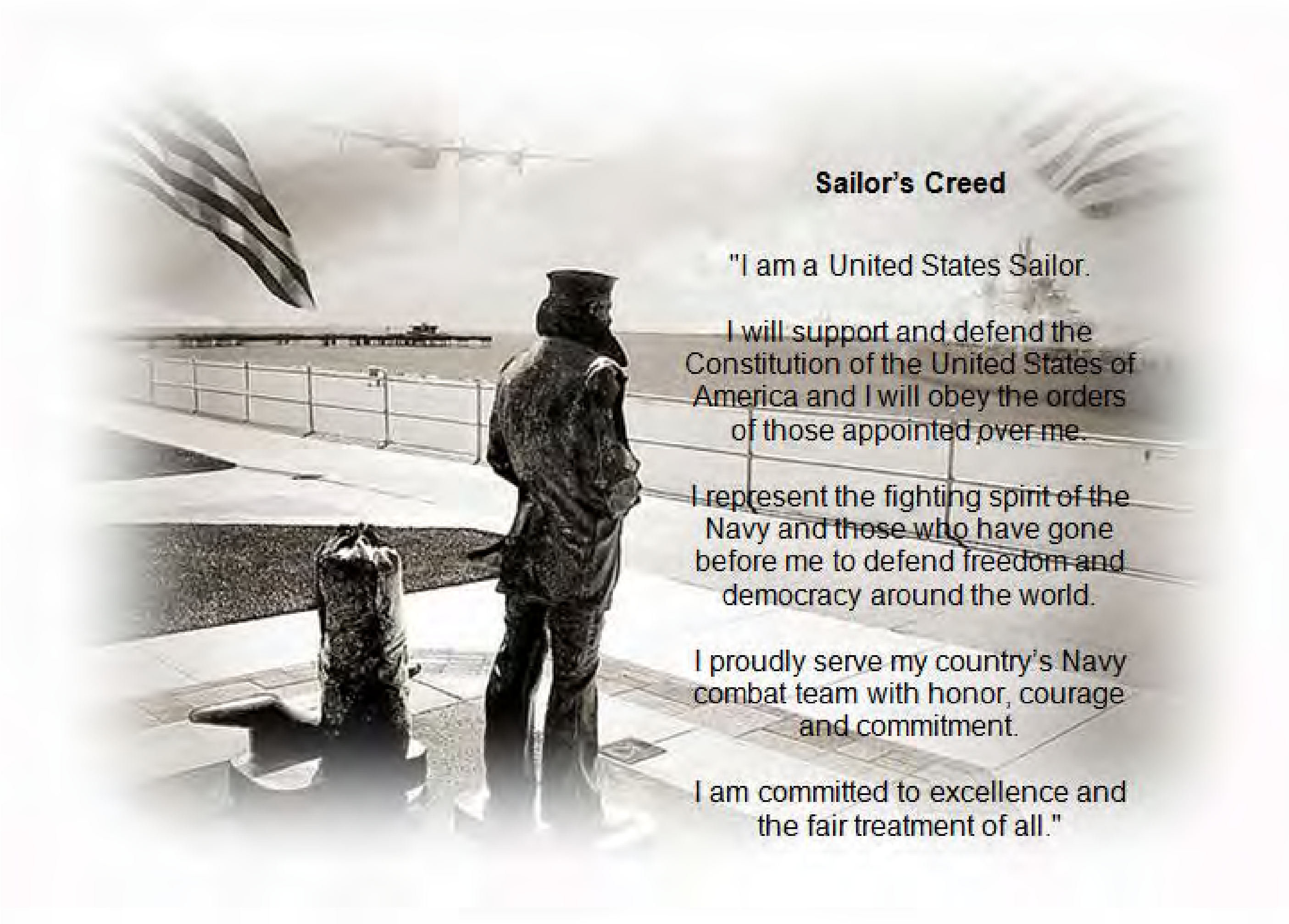
Sailor's Creed
"I am a United States Sailor.
I will support and defend the Constitution of the United States of America and I will obey the orders of those appointed over me.
I represent the fighting spirit of the Navy and those who have gone before me to defend freedom and democracy around the world.
I proudly serve my country's Navy combat team with honor, courage and commitment.
I am committed to excellence and the fair treatment of all."

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CHAPTER 1

INTRODUCTION TO THE ENGINEMAN RATING

This nonresident training course (NRTC) is designed to help you increase your knowledge in the various aspects of the Engineman (EN) rating. Knowledge of the information in this manual, combined with everyday practical experience, should help you learn to perform assigned tasks and accept greater responsibilities. At each stage of your naval career, you are aware that training on a continuous basis is essential if you are to reach your next desired pay grade, and for you to accomplish the mission of the Navy. Your contribution to the Navy depends on your willingness and ability to accept increasing responsibilities; as you advance in rate, you will accept responsibilities in military matters as well as in the occupational requirements of the Enginemen rating.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify the functions of the Engineman rating, to include duties and responsibilities.
2. Explain technical duties and responsibilities of an engineman.
3. State the purpose of the Navy Enlisted Classification Codes (NECs).
4. Describe the purpose and scope of Occupational Standards (OCCSTDs).
5. List some sources of advancement information for the Enginemen rating.
6. Describe the Ships' Maintenance and Material Management (3-M) System.
7. Identify the health programs designed to protect operators and maintenance personnel working in the machinery spaces from heat exhaustion and hearing loss.

ENGINEMAN RATING

The Engineman (EN) rating is a specific rating; it covers a narrow occupational field of duties and functions. ENs are assigned to restricted ships. On diesel ships, all Enginemen are assigned to M division, where they operate and maintain ship propulsion machinery and associated equipment such as pumps, compressors, valves, oil purifiers, heat exchangers, governors, reduction gears, shafts, and shaft bearings. Being assigned to Main Machinery (M) division, your responsibilities will vary; depending on the size of the ship you may be in charge of one of the engineering spaces, or you may act as the M division officer.

The duties of an EN assigned to a repair ship, such as the engine overhaul shop or the governor and fuel injector shop, or tender may consist mainly of repairs and other services. Engineman chief (ENC) and above may also be selected to attend Diesel Inspector’s school and become a Navy diesel engine inspector, in some cases engineman first class (EN1) can attend the course but must complete 3 under instruction (UI) inspections conducted by a certified diesel engine inspector. It will depend on your training and your field of specialization. You may also be assigned as an instructor either at one of the Engineman schools or at a recruit training station, or as a recruiter. To qualify for instructor duty, you must successfully complete a course in instructor training.

This manual is organized to give you a systematic understanding of your job. The occupational standards used in preparing the text are contained in the *Manual of Navy Enlisted Manpower* and *Personnel Classifications and Occupational Standards*, NAVPERS 18068F(series).

We recommend that you study the Engineman section of NAVPERS 18068F(series) to gain an understanding of the skills required of an EN. Then, study the subject matter in this NRTC very carefully. The knowledge you gain will enable you to become a more proficient operator and mechanic, and the Navy will profit from your skills. As you advance in the EN rate, your responsibilities for military leadership will be the same as those of petty officers in other ratings, but your responsibilities for technical leadership will be unique to your rating and directly related to your work as an Engineman. Operating and maintaining a ship's engineering plant and associated equipment requires teamwork along with a special kind of leadership that can be developed only by personnel who have a high degree of technical competence and a deep sense of personal responsibility. You should strive to improve your leadership and technical knowledge through study, observation, and practical application. As an EN, you demonstrate technical leadership when you follow orders exactly, when you observe safety precautions, when you accept responsibility, when you continue to increase your knowledge, and when you perform every detail of your work with integrity and reliability. Integrity of work is really a key factor in technical leadership, and all other factors relate to it in some way. When you perform every job just as well as you can, and when you constantly work to increase your knowledge, you demonstrate integrity of work in a concrete, practical, everyday sort of way. When your work has integrity, you are demonstrating technical leadership.

Scope of This Nonresident Training Course

Before studying any book, it is a good idea to know the purpose and the scope of that book. Here are some things you should know about this training manual:

- The occupational qualifications that were used as a guide in the preparation of this training manual were those promulgated in the *Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068F(series).
- This training manual includes information that is related to both the knowledge and the Occupational Standards for advancement to Engineman rating. However, no training manual can take the place of actual on-the-job experience for developing skill in the practical factors. This training manual can help you understand some of the whys and wherefores, but you must combine knowledge with practical experience before you can develop the required skills.
- Subsequent chapters in this training manual deal with the technical subject matter of the Engineman rating. It is designed to give you information on the occupational qualifications for advancement to in the Engineman rating. Before studying these chapters, study the table of contents and note the arrangement of information. You will find it helpful to get an overall view of the organization of this training manual before you start to study it.

TECHNICAL DUTIES AND RESPONSIBILITIES

As you attain each higher promotional level in your rating, you, as well as the Navy, benefit. The fact that you are using this training manual indicates that you have found personal satisfaction in developing your skills, increasing your knowledge, and getting ahead in your chosen career. The extent of your contribution to the Navy depends upon your willingness and ability to accept increasing responsibilities. ENs must become technical specialists in their rating; some of those traits that they perform efficiently include:

1. Operating and maintaining internal combustion engines and auxiliary engine room machinery.
2. Performing overhaul and repair work on internal combustion engines, using established procedures for disassembly, replacement, and reassembly.
3. Conducting routine tests and inspections of all engine room machinery.
4. Using measuring instruments needed in engine overhaul, such as micrometers, feeler gages, and inside and outside calipers.

5. Reading accurately such instruments as thermometers, pressure gages, and pressure indicators.
6. Operating and making repairs to distilling systems.

You can already do many of these jobs, though others you will have to learn from additional practical experience and through study. Certain practical details that relate to your responsibilities for administration, supervision, and training are discussed in subsequent chapters of this training manual.

Your Responsibilities Will Extend Both Upward and Downward

Officers and supervisors will expect you to carry out their orders. Enlisted personnel will expect you to translate the general orders to on-the-job language that can be understood and followed even by relatively inexperienced personnel. In dealing with your juniors, it is up to you to see that they perform their work properly. At the same time, you must be able to explain to officers any important needs or problems pertaining to the enlisted personnel.

You Will Have Regular and Continuing Responsibilities for Training

Even if you are fortunate enough to have a highly skilled and well trained group, you will still find that additional training is necessary. You will always be responsible for training lower rated personnel to perform their assigned tasks. Problems will require you to be a training specialist who can train individuals and groups in the effective execution of assigned tasks.

You Will Have Increasing Responsibilities for Working With Others

You will find that many of your plans and decisions affect a large number of people, some of whom are not in your division and some of whom are not even in the engineering department. It becomes increasingly important to understand the duties and responsibilities of personnel in other ratings. and plan your own work so that it will fit in with the overall mission of the organization.

As Your Responsibilities Increase, Your Ability To Communicate Clearly and Effectively Must Also Increase

The basic requirement for effective communication is knowledge of your own language. Remember that the basic function of all communication understands. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean. A second requirement for effective communication in the Navy is a sound knowledge of the Navy way of saying things. When a situation calls for the use of standard Navy terminology, use it. Still another requirement for effective communication is precision in the use of technical terms. Command of the technical language of the job is particularly important when you are dealing with lower rated personnel.

Command of technical language will also enable you to exchange ideas with other personnel of the same rating. Personnel who do not understand the precise meaning of terms used in connection with the work of their own rating are at a disadvantage when they try to read official publications relating to their work. They are also at a great disadvantage when taking written examinations for advancement.

You Will Have Increased Responsibilities for Keeping up With New Developments

Practically everything in the Navy policies, procedures, equipment, publications, and systems is subject to change and development. An EN must keep informed about all changes and new developments that might affect your rating or your work. Some changes will be called directly to your attention; others you will have to look for. Keep up to date on all sources of technical information.

Information on sources of primary concern to the EN is given later in this chapter. As you prepare to assume increased responsibilities at a higher level, you need to be familiar with (1) the military requirements and occupational standards given in the *Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068F(series); (2) any other material that may be required or recommended in the most current edition of the Bibliography for Advancement Examination Study, NAVEDTRA 10052. These materials and their use are discussed more thoroughly in *Military Requirements for Petty Officers First Class* NAVEDTRA 14145 and *Military Requirements for Chief Petty Officer* NAVEDTRA 14144(series),

Watch Duties and Responsibilities

As you progress through your rate, you may be required to assist the division officer in organizing, supervising, and instructing other personnel in their military duties as well as in their specialties. This duty includes assisting in the assignment of watch stations and other duties.

Every watch in the engineering department is a vital part of the ship's maintenance and operation program. The engineer officer is responsible for the operation and maintenance of the main engines and auxiliary machinery. However, the EN1s or ENCs and the personnel they supervise on the various watches actually do most of the work. Therefore, it is very important that the petty officers in charge learn and understand the extent of their responsibility to the engineer officer.

Engineering Officer of the Watch (EOOW)

The following excerpts from chapter 10 of Navy Regulations describe some of the duties of the officer of the engine room watch:

- "Status, Authority, and Responsibility. The EOOW is responsible for the safe and proper operation of the ship's entire engineering plant, the Engineering watch team and for the performance of the duties." Prescribed by the Engineering Department Organizational Readiness Manual (EDORM) Article 2403, and by other competent authority."
- "Directing and Relieving the EOOW. The engineer officer, or in their absence, the main propulsion assistant may direct the engineering officer of the watch concerning the duties of the watch, or may assume charge of the watch, and shall do so should it, in their judgment, be necessary."
- "Relation with the Officer of the Deck (OOD). The EOOW shall ensure that all orders received from the officer of the deck are promptly and properly executed. They shall not permit the main engines to be turned except as authorized or ordered by the OOD."
- "Reports by the EOOW. EOOW shall report promptly to the officer of the deck and the engineer officer any actual or probable derangement of machinery, boilers, or auxiliaries which may affect the proper operation of the ship."
- "Reports to the EOOW shall be promptly informed of any engineering work or change in disposition of machinery which may affect the proper operation of the plant or endanger personnel, or which is required for entry in the record of their watch."
- "Inspection and Operation of Machinery. The EOOW shall make frequent inspections of the engines, boilers, and their auxiliaries; and shall ensure that prescribed tests, methods of operation, and instructions pertaining to the safety of personnel and material are strictly observed."
- "Records and Logs. The EOOW shall ensure that the engineering log, engineer's bell book, and prescribed operating records are properly kept. On being relieved, they shall sign the engineering log and the engineer's bell book for that watch."

Engine Room Supervisor/Engineman of the Watch (ENOW)

The ENOW is responsible for the operating the main engines and associated auxiliaries, as directed by the EOOW.

Ensure that instrument reading are properly recorded and that all logs and records associated with Engine room watch stations are properly kept.

Ensure lube oil strainers are cleaned and inspected according to Engineering Operational Sequencing System (EOSS)/Planned Maintenance System (PMS) requirements.

Diesel Engine Operator

The Diesel Engine Operator is responsible for the operating the Main Propulsion Diesel Engine's (MPDE's) associated auxiliary machinery, and other duties as assigned as by the Engine Room/ Space Supervisor or EOOW.

Verify MPDE is aligned for operation in accordance with (IAW) current ships EOSS and ensure mechanical and free ends are clear from all obstructions before turning over the Engine.

Once started monitor MPDE for normal operating parameters and any indication of unusual noise and vibrations. Report problem and take immediate actions to correct abnormalities. Keep the EOOW/Space Supervisor informed of actions and intentions.

Engineering Department Duty Officer (EDO)

In ships not underway, the commanding officer may authorize the standing of a day's duty in lieu of the continuous watch of the engineering officer of the watch. When authorized, the duties of the engineering officer of the watch are assigned in port to the EDO. The EDO, assigned by the engineer officer, must be a qualified engineering officer of the watch. On some ships, chief petty officers may be assigned as the engineering department duty officer. In the temporary absence of the engineer officer, the duties of the engineer officer may be performed by the EDO. If the engineer officer is on board, the duty officer reports the condition of the department to their to the eight o'clock reports. In the absence of the engineer officer, the duty officer makes the eight o'clock reports for the department to the executive officer or Command Duty Officer (CDO). The EDO, in addition to such other duties as may be properly assigned to them, is responsible for:

1. The alertness and proper performance of all personnel of the engineering watches.
2. The safe and economical operation of all engineering machinery and systems in use.
3. The elimination of fire and flooding hazards and the prevention of sabotage.
4. The security of all engineering spaces. In order to determine the actual conditions that exist in the engineering space and to evaluate the performance of watch personnel, the duty officer must make frequent inspections of the engineering spaces.
5. The proper maintenance of all machinery operating logs, and for writing and signing the engineering log for the period he/she is on duty.

Standing Watches

As the watchstander, you will be the "eyes" of the engineering department. You will be responsible for the orderly appearance and cleanliness of your assigned station. Prior to standing watch, you should thoroughly inspect all existing conditions, such as the operating condition of machinery and firefighting equipment, leaks, and potential fire hazards. If a casualty occurs, you should take immediate steps to control it, as well as promptly notify the proper authority. You should strictly observe all operating instructions, regulations, and safety precautions. You should never leave your station unless you have permission from proper authority to do so, or are properly relieved. You should promptly execute all standing or special orders. When relieved, you should pass on to the relieving watch all information concerning existing conditions and special orders.

Engine Room Auxiliary Watch

Auxiliary watches are maintained underway and in port to provide hotel services. The engine room auxiliary watch maintained in port includes a petty officer in charge and one or more Firemen; they are responsible for seeing that an efficient and economical watch is being stood. All machinery not in operation must be checked to see that it has been properly secured. The petty officer in charge of the auxiliary watch is responsible for the proper operation of the ship's service generator and associated machinery; however, the operation of the electrical equipment is the responsibility of an Electrician's Mate. The petty officer in charge checks to see that all operating machinery is lubricated as prescribed by the operating instructions. They will ensure that the fire and flushing pumps are inspected for satisfactory operation and that the prescribed pressure is maintained in the firemain. Except in emergencies, the engine room auxiliary watch does not make any changes such as stopping, starting, or shifting ship's service generators without first notifying the Electrician's Mate and the petty officer in charge of the watch. A watch going off duty will not be considered relieved until the engine room is clean, all operating logs and records are correct, and information concerning the status of the machinery in operation, orders, special orders, and non-completed orders have been given to the relief.

Cold-Iron Watches

Under certain prescribed conditions (such as when a ship moves alongside a repair ship or tender, or into a naval shipyard, and is receiving power from these activities) a security and fire watch is usually set by each division. This security watch is commonly known as a cold-iron watch. Each cold-iron watch makes frequent inspections of the assigned area and checks for fire hazards, flooding, or other unusual conditions throughout the area. The coldiron watch keeps bilges reasonably free of water in accordance with applicable instructions. Hourly reports on existing conditions are made to the OOD. All unusual conditions are immediately reported to the OOD and to the EDO, so that the proper division or department can be notified to take the necessary corrective measures. When welding or burning is to be performed in the area, the coldiron watch checks to see that a fire watch is stationed. If the ship is in drydock, the watch must check all sea valves, after working hours, to see that the valves are secured or blanked off. The watch must make sure that oil or water is not being pumped into the drydock.

NAVY ENLISTED CLASSIFICATION CODES

The Engineman rating is a basis of a number of Navy enlisted classification (NEC) codes. The NEC coding system is a form of management control, which identifies skills and training required for specific types of operations or equipment. The Chief of Naval Personnel details skilled personnel to those ships that require these skills. There are a number of NECs that you may earn at pay grades by satisfactorily completing an applicable course of instruction at a Navy school. Your personnel office will have complete information on NECs and qualification procedures.

OCCUPATIONAL STANDARDS

Occupational standards are the minimum task requirements that are directly related to the work of each rating, and they are divided into subject matter groups. In the *Manual of Navy Enlisted Manpower and Personnel Classifications and Occupational Standards*, NAVPERS 18068F(series), Section I contains the occupational standards for advancement to each pay grade. Section II contains the NECs. The occupational standards addressed in this NRTC were those included in NAVPERS 18068F(series) and were the current occupational standards for Engineman. Your educational services officer should have a current edition of the occupational standards that apply to your rating at this time, or the current version can be found online.

PERSONNEL QUALIFICATION STANDARDS (PQS)

The Personnel Qualification Standards (PQS) program is the result of an increasing need for greater technical know-how within the Navy, and the PQS documents are the guides to the qualification of personnel for this purpose. The PQS program is found at https://wwwa.nko.navy.mil/portal/home.

Qualifier

The PQS Qualifier is designated in writing by the Commanding Officer to sign off individual watchstation line items. Qualifiers will normally be E-5 or above and, as a minimum, must have completed the PQS they are authorized to sign off. The names of designated Qualifiers should be made known to all members of the unit or department. The means of maintaining this listing is at the discretion of individual commands. For more information on the duties and responsibilities of PQS Qualifiers, see the PQS Unit Coordinator's Guide, NAVEDTR 43100-1(series).

Contents

PQS is divided into three sections. The 100 Section (Fundamentals) contains the fundamental knowledge from technical manuals and other texts necessary to satisfactorily understand the watchstation/workstation duties. The 200 Section (Systems) is designed to acquaint you with the systems you will be required to operate at your watchstation/workstation. The 300 Section (Watchstations) lists the tasks you will be required to satisfactorily perform in order to achieve final PQS qualification for a particular watchstation/workstation. All three sections may not apply to each PQS, but where applicable, detailed explanations are provided at the front of each section.

Trainee

The supervisor will tell you which watchstations/workstations you are to complete and in what order. Before getting started, turn to the 300 Section first and find your watchstation/workstation. This will tell you what you should do before starting your watchstation/workstation tasks. You may be required to complete another PQS, a school, or other watchstations/workstations within this PQS. It will also tell you which fundamentals and/or systems from this PQS you must complete prior to qualification at your watchstation/workstation. If you have any questions or are unable to locate references, contact your supervisor or qualifier.

The PQS are separated into three main subdivisions:

- 100 Series—FUNDAMENTALS
- 200 Series—SYSTEMS
- 300 Series—WATCHSTATIONS

Fundamentals (100 Section)

Keeping in mind the Law of Primacy, each PQS begins with a fundamentals section covering the basic knowledge and principles needed to understand the equipment or duties to be studied. This section will contain topics that apply broadly to the subject on which the particular PQS has been written. Each newly developed or revised PQS Book shall contain a 101 Safety Section. All references cited for study are to be selected according to their credibility and availability. NRTCs should be used as references, if appropriate.

A portion of any given fundamentals section may be devoted to ensuring the trainee's vocabulary is adequate by calling for explanations of technical terms and acronyms used within the Standard. Thus, the fundamentals section has direct application to the formal school situation or to self-study for the trainee who has not attended a specialized school.

Systems (200 Section)

Basic Building Blocks. Each piece of equipment relevant to the PQS is broken down into smaller, more comprehensible functional "systems" as the basic building blocks in the learning process. Each system is written to reflect specific watchstation requirements by identifying the equipment most relevant to one or more designated watch standers. The less complex systems may be identified and covered quickly or relegated to a lower priority to permit greater emphasis on more significant or complex systems.

Systems, Components, and Component Parts

Any given system is disassembled, for learning, into two levels. Systems have components (sometimes referred to as subsystems), and components have parts. A PQS will list all items that must be understood for operation, but will not list every item appearing on a parts list in the technical manual. Normally a number of very broad (overview) systems are disassembled into their components or component parts with the "big picture" as the learning goal.

Items listed as components in such a system may then be analyzed as separate systems and broken down into components and component parts. For example, the turbo-generators and switch-gears may be listed as components of the Ship's Service Electrical Distribution System and as individual Systems on later pages for closer study.

Watchstations (300 Section)

This section tests the trainee's readiness or ability to perform a designated task. The terminology in the PQS considers a sailor to be "on watch" whenever the sailor physically operates the equipment. The goal of the watchstation section is to guide the trainee in categorizing, analyzing, and performing the step-by-step procedures required to obtain qualification.

Operating Procedures

The PQS deliberately makes no attempt to specify the procedures to be used to complete a task or to control or correct a casualty. The only proper sources of this information are the Technical Manuals, Engineering Operating Sequencing Systems (EOSS), Naval Air Training and Operating Procedures Standardization (NATOPS), or other policy-making documents prepared for a specific installation or a piece of equipment. Additionally, the level of accuracy required of a trainee may vary from school to school, ship to ship, or squadron to squadron based upon mission requirements. Thus, proficiency may be confirmed only through demonstrated performance at a level of competency sufficient to satisfy the Commanding Officer.

Discussion Items

Though actual performance of evolutions is always preferable to observation or discussion, some items listed in each watchstation may be satisfied by discussions with a qualified supervisor due to the nature of the event or evolution.

Qualification Progress Summary

The qualification progress summary is mandatory in all books with more than one Final Qualification. It lists all of the watchstations or the aircrew evolutions’ final qualifications in the PQS and is used to track the progress of a trainee in these qualifications and ensure awareness of remaining tasks. It should be kept by the trainee and in the trainee’s training jacket and updated with an appropriate signature (Training Petty Officer, Division Officer, Senior Watch Officer, etc.) as qualifications are completed.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out the most about it. No single publication can give you all the information you will need to perform the duties of your rating. You should learn where to find other accurate, authoritative, up-to-date information on all subjects. Some of the publications discussed here are subject to change or revision from time to time, some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been entered.

Bibliography for Advancement Examination Study NAVEDTRA 10052

The *Bibliography for Advancement Examination Study*, NAVEDTRA 10052 is a very important publication for anyone preparing for advancement. This publication lists required and recommended rate training manuals and other reference material to be used by personnel working for advancement. NAVEDTRA 10052 is revised and issued once each year by the Naval Education Training and Program Development Center. Each revised edition is identified by a letter following the NAVEDTRA number; be SURE you have the most recent edition.

In NAVEDTRA 10052, the required and recommended references are listed by pay grade level. It is important to remember that you are responsible for all references used at lower levels, as well as those listed for the pay grade to which you are seeking advancement. It is important to note that all references, whether mandatory or recommended, listed in NAVEDTRA 10052, may be expected to be used as source material for the written examinations at the appropriate levels.

RTMs that are marked with an asterisk (*) in NAVEDTRA 10052 are MANDATORY at the indicated levels. A mandatory training manual may be completed by (1) passing the appropriate Enlisted Correspondence Course based on the mandatory training manual, (2) passing locally prepared tests based on the information given in the mandatory training manual, or (3), in some cases, successfully graduating from an appropriate Navy school.

Nonresident Training Courses (NRTCs)

There are two general types of NRTCs: rating manuals and subject matter manuals. Rating manuals (such as this one) are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational standards of one rating. Subject Matter manuals or Basic manuals give information that applies to more than one rating. (Example: *Tools and Their Uses*, NAVEDTRA 14256.) NRTCs have major revisions from time to time to keep them up to date technically, and as they are printed on demand and available on CD and online, minor revisions and corrections are made constantly. NRTCs are designed to help you prepare for advancement. The following suggestions may help you make the best use of these manuals and other Navy training publications when you prepare for advancement.

1. Study the occupational standards for your rating before you study the training manual, and refer to the standards frequently as you study. Remember, you are studying the manual primarily to meet these standards.
2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can study at the same time each day. Try to schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book

without any particular plan. Look at the illustrations and read bits here and there as you see things that interest you. Review the glossary, which provides definitions that apply to words or terms as they are used within the engineering field and within the text. There are many words with more than one meaning. Do not assume that you know the meaning of a word. Look it up in the glossary.

4. Look at the NRTC in more detail to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book. As you look through the book, ask yourself some questions: What do I need to learn about this? What do I already know about this? How is this information related to information given in other chapters? How is this information related to the occupational standards?
5. When you have a general idea of what is in the NRTC and how it is organized, fill in the details by intensive study. Try to cover a complete unit in each study period—it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will depend on how well you know the subject.
6. In studying any one unit—chapter, section, or subsection—write down questions as they occur to you. You may find it helpful to make a written outline of the unit, or, at least, to write down the most important ideas.
7. As you study, relate the information in the NRTC to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.
8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the NRTC, write down the main ideas that you have gotten from studying this unit. Do not just quote the book. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.
9. Think of your future as you study NRTCs. You are working for advancement to a higher rate. Anything extra that you can learn now will also help you later.

Rate Training Manuals

Most rate training manuals (RTMs) are written for the specific purpose of helping personnel prepare for advancement. You can tell whether or not a rate training manual you are using is the latest edition by checking the *Catalog of Nonresident Training Courses* (NRTCs), NAVEDTRA 12061, found online at https://wwwa.nko.navy.mil/gear/library/download?document_id=568700033. (NAVEDTRA 12061 is actually a catalog that lists all current NRTCs; you will find this catalog useful in planning your study program).

There are four rate training manuals that are specially prepared to present information on the military requirements for advancement. These manuals are:

- *Basic Military Requirements*, NAVEDTRA 14325(series)
- *Military Requirements for Petty Officer 3 & 2*, NAVEDTRA 14504(series)
- *Military Requirements for Petty Officer 1*, NAVEDTRA 14145(series)
- *Military Requirement for Chief Petty Officer,* NAVEDTRA 14144(series)

Each of the military requirements manuals is available for multiple pay grade levels. In addition to giving information on the military requirements, these four books give a good deal of useful information on the enlisted rating structure; on how to prepare for advancement; on how to supervise, train, and lead other people; and on how to meet increasing responsibilities as you advance in rating.

Some of the rate training manuals that may be useful to you when you are preparing to meet the occupational qualifications for advancement are discussed briefly in the following paragraphs.

Tools and Their Uses

Tools and their uses, NAVEDTRA 14256(series) contains a good deal of useful information on the care and use of all types of handtools and portable power tools commonly used in the Navy.

Mathematics

Mathematics, Vol. 1, NAVEDTRA 10069(series), and *Mathematics, Vol. 2*, NAVEDTRA 10071(series) may be helpful if you need to brush up on your mathematics. Volume 1 contains basic information that is needed for using formulas and for making simple computations. Volume 2 contains more advanced information than you will need for most purposes. However, occasionally, you may find the information in this book to be helpful.

Rate training manuals prepared for other Group VII (Engineering and Hull) ratings are often a useful source of information. Reference to these training manuals will broaden your knowledge of the duties and skills of other personnel in the engineering department. The training manuals prepared for Machinist's Mates and Machinery Repairmen are likely to be of particular interest to you. For a complete listing of rate training manuals, consult the *List of Training Manuals and Correspondence Courses*, NAVEDTRA 12061(series).

Naval Sea Systems Command (NAVSEA) Publications

A number of publications issued by the Naval Sea Systems Command (NAVSEA) will be of interest to you. While you do not need to know everything, you should have a general idea of where to find information in NAVSEA publications.

The Naval Ships' Technical Manual (NSTM) is a basic doctrine publication of NAVSEA. To allow the ship to distribute copies to the working spaces where information is required, chapters are now issued as separate paper-bound volumes. Some chapters are kept up to date by means of yearly revisions. Chapters are reviewed less frequently where yearly revisions are not necessary. In chapters where intra-year changes are required, either an intrayear edition or a NAVSEA Notice is distributed as a temporary supplement for use pending issue of the new edition of the chapter.

You will find chapters in NSTM of particular importance to the Engineman referenced in this training manual. For a list of all chapters in the manual, see appendix A, chapter 001.

Training Films

Training films which are available to naval personnel are a valuable source of supplementary information on many technical subjects. When selecting a film, note its date of issue in the film catalog. As you know, procedures sometimes change rapidly. Thus some films become obsolete rapidly. If a film is obsolete only in part, it may sometimes be shown effectively if before or during its showing you carefully point out to trainees the procedures that have changed. When you plan to show a film to train personnel, take a look at it in advance, if possible, so that you may spot material that may have become obsolete, then verify current procedures by looking them up in the appropriate sources before showing the film.

NAVAL EDUCATION AND TRAINING (NAVEDTRA) PUBLICATIONS

The Naval Education and Training Command and its field activities come directly under the command of the Commander, Naval Education and Training Command. Training materials published by the Naval Education and Training Command are designated as NAVEDTRA. The naval training publications described here include some that are absolutely essential for anyone seeking advancement and some that are not essential, but extremely helpful.

Bibliography for Advancement Study

Bibliography for Advancement Study NAVEDTRA 10052 (Bibs) lists recommended nonresident training courses and other reference materials that should be used by enlisted personnel who are working toward advancement. Bibs is revised and maintained by the NETPDTC. The recommended references are listed by exam date and pay grade. Since you are working for advancement to the next pay grade, study the material that is listed for that pay grade. Besides nonresident training courses, the Bibs list official publications on which you may be examined. You should not only study the sections required, but also become as familiar as possible with all publications you use.

Advancement Handbook

The purpose of the Advancement Handbook is to help you focus your preparation for the Navy-wide advancement-in-rating examinations. The Bibs together with the handbook form a comprehensive examination study package.

The publications issued by the Naval Sea Systems Command are of particular importance to engineering department personnel. Although you do not need to know everything in these publications, you should have a general idea of where to find the information in them.

Naval Ships' Technical Manual

The Naval Ships' Technical Manual is the basic engineering doctrine publication of the Naval Sea Systems Command. The manual is kept up to date by means of quarterly changes. As new chapters are issued, they are designated by a new chapter numbering system. The following chapters of the Naval Ships' Technical Manual are of particular importance to the Engineman. For your convenience, both the new and old numbers for each chapter are listed.

NEW	OLD	CHAPTER
078	(9950)	Gaskets and Packing
079 (3)	(9880, Sec. III)	Damage Control Engineering Casualty Control
233	(9412)	Diesel Engines
241	(9420)	Propulsion Reduction Gears and Coupling, Clutches and Associated Components
244	(943 1)	Propulsion Bearings and Seals
262	(9450)	Lubricating Oils, Greases, Specialty Lubricants and Lubricating Systems
503	(9470)	Pumps
505	(9480)	Piping Systems
541	(9550)	Ship's Fuel and Fuel Systems
542		Gasoline and JP-5 Fuel Systems

551	(9490)	Compressed Air Plants and Systems
556	((210)	Hydraulic Equipment (Power Transmission and Controls)
562	(9220)	Surface Ship Steering
593	(None)	Pollution Control

Deckplate

The Deckplate is published bimonthly and is a technical periodical in magazine form. It is published by NAVSEA and contains articles on design, construction, new developments in naval engineering, and repair of naval vessel and their equipment and other technical equipment.

Manufacturers' Technical Manuals

The manufacturers' technical manuals furnished with most machinery units and many items of equipment are valuable sources of information on construction, operation, maintenance, and repair. The manufacturers' technical manuals that are furnished with most shipboard engineering equipment are given NAVSEA numbers.

Blueprint Reading and Sketching

As an EN, you will read and work from mechanical drawings. You will find information on how to read and interpret drawings in *Blueprint Reading and Sketching*, NAVEDTRA 14040. You must also know how to locate applicable drawings. For some purposes, the drawings included in the manufacturers' technical manuals for the machinery or equipment may give you the information you need. In many cases, however, you will find it necessary to consult the onboard drawings. These are sometimes referred to as ship's plans or ship's blueprints, and they are listed in an index called the ship's drawing index (SDI). The SDI lists all working drawings that have a NAVSEA drawing number, all manufacturers' drawings designated as certification data sheets, equipment drawing lists, and assembly drawings that list detail drawings.

SHIPS' MAINTENANCE AND MATERIAL MANAGEMENT (3-M) SYSTEMS

The 3-M System is the nucleus for managing maintenance aboard all ships and applicable shore station equipment. This system provides all maintenance and material managers throughout the Navy with a means to plan, acquire, organize, direct, control, and evaluate the manpower and material resources expended or planned for expenditure in support of maintenance. It is imperative that all hands recognize the importance of this system, and understand the role each plays in assisting management in maintaining the material readiness of equipment in the fleet at the designated levels of reliability. The term “Management” includes the work center aboard the ship through all levels of command to the higher echelon of management at Navy Headquarters in Washington, D.C. and Chief of Naval Operations.

Planned Maintenance System (PMS)

The Planned Maintenance System (PMS) is an overall management tool that provides a simple and efficient way in which basic maintenance on all equipment can be planned, scheduled, controlled, and performed. The information in this section is intended to provide you with an overview in terms of the purposes, benefits, and limitations of the PMS.

Purposes of PMS

The PMS was established for several purposes:

- Reduce complex maintenance to simplified procedures that are easily identified and managed at all levels.
- Define the minimum planned maintenance required to schedule and control PMS performances.
- Describe the methods and tools to be used.
- Provide for the detection and prevention of impending casualties.
- Forecast and plan manpower and material requirements.
- Plan and schedule maintenance tasks.
- Estimate and evaluate material readiness.
- Detect areas requiring additional or improved personnel training and improved maintenance techniques or attention.
- Provide increased readiness of the ship.

Benefits of PMS

By using PMS, the commanding officer can readily determine whether the ship is being properly maintained. Reliability is intensified. Preventive maintenance reduces the need for major corrective maintenance, increases economy, and saves the cost of repairs. PMS assures better records since it provides additional useful data to the shipboard maintenance manager. Its flexibility allows for the programming of inevitable changes in employment schedules. This advantage helps the shipboard maintenance manager to plan preventive maintenance more effectively. Better leadership and management can be realized if a manager can reduce frustrating breakdowns and irregular hours of work. Consequently, PMS offers a means of improving morale and thus enhances the effectiveness of all hands.

Limitations of PMS

The PMS is not self-starting, and it does not automatically produce good results; considerable professional guidance is required. Continuous direction at all levels must be maintained. One individual must be assigned both the authority and the responsibility at each level of the system's operation. Training in the maintenance steps as well as in the system is necessary. No system is a substitute for the actual, technical ability required of the petty officers who direct and perform the upkeep of the equipment.

Maintenance Data System (MDS)

The Maintenance Data System (MDS) works to collect maintenance data and to store it for future use. MDS comes from the current ship's maintenance project (CSMP), automated work request, and Board of Inspection and Survey (pre-INSURV) deficiency, and is a means for the fleet to report configuration changes to equipment. As Engineman, you will be required to learn how to prepare various MDS forms. In the following sections of this chapter, we will discuss two of the MDS reports with which you will come into contact. These reports are (1) the Ship's Maintenance Action Form (OPNAV 4790/2K), and (2) the Current Ship's Maintenance Project.

Ship's Maintenance Action Form

The Ship's Maintenance Action Form, OPNAV 4790/2K, reports deferred maintenance actions and completed maintenance actions (including those previously deferred). It also allows the entry of screening and planning information for management and control of intermediate maintenance activity workloads.

The OPNAV 4790/2K is originated in the work center. It is screened by the division officer and engineer officer for accuracy and legibility. It is then initialed by the division officer and engineer officer before being forwarded to the 3-M coordinator. When it is used to defer maintenance, the 3-M coordinator will send two copies of it back to the originating work center to hold on file. When the deferred maintenance is completed, one of the copies is used to document the completion of the maintenance.

Current Ship's Maintenance Project (CSMP)

The standard CSMP is a computer-produced report. It lists deferred maintenance and alterations which have been identified through Maintenance Data Collection System (MDCS) reporting. Copies of the CSMP should be received monthly. The engineer officer gets a copy for each of the engineering department work centers. Each work center gets a copy with its own deferred maintenance only. CSMP is to provide shipboard maintenance managers with a consolidated listing of deferred corrective maintenance so they can manage and control their accomplishment. The work center supervisors are responsible for ensuring the CSMP accurately describes the material condition of their work center. Each month when a new CSMP is received, verified, and updated, the old CSMP may be destroyed. The current Ships' Maintenance and Material Management (3-M) Manual, OPNAVINST 4790.4, contains complete instructions and procedures for the completion and routing of all 3-M Systems forms.

HEALTH PROGRAMS

There are two health programs with which you will be directly involved in day-to-day operations in the engine room: heat stress and hearing conservation.

Heat Stress

Heat stress is caused by high heat and humidity in the engine room. This can be controlled somewhat by ensuring that all lagging and insulation is in its proper place, that steam and hot water leaks are corrected, and that all the ventilation systems are operating as designed. You can ensure that readings are taken and recorded at each watch or work station every hour and at any other time that the temperature exceeds 100 °F dry-bulb temperature. You can ensure that they are reported to the EOOW so that a heat survey can be conducted, stay times can be enforced, and corrective action can be taken.

For further information refer to the *Navy Occupational Safety and Health Program Manual*, OPNAVINST 5100.19, Vol. 1(series) and OPNAVINST 5100.23(series) and the Manual of Naval Preventive Medicine, NAVMED P-5010, Chapter 3.

Hearing Conservation

The loud, high-pitched noise produced by an operating propulsion plant can cause hearing loss. Hearing loss can seldom be restored. Ear protection must be worn in all areas where the sound level is 84 decibels (dB) or greater. Warning signs must be posted cautioning about noise hazards that may cause loss of hearing. For further information on health programs, refer to the *Naval Occupational Safety and Health Program Manual*, OPNAVINST 5100.19(series), and OPNAVINST 5100.23(series).

SUMMARY

In this chapter, we have discussed the Engineman rating and the different methods you can use to obtain the knowledge you must have to perform your job aboard ship. Remember, information is usually available when you need it. You just have to know where to look. This chapter serves as a guide to help you locate and use the information that you will be required to know for advancement in the Engineman rating.

End of Chapter 1

Introduction to the Enginemen Rating

Review Questions

1-1. Where can you find the skills required of an Engineman?

A. NAVPERS 20024
B. NAVPERS 18068F(series)
C. NAVPERS 15005
D. NAVPERS 18087

1-2. What is the key factor in technical leadership?

A. Knowledge
B. Leadership
C. Experience
D. Integrity

1-3. On repair tenders ENs work in all of the following work centers, except?

A. Engine Overhaul
B. Governor Overhaul
C. Fuel Injector Shop
D. Air Conditioning and Refrigeration

1-4. Which of the following is a description of the Engineman rating?

A. A general rating in the engineering group
B. A specific rating that covers a narrow occupational field of duties and functions
C. A service rating within the Machinist's Mate rating
D. A special rating held by those who operate only one kind of engine

1-5. ENs must perform all the following technical duties for advancement in rank, except?

A. Conduct routine test and inspection on equipment
B. Operate and maintain internal combustion engines
C. Charge air conditioning plants
D. Perform overhaul and repair work on internal combustion engines

1-6. When does the Engineering Duty Officer assume the watch?

A. Underway
B. Sea and anchor
C. Coming along side of another ship
D. In port

1-7. What Engineering Watches are being stood when the ship is in the shipyard?

A. Cold-Iron Watch
B. Non-Operational Watch
C. Out of Commission Watch
D. Ship Yard Watch

1-8. Where can you find information about the Navy Enlisted Classification (NEC) Codes?

A. OPNAVINST 5100.19
B. NAVPERS 18086
C. NAVEDTRA 10045
D. NAVPERS 18068F(series)

1-9. Which of the following authorities details personnel with special NECs?

A. Chief of Naval Personnel
B. Chief of Naval Support Systems
C. Chief of Naval Operations
D. Naval Weapons Command

1-10. Where at your command can you find the complete package of information on NECs and qualification procedures?

A. Engineering Log Room
B. Technical Library
C. Career Counsel
D. Personnel Office

1-11. Who must sign the Engineering log and the Engineering Bell Book prior to being relieved of watch?

A. Officer of the Deck
B. Engineering Officer of the Watch
C. Engineering Duty Officer
D. Messenger of the Watch

1-12. Which of the following publications contains the occupational standards?

A. BUPERS 18068
B. NAVEDTRA 18068
C. NAVPERS 14104
D. NAVPERS 18068F(series)

1-13. Which pay grades are covered under Section I in NAVPERS 18068F(series)?

A. E7 through E-9
B. Officers
C. All pay grades
D. Warrant Officers

1-14. What publication lists the requirements for rate training manuals and other reference material to be used by personnel for advancement?

A. Advancement Progress Cards
B. Bibliography for Advancement Examination Study NAVEDTRA 10052
C. Rate Training Manual
D. Navy Technical Manual

1-15. What can you reference to find the most up-to-date training manual for advancement?

A. NAVEDTRA 10052
B. NAVEDTRA 12061
C. NAVPER 10068
D. NAVPER 10086

1-16. How often are changes made to Naval Ship's Technical Manuals?

A. Monthly
B. Quarterly
C. Yearly
D. Every 2 years

1-17. Which courses listed in the Bibliography for Advancement for your rating must you complete to be eligible to take the advancement examination?

A. Only the course that that have letters after the chapter numbers
B. All courses listed for the engineering and hull group
C. All courses listed for the next higher pay grade
D. Courses marked with an asterisk for the next higher pay grade

1-18. What is the purpose of the Planned Maintenance System?

A. Increase the compatibility in the maintenance process
B. Keep maintenance actions general
C. Forecast and plan manpower and material requirements
D. Leave maintenance in the hands of the users

1-19. What is the OPNAVINST 4790.4?

A. Basic Military Requirements
B. Ship's Maintenance and Material Management (3M) Manual
C. Naval Occupational Safety and Health Program Manual
D. NAVSEA Publications

1-20. What is the one necessary step in a progressing Planned Maintenance Program?

A. Leadership
B. Planning
C. Material
D. Training

1-21. Where are warning signs posted for noise hazards?

A. In the area of noise hazard
B. Mess decks
C. General living area
D. Quarterdeck area

1-22. Which of the following can somewhat help control heat stress in an engine room?

A. Hot water leaks are corrected
B. Lagging and insulation is not hanging in its proper place
C. Keeping Ventilation off
D. Steam leaks to the bilge

1-23. Hearing protection must be worn where the noise level is above what maximum number of decibels?

A. 55 dB
B. 65 dB
C. 78 dB
D. 84 dB

RATE TRAINING MANUAL – User Update

SWOS makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in SWOS manuals, please write or e-mail us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

Write: SWOS Project Manager
1534 Piersey Street Suite 321
Norfolk, VA 23511-2613
COMM: (757) 444-5332
DSN: 564-5332

E-mail: Refer to the Engineman Rating page under SWOS on the NKO Web page for current contact information.

Rate____ Course Name____

Revision Date__________ Chapter Number____ Page Number(s)____________

Description

____

____

____

(Optional) Correction

____

____

____

(Optional) Your Name and Address

____

____

____

CHAPTER 2

BASIC ADMINISTRATION AND TRAINING

Every time you advance in pay grade, you increase your responsibility for administration and training. This chapter deals briefly with some of your administrative responsibilities and then touches on certain aspects of your responsibility for training others.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Describe the procedures for preparing fuel, oil, and water reports.
2. Explain the procedures for drawing fluid samples.
3. Describe Engineering Operational Sequencing System (EOSS) manuals.
4. Describe Engineering Operational Procedures (EOPs.)
5. Describe Engineering Operational Casualty Control (EOCC.)
6. Explain the Quality Assurance (QA) Program.

ENGINEERING RECORDS AND LOGS

As an Engineman (EN), you will be primarily concerned with updating logs and similar records. Some of the logs and records are official, legal records. Others are used to upkeep the ship's equipment. The standard forms for the logs and records are prepared by the various systems commands and the Chief of Naval Operations (CNO). The forms are for issue to forces afloat and are available as indicated in the *Unabridged Navy Index of Publications and Forms*, NPFC PUB 2002 D. These forms are revised as conditions warrant and personnel ordering them must be sure they order the most current forms. If you need similar forms for local use, ensure that an existing standard form will not serve the purpose before you request that a special form be prepared and printed.

Legal Engineering Records

The Engineering Log and the Engineer's Bell Book are the only legal records compiled by the engineering department. The Engineering Log is a midnight-to-midnight record of the ship's engineering department. The Engineer's Bell Book is a legal record of any orders regarding change in the movement of the propellers.

Engineering Log

The Engineering log is a complete daily record which covers important event and data pertaining to the Engineering Department and the operation of the ship's propulsion plant. The log must show the following information:

1. The total engine miles steamed for the day
2. Draft and displacement upon getting underway
3. The disposition of the engines, boilers, and principal auxiliaries and any changes in their disposition
4. Any injuries to engineering department personnel
5. Any casualties to engineering department machinery, equipment, or material

6. Other matters specified by competent authority

Depending on your training and watch position, you may have to either make entries in the Engineering Log or both make and verify such entries. Whatever the case, each entry must be made according to instructions given in (1) the *Engineering Log*, NAVSHIPS 3120/2D; (2) the *Naval Ships' Technical Manual (NSTM)*, Chapter 090; and (3) directives issued by the type commander (TYCOM). Each entry must be a complete statement using standard phraseology. The TYCOM's directives may contain other specific requirements pertaining to the Remarks section of the Engineering Logs for ships of the type.

The original Engineering Log, prepared neatly and legibly in ink, is a legal record. Do NOT keep a rough log. Keep the Engineering Log current. Enter each event onto the Engineering Log as it happens. No erasures are permitted in the log. When a correction is necessary, draw a single line through the original entry so that the entry remains legible. The correct entry must be clear and legible. Corrections, additions, or changes are made only by the person required to sign the log for the watch this person then initials the margin of the page.

The engineering officer of the watch (EOOW) should prepare the remarks for the log and should sign the log before being relieved at the end of the watch or duty day. The engineer officer verifies the accuracy and completeness of all entries and signs the log daily. The log sheets must be submitted to the engineer officer in time to allow him or her to check and sign them before noon of the day following the date of the log sheet(s). The commanding officer (CO) approves the log and signs it on the last calendar day of each month and on the date he or she relinquishes command. Completed pages of the log, filed in a post-type binder, are numbered consecutively. They begin with the first day of each month and run through the last day of the month.

When the CO (or engineer officer) directs a change or addition to the Engineering Log, the person directed must comply unless he or she believes the proposed change or addition to be incorrect. In that event, the CO or engineer officer will personally enter comments and sign the log. After the log has been signed by the CO, it may not be changed without his or her permission or direction.

Engineer's Bell Book

The *Engineer's Bell Book*, NAVSHIPS 3120/1, is a record of all bells, signals, and other orders received by the throttleman for movement of the ship's propellers. Entries are made in the Bell Book by the throttleman (or an assistant) as soon as an order is received. Entries are usually made by the assistant when the ship is entering or leaving port, or engaging in any maneuver that is likely to involve numerous or rapid speed changes. This procedure allows the throttleman to devote his or her undivided attention to answering the signals.

The Bell Book is maintained in the following manner:

1. A separate bell sheet is used for each shaft each day, except where more than one shaft is controlled by the same throttle station. In that case, the same bell sheet is used to record the orders for all shafts controlled by the station. All sheets for the same date are filed together as a single record.
2. The time of receipt of the order is recorded in column number 1.
3. The order received is recorded in column 2. Minor speed changes (generally received via revolution indicator) are recorded by entering the number of revolutions per minute (rpm) ordered. Major speed changes (normally received via engine order telegraph) are recorded using the following symbols:
    a. 1/3: ahead 1/3 speed
    b. 2/3: ahead 2/3 speed

c. I: ahead standard speed
d. II: ahead full speed
e. III: ahead flank speed
f. Z: stop
g. B1/3: back 1/3 speed
h. B2/3: -back 2/3 speed
i. BF: back full speed
j. BEM: back emergency speed

4. The number of revolutions corresponding to the major speed change ordered is entered in column 3. When the order received is recorded as rpm in column 2 (minor speed changes), no entry is made in column 3.
5. The shaft revolution counters reading (total revolutions) at the time of the speed changes is recorded in column 4. The shaft revolution counter reading—as taken hourly on the hour while underway—also is entered in column 4.

For ships and craft equipped with controllable reversible pitch propellers, the propeller pitch in feet and fractions of feet set in response to a signaled speed change, rather than the shaft revolution counter readings, is recorded in column 4. The entries for astern pitch are preceded by the letter B. Each hour, on the hour, entries are made of counter readings. These entries help in calculating engine miles steamed during the time the propeller pitch remained constant at the last value set in response to a signaled order.

On ships with gas turbine propulsion plants, a bell logger provides an automatic printout each hour. This printout is also provided whenever propeller rpm or pitch is changed by more than 5 percent, when the engine order telegraph is changed, or when the controlling station is shifted. Provision must be made for manual logging of data in the event the bell logger is out of commission (OOC).

Before going off watch, the EOOW signs the Bell Book on the line following the last entry for his or her watch. The next officer of the watch continues the record immediately thereafter. In machinery spaces where an EOOW is not stationed, the bell sheet is signed by the watch supervisor.

NOTE

A common practice is to have the throttleman sign the Bell Book before it is signed by the EOOW or his or her relief.

The Bell Book is maintained by bridge personnel in ships and craft equipped with controllable reversible pitch propellers and those in which the engines are directly controlled from the bridge. When control is shifted to the engine room, however, the Bell Book is maintained by the engine-room personnel. The last entry made in the Bell Book on the bridge shows the time that control is shifted. The first entry made in the Bell Book in the engine room shows the time that control is taken by the engine room. Similarly, the last entry made by engine-room personnel show when control is shifted to the bridge. When the Bell Book is maintained by the bridge personnel, it is signed by the officer of the deck (OOD).

Alterations or erasures are not permitted in the Bell Book. An incorrect entry is corrected by drawing a single line through the entry and recording the correct entry on the following line. Deleted entries are initialed by the EOOW, the OOD, or the watch supervisor, as appropriate.

OPERATING RECORDS AND REPORTS

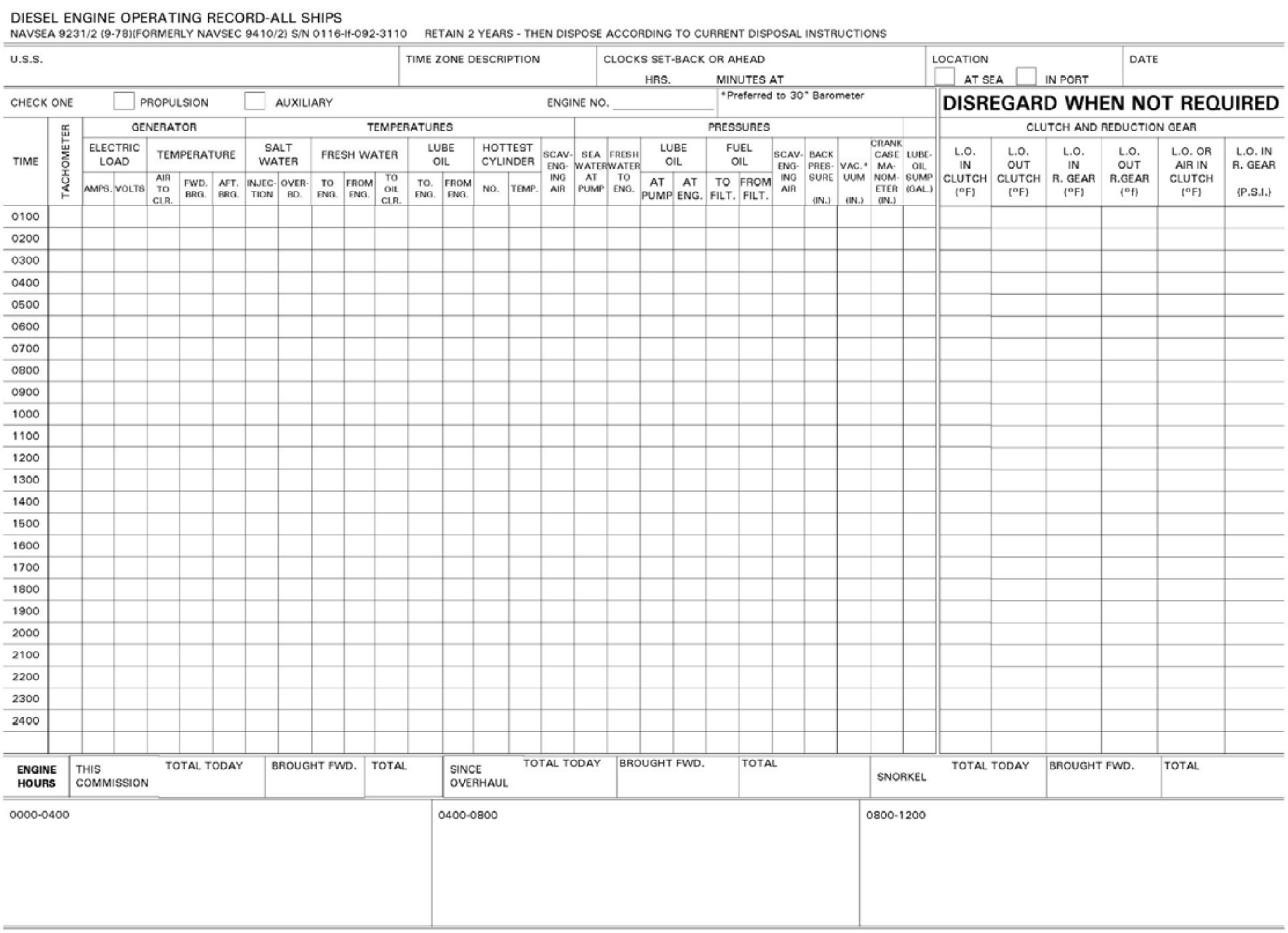
Engineering operating records are used to ensure regular inspection of operating machinery and to provide data for performance analysis. Operating records do not replace frequent inspections of operating machinery by supervisory personnel nor do they necessarily warn of impending casualties. Personnel who maintain operating records must be properly trained to correctly obtain, interpret, and record data, and to report any abnormal conditions.

The TYCOM's directives specify which engineering operating records must be maintained and prescribe the forms to be used when no standard record forms are available. The engineer officer may require additional operating records when he or she deems them necessary.

The operating records are generally retained on board for a period of 2 years, after which they may be destroyed according to current disposal regulations. Completed records must be stowed so they will be properly preserved and can be easily located.

Diesel Engine Operating Record

The *Diesel Engine Operating Record-All Ships*, NAVSEA 9231/2 (*Figure 2-1, front and back views*), is a daily record maintained for each operating diesel engine. In ships with more than one main engine in the same engine room, a separate record sheet is maintained for each operating engine.


DIESEL ENGINE OPERATING RECORD-ALL SHIPS
NAVSEA 9231/2 (9-78)(FORMERLY NAVSEC 9410/2) S/N 0116-lf-092-3110 RETAIN 2 YEARS - THEN DISPOSE ACCORDING TO CURRENT DISPOSAL INSTRUCTIONS

U.S.S. | TIME ZONE DESCRIPTION | CLOCKS SET-BACK OR AHEAD HRS. MINUTES AT | LOCATION ☐ AT SEA ☐ IN PORT | DATE

CHECK ONE ☐ PROPULSION ☐ AUXILIARY ENGINE NO. ______ *Preferred to 30" Barometer

DISREGARD WHEN NOT REQUIRED

TIME	TACHOMETER	GENERATOR: ELECTRIC LOAD AMPS.	GENERATOR: ELECTRIC LOAD VOLTS	GENERATOR: TEMPERATURE AIR TO CLR.	GENERATOR: TEMPERATURE FWD. BRG.	GENERATOR: TEMPERATURE AFT. BRG.	TEMPERATURES: SALT WATER INJECTION	SALT WATER OVER-BD.	FRESH WATER TO ENG.	FRESH WATER FROM ENG.	FRESH WATER TO OIL CLR.	LUBE OIL TO. ENG.	LUBE OIL FROM ENG.	HOTTEST CYLINDER NO.	HOTTEST CYLINDER TEMP.	SCAV-ENG-ING AIR	PRESSURES: SEA WATER AT PUMP	FRESH WATER TO ENG.	LUBE OIL AT PUMP	LUBE OIL AT ENG.	FUEL OIL TO FILT.	FUEL OIL FROM FILT.	SCAV-ENG-ING AIR	BACK PRES-SURE (IN.)	VAC.* UUM (IN.)	CRANK CASE MA-NOM-ETER (IN.)	LUBE-OIL SUMP (GAL.)	CLUTCH AND REDUCTION GEAR: L.O. IN CLUTCH (°F)	L.O. OUT CLUTCH (°F)	L.O. IN R. GEAR (°F)	L.O. OUT R.GEAR (°F)	L.O. OR AIR IN CLUTCH (°F)	L.O. IN R. GEAR (P.S.I.)
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2200																																	
2300																																	
2400																																	

ENGINE HOURS | THIS COMMISSION | TOTAL TODAY | BROUGHT FWD. | TOTAL | SINCE OVERHAUL | TOTAL TODAY | BROUGHT FWD. | TOTAL | SNORKEL | TOTAL TODAY | BROUGHT FWD. | TOTAL

0000-0400 | 0400-0800 | 0800-1200

Figure 2-1 — Diesel Engine Operating Record-All Ships, NAVSEA 9231/2. (Front view)

The watch supervisor enters the remarks and signs the record for his or her watch. The petty officer in charge of the engine room or the senior Engineman checks the accuracy of the record and signs the record in the space provided on the back of the record. Any unusual conditions noted in the record are immediately reported to the engineer officer, and the record is sent to the engineer officer for approval.

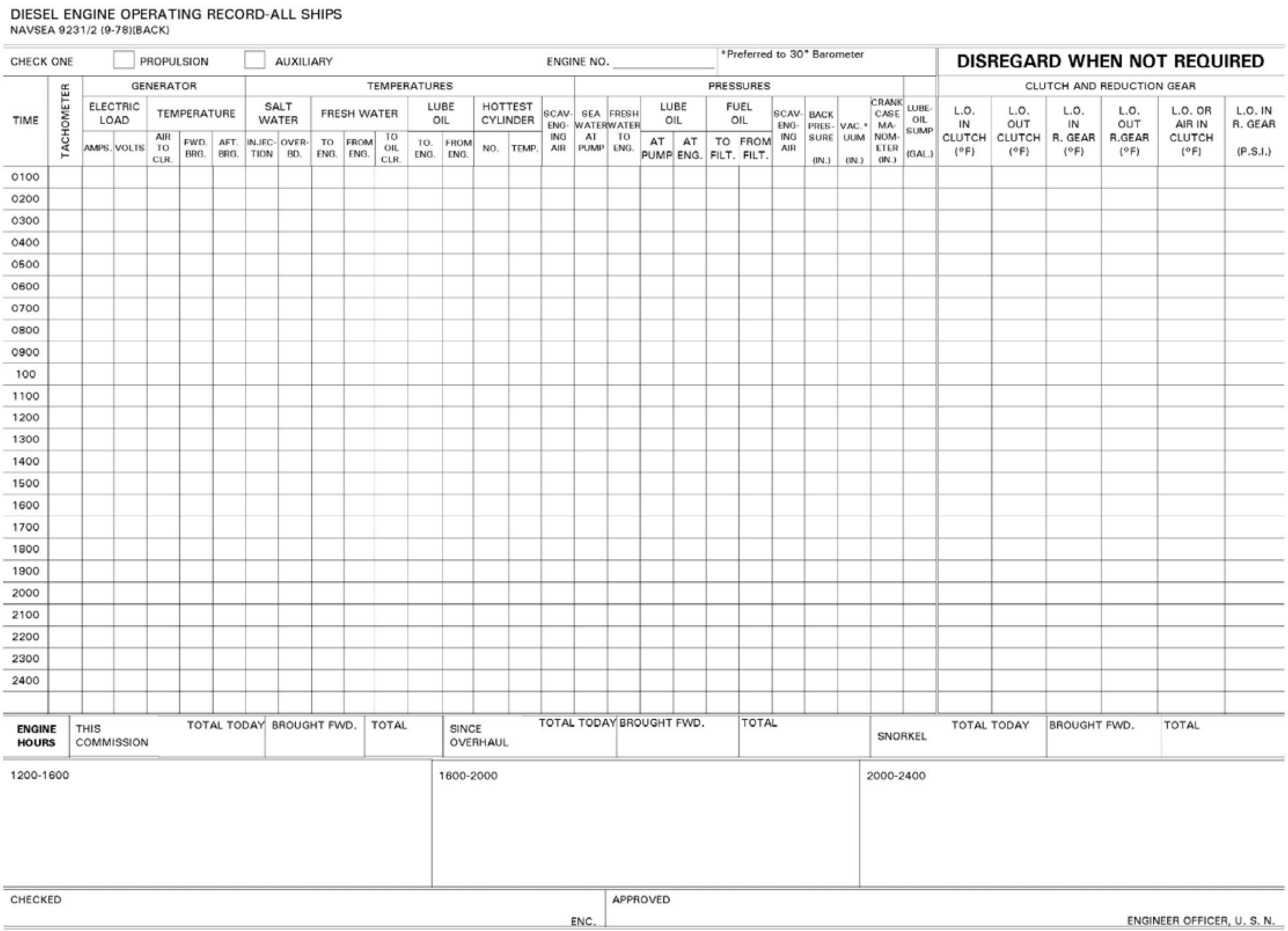

Figure 2-1 — Diesel Engine Operating Record-All Ships, NAVSEA 9231/2. (Back view)

Fuel and Water Accounts

The daily diesel fuel, lubricating oil, and water accounts are vital to the efficient operation of the engineering department. Forms and procedures necessary to account for fresh water and fuel are generally prescribed by the TYCOMs.

Fuel and Water Reports

The *Fuel and Water Report*, NAVSEA 9255/9 (*Figure 2-2, frames 1 and 2*), is a report submitted daily to the CO. This report indicates the amount of fuel oil and water on hand as of midnight. The Fuel and Water Report also includes the previous day's feed and potable water consumption figures and results of water tests. The original and one copy are submitted to the OOD in sufficient time for submission to the CO or command duty officer with the 1200 reports. The copy is retained by the OOD.

FUEL AND WATER REPORT DATE__________

TO: COMMANDING OFFICER, USS

	FUEL (gallons)		LUBE OIL STORAGE TANKS (gallons)		WATER (gallons)	
	BOILER/GT FUEL	DIESEL FUEL/ JP-5	2190	9250/23699	POTABLE	RESERVE FEED
ON HAND LAST REPORT						
RECEIVED (+)						
DISTILLED (+)						
EXPENDED (−)						
GAIN (+) LOSS (−) BY INVENTORY						
ON HAND THIS REPORT						
ON HAND %						

POTABLE WATER RECORD		
PERSONNEL ON BOARD	GALLONS USED PER PERSON	STANDARD

FEEDWATER CONSUMPTION	
NOT UNDERWAY (gallons per hour)	UNDERWAY (gallons per hour)

REMARKS:

NAVSEA 9255/9 (6–94)(FRONT) NSN 0116–LF–018–2600

Figure 2-2 — Fuel and Water Report, NAVSEA 9255/9.

Daily Boat Fueling Record

The Daily Boat Fueling Record is a routine record of daily fueling, which is highly recommended for any ship that carries or maintains a number of boats. Use of this schedule will help prevent special fueling at unusual hours and will keep the boats ready for unexpected calls. The following list contains the recommended headings for this record:

- Boat number
- Fuel capacity in gallons
- Gallons on hand
- Approximate fuel consumption in gallons per hour
- Operating hours of fuel remaining
- Fueled or not fueled to capacity

Disposal of Engineering Records and Reports

Before you destroy any of the engineering department records, study the *Disposal of Navy and Marine Corps Records, USN and USNS Vessels*, SECNAVINST P5212.5(series). This publication provides the procedures for disposing of records. For each department aboard the ship, these instructions list the permanent records that must be kept and the temporary records that may be disposed of according to an established schedule.

Both the Engineering Log and Engineer's Bell Book must be preserved as permanent records on board ship for a 3-year period unless they are requested by a naval court or board, or by the Navy Department. In such case, copies (preferably photostatic) of records that are sent from the ship are certified by the engineer officer as being true copies and are put in the ship's files.

At regular intervals, such as each quarter, records that are over 3 years old are destroyed. When a ship that is less than 3 years old is decommissioned, the current books are retained on board. If a ship is scrapped, the current books are forwarded to the nearest Naval Records Management Center.

All reports forwarded to, and received from, Naval Sea Systems Command (NAVSEA) or another superior command may be destroyed when they are 2 years old, if they are no longer required.

Finally, to control the volume of paper work, reports should only be kept on board ship if they

1. Are required,
2. Serve a specific purpose, or
3. May provide repair personnel with information not found in publications or manuals.

Equipment and Instrument Tag-Out

Whenever you make repairs, you will be required to isolate and tag-out that equipment or section of the system. The program provides a procedure to be used when a component, piece of equipment, system, or portion of a system must be isolated because of some abnormal condition. The tag-out program also provides a procedure to be used when an instrument becomes unreliable or is not operating properly. The major difference between equipment tag-out and instrument tag-out is that tags are used for equipment tag-out and labels are used for instrument tag-out.

Tag-out procedures are described in *Standard Organization and Regulations of the U.S. Navy*, OPNAVINST 3120.32(series), and represent the minimum requirements for tag-out. These procedures are mandatory and are standardized aboard ships and repair activities. The following definitions are used in the tag-out bill:

1. Authorizing officer —This individual has the authority to sign tags and labels and to have tags and labels issued or cleared. The authorizing officer is always the officer responsible for supervising the tag-out log. The CO designates authorizing officers by billet or watch station. The authorizing officer for engineering is normally the EOOW underway and the engineering duty officer (EDO) in port.
2. Department duty officer (DDO) (repair activities only) —This individual is designated as DDO on the approved watch bill or plan of the day.
3. Engineering officer of the watch (EOOW) —This individual may be either the EOOW or the EDO, depending on engineering plant conditions.
4. Officer of the deck (OOD) —This individual maybe either the OOD or the ship's duty officer, depending on the ship's condition.
5. CAUTION tag (*Figure 2-3, frame 1*) —This is a YELLOW tag used as a precautionary measure. It provides temporary special instructions or warns that unusual caution must be used to operate the equipment. These instructions must state exactly why the tag is installed. Use of phrases such as "DO NOT OPERATE WITHOUT EOOW PERMISSION" is not appropriate. Yellow tagged equipment or systems must not be operated without permission from the responsible supervisor. The CAUTION tag may not be used if personnel or equipment can be endangered while working under normal operating procedures. In such cases, a DANGER tag must be used.
6. DANGER tag (*Figure 2-3, frame 2*)—This is a RED tag that prohibits the operation of equipment that can jeopardize the safety of personnel or endanger equipment, systems, or components. Equipment may not be operated or removed when tagged with DANGER tags.
7. OUT-OF-CALIBRATION labels (*Figure 2-3, frame 3*)—These are ORANGE labels used to identify instruments that are out of calibration and do not give accurate readings. These labels warn that the instruments may be used for system operation, but only with extreme caution.
8. OUT-OF-COMMISSION labels (*Figure 2-3, frame 4*) —These are RED labels used to identify instruments that will not give accurate readings because they are either defective or isolated from the system. The instruments should not be used until they have been recertified for use.
9. Repair activity—This is any activity other than the ship's force that is involved in the construction, testing, repair, overhaul, refueling, or maintenance of the ship (intermediate or depot level maintenance activities).

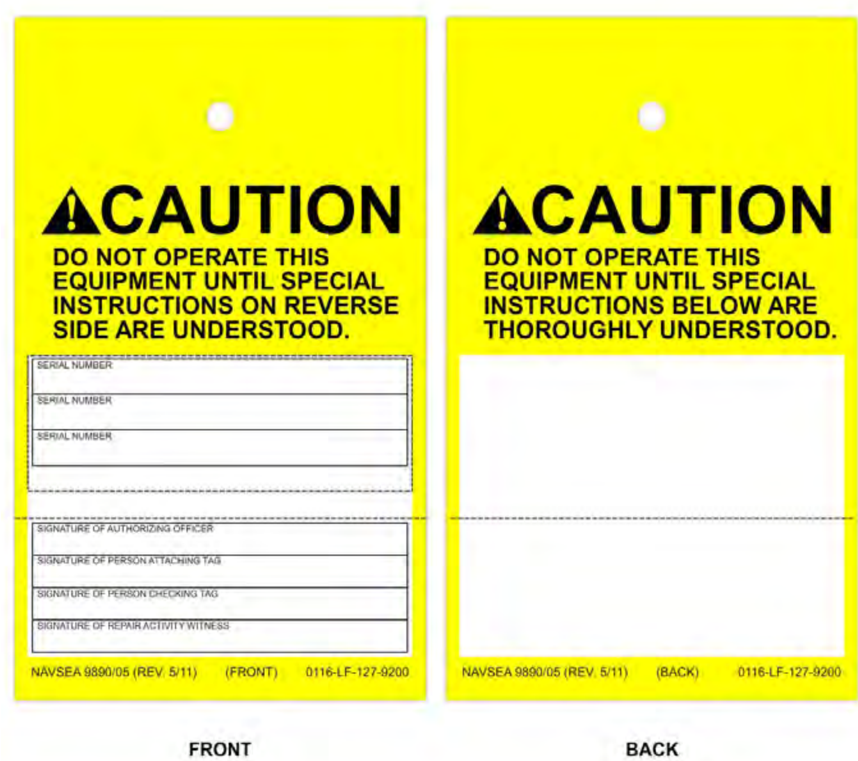

Figure 2-3 — Instrument tags and labels.

10. Ship’s force—These are personnel who are assigned to the ship and are responsible for the maintenance and operation of the ship’s systems and equipment. Only qualified personnel are authorized to make a tag-out.
11. Tag-out log—This is the control document used to administer the entire tag-out procedure.

Tag-Out Logs

A tag-out log is a record of authorization for each tag-out action. It includes the following information:

1. A copy of OPNAVINST 3120.32(series) and any amplifying directives needed to administer the system.
2. The DANGER/CAUTION Tag-Out Index and Record of Audit (Index/Audit Record). This is a sequential list of all tag-outs issued. It provides a ready reference of existing tag-outs, ensures that serial numbers are issued sequentially, and is useful in conducting audits of the log. A sample of this index is shown in *Figure 2-4*. Index pages with all tag-outs listed as cleared may be removed by the department head.
3. DANGER/CAUTION Tag-Out Record Sheet (*Figure 2-5, frames 1 and 2*). All tags that have been used in the tag-out of a particular system are logged on one DANGER/CAUTION tag-out record sheet along with the reason for the tag-out. All effective sheets are kept in one section of the log.

DANGER / CAUTION TAG-OUT INDEX AND RECORD OF AUDITS				
LOG SERIAL	DATE ISSUED	TYPE (DANGER / CAUTION)	DESCRIPTION (SYSTEM OR COMPONENT)	DATE CLEARED

NAVSEA 3120/12 (Rev. 4-2007) S/N 0116-LF-133-2400

Figure 2-4 — Danger/Caution Tag-Out Index and Record of Audit.

DANGER/CAUTION TAG-OUT RECORD SHEET

1. SYSTEM OR COMPONENT	2. LOG SERIAL NO.

3. AMPLIFYING INSTRUCTIONS (MANDATORY FOR CAUTION TAGS)

OPERATIONS/WORK ITEMS INCLUDED IN TAG-OUT

4. REASON FOR TAG-OUT AND APPLICABLE DOCUMENTATION (E.G., TWD, JSN, WAF, ETC.)	5. TAG NUMBERS USED	6. DATE/ TIME ISSUED OR ADDED	7. PETTY OFFICER IN CHARGE (SIGNATURE)	9. AUTHORIZING OFFICER (SIGNATURE)	WORK COMPLETE: 11. WORK CENTER REPRESENTATIVE	13a. DATE
			8. INDEPENDENT REVIEWER (SIGNATURE)	10. REPAIR ACTIVITY REP. (SIGNATURE) (WHEN REQD)	12. REPAIR ACTIVITY REP. (WHEN APPROP)	13b. DATE

NAVSEA 9210/9 (Rev 11-2000) (FRONT) S/N 0116-LF-981-9800 ☐ CHECK BOX IF CONTINUED ON ADDITIONAL SHEET

Figure 2-5 — Danger/Caution Tag-Out Record Sheet.

4. Instrument Log (*Figure 2-6*). Labels used with OUT-OF-CALIBRATION and OUT-OF-COMMISSION instruments are logged in the instrument log.
5. Cleared DANGER/CAUTION Tag-Out Record Sheets. Sheets that have been cleared and completed are transferred to this section of the log until they are audited by the department head.

INSTRUMENT LOG

LABEL CONDITION CODE AND NO.	DATE	INSTRUMENT NAME OR NUMBER	CONDITION AND/OR CORRECTION FACTOR	AUTHORIZED BY (SIGNATURE)	ATTACHED BY (INITIALS)	WORK NECESSARY TO CLEAR	DATE CLEARED	CLEARANCE AUTHORIZED BY (SIGNATURE)	REMOVED BY (INITIALS)

NAVSEA 9690/10 (Rev 11/2000) LABEL CONDITION CODE: OOC - OUT OF COMMISSION
CAL - OUT OF CALIBRATION S/N 0116-LF-961-6600

Figure 2-6 — Instrument Log.

Tag-Out Information

A tag-out procedure is necessary because of the complexity of modem ships and the cost, delays, and hazards to personnel that can result from the improper operation of equipment. Learn and use the following guidelines:

1. Enforce the tag-out procedure at all times. You must do this during normal operations as well as during construction, testing, repair, or maintenance.
2. Do not use tags or labels as a substitute for other safety measures. Examples are chaining or locking valves, removing fuses, or racking out circuit breakers. However, you must attach tags to the fuse panel, the racked-out circuit breaker cabinet, or a locked valve to show a need for action. You do not need to use tags where a device will be locked during normal operations.

3. Use tags to show the presence of, and the requirement for, freeze seals, blank flanges, or similar safety devices. When equipment or components are placed out of commission, use the tag-out procedures to control the status of the affected equipment. Examples are disconnecting electrical leads, providing jumpers, or pulling fuses for testing or maintenance.
4. Never use tag-outs to identify valves, to mark leaks, or for any purpose not specified in the tag-out procedure.
5. The absence of a tag or label may not be taken as permission for unauthorized operation of equipment.
6. Whenever a tag or label is issued, correct the situation requiring the tag or label so it can be removed as soon as possible.
7. The tag-out procedure is for use by the ship's personnel on the equipment and systems for which they are responsible. However, repair activity personnel should use the procedure to the maximum extent practicable with systems and equipment that are still under construction.
8. *Standard Organization and Regulations of the U.S. Navy*, OPNAVINST 3120.32(series), is also required when work is being done by an intermediate level maintenance activity on equipment or systems that are the responsibility of the ship's force. Sometimes a ship is under construction or assigned to a repair activity not under the control of the TYCOM. When that happens, the ship's force and the repair activity may have to agree on the use of tags and labels. In this case, the tag-out system should be formal in nature and familiar to both the repair activity and the ship's force.
9. Any person who knows of a situation requiring tags or labels should request that they be issued and applied.
10. When using labels, you should list on the log any associated requirements specified for installation procedures, test procedures, work permits (rip outs or reentries), or system turnover agreements.
11. Make each decision on a case-by-case basis as to whether an OUT-OF-COMMISSION or an OUT-OF-CALIBRATION instrument label is to be used. In general, if the instrument error is small and consistent, you can use an OUT-OF-CALIBRATION label and the operator may continue to use the instrument. When you use an OUT-OF-CALIBRATION label, mark on the label the magnitude and units of the required correction. However, when you use an OUT-OF-COMMISSION label, the instrument should not be used.
12. Use enough tags to completely isolate a section of piping or circuit being worked on, or to prevent the operation of a system or component from all stations that can exercise control. Use system diagrams or circuit schematics to determine the adequacy of all tag-out actions.
13. Careful planning of tag-outs can significantly reduce the number of record sheets and tags. Planning can also reduce the effort required to perform audits, particularly during periods of overhaul or repair. When you initiate the tag-out, include all known work items in the Operations/Work Items Included in Tag-Out section. If you add work items to a tag-out record sheet after initial issue, take the following action:
    a. If no additional tags are required for the new work, have the authorizing officer and, if required, the repair activity representative makes sure the work is consistent with the purpose of the tag-out. New work must be fully described in the Operations/Work Items Included in Tag-Out section of the record sheet. The authorizing officer should make a thorough review to ensure the completeness and accuracy of the existing tag-out. This is the same procedure used to initiate a new tag-out record sheet for the added work. The authorizing officer (and repair activity representative) should sign the appropriate blocks next to the added item.

b. Additional tags may be needed to provide enough isolation for work that is to be added. If so, you must follow the procedures described later in this chapter for adding tags to an existing record sheet.

Procedures

Assume that a requirement for tags has been identified, and that the affected system will be out of commission. The authorizing officer must ask the CO and department head for permission to begin the tag-out. Notify the responsible division officer of the requirement for tag-out. On ships having damage control central (DCC), the authorizing officer must notify DCC if the affected system or component will be out of commission. The Authorizing Officer should have approval from either the OOD or the EOOW if the tag-out will affect systems under their responsibility.

PREPARING TAGS AND THE RECORD SHEET. DANGER and CAUTION tags and the associated tag-out record should be prepared as follows:

1. The person designated to prepare the tag-out is normally the ship's force petty officer in charge of the work. He or she fills out and signs the record sheet and prepares the tags.
2. A tag-out record sheet is prepared for a specific purpose. All tags used for that purpose are listed on an initial record sheet and additional sheets as necessary. Each record sheet is assigned a log serial number in sequence, from the index/audit record. Log serial numbers are also used to identify all tags associated with a given purpose. Each tag is given its own sequential number as it is entered in the record sheet. For example, tag 7-16 would be the 16th tag issued on a single record sheet with the log serial number 7.
3. The tag-out record sheet includes references to other documents that apply. Some examples are work permits, work procedures, repair directives, reentry control forms, test forms, and rip-out forms. Certain information should be obtained either from reference documents or from the personnel requesting the work. Some examples are the reasons for tag-out, the hazards involved, the amplifying instructions, and the work necessary to clear the tags. This information should be detailed enough to give watch standers a clear understanding of the purpose of, and necessity for, each tag-out action.
4. Use enough tags to completely isolate the system, piping, or circuit being worked on. Be sure you use tags to prevent the operation of a system or component from all the stations that can exercise control. Use system diagrams or circuit schematics to determine the number of tags needed. Indicate the location and position/condition of each tagged item by an easily identifiable means. Some examples are MS-l, STBD TG BKR, OPEN, SHUT, BLANK FLANGE INSTALLED.
5. After you have filled out the tags and the tag-out record sheet, have a second person make an independent check of the tag-out coverage and usage. That person should use appropriate circuit schematics and system diagrams. The second person verities the completeness of the tag-out action by signing the record sheet.
6. The authorizing officer then reviews the record sheet and tags for adequacy and accuracy. When satisfied, the officer signs the record sheet and the tags.
    a. If a tag-out is requested by a repair activity, the repair activity representative (shop supervisor or equivalent) must sign the tag-out record sheet. This shows that the repair activity is satisfied with the completeness of the tag-out. Verified tags alert all personnel that the repair activity must approve the removal of the tags.
    b. If the repair activity representative's concurrence is not required, this space on the record sheet need not be filled in.

c. On ships with DCC, the authorizing officer annotates the tag-out record sheet in the upper right-hand corner with the words “DCC notified,” and then initials it. This ensures that DCC knows the extent of the tag-out and the status of the material condition of the unit.

d. The authorizing officer then authorizes installation of the tags.

7. The person attaching the tag must make sure the item tagged is in the prescribed position or condition. If the item is not in the prescribed position or condition, he or she must get permission from the authorizing officer to change it to the prescribed condition or position. As each tag is attached and the position or condition is verified, the person attaching the tag must sign the tag and initial the record sheet.

NOTE

Only a qualified person from the ship’s force may position equipment and affix tags and labels. The tags should be attached so they will be noticed by anyone who wants to operate the component. Tags must NOT be attached to breaker covers or valve caps that may be removed later.

8. After all tags have been attached, a second person must independently verify proper item positioning and tag attachment, sign each tag, and initial the record sheet. If repair activity concurrence is required, a repair activity representative must witness the verification, sign the tags, and initial the tag-out record sheet.

NOTE

Only qualified ship’s force personnel may perform the second check of tag installation.

9. Sometimes additional tags are required because of added work on an existing tag-out record sheet. In that case, the person making the change must handle the DANGER and CAUTION tags and tag-out record sheet as follows:

a. Ensure that the purpose of the existing record sheet remains unchanged by the new work and its associated tags.

b. Fill out the tag-out record sheet to reflect the added work. Prepare whatever additional tags are required. Review the reason for the tag-out, the hazards involved, the amplifying instructions, and the work necessary to clear the tags. Do this on the existing tag-out record sheet to ensure that it reflects the old work and the new work being added to the record sheet. After completing the review of the record sheet, have the petty officer in charge of the work sign the first coverage check block next to the added work item.

c. Number each tag added to the existing tag-out sequentially, beginning with the number after the last number in the original tag-out. Annotate the serial numbers of the new tags next to the associated new work item on the record sheet. Enter the updated number of effective tags at the top of the record sheet by crossing through the previous number and writing in the new number.

d. After the new tags and the tag-out record sheet have been filled out and signed by the petty officer in charge of the work, have a second person make a review. The second person makes an independent check of the tag coverage and usage by referring to appropriate schematics and diagrams. This person should sign the record sheet in the block for the new work item to show satisfaction with the completeness of the tag-out actions. This includes both the additional and the previously issued tags.

e. Request that the authorizing officer and, when required, the repair activity representative review the entire record sheet and the new tags for completeness and accuracy. They should then sign their respective blocks for the added work item. The authorizing officer will then issue the tags.

f. Do not allow work to start until all the DANGER tags required for the protection of personnel or equipment have been attached according to established procedures.

ISSUING AND REMOVING LABELS. Labels are issued and removed in a manner similar to that required for tags.

1. The authorizing officer authorizes the use of labels by signing the label and the instrument log. When labels are required for reactor plant systems and reactor plant support systems, the repair activity representative concurs by signing on the label and in the instrument log next to the signature of the authorizing officer.
2. Second check signatures are not required on the label or on the instrument log.
3. When a label like one of those shown in *Figure 2-3* is assigned, it must be affixed to the exterior surface of the affected instrument, so operators can easily determine the status of the instrument.
4. A different procedure is used for installed instruments not associated with propulsion plants on nuclear-powered ships and for portable test and radical equipment. In these cases, the labels shown in *Figure 2-3* may be replaced by those affixed by a qualified instrument repair or calibration facility.

REMOVING DANGER AND CAUTION TAGS. Remove these tags immediately after the situation requiring the tag-out has been corrected. As each work item identified on the tag-out record sheet is completed, delete it from the tag-out record sheet. Completed work items listed in the Operations/Work Items Included in Tag-Out section of the record sheet must be signed off. This is done by the authorizing officer (and repair activity representative, when required) in the designated signature block. All DANGER tags must be properly cleared and removed before a system or portion of a system can be operationally tested and restored to service. To remove individual tags, the authorizing officer must ensure that the remaining tags provide adequate protection for work, testing, or operations that still remain to be performed. Tags may only be removed following the signed authorization of the authorizing officer. When a tag-out action was initiated by a repair activity, an authorized representative of that repair activity must concur that the job is complete. A shop supervisor or equivalent must sign the tag-out record sheet before the tags may be removed. As the tags are removed, the date/time of removal must be initialed. Ditto marks are not allowed. All tags must be returned immediately to the authorizing officer. This officer then requires a system lineup or a lineup check. Tags that have been removed must be destroyed after they have been delivered to the authorizing officer. All tags associated with each specific tag-out action must be destroyed and the system or component returned to normal operating (shutdown) condition. The authorizing officer must then certify these actions by entering the date and time when the system lineup or lineup check was completed. The authorizing officer must also enter the date and time cleared on the appropriate line of the tag-out index/audit record. The completed record sheets must be removed from the effective section of the log and placed in the completed section; they will be reviewed and removed by a designated officer. On ships having a DCC, the authorizing officer must notify DCC that the tag-out has been cleared. To complete the process, the authorizing officer must annotate the completed tag-out record sheet in the lower right-hand corner on the reverse side with the words “DCC notified,” and then initial it.

- When any component is tagged more than once, the DANGER tag takes precedence over all other tags. All DANGER tags must be removed and cleared before the equipment may be operationally tested or operated.
- A missing or damaged tag is reissued by indicating on the tag-out record sheet, on the line corresponding to the damaged or missing tag, that the tag was missing or damaged and that a replacement was issued. The new tag is issued using the next number in the tag-out record sheet. The authorizing officer should sign the tag-out record sheet to authorize the clearing of damaged or missing tags and to authorize their replacement.

Enforcement

Tag-out logs are kept in the spaces designated. Supervisory watch standers must review the logs during watch relief. They must also check outstanding tags and labels and conduct an audit of the tag-out log as described in the following list. The authorizing officer must ensure that the checks and audits are performed at the required frequency and that the results are reported to the cognizant officer.

1. All outstanding tags listed on each tag-out record sheet must be checked to ensure they are installed correctly; this is done by comparing the information on the tag with the record sheet and the item on which each tag is posted. When a valve or switch position is prescribed, a visual check of the item is made unless a cover, cap, or closure must be removed. Checking the operation of a valve or switch is not authorized as part of a routine tag-out audit. A spot check of installed tags must be conducted to ensure the tags are effective; all discrepancies in actual position must be reported at once to the responsible watch/duty officer before the tag audit is continued. The date, time, type of discrepancies (including corrective action), and signature of the person conducting the check must be logged on each tag-out record sheet.
2. All outstanding tag-out record sheets must be audited against the index/audit record section. Each tag-out record sheet should be checked both for completeness and to ensure that the installed tags were checked. The date, discrepancies noted, and the signature of the person conducting the audit must be logged by a line entry in the index/audit record section of the tag-out log.
3. The installation of instrument labels and the auditing of logs must also be checked. A line entry made in the instrument log containing the date, the time, the discrepancies noted, and the signature confirms the check.
4. Checks and audits of all tag-outs are usually performed every 2 weeks.
5. Results of audits are reported to the responsible department head. The responsible department head should frequently check the tag-out log, note errors, and bring them to the attention of the persons responsible. This is to ensure that tag-out/label procedures are being enforced properly. Completed tag-out record sheets and instrument logs should be removed after the review. Any violation of the tag-out program will have serious consequences, so strict adherence to the tag-out procedure, without exception, is required of all personnel.
6. Labels must be removed immediately when the affected instrument has been satisfactorily repaired, replaced, aligned, or calibrated.
7. Tags, which have been removed, must be destroyed.

Equipment Tests

As an Engineman, you will assist in scheduling and performing various tests on your equipment. They are used to determine how your equipment is performing and if there are any equipment malfunctions. These tests are performed at various times, such as (1) before the ship goes to the shipyard for overhaul, (2) after post- deployment, (3) during a tender availability, or (4) as required by Planned Maintenance System (PMS). The tests are performed by the ship's force, intermediate maintenance activity (IMA) personnel, shipyard personnel, or an inspection team (such as a Board of Inspection and Survey [INSURV]). Detailed types of inspections are described in *COMNAVSURFLANT Maintenance Manual,* COMNAVSURFLANTINST. 9000.1C *or COMNAVSURFPAC Ship and Craft Maintenance Manual, Volumes 1 and 2, Planned Maintenance,* COMNAVSURFPACINST. 4700.1B. two types of inspections and tests that can be used to "spot" impending trouble in an internal combustion engine are called trend and spectrographic analyses.

Engine Trend Analysis

Preventive maintenance receives a great deal of attention from everyone in the field of diesel engine operation, since letting an engine run as long as it will run and fixing it only after a breakdown occurs is not only foolish, but extremely costly. You should know that vital parts of an engine last longer and operate better if they are not tampered with unnecessarily. One way to determine the condition of an engine is by monitoring its operation. This is done regularly obtaining certain engine operating data and by studying, analyzing, and comparing it with previous data. This information is then reduced to a form that all engineering personnel can interpret and decide whether the engine needs to be overhauled or just temporarily shut down for simple maintenance. For more detailed procedures, refer to NAVSEA S9233-C3-HBK-010 Rev 1, Diesel Engine, Over 400 BHP, and Trend Analysis Handbook.

Spectrographic Analysis

Spectrographic analysis is a method of determining engine or equipment wear by analyzing engine oil and hydraulic oil samples for chemicals and particles not found in new oil or hydraulic fluid. This analysis is done in laboratories on samples provided by ships according to instructions given in their sampling kits (*Table 2-1).*

Table 2-1 — Element Symbol

Iron (Fe)	Nickel (Ni)	*Sodium (Na)
Lead (Pb)	Silver (Ag)	Phosphorus (P)
Copper (Cu)	Tin (Sn)	Zinc (Zn)
Chromium (Cr)	Silicon (Si)	Calcium (Ca)
Aluminum (Al)	Boron (B)	Barium (Ba)
*Only when evidence of water is present.		

Ships must maintain accurate records of operating hours since major overhauls, oil changes, and samplings to provide the testing facility with the information requested in the sampling kit. In addition, ships must maintain a record of conditions found and repairs made as a result of laboratory recommendations.

When the shipyard or IMA laboratory receives the oil sample, a physical test and a spectrometric analysis are performed. The physical test consists of the following actions:

1. All samples are tested for fuel dilution, and a report by percent volume is provided to all concerned.
2. All samples are tested for solids by being spun in a centrifuge. Solids will settle at the bottom of the sample.

3. Allowable "use limits" are tested and recorded. When the physical test is completed, the shipyard/IMAs will make a spectrometric analysis of each used oil sample, then report to all concerned the concentrations of the elements listed in *Table 2-1*in parts per million (ppm).

Additional information on trend analysis and oil spectrometric analysis is contained in COMNAVSURFLANTINST 9000.1C or COMNAVSURFPACINST 4700.1B.

TRAINING

The higher you progress as an Engineman; you will be responsible for passing your skills and knowledge on to other, lower-rated Engineman. Your level of experience and theoretical knowledge will be successful in training others. Success in training others requires that you have or develop certain additional skills as an instructor.

Training Responsibilities

You must be technically competent before you can teach others, but your technical competence must be supplemented by the ability to organize information, to present it effectively, and to arouse and keep the interest of your trainees. You will find excellent general information on how to plan, carry out, and evaluate an instructional program in *Military Requirements for Petty Officer Second Class*, NAVEDTRA 12045, and in *Military Requirements for Petty Officer First Class*, NAVEDTRA 12046.

Each person must be trained to perform not only as an individual but also as a member of a team. Take for instance the duties of the watch standers. They are very closely related, and the actions taken by one person depend in some way upon the actions taken by other persons. The teamwork required for engine-room operations can actually be turned to a training advantage. As a person is being trained for one specific duty, he or she will naturally learn something about the other duties. The procedures for training a new person in engine-room operations vary considerably, depending upon such factors as the ship's steaming schedule, the condition of the engine-room machinery, the number of experienced personnel available to assist in the training, and the amount of time that can be devoted to the training. You will probably Begin by training the trainee to act as messenger. Then, before the trainee is assigned to any actual duty, he or she should be introduced to the engine room and become familiar with the location of all machinery, equipment, piping, and valves. The trainee must also be instructed in certain basic safety precautions and be specifically warned about the dangers of turning valve wheels or tampering with machinery. "IF IN DOUBT, ASK QUESTIONS!" is a good rule for any new person in the engine room to follow.

A person ready to be trained in the duties of messenger should be shown all the gauges that are in use, told what the gauges indicate, and shown how to take readings. The trainee should understand why the readings are important, exactly how often each gauge must be read, and how to make accurate entries in the engine-room log. When you are sure the trainee understands everything about gauges, teach the trainee how to check lube oil levels and how to clean metal edge-type filters and basket strainer-type. For a while you will have to keep a close watch on the trainee's performance of these duties. When the trainee becomes proficient in the duties of messenger, start the training in the throttleman's duties. First, let the trainee observe the throttleman; then, if conditions permit, let the trainee start and secure machinery.

Personnel should always start out under the supervision of an experienced throttleman and should remain under this supervision until the petty officer in charge of the engine room is fully satisfied that the trainee is completely qualified for this duty.

In training engine-room personnel who have not had previous engine-room experience, remember that an engine room can be a complicated and confusing place to someone who walks into it for the first time. A lot of equipment is crammed into a small space, and a lot of complex actions are going on at the same time. When training new personnel, try to think back to the time when you first went into an engine room. What aspects of engine-room operations were most confusing to you at first? What kind of training would have made your learning easier and faster? By analyzing your own early experience and reactions, you get a bearing on what a new person may experience and you may be able to provide more effective training.

When you train new personnel, remember that they vary widely in their methods and rates of learning. Some people will learn most effectively if you give them an overall view of main engine operations, including a certain amount of theory, before going into the details of the hardware and the manual operations. Others will learn most effectively if they are taught some manual skills before getting too involved with theory. Some people learn manual skills rapidly but take a long time to absorb the theory; for others, the reverse is true. And, of course, some people learn everything slowly. Some trainees benefit from patient, almost endless repetition of information; others may become bored and restless if you go over the same point too often. The important thing to remember is that your training efforts will be most successful if you are able to observe and allow for the individual differences that are bound to exist.

When training personnel who have already had some engine-room experience but who have been on some other type of ship, you may find that a certain amount of retraining is needed before the individual can qualify as an engine-room watch stander on your ship. No two engine rooms are precisely alike in all details, and no two main engines that appear to be identical behave in precisely the same way under all conditions. Each engine has its own individuality, and operating personnel must adjust to the engine to obtain the best results.

Safety Training

Because of the necessity for strict observance of safety precautions, all engine-room operational training must be rigidly controlled and supervised. On-the-job training is necessary if an individual is to acquire the actual skills needed for main engine operation. Safety precautions should be taught from the very beginning and should be emphasized constantly throughout the training program. Many of the NSTMs, manufacturer's technical manuals, and every PMS maintenance requirement card (MRC) include safety precautions. Additionally, *Naval Occupational Safety and Health (NAVOSH) Program Manual* for Forces *Afloat* OPNAVINST 5100.19B, and *NAVOSH Program Manual,* OPNAVINST 5100.23B, provide safety and occupational health information. The safety precautions are to protect you and the equipment

During preventive and corrective maintenance, the procedures may call for personal protective equipment (PPE) such as goggles, gloves, hearing protection, and respirators. When specified, your use of PPE is mandatory. You must select PPE appropriate for the job since the equipment is manufactured and approved for different levels of protection. If the procedure does not specify the PPE, and you aren't sure, ask your safety officer.

Most machinery, spaces, and tools requiring you to wear hearing protection are posted with hazardous noise signs or labels. Eye hazardous areas requiring you to wear goggles or safety glasses are also posted. In areas where corrosive chemicals are mixed or used, an emergency eye wash station must be installed.

All lubricating agents, oils, and cleaning materials are hazardous materials. Hazardous materials require careful handling, storage, and disposal. PMS documentation provides hazard warnings or refers the maintenance person to the Hazardous Materials User's Guide (HMUG). Material Safety Data Sheets (MSDSs) also provide safety precautions for hazardous materials. All commands are required to have an MSDS for each hazardous material in their inventory. You must be familiar with the dangers associated with the hazardous materials you use in your work Additional information is available from your command's hazardous material/hazardous waste coordinator.

Workers must always consider electrical safety when working around any electrical or electronic machinery or equipment. Procedures normally include special precautions and tag-out requirements for electrical safety. You should review your command's electrical safety program instruction and procedures before beginning any work on electrical or electronic equipment or before working with portable electrical tools.

In your work center or shop, there is equipment that will help you do your job easier and more quickly, requires special knowledge of safe operation and proper maintenance. As an Engineman you will be involved in providing training on how to use this equipment. All shop personnel, including you, must complete the Personnel Qualification Standard (PQS) for each piece of equipment before using it. You will assist your supervisor in providing the information and training. Normally in the shop or work center, every piece of equipment must have a posted operating procedure and a list of personnel who are qualified to use it. If a piece of equipment does not have posted operating procedures, post a copy of the procedures given in the manufacturer's manual.

Training Programs

As an Engineman, you are required to assist your supervisors in establishing or maintaining a training program for your work center. For this program you are required to teach the proper methods of equipment operation, repair, and safety. You should use all appropriate materials as teaching aids, such as manufacturer's manuals, instructions, and NSTMs. For certain types of information, you may need to consult various kinds of engineering handbooks, such as the mechanical engineering handbooks, marine engineering handbooks, piping handbooks, and other handbooks that provide detailed, specialized technical data.

In addition, you should know what schools are available. In recent years, one of the best ways to check on how well personnel retain the information being taught in the training program has been the use of the PQS.

A PQS is a written list of knowledge and skills required to qualify for a specific watch station, maintain a specific piece of equipment or system, or perform as a team member within an assigned unit.

Most standards are divided into four sections: Fundamentals, Systems, Watchstations, and a Qualification Card. The Fundamentals section contains the facts, principles, and fundamentals concerning the subject for which a person is qualifying. The Systems section deals with the major working parts of the installation, organization, or equipment with which the PQS is concerned. The Watchstation section defines the actual duties, assignments, and responsibilities needed for qualification. The Qualification Card has questions that match those in the Watchstation section and provides a space for the supervisor's or the qualifying officer's signature.

In addition to qualifying under PQS, both you and your subordinates must satisfy Maintenance and Material Management (3-M) Systems and general damage control qualification requirements.

ENGINEERING OPERATIONAL SEQUENCING SYSTEM (EOSS)

Each new ship that joins the Navy is more technically advanced and complex than the one before. The main propulsion plants call for engineering skills at ever higher levels of competence. That means more and better training of personnel who must keep the ships combat ready. The need for training and the problem of frequent turnover of trained personnel call for some kind of system that can be used to keep things going smoothly during the confusion. The Engineering Operational Sequencing System (EOSS) was developed for that purpose. It is designed to eliminate problems due to operator error during the alignment of piping systems and the starting and stopping of machinery. It involves the participation of all personnel from the department head to the fireman on watch. EOSS consists of a set of detailed written procedures, using charts, instructions, and diagrams. These aids are developed for safe operation and casualty control of a specific ship's engineering plant and configuration. EOSS improves the operational readiness of the ship's engineering plant by providing positive control of the plant. This, in turn, reduces operational casualties and extends machinery life.

EOSS is divided into two subsystems:

- Engineering Operational Procedures (EOPs)
- Engineering Operational Casualty Control (EOCC)

Engineering Operational Procedures (EOPs)

EOPs are prepared specifically for each level of operation: plant supervision (level 1), space supervision (level 2), and component/system operator (level 3). The materials for each level or stage of operation contain only the information necessary at that level. All materials are interrelated. They must be used together to maintain the proper relationship and to ensure positive control and sequencing of operational events within the plant. Ships that do not have EOSS use operating instructions and a casualty control manual for plant operations.

Engineering Operational Casualty Control (EOCC)

This subsystem of EOSS enables plant and space supervisors to RECOGNIZE the symptoms of a possible casualty. They can then CONTROL the casualty to prevent possible damage to machinery, and RESTORE plant operation to normal. The documents of the EOCC subsystem contain procedures and information that describe symptoms, causes, and actions to be taken in the most common engineering plant casualties.

Engineering Casualty Control

The best form of casualty control is prevention. If you do not let a casualty happen, you will not have to fix it.

Preventive maintenance is one of the principal factors of casualty control. Preventive inspections, tests, and maintenance are vital to casualty control. These actions minimize casualties caused by material failures. Continuous detailed inspections are necessary to discover worn or partly damaged parts, which may fail at a critical time. These inspections eliminate maladjustments, improper lubrication, corrosion, erosion, and other abnormalities that could cause early failure of a vital piece of machinery.

The inspections, tests, and maintenance called for in the 3-M Systems must be performed conscientiously since they are based on the known requirements of preventive maintenance.

Still, casualties do happen. When they do, the success of the mission, the safety of your ship, and the lives of your shipmates may depend on your ability to handle the situation. That means continuous training and frequent refresher drills to be sure you can do your part, and do it well.

Engineering casualty control is used to prevent, minimize, and correct the effects of operational and battle casualties. These casualties will be on engineering space machinery, related machinery outside of engineering spaces, and the piping installations associated with the various pieces of machinery. The mission of engineering department personnel is to maintain all engineering services in a state of maximum reliability under all conditions. If you cannot provide these services, the ship may not be able to fight.

Steps involved in handling engineering casualties can be divided into three general phases:

1. Immediate action to prevent further damage.
2. Supplementary action to stabilize the plant condition.

3. Restoration action to restore equipment to operation after a casualty. Where equipment damage has occurred, repairs may be necessary to restore machinery, plants, or systems to their original condition.

Communication of accurate information is one of the major problems in casualty control. Be sure you know the names and operations of the equipment at your normal watch station and your battle station. Be sure you know what the casualty is before you take corrective action. If you are reporting a casualty to the bridge or main control, be sure you use the correct terminology and ensure they understand what your casualty is.

The primary sources of instructions used to handle any engineering casualty and to maintain the overall damage resistance to your ship are listed as follows:

- The EOCC procedure
- The ship's casualty control manual (for a ship without EOCC)
- The ship's damage control manual
- The ship's damage control bills
- The ship's organization and regulation manual (SORM)

Symptoms of Operational Casualties

You must be on the alert for even the most minor sign of faulty operation of machinery. Pay particular and continuous attention to the following symptoms of malfunctioning:

- Unusual noises
- Vibrations
- Abnormal temperatures
- Abnormal pressures
- Abnormal operating speeds
- Leakage from systems or associated equipment

You should become thoroughly familiar with the normal operating temperatures, pressures, and speeds of equipment specified for each condition of operation; departures from normal will then be readily apparent. NEVER assume that an abnormal reading on a gauge or other indicating instrument is due to a problem with the instrument. Investigate each case to learn the cause of the abnormal reading. Substitute a spare instrument or perform a calibration test to quickly show whether an instrument error exists. Trace abnormal readings that are not caused by faulty instruments to their source. Some specific advance warnings of failure are outlined in the following paragraphs.

The safety factor commonly incorporated in pumps and similar equipment can allow a considerable loss of capacity before you see any external evidence of trouble. In pressure-governor-controlled equipment, view changes in operating speeds from normal for the existing load with suspicion. Variations from normal in chest pressures, lubricating oil temperatures, and system pressures indicate either improper operation or poor condition of the machinery. When a material failure occurs in any unit, promptly inspect all similar units to determine whether they are subject to the same type of failure. Prompt inspection may eliminate a wave of similar casualties.

Abnormal wear, fatigue, erosion, or corrosion of a part may indicate that the equipment is not being operated within its designed limits of loading, speed, and lubrication. These symptoms also may indicate a design or material deficiency. If any of these symptoms have appeared, you should routinely carry out special inspections to detect damage unless you can take action to ensure that such a condition will not recur.

Engine-Room Casualties

Even with the best-trained personnel and the best-planned maintenance programs, casualties will occur. WHEN COMBATING AN ENGINE-ROOM CASUALTY, USE YOUR EOCC.

Diesel Engine Casualties

The Engineman's duties concerning engineering casualties and their control depend upon the type of ship, which may be anything from a torpedo weapons retriever (TWR) to a carrier. An Engineman operates engines of various sizes, made by various manufacturers, and intended for different types of services.

Some examples of the types of engineering casualties that may occur and the action to be taken are given in the sections that follow. The observance of all necessary safety precautions is essential in all casualty control procedures.

1. Inoperative speed governor.
    a. Control the engine manually, if possible.
    b. Notify the engineer officer and the bridge, and request permission to secure the engine for repairs.
    c. When you get permission, check the governor control mechanism.
    d. Check the linkage for binding or sticking.
    e. Check the lubrication; flush the governor sump and refill it with proper oil.
    f. Check the setting of the needle valve.
    g. Make repairs. When you have completed the repairs, start the engine and check its operation. When it is operating properly, notify the engineer officer and the bridge.
2. Engine cooling water temperature above the allowed limit.
    a. Notify the bridge.
    b. Reduce the load and the speed of the engine.
    c. Check the freshwater level in the expansion tank.
    d. Check the saltwater discharge pressure.
    e. Check the sea suction and the discharge valves.
    f. Vent the freshwater and the saltwater pumps.
    g. Check the setting and operation of the temperature regulating valve.
3. Failed main engine lube oil pressure.
    a. Secure the engine immediately.
    b. Notify the engineer officer and the bridge.
    c. Check the sump oil level, the piping, the filters, the strainers, and the lube oil pump capacity. Make the repairs.
    d. After you have completed the repairs, notify the engineer officer and the bridge.

For more generalized examples of main engine (diesel-drive) casualties, refer to *Damage Control*, *Engineering Casualty Control*, Chapter 079, Volume 3, of NSTM.

To obtain detailed information on diesel engine casualty control procedures, refer to the manufacturer's instructions, the pertinent TYCOM's instructions, and the ship's *Engineering Casualty Control Manual*.

Watch Standing

You will spend much of your time aboard ship as a watch stander. How you stand your watch is very important to the reliability of the engineering plant and the entire ship. To be a successful watch stander, you must do the following:

- Have the skills to detect unusual noises, vibrations, or odors that may indicate faulty machinery operation.
- Take appropriate and prompt corrective measures.
- Be ready, in emergencies, to act quickly and independently.
- Know the ship's piping systems and HOW, WHERE, and WHY they are controlled.
- Know each piece of machinery: how it is constructed, how it operates, how it fits into the engineering plant, and where related equipment is controlled.
- Be able to read and interpret measuring instruments.
- Understand how and why protective devices function (relief valves, speed limiting governors, overspeed trips, and cut-in and cutout devices).
- Recognize and remove fire hazards, stow gear that is adrift, and keep deck plates clean and dry.
- NEVER try to operate a piece of equipment that is defective.
- Report all unsafe conditions to the space or plant supervisor.
- Know the status of every piece of machinery at your station.
- Promptly handle any necessary change in speed or setup, and record correctly all data concerning the operation and maintenance of the machinery.
- Be sure the log is up to date and the status boards are current.
- Know what machinery is operating and what the night orders and standing orders are before you relieve the watch.

Above all, if you don't know, ASK! A noise, odor, or condition may seem abnormal to you, but you may not be certain whether it is a problem. When that happens, call your immediate watch supervisor.

You can best gain the respect and confidence of your supervisors and shipmates if you stand a good watch. Relieve the watch on time or even a little early if possible to be sure you know the condition of the machinery and what you need to do. DO NOT TRY TO RELIEVE THE WATCH FIRST AND FIGURE OUT THE SITUATION LATER. The same applies when you are being relieved; don't be in a hurry to take off. Be sure your relief understands the situation completely. Before you are relieved, make sure your station is clean and squared away. These little considerations will strengthen your reputation and improve the overall quality of watch standing within the department.

QUALITY ASSURANCE PROGRAM

The quality assurance (QA) program was established to provide personnel with information and guidance necessary to administer a uniform policy of maintenance and repair of ships and submarines. The QA program is intended to introduce discipline into the repair of equipment, safety of personnel, and configuration control, thereby enhancing readiness.

The various QA manuals set forth minimum QA requirements for both the surface fleet and the submarine force. If more stringent requirements are imposed by higher authority, such requirements take precedence. If a conflict exists between the QA manual and previously issued letters and transmittals by the appropriate force commanders, the QA manual takes precedence. The instructions contained in the QA manual apply to every ship and activity of the force. Although the requirements are primarily applicable to the repair and maintenance done by the force IMAs, they also apply to maintenance done aboard ship by ship's force. In all cases where specifications cannot be met, a departure-from-specifications request must be completed and reported.

Because of the wide range of ship types and equipment and the varied resources available for maintenance and repair, the instructions set forth in the QA manual are necessarily general in nature. Each activity must implement its own QA program to meet the intent of the QA manual. The goal should be to have all repairs conform to QA specifications.

Program Components

The basic thrust of the QA program is to make sure you comply with technical specifications during all work on ships of both the surface fleet and submarine force. The key elements of the program are as follows:

- Administrative. This includes training and qualifying personnel, monitoring and auditing programs, and completing the QA forms and records.
- Job execution. This includes preparing work procedures, meeting controlled material requirements, requisitioning material, conducting in-process control of fabrication and repairs, testing and recertifying, and documenting any departure from specifications.

A properly functioning QA program points out problem areas to maintenance managers so they can take appropriate action in a timely manner. The following goals are common to all Navy QA programs:

1. To improve the quality, uniformity, and reliability of the total maintenance effort.
2. To improve work environment, tools, and equipment used in the performance of maintenance.
3. To eliminate unnecessary man-hour and dollar expenses.
4. To improve the training, work habits, and procedures of all maintenance personnel.
5. To increase the excellence and value of reports and correspondence originated by the maintenance activity.
6. To distribute required technical information more effectively.
7. To establish realistic material and equipment requirements in support of the maintenance effort.

Quality Assurance Organization

The QA program for naval forces is organized into different levels of responsibility. For example, the COMNAVSURFPAC QA program is organized into the following levels of responsibility: TYCOM, readiness support group/area maintenance coordinator, and the IMAs. The QA program for the Naval Surface Force for the Atlantic Fleet is organized into five levels of responsibility: force commander, audits, squadron commanders, IMAs, and force ships.

The QA program organization (Navy) begins with the commander in chief of the fleets, which provides the basic QA program organization responsibilities and guidelines.

The TYCOMs provide instruction, policy, and overall direction for implementation and operation of the force QA program. TYCOMs have a force QA officer assigned to administer the force QA program.

The COs are responsible to the force commander for QA in the maintenance and repair of the ships. The CO is responsible for organizing and implementing a program within the ship to carry out the provisions of the TYCOM QA manual.

The CO ensures that all repair actions performed by ship's force conform to provisions of the QA manual as well as other pertinent technical requirements.

The Quality Assurance Officer (QAO) is responsible to the CO for the organization, administration, and execution of the ship's QA program according to the QA manual.

The QAO is responsible for coordinating the ship's QA training program, for maintaining ship's QA records, and for test and inspection reports. The QAO conducts QA audits as required and follows up on corrective actions to ensure compliance with the QA program.

The ship quality control inspectors (SQCIs), usually the work center supervisor and two others from the work center, must have a thorough understanding of the QA program. Some of the other responsibilities an SQCI will have are as follows:

1. Inspect all work for compliance with specifications.
2. Maintain ship records to support the QA program.
3. Ensure that only calibrated equipment is used in acceptance testing and inspection of work.
4. Witness and document all tests.
5. Ensure that all materials or test results that fail to meet specifications are recorded and reported.

Ship-to-Shop Work

Many repair jobs are designated by the ship or approved by the repair activity as "ship-to-shop" jobs. For example, the repair or renewal of a damaged pump shaft might well be written up as a ship-to-shop job. The ship's force will disassemble the pump and remove the shaft. Then the shaft and any necessary blueprints or technical manuals are delivered to the designated shop of the repair activity. After the shaft has been repaired, or a new one has been made, it is picked up and brought back to the ship by the ship's force. The pump is reassembled, inspected, and tested by the ship's force to make sure it is operating satisfactorily. The important thing to remember is that the repair facility is responsible for ensuring that its personnel repair or manufacture this to the manufacturer's specifications, perform all tests required by QA, and properly fill out all the required forms. You are responsible for witnessing any test required by QA, monitoring the status of the job at all times, and reassembling and test operating the pump properly. The end results will produce a reliable, operating piece of equipment.

Levels of Essentiality

A level of essentiality is a range of controls, in two broad categories, representing a certain high degree of confidence that procurement specifications have been met. These categories are:

- Verification of material
- Confirmation of satisfactory completion of tests and inspections required by the ordering data

Levels of essentiality are codes, assigned by the ship according to the QA manual, that indicate the degree to which the ship's system, subsystem, or components are necessary in the performance of the ship's mission. These codes indicate the impact that catastrophic failure of the associated part or equipment would have on the ship's mission capability and personnel safety.

Levels of Assurance

QA is divided into three levels: A, B, and C. Each level reflects certain quality verification requirements of individual fabrication in process or repair items. Level A assurance provides for the most stringent of restrictive verification techniques. This level requires both quality controls and test or inspection methods. Level B assurance provides for adequate verification techniques, requires limited quality controls, and may or may not require tests or inspections. Level C assurance provides for minimum or “as necessary” verification techniques and requires very little quality control of tests or inspections.

The QA concept involves preventing the occurrence of defects. QA covers all events from the start of a maintenance action to its completion and is the responsibility of all maintenance personnel.

By carefully following the methods and procedures outlined in your QA program manuals and by paying careful attention to the quality of work in your area, you will contribute greatly to the operational effectiveness of your ship as well as tended units.

SUMMARY

In this chapter, we have discussed some of your important administrative and training responsibilities and the different methods you can use to properly perform these responsibilities. Remember, information is usually available when you need it. You just have to know where to look for it and make the effort to secure it.

End of Chapter 2

Basic Administration and Training

Review Questions

2-1. Which of following engineering department’s records must be preserved as permanent legal records?

A. Engineering Log/Fuel and Water Report
B. Engineering Bell Log/Monthly Summary
C. Engineering Log/Engineering Bell Book
D. Machinery History/Boiler Room Operating Record

2-2. What is the standard engine order telegraph symbol for back emergency speed?

A. Z
B. 1
C. BF
D. BEM

2-3. Which of the following documents indicates the amount of fuel on hand as of midnight, the previous day?

A. Daily Boat Fueling Report
B. Fuel and Water Account
C. Fuel and Water Report
D. Diesel Engine Operating Record

2-4. Information about engineering records that must be kept permanently, is contained in which of the following publications?

A. NSTM Chapter 080
B. SECNAVINST P5212.5(series)
C. NAVSHIPS 5084
D. NAVSHIPS 3648

2-5. When a piece of equipment fails, you must take which of the following actions before repairs can begin?

A. Isolate and tag-out the system/equipment
B. Notify the Type Commander
C. Submit an OPNAV Form 4790K
D. Request permission the relieve pressure from the system before isolation

2-6. When repairs have been completed on a piece of equipment, what must be accomplished before the operational testing of equipment or system?

A. Complete the work request
B. Warm up the system
C. Align the equipment/system in accordance with EOP
D. Clear the tags

2-7. What documents are used as a precautionary measure, providing special instructions and warning of unusual measures that must be used to operate the tagged item?

A. DANGER TAGS
B. CAUTIONS TAGS
C. OUT-OF-CALIBRATION LABELS
D. OUT-OF-COMMISSION LABELS

2-8. What documents are used to identify instruments that will not give accurate readings because they are either defective or isolated from the system?

A. Danger Tags
B. Caution Tags
C. Out-of-Calibration Labels
D. Out-of-Commission Labels

2-9. What method is used to determine if an engine needs to be overhauled or just temporarily shut down for sample maintenance?

A. The current engine operating data is compared with the previous operating data.
B. The operating data of the engine is compared with same type.
C. The temperature of the lube oil entering the cooler is compared to that leaving the cooler.
D. The present amount of lube oil consumption is compared with the previous lube oil consumption.

2-10. If your ship is home-ported on the West Coast and you need additional information concerning trend analysis and oil spectrometric analysis, to what Navy instruction should you refer?

A. OPNAVINST 43P1
B. COMNAVSURFLANTINST 9000.1C
C. COMNAVSURFPACINST 4700.1B
D. SECNAVINST P5212.5

2-11. Where would you be able to find the most information about Engine Trend Analysis?

A. NAVSEA S9233-C3-HB-010.010
B. COMNAVSURFLANTINST 9000.1C
C. COMNAVSURFPACINST 4700.1B
D. SECNAVINST P5212.5

2-12. Which of the following factors does NOT help in determining the procedures for training a new person in engine-room operations

A. Ship’s operating schedule
B. Number of experienced personnel available
C. Condition of engine-room equipment
D. Trainee’s manual skills level

2-13. What factors should be emphasized constantly throughout an engine-room training program?

A. Safety precautions
B. Trial and error techniques
C. Emergency repairs procedures
D. Machinery characteristics

2-14. What section of the PQS deals with the major working parts of the installation, organization, or equipment?

A. Fundamentals
B. Systems
C. Watchstations
D. Qualification Cards

2-15. What is required of all commands to have on hand for every piece of hazardous material in their inventory?

A. Material Safety Data Sheet
B. Material Safety Document Sheet
C. Material Safety Data List
D. Maintenance Safety Data Sheets

2-16. Which of the following is contained in the Engineering Operational Casualty Control (EOCC) subsystem?

A. Watch qualification
B. Casualty symptoms
C. Casualty reporting to the Type Commander
D. Casualty reports to Fleet Commander

2-17. When combatting an engine-room casualty, which of the following items would you use?

A. EOP
B. NSTM
C. EOCC
D. The Watch, Quarter, and Station Bill

2-18. In the Engineering Operational Procedures (EOPs), what level of operation is for the system operators?

A. 1
B. 2
C. 3
D. 4

2-19. If a major piece of equipment has any material failure, which of the following pieces of information is essential to the Engineering Officer?

A. If there is similar failure in other pieces of equipment
B. If it would be beneficial to exchange parts
C. If there is a spare keep it operational
D. If there are sufficient funds in the budget to cover the cost of repairs

2-20. To be a successful watch stander, you must be able do all of the following, EXCEPT……..

A. Operate equipment that you are qualified to operate.
B. Be able to read and interpret measuring instruments.
C. Recognize and remove hazards, stow gear that is adrift, and keep deck plates clean and dry.
D. Operate a pneumatic tool.

2-21. To get the best watch turnover information, when should you relieve the watch?

A. Right on time
B. 15 minutes late
C. A little early
D. Whenever you decide to take the watch

2-22. Which of the following duties is NOT the responsibility of the Quality Assurance Officer?

A. Coordinating the ship's QA training program
B. Maintaining the ship's record of test and inspection reports
C. Conducting QA audits as required
D. Monitoring work procedure for QA

2-23. Level B assurance provides which of the following levels of assurance?

A. Minimum verification
B. Limited verification
C. The most stringent verification
D. Adequate verification

2-24. In regards to Ship-to-Shop work, who is responsible for witnessing any test requirements?

A. The ship's QA personnel assigned to the Deck Department
B. The work center representative who requested the work to be completed
C. The repair facility supervisor
D. The repair facility QA representative

RATE TRAINING MANUAL – User Update

SWOS makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in SWOS manuals, please write or e-mail us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

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CHAPTER 3

PRECISION AND MEASURING INSTRUMENTS

As an Engineman, you must be able to identify the basic measuring and repair instruments and the basic components of these instruments. This chapter will help you to recognize the how and when to use and maintain basic measuring and repair instruments and engine test equipment. Measuring instruments are used to check tolerances and specifications during inspections and repairs of internal combustion engines and auxiliary equipment. Enginemen need measuring instruments to determine what parts are worn and need to be repaired or replaced. The following measuring and repair instruments are discussed in this chapter: dial indicator, dial/vernier caliper, micrometer, snap gauge, bore gauge, strain gauge, borescope, stroboscope, torque wrench, multiplier, adapter, ridge reamer, cylinder hone, and dynamometer.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. List and explain the use of sensitive measuring tools.
2. Explain the purpose of engine test equipment.

SENSITIVE MEASURING TOOLS

Sensitive measuring tools are measuring devices that provide measurement readings to a thousandth of an inch or less. The sensitive measuring tools you will use most are the dial indicator, dial/vernier caliper, micrometer, snap gauge, bore gauge, and strain gauge.

Dial Indicator

A dial indicator is used to measure shaft runout, shaft thrust, gear backlash, flywheel face runout, flywheel housing concentricity, and valve seat concentricity. You can mount a dial indicator on a test stand or, with clamps and a magnetic base, directly on the equipment to be measured. *Figure 3-1* shows a typical dial indicator with mounting accessories. Most dial indicators have components, such as a bezel, indicator pointer, tool post and clamp, magnetic toolholder, and sensor button that are used in taking measurements. The following procedures explain how to use the indicator to take shaft runout and crankshaft end play measurements.

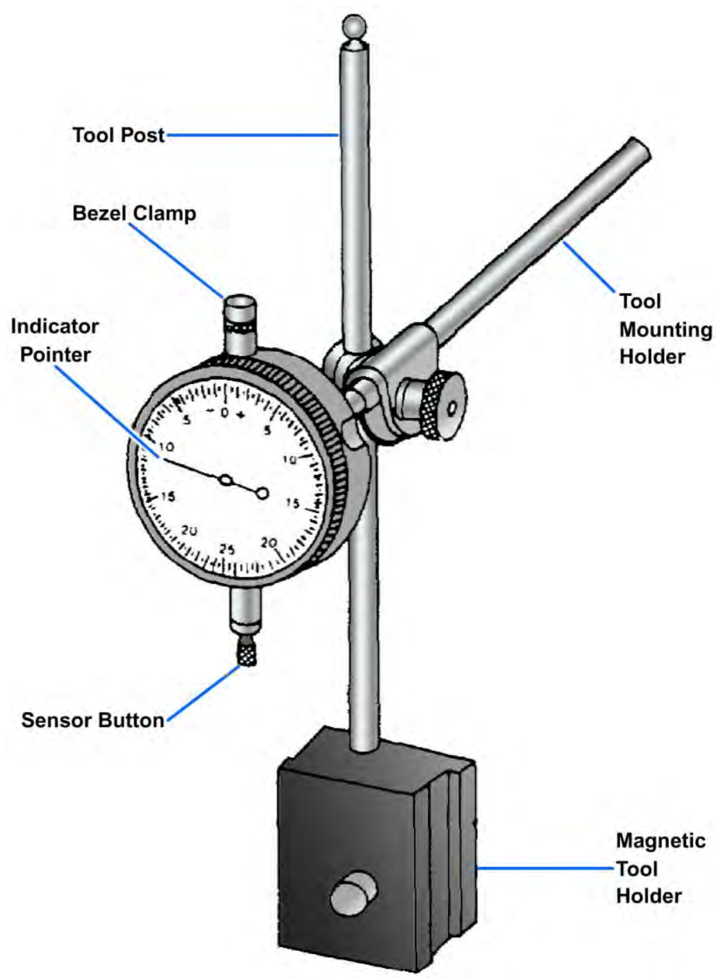

Figure 3-1 — Typical dial indicator with mounting accessories.

Shaft Runout

When you need to measure a shaft's runout, select a suitable position on the shaft, free of keyways, corrosion, or other damage. Clean the surface and remove any burrs around scratches or dents. To take the runout measurement, use the following procedure:

1. Place the shaft in well-oiled V-blocks. If the shaft is a crankshaft, place the bearing journals in the V-blocks.
2. Attach the magnetic base to a machined surface. Mount the dial indicator on a tool mounting holder and attach the holder to the base.
3. Adjust the mounting post so you can easily read the face of the dial.
4. Move the indicator toward the shaft until the sensor button just touches the surface you wish to measure.
5. Continue moving the indicator slowly toward the shaft until the dial pointer has moved to the midpoint of its travel on the dial face.
6. Leave the pointer at midtravel and turn the bezel until the zero on the dial is aligned with the pointer.
7. You can now rotate and watch the pointer to see if it moves. The total amount the pointer moves is called the total indicator reading (TIR). If the shaft is straight, the pointer should remain at zero.

Crankshaft End Play or Thrust Readings

To measure crankshaft end play or thrust, use the following procedure:

1. Attach the dial indicator to a convenient place near the vibration damper.
2. Position the dial indicator gauge so the contact point touches the front of the vibration damper and moves the dial indicator near the midpoint of its range.
3. Insert one end of a pry bar between a main bearing cap and a crankshaft counterweight.

> **NOTE**
>
> Do not insert the prybar between the vibration damper and the block to measure the crankshaft end play. You may dent the damper and render it ineffective.

4. Move the crankshaft toward the dial indicator. Be sure to maintain a constant pressure on the prybar.
5. Set the dial indicator to zero.
6. Remove the prybar and then reinsert it on the other side of the main bearing cap.
7. Carefully pry the crankshaft in the opposite direction to measure the crankshaft end play. Repeat your measurement a minimum of two times for accuracy.

Dial/Vernier Caliper

The dial/vernier caliper is used to measure the inside or outside diameter of an object. *Figure 3-2* shows a typical dial/vernier caliper. Most dial/vernier calipers have a slide, slide lockscrew, thumb button, scale, dial with measured increments of 0.001 inch, and a bezel.

For specific instructions on how to take measurements with a dial/vernier caliper, refer to either the manufacturer’s instructions or to *Tools and Their Uses*, NAVEDTRA 14256.

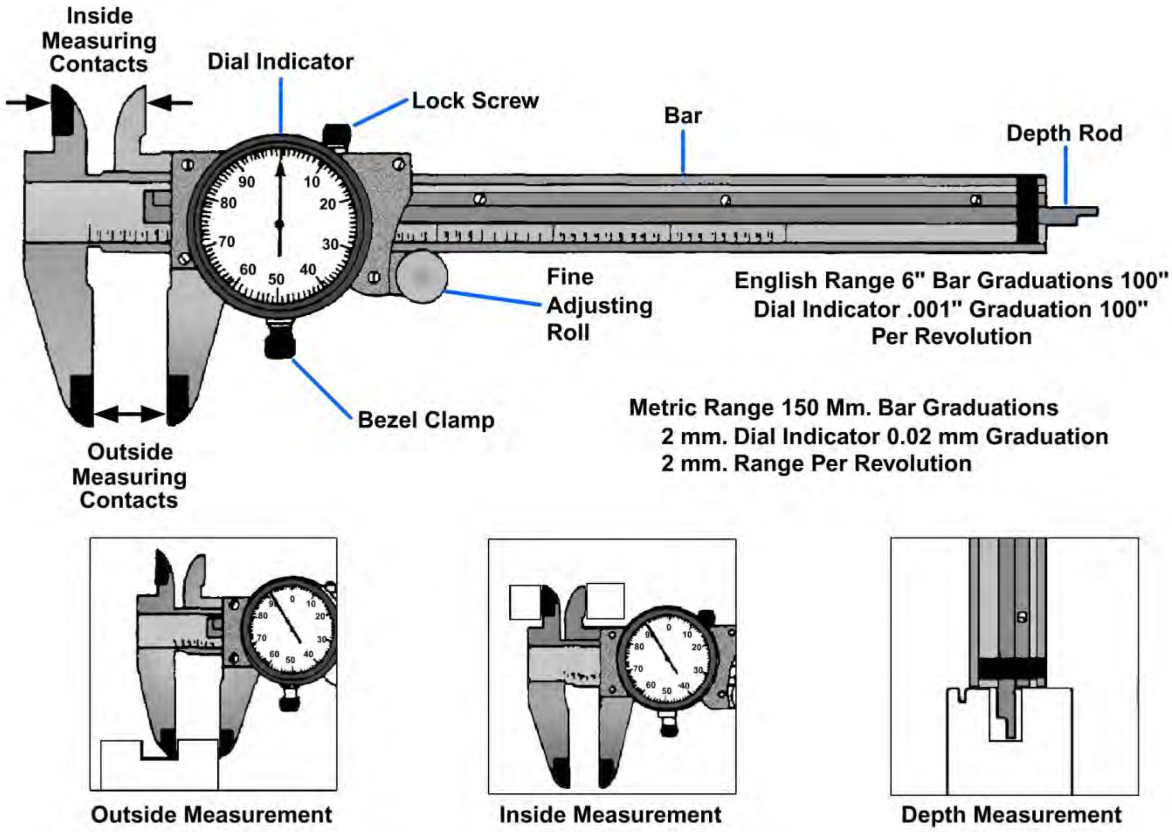

Figure 3-2 — Typical dial/vernier caliper.

Regardless of what type of caliper you use, be sure to take the following precautions to avoid damaging it:

1. Wash your hands before handling the vernier caliper to remove dirt and oils that might damage the caliper.
2. Wipe the caliper components clean both before and after using the caliper.
3. DO NOT drop or otherwise mishandle the caliper. *Figure 3-3* illustrates the use of a dial/vernier caliper in measuring the inside and outside diameters of two different components.

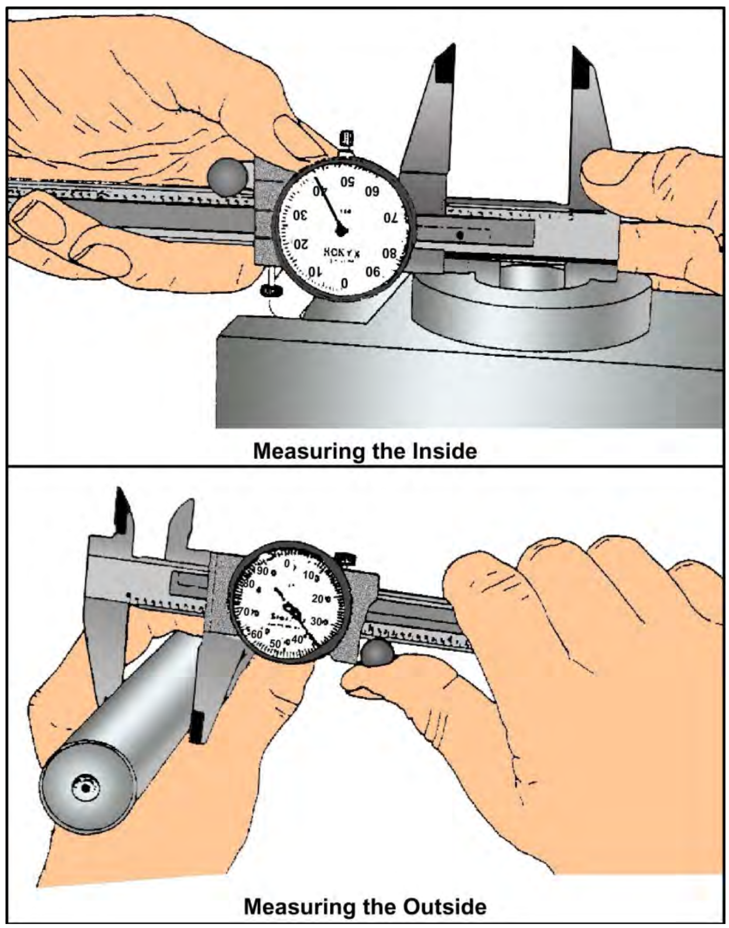

Figure 3-3 — Measuring inside and outside diameters with a dial/vernier caliper.

Micrometer

The micrometer is a precision measuring instrument used to measure distances between surfaces in thousandths of an inch. *Figure 3-4* shows the most common types of micrometers.

Most micrometers have a frame, anvil, spindle, sleeve, thimble, and ratchet stop.

Micrometers are used to measure the outside diameters; inside diameters; the distance between parallel surfaces; the depth of holes, slots, counterbores, and recesses; and the distance from a surface to some recessed part. Instructions on how to read a micrometer are given in the manufacturer's owner's manual and *Tools and Their Uses*, NAVEDTRA 14256

Whenever you use a micrometer, carefully observe the "DO's" and "DON'Ts" in the following list to obtain accurate measurements and to protect the instrument:

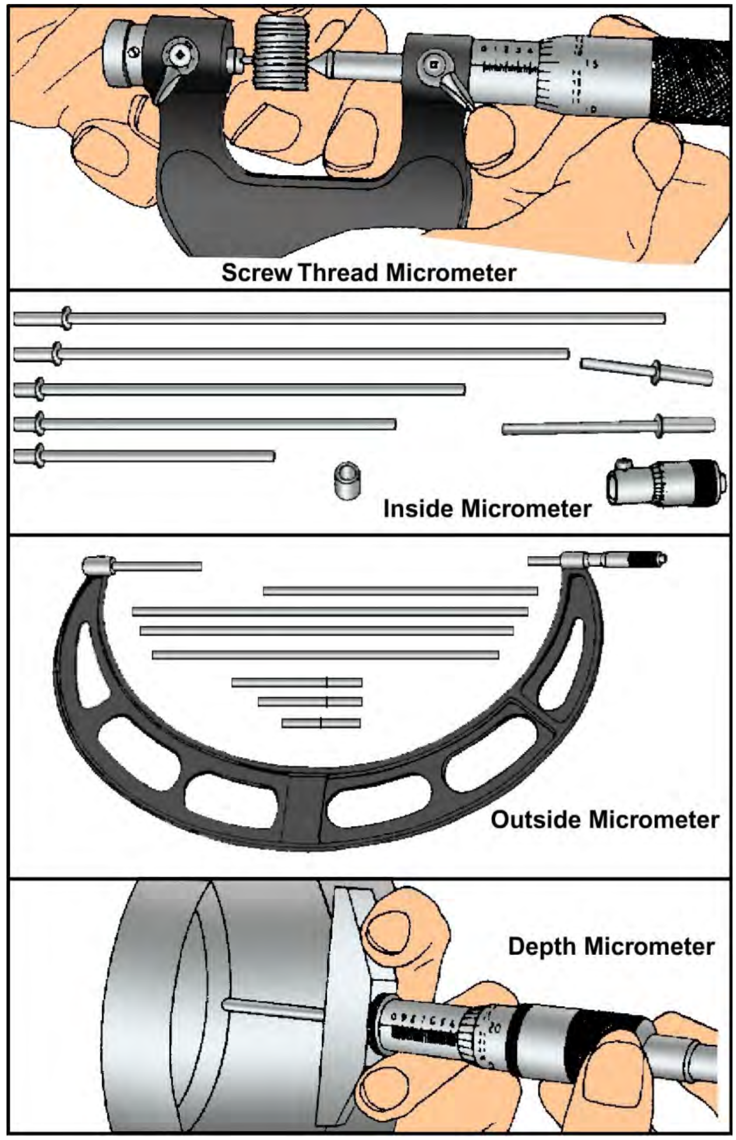

Figure 3-4 — Common types of micrometers.

1. Always stop the work before you take a measurement. DO NOT measure moving parts because the micrometer may get caught in the rotating work and be severely damaged.
2. Always open a micrometer by holding the frame with one hand and turning the knurled sleeve with the other hand. Never open a micrometer by twirling the frame, because such a practice will put unnecessary strain on the instrument and cause excessive wear of the threads.
3. Apply only moderate force to the knurled thimble when you take a measurement. Always use the friction slip ratchet if there is one on the instrument. Too much pressure on the knurled sleeve will not only result in an inaccurate reading, but also will cause the frame to spring and force the measuring surface out of line.
4. When a micrometer is not in use, place it where it will not drop.
5. Before you store a micrometer, back the spindle away from the anvil; wipe all exterior surfaces with a clean, soft cloth, and coat the surfaces with light oil. Do not reset the measuring surfaces to close contact because the protecting film of oil on these surfaces will be squeezed out.

Snap Gauge

The snap gauge compares the outside diameters of parts such as shafts and journals to a standard. It can compare diameters from zero to 8 inches at accuracy of 0.0001 inch. *Figure 3-5, frames 1 and 2* show a typical snap gauge.

Most snap gauges consist of a frame with an insulated handle, a hex wrench mounted in the handle, dial indicator digits calibrated in 0.001-inch divisions, a bezel clamp, adjustment wheels, locking wheels, a backstop, a lower anvil, an upper anvil, and a guard.

Whenever you use a snap gauge, use the handle and avoid touching the gauge proper because body heat may affect the reading. For the same reason, handle the standard plugs only by their plastic end. Clean the anvils and the backstop with a clean cloth. To use the snap gauge, follow the manufacturer's operating instructions.

After recording the readings and comparing them with the design specifications, clean and store the snap gauge in its appropriate storage location.

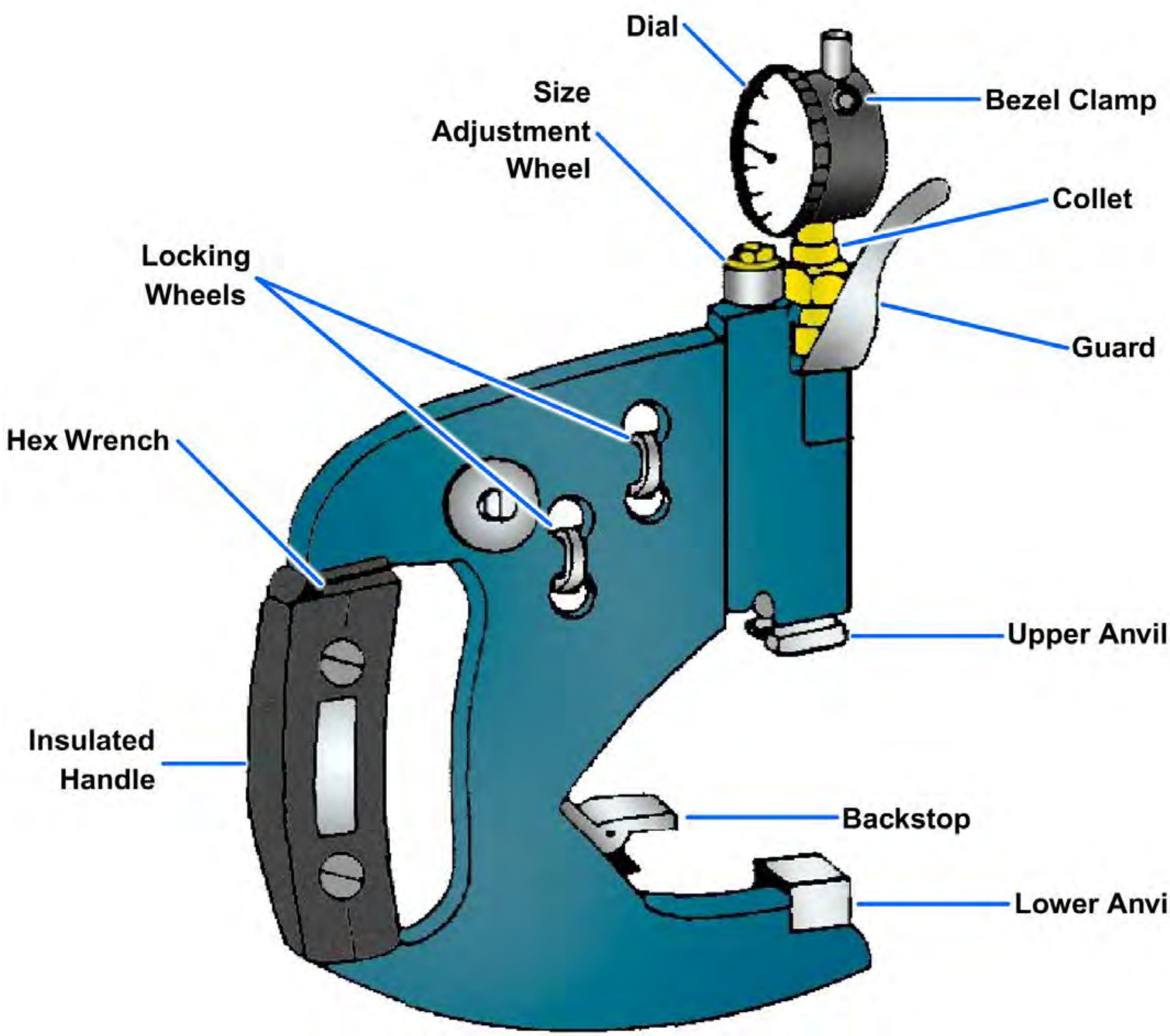

Figure 3-5 — Typical snap gauge.

Bore Gauges

The dial bore gauge is one of the most accurate tools for measuring a cylindrical bore or for checking a bore for out-of-roundness or taper. The gauge does not give a direct measurement. It identifies the amount of deviation from a preset size or the amount of deviation from one part of the bore to another. A master ring gauge, outside micrometer, or vernier caliper can be used to preset the gauge. *Figure 3-6, frames 1 and 2* show a typical bore gauge. Most bore gauges consist of a dial indicator, extension pieces, bezel and locknut, spring-loaded guide, and sensor button.

Before starting a measuring procedure, expose both the bore gauge and the master ring gauge--or any other tools used to preset the bore gauge--and the part to be measured to the same work place environment for one hour. If you fail to do this, a temperature differential may cause your readings to be inaccurate. When you use the bore gauge, touch only its insulated handle.

The gauge has two stationary spring-loaded points and an adjustable point to permit a variation in range. These points are evenly spaced to allow accurate centering of the tool in the bore. A fourth point, the tip of the dial indicator, is located between the two stationary points. By simply rocking the tool in the bore, you can observe the amount of variation on the dial. Always follow the bore gauge manufacturer's operating manual. Measure the bore and mark the areas you measure. A good practice is to check the bore gauge in the standard after you take each set of measurements to ensure that readings are accurate.

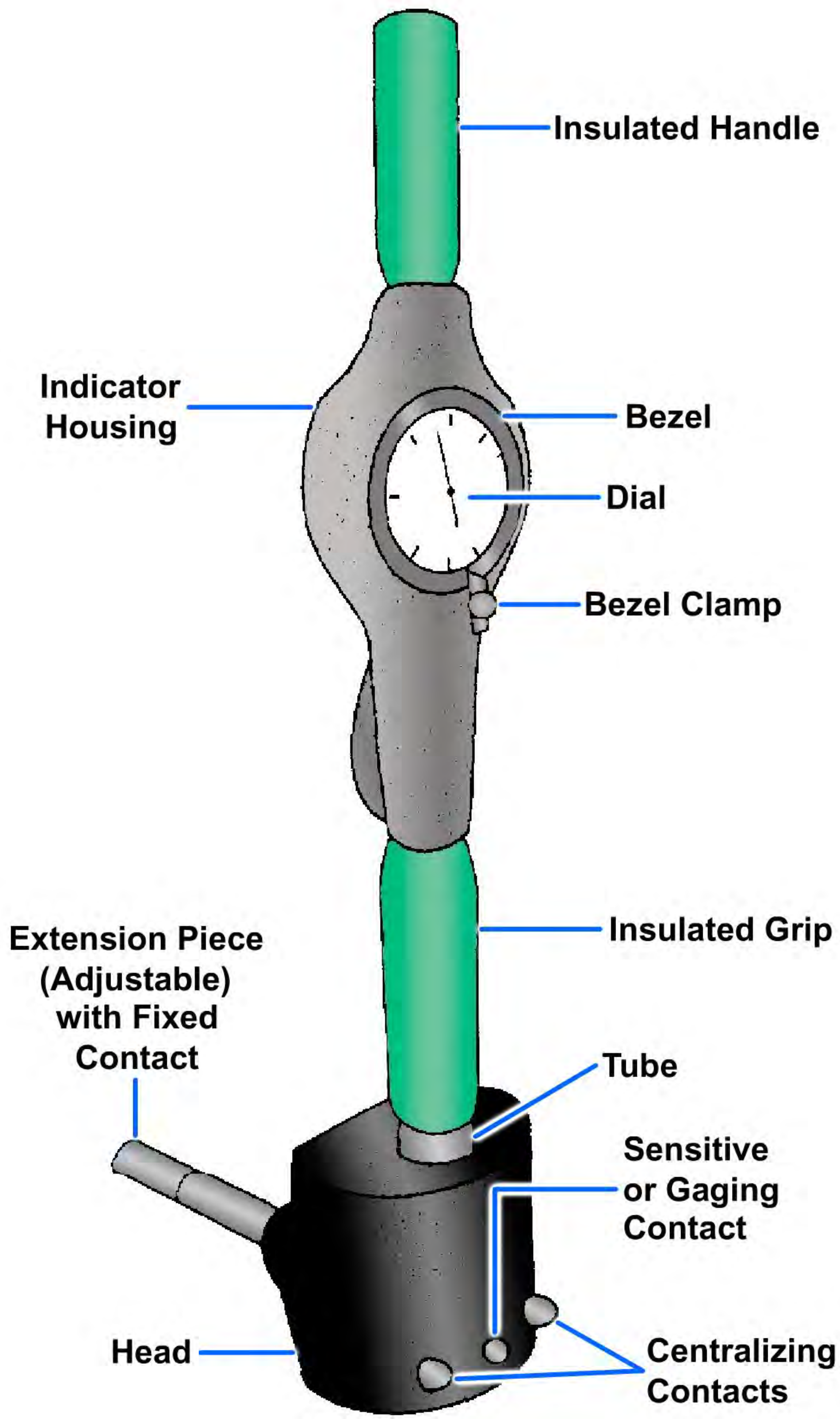

Figure 3-6 — Typical bore gauge.

Strain/Deflection Gauge

A strain or deflection gauge is used to check the crankshaft alignment on large diesel engines. It is a specially adapted dial indicator that fits between the crank webs. The strain gauge reads the flexing motion of the webs directly as the crankshaft is slowly rotated (correct engine rotation). The gauge dial reads in 0.001-inch graduations. The strain gauge consists of a dial indicator, contact point, balancing attachment, clamping nut, spring plunger, rods and extension, and bezel.

Before you take a reading, be sure the engine is completely assembled and cold. Place the strain gauge between the webs of a crankthrow, as far as possible from the axis of the crankpin. The ends of the indicator should rest in the prick-punch marks in the crank webs. If these marks are not present, consult the manufacturer's technical manual for the proper location of the marks. Ensure that the strain gauge is at the same temperature as the engine. A temperature differential may cause inaccurate readings. Readings are generally taken at the four crank positions; top dead center, inboard, near or at bottom dead center, and outboard. However, the manufacturer's technical manual for the specific engine provides information concerning the proper positions of the crank for taking readings. In some situations, due to the position of the dial, you may need to use a mirror and a flashlight to read the gauge.

Once you have placed the indicator in position for the first reading, DO NOT touch the gauge until you have taken and recorded all four readings. Variations in the readings taken at the four crank positions indicate distortion of the crank, which may be caused by any of several factors, such as a bent crankshaft, worn bearings, or improper engine alignment. The manufacturer's technical manual will provide you with the maximum allowable deflection. *Figure 3-7* shows the locations for taking crankshaft deflection readings.

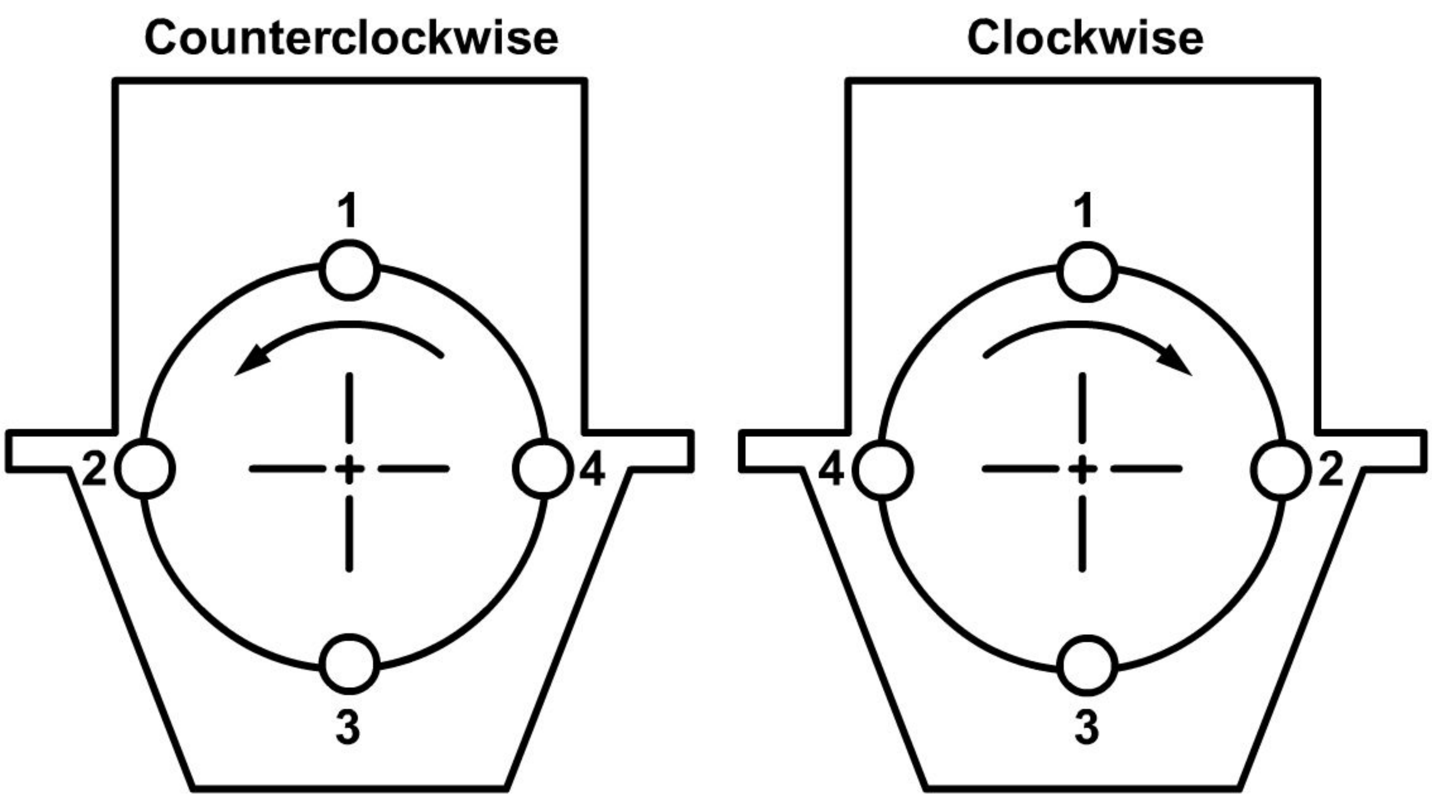

Figure 3-7 — Locations for taking crankshaft deflection readings.

A borescope (*Figure 3-8, frames 1 and 2*) is used to inspect internal parts of an engine without having to disassemble the engine. This instrument helps a great deal in estimating the amount of repair work needed and the time required for the repair.

Figure 3-8 — Typical borescope.

As with any optical instrument, handle the borescope with care to avoid damaging its lenses and mirrors. The borescope is powered by alternating current, so, before you first use it, be sure to read and follow the manufacturer's operating instructions. The borescope can be inserted through any engine opening, such as a cylinder port, to identify problems such as cracked pistons, cracks in the cylinder head, burned valves, and scuffed or pitted liners. You can remove the crankcase cover to inspect the bottom section of the engine.

Stroboscope

A stroboscope (*Figure 3-9, frames 1 and 2*) is a flashing light source used to measure the speed of fast-moving objects. It produces the optical effect of stopping or slowing down an object to allow you to observe and analyze the object's motion. A stroboscope consists of a power switch, rpm control dial, range switch, calibration indicator light, calibration screws, combination adjustments, reflector lamp assembly, and other electrical accessories. Before you use the stroboscope, be sure to read and follow the manufacturer's operating instructions. The instrument

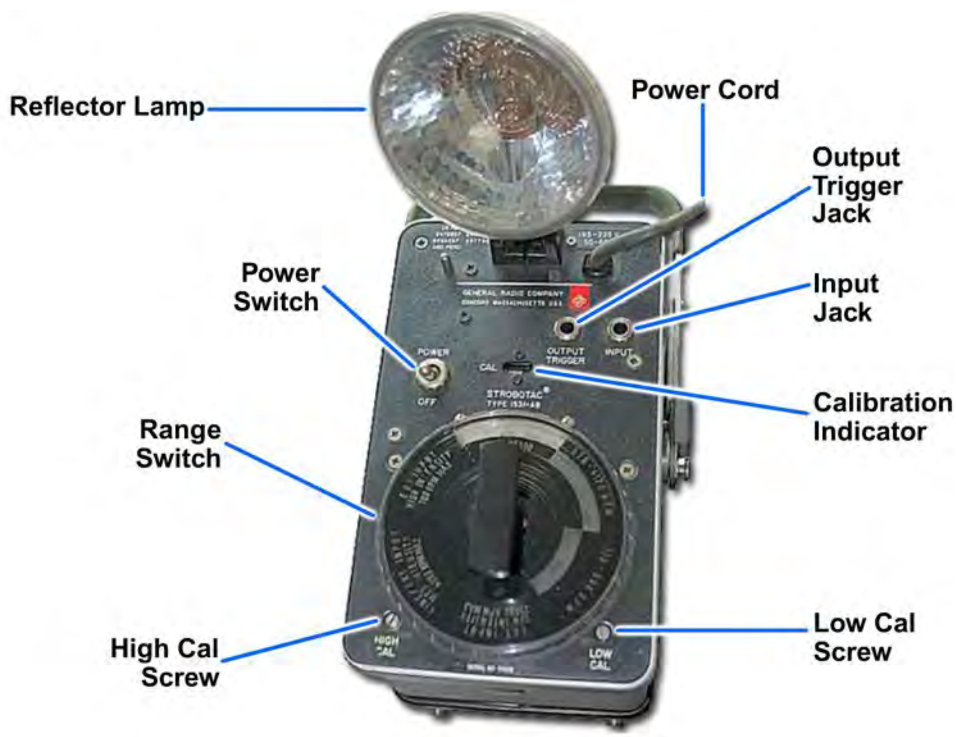

Figure 3-9 — Typical stroboscope.

commonly operates from a 120-volt, 60-Hz, and alternating current supply. Any change in current frequency will affect the flashing speed and affect the stroboscope's accuracy for speed measurements. The stroboscope can be used to measure the speed and to observe the motion of rotating, reciprocating, or vibrating mechanisms.

WARNING

Never leave the stroboscope unattended while it is in use. Since the stroboscope makes a moving object appear to be standing still, someone could be seriously injured by the apparently "stationary" object.

Torque Wrench

The torque wrench is used to measure an object's resistance to turning and to provide precise tightening of threaded fasteners. *Figure 3-10, Frames 1, 2 and 3* shows three types of torque wrenches. To use a torque wrench, first select the proper torque value for the torqueing procedure you are using. Next, select the torque wrench with the correct capacity. The torque value should be in the second or third quarter of the wrench's torque scale because the first and last quarters of the scale are not as accurate as the middle quarters.

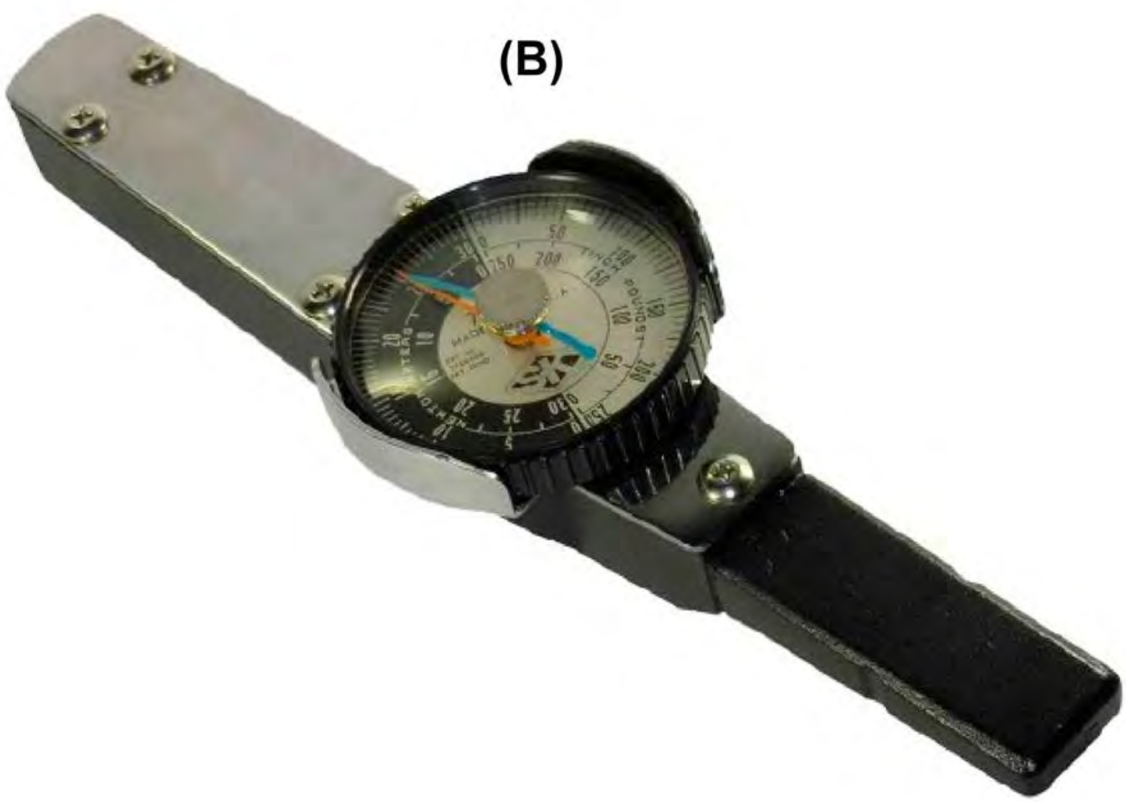

Figure 3-10 — Typical torque wrenches.

Torque Multiplier

Torque multipliers are geared devices attached to the torque wrench (*Figure 3-11*) to increase the force of torque. The preferred ratio of the torque multiplier is 4 to 1. To use a torque multiplier, select one with an output capacity above the required torque. Be sure to follow the manufacturer's operating manual to avoid personnel injury and damage to the equipment.

Figure 3-11 — Torque multipliers.

Torque Adapters

Torque adapters allow the torque wrench to be used to tighten parts and fasteners other than standard nuts and bolts. Adapters are available in a variety of shapes geared to the repair of different parts of the diesel engine. Several types of torque adapters are shown in *Figure 3-12*.

Figure 3-12 — Torque adapters.

When you use an extension adapter, the torque applied to the part or fastener will be greater than the torque indicated on the torque wrench. Therefore, you must account for the length of the adapter to apply the proper torque to the part or fastener. *Figure 3-13* illustrates the points of measurement. The torque applied by the adapter is directly related to the length of the adapter. As the length of the adapter increases, so does the applied torque. To determine the actual torque applied to the part or fastener, assume that the length of the torque wrench is L and the length of the adapter is A. Assume also that Tw is the torque indicated on the scale of the torque wrench and Ta is the torque exerted at the end of the

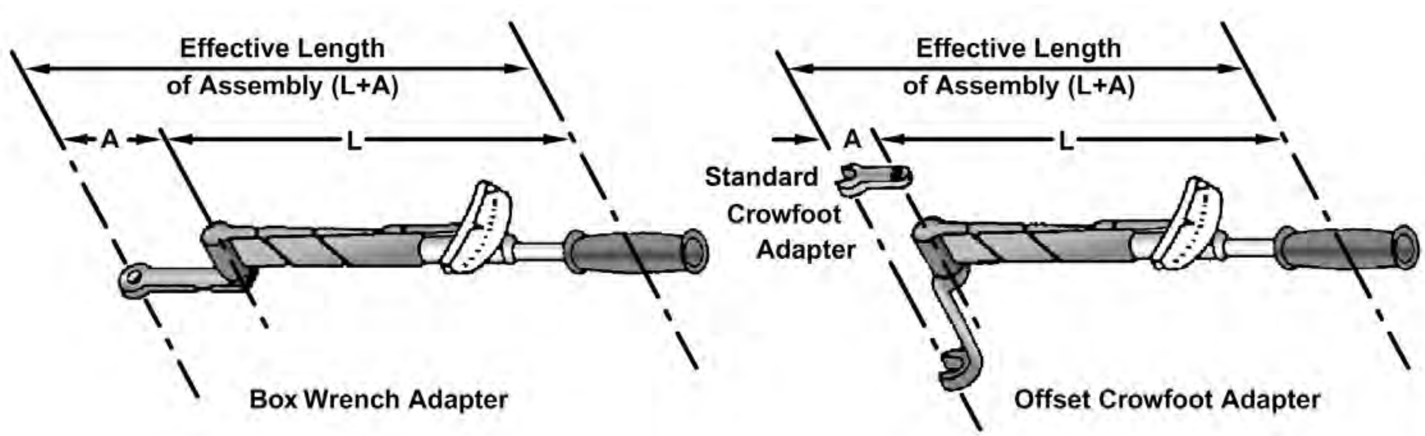

Figure 3-13 — Torque adapters and points of measurement.

adapter. To determine Ta (*Figure 3-14*), simply multiply the torque indicated on the torque wrench (Tw) by the ratio of the total effective length of the assembly (L + A) to the length of the torque wrench (L).

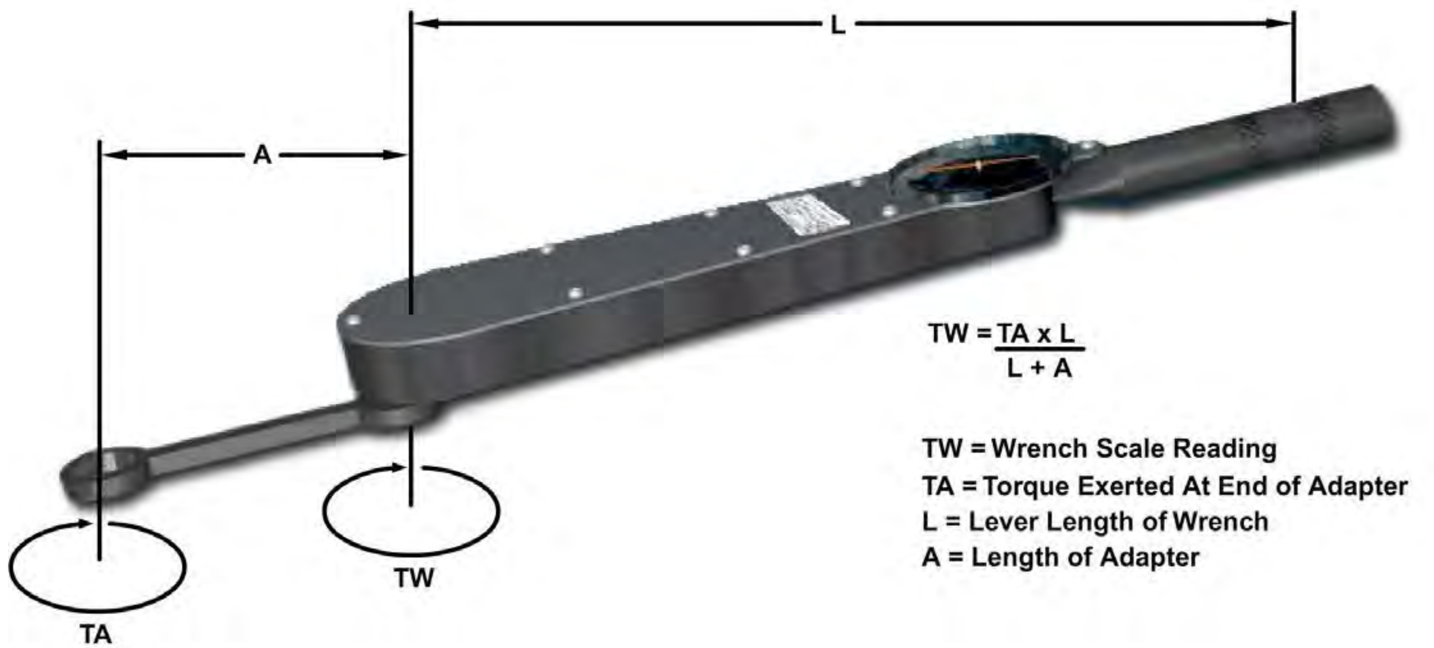

Figure 3-14 — Torque wrench formula.

An easy to remember rule of thumb is that the applied torque will be greater than the indicated torque by an amount equal to the length of the adapter compared to the length of the torque wrench. For example, if the adapter is the same length as the torque wrench, the applied torque will be twice as great as the indicated torque. If the adapter is one-third as long as the torque wrench, the applied torque will be one-third greater than the indicated torque. *Table 3-1* and *Figure 3-15* illustrate how to calculate applied torque.

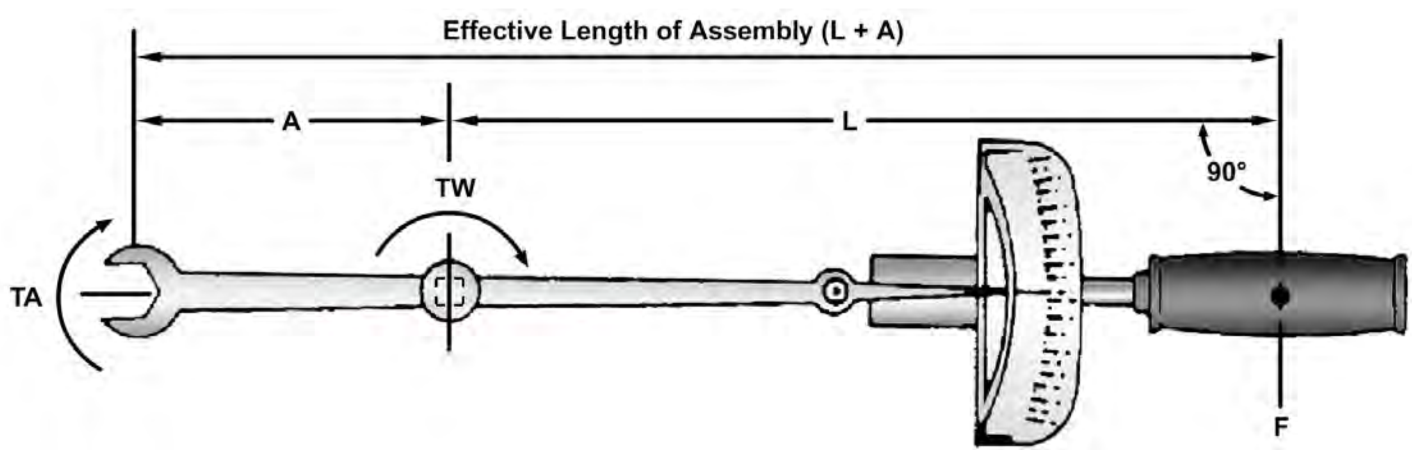

Figure 3-15 — How to calculate applied torque.

Table 3-1 — How to calculate applied torque

Determining applied torque	$$Ta = Tw \times \frac{(L + A)}{L}$$
	$Ta = Torque\ exerted\ at\ the\ end\ of\ the\ adapter$
	$Tw = Wrench\ scale\ reading$
	$L = Lever\ length\ of\ the\ wrench$
	$A = Length\ of\ the\ adapter$
Determining indicated torque (when desired torque is known)	$$Tw = \frac{Ta \times L}{(L + A)}$$
	$Tw = Wrench\ scale\ reading$
	$Ta = Torque\ exerted\ at\ the\ end\ of\ the\ adapter$
	$L = Lever\ length\ of\ the\ wrench$
	$A = Length\ of\ the\ adapter$
Determining adapter or extension length	$$A = \frac{(Ta - Tw) \times L}{Tw}$$
	$A = Length\ of\ the\ adapter$
	$Ta = Torque\ exerted\ at\ the\ end\ of\ the\ adapter$
	$Tw = Wrench\ scale\ reading$
	$L = Lever\ length\ of\ the\ wrench$
At times it is necessary to calculate the wrench scale reading for several torques using the same wrench adapter assembly. In such cases, it is convenient to determine a **CONVERSION CONSTANT** for the assembly, which will simplify calculations.	The following formula shows the constant: $$C = \frac{L}{L + A}$$
	CONVERSION CONSTANT
	$C = Conversion\ constant\ for\ wrench\ and\ adapter$
	$L = Lever\ length\ of\ the\ wrench$
	$A = Length\ of\ the\ adapter$
Torque wrenches that are so constructed that the position of applied load can be carried on the frame or handle of the wrench WILL NOT work correctly with adapters or extensions. The following calculations or formulas apply to either adapters or extensions having the axis of their work engaging member intersecting the extended center line of the torque wrench frame. Tw is the torque indicated on the scale of the torque wrench; Ta is the torque exerted at the end of the adapter.	$$Ta = (L + A) \times F$$
The force F exerted on the handle of the wrench equals the torque developed by the wrench at Tw, which is the torque indicated on the scale, divided by the lever length of the wrench L.	$$F = \frac{Tw}{L}$$

Ridge Reamer

A ridge reamer is used to remove ridges formed at the tops of cylinders by piston rings moving up and down in the cylinders. *Figure 3-16* illustrates a typical ridge reamer. The ridge reamer consists of a carbon cutter, adjustable guides, adjustable cutter head, adjustable cutter, and threaded feed screw.

Whenever you use a ridge reamer, you must wear eye protection, such as a face shield or goggles. Remember that the cutter will take out the ridge with a lathe-like cutting action. Read and follow the manufacturer's manual on how to use the reamer. After all the ridges are removed, take a measurement with a bore gauge, and verify that the cylinder is within specifications.

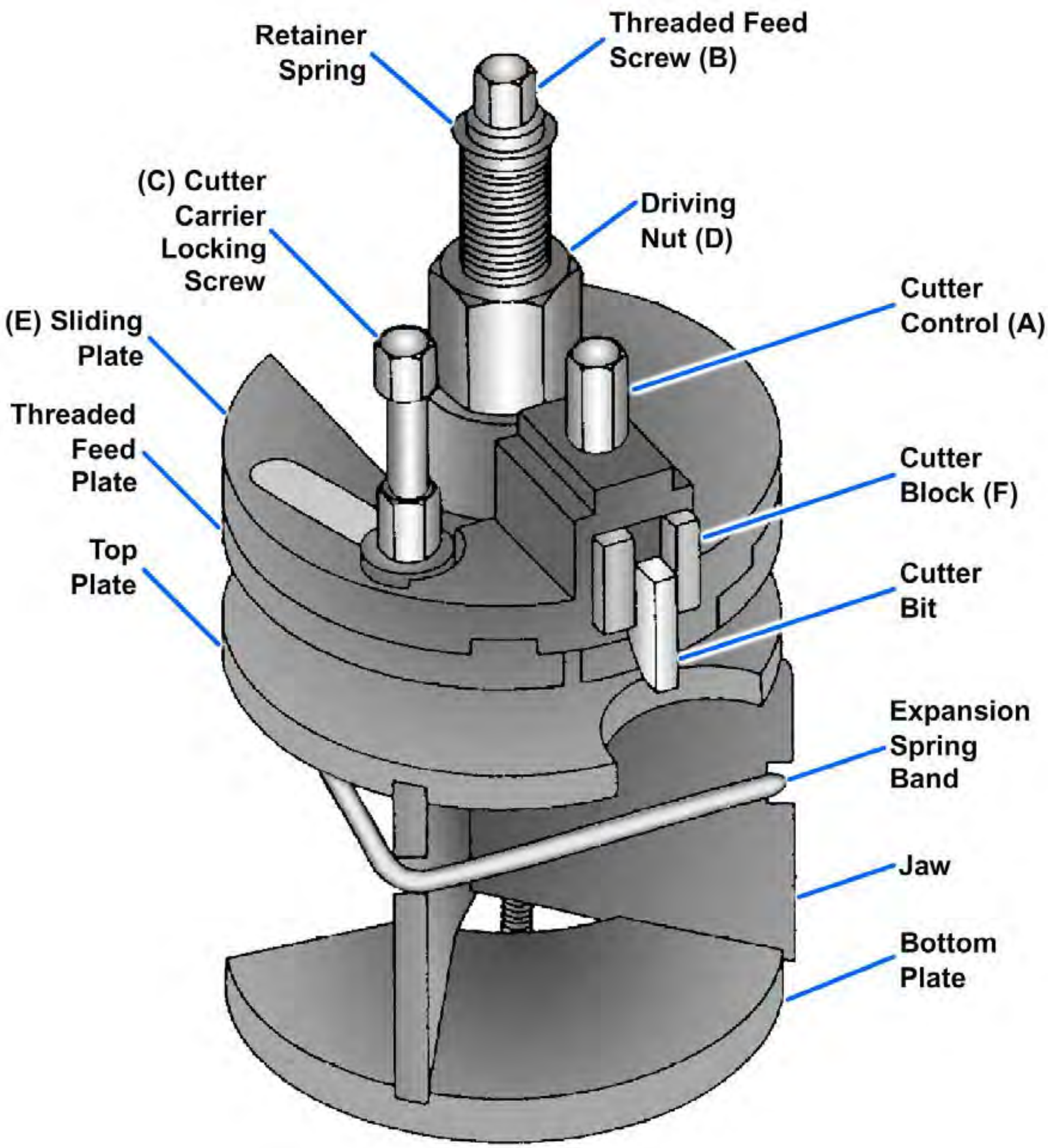

Figure 3-16 — Typical ridge reamer.

Cylinder Hone

To reuse the cylinder sleeve, you must refinish the glazed surface caused by piston ring travel. Honing will remove high spots and a slight taper or out-of-roundness. Do NOT hone new or chromium-plated liners unless specified by the liner manufacturer. *Figure 3-17* shows a typical cylinder hone.

Before you use a cylinder hone, read or review the operator's manual. When you use a hone, use only an approved cleaning solvent and ensure that there is adequate ventilation in the work area. When solvent fumes are present, do not allow eating, drinking, smoking, open flames, or lights in the work area. Dispose of hazardous materials, such as solvent-soaked rags and used solvents, properly.

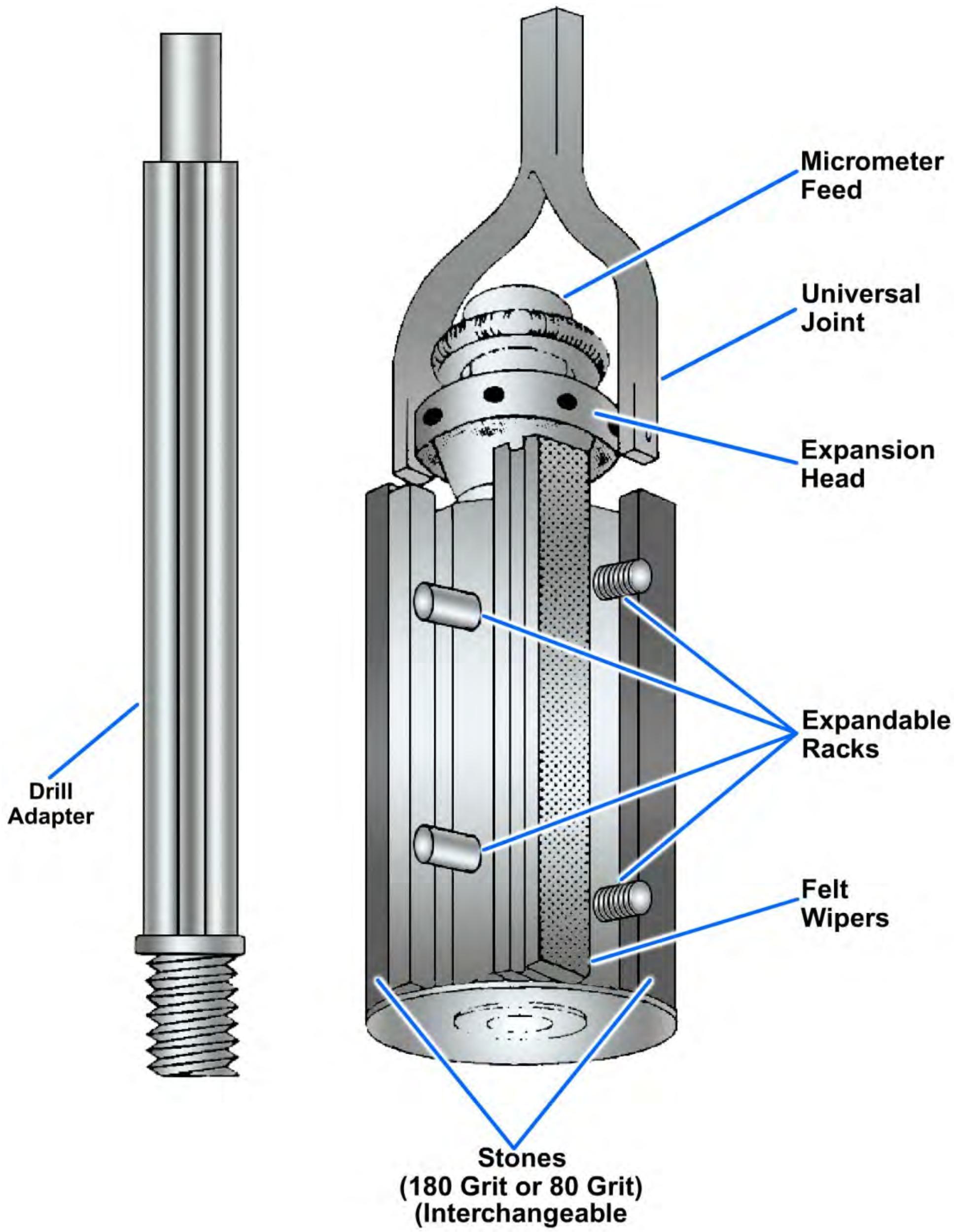

Figure 3-17 — Typical cylinder hone.

Engine Test Equipment

When an engine has been repaired or overhauled, it may need to be tested for proper operation and power output. A piece of test equipment used to conduct such tests is the dynamometer. The dynamometer is used to apply specific loads to an engine. It allows the technician to inspect and check the engine while it is operating. The dynamometer absorbs and measures the engine's output. The basic components of a dynamometer are the frame, engine mounts, absorption unit, heat exchanger, and torque and measuring device. To properly operate a dynamometer you must complete a shop qualifications course. Dynamometers are found primarily in shore activity shops. For maintenance, refer to the assigned Planned Maintenance System (PMS) for the equipment. If your shop has no PMS maintenance for the dynamometer, follow the maintenance schedule recommended by the manufacturer.

Summary

In this chapter, you have learned to identify the necessary measuring and repair instruments and their basic components and how to use them. Additionally, you have learned basic information about the dynamometer, its operation and maintenance. For additional information about basic measuring and repair instruments and the dynamometer, refer to each item's manufacturer's manual, assigned PMS, and your work center's shop equipment qualifications program.

End of Chapter 3

Precision and Measuring Instruments

Review Questions

3-1. What is the correct method to follow when opening a micrometer?

A. Twirl the frame.
B. Hold the knurled sleeve with both hands and twirl the frame.
C. Hold the frame with one hand and turn the knurled sleeve with the other hand.
D. Twirl the knurled sleeve.

3-2. Why must you expose the bore gauge and its special tools to the same environment before measuring?

A. Because it is a good practice to have all the tools and the parts measured in one place
B. Because doing so will give some time to read the bore gauge operating manual
C. Because by doing this, you can check what else you need before starting a measurement
D. Because the temperature differential may cause your reading to be inaccurate

3-3. When a strain/deflection gauge is used, readings are generally taken in how many crank positions?

A. 1
B. 2
C. 4
D. 6

3-4. If you use an extension to a torque adapter, how should the torque be applied to the part or fastener compared to the torque indicated on the torque wrench?

A. The same
B. Greater
C. Less
D. Negative

3-5. In what location would you most likely use a dynamometer?

A. Ship repair locker
B. Tender
C. Shore activity shop
D. Machine shop

3-6. When taking crankshaft End Play or Thrust Reading, which of the following steps is part of the procedure you must use?

A. Attach a dial indicator gauge as far possible away from the vibration damper.
B. Set the dial indicator to zero.
C. Position the dial indicator gauge so the contact point touches the back of the vibration damper.
D. Move the crankshaft away from the dial indicator.

3-7. How does the strain/deflection gauge check crankshaft alignment on large diesel engines?

A. Distance between crank web and journal
B. Distance between crank web and counterweight
C. Distance between counterweight and journal
D. Flexing motion of the web

3-8. Which of the following measurements of speed is not measured by a stroboscope?

A. In-line
B. Vibration
C. Reciprocating
D. Rotating

3-9. Ridge reamers are used to remove ridges on cylinders; how are these ridges formed?

A. Carbon build up from high exhaust temperatures
B. Dirty lube oil
C. Excessive lube oil
D. Piston rings moving up and down in the cylinder

3-10. Most micrometers read down to what fraction on an inch?

A. .00001
B. .0001
C. .001
D. .01

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CHAPTER 4

RECIPROCATING INTERNAL-COMBUSTION ENGINE

The engines with which you will be working will convert heat energy into work by burning fuel in a confined chamber within the engine; thus the term INTERNAL COMBUSTION. Because they have pistons that employ a back-and-forth motion, diesel and gasoline engines are also classified as RECIPROCATING engines. The occupational standards for advancement in the Engineman rating require you to know a great deal about reciprocating internal-combustion engines. Some of the required knowledge has been introduced and explained in the training manual, *Fireman*, NAVEDTRA 14104. This chapter provides additional information to help you to understand the differences between the various types of engines and the principles by which an internal-combustion engine operates.

This chapter is designed to help you understand the maintenance and repair of internal combustion engines. Enginemen should be able to describe the basic procedures used to test and repair diesel engines and identify the procedures used to troubleshoot diesel and gasoline engines. This chapter will cover the general procedures used to repair and overhaul gasoline engines; the procedures used to inspect, test, and repair jacking gear; and the procedures used to troubleshoot and repair fuel and oil purifiers.

To help ensure that an engine will operate efficiently, you must follow its preventive maintenance schedule. You will reduce engine casualties and help the engine achieve its normal number of operating hours between overhaul periods.

When you must finally perform an engine repair or overhaul, take the following precautions:

- Plan the work in definite steps
- Have the necessary tools and parts on hand before you begin a repair or overhaul
- Have the necessary forms ready to record the clearances, dimensions, and other vital measurement readings that must be kept as part of the engine's history
- Always check precision measuring instruments before you use them; then recheck your readings
- Keep the work area clean

The test, maintenance, and repair procedures presented in this chapter are general in nature. The specific procedures vary with different engines. Before you begin a maintenance or repair procedure, consult the manufacturer's technical manual or the equipment's preventive maintenance schedules.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Discuss the cycle of operation of an internal combustion engine.
2. Describe what take place during the mechanical cycle of an internal combustion engine.
3. Explain the difference in combustion cycles for internal combustion engines.
4. Describe the classification of engines according to actions of the pistons in an internal combustion engine.
5. Explain the purpose for inspecting and testing the engine frame or block.
6. Describe how to repair the engine frame or block.

7. Explain the procedures for inspecting, testing, and repairing the cylinder liners.
8. Discuss the routine of inspecting, testing, and repairing cylinder heads.
9. Describe the process of inspecting, testing, and repairing valves and valves assemblies.
10. Explain the procedures for inspecting, maintaining, and repairing piston rings and pistons.
11. Identify the purpose for inspecting, testing, and repairing connecting rods.
12. Describe the procedures for troubleshooting internal combustion engines.
13. List some of the different irregular engine operations.
14. Explain the functions of fuel and lube oil purifiers.

CYCLES OF OPERATION

The operation of an internal-combustion engine involves the admission of fuel and air into a combustion space and the compression and ignition of the charge. The combustion process releases gases and increases the temperature within the space. As temperature increases, pressure increases, and the expansion of gases forces the piston to move. The movement is transmitted through specially designed parts to a shaft. The resulting rotary motion of the shaft is used for work. Thus, the expansion of the gases within the cylinder is transformed into rotary mechanical energy. In order for the process to be continuous, the expanded gases must be removed from the combustion space, a new charge must be admitted, and combustion must be repeated.

In the process of engine operation, beginning with the admission of air and fuel and following through to the removal of the expanded gases, a series of events or phases takes place. The term cycle identifies the sequence of events that takes place in the cylinder of an engine for each power impulse transmitted to the crankshaft. These events always occur in the same order each time the cycle is repeated. The number of events occurring in a cycle of operation depends upon whether the engine is diesel or gasoline. *Table 4-1* shows the events and their sequence in one cycle of operation of each of these types of engines.

Table 4-1 — Sequence of Events in a Cycle of Operation in a Diesel and Gasoline Engine

DIESEL ENGINE	GASOLINE ENGINE
Intake of air.	Intake of fuel and air.
Compression of air.	Compression of fuel-air mixture.
Injection of fuel.	
Ignition and combustion of charge.	Ignition and combustion of charge.
Expansion of gases.	Expansion of gases.
Removal of waste.	Removal of waste.

The principal difference, as shown in the table, in the cycles of operation for diesel and gasoline engines involves the admission of fuel and air to the cylinder. While this takes place as one event in a gasoline engine, it involves two events in a diesel engine. Consequently, there are six main events that take place in the cycle of operation of the diesel engine and five main events that take place in the cycle of the gasoline engine. The number of events that take place is NOT identical to the number of piston strokes that occur during a cycle of operation. Even though the events of a cycle are closely related to piston position and movement, ALL of the events will take place during a cycle regardless of the number of piston strokes involved. A cycle of operation in either a diesel or gasoline engine involves two basic factors—heat and mechanics. The means by which heat energy is transformed into mechanical energy involves many terms such as matter, molecules, energy, heat, temperature, the mechanical equivalent of heat, force, pressure, volume, work, and power. The method by which an engine operates is referred to as the MECHANICAL, or operating, CYCLE of an engine. The heat process that produces the forces that move engine parts is referred to as the COMBUSTION CYCLE. Both mechanical and combustion cycles are included in a cycle of operation of an engine.

MECHANICAL CYCLES

We have talked about the events taking place in a cycle of engine operation, but we have said very little about piston strokes except that a complete sequence of events will occur during a cycle regardless of the number of strokes made by the piston. The number of piston strokes occurring during any one cycle of events is limited to either two or four, depending on the design of the engine. Thus, we have a 4-stroke cycle and a 2-stroke cycle. These cycles are known as the mechanical cycles of operation.

Mechanical cycles, 4-stroke and 2-stroke, are used in both diesel and gasoline reciprocating engines; most gasoline engines in Navy service operate on the 4-stroke cycle, most diesels operate on the 2-stroke cycle. You may be required to operate and maintain engines that operate on either of these mechanical cycles. You should be familiar with the principal differences in these cycles. The relationship between the events and piston strokes occurring in a cycle of operation involves some of these differences. A thorough understanding of the relationship will aid you in carrying out your duties in connection with engine operation and maintenance.

Relationship of Events and Strokes in a Cycle

A piston stroke is the distance a piston moves between limits of travel. The cycle of operation in an engine that operates on the 4-stroke cycle involves four piston strokes—INTAKE, COMPRESSION, POWER, and EXHAUST. In the 2-stroke cycle, only two strokes are involved—POWER and COMPRESSION. The strokes are named to correspond with the events. However, since six events are listed for diesel engines, more than one event must take place during some of the strokes, especially in the 2-stroke cycle. Even so, it is common practice to identify some of the events as strokes of the piston. This is because such events as intake, compression, power, and exhaust in a 4 stroke cycle involve at least a major portion of a stroke and, in some cases, more than one stroke. The same is true of power and compression events and strokes in a 2-stroke cycle. In associating the events with strokes, you should not overlook other events taking place during a cycle of operation. You will have to consider all events in the operation of an engine when you begin to deal with maintenance problems involving the timing of fuel injection systems.

4-Stroke Cycle Diesel Engine

To help you understand the relationship between events and strokes, we will discuss the number of events that occur during a specific stroke. We will also discuss the duration of an event with respect to a piston stroke and the cases where one event overlaps another. We can demonstrate the relationship of events to strokes by showing the changing situation in a cylinder during a cycle of operation. *Figure 4-1, frames 1 through 6* illustrates these changes for a 4-stroke cycle diesel engine.

The relationship of events to strokes is more readily understood if the movements of a piston and its crankshaft are considered first. In *Figure 4-1,* each view showing piston travel is reflected on the graph and illustrates the approximate piston position and valve action. Top center and bottom center identify points where changes in direction of motion take place. In other words, when the piston is at top center, upward motion has stopped and downward motion is ready to begin. With respect to motion, the piston is “dead.” Likewise, when the piston is at bottom center, downward motion has stopped and upward motion is ready to begin and the piston is said to be at bottom “dead” center. The points which designate changes in direction of motion for a piston and crank are frequently called

TOP DEAD CENTER (TDC) and BOTTOM DEAD CENTER (BDC). You should keep TDC and BDC in mind since they identify the start and end of a STROKE (180 degrees of crankshaft rotation) and since they are the points from which the start and end of EVENTS are established.

Let's pick up the action of the piston of a 4-stroke cycle engine as it moves up the cylinder towards TDC. Refer to *Figure 4-1,* and locate the top arrow labeled EXHAUST EVENT OF PRECEDING CYCLE. This arrow indicates that the exhaust valve or valves at the top of the cylinder are open as the piston reaches TDC. And, several degrees after TDC, the dashed line indicates that the exhaust valves are closed. Now, locate the arrow labeled INTAKE EVENT (AIR). Notice that this arrow starts at the same point in the cycle as the exhaust event for the preceding cycle. The shaded parts of the two top arrows indicate that during this part of the cycle, both the intake and exhaust valves will be open. This is necessary because the incoming air must be allowed to flow through the cylinder to "sweep out" or scavenge any exhaust gases remaining from the preceding combustion event. The remainder of the arrow labeled INTAKE EVENT (AIR) shows that the intake valves remain open as the piston moves toward BDC and slightly past BDC. The dashed line just past BDC indicates when the intake valves are closed, and the compression stroke begins. Now, the piston continues moving up to compress the air trapped in the cylinder, because during this event, both the intake and exhaust valves are closed. The action of the pistons in compressing the air rapidly increases the pressure within the cylinder. This action, in turn, results in a rapid increase in temperature. The increase in temperature occurs because the molecules of air are being squeezed into a smaller and smaller space. Just before the piston reaches TDC, fuel is injected into the cylinder as a spray of finely atomized droplets (very tiny drops). As some of the molecules of the hydrocarbon fuel come into contact with hot molecules of oxygen, the combustion process begins. The rapid burning of the fuel as it mixes with the oxygen results in a drastic increase in temperature and pressure as the gases released by the combustion process expand. Since the piston is free to move, the rapidly expanding gases force the piston to begin its downward stroke, which is indicated by the arrow labeled POWER EVENT (EXPANSION OF GASES). The power stroke continues to the point indicated by the dashed line, at which time the exhaust valves open. The arrow labeled EXHAUST EVENT (WASTE GASES) shows that the exhaust valves are open as the piston moves towards BDC . . . past BDC . . . and up towards TDC, at which point the cycle of events repeats.

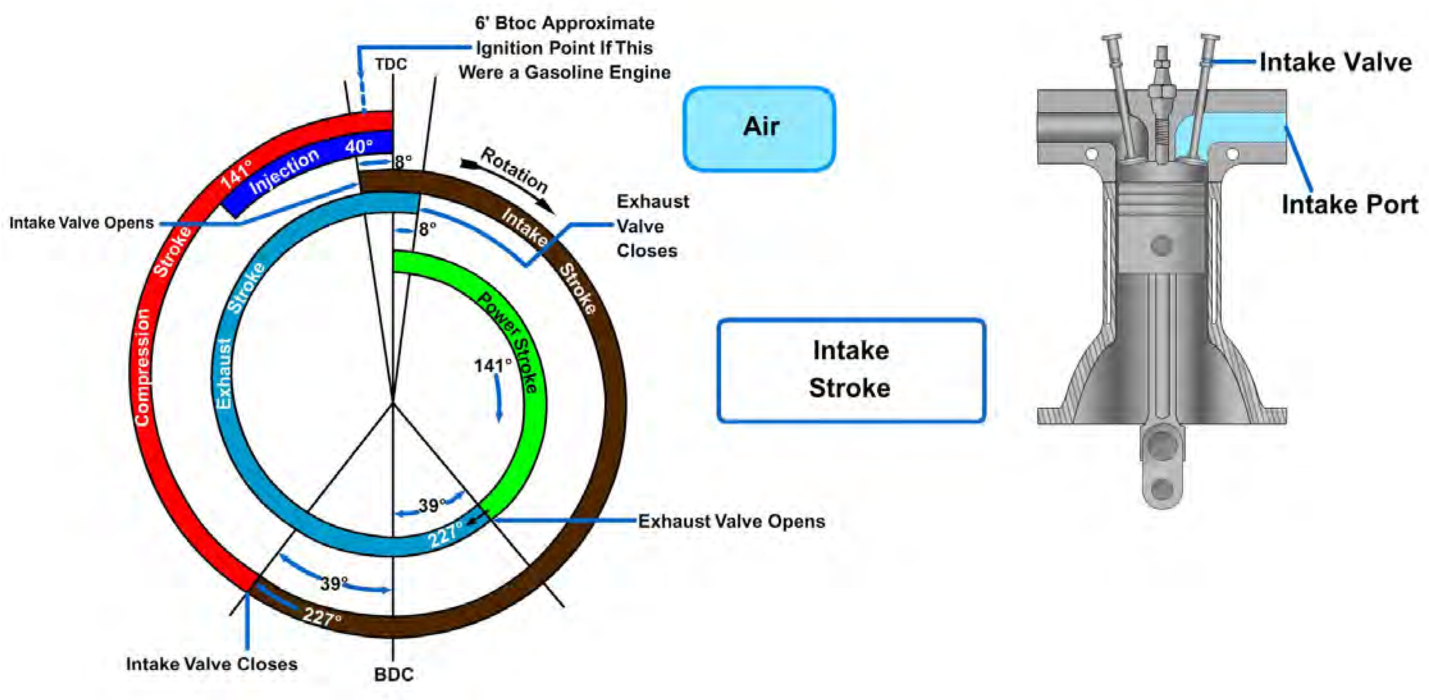

Figure 4-1 — Strokes and events in a 4-stroke cycle diesel engine.

In summary, during the 4-stroke cycle, the piston moves up and down within the cylinder, and the crankshaft makes two complete revolutions, for a total travel of 720 degrees. In other words, 4-stroke cycle engines have only one power event per cylinder during 720 degrees of crankshaft rotation.

2-Stroke Cycle Diesel Engine

Now let's analyze the sequence of events for a 2-stroke cycle engine. Refer to *Figure 4-2*. First of all, you should be aware of one of the primary physical differences between 4-stroke and 2-stroke cycle engines: 2-stroke engines do not use intake valves. To work properly, a 2-stroke engine must have some means of forcing air into the cylinder for the scavenging event. Two-stroke diesel engines may use an external blower or turbocharger (or both) to perform this function. Notice the location of the ports in the cylinder through which air must flow. They are located near the bottom of the cylinder.

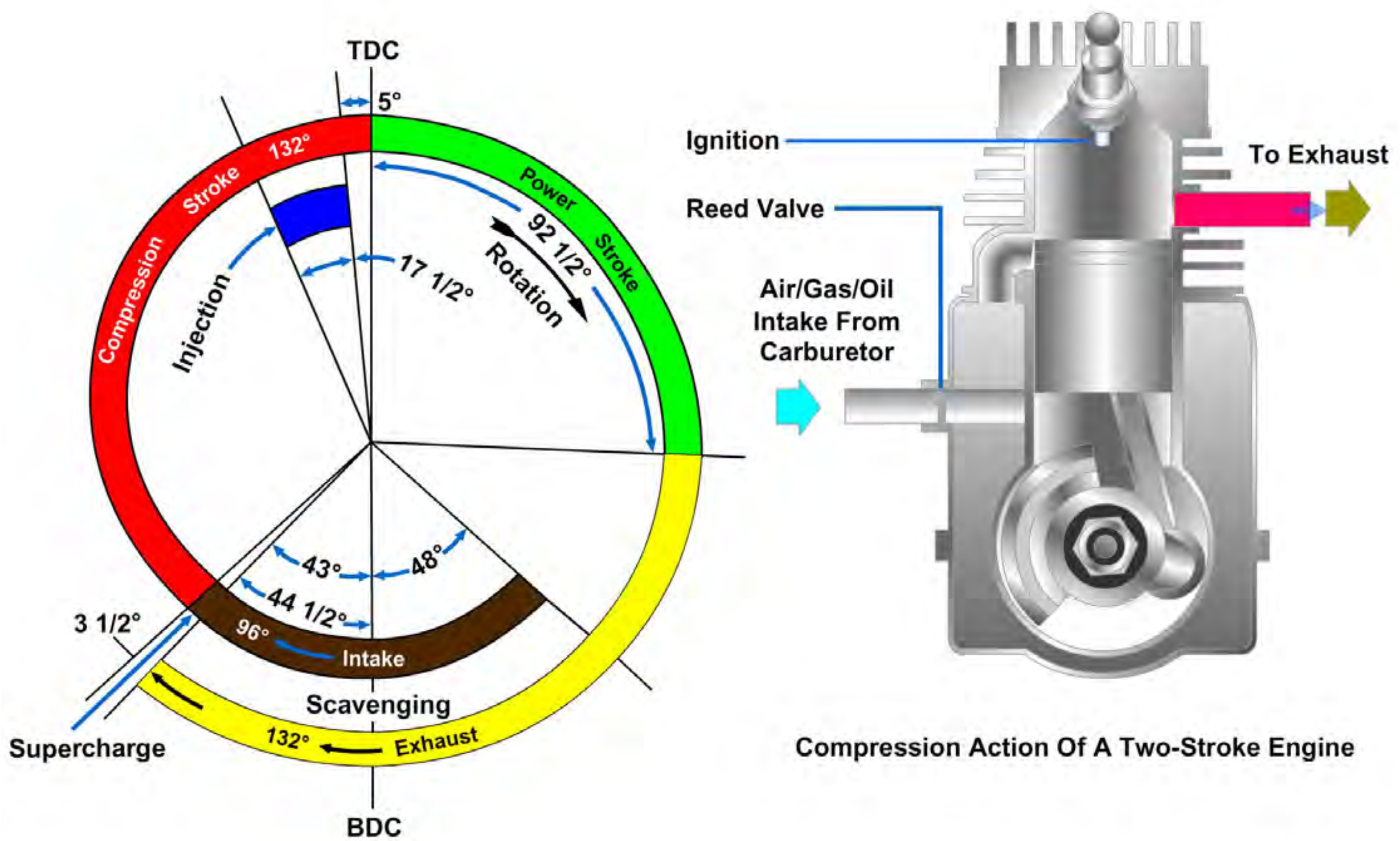

Figure 4-2 — Strokes and events in a 2-stroke cycle diesel engine cylinder.

Now, let's take a look at the 2-stroke cycle of events. Locate the engine labeled SCAVENGING. The scavenging event (which is very similar to the air intake event of a 4-stroke cycle engine) begins almost 45 degrees BEFORE the piston reaches BDC. During this time, the exhaust valve or valves are open. As the piston moves down to BDC, it uncovers the ports near the bottom of the cylinder. (This arrangement serves the same function as the intake valves in a 4-stroke cycle engine). The blower on the side of the engine forces air to flow into the bottom of the cylinder and out through the exhaust valves at the top of the cylinder. This action serves to scavenge any exhaust gases that might remain in the cylinder and to fill the cylinder with a fresh "charge" of air. The first dashed line to the left of BDC shows that the exhaust valves are shut at this point. The piston continues to move up and the next dashed line shows the point at which the intake ports are blocked by the piston. At this point, the compression stroke begins. The piston compresses the air within the cylinder, causing its pressure and temperature to increase rapidly. At a point several degrees before the piston reaches TDC, fuel is injected into the cylinder. The heat of the compressed air ignites the fuel and the process of combustion causes a drastic increase in temperature and pressure within the cylinder. The rapid expansion of combustion gases forces the piston to move down for the power stroke. The power stroke continues until the exhaust valves are open. This part of the cycle indicates the beginning of the exhaust event. In summary, a 2-stroke engine cycle will have one power event per cylinder for every 360 degrees of rotation of the crankshaft.

Comparison of 2-Stroke and 4-Stroke Cycle Diesel Engines

Figure 4-3 shows a comparison of the events that occur during the same length of time for both 2-stroke and 4-stroke cycle engines. The graph shows that, during the same amount of time, a 2-stroke engine will have two power events while a 4-stroke engine will have only one. This might lead you to believe that 2-stroke cycle engines are more efficient than 4-stroke engines; however, that is not the case. In order to work properly, a 2-stroke engine must have some method of forcing air into and through the cylinders. And, since this air pump (blower) is driven by the engine, it robs some of the horsepower that would otherwise be available to drive the load. Also, the combustion process in a 2-stroke engine is not as complete as it is in a 4-stroke cycle engine. Since each type of engine has certain advantages over the other, the Navy uses both 2-stroke and 4-stroke cycle engines for main propulsion and electrical generating service.

The illustrations we have used to represent the cycles of operation are for demonstration purposes only. The exact number of degrees before or after TDC or BDC at which an event starts and ends will vary among engines.

Diagrams that show the mechanical cycles of operation in gasoline engines are somewhat similar to those described in this chapter for diesel engines, except that there would be one less event taking place during the gasoline engine cycle. Since air and fuel are admitted to the cylinder of a gasoline engine as a mixture during the intake event, the injection event does not apply.

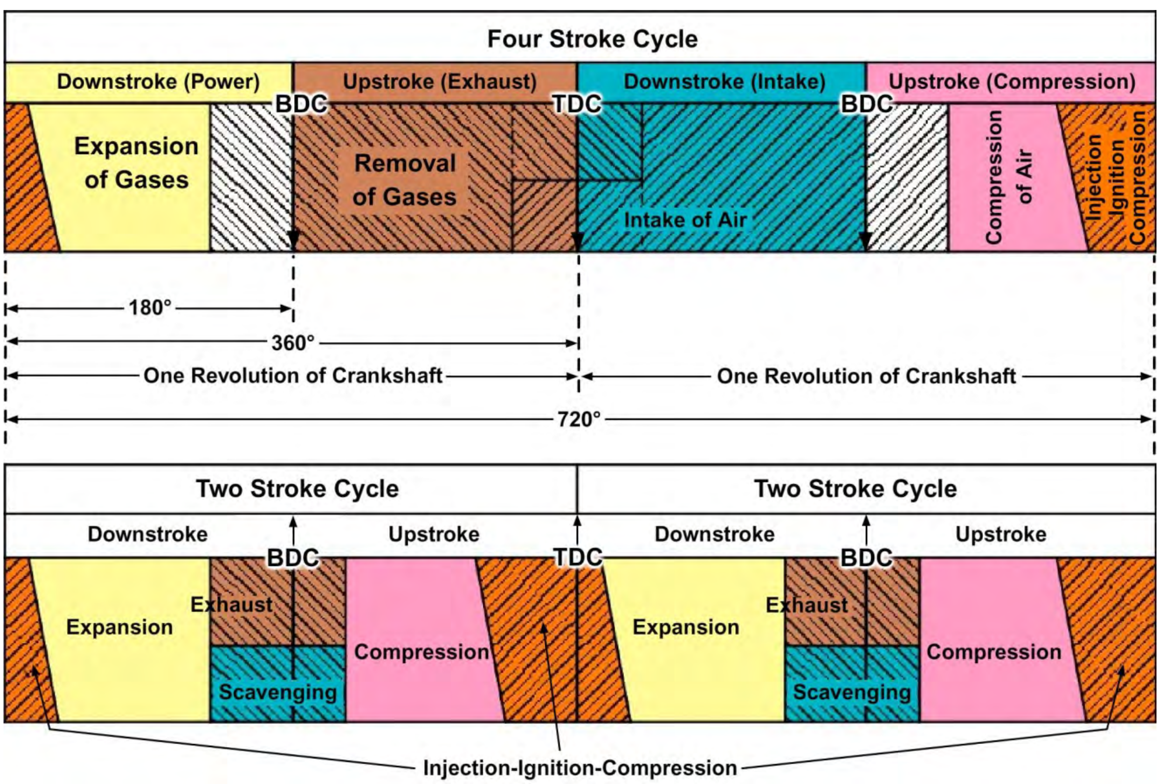

Figure 4-3 — Comparison of the 2- and 4-stroke cycles.

COMBUSTION CYCLES

We cannot discuss the mechanics of engine operation without dealing with heat. Such terms as ignition, combustion, and expansion of gases indicate that heat is essential to a cycle of engine operation.

Of the principal differences between these types of engines must involve the heat processes that produce the forces that make the engine operate. The heat processes are sometimes called COMBUSTION or HEAT CYCLES.

The two most common combustion cycles associated with reciprocating internal-combustion engines are the OTTO cycle (gasoline engines) and the DIESEL cycle (diesel engines). Each of these combustion cycles will be discussed.

In talking about combustion cycles, we must bring up another important difference between gasoline and diesel engines—the difference in COMPRESSION PRESSURE. Compression pressure is directly related to the combustion process in an engine. Diesel engines have a much higher compression pressure than gasoline engines. The higher compression pressure in diesels explains the difference in the methods of ignition used in gasoline and diesel engines.

Methods of Ignition

When the gases within a cylinder are compressed, the temperature of the confined gases rises. As the compression increases, the temperature rises. In a gasoline engine, the compression temperature is always lower than the point at which the fuel will ignite spontaneously. Thus, the heat required to ignite the fuel must come from an external source (spark plug). This method is referred to as SPARK IGNITION. On the other hand, the compression temperature in a diesel engine is far above the ignition point of the fuel oil. Therefore, ignition of the fuel takes place as a result of heat generate by compression of the air within the cylinder, an action referred to as COMPRESSION IGNITION.

The difference in the methods of ignition that there is a basic difference in the combustion cycles upon which diesel and gasoline engines operate. The difference involves the behavior of the combustion gases under varying conditions of pressure, temperature, and volume. Since this is so, you should be familiar with the relationship of these factors before considering the combustion cycles individually. (The basic laws and processes involved in a volume, temperature, and pressure relationship are discussed under the properties of gases in Fireman, NAVEDTRA 14104.) You should also be aware that compression ratio (clearance volume) refers to the comparison between the volume above the piston at BDC to the volume above the piston at TDC.

Relationship of Temperature, Pressure, and Volume

The relationship of temperature, pressure, and volume as found in an engine can be illustrated by a description of what takes place in a cylinder that is fitted with a reciprocating piston (*Figure 4-4, frames 1-4)*. Note the instruments that indicate the pressure within the cylinder and that the temperature both inside and outside the cylinder is approximately 70 °F. Assume the cylinder is an airtight container, as it is in our example. Now compare *frames 1 and 2* of *Figure 4-4*. If a force pushes the piston toward the top of the cylinder, the entrapped charge is compressed. In *Figure 4-4, frames 2 and 3*, the compression progresses. The VOLUME of the air DECREASES, the PRESSURE INCREASES, and the TEMPERATURE RISES. These changing conditions continue as the piston moves. When the piston nears TDC (*Figure 4-4, frame 4)* there has been a marked decrease in volume. Also, both pressure and temperature are much greater than at the beginning of compression. Notice that the pressure has gone from 0 psi to 470 psi and the temperature has increased from 70 °F to approximately 450 °F. These changing conditions indicate that mechanical energy in the form of force applied to the piston has been transformed into heat energy in the compressed air. The temperature of the air has been raised sufficiently to cause ignition of the fuel that is injected into the cylinder.

Further changes take place after ignition. Since ignition occurs shortly before TDC, there is little change in volume until the piston passes TDC. However, there is a sharp increase in both pressure and temperature shortly after ignition takes place. The increased pressure forces the piston downward. As the piston moves downward, the gases expand (increase in volume), and pressure and temperature decrease rapidly. These changes in volume, pressure, and temperature are representative of the changing conditions in the cylinder of a diesel engine.

In comparison with the requirement of a diesel engine, a gasoline engine needs a lower compression ratio and lower combustion chamber temperatures. The reason for this is that the heat of compression of a diesel engine would ignite a gasoline and air mixture before the piston could approach the top of its stroke. This pre-ignition would tend to drive the piston back down the cylinder and place an excessive, damaging strain on the engine. As a rule, gasoline engines use compression ratios under 10:1. It is the electric spark that causes ignition of the fuel to occur.

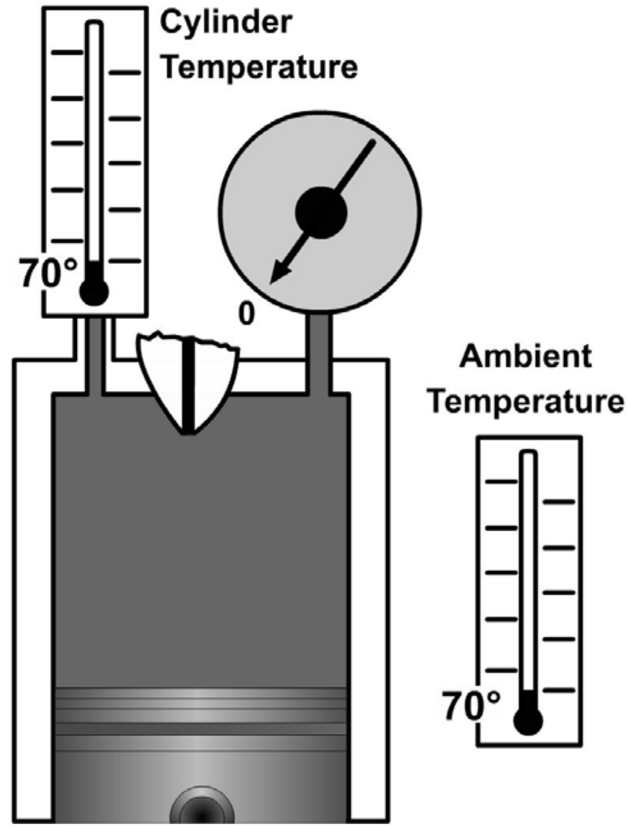

Figure 4-4 — Volume, temperature, and pressure relationships in a cylinder.

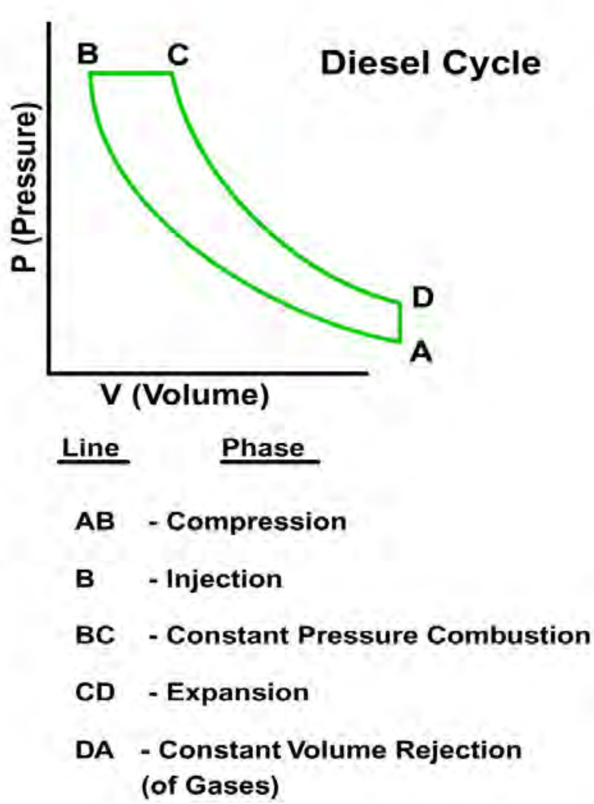

Figure 4-5 — Pressure-volume diagrams for theoretical combustion cycles.

The changes in volume and pressure in an engine cylinder can be illustrated by diagrams similar to those shown in *Figure 4-5, frames 1 and 2*. Such diagrams are made by devices that measure and record the pressures at various piston positions during a cycle of engine operation. Diagrams such as these that show the relationship between pressures and corresponding piston positions are called PRESSURE-VOLUME DIAGRAMS or INDICATOR CARDS.

On diagrams that provide a graphic representation of cylinder pressure as related to volume, the vertical line P on the diagram represents pressure and the horizontal line V represents volume (*Figure 4-5*). When a diagram is used as an indicator card, the pressure line is marked off in inches. Thus, the volume line can be used to show the length of the piston stroke that is proportional to volume. The distance between adjacent letters on each of the diagrams *(Figure 4-5, frames 1 and 2)* represents an event of a combustion cycle. A combustion cycle includes compression of air, burning of the charge, expansion of gases, and removal of gases.

The diagrams shown in *Figure 4-5* provide a means by which the Otto and diesel combustion cycles can be compared. Referring to the diagrams as we discuss these combustion cycles will help you to identify the principal differences between these cycles. The diagrams shown are theoretical pressure-volume diagrams. Diagrams representing conditions in operating engines will be given later.

In theory, the Otto combustion cycle is one in which combustion, caused by an electric spark, and occurs at constant volume. The Otto cycle and its principles serve as the basis for modern gasoline engine design. In the Otto cycle (*Figure 4-5, frame 1),* compression of the charge in the cylinder occurs at line AB. Spark ignition occurs at point B. Because of the volatility of the mixture, combustion practically amounts to an explosion. Combustion, represented by line BC, occurs (theoretically) just as the piston reaches TDC. During combustion, there is almost no piston travel. Thus, there is no change in the volume of the gas in the cylinder. This lack of change in volume accounts for the descriptive term, CONSTANT VOLUME. During combustion, there is a rapid rise in temperature followed by a pressure increase. The pressure increase performs the work during the expansion phase, as represented by line CD in *Figure 4-5*. The removal of gases, represented by line DA in *Figure 4-5*, is at CONSTANT VOLUME.

When discussing diesel engines, we must point out that there is a difference between the theoretical, or “true,” diesel cycle and the “actual” diesel cycle that really occurs in an operating diesel engine. The true diesel cycle may be defined as one in which combustion, induced by compression ignition, theoretically occurs at a constant pressure. Compression (*Figure 4-5, frame 2*) of the air (line AB) increases its temperature to a point that ignition occurs automatically when the fuel is injected. Fuel injection and combustion are controlled to give constant pressure combustion (line BC). This phase is followed by expansion (line CD) and CONSTANT-VOLUME REJECTION of the gases (line DA).

In the true diesel cycle, the burning of the mixture of fuel and compressed air is a relatively slow process when compared with the quick, explosive type of combustion process of the Otto cycle. In the true diesel cycle, the injected fuel penetrates the compressed air, some of the fuel ignites, then the rest of the charge bums. The expansion of the gases keeps pace with the change in volume caused by piston travel. Thus, combustion is said to occur at CONSTANT PRESSURE (line BC).

Actual Combustion Cycles

The preceding discussion covered the theoretical (true) combustion cycles which serve as the basis for modern engines. In actual operation, modern engines operate on modifications of the theoretical cycles. However, some characteristics of the true cycles are incorporated in the actual cycles of modern engines, as you will see in the following discussion of examples representing the actual cycles of operation in gasoline and diesel engines.

The examples we will use are based on the 4-stroke mechanical cycle so that you may compare the cycles found in both gasoline and diesel engines. (The majority of gasoline engines use this 4-stroke mechanical cycle.) We will also point out differences existing in diesel engines operating on the 2-stroke cycle. The diagrams in *Figure 4-6, frames 1-2 and Figure 4-7* are representative of the changing conditions in a gasoline and a diesel cylinder during actual engine operation. Some of the events are exaggerated to show more clearly the changes that take place and, at the same time, to show how the theoretical and actual cycles differ.

The compression ratio situation and a pressure-volume diagram for a 4-stroke Otto cycle are shown in *Figure 4-6, frame 2* shows the piston on BDC at the start of an upstroke. (In a 4-stroke cycle engine, this stroke could be identified as either the compression stroke or the exhaust stroke.) Study *Figure 4-6, frames 1 and 2*. Notice that in moving from BDC to TDC (*Figure 4-6, frame 2)*, the piston travels five-sixths of the total distance AB. In other words, the VOLUME has been decreased to one-sixth of the volume when the piston was BDC. Thus, the compression ratio is 6:1.

Figure 4-6, frame 1 shows the changes in volume and pressure during one complete 4-stroke cycle. Notice that lines representing the COMBUSTION and EXHAUST phases are not as straight as they were in the theoretical diagram. The vertical line at the left represents cylinder pressure in pounds per square inch (psi). Atmospheric pressure is represented by a horizontal line called the ATMOSPHERIC PRESSURE LINE. Pressures below this line are less than atmospheric pressure, while pressures above the line are more than atmospheric. The bottom horizontal line represents cylinder volume and piston movement. The volume line is divided into six parts that correspond to the divisions of volume shown in view A. Since piston movement and volume are proportional, the distance between 0 and 6 indicates the volume when the piston was at BDC, and the distance from 0 to 1 indicates the volume with the piston at TDC. Thus, the distance from 1 to 6 corresponds to total piston travel with the numbers in between identifying changes in volume that result from the reciprocating motion of the piston. The curved lines in *Figure 4-6, frame 1* represents the changes of both pressure and volume that take place during the four piston strokes of the cycle.

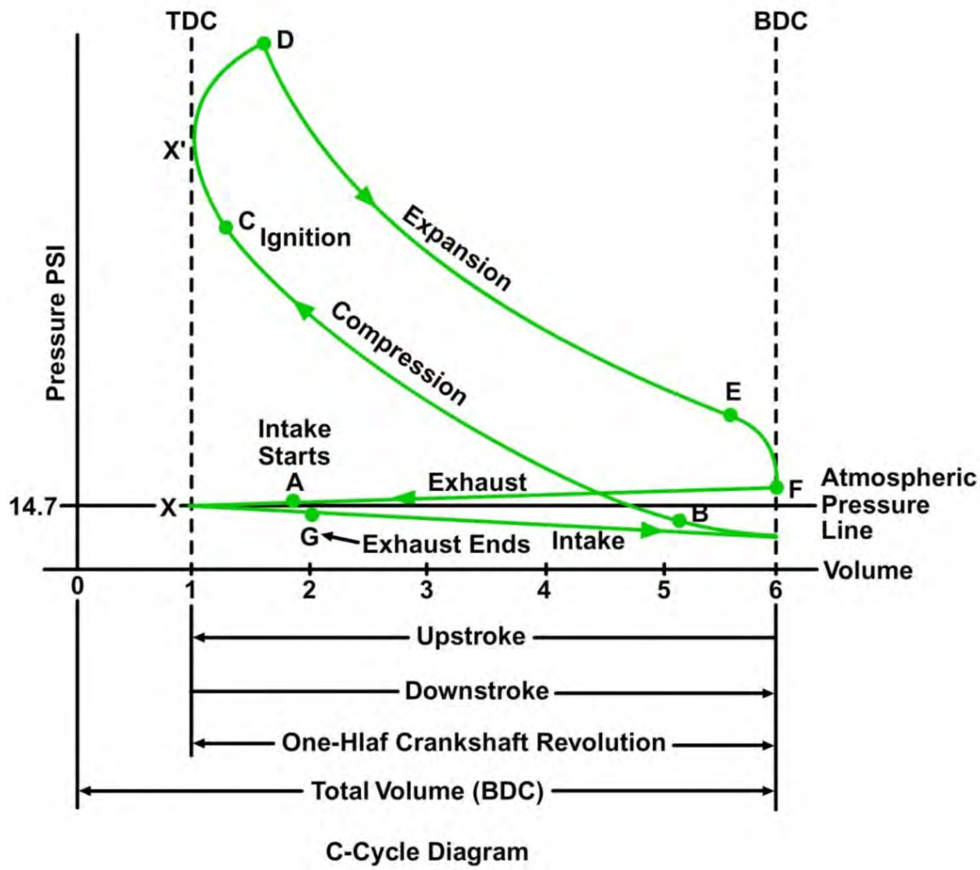

Figure 4-6 — Pressure–volume diagram for an Otto gasoline 4-stroke cycle.

To make it easier for you to compare the discussion on the relationship of strokes and events in the diesel 4-stroke cycle (*Figure 4-1*) with the discussion on the Otto 4-stroke cycle (*Figure 4-6*), we will begin the cycle of operation at the INTAKE. Refer to *Figure 4-6*. In the Otto cycle, the INTAKE event includes the admission of fuel and air. As indicated earlier, the INTAKE event starts before TDC, or at point A in *Figure 4-6, frame 1*. Note that pressure is decreasing and that after the piston reaches TDC and starts down, a vacuum is created that facilitates the flow of the fuel-air mixture into the cylinder. The INTAKE event continues a few degrees past BDC and ends at point B. Since the piston is now on an upstroke, COMPRESSION takes place and continues until the piston reaches TDC. Notice the increase in pressure (X to X') and the decrease in volume (F to X). Spark IGNITION at point C starts COMBUSTION, which takes place very rapidly. There is some change in volume since the COMBUSTION phase starts before TDC and ends after TDC.

Pressure increases sharply during the COMBUSTION phase (curve CD). The increase in pressure provides the force necessary to drive the piston down again. The gases continue to expand as the piston moves toward BDC. The pressure decreases as the volume increases, from D to E. The EXHAUST event starts at point E, a few degrees before BDC. The pressure drops rapidly until the piston reaches BDC. As the piston moves toward TDC, there is a slight drop in pressure as the waste gases are discharged. The EXHAUST event continues a few degrees past TDC to point G so that the incoming charge aids in removing the remaining waste gases.

The actual diesel combustion cycle (*Figure 4-7*) is one in which the COMBUSTION phase, induced by COMPRESSION/IGNITION, begins on a constant-volume basis and ends on a constant-pressure basis. In other words, the ACTUAL CYCLE is a combination of features found in both the Otto and the theoretical diesel cycles. The actual cycle is used as the basis for the design of practically all modern diesel engines and is referred to as a MODIFIED DIESEL CYCLE.

An example of a pressure-volume diagram for a modified 4-stroke diesel engine is shown in *Figure 4-7*. Notice that the volume line is divided into 16 units. These units indicate a 16:1 compression ratio. The higher compression ratio accounts for the increased temperature necessary for ignition of the charge. Fuel is injected at point C and COMBUSTION is represented by line CD. While combustion in the Otto cycle is at constant-volume practically throughout the phase, combustion in the actual diesel cycle takes place with volume that is practically constant for a short period of time. During this period of time, there is a sharp increase in pressure until the piston reaches a point slightly past TDC. Then, combustion continues at a relatively constant pressure which drops slightly as combustion ends at point D.

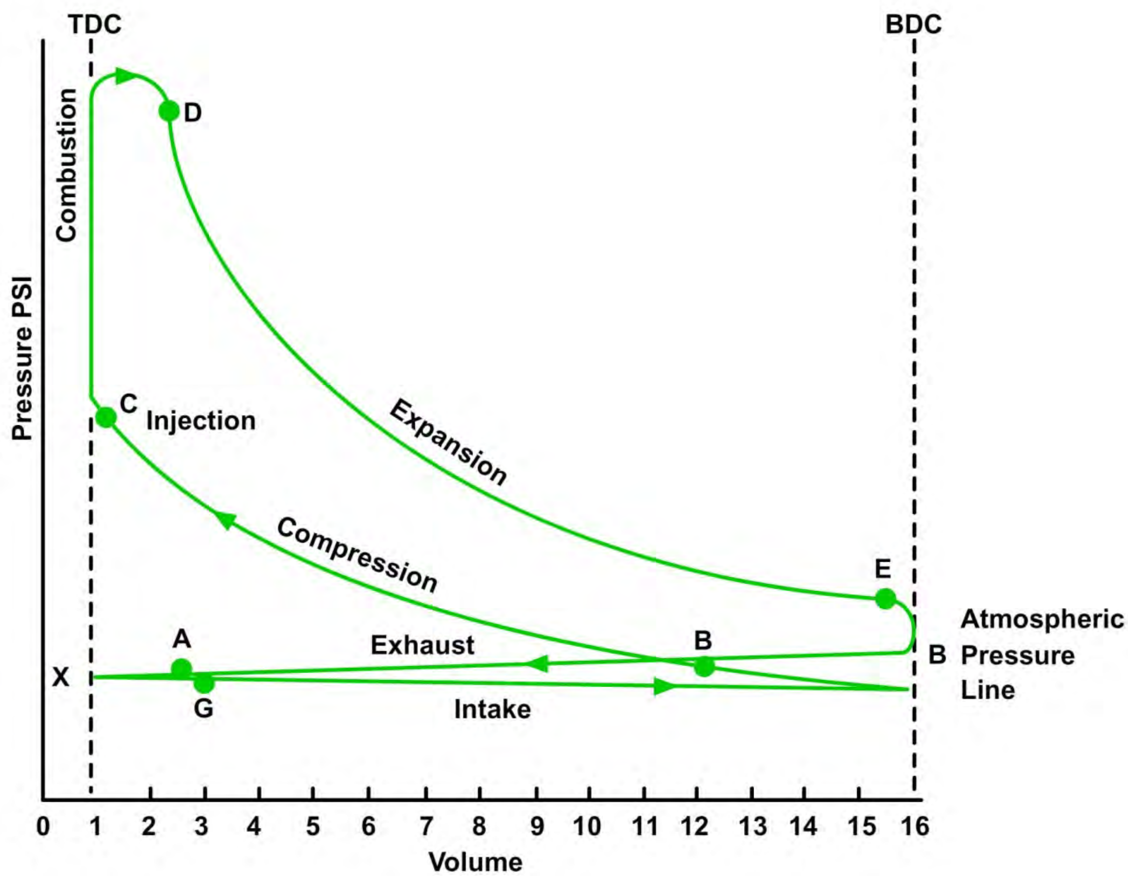

Figure 4-7 — Pressure-volume diagram for a diesel 4-stroke cycle.

Pressure-volume diagrams for gasoline and diesel engines that operate on the 2-stroke cycle are similar to those just discussed. The only difference is that separate exhaust and intake curves do not exist. They do not exist because intake and exhaust occur during a relatively short interval of time near BDC and do not involve full strokes of the piston as in the 4-stroke cycle. Thus, a pressure-volume diagram for a 2-stroke modified diesel cycle will be similar to the diagram formed by the F-B-C-D-E-F cycle illustrated in *Figure 4-7*. The exhaust and intake phases will take place between E and B with some overlap of the events (*Figure 4-2*).

The preceding discussion has pointed out some of the main differences between engines that operate on the Otto cycle and those that operate on the diesel cycle. These differences include:

- Mixing of fuel and air
- Compression ratio
- Method of ignition
- Combustion process

In regard to differences in engines, there is another variation you may find in the engines you operate and maintain. Sometimes, the manner in which the pressure of combustion gases acts upon the piston is used as a method of classifying engines. This method of classification is discussed in the information that follows.

CLASSIFICATION OF ENGINES ACCORDING TO THE ACTION OF PRESSURE ON PISTONS

Engines are classified in many ways. You are already familiar with some classifications, such as those based on:

1. The fuels used (diesel fuel and gasoline).
2. The ignition methods (spark and compression).
3. The combustion cycles (Otto and diesel).
4. The mechanical cycles (2-stroke and 4-stroke).

Additional information will be given in subsequent chapters of this manual on some of the factors related to the above classifications as well as to other types of classifications, such as those based on:

1. The cylinder arrangements (V, in-line, opposed).
2. The cooling media (liquid and air).
3. The way air enters the cylinder and the exhaust leaves the cylinder (port-scavenging and valve scavenging).

Classification of internal combustion engines according to combustion-gas action is based on whether the pressure created by the combustion gases acts upon one surface of a single piston or against single surfaces of two separate and opposed pistons. The two types of engine under this classification are commonly referred to as SINGLE-ACTING and OPPOSED-PISTON engines.

You should understand that the opposed-piston engine is actually a form of a single-acting engine since pressure is applied to only one surface of the pistons. For the purpose of this rate training manual, we will provide separate discussions on the single-acting (one piston per cylinder) and opposed-piston (two pistons per cylinder) engines.

Single-Acting Engines

Engines of the single-acting type have ONE PISTON per cylinder, with the pressure of combustion gases acting on only one surface of the piston. This is a feature of design rather than of principle, The pistons in most single-acting diesel engines are of the trunk type (length greater than diameter). The barrel or wall of a piston of this type has one end closed (crown) and one end open (skirt). Only the piston crown serves as part of the combustion space surface. Thus, with respect to the surfaces of a piston, pressure is single acting. All 4-stroke cycle engines (*Figure 4-8*) and most 2-stroke cycle engines (*Figure 4-9*) are single acting.

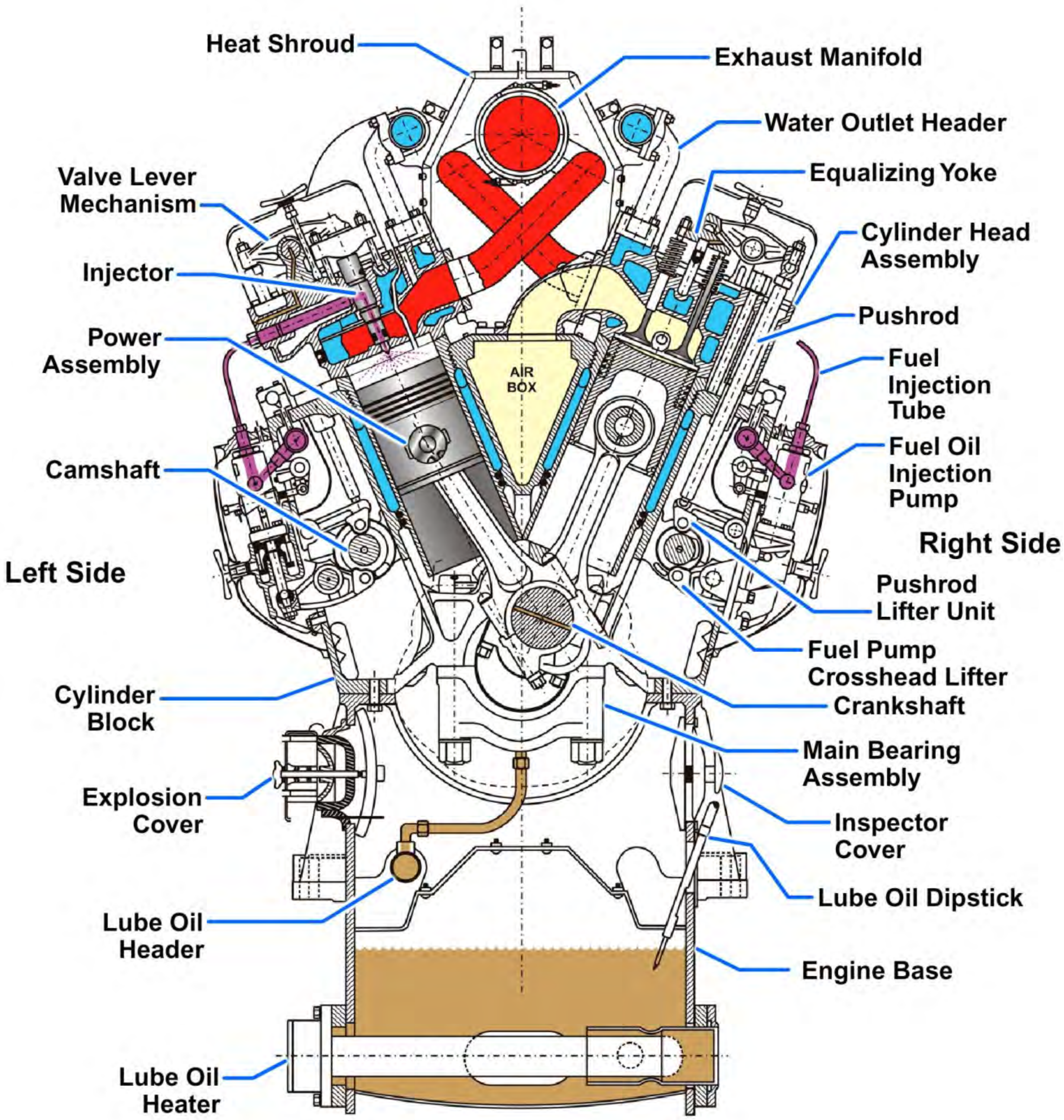

Figure 4-8 — Cross section of a 4-stroke cycle, single-acting engine.

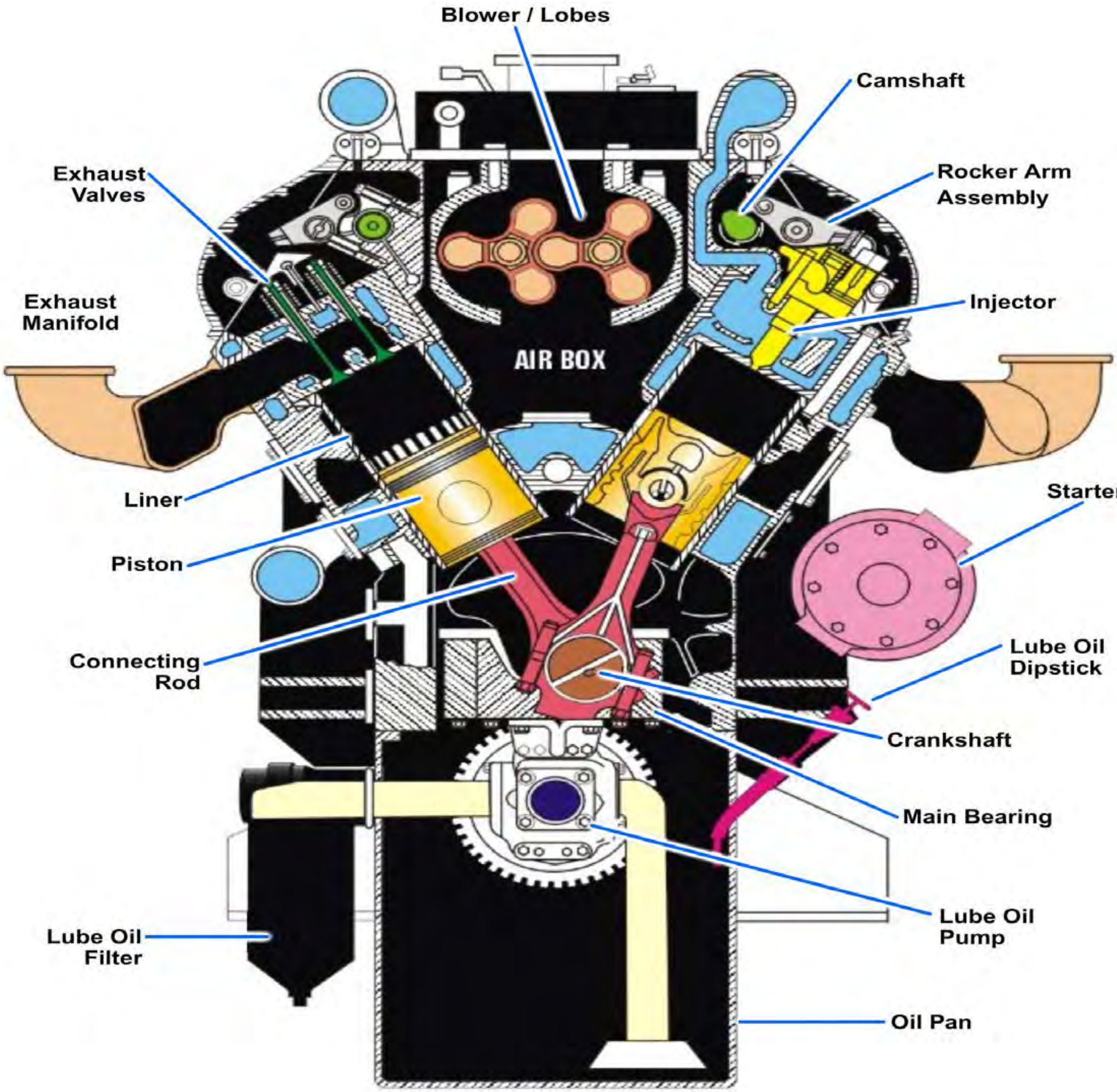

Figure 4-9 — End cross section of a 2-stroke cycle, single-acting diesel engine.

Opposed-Piston Engines

With respect to the combustion-gas action, the term OPPOSED-PISTON identifies those engines that have TWO PISTONS and ONE COMBUSTION SPACE in each cylinder (*Figure 4-10*). The pistons are arranged in opposed positions; that is, crown to crown, with the combustion space in between. When combustion takes place, the gases act against the crowns of both pistons, driving them in opposite directions. Thus, the term opposed not only signifies that the gases act in opposite directions (with respect to pressure and piston surfaces), but also classifies piston arrangement within the cylinder.

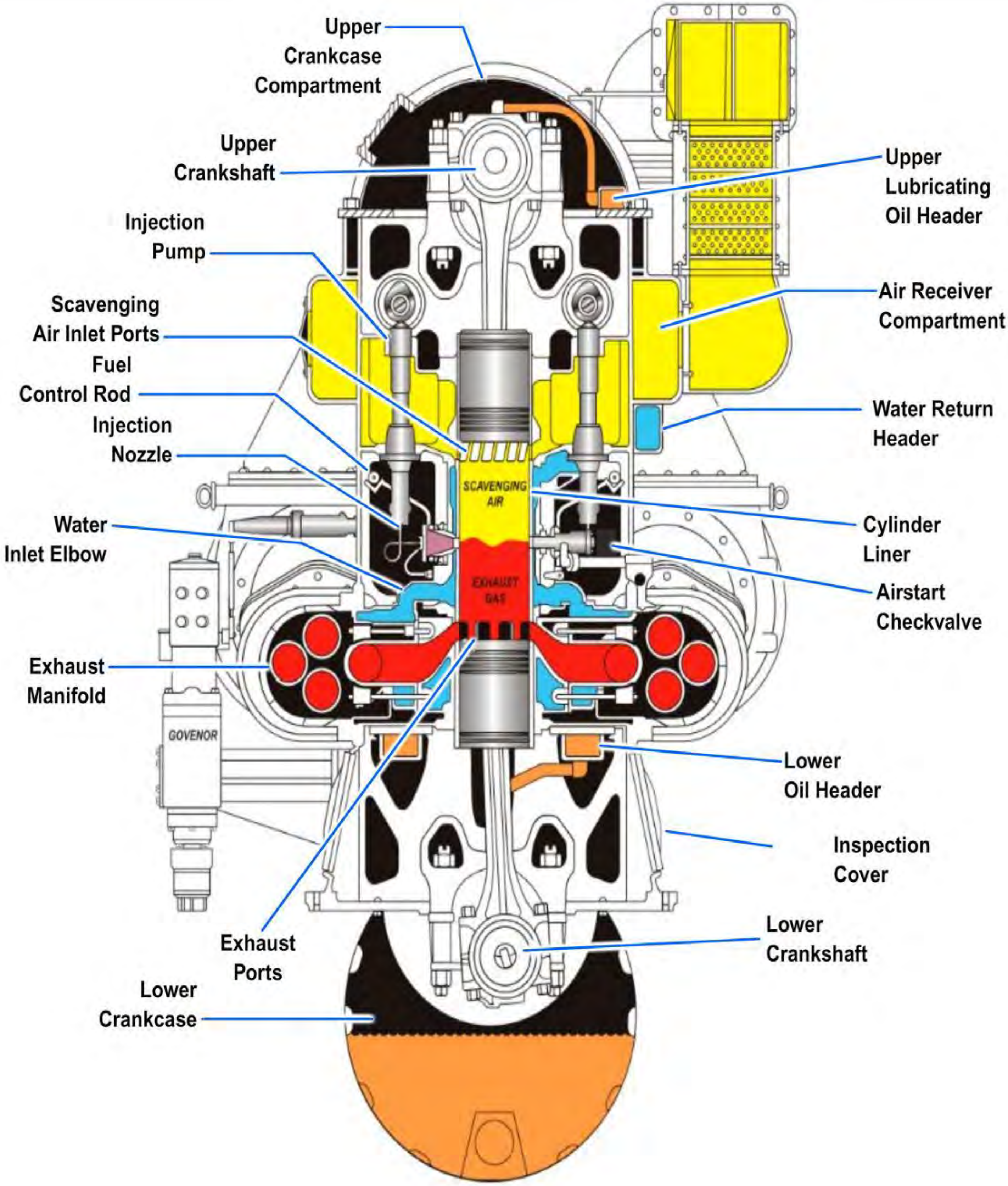

Figure 4-10 — Cross section of 2-stroke cycle, opposed-piston diesel engine.

In engines that have the opposed-piston arrangement, two crankshafts (upper and lower) are required for transmission of power. Both shafts contribute to the power output of the engine. In opposed-piston engines that are common to Navy service, the crankshafts are connected by a vertical gear drive which provides the power developed by the upper crankshaft. This power is delivered through the vertical drive shaft to the lower crankshaft. Large roller bearings and thrust bearings support and guide the vertical drive shaft (*Figure 4-11*).

The cylinders of opposed-piston engines do not have valves. Instead, they employ scavenging air ports located near the top of the cylinder (*Figure 4-10).* These ports are opened and closed by the upper piston. Exhaust ports, located near the bottom of the cylinder, are closed and opened by the lower piston.

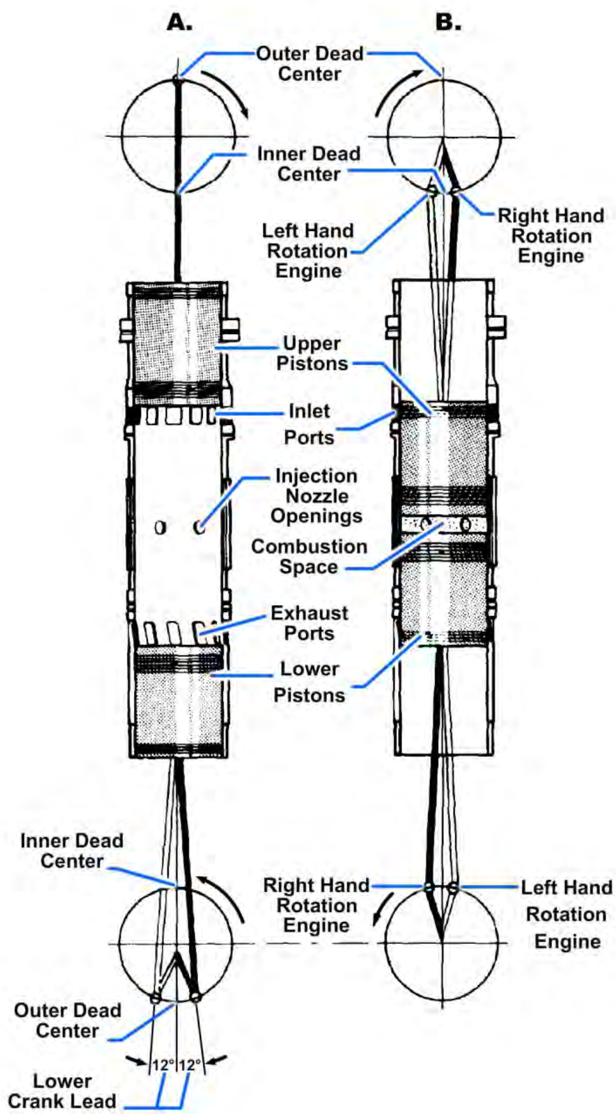

Figure 4-12 — Lower crank lead in an opposed-piston engine.

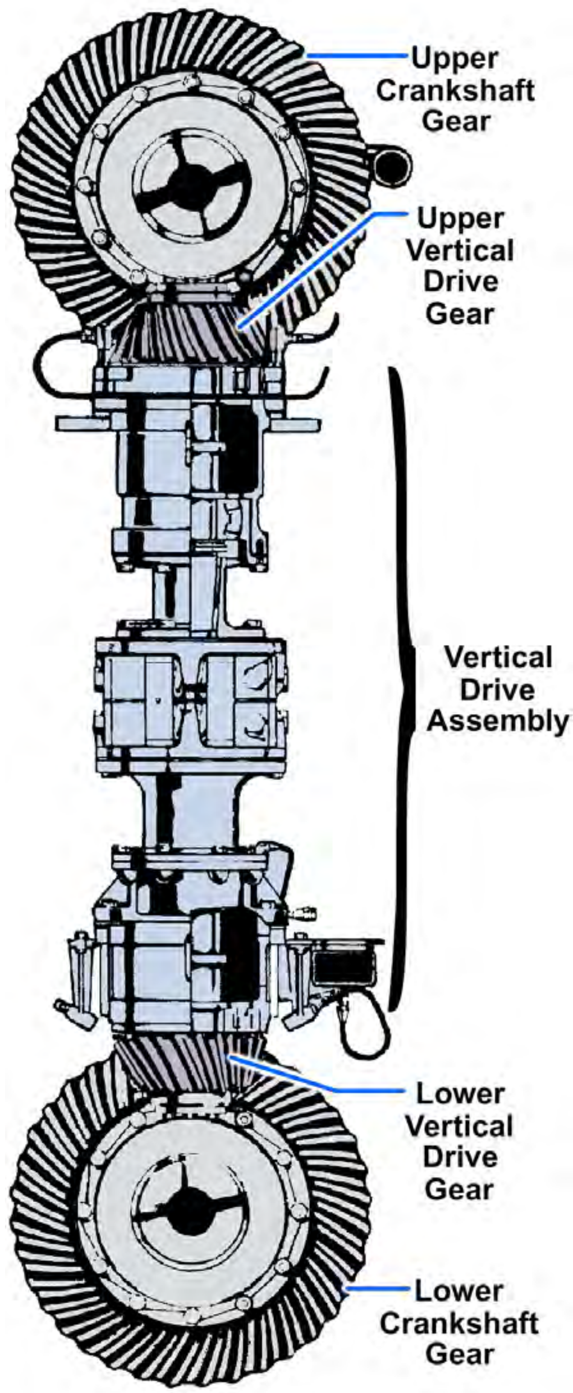

Figure 4-11 — Vertical drive assembly in a opposed- piston engine.

Movement of the opposed pistons is such that the crowns are closest together near the center of the cylinder. When in this position, the pistons are not at the true piston dead centers. This is because the lower crankshaft operates a few degrees in advance of the upper shaft. The number of degrees that a crank on the lower shaft travels in advance of the corresponding crank of the upper shaft is called LOWER CRANK LEAD *(Figure 4-12)*.

In *Figure 4-12, A* the lower crankshaft is 12 degrees past outer dead center (ODC), when the upper piston is ON outer dead center. In other words, the lower shaft leads the upper shaft by 12 degrees of rotation. Outer dead center (ODC) and inner dead center (IDC) of an opposed piston engine correspond, respectively, to BDC and TDC of single-acting engines.

In *Figure 4-12, view B* the lower shaft is shown a few degrees past IDC and the upper shaft the same number of degrees before IDC. (Keep in mind that the upper and lower shafts rotate in opposite directions.) With the shafts at these positions, the pistons are closest together and are sometimes referred to as being at COMBUSTION DEAD CENTER. Note that the midpoint between the shaft positions is piston dead center.

Opposed-piston engines used by the Navy operate on the 2-stroke cycle. In engines of the opposed-piston type, as in 2-stroke cycle single-acting engines, there is an overlap of the various events occurring during a cycle of operation. INJECTION and the burning of the fuel start during the latter part of the COMPRESSION event and extend into the POWER phase. There is also an overlap of the EXHAUST and SCAVENGING periods.

The events in the cycle of operation of an opposed-piston, 2-stroke, diesel engine cycle are shown in *Figure 4-13, frames 1-6*.

In *Figure 4-13, frame* 1 the cylinder is charged with air and the pistons are moving toward IDC. Since the scavenging air ports are covered by the upper piston and the exhaust ports are covered by the lower piston, COMPRESSION is taking place. A few degrees before the lower piston reach IDC, the fuel is injected as indicated in *Figure 4-13, frame 2*, and COMBUSTION occurs. Injection is completed, as indicated in *Figure 4-13, frame 3*, slightly before the pistons reach combustion dead center, where compression is highest. The combustion of the fuel almost doubles the pressure shortly after this point in the cycle. As the gases expand, as indicated in *Figure 4-13, frame 4*, the pistons are driven in opposite directions toward the ODCs, and power is transmitted to both crankshafts. As each of the pistons approaches ODC, the lower piston uncovers the exhaust ports to allow the waste gases to escape from the combustion space. Then, the upper piston uncovers the scavenging air ports, as in *Figure 4-13, frame 5*. The flow of scavenging air forces the remaining gas out of the cylinder, next the lower piston covers the exhaust ports, as indicated in *Figure 4-13, frame 6*, and air continues to fill the cylinder until the upper piston covers the scavenging air ports. Thus, the cycle is completed.

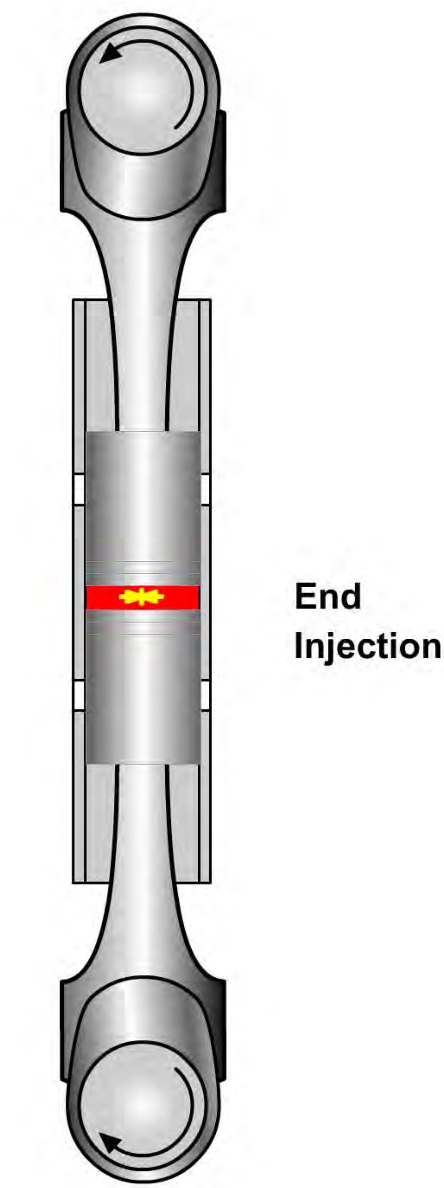

Figure 4-13 — Events in an operating cycle of an opposed-piston engine.

In the cycle of operation just described, the exhaust ports are uncovered (*Figure 4-13, frame 5*) and covered (*Figure 4-13, frame 6*) slightly before the intake ports are opened. Lower crank lead influences scavenging as well as power output.

Since the intake ports are open for a brief interval after the exhaust ports close, air can be forced into the cylinder at a pressure above that of the atmosphere. (In other words, the cylinder can be supercharged.) This feature results in the development of more power than would be possible if pressure were normal.

Crank lead also results in less power being delivered to the upper shaft than to the lower shaft. The amount of power transmitted to each crankshaft differs because, by the time the upper piston reaches IDC after INJECTION and COMBUSTION, the lower piston has already entered the POWER phase of the cycle.

The lower piston, therefore, receives the greater part of the force created by COMBUSTION. In other words, by the time the upper piston reaches IDC and begins to transmit power, the volume of the gases has already begun to increase. Therefore, the pressure acting on the upper piston is less than the pressure that was acting on the lower piston when it began to deliver power.

The amount of power delivered by the lower crankshaft varies with the engine model. In some engines, from 70 to 80 percent of the total power output is delivered by the lower crankshaft. The power available from the upper shaft is already less than that from the lower shaft because of lower crank lead. The power from the upper shaft is further reduced insofar as engine output is concerned, by the load of the engine accessories which the upper shaft generally drives.

Modern engines of the opposed-piston design have several advantages over single-acting engines of comparable rating. Some of these advantages are:

- Less weight per horsepower developed
- Lack of cylinder heads and valve mechanisms (and the cooling and lubricating problems associated with them)
- Fewer moving parts

Single-acting engines have their own advantages, such as not requiring blowers, if they are of the 4-stroke cycle design. These engines are more efficient if they are supercharged with a turbocharger, which is driven by the otherwise wasted energy of exhaust gases. Certain repairs are easier on a single-acting engine since the combustion space can be entered without the removal of an engine crankshaft and piston assembly.

INSPECTING AND TESTING THE ENGINE FRAME OR BLOCK

Before you begin an inspection or test, make sure the outside of the engine is cleaned thoroughly. This will help you spot cracks, leaks, and other problems more easily than if the engine is dirty.

Visual Inspections

Inspect the top surface of the cylinder block, the top and bottom crankcase flanges, and the oil pan for warpage. You can use a straightedge, a feeler gauge, and a good light. *Figure 4-14* illustrates how to use a straightedge and a feeler gauge to check the top surface of the cylinder block. Compare your measurements to the manufacturer's specifications to determine if the surface is warped. Visually inspect the cylinder block for cracks, breaks, or other damage.

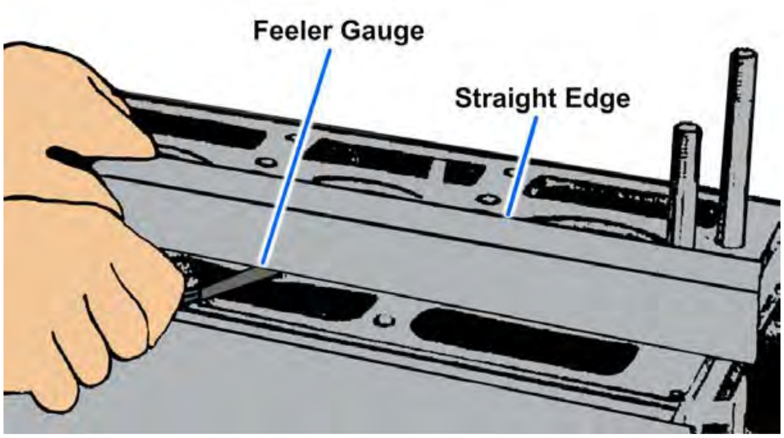

Figure 4-14 — Checking the top surface of a typical cylinder block.

Measurements

Visually inspect the engine block's bolts to determine if they are bent, broken, or worn.

Measure the bore in the cylinder block with a dial indicating bore gauge, to determine if wear or an out-of-round condition exceeds the manufacturer's specification. *Figure 4-15* illustrates the use of a bore gauge to measure a cylinder bore.

Inspect and measure the engine block's hold-down bolt holes. Use a telescoping snap gauge to determine if wear has caused enlargement of the holes. If a telescoping snap gauge is not available, try to move each bolt from side to side with your fingers. If a bolt moves from side to side, its hole has enlarged and must be repaired. Always follow the manufacturer's instructions on how to correct a hole enlargement problem.

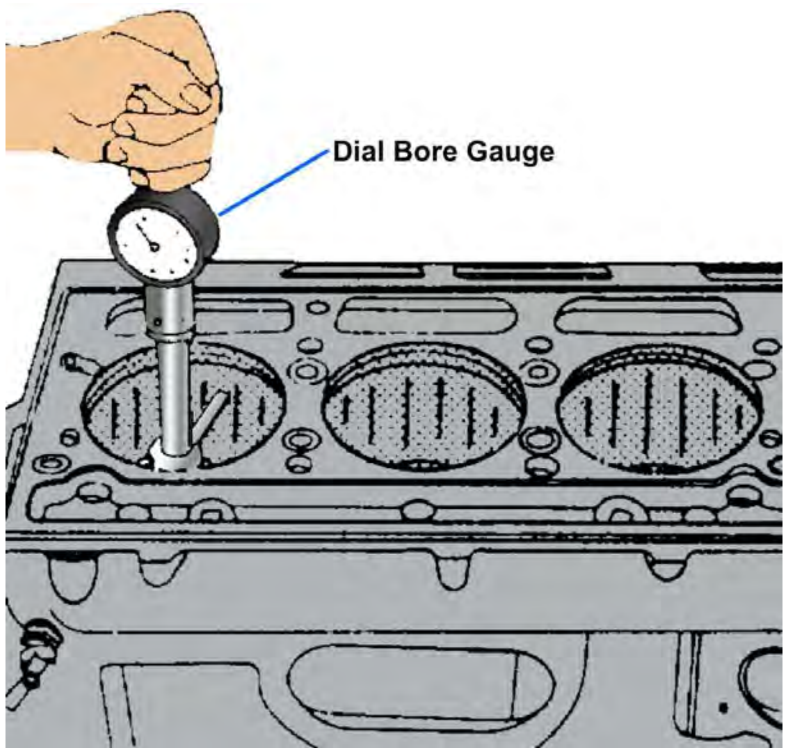

Figure 4-15 — Checking the cylinder bore for wear or out-of-roundness.

Dye Penetrant Test

Conduct a preliminary dye penetrant test on the engine block's surface to identify cracks that you cannot see otherwise. Be sure to follow the manufacturer's instructions on how to conduct this test. Remember that only a certified nondestructive testing technician can perform a dye penetrant test that meets the requirements of quality assurance.

Air and Water Pressure Tests

Test the cylinder block for cracks in the cylinder bores between the water jacket and the oil passages by using either air pressure or water pressure. The purpose of each test is to pressurize the water jacket to the point, within safe limits, that leaks show.

Air Pressure Test

Before you perform the air pressure test, make sure you completely strip and clean the block. Then, follow these basic procedures:

1. Seal all of the block's freshwater passages with gaskets and flanges.
2. Connect a low-pressure air hose to a fixture on one of the flanges. Immerse the block into a tank of water heated to the engine's normal operating temperature. Allow the engine to soak for approximately 20 to 40 minutes, as specified by the manufacturer. This allows the block to warm to the temperature of the water.
3. Apply approximately 40 psi of pressure to the block and watch for bubbles. Determine what repair is needed or can be made when you identify the source of the bubbles.

If you cannot dip the block, you may still perform the air pressure test. Attach the hose to a fixture secured to an opening of the water jacket. Pressurize the water jacket. Carefully spray soapy water over the block and look for air bubbles caused by the pressurized air.

Water Pressure Test

The water pressure test is similar to the air pressure test, except that defects are indicated by water leaks rather than by air leaks. Before you perform the water pressure test, strip and clean the block, then follow these procedures:

1. Seal off all but one of the freshwater openings with flanges and gaskets. Make seals airtight.
2. Fill the water jacket with fresh water until all air is purged from the water jacket. Seal the fill opening with a flange that contains an air hose coupling.
3. Attach an air hose and pressurize the water jacket to approximately 40 psi (see the manufacturer's manual). Maintain the pressure in the water jacket for at least 2 hours.
4. Inspect the cylinder bores, air box, oil passages, crankcase, and cylinder block exterior for the presence of water.

REPAIRING THE ENGINE FRAME OR BLOCK

Some engine block repairs are cost efficient, while others are not. The following paragraphs briefly discuss basic repairs to the block itself. Later paragraphs discuss repairs to block components.

Leaking Water Jacket

Most engine blocks that have a leaking water jacket are not worth the cost to repair. To determine if such a block can be repaired economically, consult the appropriate MILSTD and technical manuals for the engine.

Warped Cylinder Block or Crankcase Flanges

You may use a hand surface grinder to correct small amounts of surface warpage. Do not remove more metal than necessary. The manufacturer's manual will specify how much metal you may remove with the hand grinder. If the warpage exceeds the maximum allowed for hand grinding, send the block to the machine shop for machine grinding.

Worn Bolt Holes

Over a period of time, bolt holes may become oversize due to wear from threading and unthreading the fasteners. You may correct a worn bolt problem by one of three primary methods, depending on the situation.

1. If the bolt hole is slightly oversize, you may be able to simply use a larger bolt in the hole, if such use is authorized for the component the bolt fastens down.
2. If enough metal remains around the hole, you may be able to install a helicoil. Check the helicoil installation instructions and appropriate technical manuals to determine whether or not a helicoil is acceptable.
3. You may also fill the hole with weld metal and then drill and tap a new hole.

Whatever method you use to correct the problem, always check the bolt and bolt hole for proper fit.

INSPECTING, TESTING, AND REPAIRING CYLINDER LINERS

Cylinder liners may become damaged or worn excessively. The following paragraphs discuss the more common causes and repairs.

Cracked, Broken, and Distorted Liners

You should suspect one or more cylinder liners whenever you notice one of the following indications:

- Excessive water in the lubricating oil
- An accumulation of water in one or more cylinders of a secured engine
- An abnormal loss of water in the cooling system
- High cooling water temperature or fluctuating pressure (caused by combustion gases blowing into the water jacket)
- Oil in the cooling water

When you suspect that a liner is cracked, try to locate the cracks visually. If you cannot locate the cracks visually, use another testing method, such as the water pressure test or air pressure test described earlier. To check liners with integral cooling passages, plug the outlets and fill the passages with glycol-type antifreeze. This liquid will leak from even the smallest cracks.

Cracks in dry liners may be more difficult to locate because there is no liquid to leak through the cracks. You may need to use magnaflux equipment or penetrating dye to locate these cracks.

Causes

Cylinder liners may crack because of poor cooling, improper fit of piston or pistons, incorrect installation, foreign bodies in the combustion space, or erosion and corrosion. Improper cooling, which generally results from restricted cooling passages, may cause hot spots in the liners, resulting in liner failure due to thermal stress. Scale formation on the cooling passage surfaces of liners may also cause hot spots; wet liners are subject to scale formation. You may remove the scale by following the procedures outlined in chapter 233 of the *Naval Ships' Technical Manual (NSTM)*.

Proper cooling of dry liners requires clean contact surfaces between the liners and the cylinder block. Distortion, wear, or breakage may result if a liner is not properly seated. Causes of improper liner seating may be metal chips, nicks, or burrs, or improper fillets; in *Figure 4-16* an improper fillet on the cylinder deck prevents the liner from seating properly. To correct an improper fillet, grind it down until the lower surface of the flange seats properly on the mating surface of the cylinder deck.

An oversized sealing ring may cause improper positioning of the liner. As the sealing ring is over-compressed, the rubber loses its elasticity and becomes hard, which may cause the liner to become distorted.

Use feeler gauges to check the clearance between the mating surfaces. If the manufacturer's technical manual specifies the distance from the cylinder deck to the upper surface of the liner flange, use this dimension to check on the seating of the liner.

Obstructions in the combustion chamber may be destructive not only to the liner but also to the cylinder head and other parts.

Repairs

Replacement is the only satisfactory means of correcting cracked, broken, or badly distorted cylinder liners.

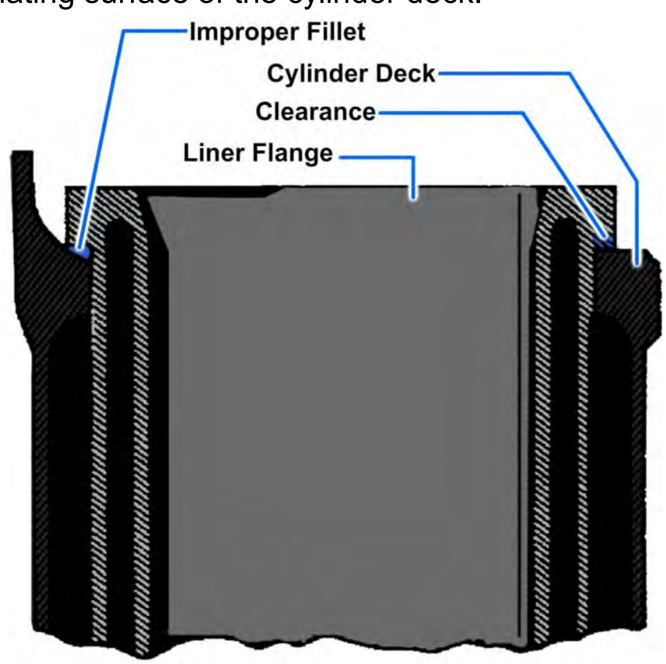

Figure 4-16 — Improperly seated cylinder liner.

Scored Cylinder Liners

Scored cylinder liners may become scored (scratched) by several means. These scratches degrade the engine's performance and require some type of repair.

Scored cylinder liners may be caused by broken piston rings, a defective piston, improper cooling, improper lubrication, or the presence of foreign particles or objects. Dust particles drawn into an engine cylinder will mix with the oil and become an effective but undesirable lapping compound that may cause extensive damage.

Causes

Scoring may be in the form of deep or shallow scratches in the liner surface. With most liner scoring, there will be corresponding scratches on the piston and piston rings. The symptoms of scoring may be low firing or compression pressure and rapid wear of piston rings.

The best method for detecting scoring is visual inspection through liner ports, through the crankcase housing with pistons in their top position, or when the engine is disassembled.

Badly worn pistons and rings may cause scoring because blowby of combustion gases increases the temperature of the liner and may reduce the oil film until metal-to-metal contact takes place. Inspect the pistons and rings carefully. A piston with a rough surface (such as one that has seized) will score the liner.

Scoring as a result of insufficient lubrication or dirt in the lubricating oil can be prevented if lubricating equipment (filters, strainers, and centrifuges) is maintained properly.

Repairs

Ship's force personnel normally do not repair scored liners; they replace them with spare liners. When necessary, liners with minor scoring may be kept in service, if the cause of scoring is eliminated and the minor defects can be corrected. The surface of the liner must be inspected carefully, especially in the region next to the ports, for any burrs, projections, or sharp edges that will interfere with piston and ring travel. Most projections can be removed by handstoning, using a fine stone*. Figure 4-17, frames 1 and 2* shows a liner before and after the ports were stoned.

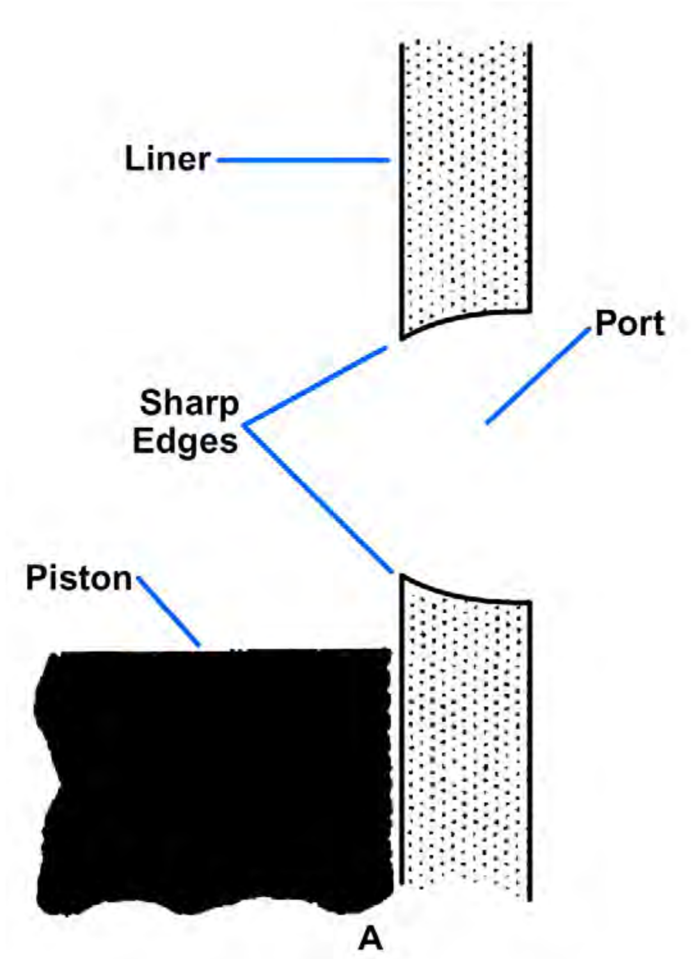

Figure 4-17 — Liner before and after stoning.

Excessively Worn Liners

Over a period of time, cylinder liners become worn simply because of engine operation. The best method of finding excessive wear is to take measurements of the cylinder liner with an inside micrometer caliper. Two types of liner wear check are illustrated in *Figure 4-18*.

Excessive maximum diameter results from general wear equally around the cylinder. Out-of-roundness is produced by the piston thrusting against one or two sides of the cylinders.

Clearance between a piston and a liner is generally checked by measuring both parts with a micrometer. On smaller engines, you can use a feeler gauge. Clearance in excess of that specified by the manufacturer is generally due to liner wear, which normally is greater than piston wear.

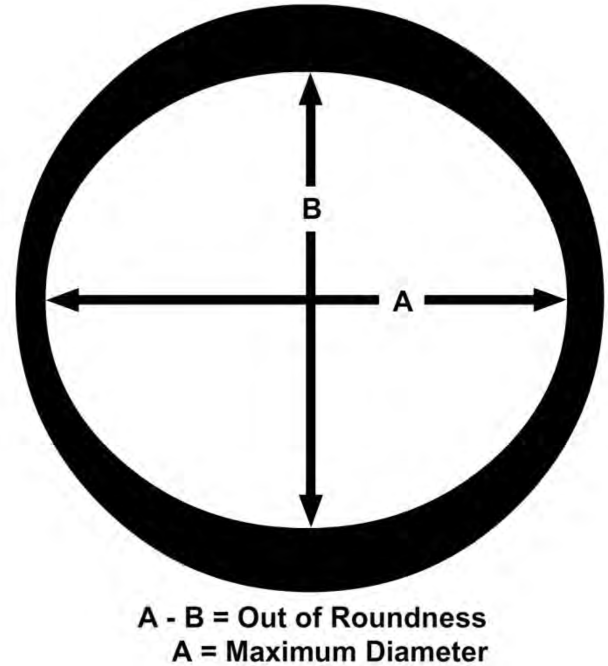

Figure 4-18 — Measurements for determining liner wear.

To determine liner wear, take measurements at three levels in the liner. Take the first measurement slightly below the highest point to which the top ring travels; take the next measurement slightly above the lowest point of compression ring travel; and take the third measurement at a point about midway between the first two. (Record all readings, so that rapid wear of any particular cylinder liner will be evident.) If wear or out-of-roundness exists beyond specified limits, replace the liner. *Figure 4-19, frames 1 and 2* shows two examples of taking inside measurements. The liner shown in *Figure 4-19, frame 2* requires at least twice as many measurements as other types of liners because it is from an opposed piston.

You will not get accurate measurements unless you position the caliper or gauge properly in the liner. Common errors in positioning are illustrated in *Figure 4-20, views A and B*. Hold one end of the caliper firmly against the liner wall as shown in *Figure 4-19, frame 1*.

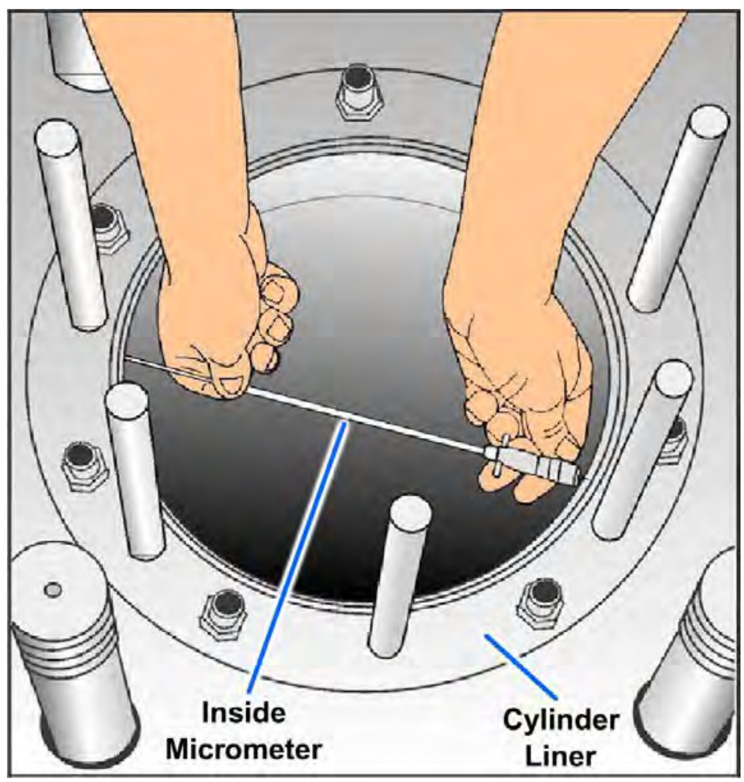

Figure 4-19 — Measuring the inside of a cylinder liner.

Then move the free end back and forth, and up and down, until you establish the true diameter of the liner. The moving end will trace a path similar to that illustrated in *Figure 4-21*.

Considerable experience in using an inside micrometer or cylinder gauge is necessary to ensure accuracy.

Improper starting procedures will cause excessive wear on the liners and pistons. When an engine is first started, sometime may elapse before the flow of lubricating oil is completed; also, the parts are cold and condensation of corrosive vapors is accelerated accordingly. These two factors (lack of lubrication and condensation of corrosive vapors) make the period immediately after starting a critical time for cylinder liners. If an independently driven oil pump is installed, it must be used to prime the lube oil system and build up oil pressure before the engine is started The engine should not be subjected to high load during the warm-up period.

The cooling water of an engine should always be maintained within the specified temperature ranges. If the temperature is allowed to drop too low, corrosive vapors will condense on the liner walls.

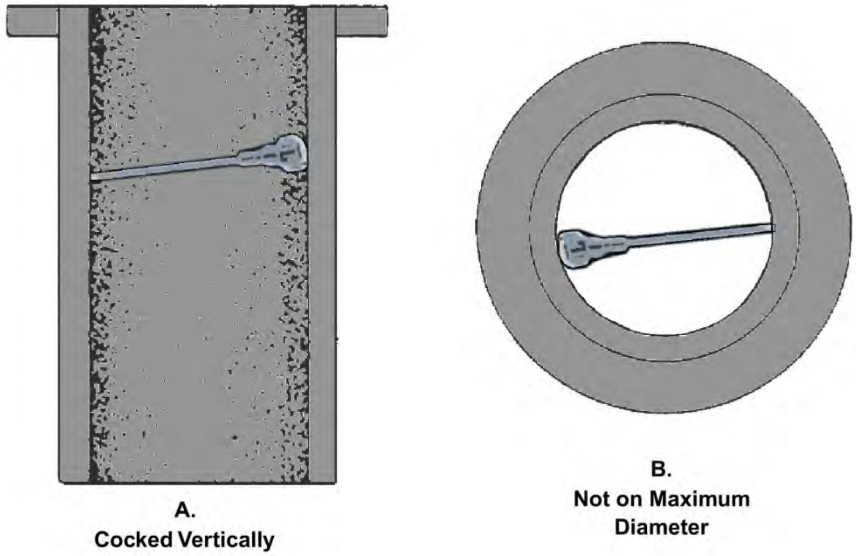

Figure 4-20 — Errors to avoid when taking liner measurements.

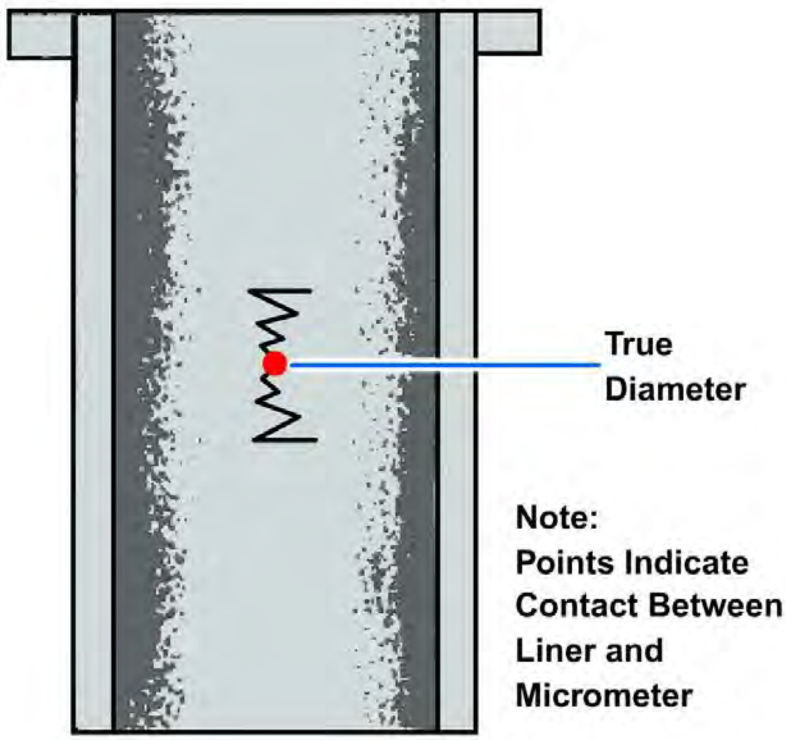

Figure 4-21 — Trace of caliper end when determining the true diameter of a liner.

Repairs

Cylinder liners worn beyond the maximum allowable limit should be replaced. You will find the maximum allowable wear limits for engines in the appropriate manufacturer's technical manual or the Diesel Engine Wear Limit Chart available from the Naval Sea Systems Command. In the absence of such specific information, the following wear limits (established by NAVSEA) apply in general to:

1. Two-stroke cycle engines with aluminum pistons: 0.0025 inch per inch diameter.
2. Slow-speed engines over 18-inch bore: 0.005 inch per inch diameter.

3. All other engines: 0.003 inch per inch diameter. If you must remove a liner, follow the instructions given on the appropriate maintenance requirement card (MRC) or in the manufacturer's technical manual for the particular type of engine. *Figure 4-22* illustrates the method generally used to remove a cylinder liner.

To remove the cylinder liner, proceed as follows:

1. Drain the water from the engine.
2. Remove the cylinder head.
3. Remove the piston(s).
4. Attach the special liner puller to the liner studs and tighten the nuts by hand. (The nuts must be hand tightened; if a wrench is used, the threads on both the nuts and the studs may be damaged.)
5. Attach the hook of the chain fall and pull slightly until the liner breaks free (*Figure 4-22*). If the liner fails to break loose immediately, apply pressure at the bottom of the liner. To do this, place a block of wood on the crankshaft throw, and force it up against the liner by rotating the turning gear.
6. Lift the liner up until it clears the top of the engine block and remove it to a safe place. You may need to rotate the liner slightly while removing it from the engine block.

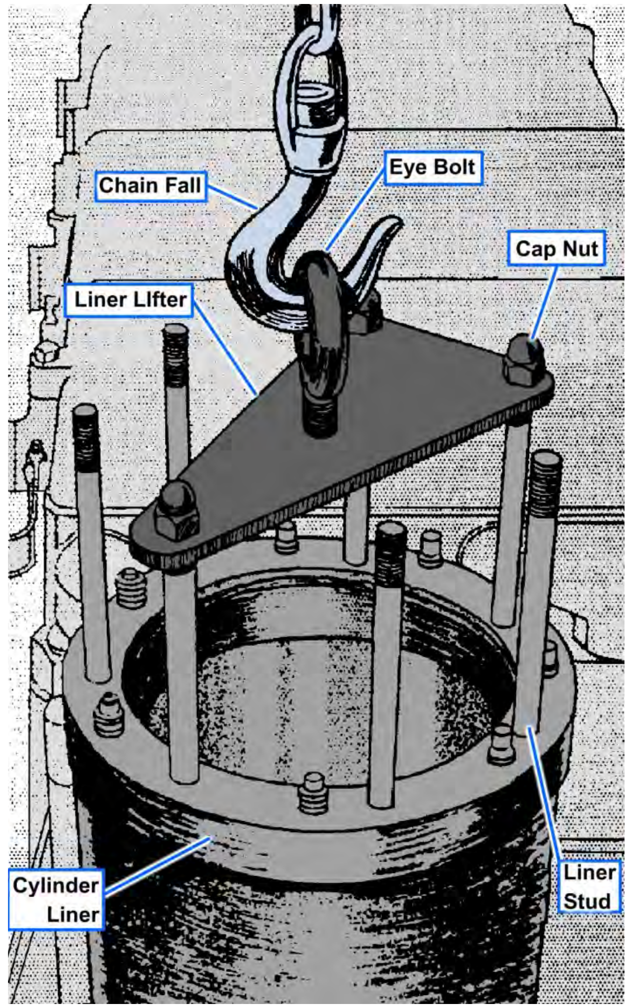

Figure 4-22 — Removing a cylinder liner.

INSPECTING, TESTING, AND REPAIRING CYLINDER HEADS

Conditions requiring repair of a cylinder head are similar to those for cylinder liners and can be grouped under cracks, corrosion, distortion, and fouling.

Cracks

Cracks in cylinder heads are best located by either visual inspection or magnetic powder inspection. On some types of engines, a defective cylinder can be located by bringing the piston of each cylinder, in turn, to top dead center and applying compressed air. When air is applied to a damaged cylinder, a bubbling sound indicates leakage.

When the cylinder head is removed from the engine, it can be checked for cracks by the hydrostatic test used on cylinder liners equipped with integral cooling passages.

Cracks generally occur in cylinder heads on the narrow metal sections between such parts as valves and injectors. The cracks may be caused by adding cold water to a hot engine, by restricted cooling passages, by obstructions in the combustion space, or by improper tightening of studs.

Aboard ship, cracked cylinder heads usually must be replaced. It is possible to repair them by welding, but this process requires special equipment and highly skilled personnel normally found only at repair activities.

Corrosion

Burning and corrosion of the mating surfaces of a cylinder head may be caused by a defective gasket. Although regular planned maintenance ordinarily prevents this type of trouble, burning and corrosion may still take place under certain conditions. When corrosion and burning occur, there may be a loss of power due to combustion gas leakage out of or water leakage into the combustion space. Other symptoms of leakage may be (1) hissing or sizzling in the head where gases or water may be leaking between the cylinder head and the block, (2) bubbles in the cooling water expansion tank sight glass, or (3) overflow of the expansion tank.

Gaskets and grommets that seal combustion spaces and water passages must be in good condition; otherwise the fluids will leak and cause corrosion or burning of the area contacted. Improper cooling water treatment may also accelerate the rate of corrosion.

In general, cylinder heads that are burned or corroded by gas or water leakage are so damaged that they must be replaced.

Distortion

Warpage or distortion of cylinder heads becomes apparent when the mating surfaces of the head and block fail to match properly. If distortion is severe, the head will not light over the studs. Distortion may be caused by improper welding of cracks or by improper tightening of the cylinder head studs. Occasionally, new heads may be warped.

Repair of distorted or damaged cylinder heads is often impracticable. They should be replaced as soon as possible and turned in to the nearest supply activity, which will determine the extent of damage and the method of repair.

Fouling

If the combustion chambers become fouled, the efficiency of combustion will decrease. Combustion chambers are designed to create the desired turbulence for mixing the fuel and air; any accumulation of carbon deposits in the space will impair both turbulence and combustion by altering the shape and decreasing the volume of the combustion chamber.

Symptoms of fouling in the combustion chambers are smoky exhaust, loss of power, or high compression. Such symptoms may indicate the existence of extensive carbon formation or clogged passages. In some engines, these symptoms indicate that the shutoff valves for the auxiliary combustion chambers are stuck.

Combustion chambers may also become fouled because of faulty injection equipment, improper assembly procedures, or excessive oil pumping.

Cleaning of fouled combustion spaces generally involves removing the carbon accumulation. The best method is to soak the dirty parts in an approved solvent and then wipe off all traces of carbon. You may use a scraper to remove carbon, but be careful to avoid damaging the surfaces. If oil pumping is the cause of carbon formation, check the wear of the rings, bearings, pistons, and liners. Replace or recondition excessively worn parts.

INSPECTING, TESTING, AND REPAIRING VALVES AND VALVE ASSEMBLIES

Regardless of differences existing in engine construction, there are certain troubles common to all assemblies.

Sticking Valves

Sticking valves will produce unusual noise at the cam followers, pushrods, and rocker arms and may cause the engine to misfire. Sticking is usually caused by resinous deposits left by improper lube oil or fuel.

To free sticking valves without having to disassemble the engine, use one of several approved commercial solvents. If the engine is disassembled, use either a commercial solvent or a mixture of half lube oil and half kerosene to remove the resins. Do NOT use the kerosene mixture on an assembled engine, since a small amount of this mixture settling in a cylinder could cause a serious explosion.

Bent Valves

Bent or slightly warped valves tend to hang open. A valve that hangs open not only prevents the cylinder from firing, but also is likely to be struck by the piston and bent so that it cannot seat properly. Symptoms of warped or slightly bent valves will usually show up as damage to the surface of the valve head. To lessen the possibility that cylinder head valves will be bent or damaged during overhaul, NEVER place a cylinder head directly on a steel deck or grating; use a protective material such as wood or cardboard. Also, NEVER pry a valve open with a screwdriver or similar tool.

Weak Springs

Valves may close slowly, or fail to close completely, because of weak springs. At high speeds, valves may “float,” thus reducing engine efficiency. Valve springs wear quickly when exposed to excessive temperatures and to corrosion from moisture combining with sulfur present in the fuel.

Burned Valves

Burned valves are indicated by irregular exhaust gas temperatures and sometimes by excessive noise. In general, the principal causes of burned valves are carbon deposits, insufficient tappet clearance, defective valve seats, and valve heads that have been excessively reground.

The principal cause of burned exhaust valves is small particles of carbon that lodge between the valve head and the valve seat. These particles come from incomplete combustion of the fuel or oil left by the piston rings in the cylinder. The particles hold the valve open just enough to prevent the valve head from touching the valve seat. The valve is cooled by several means, including its contact with the valve seat. When carbon particles prevent contact, the heat normally transferred from the valve head to the seat remains in the valve head. The valve seat seldom burns because the water jackets surrounding the seat usually provide enough cooling to keep its temperature below a dangerous point.

When cleaning carbon from cylinder heads, remove all loose particles from the crevices; be extremely careful that you do not nick or scratch the valve or seat. Removing the valves from the engine will make it easier to clean the passages and remove the carbon deposits from the underside of the valve heads.

Check the tappet clearance adjustments at frequent intervals to be certain they are correct and that the locking devices are secure.

Most engines are equipped with valve seat inserts made of hard, heat-resisting, alloy steel. Occasionally, a seat will crack and allow the hot gases to leak, burning both the insert and the valve. Sometimes a poor contact between the valve seat insert and the counterbore prevents the heat from being conducted away, and the high temperatures deform the insert. When this occurs, both the seat and the valve will burn; the seat insert must be replaced.

Loose Valve Seats

You can avoid causing loose valve seats only by installing them properly. Clean the counterbore thoroughly to remove all carbon before shrinking in an insert. Chill the valve seat with dry ice and place the cylinder head in boiling water for approximately 30 minutes; then drive the insert into the counterbore with a valve insert installing tool, as illustrated in *Figure 4-23*. Never strike a valve seat directly. Do the driving operation quickly, before the insert reaches the temperature of the cylinder head.

When replacing a damaged valve with a new one, inspect the valve guides for excessive wear. If the valve moves from side to side as it seats, replace the guides.

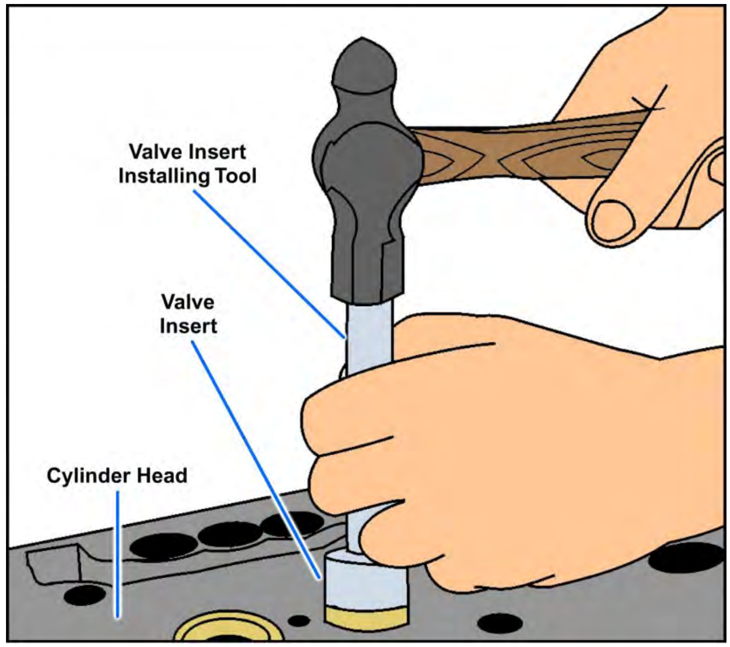

Figure 4-23 — Driving a valve insert into the cylinder head counterbore.

Pitting

If the valve seat is secured firmly in the counterbore and is free of cracks and burns, you may remove slight damage such as pitting by hand grinding (*Figure 4-24*). Generally, you will use Prussian blue to check the valve and valve seat, but if this is not available, use any thin dark oil-based paint. Allow the valve to seat by dropping it on the valve seat from a short distance. If the surfaces fail to make complete contact, regrinding is necessary.

In any valve reconditioning job, the valve seat must be concentric with the valve guide. You can determine the concentricity with a dial indicator, as shown in *Figure 4-25*.

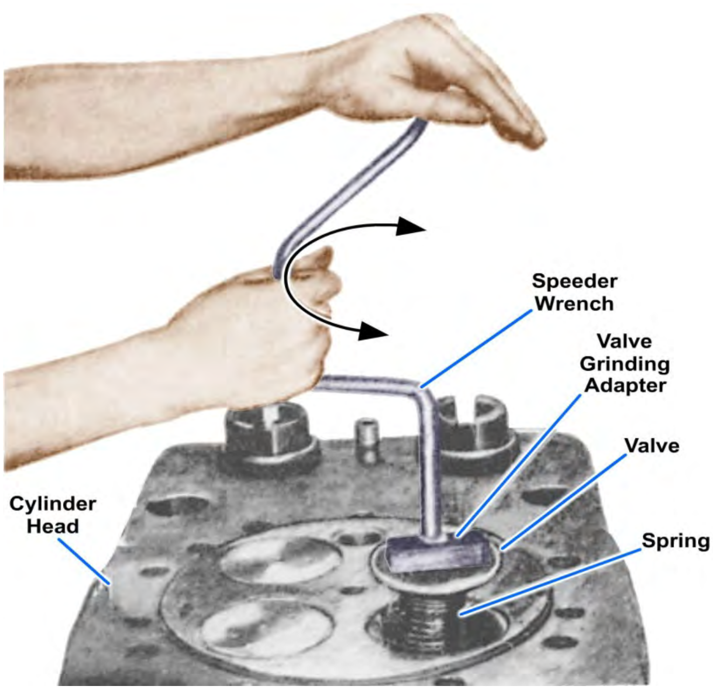

Figure 4-24 — Hand grinding a valve and valve seat.

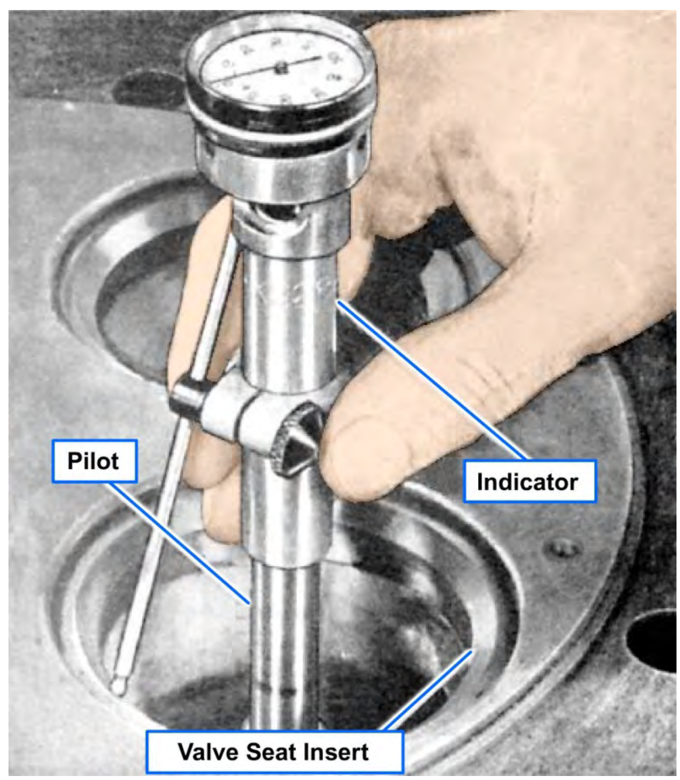

Figure 4-25 — Determining concentricity of the valve seat with a dial indicator.

If you must grind a valve seat, hold hand grinding to a minimum and never use it in place of machine grinding, in which a grinding stone is used to refinish the seat (*Figure 4-26*). Grind the seat a few seconds at a time until it is free of pits. Check the seat after each cut.

The primary objection to hand grinding the valve to the seat is that a groove or indentation may be formed in the valve face. Since the grinding is done when the valve is cold, the position of the groove with respect to the seat is displaced as the valve expands slightly when the engine is running. This condition is illustrated (greatly exaggerated) in *Figure 4-27*. When the valve is hot, its ground surface does not make contact at all with the ground surface of the seat. Therefore, hand grinding should be used only to remove slight pitting or as the final and finishing operation in a valve reconditioning job.

Figure 4-26 — Machine grinding a valve seat.

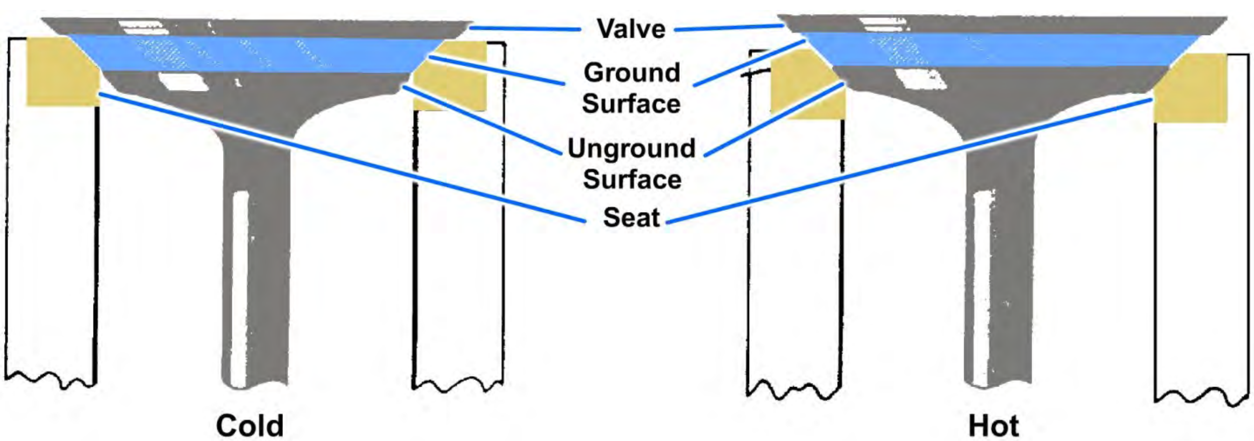

Figure 4-27 — Excessively band-ground valve.

Some valves and seat are not pitted sufficiently to require replacement but are pitted to such an extent that hand grinding would be unsatisfactory. Such valves may be refaced on a lathe (*Figure 4-28*), and the valve seats may be reseated by power grinding equipment (*Figure 4-26*).

Normally, these operations are done at a repair base or naval shipyard.

A valve head that is excessively reground to such an extent that its edge is sharp, or almost sharp, will soon burn. A sharp edge cannot conduct the heat away fast enough to prevent burning. This is the factor that limits the extent to which a valve may be refaced.

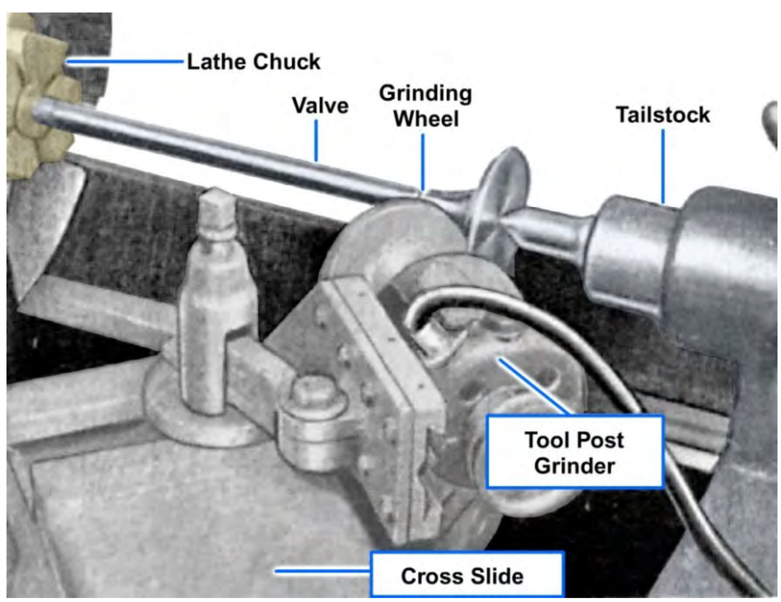

Figure 4-28 — Facing a valve on a lathe.

Broken Valve Springs

Broken valve springs cause excessive valve noise and may cause erratic exhaust gas temperatures. The actual breaking of the valve springs is not always the most serious consequence. Actions following the breaking cause the most serious damage to the engine.

When a spring breaks, it may collapse just enough to allow the valve to drop into the cylinder, where it may be struck by the piston. In addition, the valve stem locks or keepers may release the valve and allow it to drop into the cylinder, causing severe damage to the piston, cylinder head, and other nearby parts. You can take a number of precautions to prevent or minimize corrosion and metal fatigue, which cause valve springs to break.

Before you reassemble a valve assembly, be sure to thoroughly clean and inspect the valve spring. (Use kerosene or diesel fuel for cleaning. NEVER use an alkaline solution; it will remove the protective coating.) The condition of the surface of a valve spring is the best indication of impending failure. (Use magnafluxing to help find cracks that would otherwise be invisible.)

The free length of a valve spring should be within the limits specified in the manufacturer's technical manual. If such information is not available, compare the length of a new spring with that of the used spring. If the length of the used spring is more than 3 percent shorter than that of the new spring, replace the used spring immediately. Remember, however, that loss of spring tension will NOT always show up as a loss in overall length. Springs may be the proper length, but they may have lost enough tension to warrant replacement.

Do not reinstall springs with nicks, cracks, or surface corrosion. Replace them. To minimize corrosive conditions, use clean lube oil, eliminate water leaks, and keep vents open and clean.

Worn Valve Keepers and Retaining Washers

Worn valve keepers and retaining washers may result if valve stem caps (used in some engines) are improperly fitted. Trouble occurs when the cap does not bear directly on the end of the stem, but bears instead on the valve stem lock or the spring retaining washer. This transmits the actuating force from the cap to the lock or the retaining washer, and then to the stem, causing excessive wear on the stem groove and the valve stem lock. As a result, the retaining washer will loosen and the valve stem may break.

An improper fit of a valve stem cap may be due to the use of improper parts or the omission of spacer shims. Steel spacer shims, required in some caps to provide proper clearance, are placed between the end of the valve stem and the cap; leaving out the shims will cause the shoulder of the cap to come in contact with the lock. When you disassemble a valve assembly, determine whether or not shims are used. If shims are, used record their location and exact thickness. Valve caps must be of the proper size, or troubles similar to those resulting from shim omission will occur. Never attempt to use caps or any other valve assembly parts that are worn.

Broken Valve Heads

Broken valve heads usually cause damage to the piston, liner, cylinder head, and other associated parts. This damage is generally repairable only by replacement of these parts.

Whether the causes of broken valve heads are mechanical deformation or metal fatigue, you must take every precaution to prevent their occurrence. If a valve head breaks loose, be sure to make a thorough inspection of all associated parts before you replace the valve.

Rocker Arms and Pushrods

The principal trouble that rocker arms and pushrods may have is WEAR, which may occur in bushings, or on the pads, end fittings, or tappet adjusting screws.

Worn rocker arm bushings are usually caused by lubricating oil problems. A bushing with excessive wear must be replaced. When installing a new bushing, you usually need to use a reamer for the final fit.

Wear at the points of contact on a rocker arm is generally in the form of pitted, deformed, or scored surfaces. Wear on the rocker arm pads and end fittings are greatly accelerated if lubrication is insufficient or if there is excessive tappet clearance. Pushrods are usually positioned to the cam followers and rocker arms by end fittings. The pads are the rocker arm ends that bear the valve stem or valve stem cap. When the tappet clearance is excessive, the rods shift around, greatly increasing the rate of wear of both the rocker arm and the rod contact surfaces. Worn fittings necessitate the replacement of parts. Continued use of a poor fitting and worn pushrod is likely to result in further damage to the engine, especially if the rod should come loose.

Worn tappet adjusting screws and locknuts usually make maintaining proper clearances and keeping the locknuts tight very difficult. Wear of the adjusting screws is usually caused by loose locknuts, which allow the adjusting screw to work up and down on the threads each time the valve is opened and closed. To prevent this wear, tighten the locknuts after each adjustment and check the tightness at frequent intervals.

If the threads are worn, replace the entire rocker arm. Do NOT attempt to repair the threads or to use a new tappet adjusting screw except in cases of emergency.

The adjustment of the rocker arm assembly consists chiefly of adjusting the tappets for proper running clearance. The valve clearance for both intake and exhaust valves should be readjusted after overhaul. The procedure for adjusting the rocker arm tappets of a typical 4-stroke cycle engine is as follows:

1. Rotate the crankshaft and move the piston whose tappets you plan to adjust to top dead center of the compression stroke.
2. Loosen the locknut (jam nut) on the tappet screw, and insert a screwdriver in the slot of the screw.
3. Insert a feeler gauge of the proper thickness between the tappet bearing and the end of the valve stem.
4. Tighten the tappet screw (*Figure 4-29*) until the feeler gauge will just slide freely between the bearing and the valve stem.
5. Tighten the jam nut and check the clearance. The jam nut has a tendency to increase the clearance when tightened; therefore, ALWAYS check the clearance after you tighten the jam nut.

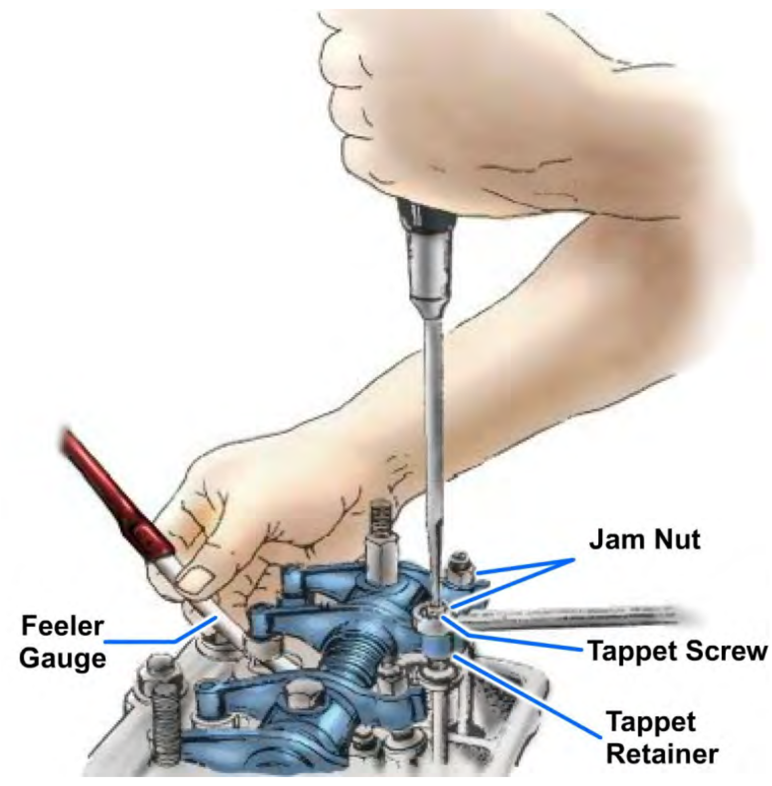

Figure 4-29 — Adjusting valve clearance.

The procedure just outlined is a preliminary or cold engine check. Check and readjust the clearance, if necessary, after the engine has been in operation for a short time and has reached the normal operating temperature. The manufacturer’s technical manual will give the recommended valve clearances for a specific make and model of engine and will indicate whether the clearances given apply to cold or hot engines.

Cam Followers and Lash Adjusters

Regardless of the type of cam follower, wear is the most common trouble. Worn rollers will usually develop holes or pit marks in the roller surfaces. The mushroom type may develop a shallow channel when the cam follower fails to revolve and the cams wipe the same surface each time the camshaft revolves.

Normal use will cause surface disintegration, usually as the hardened surfaces begin to fatigue. The condition is aggravated by abrasive particles. Nicks and dents on rollers will also cause disintegration.

You must make constant checks for defective rollers or surfaces and for nicks, scratches, or dents in the camshaft. In roller-type cam followers you must replace a worn cam follower body and guide or roller needle bearings (if used).

Defective or poorly operating valve adjusters allow clearance or lash in the valve gear. Noisy operation of a lash adjuster indicates that there is insufficient oil in the cylinder of the unit. When you discover a noisy lash adjuster and the oil supply or pressure is not the source of trouble, remove and disassemble the unit according to the manufacturer's instructions.

Since the parts of lash adjusters are not interchangeable, disassemble only one unit at a time. Check for resinous deposits, abrasive particles, a stuck ball check valve, a scored check valve seat, and excessive leakage. Carefully wash all parts of the hydraulic lash adjuster in kerosene or diesel fuel. Check such parts as the cam follower body, plunger or piston, and hydraulic cylinder for proper fit.

INSPECTING AND REPAIRING CAMSHAFTS

Camshafts can be saved when the cams alone are damaged, if the cams are of the individual type, since such cams may be removed and replaced. *Figure 4-30* illustrates the method of removing an individual cam from its shaft.

When you remove a camshaft from an engine, clean it thoroughly with either kerosene or diesel fuel. After cleaning the shaft, dry it with compressed air. After cleaning the cam and journal surfaces, inspect them for any signs of scoring, pitting, or other damage.

When you remove or insert a camshaft through the end of the camshaft recess, rotate it slightly. Rotating the camshaft allows it to enter easily and reduces the possibility of damage to the cam lobes and bearings. After you visually inspect a camshaft, place it on V-blocks and measure the shaft runout by using a dial indicator. When you measure the runout, take the out-of-roundness into consideration. Compare your measurements to the manufacturer's specifications.

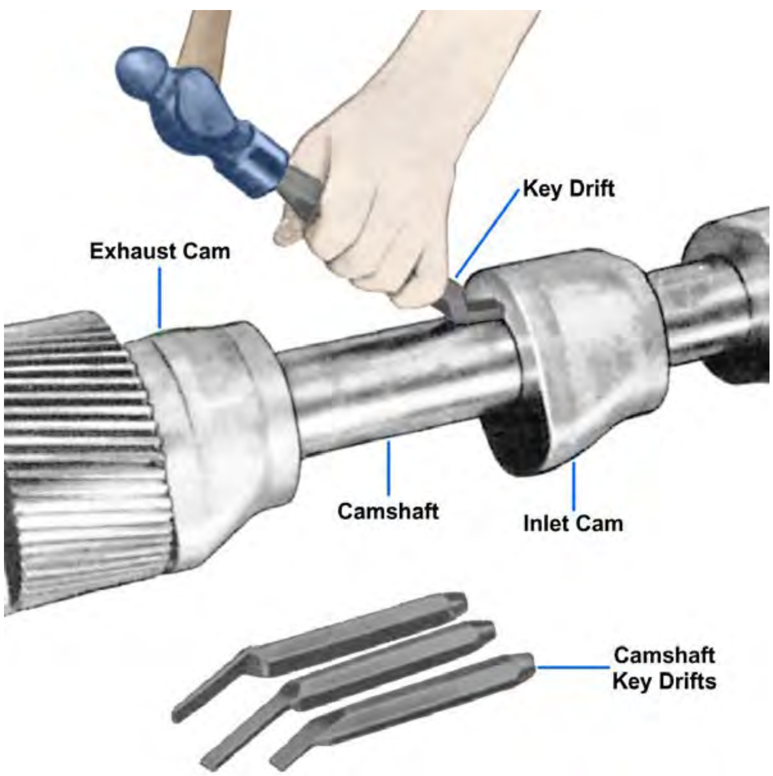

Figure 4-30 — Removing an individual cam.

Also, measure the camshaft bearing journals with a micrometer. *Figure 4-31* illustrates a camshaft with bearing journals.

A camshaft needs to be replaced if the following conditions occur:

1. The lobes are damaged, as lobes cannot be repaired.
2. Runout exceeds the manufacturer's specifications.
3. Wear on the shaft bearing journals exceeds the manufacturer's specifications.
4. The keyways are damaged.

Before you reinstall a good camshaft, remove the minor surface defects on the cams and the camshaft by using crocus cloth or a fine stone.

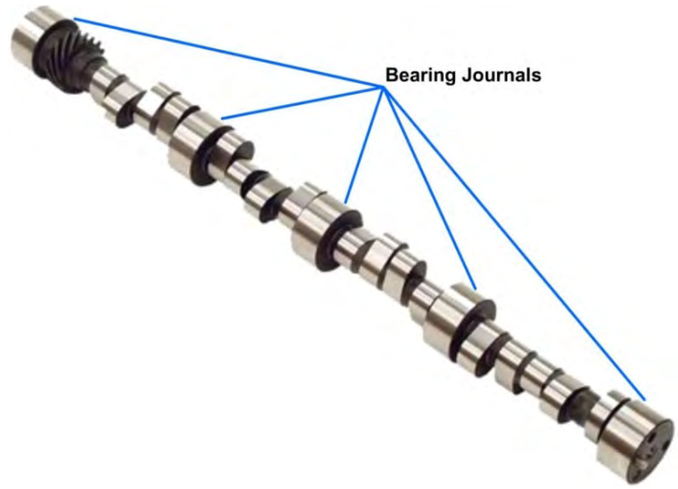

Figure 4-31 — Camshaft with bearing journals in a V-type engine.

INSPECTING, MAINTAINING, AND REPLACING PISTON RINGS AND PISTONS

The following paragraphs are general procedures for inspections, maintenance, and replacement of piston rings and pistons. You must consult the manufacturer's technical manual for specific instructions.

Piston Rings

Over a period of time all piston rings wear. Some stick and may even break. While you may be able to free stuck rings and make them serviceable, you must replace excessively worn or broken rings with new ones. The installation of a new set of rings in an engine requires great care. Most of the damage that is done occurs when the rings are being placed in the grooves of a piston or when the piston is being inserted into the cylinder bore.

Be very careful when you remove the piston and connecting rod from the cylinder. In most engines, you should not remove a piston from a cylinder until you have scraped the cylinder surface above the ring travel area. In addition to removing all carbon, you must remove any appreciable ridge before removing the piston. Use a metal scraper and place a cloth in the cylinder to catch all metal cuttings. You can usually scrape enough from the lip of a cylinder to allow the piston assembly to slide out of the liner. After removing the piston, you can make a more detailed inspection of the ridge.

Finish scraping the remaining ridge, but be careful not to go too deep. Finish the surface with a handstone. For large ridges, you may need to remove the liner and use a small power grinder. With the piston and connecting rod removed, check the condition and wear of the piston pin bushing, both in the piston and in the connecting rod.

The best way to remove and install piston rings is with a tool similar to that shown in *Figure 4-32, frames 1 and 2.* These tools generally have a device that limits the amount the ring can be spread and prevents the rings from being deformed or broken.

A ring that is securely stuck in the groove will require additional work. You may need to soak the piston overnight in an approved cleaning solvent or in diesel oil. If soaking does not free the ring, you must drive it out with a brass drift. The end of the drift should be shaped and ground to permit its use without damage to the lands.

After removing the rings, thoroughly clean the piston with special attention to the ring grooves. (Diesel oil or kerosene are satisfactory cleaning agents.) In addition, you may need to clean excessive deposits from the oil return holes in the bottom of the oil control ring grooves with a twist drill of a diameter corresponding to the original size of the holes.

Figure 4-32 — Piston ring tools used for removal or installation.

Make another complete inspection after cleaning the piston. Check all parts for any defects that could require replacement of the piston. Give particular attention to the ring grooves, especially if the pistons have been in service for a long period of time. A certain amount of enlargement of the width of the grooves is normal, and SHOULDERING of the groove may occur. Shouldering, as illustrated in *Figure 4-33*, results from the "hammering out" motion of the rings. The radial depth of thickness of the ring is much less than the groove depth, and while the ring wears away an amount of metal corresponding to its own width, the metal at the bottom of the groove remains unchanged. Shouldering usually requires replacement of the piston since the shoulders prevent the proper fitting of new rings.

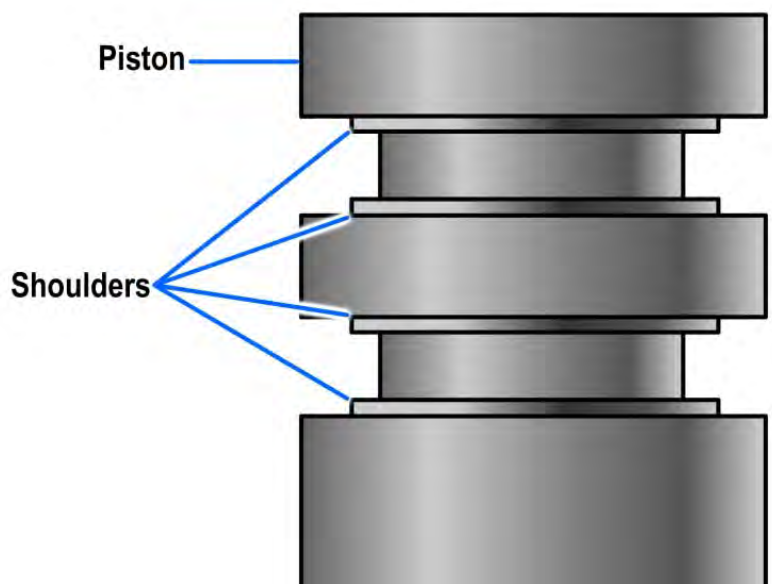

Figure 4-33 — Ring groove shoulders due to wear.

After determining that a piston is serviceable, inspect the rings carefully to determine whether they can be reused. If they do not meet specifications, you must install new rings.

When installing rings, measure the gap with a feeler gauge; to measure the gap, place the new rings inside the cylinder liner *(Figure 4-34, frame 1*) or in a ring gauge. When the gap is measured with the ring in the liner (*Figure 4-34, frame 2*), two measurements are necessary—one just below the upper limit of ring travel, and the other within the lower limit of travel. These measurements are necessary because the liner may have a slight amount of taper caused by wear. The ring gap must be within the limits specified in the manufacturer's technical manual. If the gap of a new ring is less than specified, file the ends of the ring with a straight-cut mill file to obtain the proper gap. If the gap is more than specified, install oversized rings.

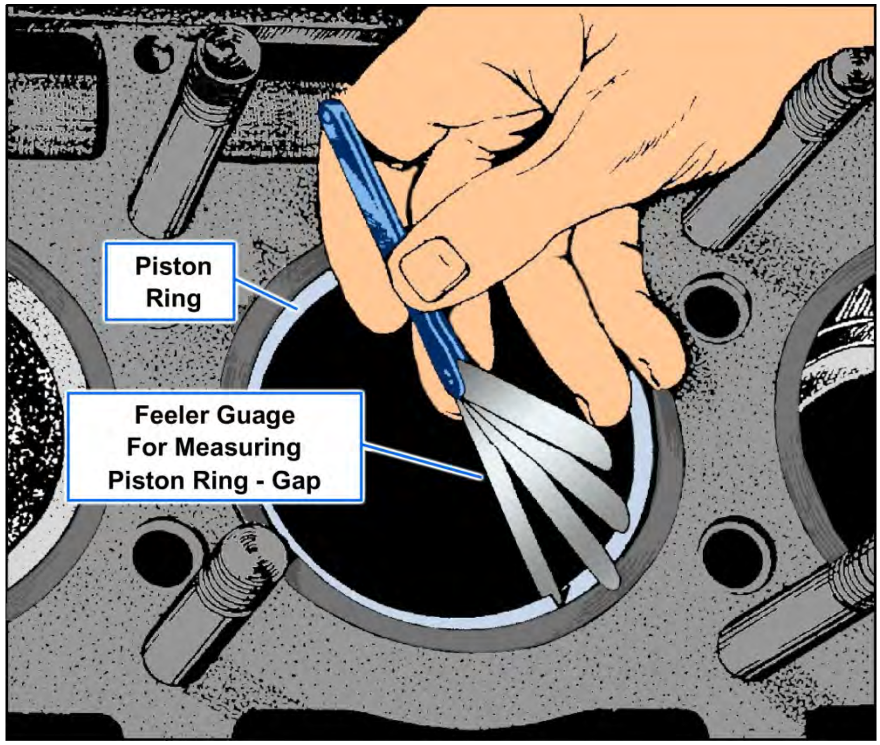

Figure 4-34 — Leveling a piston ring and measuring ring gap clearance in a cylinder bore.

To measure the ring gap of used rings, hold the rings in place on the piston with a ring compressing tool (*Figure 4-35*). But before you measure the ring gap with the ring on the piston, first measure the piston for wear and out-of-roundness.

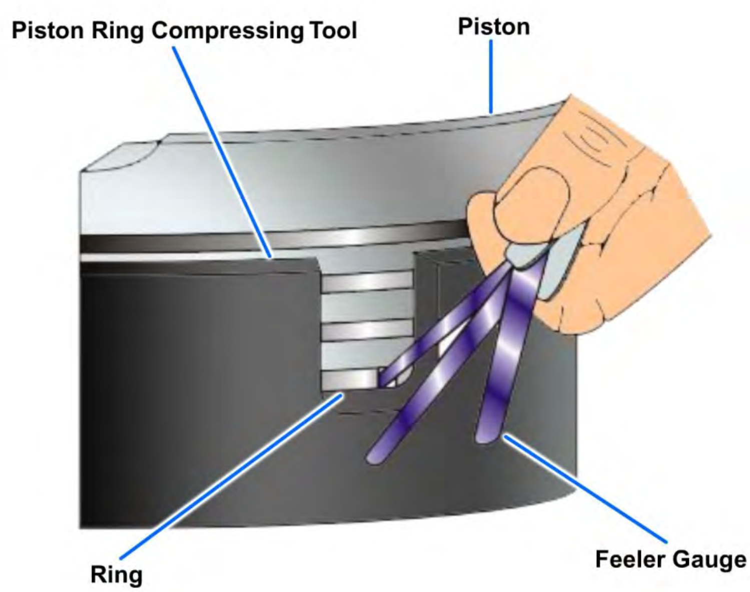

Figure 4-35 — Checking ring gap clearance.

After ensuring the proper gap clearance, you can reinstall the piston pin and connecting rod. During reassembly and installation of a piston and connecting rod assembly, be sure that all parts are well lubricated. Install the rings on the piston with tools similar to those used for ring removal. When installing piston rings, spread them as little as possible to avoid breaking the rings. Insert the lowest ring first. When all the rings have been installed, check the ring-to-land clearance (*Figure 4-36*). If the clearance is too small, the ring may bind or seize, allowing improper sealing and blowby to occur. If the clearance is excessive, the ring may flutter and break itself or the piston land.

After you have properly installed all the rings, coat the entire assembly with oil, then insert it into the cylinder bore. Position the rings so the gap of each successive ring is on an alternate side and the gaps are in line with the piston pin bosses. On large engines, use a chain fall to hold the piston assemble in position as you lower it into the cylinder (*Figure 4-37*).

When a piston is being inserted into a cylinder, the piston rings must be compressed evenly. Special funnel-type tools, similar to the one shown in *Figure 4-37,* are usually provided for this purpose. Another type of ring compressing tool is a steel band that can be placed around the ring and tightened.

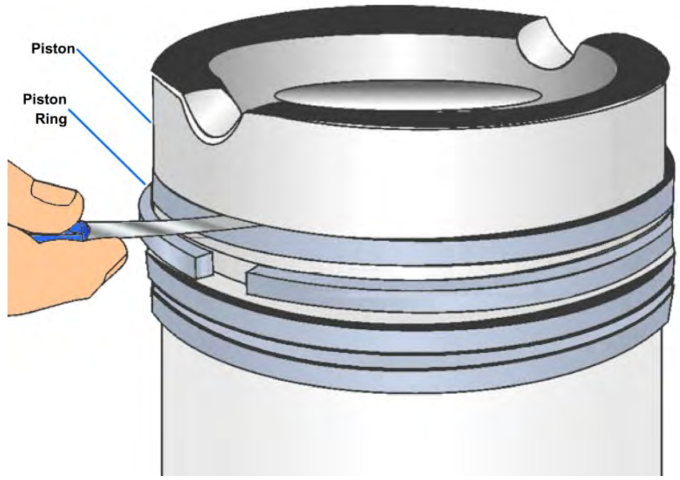

Figure 4-36 — Checking ring groove side clearance.

Pistons

Trunk-type pistons are subject to forces such as gas pressure, side thrust, inertia, and friction. These forces, together with overheating and the presence of foreign matter may cause troubles such as undue piston wear, crown and land dragging, cracks, piston seizure, clogged oil holes, and piston pin bushing wear.

Excessive Piston-to-Liner Clearance

Symptoms of excessive clearance between a piston and its cylinder are piston slap and excessive oil consumption. Piston slap occurs just after top dead center and bottom dead center, as the piston shifts its thrust from one side to the other. As the cylinder taper increases with wear, oil consumption increases. Since taper causes the rings to flex on each stroke of the piston, excess ring wear occurs, allowing lube oil to pass and be burned in the cylinder. This results in the accumulation of excessive carbon deposits.

Figure 4-37 — Installing a piston in a cylinder bore with a funnel-type ring compressor.

Crown and Land Dragging

Pistons and liners may become sufficiently worn to permit the piston to cock over in the cylinder. This allows the crown and ring lands to drag on the cylinder wall. The results of dragging can be determined by visually inspecting the parts of the piston in question.

Piston Wear

Although piston wear is normal in all engines, the amount and rate of piston wear depend on several controllable factors.

One of the controllable factors is LUBRICATION. An adequate supply of oil is essential to provide the film necessary to cushion the piston and other parts within the cylinder and prevent metal-to-metal contact. Inadequate lubrication will not only cause piston wear and crown and land dragging, but also may cause piston seizure and piston pin bushing wear.

Lack of lubrication is caused either by a lack of lube oil pressure or by restricted oil passages. The pressure-recording instruments usually give warning of low oil pressure before any great harm results. However, clogged passages offer no such warnings, and their discovery depends on the care that is exercised in inspecting and cleaning the piston and connecting rod assembly.

Another controllable factor that may be directly or indirectly responsible for many piston troubles is IMPROPER COOLING WATER TEMPERATURE.

If an engine is not operated within the specified temperature limits, lubrication troubles will develop. High cylinder surface temperatures will reduce the viscosity of the oil. As the cylinder lubricant thins, it will run off the surfaces. The resulting lack of lubrication leads to excessive piston and liner wear. However, if temperatures are below those specified for operation, viscosity will be increased, and the oil will not readily reach the parts requiring lubrication.

Oil plays an important role in the cooling of the piston crown. If the oil flow to the underside of the crown is restricted, deposits caused by oxidation of the oil will accumulate, lowering the rate of heat transfer. Therefore, the underside of the piston crown should be thoroughly cleaned whenever pistons are removed While insufficient and uneven cooling may cause ring land failure, excessive temperatures may cause piston seizure; an increase in the rates of oxidation of the oil, resulting in clogged oil passages; or damage to piston pin bushings.

Seizure or excessive wear of pistons may be caused by IMPROPER PIT. New pistons or liners must be installed with the piston-to-cylinder clearances specified in the manufacturer’s instruction manual.

Piston Pins and Sleeve Bearings or Bushings

Every time you remove a piston assembly from an engine, inspect it for wear. Measure the piston pins and sleeve bearings or bushings with a micrometer, as shown in *Figure 4-38, frames 1 and 2*, to determine whether wear is excessive.

You can press bushings out of the rod with a mandrel and an arbor press or with special tools, as shown in *Figure 4-39*. You can also remove bushings by first shrinking them with dry ice. Dry ice will also make it easier to insert the new bushing.

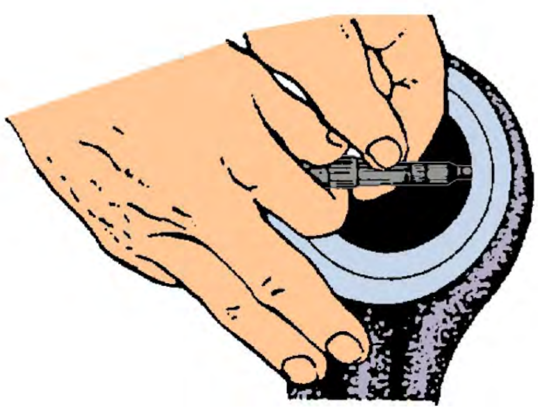

Figure 4-38 — Measuring a piston pin and piston bushing for wear.

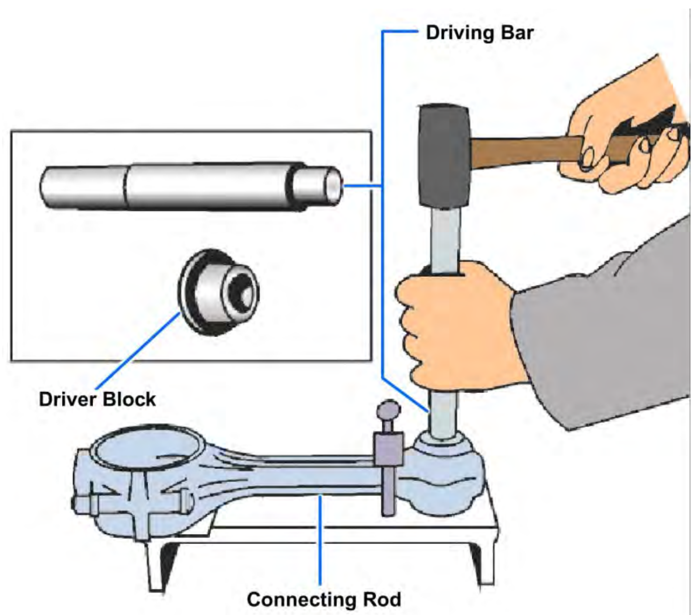

Figure 4-39 — Removing or installing a piston pin bushing.

When you insert new bushings, be sure that the bore into which they are pressed is clean and that the oil holes in the bushing and the oil passages in the rod are aligned. To obtain proper clearance, sometimes you will need to ream a piston pin bushing after it has been installed. *Figure 4-40* shows equipment used to ream a bushing.

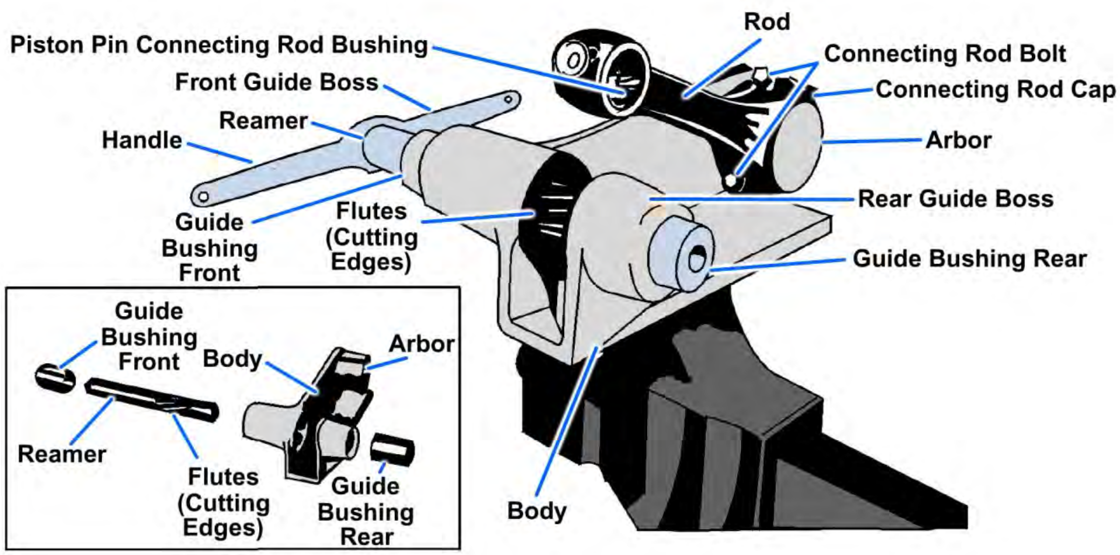

Figure 4-40 — Reaming equipment.

After installing a new bushing, check the alignment of the rod with equipment such as that illustrated in *Figure 4-41*. Be sure to check the manufacturer's technical manual for details concerning clearances and alignment procedures.

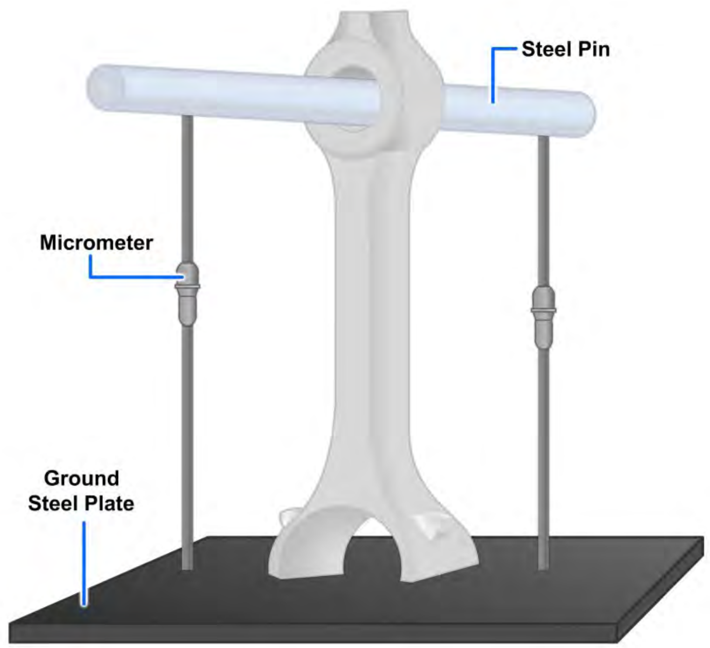

Figure 4-41 — Checking the alignment of a connecting rod.

INSPECTING, MAINTAINING, AND REPAIRING CONNECTING RODS

Most connecting rod troubles involve either the connecting rod bearing or the piston pin bearing.

There are, however, certain unavoidable troubles, such as cracked connecting rods caused by defective material. Such cracks must be discovered before they develop to a point that the rod fails. Magniflux testing is considered the best method for locating cracks. If you discover a crack in a connecting rod, replace the rod; do not try to repair it. If you have to replace a damaged rod, send it, with other damaged parts, to a salvage center for possible reclamation.

Do not repair defective connecting rod bolts, except for removing small burrs by using a fine rectangular file. If you doubt the condition of a bolt or a nut, replace it.

Check the connecting rod bore for out-of-roundness with an inside micrometer. Make the correction and recheck the bore. If the distortion is permanent, replace the rod.

You can make plugged oil passages of connecting rods serviceable by running a wire through them. In extreme cases, you may need to drill the passages free of foreign matter.

Repairing Crankshafts and Journal Bearings

The repair of crankshafts and bearings varies depending on the extent of damage. Out-of-round journals may be reground and undersize bearing shells may be installed, but this requires personnel skilled in the use of precision tools. If a new shaft is available, it should be installed and the damaged shaft should be sent to a salvage reclamation center. Under certain conditions, scored crankshaft journals or damaged journal bearings may be kept in service if proper repair is performed.

Repair of SCORED JOURNALS depends on the extent of scoring. If a crankshaft has been overheated, the effect of the original heat treatment will have been destroyed. In this case, the crankshaft should be replaced.

If journal scoring is only slight, you can use an oilstone for dressing purposes if you take precautionary measures with respect to abrasives during the procedure. During the dressing operation, plug all oil passages within the journal and those connecting the main bearing journal and the adjacent connecting rod journal.

In the dressing procedure, use a fine oilstone, followed with crocus cloth, to polish the surface. After dressing journals, always wash them with diesel oil. This procedure must include washing the internal oil passages as well as the outside journal surfaces. Some passages are large enough to accommodate a cleaning brush; smaller passages can be cleaned by blowing them out with compressed air. Always dry the passages by blowing compressed air through them.

NEVER STOW A CRANKSHAFT OR BEARING PART ON ANY METAL SURFACE. When you remove a shaft from an engine, place it on a wooden plank with all journal surfaces protected. If the shaft is to be exposed for some time, protect each journal surface with a coating of heavy grease. Always place bearings on wooden boards or clean cloths.

CRANKSHAFT overhaul consists of an inspection, servicing for scoring and wear, and a determination of each crank web deflection. Take crank web deflection readings according to the Planned Maintenance System (PMS).

A strain gauge, often called a crank web deflection indicator, is used to take deflection readings. The gauge is merely a dial-reading inside micrometer used to measure the variation in the distance between adjacent crank webs as the engine shaft is barred over. *Figure 4-42* shows a strain gauge between crank webs.

Figure 4-42 — Using a strain or deflection gauge between crank webs.

When you install the gauge, or indicator, between the webs of a crank throw, be sure to place the gauge as far as possible from the axis of the connecting rod journal. Rest the ends of the indicator in prick-punch marks in the crank webs. If these marks are not present, make them so that the indicator can be placed in its correct position. Consult the manufacturer’s technical manual for the proper location of new marks.

Readings are generally taken at the four crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others, the connecting rod may interfere, making it necessary to take the reading as near as possible to bottom dead center without having the gauge come in contact with the connecting rod. When the gauge is in its lowest position, the dial will be upside down, making it necessary to use a mirror and flashlight to obtain a reading.

> **NOTE**
>
> Once you have placed the indicator in position for the first deflection reading, do not touch the gauge until you have taken and recorded all four readings.

Deflection readings are also used to determine correct alignment between the engine and the generator or between the engine and the coupling. However, when determining alignment, you should take a set of deflection readings at the crank nearest the generator or the coupling. In aligning an engine and generator, you may need to install new chocks between the generator and its base to bring the deflection within the allowable value. You may also need to shift the generator horizontally to obtain proper alignment. To align an engine and a coupling, first, correctly align the coupling with the drive shaft; then, properly align the engine to the coupling, rather than aligning the coupling to the engine.

Bearing Troubles

Severe bearing failures are indicated during engine operation by a pounding noise or by the presence of smoke in the vicinity of the crankcase. Impending failures may sometimes be identified by a rise in the lubricating oil temperature or a lowering of the lubricating oil pressure. Impending bearing failure may be detected during periodic maintenance checks or during engine overhauls by inspection of the bearing shells and backs for pits, grooves, scratches, or evidence of corrosion.

The indication of an impending failure does not necessarily mean that the bearing has completed its useful life. Journal bearings may perform satisfactorily with as much as 10 percent of the load-carrying area removed by fatigue failure. Other minor casualties may be repaired so that a bearing will give additional hours of satisfactory service.

Bearings should not be rejected or discarded for minor pits or minute scratches; however, areas indicating metallic contact between the bearing surface and the journal do mean replacement is needed. Use a bearing scraping tool to smooth minute pits and raised surfaces.

Place a film of clean lubricating oil on the journals and the bearing surfaces before you reinstall them.

Installing Journal Bearings

Always check the markings of the lower and upper bearing halves so you install them correctly. Many bearings are interchangeable when new, but once they have become worn to fit a particular journal they must be reinstalled on that particular journal. You must mark or stamp each bearing half with its location (cylinder number) and the bearing position (upper or lower) to prevent incorrect installation.

You must also pull the connecting rod bearing cap nuts down evenly on the connecting rod bolts to prevent possible distortion of the lower bearing cap and consequent damage to the bearing shells, cap, and bolts. Use a torque wrench (*Figure 4-43*) to measure the

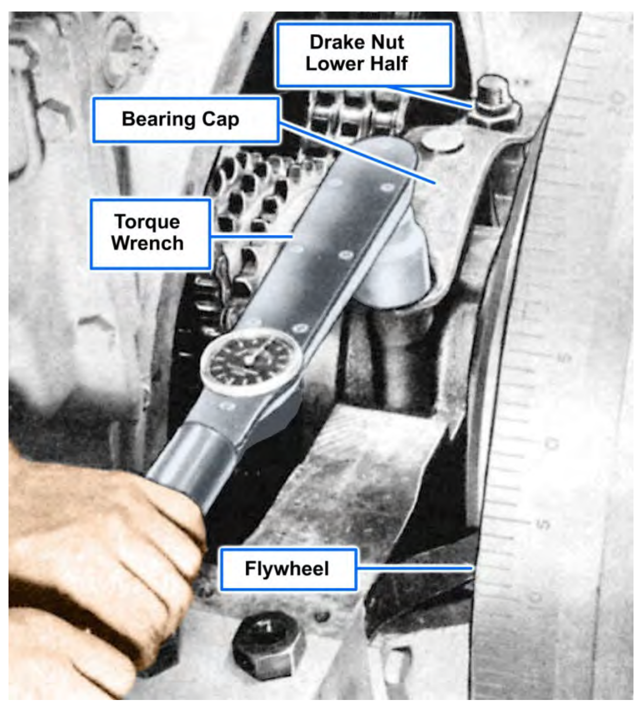

Figure 4-43 — Using a torque wrench to tighten a main bearing.

torque applied to each bolt and nut assembly. Apply the same torque to each bolt. If a manufacturer recommends the use of a torque wrench, the specified torque will be listed in the manufacturer's technical manual.

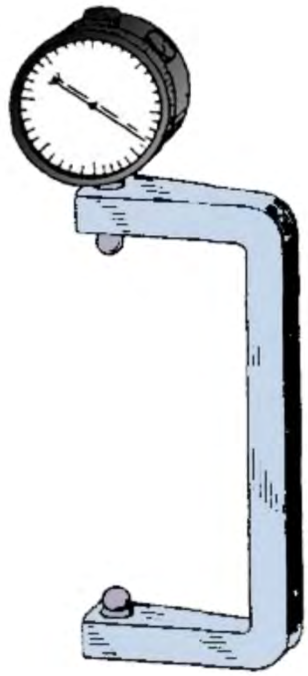

Figure 4-44 — Gauge used for measuring bolt elongation.

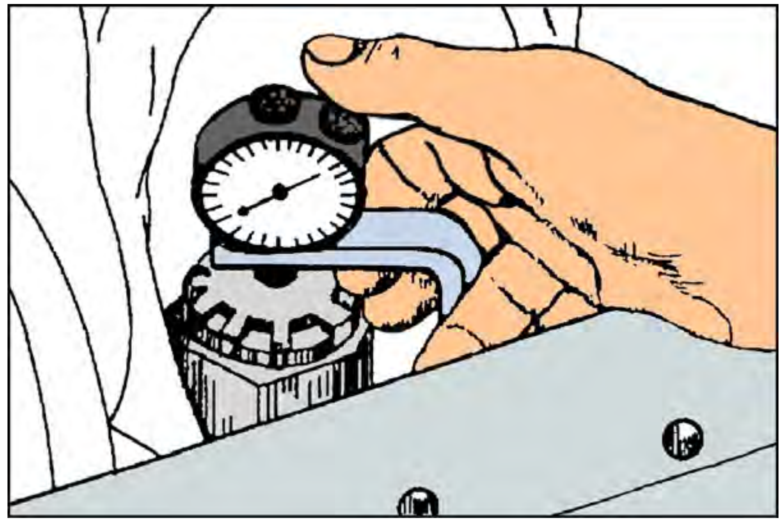

Figure 4-45 — Measuring bolt elongation.

Another method for pulling down the nuts evenly is to stretch each bolt an equal amount and measure the distance from end to end of the bolt before and after tightening. *Figure 4-44* shows the type of gauge used, and *Figure 4-45* illustrates the gauge in use. The proper elongation is listed in the engine manufacturer's technical manual.

After you reassemble a bearing, always bar or jack over the engine by hand through several revolutions. Check to see that all reciprocating and rotating parts function freely and that the main and connecting rod bearings do not bind on the crankshaft. Turn larger diesel engines over first by the manual jacking gear provided and then by the engine starting system.

Measuring Bearing Clearances

Do not use leads, shim stock, or other such items to determine clearance of precision bearings. These items may seriously damage the soft bearing material. Instead, use a micrometer fitted with a spherical seat to measure the thickness of bearing shells. Place the spherical tip against the inside of the bearing shell to obtain an accurate reading and to prevent injury to the bearing material. *Figure 4-46* shows a micrometer caliper fitted with a steel ball for measuring bearing thickness. An alternate method for determining clearance is with a Plastigage (*Figure 4-47, frames 1 and 2*). The Plastigage will not leave an impression in the soft bearing metal because the gauge material is softer than the bearing. To use this method, place a length of the Plastigage of proper gauge across the bearing. Then, assemble the bearing cap and tighten it in place. DO NOT TURN the crankshaft, as that will destroy the Plastigage. After you install and properly fasten the bearing cap,

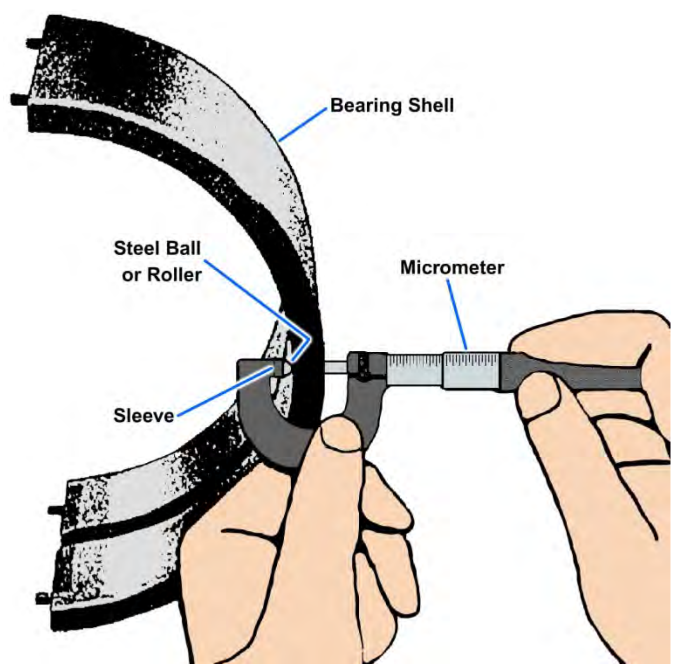

Figure 4-46 — Measuring bearing shell thickness.

remove it. Compare the width of the crushed Plastigage with the Plastigage chart to determine the exact clearance.

You must take measurements at specified intervals, usually at every overhaul, to establish the amount of bearing wear. Also take a sufficient number of crankshaft journal diameter measurements at suitable points to determine possible out-of-roundness.

With some types of engines, a crankshaft bridge gauge (*Figure 4-48*) is used to check the wear of the main bearing shells. To use the gauge, place it on the crankshaft and measure the clearance between the bridge gauge and the shaft with a feeler gauge. Any variation between the measured clearance and the correct clearance (usually stamped on the housing of each bearing) indicates that main bearing wear has occurred. The maximum limits of wear are listed in the manufacturer's technical manual. Some engine manufacturers recommend that bridge gauge readings be taken at every overhaul in conjunction with crank web deflection measurements.

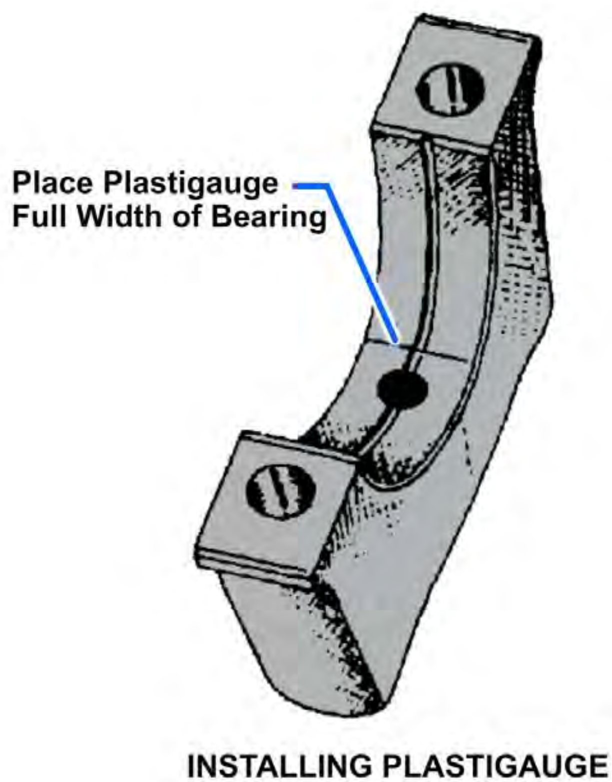

Figure 4-47 — Checking bearing clearance with a Plastigage.

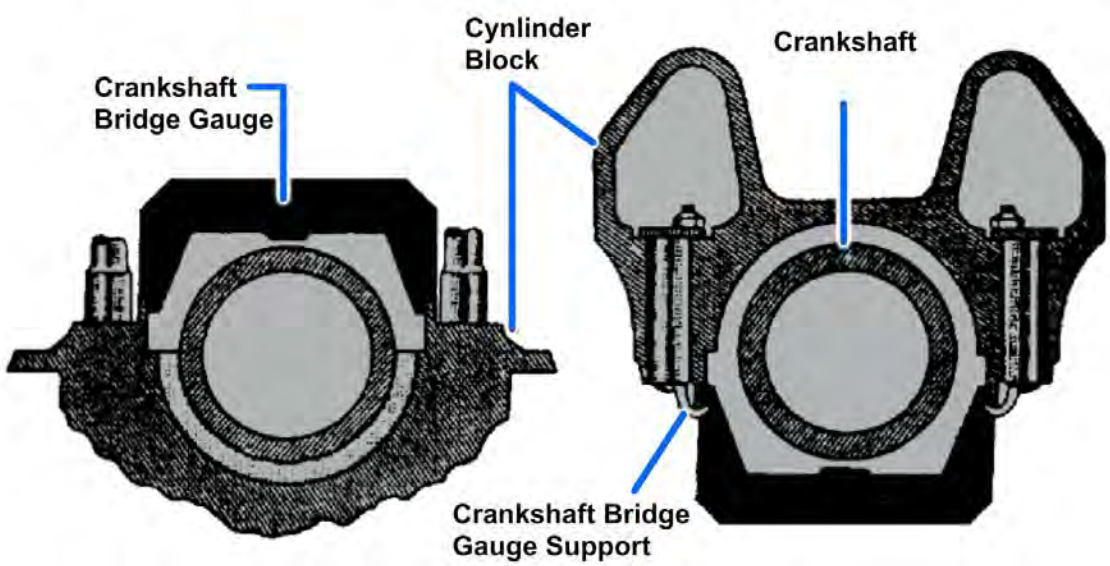

Figure 4-48 — Crankshaft bridge gauge.

TROUBLESHOOTING INTERNAL-COMBUSTION ENGINES

The procedures for troubleshooting internal-combustion engines are somewhat similar for both diesel and gasoline engines. Since most of the internal-combustion engines used by the Navy are diesel, the following sections deal primarily with this type of engine.

This chapter is concerned with troubles that occur both when an engine is starting and running. The troubles are chiefly the kind that can be identified by erratic engine operation, warnings by instruments, or inspection of the engine parts and systems and that can be corrected without major repair or overhaul. There is also a section devoted to the systems of the gasoline engine that are basically different from those of the diesel engine.

Keep in mind that the troubles listed here are general and may or may not apply to a particular diesel engine. When you work with a specific engine, check the manufacturer's technical manual and any instructions issued by the Naval Sea Systems Command.

An engine may continue to operate even when a serious casualty is imminent. However, symptoms are usually present. Your success as a troubleshooter depends partially upon your ability to recognize these symptoms when they occur. You will use most of your senses to detect trouble symptoms. You may see, hear, smell, or feel the warning of trouble to come. Of course, common sense is also a requisite. Another factor in your success as a troubleshooter is your ability to locate the trouble once you decide something is wrong with the equipment. Then, you must be able to determine as rapidly as possible what corrective action to take. In learning to recognize and locate engine troubles, experience is the best teacher.

Instruments play an important part in detecting engine troubles. You should read the instruments and record their indications regularly. If the recorded indications vary radically from those specified by engine operating instructions, the engine is not operating properly and some type of corrective action must be taken. You must be familiar with the specifications in the engine operating instructions. You should know the probable effect on the engine when instrument indications vary considerably from the specified values. When variations occur in instrument indications, before taking any corrective action, be sure the instruments are not at fault before you try corrective actions on the engine. Check the instruments immediately if you suspect them of being inaccurate.

Periodic inspections are also important in detecting engine troubles. Such inspections will reveal the failure of visible parts, presence of smoke, or leakage of oil, fuel, or water. Cleanliness is probably one of the greatest aids in detecting leakage.

When you secure an engine because of trouble, your procedure for repairing the casualty should follow an established pattern, if you have diagnosed the trouble. If you do not know the location of the trouble, find it. To inspect every part of an engine whenever trouble occurs would be an almost endless task. You can find the cause of the trouble much more quickly by following a systematic and logical method of inspection; generally speaking, a well-trained troubleshooter can isolate the trouble by identifying it with one of the engine systems. Once you have associated the trouble with a particular system, the next step is to trace out the system until you find the cause of the trouble. Troubles generally originate in only one system, but remember that troubles in one system may cause damage to another system or to basic engine parts. When a casualty involves more than one system of the engine, trace each system separately and make corrections as necessary. It is obvious that you must know the construction, function, and operation of the various systems as well as the parts of each system for a specific engine before you can satisfactorily locate and remedy troubles.

Even though there are many troubles that may affect the operation of a diesel engine, satisfactory performance depends primarily on sufficiently high compression pressure and injection of the right amount of fuel at the proper time. Proper compression depends basically on the pistons, piston rings, and valve gear, while the right amount of fuel obviously depends on the fuel injectors and their actuating mechanism. Such troubles as lack of engine power, unusual or erratic operation, and excessive vibration may be caused by either insufficient compression or faulty injector action.

Even though a successful troubleshooter generally associates certain troubles with a particular system or assembly, the following sections discuss troubles according to when they might be encountered, either before or after the engine starts.

Engine Fails To Start

In general, the troubles that prevent an engine from starting are:

1. The engine can neither be cranked nor barred over.
2. The engine cannot be cranked, but it can be barred over.
3. The engine can be cranked, but it still fails to start.

Figure 4-49 illustrates various conditions that commonly cause difficulties in cranking, jacking over, or starting the engine.

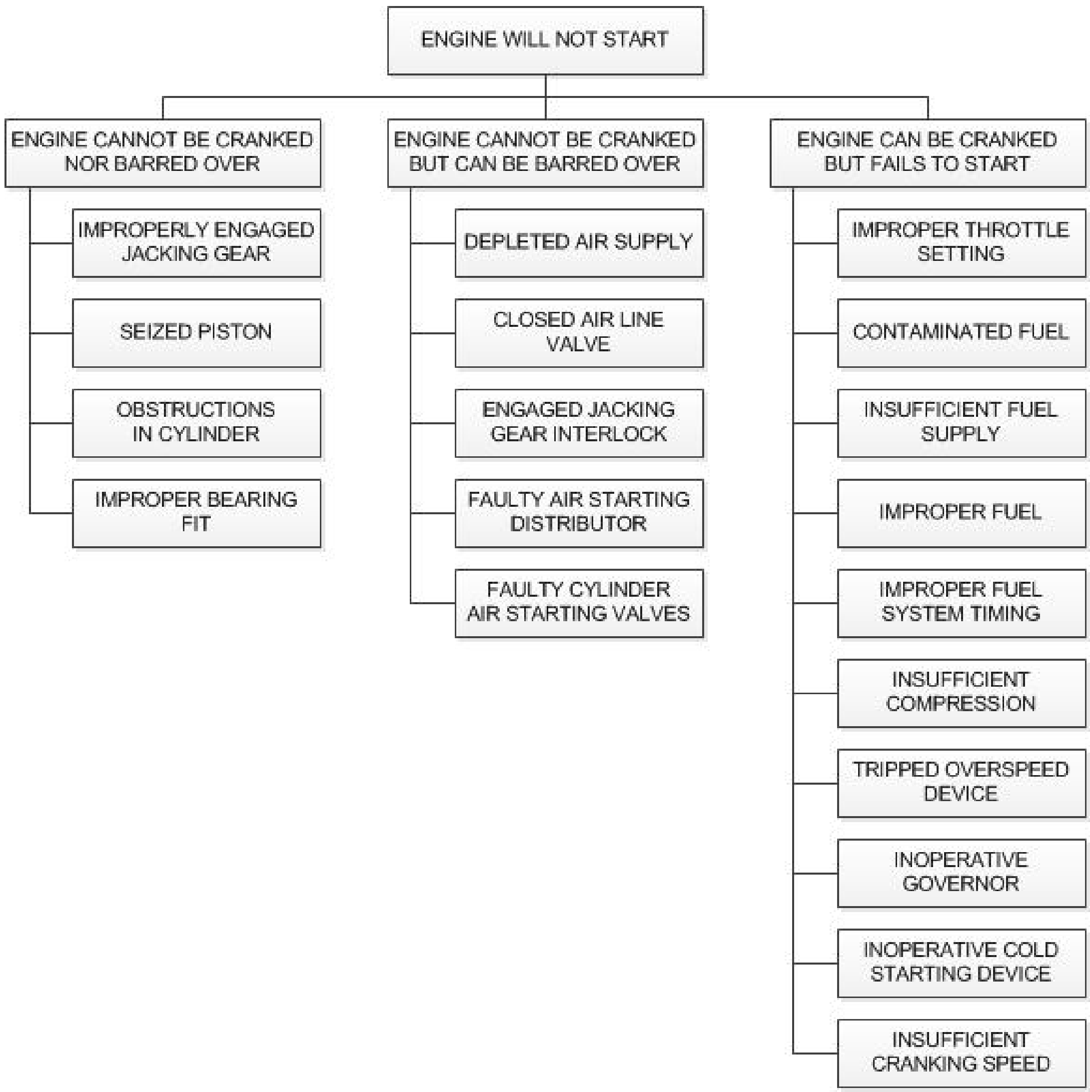

Figure 4-49 — Troubles that may prevent a diesel engine from starting.

Engine cannot be Cranked or Barred Over

Most pre-starting instructions for large engines require you to turn the crankshaft one or more revolutions before applying starting power. If you cannot turn the crankshaft over, check the turning gear to be sure it is properly engaged. If the turning gear is properly engaged and the crankshaft still fails to turn over, check to see whether the cylinder test valves or indicator valves are closed and are holding water or oil in the cylinder. When the turning gear operates properly and the cylinder test valves are open but the engine still cannot be cranked or barred over, check for a serious problem. A piston or other part may be seized or a bearing may be fitting too tightly. Sometimes you may need to remove a part of an assembly to remedy the difficulty.

Some engines have ports through which pistons can be inspected. If inspection reveals that the piston is defective, remove the piston assembly. *Figure 4-50* illustrates testing for stuck piston rings through the scavenging air-port.

If the condition of an engine without cylinder ports indicates that a piston inspection is required, you must take the whole piston assembly out of the cylinder.

Engine bearings must be carefully fitted or installed according to the manufacturer's instructions. When an engine cannot be jacked over because of an improperly fitted bearing, someone probably failed to follow instructions when the unit was being reassembled.

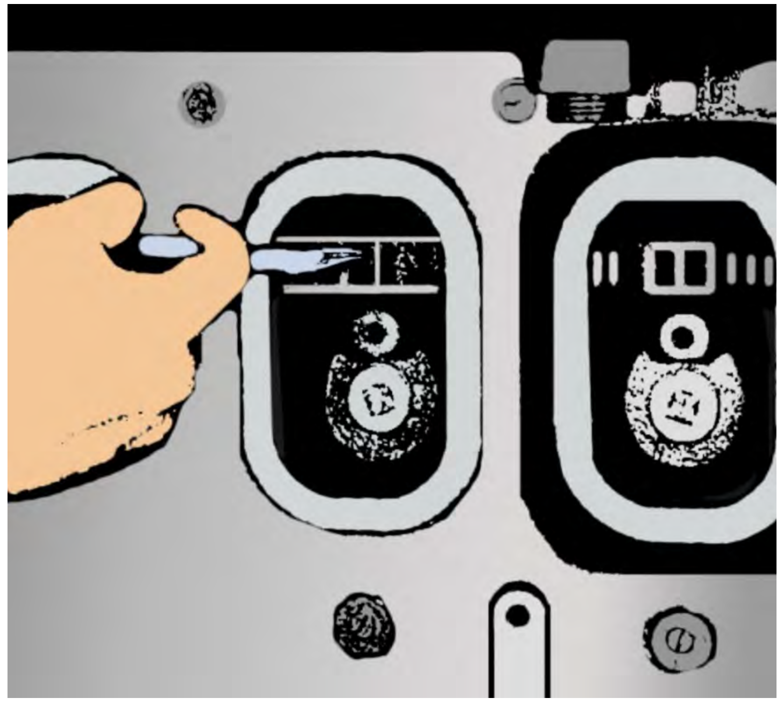

Figure 4-50 — Checking the condition of the piston rings.

Engine Cannot Be Cranked but Can Be Barred Over

You can trace most of the troubles that prevent an engine from cranking, but are not serious enough to prevent barring over, to the starting system. Although other factors may prevent an engine from cranking, only troubles related to starting systems are identified in this chapter.

If an engine fails to crank when you apply starting power, first check the turning or jacking gear to be sure it is disengaged. If this gear is not the source of the trouble, the trouble is probably with the starting system.

Engine Can Be Cranked, but Fails to Start

Although the design of air starting systems may vary, the function remains the same. In general, such systems must have a source of air, such as the compressor or the ship's air system; a storage tank; air flask(s); an air timing mechanism; and a valve in the engine cylinder to admit the air during starting and to seal the cylinder while the engine is running.

All air starting systems have a unit that admits starting air to the proper cylinder at the proper time. The type of unit as well as its name—timer, distributor, air starting pilot valve, air starting distributor, or air distributor—may vary from one system to another. The types of air timing mechanisms are the direct mechanical lift, the rotary distributor, and the plunger-type distributor valve. The timing mechanism of an air starting system is relatively trouble-free except as noted in the following situations.

Direct Mechanical Lift

The direct mechanical lift air timing mechanism includes cams, pushrods, and rocker arms. These parts are subject to the same failures as engine cams, pushrods, and rocker arms. Therefore, you can find the causes of trouble in the actuating gear and the necessary maintenance procedures under information covering similar engine parts.

Most troubles are a result of improper adjustment. Generally, this involves the lift of the starting air cam or the timing of the air starting valve. The starting air cam must lift the air starting valve enough to give a proper clearance between the cam and the cam valve follower when the engine is running. If there is not enough clearance between these two parts, hot gases will flow between the valve and the valve seat, overheating them. Since the starting air cam regulates the opening of the air starting valve, check those with adjustable cam lobes frequently to ensure that the adjusting screws are tight.

Obtain the proper values for lift, tappet clearance, and time of valve opening for a direct mechanical lift timing mechanism from the manufacturer's technical manual for the particular engine. Make adjustments only as specified.

Rotary Distributor

The rotary distributor timing mechanism requires a minimum of maintenance, but there may be times when the unit becomes inoperative and you will need to disassemble and inspect it. Generally, the difficulty is caused by a scored rotor, a broken spring, or improper timing.

Foreign particles in the air can score the rotor, resulting in excessive air leakage. You must, therefore, keep the air supply as clean as possible. Lack of lubrication also causes scoring. If the rotor in a hand-oiled system becomes scored because of insufficient lubrication, the equipment could be at fault, or the lubrication instructions may not have been followed. To prevent problems in either a hand-oiled or pressure-lubricated system, check the piping and the passages to see that they are open. When scoring is not too serious, lap the rotor and body together. Use a thin coat of Prussian blue to determine whether the rotor contacts the distributor body.

A broken spring may be the cause of an inoperative timing mechanism if a coil spring is used to maintain the rotor seal. If the spring is broken, replace it to ensure an effective seal.

An improperly timed rotary distributor will prevent an engine from cranking. Use the information given in the instructions for the specific engine to check the timing.

Plunger-Type Distributor Valve

In a plunger-type distributor valve timing mechanism, the valve requires little attention. However, it may stick occasionally and prevent the air starting system from functioning properly. On some engine installations, the pilot air valve of the distributor may not open, while on other installations this valve may not close. The trouble may be caused by dirt and gum deposits, broken return springs, or lack of lubrication. Deposits and lack of lubrication will cause the unit valve plungers to bind and stick in the guides, while a broken valve return spring will keep the plunger from following the cam profile. Disassemble and thoroughly clean a distributor valve that sticks; replace any broken springs.

Pressure-Actuated Valves

In a pressure-actuated valve, the most frequent trouble is sticking. The valve may stick open for a number of reasons. A gummy or resinous deposit may cause the upper and lower pistons to stick to the cylinders. (This deposit is formed by the oil and condensate that may be carried into the actuating cylinders and lower cylinders. Oil is necessary in the cylinders to provide lubrication and to act as a seal; however, moisture should be eliminated.) You can prevent this resinous deposit from forming by draining the system storage tanks and water traps as specified in the operating instruction. The deposit on the lower piston may be greater than that in the actuating cylinder because of the heat and combustion gases that add to the formation if the valve remains open. When the upper piston is the source of trouble, you can usually relieve the sticking, without removing the valve, by using light oil or diesel fuel and working the valve up and down. When you use this method, be sure that the valve surfaces are not burned or deformed. If this method does not relieve the sticking condition, you will need to remove, disassemble, and clean the valve.

Pressure-actuated starting valves sometimes fall to operate because of broken or weak valve return springs. Replacement is generally the only solution to this condition; however, some valves are constructed with a means of adjusting spring tension. In such valves, increasing the spring tension may eliminate the trouble.

Occasionally the actuating pressure of a valve will not release, and the valve will stick open or be sluggish in closing. The cause is usually clogged or restricted air passages. Combustion gases will enter the air passageways, burning the valve surfaces. These burned surfaces usually must be reconditioned before they will maintain a tight seal. Keeping the air passages open will eliminate extra maintenance work on the valve surfaces.

Mechanical Lift Valves

The mechanical lift-type air starting valve is subject to leakage which, in general, is caused when the valve sticks open. Any air starting valve that sticks or leaks creates a condition that makes an engine hard to start. If the leakage in the air starting valve is excessive, the loss in pressure may prevent the engine from starting.

Leakage in this type of valve can be caused by an overtightened packing nut. Nut over tightening may prevent the air valve from seating. As in the pressure-actuated valve, there may not be enough return spring tension to return the valve to the valve seat after admitting the air charge.

Obstructions such as particles of carbon between the valve and valve seat will hold the valve open, permitting combustion gases to pass. A valve stem bent by careless handling during installation may also prevent a valve from closing properly. If a valve hangs open for any of these reasons, hot combustion gases will leak past the valve and valve seat.

Completely disassemble and inspect a leaking valve. It is subject to a resinous deposit similar to that found in a pressure-actuated air valve. Use a specified cleaning compound to remove the deposit. Be sure the valve stem is not bent. Check the valve and valve seat surfaces carefully. Eliminate scoring or discoloration by lapping with a fine lapping compound. You may use jewelers' rouge or talcum powder with fuel oil for lapping.

From the preceding discussion, you have learned that the air starting system may be the source of many troubles that will prevent an engine from cranking even though it can be barred over. You will avoid a few of these troubles by following pre-starting and starting instructions. One such instruction, sometimes overlooked, is that of opening the valve in the air line. Obviously, with this valve closed the engine will not crank. Recheck the instructions for such oversights as a closed valve, an empty air storage receiver, or an engaged jacking gear before starting any disassembly.

Electric Start Malfunction

Electric starting system malfunctions fall into the following categories:

1. Nothing happens when the starter switch is closed.
2. The starter motor runs, but it does not engage the engine.
3. The starter motor engages, but it cannot turn the engine.

If nothing happens when you close the starter switch, there is a failure in the electrical system. The failure could be an open circuit caused by broken connections or burned out components. Test the circuit continuity to make sure the relay closes and the battery provides sufficient voltage and current to the starter circuit. If the circuit is complete, there may be resistance through faulty battery connections. Considerable current is needed to operate the solenoid and starter motor.

If the starter runs without engaging, it will produce a distinctive hum or whine. The lack of engagement is usually caused by dirt or corrosion, which keeps the solenoid or Bendix gears from operating properly.

If the starter motor engages the flywheel ring gear but is not able to turn the engine or cannot turn it quickly enough to obtain starting speed, the cause may be lack of battery power or, more likely, a mechanical problem. If the engine can be barred over, there is excessive friction in the meshing of the starter pinion and the ring gear. Either the teeth are burred, or the starter pinion is out of alignment. Either case would have been preceded by noise the last time the starter was used. A major repair may be necessary.

Other problems and malfunctions of electric starting systems are discussed in association with gasoline engines at the end of this chapter.

Engine Cranks but Fails to Start

Even when the starting equipment is in an operating condition, an engine may fail to start. Most troubles that prevent an engine from starting are associated with fuel and the fuel system. However, defective or inoperative parts or assemblies may be the source of some trouble. Failure to follow instructions may be the cause of an engine failing to start. The corrective action is obvious for such items as leaving the fuel throttle in the OFF position and leaving the cylinder indicator valves open. If an engine fails to start, follow the prescribed starting instructions and recheck the procedure.

Foreign Matter in the Fuel Oil System

In the operation of an internal-combustion engine, cleanliness is of paramount importance. This is especially true in the handling and care of diesel fuel oil. Impurities are the prime source of fuel pump and injection system troubles. Sediment and water cause wear, gumming, corrosion, and rust in a fuel system. Even though fuel oil is generally delivered clean from the refinery, handling and transferring increase the chances that fuel oil will become contaminated.

Corrosion often leads to replacement or at least to repair of the part. You must continually take steps to prevent water from accumulating in a fuel system, not only to eliminate the cause of corrosion but also to ensure proper combustion in the cylinders. Centrifuge all fuel.

Water in fuel will cause irreparable damage to the entire fuel system in a short time. It corrodes the fuel injection pump, where close clearances must be maintained, and also corrodes and erodes the injection nozzles. The slightest corrosion can cause a fuel injection pump to bind and seize which, if not corrected, will lead to excessive leakage. Water will erode the orifices of injection nozzles until they will not spray the fuel properly, thus preventing proper atomization. When this occurs, incomplete combustion and engine knocks result.

Air in the fuel system is another possible trouble that may prevent an engine from starting. Even if the engine will start, air in the fuel system will cause the engine to miss and knock, and perhaps to stall.

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high-pressure pumps and lines. In many systems, the expansion and compression of such air may take place even if the injection valves do not open. If this occurs, the pump is AIRBOUND. To determine if there is air in a fuel system, bleed a small amount of fuel from the top of the fuel filter; if the fuel appears quite cloudy, there are probably small bubbles of air in the fuel.

Insufficient Fuel Supply

An insufficient fuel supply may result from a defective or inoperative part in the system. Such items as a closed inlet valve in the fuel piping or an empty supply tank are more likely to be the fault of the operator than of the equipment. But an empty tank may be caused by leakage, either in the lines or in the tank.

LEAKAGE-You can usually trace leakage in the low-pressure lines of a fuel system to cracks in the piping. Usually these cracks occur on threaded pipe joints at the root of the threads. Such breakage is caused by the inability of the nipples and pipe joints to withstand shock, vibration, and strains resulting from the relative motion between smaller pipes and the equipment to which they are attached.

Metal fatigue can also cause breakage. Each system should have a systematic inspection of its fittings and piping to determine if all the parts are satisfactorily supported and sufficiently strong. In some instances, nipples may be connected to relatively heavy parts, such as valves and strainers, which are free to vibrate. Since vibration contributes materially to the fatigue of nipples, rigid bracing should be installed. When practicable, bracing should be secured to the unit itself, instead of to the hull or other equipment.

Breakage can also cause leakage in the high-pressure lines of a fuel system. The breakage usually occurs on either of the two end fittings of a line and is caused by lack of proper supports or by excessive nozzle opening pressure. Supports are usually supplied with an engine and should not be discarded. Excessive opening pressure of a nozzle-generally due to improper spring adjustment or to clogged nozzle orifices-may rupture the high-pressure fuel lines. A faulty nozzle usually requires removal, inspection, and repair plus the use of a nozzle tester.

In an emergency, you can usually repair a high-pressure fuel line by silver soldering a new fitting to the line. After making the silver solder repair, test the line for leaks and be certain no restrictions exist.

The principal causes of fuel tank leakage are improper welds and metal fatigue. Metal fatigue is usually the result of inadequate support; excessive stresses develop in the tank and cause cracks.

Clogged Fuel Filters

Another problem that can limit the fuel supply to such an extent that an engine will not start is clogged fuel filters. Definite rules for filter replacement cannot be established for all engines. But instructions generally state that elements will not be used longer than a specified time. Since there are reasons that an element may not always function properly for its expected service life, it should be replaced whenever it is suspected of being clogged.

Filter elements may become clogged because of dirty fuel, too small filter capacity, failure to drain the filter sump, and failure to use the primary strainer. Usually, clogging is indicated by such symptoms as stoppage of fuel flow, increase in pressure drop across the filter, increase in pressure upstream of the filter, or excessive accumulation of dirt on the element (observed when the filter is removed for inspection). Symptoms of clogged filters vary in different installations, and each installation should be studied for external symptoms, such as abnormal instrument indications and engine operation. If external indications are not apparent, visual inspection of the element will be necessary, especially if it is known or suspected that dirty fuel is being used.

Fuel filter capacity should at least equal fuel supply pump capacity. A filter with a small capacity clogs more rapidly than a larger one, because the space available for dirt accumulation is more limited. There are two standardized sizes of fuel filter elements—large and small. The small element is the same diameter as the large but is only one-half as long. This construction permits substitution of two small elements for one large element.

You can increase the interval of time between element changes by using the drain cocks on a filter sump. Removal of dirt through the drain cock will make room for more dirt to collect.

If new filter elements are not available for replacement and the engine must be operated, you can wash some types of totally clogged elements and get limited additional service. This procedure is for emergencies only. An engine must never be operated unless all the fuel is filtered; therefore, a “washed filter” is better than none at all.

Fuel must never flow from the supply tanks to the nozzles without passing through all stages of filtration. Strainers, as the primary stage in the fuel filtration system, must be kept in good condition if sufficient fuel is to flow in the system. Most strainers have a blade mechanism that can be turned by hand. If you cannot readily turn the scraper by hand, disassemble and clean the strainer. This minor preventive maintenance will prevent the scraping mechanism from breaking.

Transfer Pumps

If the supply of fuel oil to the system is to be maintained in an even and uninterrupted flow, the fuel transfer pumps must function properly. These pumps may become inoperative or defective to the point that they fail to discharge sufficient fuel for engine starting. Generally, when a pump fails to operate, some parts have to be replaced or reconditioned. For some types of pump, it is customary to replace the entire unit. However, for worn packing or seals, satisfactory repairs may be made. If plunger-type pumps fail to operate because the valves have become dirty, submerge and clean the pump in a bath of diesel oil.

Malfunctioning of the Injection System

The fuel injection system is the most intricate of the systems in a diesel engine. Since the function of an injection system is to deliver fuel to the cylinder at a high pressure, at the proper time, in the proper quantity, and properly atomized, special care and precautions must be taken in making adjustments and repairs.

High-Pressure Pump

If a high-pressure pump in a fuel injection system becomes inoperative, an engine may fail to start. Information on the causes and remedies for an inoperative pump can be found in the manufacturer's technical manual. Any ship using fuel injection equipment should have available copies of the applicable manufacturer's technical manual.

Timing

Regardless of the installation or the type of fuel injection system used, the timing of the injection system must be correct to obtain maximum energy from the fuel. Early or late injection timing may prevent an engine from starting. Operation will be uneven and vibration will be greater than usual.

If fuel enters a cylinder too early, detonation generally occurs, causing the gas pressure to rise too rapidly before the piston reaches top dead center. This in turn causes a loss of power and high combustion pressure. Low exhaust temperature may be an indication that fuel injection is too early.

If fuel is injected too late in the engine cycle, overheating, lowered firing pressure, smoky exhaust, high exhaust temperature, or loss of power may occur.

Insufficient Compression

Proper compression pressures are essential if a diesel engine is to operate satisfactorily. Insufficient compression may cause an engine to fail to start. If you suspect low pressure as the reason, check the compression with the appropriate instrument. If the test indicates pressures below standard, disassembly is required for complete inspection and correction.

Inoperative Engine Governor

There are many troubles that may cause a governor to become inoperative. The most frequent trouble associated with starting an engine is generally caused by bound control linkage or, if the governor is hydraulic, by low oil level. Whether the governor is mechanical or hydraulic, binding of linkage is generally due to distorted, misaligned, defective, or dirty parts. If you suspect binding, move the linkage and governor parts by hand and check their movement.

Low oil level in hydraulic governors may be caused oil leaking from the governor or failure to maintain the proper oil level. Leakage of oil from a governor can generally be traced to a faulty oil seal on the drive shaft or power piston rod, or to a poor gasket seal between parts of the governor case.

Check the condition of the oil seals if oil must be added too frequently to governors with independent oil supplies. Oil seal leakage may or may not be visible on external surfaces. There will be no external sign if leakage occurs through the seal around the drive shaft, while leakage through the seal around the power piston will be visible.

Oil seals must be kept clean and pliable. Store them properly so they do not become dirty or dry and brittle. Leaky oil seals cannot be repaired. They must be replaced. You can prevent some leakage troubles simply by following proper installation and storage instructions for the seals.

Inoperative Overspeed Safety Devices

Overspeed safety devices are designed to shut off fuel or air in case of excessive engine speed. These devices must be maintained in operable condition at all times. Inoperative overspeed devices may also cause an engine not to start. They may be inoperative because of improper adjustment, faulty linkage, or a broken spring, or the overspeed device may have been accidentally tripped during the attempt to start the engine.

If the overspeed device fails to operate when the engine overspeeds, the engine may be secured by manually cutting off the fuel oil or the air supply to the engine. Most engines have special devices or valves to cut off the air or fuel in an emergency.

Insufficient Cranking Speed

If the engine cranks slowly, the necessary compression temperature cannot be reached. Low starting air pressure may be the cause of such trouble.

Slow cranking speed may also be the result of an increase in the viscosity of the lubricating oil. This trouble occurs during periods when the air temperature is lower than usual. The oil specified for use during normal operation and temperature is not generally suitable for cold climate operation.

IRREGULAR ENGINE OPERATION

As the engine operator, you must constantly be alert to detect any symptoms that might indicate trouble. Such symptoms may be sudden or abnormal changes in the supply, temperature, or pressure of the lubricating oil or cooling water. Color and temperature of the exhaust may also indicate abnormal conditions. Check them frequently. Fuel, oil, and water leaks indicate possible troubles. You will soon become accustomed to the normal sounds and vibrations of a properly operating engine. If you are alert, an abnormal or unexpected change in the pitch or tone of an engine’s noise or a change in the magnitude or frequency of a vibration will warn you that all is not well. A new sound such as a knock, a drop in the fuel injection pressure, or a misfiring cylinder are other trouble warnings for which you should be constantly alert during engine operation.

The following discussion on possible troubles, their causes, and the corrective action necessary is general rather than specific. The information is based on instructions for some of the engines used by the Navy and is typical of most. A few troubles listed may apply to only one model. For specific information on any particular engine, consult the manufacturer’s technical manual.

Engine Stalls Frequently or Stops Suddenly

Factors that may cause an engine to stall include misfiring, low cooling water temperature, improper application of load, improper timing, and obstruction in the combustion space or in the exhaust system, insufficient intake air, piston seizure, and defective auxiliary drive mechanisms.

Misfiring

When an engine misfires or fires erratically or when one cylinder misfires regularly, the possible troubles are usually associated with the fuel or fuel system, worn parts, or the air cleaner or silencer. In determining what causes a cylinder to misfire, you should follow prescribed procedures in the appropriate technical manual.

Many of the troubles caused by fuel contamination require overhaul and repair. However, a cylinder may misfire regularly in some systems because of the fuel pump cutout mechanism. Some fuel pumps have this type of mechanism so the fuel supply can be cut off from a cylinder to measure compression pressures. When a cylinder is misfiring, check first for an engaged cutout mechanism (if installed), and disengage it during normal engine operation.

Loss of Compression

A cylinder may misfire due to loss of compression, which may be caused by a leaking cylinder head gasket, leaking or sticking cylinder valves, worn pistons, liners or rings, or a cracked cylinder head or block. If loss of compression pressure causes an engine to misfire, check the compression pressure of each cylinder. Some indicators measure compression as well as firing pressure while the engine is running at full speed. Others check only the compression pressures with the engine running at a relatively slow speed. *Figure 4-51, frames 1 through 3* illustrates the application of some different types of pressure indicators.

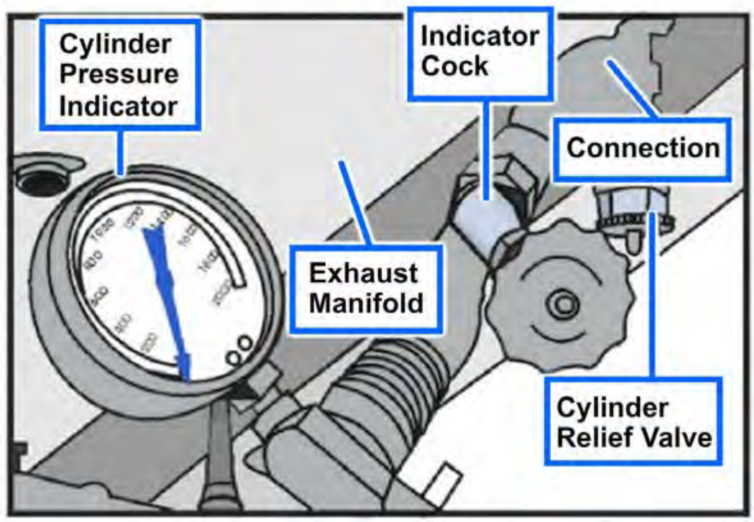

Figure 4-51 — Engine cylinder pressure indicator application.

After you install an indicator, operate the engine at the specified rpm and record the cylinder compression pressure. Follow this procedure on each cylinder in turn. The pressure in any one cylinder should not be lower than the specified psi, nor should the pressure for any one cylinder be excessively lower than the pressures in the other cylinders. The maximum pressure variation permitted between cylinders is given on engine data sheets or in the manufacturer's technical manual. A compression leak is indicated when the pressure in one cylinder is considerably lower than that in the other cylinders.

If a test indicates a compression leak, you will have to do some disassembly, inspection, and repair. Check the valve seats and cylinder head gaskets for leaks, and inspect the valve stems for sticking. A cylinder head or block may be cracked. If these parts are not the source of trouble, compression is probably leaking past the piston because of insufficient sealing of the piston rings.

Improper Cooling Water Temperature

If an engine is to operate properly, the cooling water temperature must be maintained within specified temperature limits. When cooling water temperature drops lower than recommended for a diesel engine, ignition lag is increased, causing detonation, which results in rough operation. This may cause the engine to stall.

If the water temperature is higher than normal, the engine may not cool properly and may suffer heat damage. Water temperature is controlled primarily by a thermostatic valve (thermostat). The thermostat normally operates with a minimum of trouble. High or low cooling water temperature may indicate a malfunctioning thermostat. But before you remove the thermostat to check it, check to see whether the improper temperature may be caused by an insufficient engine load or an inaccurate temperature gauge.

When you suspect that the thermostat is not operating properly, remove it from the engine and test it. Use the following procedure to test the thermostat:

1. Obtain an open-topped container such as a bucket or a pot.
2. Heat the water to the temperature at which the thermostat is supposed to start opening. This temperature is usually specified in the appropriate technical manual. Use an accurate thermometer to check the water temperature. Use a hot plate or a burner as a source of heat. Stir the water frequently to ensure uniform distribution of the heat.
3. Suspend the thermostat by a string or a wire so that operation of the bellows will not be restricted.
4. Immerse the thermostat and observe its action. Check the thermometer readings carefully to see whether the thermostat begins to open at the recommended temperature.
5. Increase the temperature of the water until the specified FULL OPEN temperature is reached. The immersed thermostat should be fully open at this temperature. Replace the thermostat if it does not open when you test it, or if the temperatures at which the thermostat opens and closes vary more than allowed from the manufacturer’s specifications.

The Fulton-Sylphon automatic temperature regulator is relatively trouble-free. The unit controls temperatures by a valve that bypasses some water around the cooler. This system provides a full flow of the water, although only a portion may be cooled. In other words, the full volume of cooling water is circulated at the proper velocity, which eliminates the possibility of steam pockets in the system.

Usually, if the automatic temperature regulator fails to maintain cooling water at the proper temperature, it simply needs to be readjusted. However, the element of the valve may be leaking or some part of the valve may be defective. Failure to follow the proper adjustment procedure is the only cause for improper adjustment of an automatic temperature regulator. Check and follow the proper procedure in the manufacturer’s technical manual issued for the specific equipment.

Adjust the regulator by changing the tension of the spring (which opposes the action of the thermostatic bellows) with a special tool that turns the adjusting stem knob or wheel. Increasing the spring tension raises the temperature range of the regulator, and decreasing it lowers the temperature range.

When you place a new valve of this type into service, you must take a number of steps to ensure that the valve stem is the proper length and that all scale pointers make accurate indications.

Obstruction in the Exhaust System

This type of trouble seldom occurs if proper installation and maintenance procedures are followed. When a part of an engine exhaust system is restricted, there will be an increase in the exhaust back pressure. This may cause high exhaust temperatures, loss of power, or even stalling. An obstruction that causes excessive back pressure in an exhaust system is generally associated with the silencer or muffler.

The manifolds of an exhaust system are relatively trouble-free if related equipment is designed and installed properly. Improper design or installation may cause water to back up into the exhaust manifold. In some installations, the design of the silencer may cause water to flow into the engine. The source of water that may enter an engine must be found and eliminated. This may require replacing some parts of the exhaust system with components of an improved design or may require relocating such items as the silencer and piping.

Accumulation of salt or scale in the manifold usually indicates that water has been entering from the silencer. Turbochargers on some engines have been known to seize because salt water entered the exhaust gas turbine from the silencer. Entry of water into an engine may also be detected by the presence of corrosion or of salt deposits on the engine exhaust valves.

If inspection reveals signs of water in an engine or in the exhaust manifold, take steps immediately to correct the trouble. Check the unit for proper installation. Wet-type silencers must be installed with the proper sizes of piping. If the inlet water piping is too large, too much water may be injected into the silencer.

Dry-type silencers may become clogged with an excessive accumulation of oil or soot. When this occurs, exhaust back pressure increases, causing troubles such as high exhaust temperature, loss of power, or possible stalling. A dry-type silencer clogged with oil or soot is also subject to fire. Clogging can usually be detected by fire, soot, or sparks coming from the exhaust stack. An excessive accumulation of oil or soot in a dry-type silencer may be due to a number of factors, such as failure to drain the silencer, poor condition of the engine, or improper engine operating conditions.

Insufficient Intake Air

Insufficient intake air, which may cause an engine to stall or stop, may be due to blower failure or to a clogged air silencer or air filter. Even though all other engine parts function perfectly, efficient engine operation is impossible if the air intake system fails to supply a sufficient quantity of air for complete combustion of the fuel.

Clogged Air Cleaners and Silencers

Sometimes an engine will fire erratically or misfire because of a clogged air cleaner or silencer. Air cleaners must be cleaned at specified intervals, as recommended in the engine manufacturer’s technical manuals. A clogged cleaner reduces the intake air, thereby affecting the operation of the engine. Clogged air cleaners may cause not only misfiring or erratic firing but also such difficulties as hard starting, loss of power, engine smoke, and overheating.

When you clean an air cleaner element, if you use a volatile solvent, be SURE the element is dry before you reinstall it on the engine. Volatile solvents are excellent cleaning agents but, if permitted to remain in the filter, may cause engine overspeeding or a serious explosion.

Oil-bath type air cleaners and filters cause very little trouble if serviced properly. The frequency of cleaning is usually based on a specified number of operating hours, but more frequent cleaning may be necessary where unfavorable conditions exist.

When you fill an oil bath-type cleaner, follow the manufacturer’s instructions. Most air cleaners of this type have a FULL mark on the oil reservoir. Filling beyond this mark does not increase the efficiency of the unit and may lead to serious trouble. When the oil bath is too full, the intake air may draw oil into the cylinders. This excess oil-air mixture, over which there is no control, may cause an engine to “run away,” resulting in serious damage.

Blower Failure

Troubles that may prevent a centrifugal blower from performing its function usually involve damage to the rotor shaft, thrust bearings, turbine blading, nozzle ring, or blower impeller. Damage to the rotor shaft and thrust bearings usually results from insufficient lubrication, an unbalanced rotor, or operation with excessive exhaust temperature.

Centrifugal blower lubrication problems may be caused by failure of the oil pump to prime, low lube oil level, clogged oil passages or oil filter, or a defective relief valve, which is designed to maintain proper lube oil pressure.

If an unbalanced rotor is the cause of shaft or bearing trouble, there will be excessive vibration. Unbalance may be caused by damaged turbine wheel blading or by a damaged blower impeller.

Operating a blower when the exhaust temperature is above the specified maximum safe temperature generally causes severe damage to turbocharger bearings and other parts. Make every effort to find and eliminate causes of excessive exhaust temperature before the turbocharger is damaged.

Turbine blading damage may be caused by operation with an excessive exhaust temperature, operation at excessive speeds, bearing failures, failure to drain the turbine casing, the entrance of foreign bodies, or by turbine blades that break loose.

Damage to an impeller may be caused by thrust or shaft bearing failure, entrance of foreign bodies, or loosening of the impeller on the shaft.

Since blowers are high-speed units and operate with a very small clearance between parts, minor damage to a part could cause extensive blower damage and failure.

Worn gears are one source of trouble in positive-displacement blowers. A certain amount of gear wear is expected, but damage caused by excessively worn gears indicates improper maintenance procedures. Whenever you inspect a positive-displacement blower, record the backlash values, according to PMS. You can use this record to establish the rate of increase in wear, to estimate the life of the gears, and to determine when it will be necessary to replace the gears.

Scored rotor lobes and casing may cause blower failure. Scoring of blower parts may be caused by worn gears, improper timing, bearing failure, improper end clearance, or by foreign matter. Any of these troubles may be serious enough to cause the rotors to contact and damage the blower extensively.

Timing of blower rotors involves both gear backlash and the clearances between the leading and trailing edges of the rotor lobes and between rotor lobes and the casing. You can measure the clearance between these parts with thickness gauges, as illustrated in *Figure 4-52*. If the clearances are incorrect, check the backlash of the drive gear first. Then retime the rotors according to the method outlined in the manufacturer’s technical manual.

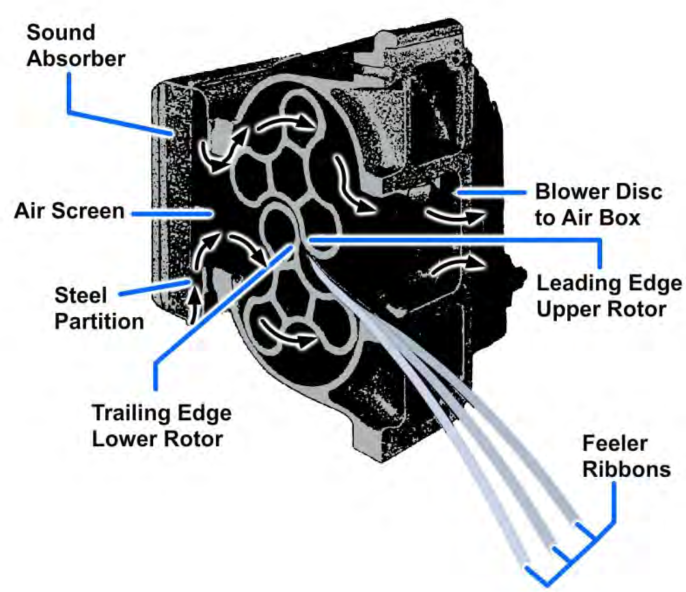

Figure 4-52 — Checking clearances of positive-displacement blower lobes.

Failure of serrated blower shafts may be due to failure to inspect the parts or of improper replacement of parts. When you inspect serrated shafts, be sure that they fit snugly and that wear is not excessive. When serrations of either the shaft or the hub have failed for any reason, replace both parts.

Obstruction in the Combustion Space

Such items as broken valve heads and valve stem locks or keepers that come loose because of a broken valve spring may cause an engine to come to an abrupt stop. If an engine continues to run when such obstructions are in the combustion chamber, the piston, liner, head, and injection nozzle will be severely damaged.

Piston Seizure

Piston seizure may also cause an engine to stop suddenly. The piston becomes galled and scuffed. When this occurs, the piston may possibly break or extensive damage may be done to other major engine parts. The principal causes of piston seizure are insufficient clearance, excessive temperatures, or inadequate lubrication.

Defective Auxiliary Drive Mechanisms

Defects in auxiliary drive mechanisms may cause an engine to stop suddenly. Since most troubles in gear trains or chain drives require some disassembly, this discussion will be limited to the causes of such troubles.

Gear failure is the principal trouble in gear trains. Engine failure and extensive damage can occur because of a broken or chipped gear. If you hear a metallic clicking noise in the vicinity of gear housing, it is almost a certain indication that a gear tooth has broken.

Gears are most likely to fail because of improper lubrication, corrosion, misalignment, torsional vibration, excessive backlash, wiped bearings and bushings, metal obstructions, or improper manufacturing procedures.

Gear shafts, bushings and bearings, and gear teeth must be checked during periodic inspections for scoring, wear, and pitting. All oil passages, jets, and sprays should be cleaned to ensure proper oil flow. All gear-locking devices must fit tightly to prevent longitudinal gear movement.

Chains are used in some engines for camshaft and auxiliary drives; in other engines, chains are used to drive certain auxiliary rotating parts. Troubles in chain drives are usually caused by wear or breakage. Troubles of this nature may be caused by improper chain tension, lack of lubrication, sheared cotter pins, or misalignment. *Figure 4-53* is a summary of the possible troubles that may cause an engine to stall frequently or stop suddenly.

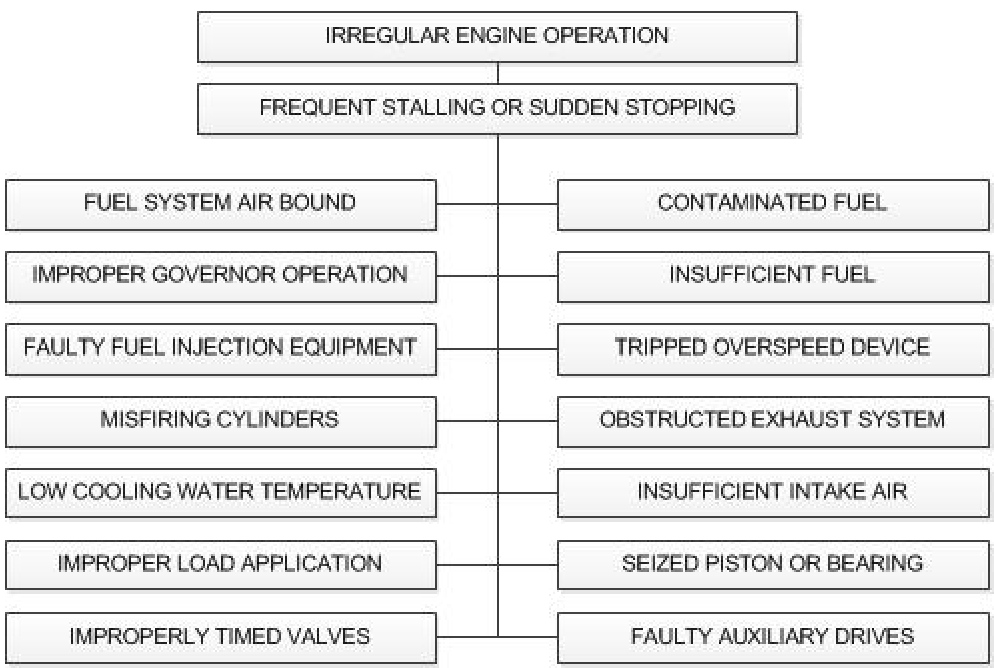

Figure 4-53 — Possible troubles that may cause an engine to stall frequently or stop suddenly.

Engine Will Not Carry a Load

Many of the troubles that can lead to loss of power in an engine may also cause the engine to stop and stall suddenly or may even prevent it from starting. Compare the list of some of the troubles that may cause a power loss (*Figure 4-54*) with those in *Figures 4-49* and *4-53*. Such items as insufficient air, insufficient fuel, and faulty operation of the governor appear on all three charts. Many of the troubles listed are closely related, and the elimination of one may eliminate others.

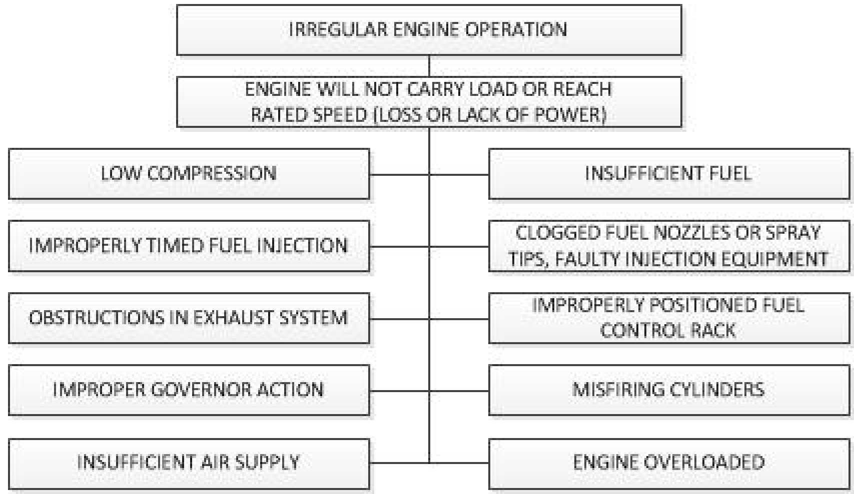

Figure 4-54 — Possible causes of insufficient power in an engine.

The operator of an internal-combustion engine may be confronted with additional major difficulties, such as those indicated in *Figure 4-55*. Here, again, you can see that many of these possible troubles are similar to those that have already been discussed in connection with starting failures and with engine stalling and stopping.

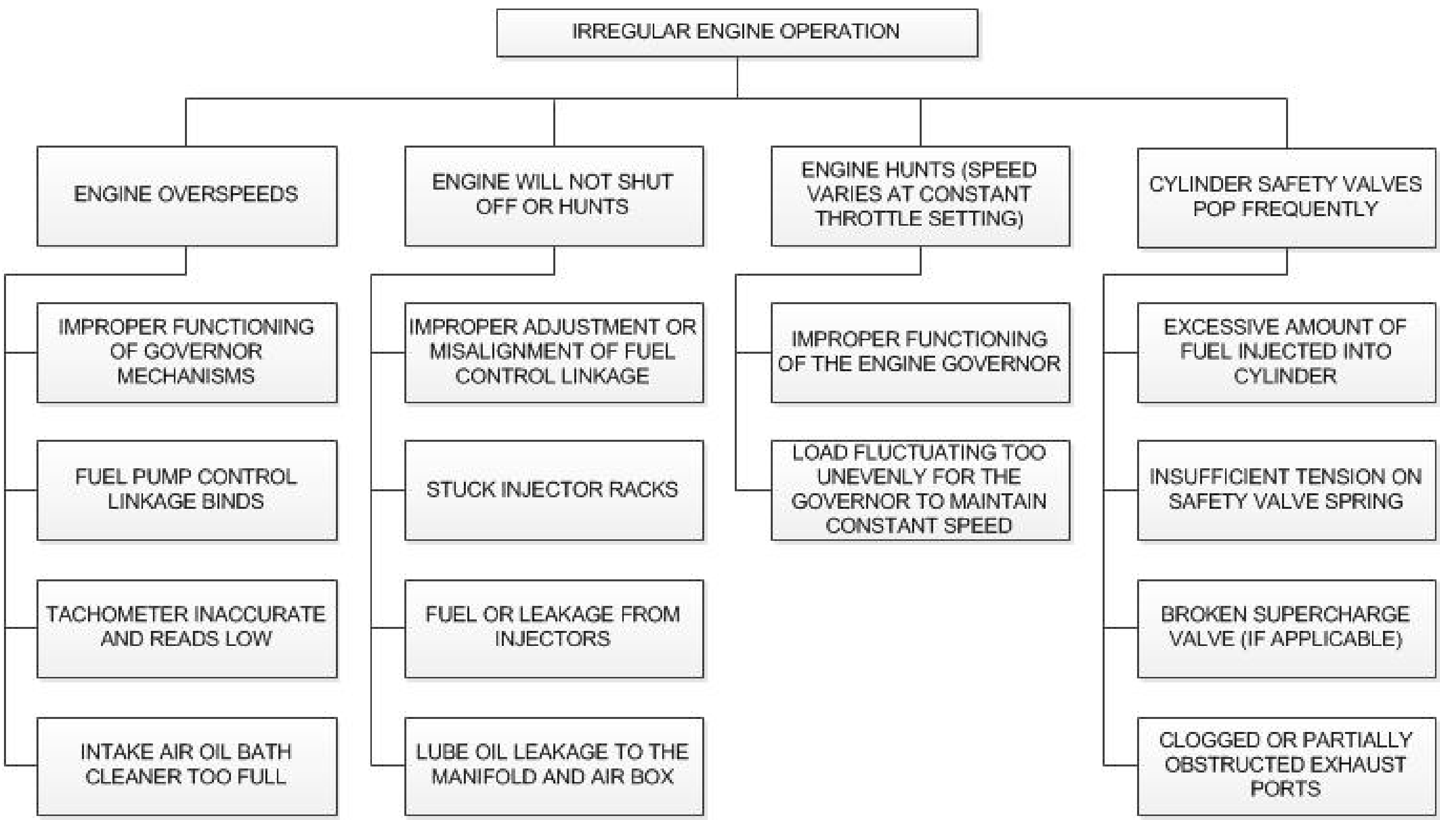

Figure 4-55 — Additional causes of irregular engine operation.

Engine Overspeeds

When an engine overspeeds, the trouble is usually caused by either the governor mechanism or the fuel control linkage, as previously discussed. When you need information on a specific fuel system or speed control system, check the manufacturer's technical manual and the special technical manuals for the particular system. These special manuals are available for the most widely used models of hydraulic governors and overspeed trips, and they contain specific details on testing, adjusting, and repairing each controlling device.

Engine Hunts or Will Not Stop

Some troubles that may cause an engine to hunt, or vary its rpm at constant throttle setting, are similar to those that may cause an engine to resist stopping. Generally, these two forms of irregular engine operation are caused by troubles originating in the speed control system and the fuel system.

Speed Control System

The speed control system of an internal-combustion engine includes those parts designed to maintain the engine speed at some exact value or between desired limits, regardless of changes in the load on the engine. Governors are provided to regulate fuel injection so the speed of the engine can be controlled as the load is applied. Governors also prevent overspeeding as may happen in rough seas when the load is suddenly reduced as the propellers leave the water.

Fuel Control Racks

Fuel control racks that have become sticky or jammed may cause governing difficulties. If the control rack of a fuel system is not functioning properly, the engine speed may increase as the load is removed, the engine may hunt continuously, or it may hunt only when the load is changed. A sticky or jammed control rack may prevent the engine from responding to changes in throttle setting and may even prevent it from stopping. Any such condition could be serious in an emergency situation. You can check for a sticky rack by stopping the engine, disconnecting the linkage to the governor, and then attempting to move the rack by hand. There should be no apparent resistance to the motion of the rack if the return springs and linkage are disconnected. A stuck control rack may be caused by the plunger's sticking in the pump barrel; dirt in the rack mechanism; damage to the rack, sleeve, or gear; or improper assembly of the injector pump.

If the rack sticks or jams, you must determine the cause and replace any damaged parts. If sticking is due to dirt, thoroughly clean all the parts to correct the trouble. You can avoid errors in assembly by carefully studying the assembly drawings and instructions.

Leakage of Fuel Oil

Leakage of fuel oil from the injectors may cause an engine to continue to operate when you attempt to shut it down. Regardless of the type of fuel system, the results of internal leakage from injection equipment are, in general, somewhat the same. Injector leakage will cause unsatisfactory engine operation because of the excessive amount of fuel entering the cylinder. Leakage may also cause detonation, crankcase dilution, and smoky exhaust, loss of power, and excessive carbon formation on the spray tips of nozzles and other surfaces of the combustion chamber.

Accumulation of Lube Oil

Another trouble that may prevent you from stopping an engine is accumulation of lube oil in the intake air passages-manifold or air box. Such an accumulation creates an extremely dangerous condition. You can detect excess oil by removing the inspection plates on the covers and examining the air box and manifold. If you discover oil, remove it and perform the necessary corrective maintenance. If oil is drawn suddenly in large quantities from the manifold or air box into the cylinder of the engine and burns, the engine may run away. The engine governor has no control over the sudden increase in speed.

An air box or air manifold explosion is also a possibility if excess oil is allowed to accumulate. Some engine manufacturers have provided safety devices to reduce the hazards of such explosions.

Excess oil in the air box or manifold of an engine also increases the tendency of carbon to form on liner ports, cylinder valves, and other parts of the combustion chamber.

The causes of excessive lube oil accumulation in the air box or manifold will vary depending on the specific engine. Generally, the accumulation is due to an obstruction in either the air box or separator drains.

In an effort to reduce the possibility of crankcase explosions and runaways, some engine manufacturers have designed a means to ventilate the crankcase. In some engines, a passage between the crankcase and the intake side of the blower provides ventilation. In other engines, an oil separator or air maze in the passage between the crankcase and blower intake provides ventilation. In either type of installation, stopped up drains will cause an excessive accumulation of oil. Oil may enter the air box or manifold from sources other than crankcase vapors. A defective blower oil seal, a carryover from an oil-type air cleaner, or defective oil piping may be the source of trouble.

Another possible source may be an excessively high oil level in the crankcase. Under this condition, an oil fog is created in some engines by the moving parts. An oil fog may also be caused by excessive clearance in the connecting rod and main journal bearings. In some types of crankcase ventilating systems, the oil fog will be drawn into the blower. When this occurs, an abnormal amount of oil may accumulate in the air box. Removal of the oil will not remove the trouble. The cause of the accumulation must be determined and the necessary repair made.

If a blower oil seal is defective, replacement is the only satisfactory method of correction. When you install new seals, be sure the shafts are not scored and the bearings are in satisfactory condition. Take special precautions during the installation to avoid damaging the oil seals. Damage to an oil seal during installation is usually not discovered until the blower has been reinstalled and the engine has been put into operation. Be sure an oil seal gets the necessary lubrication. The oil not only lubricates the seal, reducing friction, but also carries away any heat that is generated. For most purposes, soak new oil seals in clean, light lube oil before you install them.

Cylinder Safety Valves

On some engines, a cylinder relief (safety valve) is provided for each cylinder. The valve opens when the cylinder pressure exceeds a safe operating limit. The valve opens or closes a passage leading from the combustion chamber to the outside of the cylinder. The valve face is held against the valve seat by spring pressure. Tension on the spring is varied by an adjusting nut, which is locked when the desired setting is attained.

Cylinder relief valves should be set at the specified lifting pressure. Continual lifting (popping) of the valves indicates excessive cylinder pressure or malfunction of the valves, either of which should be corrected immediately. Repeated lifting of a relief valve indicates that the engine is being overloaded, the load is being applied improperly, or the engine is too cold. Also, repeated lifting may indicate that the valve spring has become weakened; ignition or fuel injection is occurring too early, the injector is sticking and leaking, too much fuel is being supplied, or, in air injection engines, the spray valve air pressure is too high. When frequent popping occurs, stop the engine and determine and remedy the cause of the trouble. In an emergency, cut off the fuel supply in the affected cylinder. NEVER lock relief valves closed, except in an emergency. When you must take emergency measures, be sure to repair or replace the valves, as necessary, as soon as possible.

When excessive fuel is the cause of frequent safety valve lifting, the trouble may be due to the improper functioning of a high-pressure injection pump, a leaky nozzle or spray valve, or a loose fuel cam (if adjustable). In some systems, such as the common rail, the fuel pressure may be too high.

A safety valve that is not operating properly should be removed, disassembled, cleaned, and inspected. Check the valve and valve seat for pitting and excessive wear and the valve spring for possible defective conditions. When you remove a safety valve for any reason, you must reset the spring tension. This procedure varies to some extent, depending on the valve construction.

Except in emergencies, it is advisable to shut the engine down when troubles cause safety valve popping.

Clogged or partially obstructed exhaust ports may also cause the cylinder safety valve to lift. This condition will not occur often if proper planned maintenance procedures are followed. If it does occur, the resulting increase in cylinder pressure may be enough to cause safety valve popping. Clogged exhaust ports will also cause overheating of the engine, high exhaust temperatures, and sluggish engine operation.

You can prevent clogged cylinder ports by removing carbon deposits at prescribed intervals. Some engine manufacturers make special tools for port cleaning. Round wire brushes of the proper size are satisfactory for this work you must be careful in cleaning cylinder ports to prevent carbon from entering the cylinder—bar the engine to such a position that the piston blocks the port.

Symptoms of Engine Trouble

In learning to recognize the symptoms that may help locate the causes of engine trouble, you will find that experience is the best teacher. Even though written instructions are essential for efficient troubleshooting, the information usually given serves only as a guide. It is very difficult to describe the sensation that you should feel when checking the temperature of a bearing by hand; the specific color of exhaust smoke when pistons and rings are worn excessively; and, for some engines, the sound that you will hear if the crankshaft counterweights come loose. You must actually work with the equipment to associate a particular symptom with a particular trouble. Written information, however, can save you a great deal of time and eliminate much unnecessary work. Written instructions will make detection of troubles much easier in practical situations.

A symptom that indicates that trouble exists may be in the form of an unusual noise or instrument indication, smoke, or excessive consumption or contamination of the lube oil, fuel, or water. *Figure 4-56* is a general listing of various trouble symptoms that you may encounter.

NOISES–The unusual noises that may indicate that trouble exists or is impending may be classified as pounding, knocking, clicking, and rattling. Each type of noise must be associated with certain engine parts or systems that might be the source of trouble.

Pounding or hammering is a mechanical knock (not to be confused with a fuel knock). It may be caused by a loose, excessively worn, or broken engine part. Generally, troubles of this nature will require major repairs.

Detonation (knocking) is caused by the presence of fuel or lubricating oil in the air charge of the cylinders during the compression stroke. Excessive pressures accompany detonation. If detonation is occurring in one or more cylinders, stop the engine immediately to prevent possible damage.

Clicking noises are generally associated with an improperly functioning valve mechanism or timing gear. If the cylinder or valve mechanism is the source of metallic clicking, the trouble may be due to a loose valve stem and guide, insufficient or excessive valve tappet clearances, a loose cam follower or guide, broken valve springs, or a valve that is stuck open. A clicking in the timing gear usually indicates that there are some damaged or broken gear teeth.

Rattling noises are generally due to vibration of loose engine parts. However, an improperly functioning vibration damper, a failed antifriction bearing, or a gear-type pump operating without prime are also possible sources of rattling noises.

NOISES	INSTRUMENT INDICATIONS			SMOKE	CONTAMINATION OF LUBE OIL, FUEL, OR WATER
	PRESSURE	TEMPERATURE	SPEED		
Pounding (mechanical)	Low lube oil pressure	Low lube oil temperature	Idling speed not normal	Black exhaust smoke	Fuel oil in the lube oil
	High lube oil pressure	High lube oil temperature	Maximum speed not normal	Bluish-white exhaust smoke	Water in the lube oil
Knocking (detonation)	Low fuel oil pressure (in low-pressure fuel supply system)	Low cooling water temperature (fresh)		Smoke arising from crankcase	Oil or grease in the water Water in the fuel oil
Clicking (metallic)	Low cooling water pressure (fresh)	High cooling water temperature (fresh)		Smoke arising from cylinder head Smoke from engine auxiliary equipment (blowers, pumps, etc.)	Air or gas in the water Metal particles in lube oil
	Low cooling water pressure (salt)	Low cylinder exhaust temperature			
Rattling	High cooling water pressure (salt)	High exhaust temperature in one cylinder			
	Low compression pressure				
	Low firing pressure				
	High firing pressure				
	Low scavenging air receiver pressure (super-charge engine)				
	High exhaust back pressure				

Figure 4-56 — Symptoms of engine troubles.

When you hear a noise, first make sure it is a trouble symptom. Each diesel engine has a characteristic noise at any specific speed and load. The noise will change with a change in speed or load. As an operator, you must become familiar with the normal sounds of the engine. Investigate all abnormal sounds promptly. Knocks that indicate a trouble may be detected and located by special instruments or by the use of a "sounding bar," such as a solid iron screwdriver or bar.

Instrument Indications

As an engine operator, you will probably rely more on the instruments to warn you of impending troubles than on all the other trouble symptoms combined. Regardless of the type of instrument being used, the indications are of no value if the instrument is inaccurate. Be sure an instrument is accurate and operating properly before you accept a low or high reading. Test all instruments at specified intervals or whenever you suspect them of being inaccurate.

Smoke

Smoke can be quite useful as an aid in locating some types of trouble, especially if used in conjunction with other trouble symptoms.

The color of exhaust smoke, a good indication of engine performance, can also be used as a guide in troubleshooting. The exhaust of an efficiently operating engine has little or no color. A dark, smoky exhaust indicates incomplete combustion; the darker the color, the greater the amount of unburned fuel in the exhaust. Incomplete combustion may be due to a number of troubles. Some manufacturers associate a particular type of trouble with the color of the exhaust. The more serious troubles are generally identified with either black or bluish-white exhaust colors.

Excessive Consumption of Lube Oil, Fuel, or Water

You should suspect engine trouble whenever excessive consumption of any of the essential liquids occurs. The possible troubles indicated by excessive consumption will depend on the system in question. Leakage, however, is one trouble that may be common to all. Before you start any disassembly, check for leaks in the system in which excessive consumption occurs.

TROUBLESHOOTING GASOLINE ENGINES

The troubleshooting procedures used for a marine gasoline engine are, in many ways, similar to those for a diesel engine. The two types of engines are quite similar with two exceptions, the manner of getting fuel and air into the cylinders and the method of ignition.

When a gasoline engine fails to start, one of three conditions exists. The engine is not free to turn, the starter does not crank the engine, or the engine cranks but does not start. *Figure 4-57* lists many of the conditions and sources of such difficulties,

If the engine will not turn over, some part is probably seized. In this case you should make a thorough inspection, which may necessarily include some disassembly.

Starter Does Not Run

If the starter fails to turn, the trouble can usually be traced to the battery, connections, switch, or starter motor. Symptoms of battery trouble generally occur before the charge gets too low to perform the required work Battery failure is normally preceded by a gradual decline in the strength of the battery charge. A dead battery may be the result of insufficient charging, damaged plates, or improper starting technique.

The generator, used to maintain the charge of the starting battery, may become defective. The normal symptoms are a low battery charge when the engine is started and a zero or low ammeter reading when the engine is running.

The battery must be in good condition to ensure the proper operation of the ignition system. A starter draws a heavy current from the best of batteries. When the battery is weak, it will be unable to operate the ignition system satisfactorily for starting because the heavy starting current will drop the voltage to an extremely low value.

⚠ CAUTION ⚠

Keep flames and sparks of all kinds away from the vicinity of storage batteries. A certain amount of hydrogen gas is given off from a battery at all times. In confined spaces this gas can form a dangerous explosive mixture.

When you use tools around a battery, be careful not to short circuit the battery terminals. Never use a tool or metal object to make a so-called test of a storage battery.

Keep batteries in exposed locations subject to low temperatures fully charged during cold weather. In extreme cold weather, remove storage batteries and place them in a warm compartment, if possible.

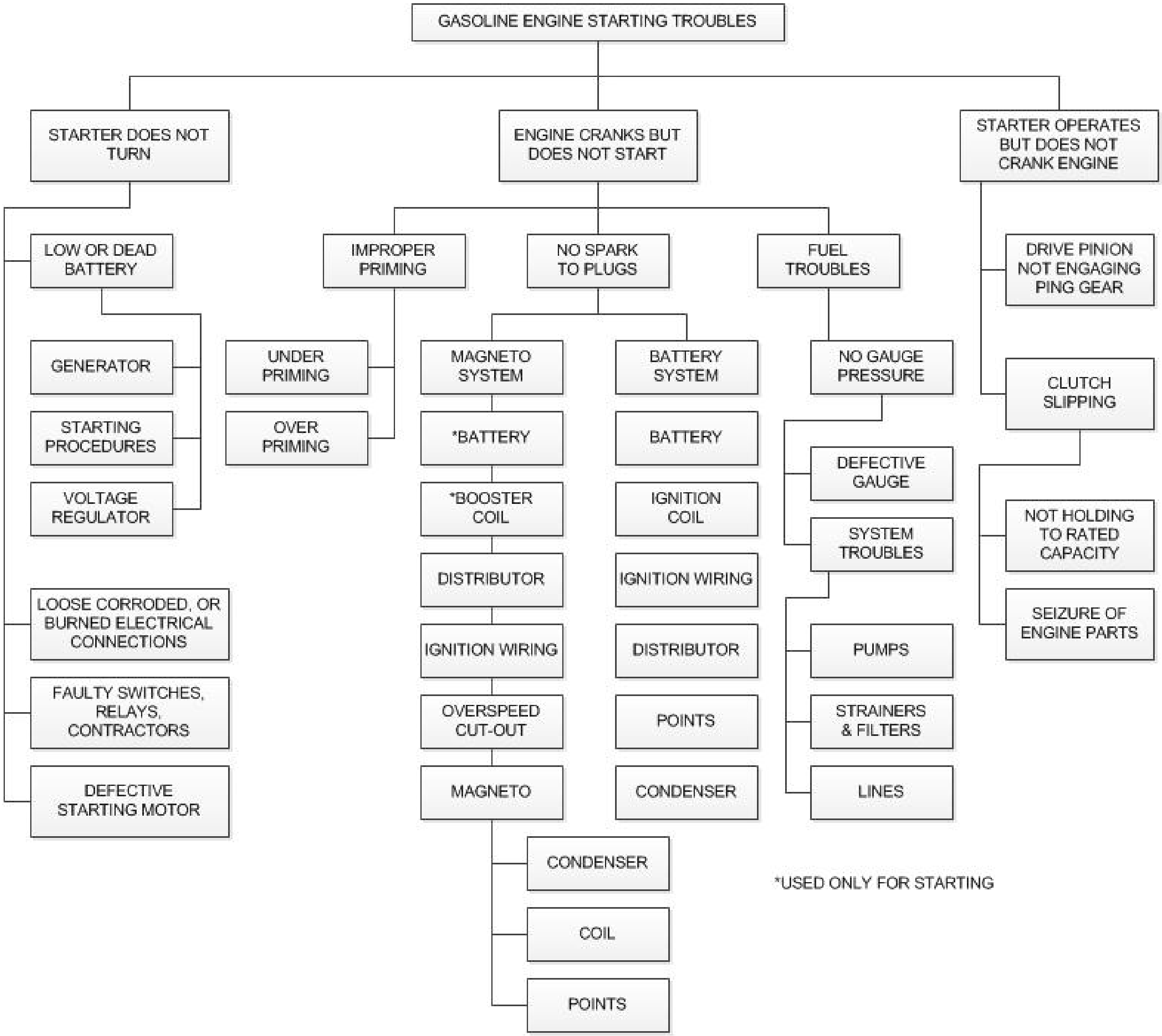

Figure 4-57 — Possible sources of trouble when a gasoline engine fails to start.

Electrical connections are another possible source of trouble if the starter does not turn. All connections must be tight and free from corrosion to provide maximum voltage and amperage from the battery. Battery terminals, since they are more vulnerable to corrosion, looseness, and burning, are the principal sources of trouble.

Burned battery terminals may be caused by a loose connection, a corroded terminal, or a short circuit. Burning of terminals usually occurs when an engine is being started. Burning may be indicated by such things as smoke, a flash, or a spattering of molten metal in the vicinity of the battery. Switches, electrical relays, or contactors that are defective or inoperative may be the reason a starter will not turn. Contactors, being subject to extremely high current, must be maintained in the best possible condition. Starting contactors are either manually or magnetically operated and are designed to be operated for only short periods of time.

Starter motor troubles can be traced for the most part to the commutator, brushes, or insulation. If motors are to function properly, they must be kept clean and dry. Dirt and moisture make good commutation impossible. Dirty and fouled starter motors may be caused by failure to replace the cover band, by water leakage, or by excess lubrication.

Most starter motors have a cover to protect the commutator and windings. If you neglect to replace the cover or remove it as an aid to ventilation and cooling, dirt and water are sure to damage the equipment.

Although lubrication of bearings is essential for proper operation, excessive lubrication may lead to trouble in a starter motor. Excess lubricant in the shaft bearings may leak or be forced past the seal and foul the insulating material, commutator, and brushes. The lubricant prevents a good electrical contact between the brushes and the commutator, causing the commutator to spark and heat and the brushes to burn.

Burned brushes are another possible source of trouble if the starter motor is inoperative. Burning may be caused by loose brush holders, improper brush spring tension, a brush stuck in the holder, a dirty commutator, improper brush seating surface, or overloading the starter.

Starter Motor Operates but Does Not Crank Engine

If the starter motor and battery are in good operating condition but the starter fails to crank the engine, the trouble will usually be in the drive connection between the motor and the ring gear on the flywheel. Troubles in the drive assembly are usually in the form of broken parts or a slipping clutch (if applicable). A slipping clutch may be the result of the engine not being free to turn or the clutch not holding up to its rated capacity.

Even though seldom encountered, a stripped ring gear on the flywheel may be the source of trouble if the starter motor does not turn the engine.

Engine Cranks but Fails To Start

Starting troubles and their causes and corrections may vary to some degree. If the prescribed prestarting and starting procedures are followed and a gasoline engine fails to start, the source of trouble will probably be improper priming or choking, a lack of fuel at various points in the system, or a lack of spark at the spark plugs.

Improper priming may be either underpriming or overpriming. Priming instructions differ, depending on the engine. Information on priming also applies to engines equipped with chokes. A warm engine should never be primed. Some engines may require no priming except when they are started under cold weather conditions.

On some installations, underpriming can be checked by the feel of the primer pump as it is operated. On other installations, underpriming may be due to insufficient use of the choke.

Over-priming is undesirable because it results in a flooded engine and makes starting difficult. It also causes excess gasoline to condense in the intake manifolds, run down into the cylinders, wash away the lubricating oil film, and cause pistons or rings to stick

You can determine flooding by removing and inspecting a spark plug. A wet plug indicates flooding. If you find the engine to be flooded, be sure to dry out or deflood it according to prescribed instructions. Improper carburetion may be the source of trouble if a gasoline engine fails to start. On some engines a check of the fuel pressure gauge will indicate whether lack of fuel is the cause. If the gauge shows the prescribed pressure, the trouble is not lack of fuel; if the gauge shows little or no fuel pressure, you should check the various parts of the delivery system to locate the fault.

In some installations, you can determine whether the trouble is in the gauge or in the fuel system by using the following procedure: (1) remove the carburetor plug next to the fuel pressure gauge connection; and (2) use a suitable container to catch the gasoline, and operate the pump used to build up starting fuel pressure. If fuel is reaching the carburetor, gasoline will spurt out of the open plug hole; this indicates that the gauge is inoperative. If no fuel flows from the plug opening, the trouble is probably in the fuel system, somewhere between the fuel tank and carburetor. Even though all installations do not have a fuel pressure gauge, the procedure for checking the fuel system is much the same.

If a wobble pump is installed to build up starting fuel pressure, you can determine whether the pump is operating correctly by the feel and sound of the pump. If the pump feels or sounds dry, the trouble is between the pump and the supply tanks. The trouble might be caused by a clogged fuel line strainer or by an air leak in the line. If the wobble pump is pumping, the trouble may be in the line to the engine fuel pump or in the engine fuel pump itself.

Check the fuel lines for cracks, dents, loose connections, sharp bends, and clogging. You can remove the fuel line at the pump and use air to determine if the line is open.

Check fuel pumps for leaks at the pump gaskets or in the fuel line connections. Check fuel pump filters or sediment bowl screens for restrictions. Check the bypass for operation. If the bypass valve is defective, replace the fuel pump. In diaphragm-type fuel pumps, the filter bowl gasket, the diaphragm, or the valves may be the source of trouble. Check for air leaks in the diaphragm by submerging the discharge end of the fuel line in gasoline and looking for air bubbles while cranking the engine. If the engine will run, a leaky diaphragm is indicated by gasoline leakage from the pump air vent.

Carburetor trouble may be the cause if fuel does not reach the cylinders. You can check this by removing the spark plugs and looking for moisture. If there is no trace of gasoline on the plugs, the carburetor may be out of adjustment, the float level may be too low, or the jets may be clogged. If the fuel level in the carburetor float bowl is low, the float valve is probably stuck on the seat. If the fuel level in the float is correct, yet no fuel is delivered to the carburetor throat, the carburetor will have to be removed, disassembled, and cleaned.

Faulty ignition system parts may be the source of starting difficulties. You may encounter two kinds of ignition systems—the MAGNETO type and the BATTERY type. Even though the parts of these systems differ in some respects, their function is the same; namely, to produce a spark in each cylinder of the engine at exactly the proper time in relation to the position of the pistons and the crankshaft. Also, the system is designed so the sparks in all cylinders follow each other in proper sequence.

Engine Fails to Stop

If a gasoline engine fails to stop when the ignition switch is turned to the OFF position, the trouble is usually caused by a faulty ignition circuit, improper timing, the octane rating number of the fuel being too low for the design of the engine, or the engine being overheated.

In a magneto-type ignition system, an open ground connection may cause an engine to run after the ignition switch is turned off. When a magneto ground connection is open, the magneto will continue to produce sparks as long as the magneto armature magnets rotate, and the engine will continue to run. In other words, when the magneto ignition switch contact points are closed, the ignition should be SHUT OFF. This is not true of the booster coil circuit of a magneto-type system, nor of the usual battery-type ignition system. In these systems, an open ground or open switch points prevent current flow. If the switch of a battery-type ignition system fails to stop the engine, the contact switch points have probably remained closed.

If the ignition switch and the circuit are in good condition, failure to stop may be caused by overheating. If the engine is overheated, normal compression temperature may become high enough to ignite the fuel mixture even though no spark is being produced in the cylinders. When this happens in a gasoline engine, the engine is, in reality, operating on the diesel principle.

Normally, you will detect the symptoms of overheating before the temperature gets too high. The causes of overheating in a gasoline engine are much the same as those for a diesel engine.

Other troubles and their symptoms, causes, and corrections that may occur in a gasoline engine are similar to those found in a diesel engine. Troubles leading to the loss of rpm, irregular operation, unusual noises, abnormal instrument indications, and excessive consumption or contamination of the lube oil, fuel, or water can usually be handled in the same way for gasoline and diesel engines.

Fuel and Oil Purifiers

For maximum efficiency, purifiers should be operated at their maximum designed speed and rated capacity. An exception to operating a purifier at its designed rated capacity is when the unit is used as a separator with 9000 series detergent oil. Some engines using the 9000 series oils are exposed to large quantities of water. When the oil becomes contaminated with water, it has a tendency to emulsify. The tendency to emulsify is most pronounced when the oil is new and gradually decreases during the first 50 to 75 hours of engine operation. During this period, the purifier capacity should be reduced to approximately 80 percent of its rated capacity.

Most oils used in Navy installations can be heated to 180 °F without damage to the oils. Prolonged heating at higher temperatures is not recommended because such oils tend to oxidize at high temperatures. Oxidation results in rapid deterioration. In general, oil should be heated enough to produce a viscosity of approximately 90 seconds Saybolt universal (90 SSU), but the temperature should not exceed 180 °F. The following temperatures are recommended for purifying oils in the 9000 series (*Table 4-2*):

Table 4-2 — 9000 Series Oil Purifying Recommended Temperatures

MILITARY SYMBOL	TEMPERATURE (°F)
9110	140
9170	160
9250	175
9500	180

Pressure should not be increased above normal to force high viscosity oil through the purifier. Instead, the viscosity should be decreased by heating the oil. Pressure in excess of that normally used to force oil through the purifier will result in less efficient purification. On the other hand, a reduction in the pressure that forces the oil into the purifier will increase the length of time the oil is under the influence of centrifugal force and, therefore, will tend to improve results.

Discharge Ring (Ring Dam)

If the oil discharged from a purifier is to be free of water, dirt, and sludge and if the water discharged from the bowl is not to be mixed with oil, the proper size discharge ring (ring dam) must be used. The size of the discharge ring depends on the specific gravity of the oil being purified; diesel fuel oil, JP-5, and lubricating oils all have different specific gravities and, therefore, require different sized discharge rings. While all discharge rings have the same outside diameter, their inside diameters vary. Ring sizes are indicated by even numbers; the smaller the number, the smaller the ring size. The inside diameter in millimeters is stamped on each ring. Sizes vary in increments of 2 millimeters. Charts, provided in the manufacturers' technical manuals, specify the proper ring size to be used with an oil of a given specific gravity. Generally, the ring size indicated on such a chart will produce satisfactory results. If the recommended ring fails to produce satisfactory purification, you must determine the correct size by trial and error. In general, you will obtain the most satisfactory purification of the oil when the ring is the largest size that can be used without losing oil along with the discharged water.

Maintenance of Purifiers

Clean the bowl of the purifier daily according to the PMS, and carefully remove all sediment. The amount of dirt, grit, sludge, and other foreign matter in the oil may warrant more frequent cleaning. If you do not know the amount of foreign matter in oil, have the purifier shut down and examined and cleaned once each watch, or more often if necessary. The amount of sediment found in the bowl indicates how long the purifier may be operated between cleaning.

Have periodic tests made to make sure the purifier is working properly. When the oil in the system is being purified by the batch process, tests should be made at approximately 30-minute intervals. When the continuous process of purification is used, tests should be made once each watch. Analysis of oil drawn from the purifier is the best method of determining the efficiency of the purifier. However, the clarity of the purified oil and the amount of oil discharged with the separated water will also indicate whether the unit is operating satisfactorily.

SUMMARY

This chapter covered the general procedures concerning repairs, troubleshooting, maintenance, and overhaul of internal combustion engines. Additionally, it covered the general maintenance of jacking gear and fuel and oil purifiers. Read and use the correct references, such as the manufacturers' manuals and the PMS, to operate and care for your equipment.

In this chapter, we have covered the principles of operation associated with 2- and 4-stroke cycle engines and opposed-piston engines. It is essential that you fully understand the principles of operation of these engines. To do so, you must know the meaning and significance of such terms as OTTO CYCLE, THEORETICAL DIESEL CYCLE, ACTUAL DIESEL CYCLE, POWER STROKE, COMPRESSION STROKE, SCAVENGING, and SUPERCHARGING.

End of Chapter 4

Reciprocating Internal-Combustion Engine

Review Questions

4-1. Diesel engines are classified as reciprocating internal-combustion engines because which of the following actions?

A. Use energy from fuel burned outside their cylinder
B. Burn fuel in a combustion chamber that moves back and forth
C. Burns fuel in a confined chamber where the energy from the fuel moves a piston back and forth
D. Use a continuous combustion process to impart rotary motion to the piston

4-2. The thermal energy produced by thermal combustion in an engine is transformed into what kind of energy?

A. Expansion
B. Internal
C. External
D. Mechanical

4-3. One cycle of engine operation includes?

A. One combustion cycle
B. One mechanical cycle
C. Either a half of a mechanical or an entire mechanical cycle depending on the type of engine
D. One mechanical and one combustion cycle

4-4. When is fuel injected into a cylinder of a diesel engine?

A. Before air in the cylinder is compressed
B. After air in the cylinder is compressed
C. After combustion gases in the cylinder have expanded
D. As air is taken into the cylinder

4-5. What two events occur simultaneously in a 2-stroke cycle engine?

A. Scavenging and compression
B. Exhaust and scavenging
C. Ignition and expansion
D. Exhaust and compression

4-6. After ignition of the fuel and before the piston reaches Top Dead Center, (TDC), there is little change in which of the following conditions in a diesel engine?

A. Pressure
B. Temperature
C. Energy
D. Volume

4-7. An engine having a combustion chamber located between a cylinder head and the crown of a piston is which of the following types?

A. Double-acting
B. Single-acting
C. Horizontal-acting
D. Opposed-acting

4-8. Crank lead is used to cause which of the following conditions?

A. Longer combustion events
B. Exhaust events lasting longer that scavenging events
C. Exhaust events starting before scavenging events
D. Higher combustion temperatures

4-9. Before you begin an inspection or test of an engine frame or block what should you do first?

A. Consult the manual because specific procedures vary with engines
B. Check the engine's preventive maintenance schedule
C. Clean the outside of the engine thoroughly
D. Warm up the engine

4-10. Broken piston rings will cause which of the following problems?

A. Scored cylinder liners
B. Connecting bearing failure
C. High lube oil temperature
D. High freshwater temperature

4-11. How do you determine liner wear?

A. Take piston and liner measurement and get the difference
B. Take measurement at three levels in the liner
C. Compare wear of the piston rings
D. Compare compression readings

4-12. Under which of the following conditions are corrosive vapors most likely to condense on the cylinder liner walls of an engine?

A. While operating at temperatures exceeding normal
B. While operating with the lube oil pressure below normal
C. While warming up after it is first started
D. While operating in such a way that normal lube oil pressure is exceeded

4-13. You are inspecting a cylinder head for cracks. Which of the following is NOT a correct procedure to use?

A. Perform a compression test
B. After bringing the piston of each cylinder to TDC, apply compressed air
C. Examine by sight or with magnetic powder
D. Perform a hydrostatic test that is used on a water-jacket cylinder

4-14. What should you do if you discover a warped or distorted cylinder head during an inspection?

A. Machine the head to correct tolerance
B. Replace the head as soon as possible
C. Over-torque the head to compensate for the warpage
D. Reduce the load on the engine

4-15. What valve problems will cause a valve to hang open?

A. Burned
B. Floating
C. Sticking
D. Bent

4-16. What valve casualty is usually caused by resinous deposits left by improper lube oil or fuel?

A. Burned
B. Sticking
C. Weak
D. Bent

4-17. Which of the following valve casualties will cause the valves to fail to close completely?

A. Burned
B. Floating
C. Sticking
D. A weak spring

4-18. When replacing a valve seat insert, which of the following procedures should you follow?

A. Plan the operation so that the insert is placed slowly and precisely
B. Use boiling water to heat the valve seat
C. Drive the insert down with a special tool
D. Shrink the valve guide or counterbore with dry ice

4-19. Which of the following defects does NOT warrant valve spring replacement?

A. Loss of 2 percent of length
B. Damage to protective coating
C. Hairline cracks
D. Rust pits

4-20. To adjust the intake valve tappet valve of a 4-stroke cycle engine, the piston must be in what position?

A. On the intake stroke
B. On the compression stroke
C. Between the compression and power stroke
D. Between the intake and compression stroke

4-21. After setting a tappet clearance and locking the adjusting screw with a locknut, what is your next step?

A. Recheck the clearance
B. Adjust the next tappet
C. Warm the engine and reset the clearance
D. Check the manufacture's manual to see if the clearance is correct

4-22. Which of the following actions should you take to insert a camshaft into the camshaft recess?

A. Rotate as you push it in
B. Shake it up and down
C. Apply grease to it
D. Hit it with a sledge

4-23. To scour the top of a cylinder bore before pulling out the piston, you should use which of the following tools?

A. Power grinder
B. File
C. Metal scraper
D. Emery cloth

4-24. In addition to ring gap, what other factors must you measure to ensure correct ring fit?

A. Ring end gap
B. Ring-to-land-clearance
C. Ring width
D. Ring circumference

4-25. If the oil flow to a piston is restricted, where will the deposits be formed?

A. On the underside or the piston crown
B. Behind the compression ring
C. On the piston walls
D. On the topside of the piston crown

4-26. When inserting new piston pin bushing, what are the three things you must check?

A. Alignment, clearance, and appearance
B. Cleanliness, clearance, and appearance
C. Appearance, alignment, and cleanliness
D. Cleanliness, alignment, and clearance

4-27. A rough spot or slight score on a crankshaft journal should be removed by dressing with which of the following material?

A. Fine sandpaper
B. Rough sandpaper
C. Fine oilstone
D. Grinder

4-28. Impending bearing failures may be indicated by which of the following factors?

A. Higher than normal lube oil pressure and lower than normal lube oil temperature
B. Lower than normal lube oil pressure and higher than normal lube oil temperature
C. Higher than normal lube oil pressure and temperature
D. Lower than normal lube oil pressure and temperature

4-29. Which of the following means of determining clearances will NOT leave an impression in the soft bearing metal?

A. Leads
B. Shim stock
C. Feeler gauge
D. Plastigage

4-30. Which if the following actions will be the greatest aid in detecting minor leaking?

A. Standing watch
B. Conducting administrative inspection
C. Conducting material inspection
D. Conducting routine cleaning

4-31. Which of the following is a symptom of excessive clearance between a piston and its cylinder?

A. Piston slap
B. Less oil consumption
C. Minimal carbon deposits
D. Blue exhaust

4-32. If an engine cannot be cranked, but can be barred over, which of the following systems is most probable the source of trouble?

A. Starting
B. Fuel
C. Ignition
D. Lubrication

4-33. Which of the following practices tends to reduce or eliminate the formation of gummy deposits that cause upper and lower pistons of pressure-activated air-starting valves to stick in the cylinders?

A. Increasing the tension of the valve return spring
B. Draining the storage tank and water traps of the air-starting system
C. Jacking the engine over manually before starting to free any valves that may be stuck
D. Decreasing the tension of the valve return spring

4-34. What is the main reason for troubles in the fuel and injection pumps?

A. Contaminated fuel
B. Improper adjustments
C. Coated fuel lines
D. Excessive vibrations

4-35. What are the two main causes of leakage in fuel tanks?

A. Corrosion and excessive fuel line pressure
B. Metal fatigue and improper welds
C. Vibration and metal fatigue
D. Clogged fuel lines and corrosion

4-36. Which of the following actions will cause the overspeed safety device of an engine to become inoperative?

A. Trying to start the engine with low air-starting pressure
B. Tripping the device accidentally while trying to start the engine
C. Shutting off the fuel supply after starting the engine
D. Shutting off the air supply after starting the engine

4-37. What diesel engine system is likely to be at fault if a cylinder misfires regularly?

A. Lubrication
B. Fuel
C. Exhaust
D. Ignition

4-38. What corrective actions should you take if the water in the cooling system of a diesel emergency generator overheats because the thermostat fails to function?

A. Clean the bellows of the element
B. Adjust the tension of the regular spring
C. Clean the freshwater cooler
D. Replace the thermostat

4-39. Which of the following troubles in the engine exhaust system will cause back pressure?

A. Obstruction in the combustion space
B. Thermostat failure
C. Restricted exhaust
D. Restricted oil filter

4-40. How can you determine whether blower rotor gears are worn excessively?

A. Measure the clearance between the leading and the trailing edges of the rotor lobes
B. Measure the backlash of the gear sets
C. Measure the clearance between the rotor lobes and the casing
D. Check the timing of the rotors

4-41. What should you do immediately after disconnecting the linkage to the governor, if you are checking an engine for a stuck control rack?

A. Visually inspect the rack
B. Try to move the rack by hand
C. Test the return springs
D. Clean the remove rack

4-42. Which of the following is result of the engine having clogged exhaust ports during operation?

A. Low exhaust temperature
B. Overheating of the lube oil
C. Popping of the cylinder safety valves
D. Dirty fuel oil

4-43. What kind of noise will most likely be coming from an engine operating with a broken engine part?

A. Rattling
B. Clicking
C. Pounding
D. Knocking

4-44. When the starting motor of a gasoline engine turns but fails to crank the engine, the trouble is usually found where?

A. Drive assembly
B. Engine timing
C. Fuel system
D. Ignition system

4-45. You are checking for trouble in a fuel system that has a wobble pump. If the pump feels or sounds dry, where is the most likely cause?

A. In the carburetor
B. In the line to the fuel pump
C. In the fuel pump
D. Between the fuel pump and the supply pump

4-46. Oil purifies are designed give maximum efficiency when you operate the purifier at what limits?

A. Minimum speed
B. A speed determined by prevailing conditions
C. A speed between minimum and maximum and below rated speed
D. Maximum designed speed and rated capacity

4-47. When the military symbol 9500 lube oil is to be purified, it should be heated to what specific temperature?

A. 140 °F
B. 160 °F
C. 175 °F
D. 180 °F

4-48. What is the best method of determining the efficiency of a purifier?

A. Oil clarity test
B. Oil analysis
C. Batch process
D. Bowl sediment check

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CHAPTER 5

PRINCIPAL STATIONARY PARTS OF AN ENGINE

Most internal-combustion engines of the reciprocating type are constructed in the same general pattern. Although engines are not exactly alike, certain features common to all of them, and the main parts of most engines are similarly arranged. Gasoline engines and diesel engines have the same basic structure. The descriptions of the engine parts and systems in this rate training manual will apply generally to both types of engines. However, differences do exist, and we will point these differences out wherever they occur. The main differences between diesel and gasoline engines exist in the fuel systems and the methods of ignition.

The main parts of an engine, excluding accessories and systems, may be divided into two principal groups: (1) those parts that do not involve motion, such as the structural frame and its components and related parts; and (2) those parts that involve motion. This chapter deals with the main stationary parts of an engine. After reading this chapter, you should be able to identify the principal stationary parts of an engine in terms of basic design, location, and function.

The stationary parts of an engine maintain the moving parts in their proper relative position so that the gas pressure produced by combustion can "push" the pistons and rotate the crankshaft. The prime requirements for the stationary parts of Navy diesel engines are:

- Ample strength.
- Low weight.
- Minimum size.
- Simplicity of design.

Ample strength is necessary if the parts are to withstand the extreme forces that are developed within the engine. Space limitations aboard ship make minimum weight and size essential. Simplicity of design is of great importance when maintenance and overhaul procedures are performed.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify piping systems.
2. Explain the different parts of the engine's frame.
3. Describe the components and functions of the cylinder assemblies.
4. List and discuss the purpose of engine mountings.

PIPING

The control and application of fluid power would be impossible without a suitable means of conveying the fluid from the power source to the point of application, for this purpose let's call it piping. Piping must be designed and installed with the same care applicable to other components of the systems; attention must be given to the various types, materials, and sizes of lines available for the fluid power system. The three most common lines used in fluid power systems are pipe, tubing, and flexible hose. They are sometimes referred to as rigid (pipe), semi-rigid (tubing), and flexible piping. In the Navy, a distinction is made between pipe and tubing. The distinction is based on the method used to determine the size of the product. There are three important dimensions of any tubular product—outside diameter (OD), inside diameter (ID), and wall thickness. The product is called tubing if its size is identified by the actual measured outside diameter and by actual wall thickness. The product is called pipe if its size is identified by a nominal dimension and wall thickness.

Piping System Designations and Markings Color Coding

Surface ship piping located inside the ship shall be painted as indicated in *Table5-1.* Paint piping located on weather decks the same color as the surrounding structure. Handwheels and operating levers on valves located inside the ship should be color-coded per *Table 5-1*. Handwheels and operating levers on surface ship reactor plant system valves are not color-coded except where specifically required by Government-furnished reactor plant drawings. Markings shall be spaced not more than 15 feet apart (*Figure 5-1),* as measured along the run of piping, and shall be applied in conspicuous locations, preferably near control valves. Piping in machinery spaces shall be marked at least twice, once near entry and once near exit. Systems serving propulsion plants and systems conveying flammable or toxic fluids shall be marked at least twice in each space. At the interconnection of systems, each system shall be marked nearby, wherever practicable. Where the service of the pipe is obvious, such as a short vent or drain from a tank or where adjacent machinery, equipment, or valve marking makes pipe marking superfluous, marking is not required.

Table 5-1 — Color code table

SYSTEM	COLOR	SYSTEM	COLOR
Lube-oil	Yellow& Black striped	Oil Pollution Abatement (OBA)	Black
Aqueous film forming foam (AFFF) discharge	Red& Green striped	Jacket Water	Light Blue & Black striped
Gasoline	Yellow	AFFF Solution Mixed	Red & Dark Green striped
Fresh Water (surface)	Light Blue	Steam & Steam Drains	White
Hydraulics	Orange	Potable	Dark Blue
Refrigerant	Purple	High-Pressure Air (+1,000 psi)	Dark Gray
Sewage	Gold	Low-Pressure Air (below 150 psi)	Tan
Halon	Gray &White striped	Oxygen	Green
Firemain	Red	Seawater	Dark Green
Chilled Water	Light Blue & Dark Blue Striped	JP-5	Light Purple
AFFF Concentrate	Light Blue& Red striped	Fuel	Yellow

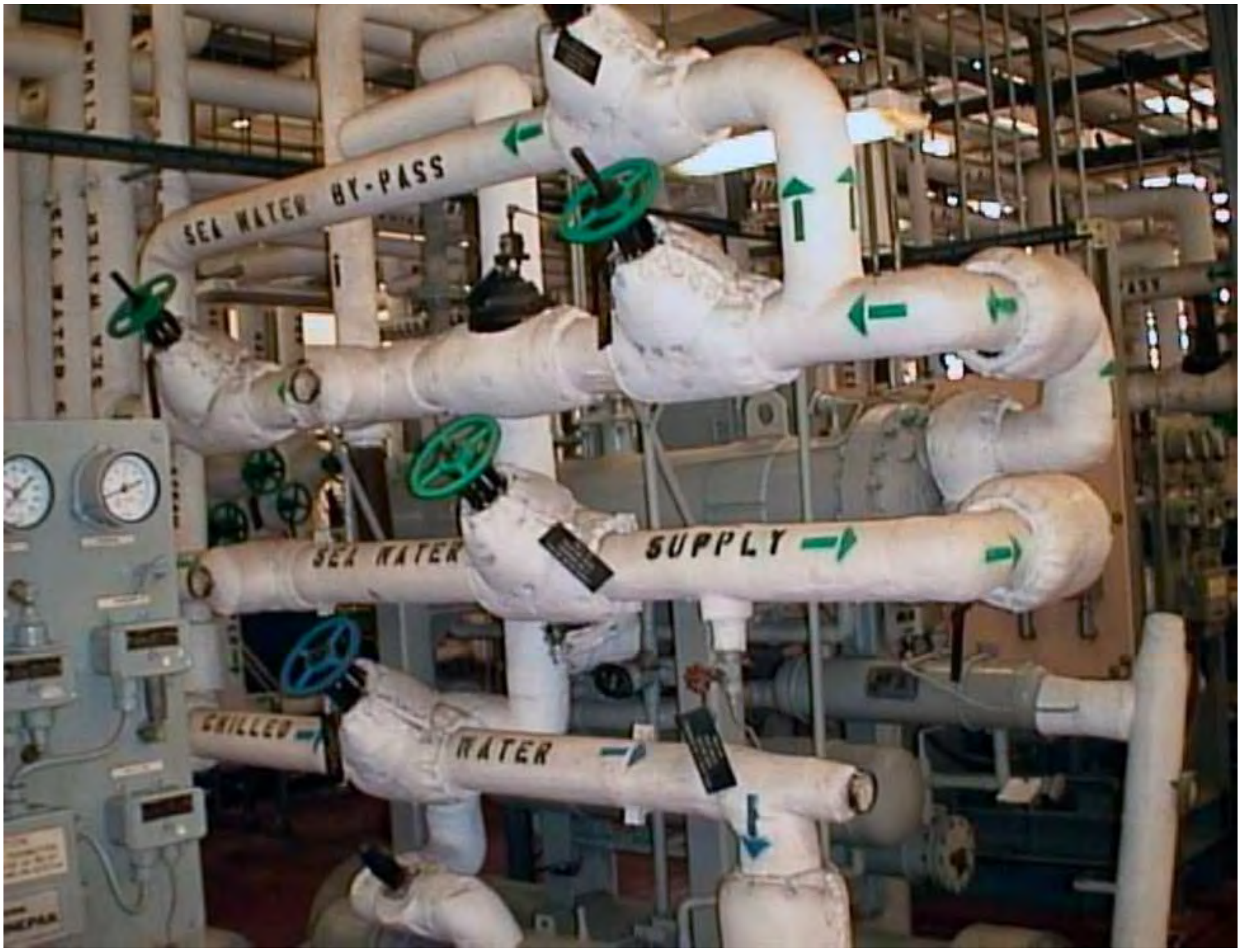


Figure 5-1- Piping directional flow.

Piping Materials

The pipe and tubing used in fluid systems today are commonly made from steel, copper, brass, aluminum, and stainless steel. The hose assemblies are constructed of rubber or Teflon. Steel piping and tubing are relatively inexpensive and have a high tensile strength. Copper and brass piping and tubing have a high resistance to corrosion and are easily drawn or bent. Pipe or tubing made from these materials is unsuitable for systems with high temperatures, stress, or vibration because they have a tendency to harden and break. Aluminum has many characteristics and qualities required for fluid systems. It has a high resistance to corrosion, is lightweight, is easily drawn or bent, and (when combined with certain alloys) will withstand high pressures and temperatures. Stainless steel piping or tubing is relatively lightweight and is used in a system that will be exposed to abrasion, high pressure, and intense heat. Its main disadvantage is high cost.

Standards that match Navy standards are shock damage and the requirement for the lightest weight possible, consistent with good design. Generally, use of these more critical materials is restricted to combatant ships. In the case of seawater piping systems, the use of copper-nickel alloy material has become widespread because of its resistance to seawater corrosion.

Fluid Turbulence

Early deterioration may occur where fluid turbulence exists downstream of throttled valves or at sharp bends. Ledges and projections inside seawater piping systems operating at velocities above 12 feet per second (ft./sec) cause sufficient turbulence to erode copper-nickel tubing in a relatively short time; therefore, streamlined fittings and joints should be provided.

Piping and piping component minimum wall thicknesses are determined by considering the fiber stresses permitted for a material at the system design temperature and pressure, manufacturing tolerances, and corrosion allowances. Replacement material shall be of the same material, size, and wall thickness as the original to avoid interfering with system design from the standpoint of system capacity and thermal expansion and contraction. It also prevents the possibility of setting up a galvanic couple between dissimilar materials with attendant electrolytic corrosion and precludes erosion resulting from interior misfit.

⚠ **CAUTION** ⚠

Do not use copper in diesel engine oil or fuel lines.

Flexible Hose Assemblies

The flexible hose assembly (*Figure 5-2, frames 1–3*) is a specific type of flexible device that uses reinforced rubber hose and metal end fittings. It is used to absorb motion between resiliently mounted machinery and fixed or resiliently mounted piping systems. The motion to be considered may be of either relatively large size due to high-impact shock or of smaller size due to the vibratory forces of rotating machinery. The configuration selected must contain enough hose to accommodate shock and vibratory motion without stressing the hose assembly or machinery to an unacceptable degree.

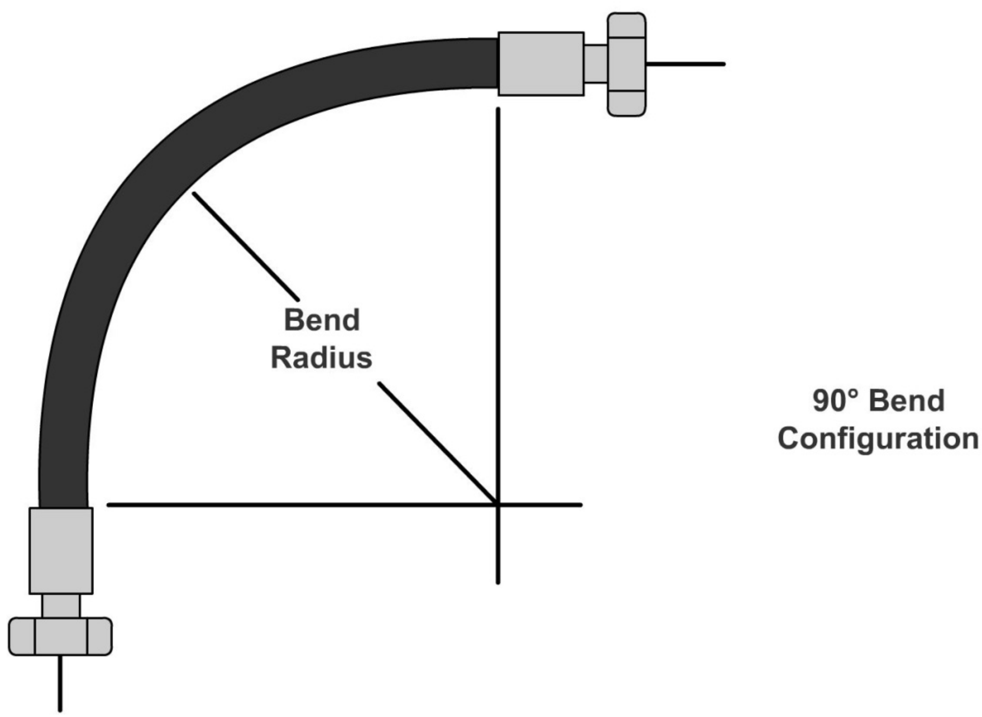


Figure 5-2 — Flexible hoses.

Hose is identified by the manufacturer's part number and the size or dash number. Some hoses have identification tags *(Figure 5-3).* The dash number is the nominal hose inside diameter in sixteenths of an inch. Hose built to military specification (MILSPEC) requirements have the number of the specification and, where applicable, the class of hose, the quarter and year of manufacture, and the manufacturer's trademark. This information is molded or otherwise permanently repeated periodically on the hose cover. Other information permanently marked on the hose cover is the manufacturer's code and the date of manufacture.

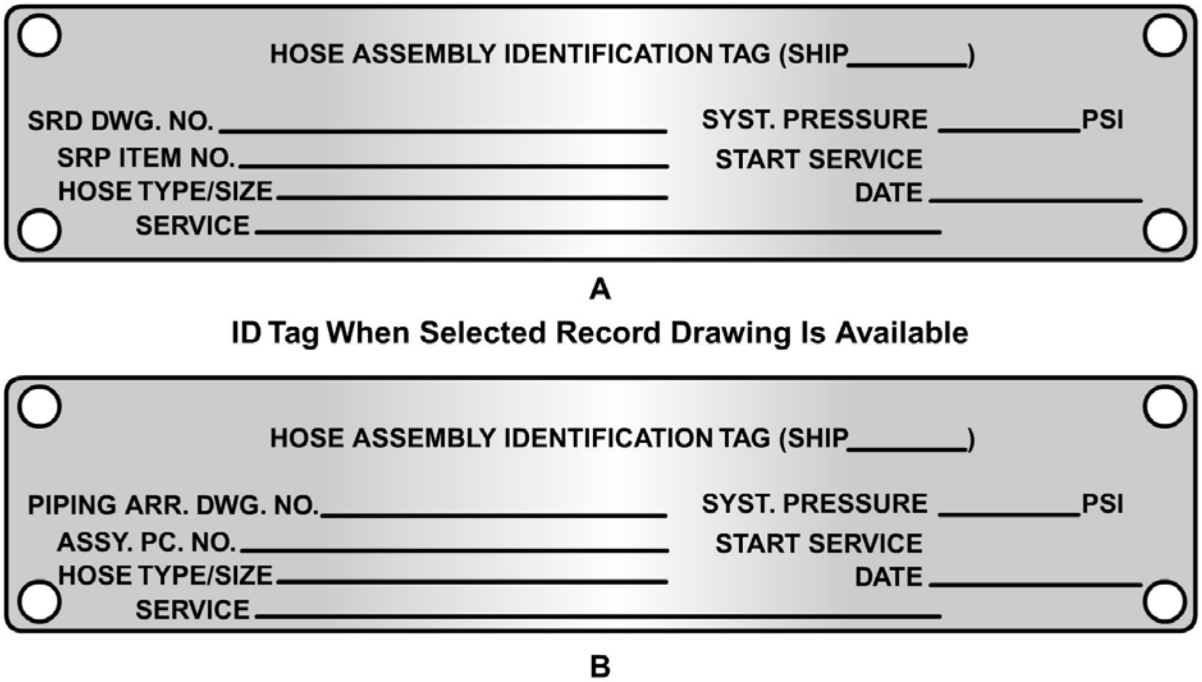


Figure 5-3 — Hose assembly identification tag.

Inspection of Hose and Fittings Prior To Make-Up

The basic inspection methods for hose and fittings are listed as follows:

1. Ensure that the hose and couplings are the correct ones for the intended use and that the age of the rubber hose does not exceed a shelf life of 4 years. Teflon and metal hose have no limiting shelf life.
2. Inspect for signs that the hose has been twisted. Use the hose lay line for a guide to determine whether or not any twist is present. If twisted, reject.
3. Inspect for signs that the hose has been kinked or bent beyond its minimum bend radius. If suspect, reject.
4. Inspect for signs of loose inner liner. If found, cut the hose to see if this condition exists throughout the entire length. .If suspect, reject.
5. Visually check the inner liner and outer rubber cover of the hose for breaks, hairline cuts, or severe abrasions. If any suspect areas are found, reject.
6. Inspect the fittings for defects, such as cracked nipples and damaged threads. If suspect or if defects are found, reject.

Procedures for making up hoses and fittings can also be found in the *Naval Ships' Technical Manual (NSTM),* chapter 505, or the appropriate manufacturer's catalog or manual, and are not covered here due to the many types available. After assembling the hose and fittings, visually inspect the entire configuration to ensure the following conditions.

1. The hose inner liner and outer cover are intact and contain no cuts or harmful abrasions.
2. The hose has not been twisted (check the lay line).
3. The circumferential chalk line on the hose next to the coupling has been drawn before the hydrostatic test.

4. The internal spring (if installed) is evenly spaced and flat against the inner liner.
5. A gap exists between one of the end fittings and the end of the spring.

Hydrostatic Test

Upon completion of visual inspection, hydrostatically shop tests the hose assembly with fresh water. For each style and size of hose, test the pressure to ensure that it is twice the maximum allowable pressure shown in chapter 505 of the NSTM*.* When you test pressure, hold for not more than 5 minutes or less than 60 seconds. When test pressure is reached, visually inspect the hose assembly for the following defects:

1. Leaks or signs of weakness
2. Twisting of the hose (indicates that some twist existed before pressure was applied)
3. Slippage of the hose out of the coupling (a circumferential chalk line can help determine)

If any of these defects occur, reject the assembly.

⚠ CAUTION ⚠

Do not confuse hose elongation under pressure with coupling slippage. If the chalk line returns to near its original position, no slippage has occurred and the assembly is satisfactory. If there is any doubt, perform a second test. If doubt persists after second test, reject the assembly.

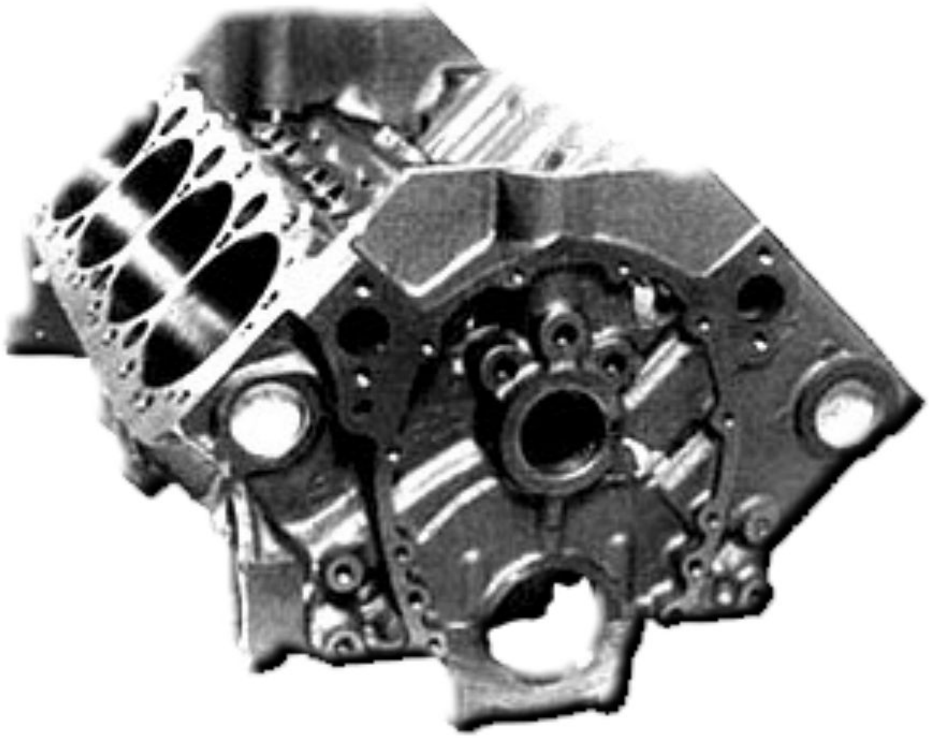
ENGINE FRAMES

The term *frame* is sometimes used to identify a single part of an engine or several stationary parts that are fastened together, which support most of the moving engine parts and engine accessories. When we talk about the frame, we will use the latter meaning in our discussion. As the load-carrying part of the engine, the frame may include such parts as the cylinder block, base, sump or oil pan, and end plates.

Cylinder Blocks

A cylinder block is the part of the engine frame that supports the engine's cylinder liners, head (or heads), and crankshaft. (In modern engines, the term *crankcase* identifies the location of the crankshaft and not a separate component of the frame.) The blocks for most large engines are of welded-steel construction. In this type of construction, the block is made of steel forgings and plates that are welded horizontally and vertically for strength and rigidity. These plates are located where loads occur. Deck plates are generally fashioned to house and hold the cylinder liners. The uprights and other members are welded with the deck plates into one rigid unit. Blocks of small high-speed engines are often of cast iron en bloc (in one piece) construction.

A cylinder block may contain passages to allow circulation of cooling water around the liners for cooling of the cylinder. However, if the liner is constructed with integral cooling passages, the cylinder block generally will not have cooling passages. Many blocks have drilled lube oil passages. Most two-stroke cycle engines have air passages in the block. A passage that is an integral part of an engine block may serve as a part of the cooling, lubricating, or air system. Some engines may have a separate block for each group of cylinders. Examples of cylinder blocks common to Navy service are shown in *Figure 5-4, frames 1-3*, and *Figure 5-5* shows a cylinder block with air and water passages.



"V" Type Engine Block

Figure 5-4, Frames 1-3 — Different engine blocks.

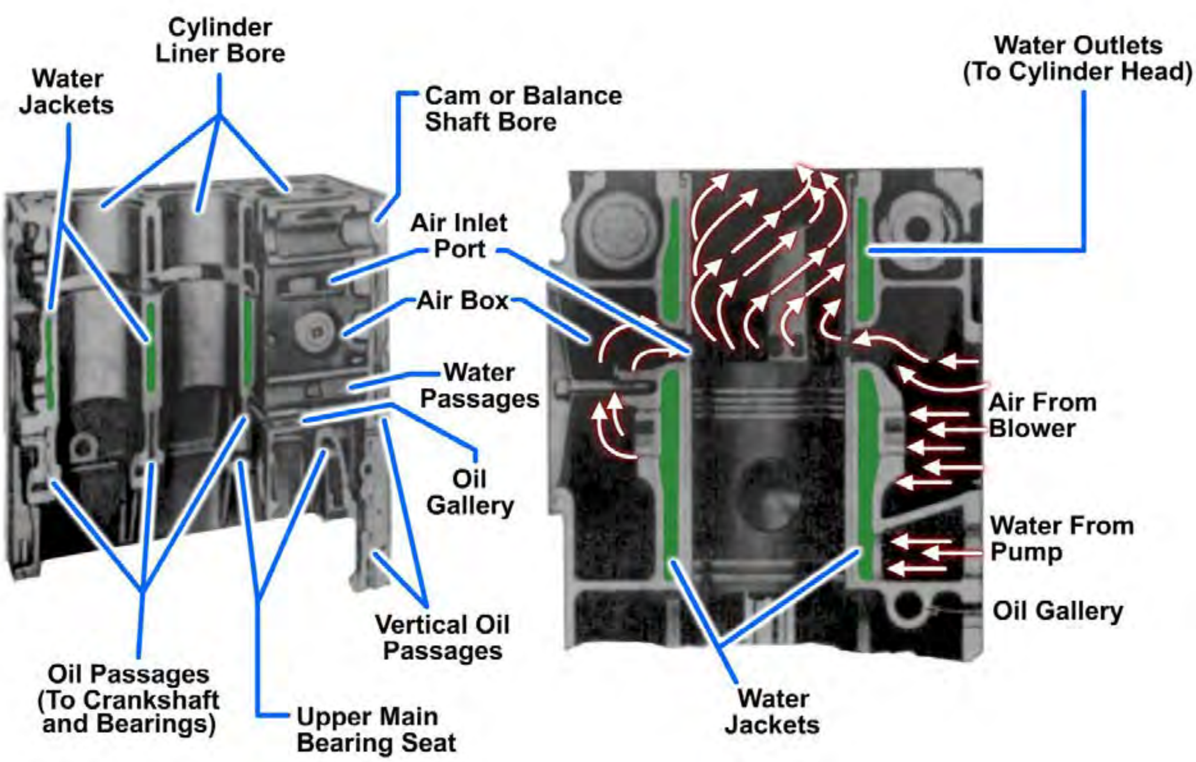


Figure 5-5 — Cutaway view of a cylinder block showing air and water passages.

The cylinder block shown in *Figure 5-6* is made up of two 8-cylinder alloy cast-iron sections. The front and rear block sections are bolted together to form a rigid self-supporting, 16-cylinder, V-type arrangement, which accommodates the cylinder assemblies, crankshaft, and engine-mounted components. Water passages are cast in the block to provide coolant to the cylinder liners and the cylinder heads. Main oil galleries are drilled in the block to direct lubricating oil to the crankshaft main bearings and related parts. The front and rear block sections are not interchangeable.

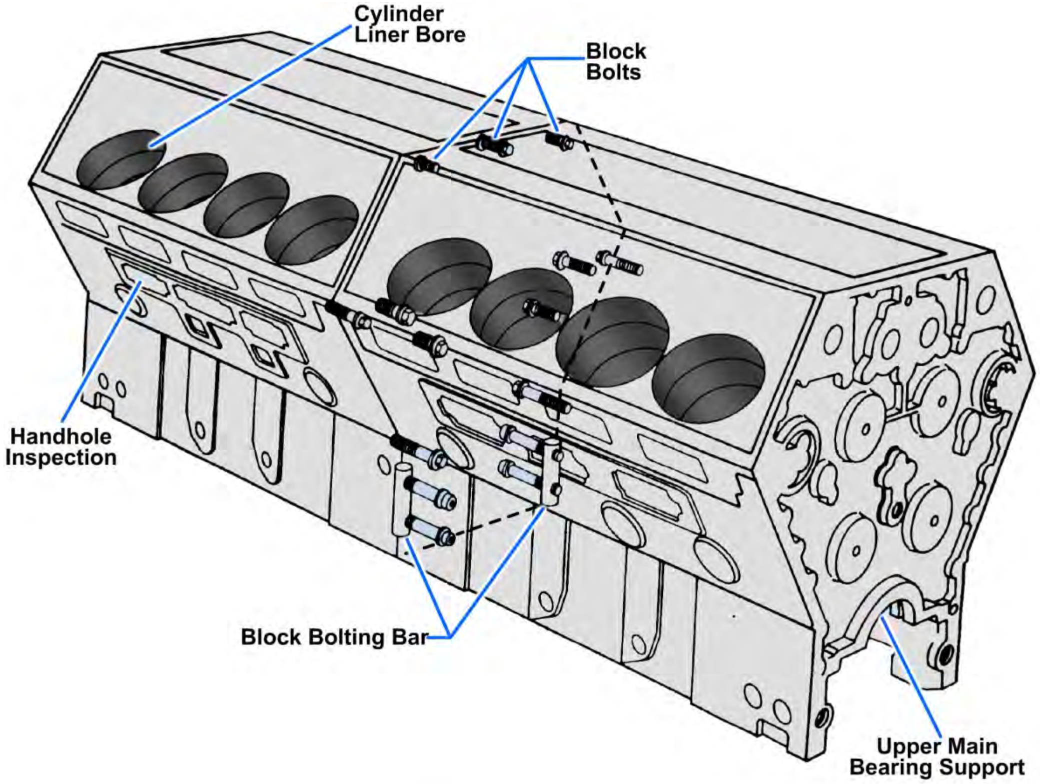


Figure 5-6 — A16-cylinder, 2-piece block.

Cylinder block for a large diesel engine that consists of steel plates and forgings is shown in *Figure 5-7*. The steel plates and forgings are welded together to provide the structural support for the stationary and moving components. The upper deck contains the cylinder assemblies and related gear. The lower deck, which forms the crankcase, is mounted with an oil pan to the bedplates. The oil pan is not shown in *Figure 5-7*.

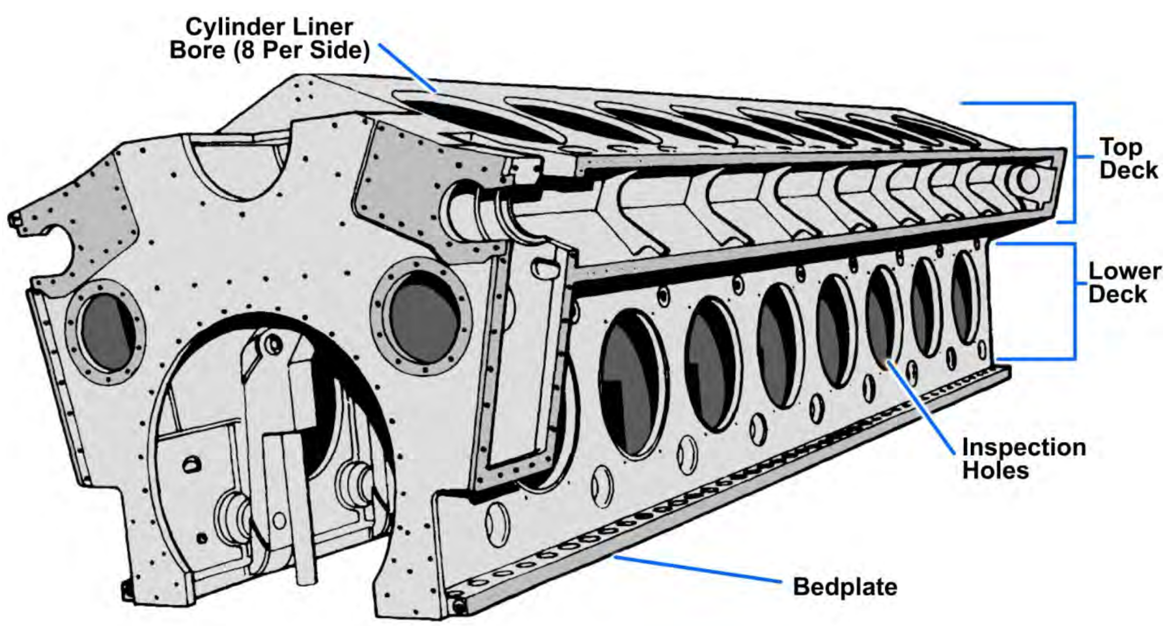


Figure 5-7 — A Colt-Pielstick PC2.5 16-cylinder block.

End Plates

Some engines have flat steel plates attached to each end of the cylinder block. End plates add rigidity to the block and provide a mounting surface for parts such as gears, blowers, pumps, and generators. The type of plate that would attach to the cylinder block shown in *Figure 5-4* is shown in *Figure 5-8*.

Bases

In the majority of large engines, a base is used to support the cylinder block. The base shown in *Figure 5-9* is a welded-steel structure. Not only does the base support the cylinder block, but it also provides a mounting surface for accessories to the engine and serves as a reservoir for the lubricating oil used by the engine. Many of the smaller engines do not have a separate base. Instead, they have an oil pan, which is secured directly to the bottom of the block. The engine block shown in *Figure 5-4* uses such a pan.

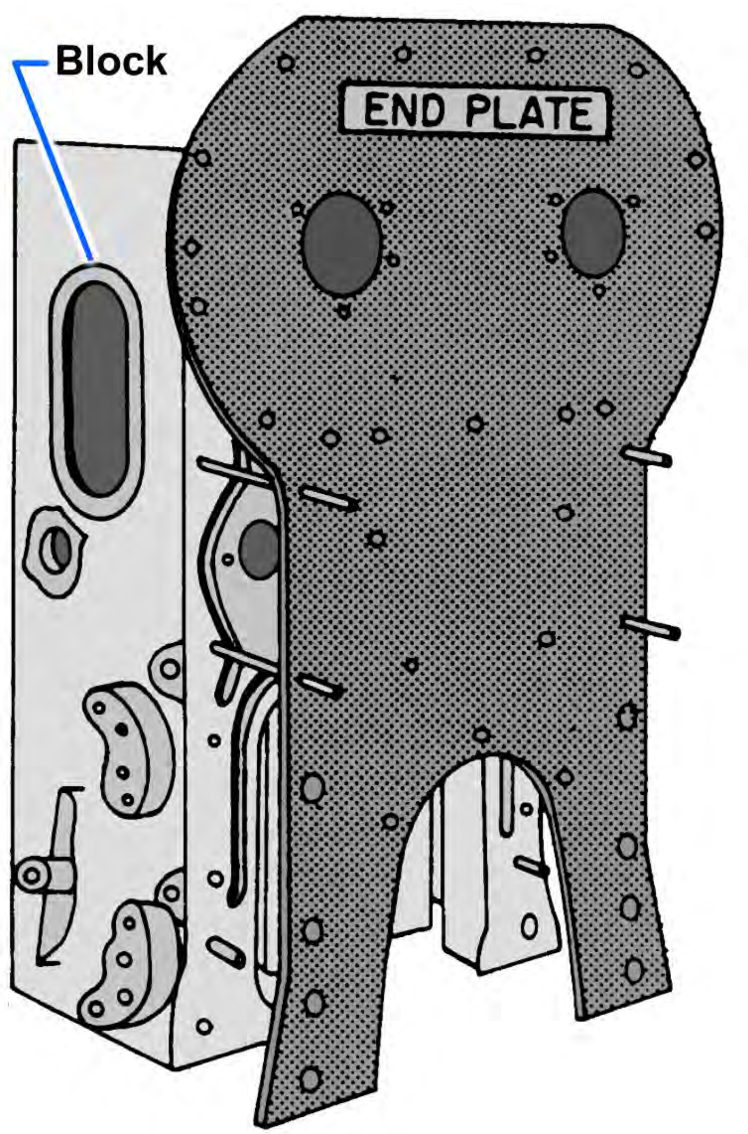


Figure 5-8 — Front end plate on a cylinder block.

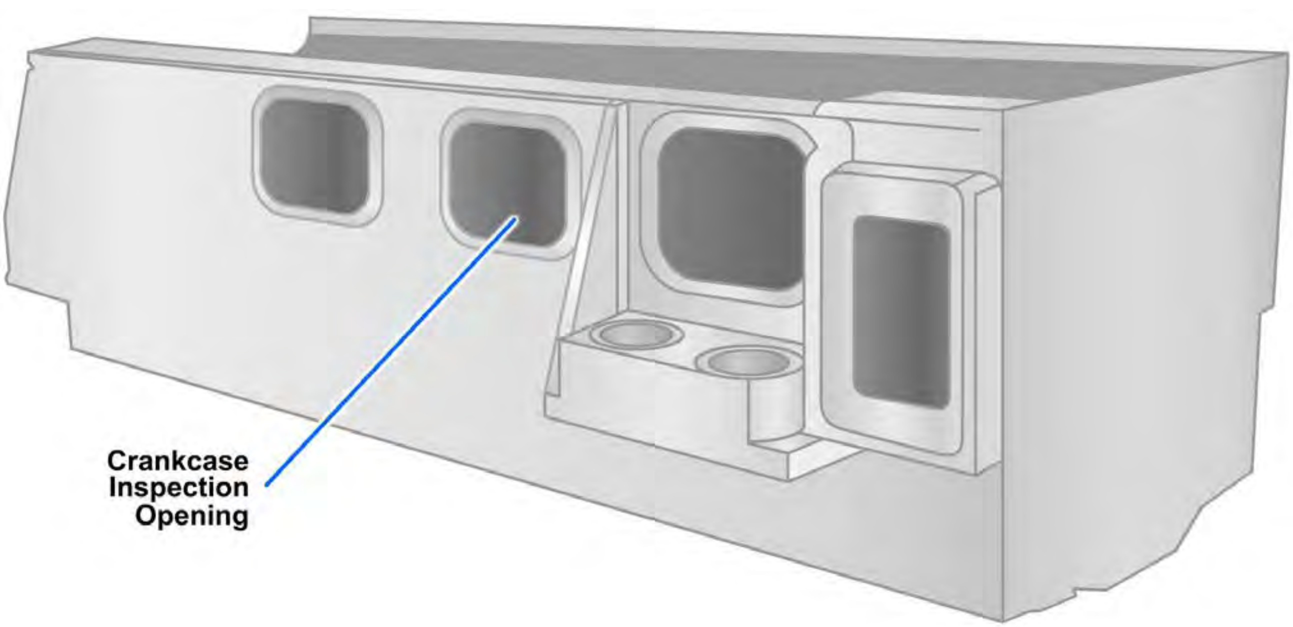


Figure 5-9 — An example of a cylinder base.

Sumps and Oil Pans

A reservoir that is used for the collecting and holding of lubricating oil is a necessary part of the structure of an engine. The reservoir may be called a sump or an oil pan, depending on the design of the engine. In most engines, the reservoir is usually attached directly to the engine. In dry sump engines, however, the oil pan merely catches the lubricating oil as the oil drains through the engine. The lubricating oil, as it reaches the oil pan immediately drains by gravity flow from the oil pan to a reservoir (located apart from the engine), where the lube oil for the engine is collected so it can be cooled and be filtered. Thus, in dry sump engines, the oil pan remains essentially dry. Regardless of the design of the engine, the oil reservoir serves the same purpose wherever it is located.

Access Openings and Covers

Many engines, especially the larger ones, have openings in some part of the engine frame (*Figures 5-7 and 5-9*). These openings permit access to the cylinder liners, main and connecting rod bearings, injector control shafts, and various other internal engine parts. Access doors are usually secured with hand wheel or nut-operated clamps and are fitted with gaskets to keep dirt and foreign material out of the interior of the engine. On some engines, the covers (sometimes called doors or plates) for access openings are constructed to serve as safety devices. A safety cover is a cover that is equipped with a spring-loaded pressure plate (*Figure 5-10*). The spring maintains a pressure that keeps the plate sealed under normal operating conditions. In the event of a crankcase explosion or extreme pressure within the crankcase, the excess pressure overcomes the spring tension, and the plate in the safety cover acts as a vent to allow combustible gases to escape to the atmosphere. This release of excess pressure serves to minimize damage to the engine.

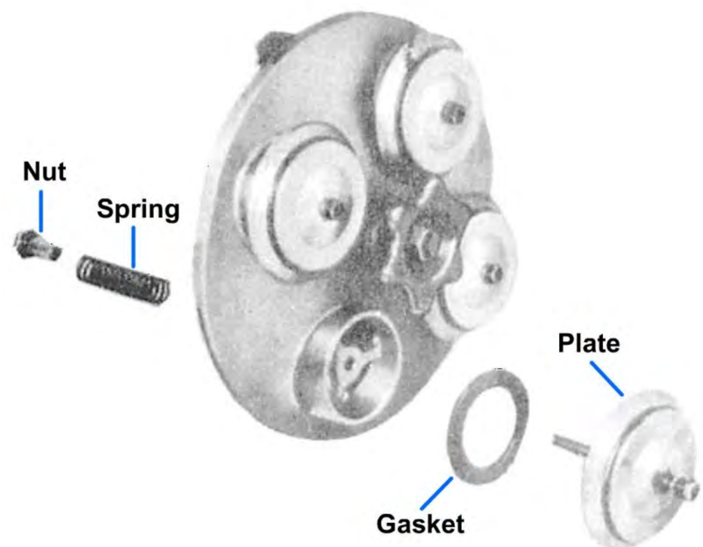


Figure 5-10 — A safety handhole cover.

Bearings

The bearings of an engine make up an important group of parts. Some bearings remain stationary in performing their functions, while others move. The primary function of bearings is to support rotating shafts and other moving parts and to transmit loads from one engine part to another. To accomplish this function in a practical manner, bearings must (1) reduce the friction between the moving surfaces by separating them with a film of lubricant, and (2) carry away the heat produced by unavoidable friction.

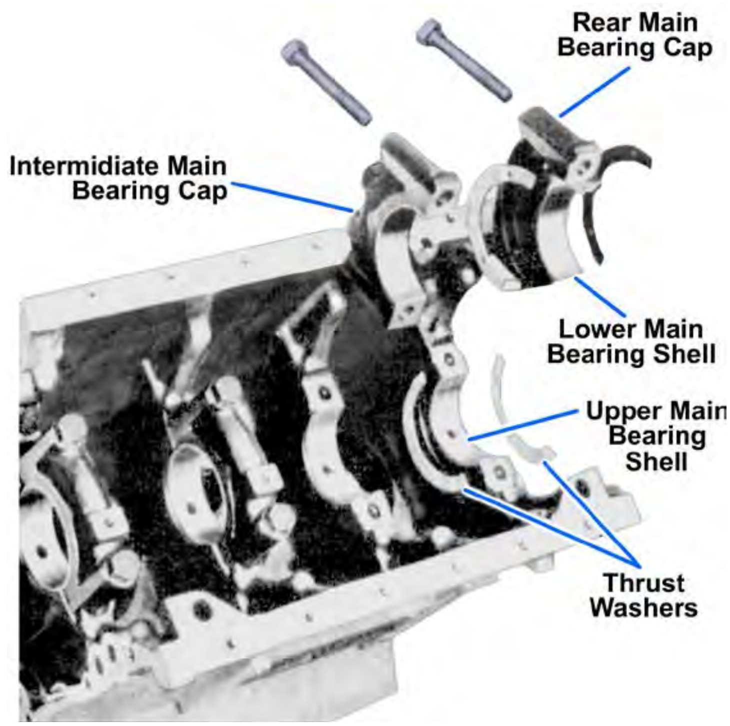


Figure 5-11 — Upper and lower main bearing shell, bearing caps, and rear main bearing thrust washers.

One group of stationary bearings serves to support the crankshaft. These bearings are generally called main bearings (*Figure 5-11*). The main bearings consist of an upper bearing (shell) seated in the cylinder block main bearing support and a lower bearing (shell) seated in the main bearing cap. The thrust washers shown in *Figure 5-11* are used to take up the axial (back-and-forth) movement of the crankshaft.

CYLINDER ASSEMBLIES

The cylinder assembly completes the structural framework of an engine. As one of the main stationary parts of an engine, the cylinder assembly, along with various related working parts, serves as the area where combustion takes place. A cylinder assembly consists of the head, which covers the top of the cylinder, the cylinder liner, the gasket that forms a seal between the block (or frame) and the head, and the fasteners (usually studs with nuts) that hold the assembly together (*Figure 5-12*).

The design of the parts of the cylinder assembly varies considerably from one type of engine to another. Regardless of differences in design, the basic components of all cylinder assemblies, along with related moving parts, function to provide a gastight and liquid-tight space. Differences other than those in design can be found in various cylinder assemblies. For example, a gasket is necessary between the head and the block of most cylinder assemblies. However, such gaskets are not used on all engines. When a gasket is not a part of the assembly, the mating surfaces of the head and the block are accurately machined to form a seal between the two parts. Other differences are pointed out in the discussion that follows.

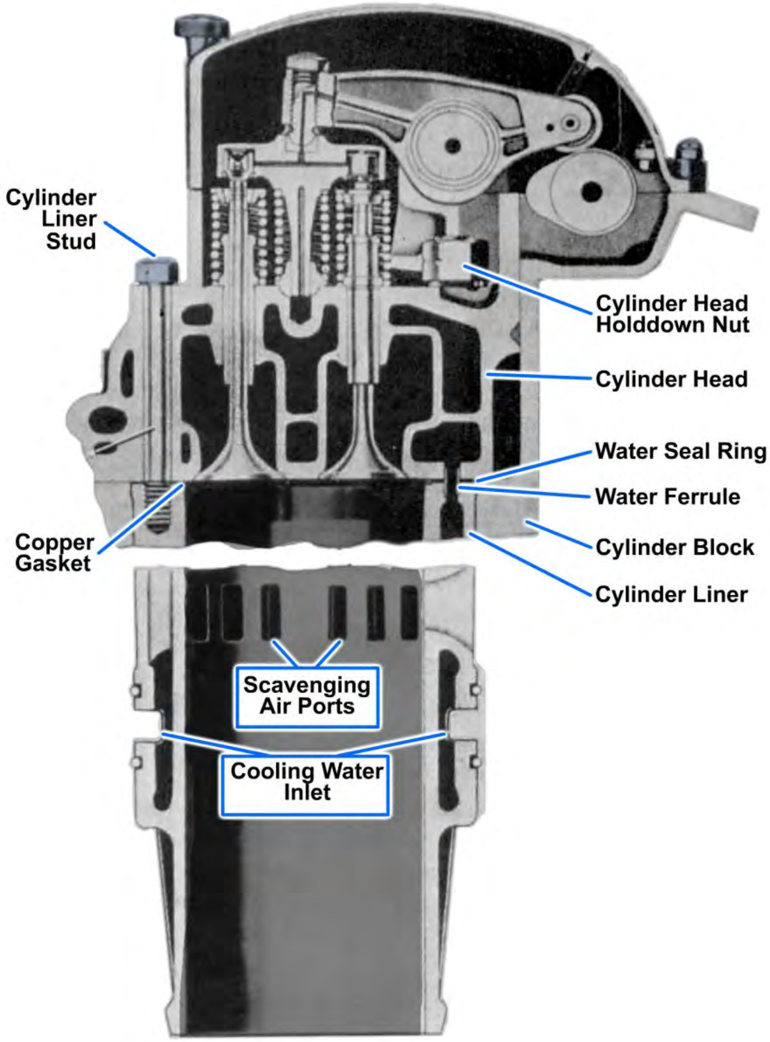


Figure 5-12 — Principal stationary parts of a cylinder assembly.

Cylinder Liners

The barrel or bore in which an engine piston moves back and forth may be an integral part of the cylinder block, or it may be a separate sleeve or liner. The first type, common in gasoline engines, has the disadvantage of not being replaceable. When excessive wear occurs in a block of this type, the cylinder must be rebored or honed. Reconditioning of this type cannot be repeated indefinitely and, in time, the entire block must be replaced. Another disadvantage is the inconvenience, especially in large engines, of having to remove the entire cylinder block from a ship in order to recondition the cylinders. For these reasons, diesel engines are constructed with replaceable cylinder liners. The cylinder liners we will discuss are representative of those used in diesel engines.

The material of a liner must withstand the extreme heat and pressure developed within the combustion space at the top of the cylinder and, at the same time, must permit the piston and its sealing rings to move with a minimum of friction. Close-grained cast iron is the material most commonly used for liner construction. (Steel, however, is sometimes used.) Some liners are plated on the wearing surface with porous chromium because chromium has greater wear-resistant qualities than other materials. Also, the pores in the plating tend to hold the lubricating oil and aid in maintaining the lubrication oil film that is necessary for reduction of friction and wear.

Cylinder liners may be divided into two general classifications or types—dry or wet. The dry liner does not come in contact with the coolant. Instead, it fits closely against the wall of the cooling jacket in the cylinder block. With the wet liner, the coolant comes in direct contact with the liner. Wet liners may have a cooling water space between the engine block and liner, or they may have integral cooling passages. Liners with integral cooling passages are sometimes referred to as water-jacket liners.

Dry Liners

Dry liners have relatively thin walls compared to wet liners (*Figure 5-13*). The cross section of a dry liner can be seen in the right-hand view of *Figure 5-5*. Note that the coolant circulates through passages in the block and does not come in contact with the liner.

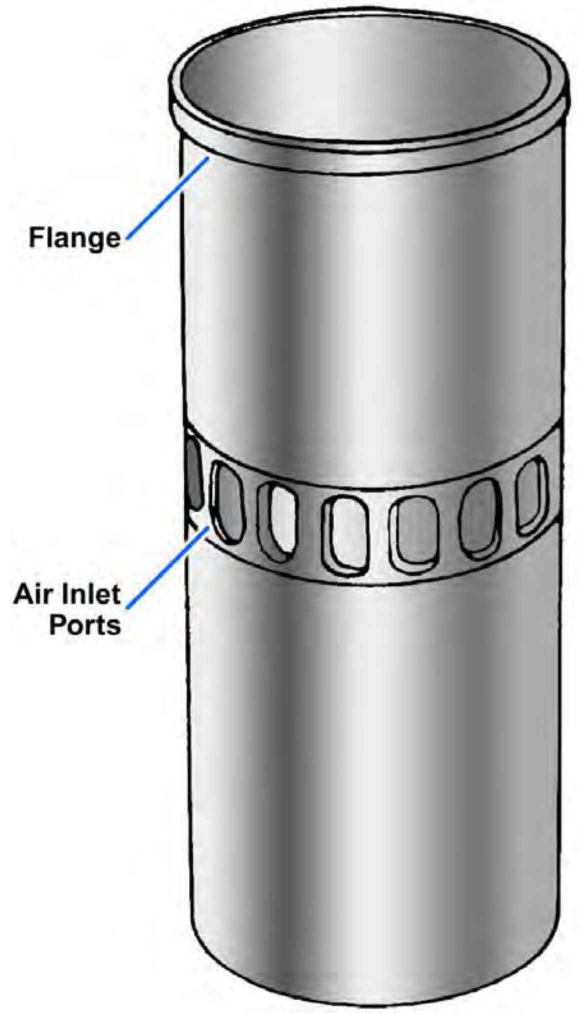


Figure 5-13 — A dry cylinder liner.

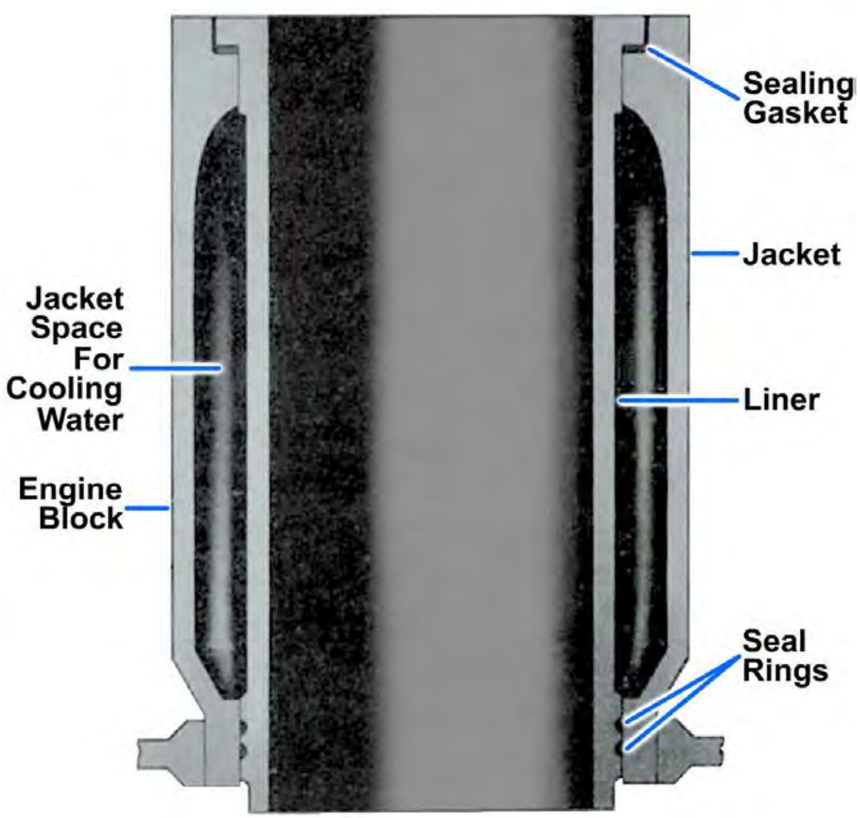


Figure 5-14 — Cross section of a wet cylinder liner.

Wet Liners

In wet liners that do not have integral cooling passages, the water jacket is formed by the liner and a separate jacket, which is a part of the block (*Figure 5-14*). A static seal must be provided at both the combustion and crankshaft ends of the cylinders to prevent the leakage of coolant into the oil pan sump or combustion space. Generally, the seal at the combustion end of a liner consists of either a gasket under a flange or a machined fit. Rubber or neoprene rings generally form the seal at the crankshaft end of the liner. Liners of this type are constructed to permit lengthwise expansion and contraction. The walls of a wet liner must be strong enough to withstand the full working pressure of the combustion gases.

Water-Jacket Liners

A cylinder sleeve of the water-jacket type has its own coolant jacket as an integral part of the liner assembly. The jacket may be brazed on (*Figure 5-15)*, cast on (*Figure 5-16*), shrunk on, or sealed on *(Figure 5-17)* the liner. The liner shown in *Figure 5-15* is a brazed-on jacket type with a separate water jacket brazed onto the cylinder liner. In this type of liner, the inlet water circulates around the bottom of the liner. The water then progresses upward and discharges through drilled passages at the top of the liner into the cylinder head. Seals are placed around each drilled water passage so that the water passages will be watertight when the cylinder head is installed.

The water-jacket liner shown in *Figure 5-16* is of the cast-on jacket type. The water jacket is formed by the inner and outer walls of the liner. Ports divide the water space into lower and upper spaces, which are connected by vertical passages between the ports. The flow path for cooling in this liner is basically the same as in the brazed type of liner. The water-jacket liner shown in *Figure 5-17, view A* is of the sealed-on jacket type. This assembly consists of two components, the liner (*Figure 5-17, view B*) and the liner jacket (*Figure 5-17, view C*). The cylinder liner is sealed within the liner jacket by upper and lower O-rings. The liner (*Figure 5-17, view B*) is constructed with vertical ribs in the middle, between the inlet and exhaust ports. These ribs direct the water travel upward, absorbing heat from this part of the cylinder. Midway up the liner, openings are provided for the two injection nozzles, an air start check valve, and a cylinder relief valve. Additional information on liners can be found in *NSTM,* chapter 233.

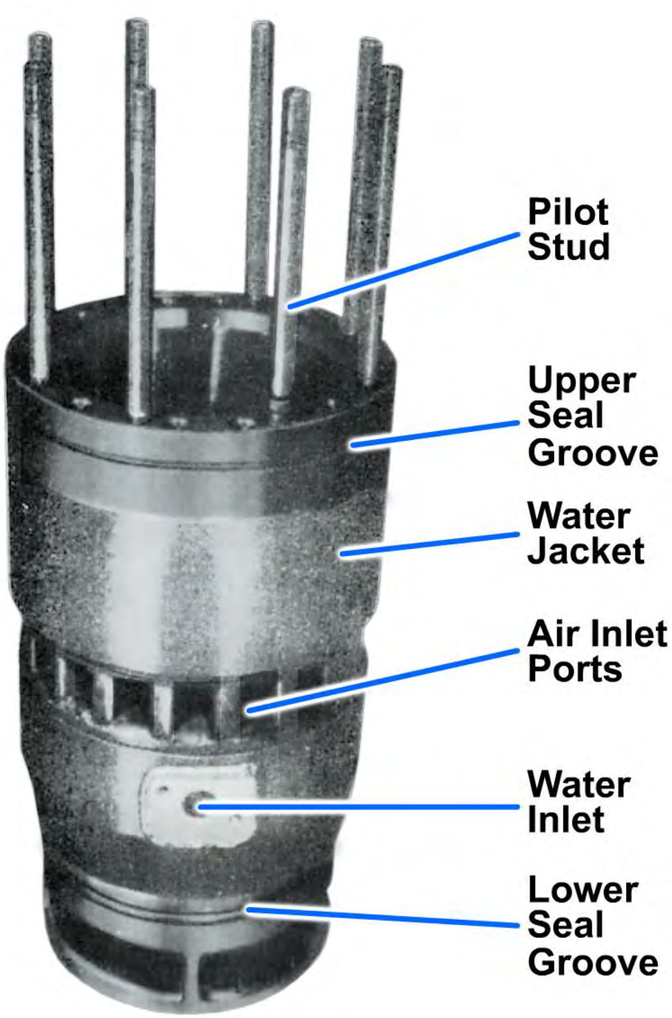


Figure 5-15 — A brazed-on water-jacket cylinder liner.

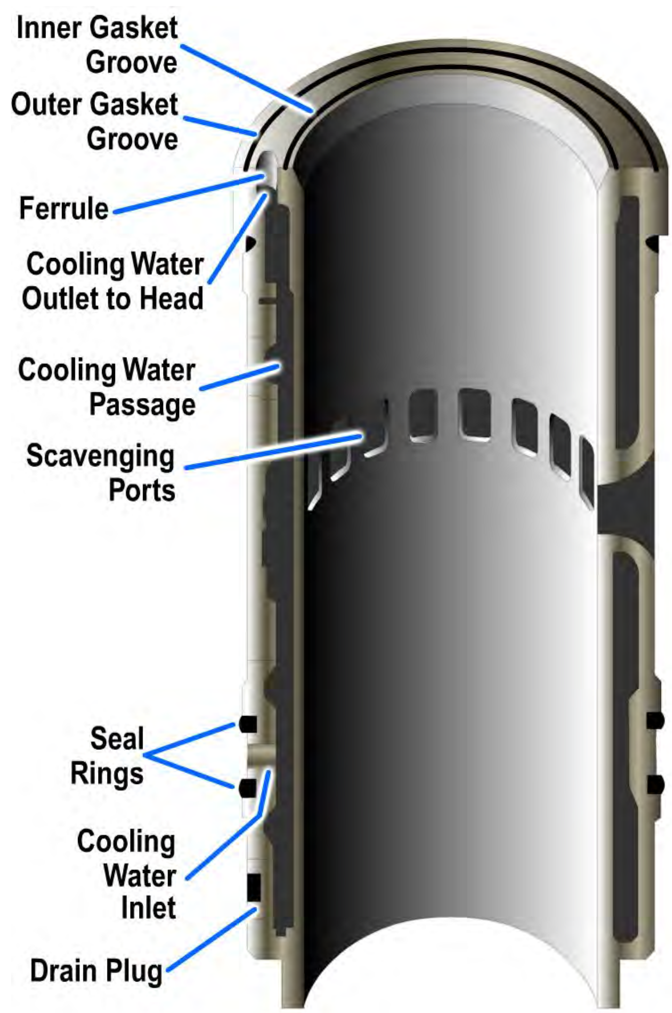


Figure 5-16 — Cross section of a cast-on water-jacket cylinder liner with air ports.

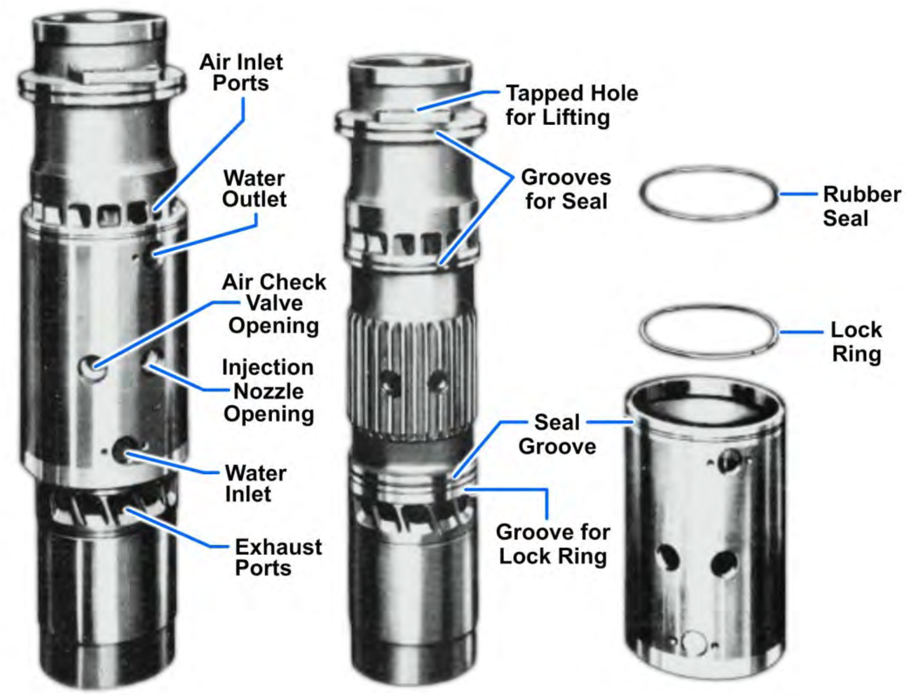


Figure 5-17 — A water-jackets cylinder liner assembly with a sealed-on jacket.

Cylinder Heads

The liners or bores of an internal-combustion engine must be sealed tightly to form the combustion chambers. In Navy engines, except for engines of the opposed piston type, the space at the combustion end of a cylinder is formed and sealed by a cylinder head that is a separate unit from the block or liner.

A number of engine parts that are essential to engine operation may be found in or attached to the cylinder head. The cylinder head for a four-stroke cycle engine will house intake and exhaust valves, valve guides, and valve seats, whereas the head for a two-stroke cycle engine the head will carry many of the same parts with the exception of the intake valves. Rocker arm assemblies are frequently attached to the cylinder head. The fuel injection valve is almost always in the cylinder head or heads of a diesel engine, while the spark plugs are always in the cylinder head of gasoline engines. Cylinder heads of a diesel engine may also be fitted with air starting valves, indicator cocks, and safety valves.

The design and material of a cylinder head must be such that it can withstand the rapid changes of temperature and pressure that take place in the combustion space and the mechanical stress that results from the head being bolted securely to the block. Cylinder heads are made of heat-resistant alloy cast-iron or aluminum alloy.

The number of cylinder heads found on diesel engines varies considerably. Small engines of the in-line cylinder arrangement use one head for all cylinders. A single head may cover all the cylinders in each bank in some V-type engines. Large diesel engines generally have one cylinder head for each cylinder, although some engines use one head for each pair of cylinders.

A cylinder head of the type used to seal all cylinders of one bank of a V-type block is shown in *Figure 5-18, Frames 1-2*. The cylinder head, over each bank of cylinders, is a one-piece casting that can be removed from the engine as an assembly containing such moving parts as the cam followers and guides, push rods, rocker arms, exhaust valves, and fuel injectors. The cylinder head shown in *Figure 5-19, views A, B, and C* is used when one cylinder head is required for each cylinder. The cylinder head is made of high-strength, cast-iron alloy with specially designed cast passages for water and exhaust gases. Drilled holes (*Figure 5-19, view C*) at the bottom of the cylinder head match the water discharge holes in the liner. Other passages in the cylinder head line up with mating elbows in the cylinder block to conduct exhaust gases through the water manifold to the exhaust manifold. Another opening located in the center of the cylinder head (*Figure 5-19, view A*) is where the fuel injector is installed.

Another cylinder head of the type used to seal one cylinder of a block is shown in *Figure 5-20*. This cylinder head is different in construction compared to the heads we have discussed. The cylinder heads shown in *Figures 5-18 and 5-19* must be removed from the block before the exhaust valves can be serviced. The cylinder head in *Figure 5-20*, however, features a caged design that allows for replacement of the exhaust valves and seats in minimal time without removal of the secured cylinder head.

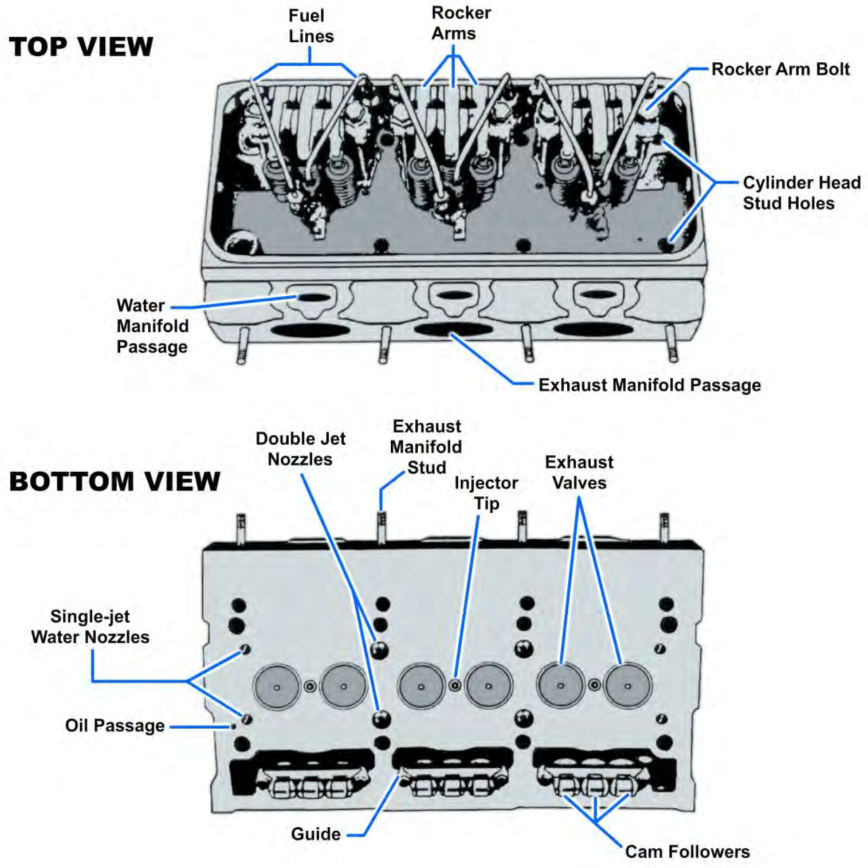
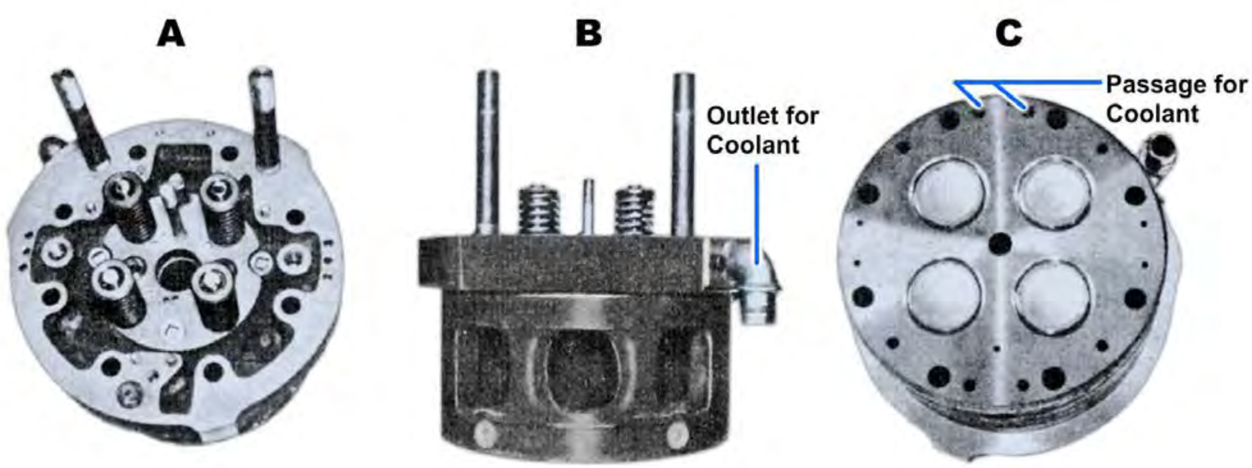


Figure 5-18, Frames 1-2— A multiple cylinder head for a V-type engine.



5-19 — Various views of a cylinder head.

Cylinder Head Studs and Gaskets

In many engines, the seal between the cylinder head and the block depends principally upon the integrity or smoothness of the metal surfaces, the gaskets, and the tightness of the fasteners.

Studs

Cylinder head studs are manufactured from round rod, generally of alloy steel. Threads are cut on both ends. The threads that screw into the block are generally made with finer threads than those on the nut end. This design allows for a tighter fit in the block, which keeps the stud from loosening when the stud nut is removed.

Figure 5-21 illustrates a sequence for the tightening of fasteners for two types of cylinder heads. This sequence is not a hard and fast rule but can be followed in the absence of more specific information. Fasteners are generally tightened sufficiently to seat the cylinder head lightly (finger tight). At least two or three rounds of tightening should be made before all fasteners are brought up to the specified torque for the studs being used.

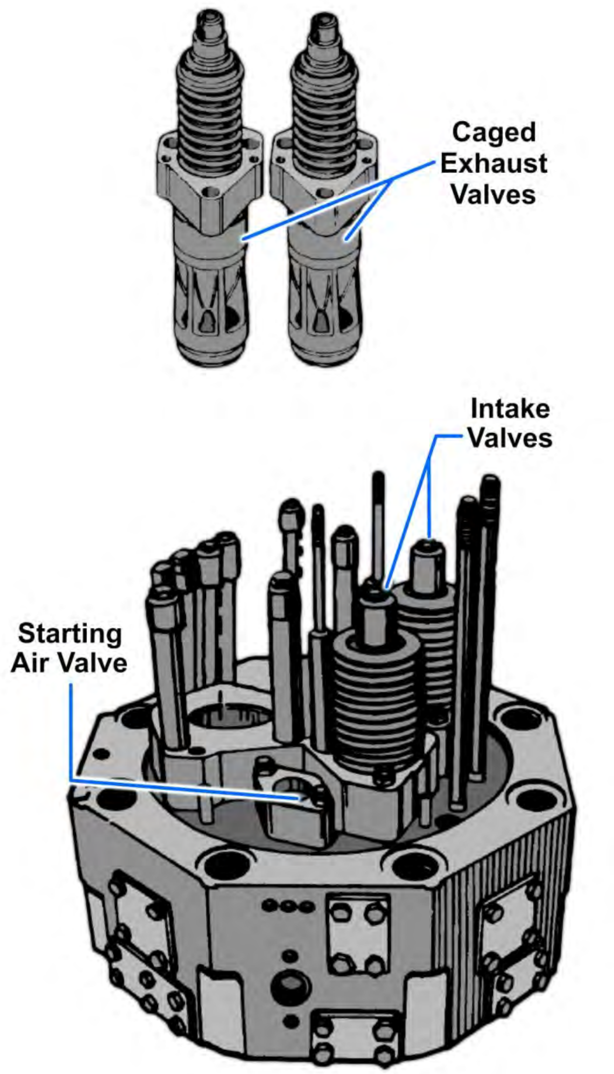


Figure 5-20 — A Colt-Pielstick cylinder head with valves.

When installing studs and nuts, you should carefully clean the threads of the studs and the nuts by wire-brushing and applying an approved solvent. Do not forget to inspect the blind holes and threads in the block. Cleaning will minimize wear and distortion of threads resulting from dirt. It will also increase the accuracy of the torque wrench readings. (A torque wrench reading higher than that reached when the threads are clean will be necessary to reach the required tension when the threads are dirty.)

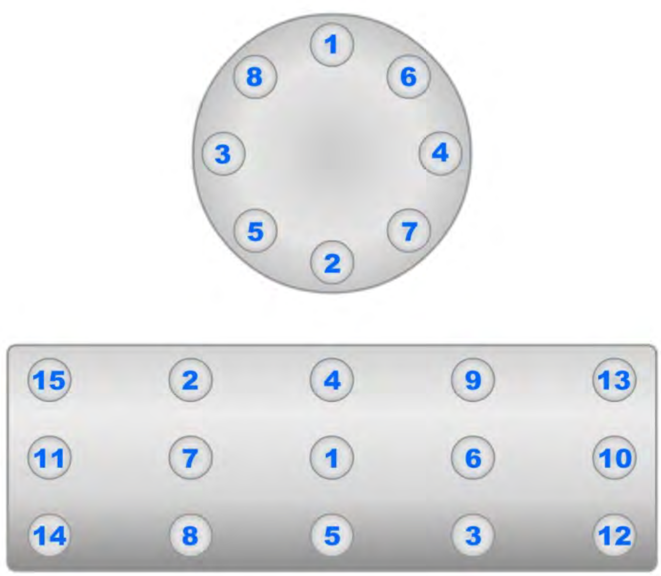


Figure 5-21 — Sequence for tightening cylinder head studs (fasteners).

⚠ CAUTION ⚠

Torque specifications are normally for clean, dry, threaded fasteners. Torque specifications for lubricated fasteners are not the same as those for dry fasteners.

All stud nuts should be tightened equally and according to specifications given in the manufacturer's technical manual. Over-tightening is as undesirable as under-tightening. Sometimes studs that are relatively inaccessible are neglected during the periodic checks for tightness. Such an oversight may result in studs coming loose and failing.

Gaskets

Even though gasket design is quite varied, all gaskets have compressibility as a common property. The principle by which this property is put to use in forming a seal between mating parts is illustrated in *Figure 5-22*.

The mating surfaces of a cylinder block and head may appear to be quite smooth; however, if these surfaces are highly magnified, existing irregularities can be seen. Irregularities such as those illustrated in *Figure 5-22, view A* are sufficient to allow leakage of the combustion gases, oil, or coolant unless some compressible material is used between the mating surfaces (*Figure 5-22, view B*).

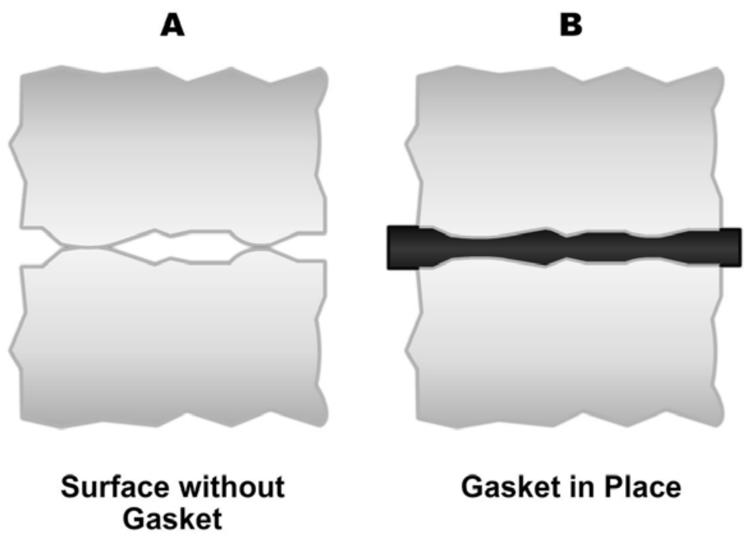
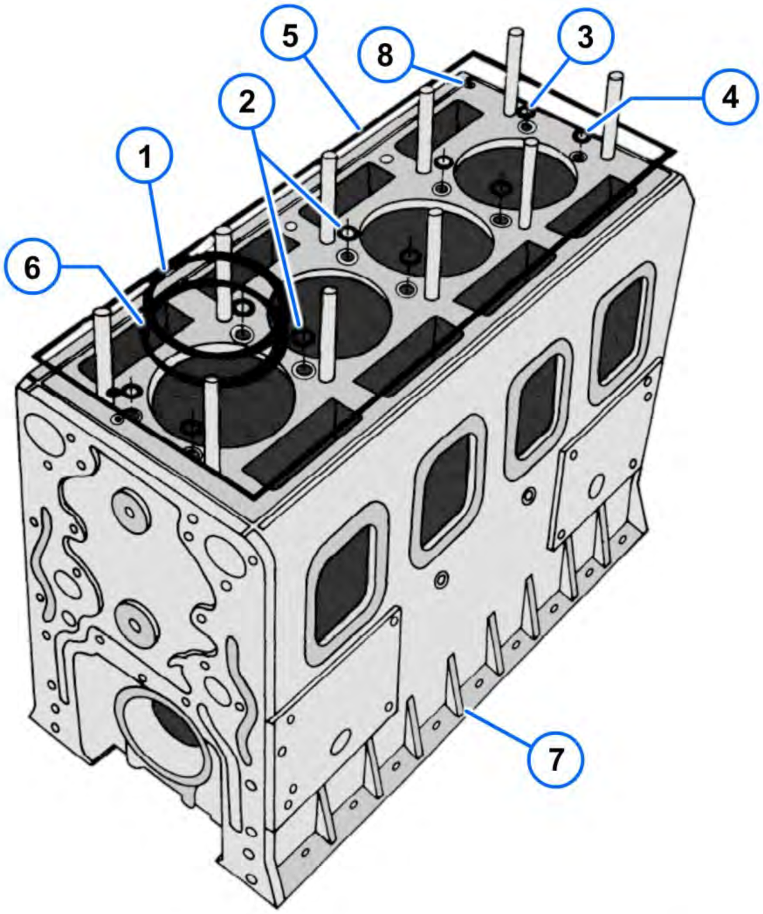


Figure 5-22 — The principle of a gasket.

Materials used in the manufacture of gaskets vary as widely as does gasket design. Gaskets can be made from copper and other relatively soft metals, such as laminated steel sheets, fiber, cork, rubber, synthetic rubber, and a combination of materials, such as copper and asbestos. Combinations of gaskets, seal rings, and grommets or similar devices (*Figure 5-23*) may be used in cylinder assemblies. These combinations serve to prevent the leakage of oil, water, and combustion gases between the cylinder block and the head. For additional information on gaskets, refer to *NSTM,* chapter 078.



1. Gasket – Cylinder Liner Compression
2. Seal Ring – Water Hole
3. Seal Ring – Water Hole End
4. Seal Ring – Water and Oil Hole
5. Seal – Cylinder Head Oil
6. Insert – Cylinder Liner
7. Block – Cylinder
8. Plug – Cylinder Head Oil Seak Cover

Figure 5-23 — Cylinder head gasket and oil and water seal.

ENGINE MOUNTINGS

The devices in an engine that serve to secure the engine in place, such as mountings, are not an actual part of the engine. However, a discussion of these devices is included in this chapter because they are obviously essential for installation purposes and play an important part in reducing the possibility of damage to the engine and to the machinery driven by the engine.

Different terms are used in identification of the devices that secure an engine to a ship. Terms such as base, subbase, bed, frame, rails, mountings, and securing devices appear in various engine technical manuals. To avoid confusion with our discussion on the engine base, we will use the word *subbase* to refer to the supporting and connecting pedestal between an engine and the hull structure of a ship. We will also describe two devices used to attach the subbase for a diesel engine to the hull of a ship.

Subbase

The size and design of the subbase depends on the engine involved and its use. In many installations, the engine and the mechanism that it drives are mounted on a common subbase. One advantage of mounting both units on a common subbase is that misalignment is less likely to occur than when the units are mounted separately. Diesel-driven, electrical generator sets are usually secured to a common subbase.

A different type of mounting or subbase involves the use of hand-fitted chocks, or blocks, between the engine and the supporting structure of the ship. Bolts are the devices used to secure the engine rigidly in place and to maintain alignment.

Securing Devices

The securing devices that are used to fasten a subbase to the structure of a ship may be classified, in general, as rigid or flexible. Propulsion engines are secured rigidly so that misalignment will not occur between the engine, reduction gear (or other driven mechanisms), and the propeller shaft. Engines that drive auxiliary equipment, such as fire pumps or generators, may be secured by either rigid or flexible devices.

In installations where rigidity is of prime importance, bolts are used as the securing devices. Flexible securing devices are generally used between the subbase of a generator set and the structure of the ship. Flexible devices may also be placed between the engine and the subbase. Although flexible devices are not necessary for every type of generator set, they are desirable for generator sets that are mounted near the side of the hull. In this case, flexible devices will serve to reduce vibration. Flexible devices also aid in the prevention of damage from shock loads imposed by external forces. Securing devices are of two general types: vibration isolators and shock absorbers. Both types may be incorporated in a single securing device.

Vibration Isolators

Vibration isolators are designed to absorb the forces of relatively minor vibrations that are common to operating diesel engines. Such vibrations are referred to as high-frequency, low-amplitude vibrations, and they result from an unbalanced condition created by the motion of operating engine parts.

Isolators can be equipped with coil springs or flexible pads to absorb the energy of engine vibrations. An isolator reacts in the same manner, whether it is the spring type or the flexible pad type. Examples of both types of isolators are shown in *Figure 5-24, views A and B*. Four or more spring-type isolators, shown in *Figure 5-24, view A* are used to support a generator set. The flexible pad or “rubber sandwich” type of isolator, shown in *Figure 5-24, view B*, is used for the mounting of small Navy engines. The rubber block in the isolator shown in *Figure 5-24, view B* is bonded to steel plates that are fitted for attachment to the engine and the subbase.

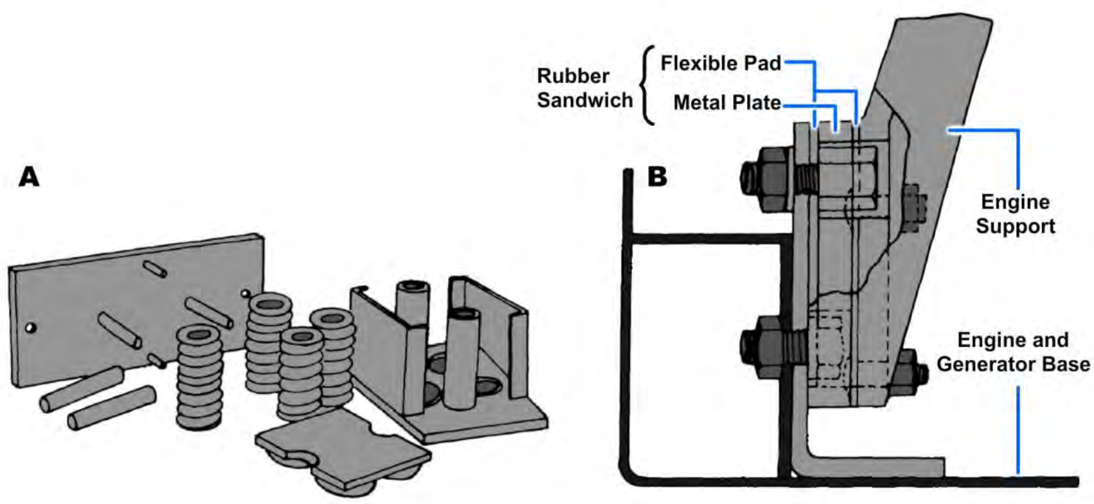


Figure 5-24 — Vibration isolators.

Shock Absorbers

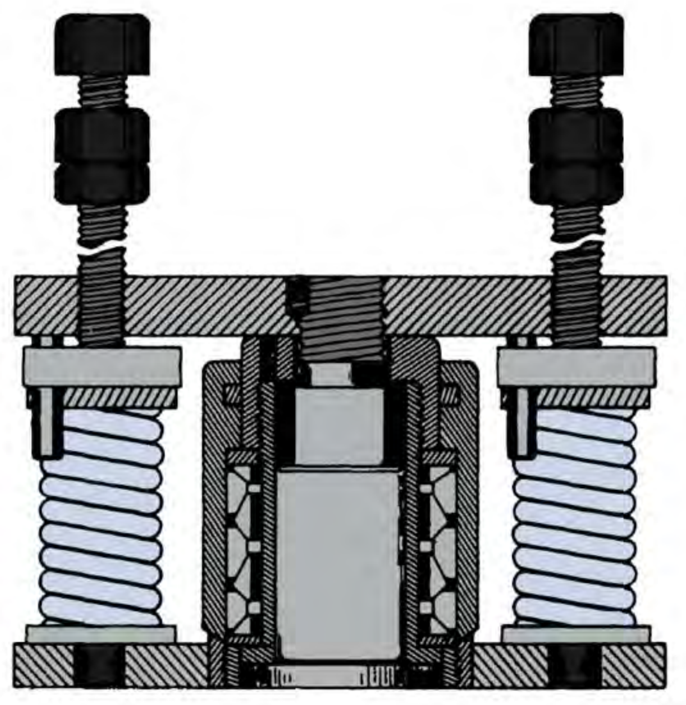


Figure 5-25 — Shock absorber.

Shock absorbers are used to absorb vibration forces that are greater than those originating in the engine. Such forces, or shock loads, may be induced by the detonation of depth charges, torpedoes, bombs, and other devices. The shock absorber operates on the same principle as the vibration isolator but provides additional support to protect the engine against severe shock loads. A type of shock absorber in use in the Navy is illustrated in *Figure 5-25*.

SUMMARY

An understanding of the function or purpose of each part of a diesel engine is fundamental to safe operation and effective engine maintenance. This chapter has provided a description of the principal stationary parts and how these parts function as a group to maintain the major moving parts of the engine in their proper relative positions. The stationary parts include items such as the subbase, block or frame, oil pan, bearings, end plates, and cylinder assemblies. Except for the cylinder assemblies and bearings, these parts, as a group, are sometimes referred to as the frame, which is the load-carrying part of the engine. Cylinder assemblies complete the structural framework of an engine. In addition to forming the combustion space, parts of a cylinder assembly serve as a mounting place for other engine parts that are essential to engine operation.

You should be familiar with the differences in design of these parts, as well as with the function of each part and how each part is related to the other parts of the engine. If your knowledge is weak in any of these areas, go back and review the information in this chapter before proceeding to chapter 6.

End of Chapter 5

Principal Stationary Parts of an Engine

Review Questions

5-1. When tubular objects are measured, which of the following dimensions is NOT as important?

A. Outside diameter (OD)
B. Inside diameter (ID)
C. Wall thickness
D. Total diameter (TD)

5-2. What is the standard color code for piping on fuel system pipes?

A. Green
B. Yellow
C. Dark gray
D. Yellow with black stripes

5-3. What is the general reason that copper-nickel alloy material has become widely used in the Navy for seawater systems piping?

A. Lighter and easy to move around
B. Not as expensive
C. Resistance to seawater corrosion
D. Easier to weld

5-4. What Naval Ships' Technical Manual (NSTM) chapter would you use as a reference for information about hoses and fittings?

A. Chapter 100
B. Chapter 210
C. Chapter 505
D. Chapter 660

5-5. In a modern internal-combustion engine, the load-carrying part of the engine is referred to as the?

A. Bedplate or base
B. Sump or oil pan
C. Cylinder block
D. Frame

5-6. In the majority of large engines, what component serves to support the cylinder block?

A. Sump
B. Base
C. Bedplate
D. Oil pan

5-7. Why do main diesel engines have oil galleries drilled into their blocks?

A. To direct lubricating oil to the crankshaft main bearing
B. To direct oil to the rocker arm assembly
C. To direct lubricating oil to the piston crowns
D. To direct lubricating oil to the camshaft

5-8. Where does the lubricating oil go after it leaves the sump on an engine with a dry sump?

A. Back to the engine
B. To the reservoir
C. To the lube oil purifier
D. To the stripping pump

5-9. What is the name of the bearing that supports the crankshaft in a diesel engine?

A. Thrust bearing
B. Connecting rod bearing
C. Main bearing
D. Supporting bearing

5-10. By what means is the water jacket formed in a wet-type cylinder liner that does NOT have integral cooling passages?

A. An integral cooling passage in the block
B. A liner and a separate jacket that is part of the block
C. Individual tubes that are inserted in the block
D. A liner an integral cooling passage and is part of the block

5-11. The spark plugs of a gasoline engine are always found in the cylinder head. In a diesel engine, what engine part almost invariably is located in the cylinder head or heads?

A. Fuel injecting valves
B. Air starting valves
C. Intake valves
D. Rocker arm assembly

5-12. What Naval Ship's Technical Manual (NSTM) chapter can you find information on jacket-water liners?

A. Chapter 200
B. Chapter 233
C. Chapter 505
D. Chapter 660

5-13. Compressibility is a common property of all gaskets. Which of the following materials can be used in the manufacturing of gaskets?

A. Plywood
B. Tin
C. Copper
D. Aluminum

5-14. What device is the supporting and connecting pedestal between an engine and the ship's structure?

A. Engine base
B. Subbase
C. Chock
D. Stub

5-15. What Naval Ship's Technical Manual (NSTM) chapter would you find information pertaining to gaskets?

A. Chapter 078
B. Chapter 100
C. Chapter 233
D. Chapter 660

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CHAPTER 6

PRINCIPAL MOVING AND RELATED COMPONENTS

Many of the principal parts that are within the main structure of an engine are moving parts. These moving parts convert the thermal energy released by combustion in the cylinder to mechanical energy, which is then available for useful work at the crankshaft. In this chapter we will discuss the moving and related parts that seal and compress gases in the cylinder and transmit the power developed in the cylinder to the crankshaft. After reading the information in this chapter, you should be able to recognize and describe the basic types, functions, and characteristics of valves, valve actuating mechanisms, piston and rod assemblies, crankshafts, flywheels, and jacking gears.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the purpose of valve-actuating mechanisms.
2. List the principal moving components of a diesel engine.
3. Describe the function of the crankshaft of an engine.
4. List some of the different types of bearings.
5. Explain the purpose of a flywheel.
6. Explain the function of the jacking gear.

VALVE-ACTUATING MECHANISMS

Valve mechanisms may vary considerably in construction and design, even though the function remains the same. The basic types of valve mechanisms are described briefly in *Fireman*, NAVEDTRA 14104.

Actuating mechanism, as used in this chapter, is that combination of parts that receives power from the drive mechanism and transmits the power to the engine valves. In order for the intake and exhaust valves, fuel injection, and air start to operate, there must be a change in the type of motion. The rotary motion of the camshaft must be changed to a reciprocating motion. The group of parts that, by changing the type of motion, causes the valves of an engine to operate is generally referred to as the valve-actuating mechanism. A valve-actuating mechanism may include the camshaft, cam followers, pushrods, rocker arms, and valve springs. In some engines, the camshaft is so located that pushrods are not needed. In such engines, the cam follower is a part of a rocker arm.

Valves

The intake and exhaust valves used in internal combustion engines are of the poppet type.

Poppet valves have heads with cone-shaped or beveled edges and beveled seats, which give the valves a self-centering action, as shown in *Figures 6-1 and 6-2.*

Exhaust valves are usually made of silicon chromium steel or steel alloys. Usually, there is a high content of nickel and chromium included in the steel or alloy so that the valves can resist corrosion caused by high-temperature gases. A hard alloy, such as Stellite, is often welded to the seating surface of the valve face and to the tip of the valve stem. The hard alloy increases the wearing qualities of the surfaces, which make contact when the valve closes. Low-alloy steels are generally used for intake valves because these valves are not exposed to the corrosive action of the hot exhaust gases. Consequently, intake valves are capable of longer periods of trouble-free operation.

In some exhaust valves, sodium is used as an agent for cooling the valves. Sodium-filled poppet valves are provided with a chamber that is formed by the hollow stem that extends well up into the valve head. At operating temperatures, the sodium becomes a liquid and splashes up and down inside the hollow valve stem. The sodium is an effective agent that serves to transfer the heat from the hot exhaust valve head through the stem and valve guides and to the engine cooling system. Although sodium-filled exhaust valves are effective, they are not commonly used.

Valve seat inserts (*Figure 6-1*) are provided in most diesel engine cylinder heads so that valve seat life is extended. Valve seat inserts also have the advantage of being replaceable. Several different types of materials are used in the manufacture of valve seat inserts. Intake valve seats are manufactured from special alloys of cast iron. Exhaust valve seats are made from stellite and hardened chrome vanadium steel. Valve seat inserts are installed with an interference fit.

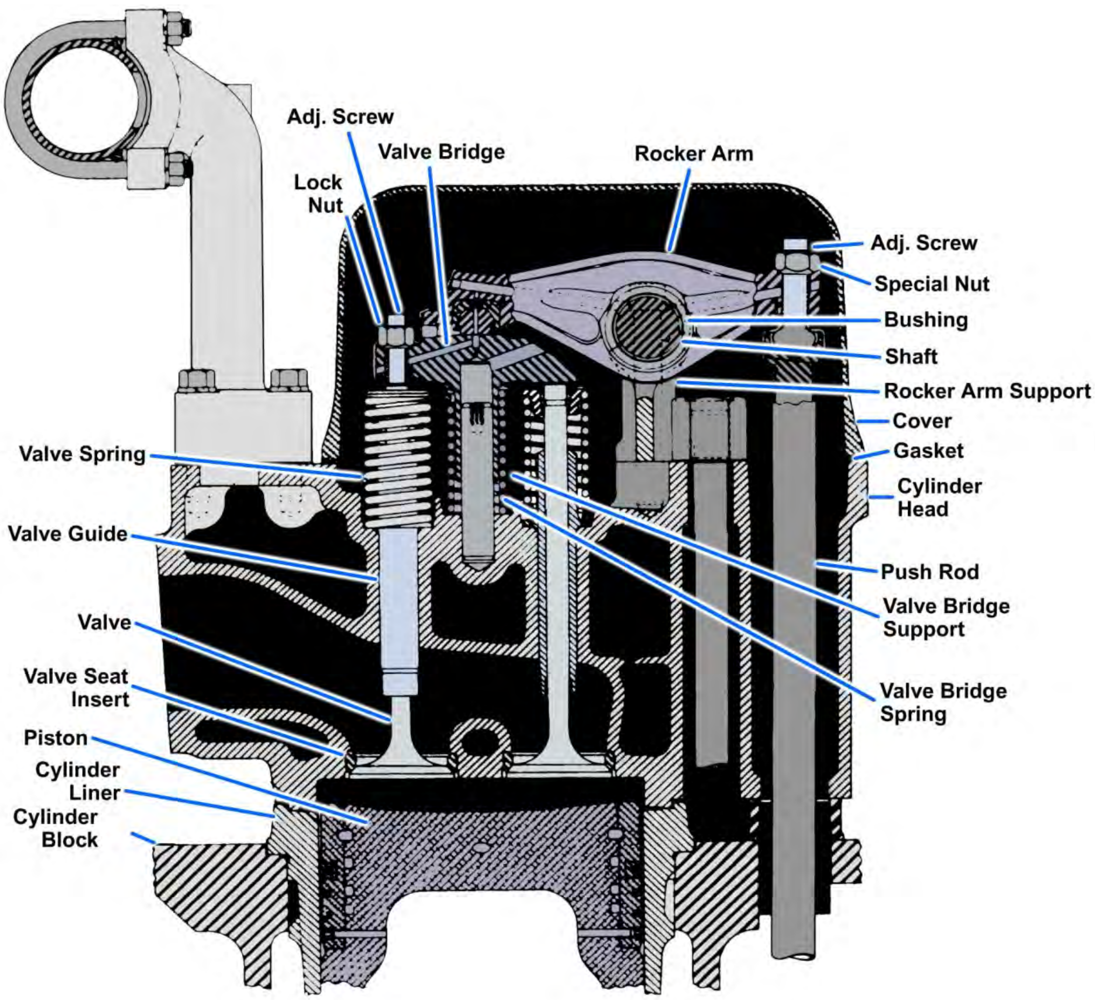


Figure 6-1 — Valve operating mechanism.

Replaceable valve guides (*Figure 6-1*) are provided for most diesel engines. Replaceable valve guides are made of a cast iron alloy that has a superior wearability and is more corrosion resistant than the alloy that is used in the cylinder head. Replaceable valve guides not only provide a guide and bearing for each valve stem but also aid in conducting heat from each valve stem to the water jacket that surrounds the guide.

Valve Springs

Valve springs are mechanisms that serve to close the valves. Valve springs are made of highly tempered round steel wire that is wound in a spiral coil. Only a small percentage of the spring force is required to keep the valve tight on the valve seat of the head. The majority of the spring force is used to keep the pushrod (*Figure 6-1*) or the rocker arm (*Figure 6-2*) in contact with the cam while the valve is being opened and closed. This force of the valve spring prevents the bouncing or fluttering of the valve that would otherwise occur from the rapid motion of the opening and closing of the valve at high speeds. So the spring can have sufficient force, it is always compressed when it is installed. (It is further compressed, of course, whenever the valve is opened.)

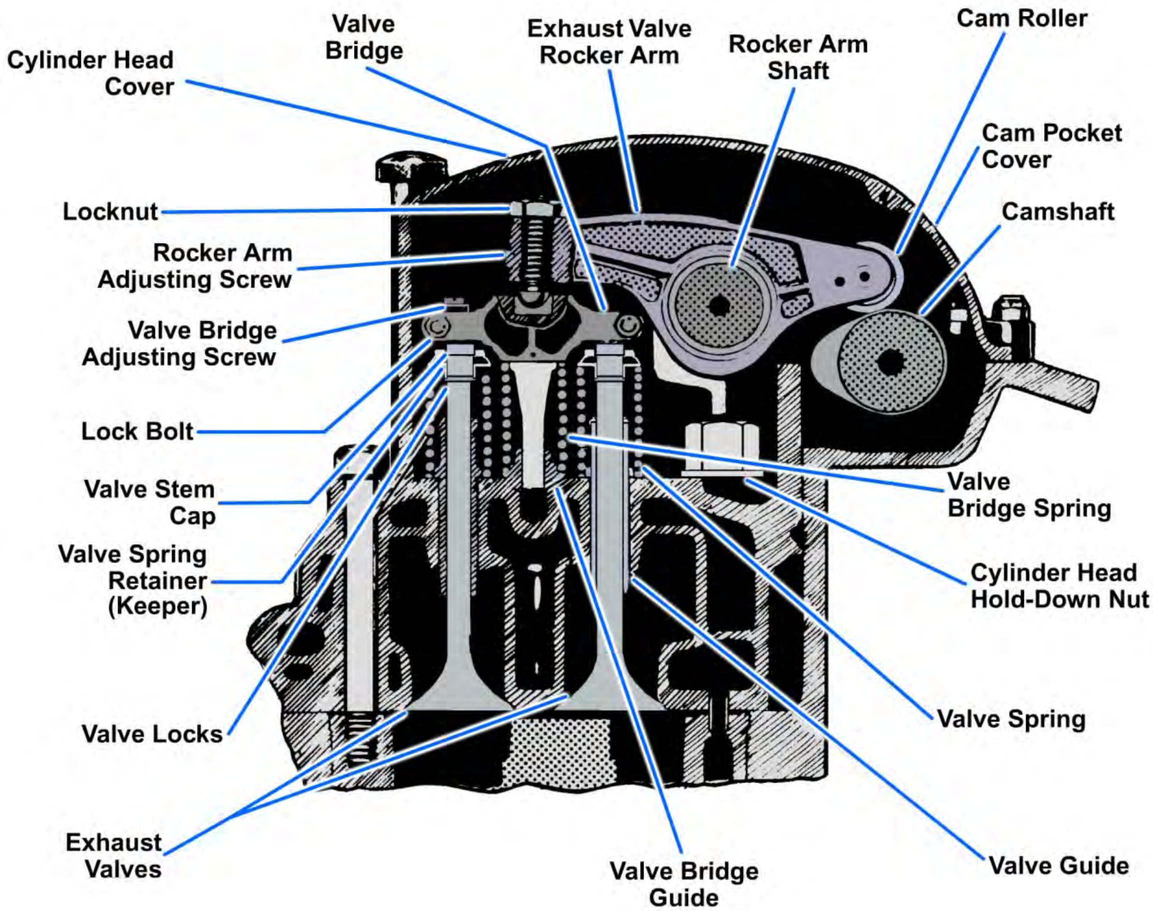


Figure 6-2 — Valve operating mechanism with valve bridge.

Valve Spring Retainers

Valve springs are mounted between supports. These supports, commonly referred to as spring seats, are located at the ends of the spring. The lower spring seat may be simply a recess in the top of the cylinder head, or a steel washer that rests on top of the cylinder head, and is shaped to fit the bottom coil of the spring. The upper spring seat, called the spring retainer, is a steel washer that is shaped to fit the top of the spring. The upper spring seat is attached to the top of the valve stem by removable fastenings commonly known as valve keepers.

Valve Keepers

A widely used type of valve spring retainer is provided with a conical recess in the upper seat. The valve stem is locked in the recess by means of a conical split collar, called a lock or keeper. This collar fits around the stem and into one or more grooves turned in the valve stems (*Figure 6-2*).

Valve Rotators

On some engines that are subjected to long periods of idle or light loads, valve rotators may be used to keep the valves from sticking due to distribution of wear on the valve stem and valve guide.

Without rotation, the combustion deposits that form on the valve stem, face, and seat would be cleaned off on one side only. Standard valve spring seats allow rotation but do not assure it. With controlled rotation, carbon deposits are cleaned off all around the valve stem, face, and seat. Valve rotators may be installed below or above the valve spring according to design requirements.

Camshafts

A camshaft is a shaft with eccentric projections called cams. The camshaft of an engine is designed to control the operation of the valves and fuel injection pump usually through various intermediate parts. On some engines, a balance shaft is used to counterbalance the rotation of the weighted camshaft and to stabilize the oscillatory impulses developed within the engine. See *Figure 6-3* for the location of the balance shaft and weight assemblies.

The camshaft may be constructed in several ways. It can be forged in one piece (*Figure 6-3*) in which the cams themselves are integral to the shaft. (This is the most common design in small to medium engines.) A camshaft of a large engine may consist of a shaft with separate forged steel or cast iron cams keyed and shrunk on the. Another construction used on larger engines is a camshaft that is made from sections, which are bolted together. Some engines have two camshafts and others have only one, depending on the design of the engine.

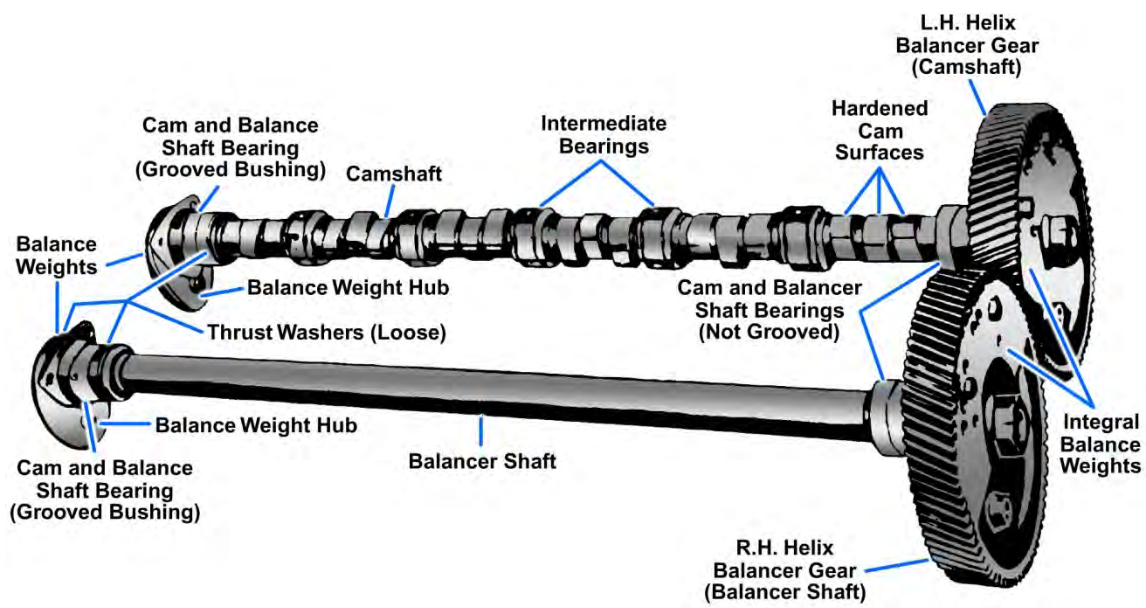


Figure 6-3 — Cam and balancer shaft assemblies.

To reduce wear and to withstand repeated shock action, camshafts are made of low-carbon alloy steel with the cam and journal surfaces carburized (case-hardened) before the final grinding is done.

The cams are arranged on the shaft so that the proper firing order of the cylinders being served can take place. If one cylinder is properly timed, the remaining cylinders are automatically in time. All cylinders will be affected if there is a change in timing. The shape of the cam determines the point of opening and closing; the speed of opening and closing; and the amount of valve lift.

The camshaft in a 4-stroke cycle diesel engine carries the cams for actuating the intake and exhaust valves. In addition, the camshaft may carry cams for fuel injection equipment or air starting valves. In a 2-stroke cycle diesel engine there is no requirement for an intake cam due to the use of intake ports.

The location of the camshaft differs in various engines. The camshaft may be located low (near the crankshaft) and may use long pushrods (*Figure 6-1*), or the camshaft may be located at the cylinder head level without pushrods *(Figure 6-2*). Variations of camshaft location are shown in *Figure 6-4, View A through C.*

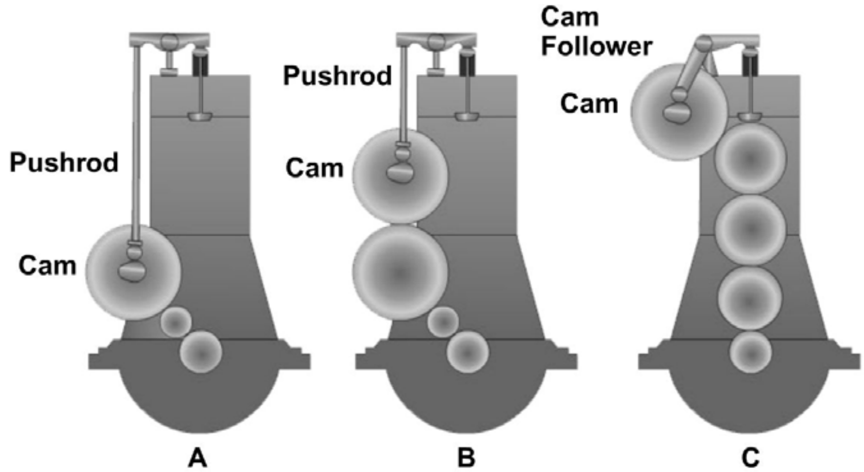


Figure 6-4 — Various camshaft locations.

Cam Followers and Lash Adjusters

In the valve-actuating mechanism, cam followers change the rotary motion of the camshaft to reciprocating motion. This action opens the valves. Cam followers ride the flat of the cam and are raised as the cam rotates by the high side of the cam and lowered by tension from the valve in internal-combustion engines as shown in *Figure 6-5.*

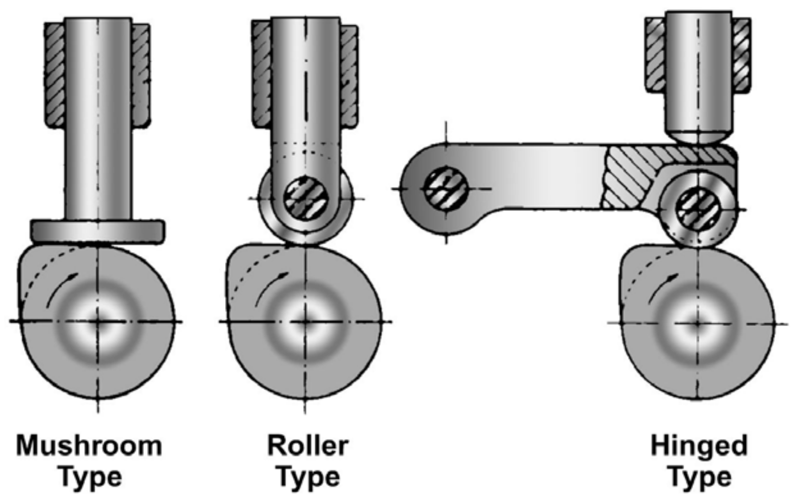


Figure 6-5 — Cam followers.

Hydraulic valve lifters (lash adjusters) are used on some engines to avoid the necessity of a clearance needed in the valve gear to allow for expansion resulting from temperature changes. Hydraulic valve lifters also eliminate the need for manual adjustment to take care of the wear at various points of the valve gear. They may be installed on the rocker arms, valve bridge, or cam follower. *Figure 6-6* shows a larger sectional view of the hydraulic lash adjuster shown in *Figure 6-7.*

Hydraulic lash adjusters may vary in design but generally consist of such basic parts as a cylinder, a piston or plunger, a ball check valve, and a spring. As precision parts, hydraulic valve lifters or adjusters require special care in handling and must be kept exceptionally clean.

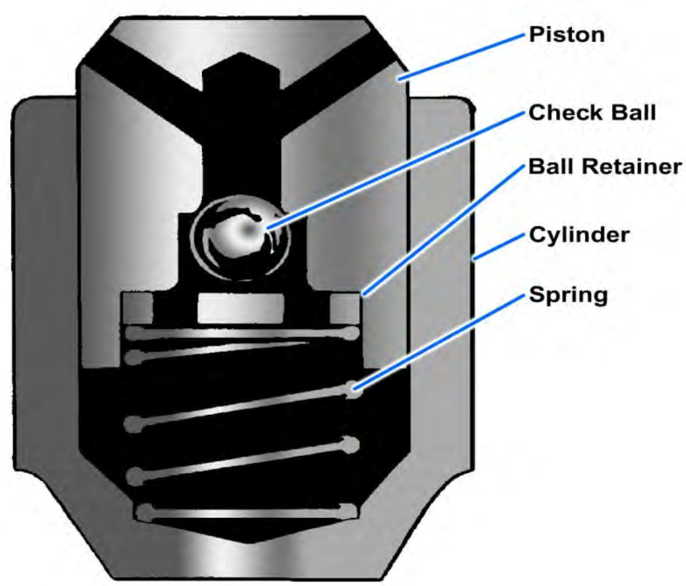


Figure 6-6 — Hydraulic lash adjuster.

Rocker Arms and Pushrods

Rocker arms (levers) are part of the valve-actuating mechanism. A rocker arm is designed to pivot on a pivot pin or shaft that is secured to a bracket. The bracket is mounted on the cylinder head. One end of a rocker arm is in contact with the top of the valve stem, and the other end is actuated by the camshaft.

In some installations where the camshaft is located near the cylinder head, the rocker arm may be actuated from the cam by the use of cam followers. *Figure 6-7* illustrates a design of this type in which a cylinder head is fitted with three rocker arms or levers. *Figure 6-7* is a cutaway view with one rocker arm shown. The two outer arms operate the exhaust valves, and the inner arm operates the fuel injector. Since there are four exhaust valves per cylinder, each exhaust rocker arm must operate a pair of valves through a valve bridge. The valve bridge enables the rocker arm to operate two valves simultaneously. The valve bridge in this engine is made of forged steel and has a hardened ball socket into which the ball end of the rocker arm adjusting screw fits. The valve bridge has two arms, each of which fits over an exhaust valve. The valve bridge spring keeps valve bridge tension off the valve stems until the bridge is actuated by the rocker arm. When the valve end of the rocker arm is forced down by the cam action, the valve bridge moves down, compressing the valve springs and opening the valves. By the time the action of the cam lobe has ceased, the valve springs will have closed the valves. The valve operating mechanism shown in *Figure 6-7* is representative of those in which the location of the camshaft eliminates the need for pushrods. (Note that the lobes of the cam come in direct contact with the rocker arm cam rollers.)

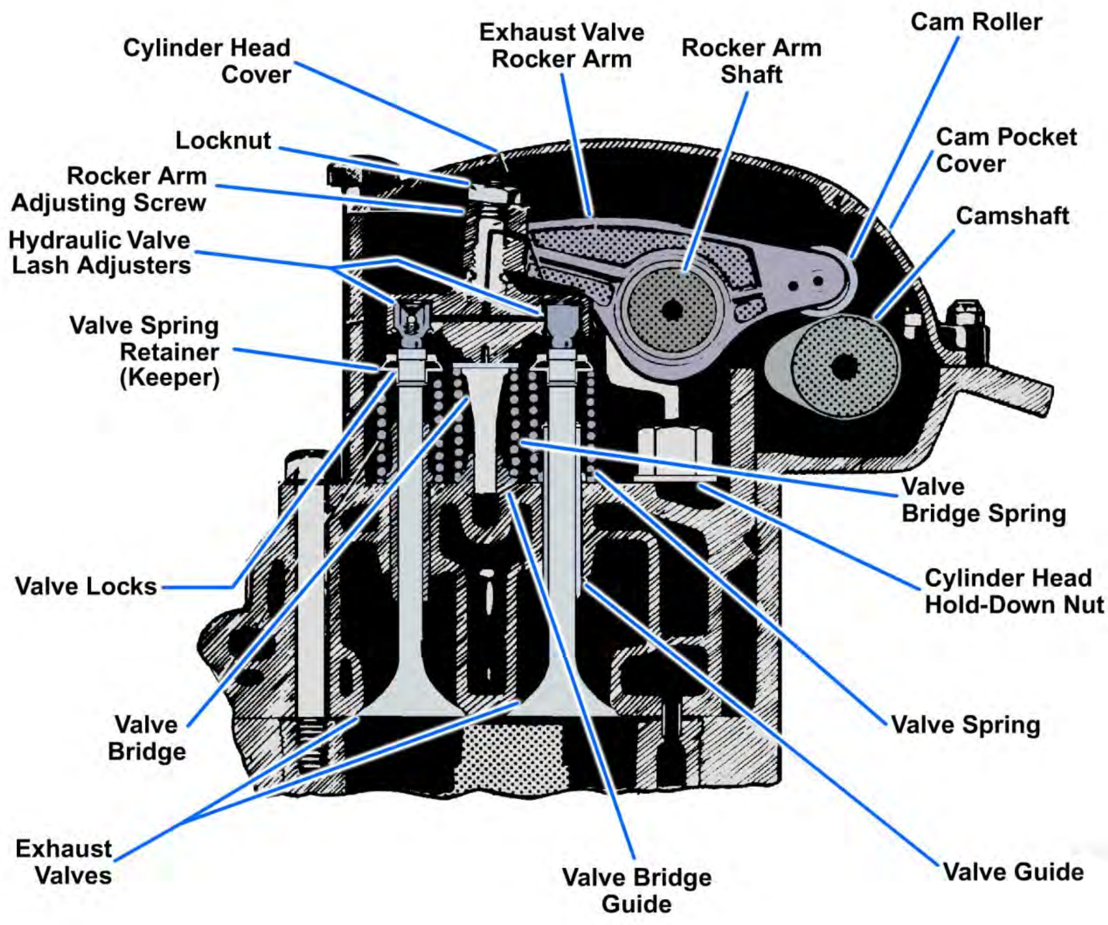


Figure 6-7 — A typical valve gear.

In installations where the camshaft is located below the cylinder head, the rocker arms are actuated by pushrods (*Figure 6-8*) The lifters (cam followers) have rollers which are forced by the valve springs to follow the profiles of the cams. The pushrods transmit the motion from the roller type of lifter for intake and exhaust valve operation and are activated by their respective intake and exhaust lobes of the camshaft. The intake and exhaust valves in *Figure 6-8* are operated by mechanisms similar to those represented in *Figure 6-7* with two exceptions. The unit in *Figure 6-8* has no design requirement for an injector rocker arm because of the type of fuel system used. Also, the unit in *Figure 6-8* is a 4-stroke cycle unit and requires both an intake and exhaust valve rocker arm.

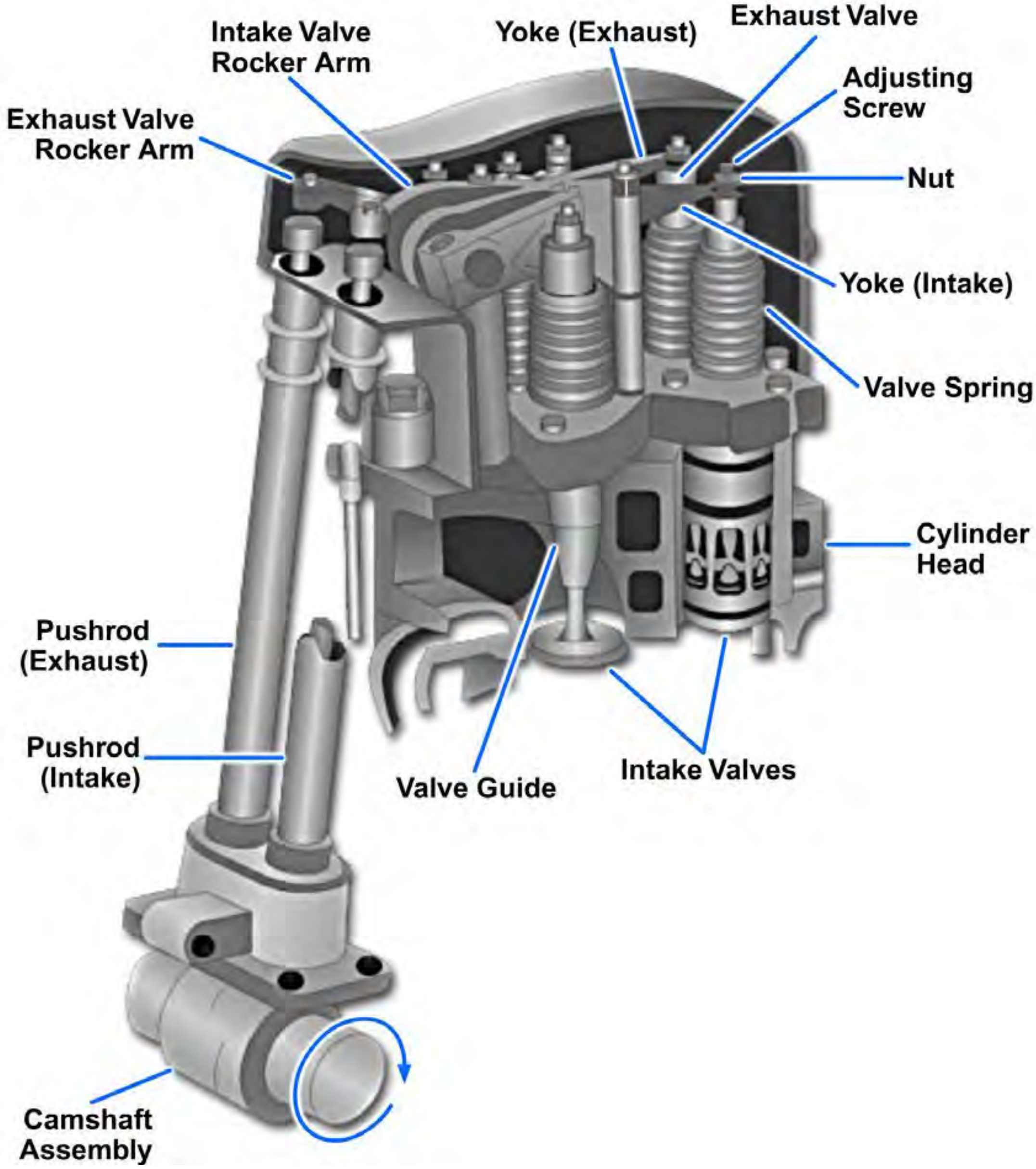


Figure 6-8 — Valve rocker arm operation.

PRINCIPAL MOVING COMPONENTS

In this chapter, the principal moving component refers to the parts that convert the thermal energy released by combustion in the cylinder to mechanical energy, and then becomes available for useful work. The principal moving parts of an engine consist of the piston and connecting rod assemblies, crankshaft, bearings, and flywheel. Piston and connecting rod assemblies of an engine will include the piston, piston rings, piston pin, and connecting rod. These units and their functions in engine operation are discussed separately in the following sections.

Pistons

As one of the major moving parts in the power-transmitting assembly, the piston must be so designed that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep inertial loads on related parts to a minimum. The piston aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits some of the heat through the piston rings to the cylinder wall.

Pistons have been constructed of a variety of metals—cast iron, nickel-coated cast iron, steel alloy, and aluminum alloy. Pistons of cast iron and aluminum are most commonly used at the present time. Cast iron gives longer service with little wear; it can be fitted to closer clearances because it expands less with high temperatures and it distorts less than aluminum. Lighter weight and higher conductivity are the principal advantages of aluminum pistons.

Cast iron is generally associated with the pistons of slow-speed engines, but it is also used for the pistons of some high-speed engines. In these pistons, the piston walls are of very thin construction, requiring additional cooling. Pistons perform a number of functions. A piston, in addition to transmitting the force of combustion to the connecting rod and conducting the heat of combustion to the cylinder wall, may serve as a valve in opening and closing the ports of a 2-stroke cycle engine.

Trunk-Type Pistons

There are two distinct types of pistons: the trunk type and the crosshead type. Variations in the design of trunk-type pistons can be seen in *Figures 6-9* and *6-10*.

The crown, or head, of a piston acts as the moving surface that changes the volume of the content of the cylinder (compression), removes gases from the cylinder (exhaust), and transmits the energy of combustion (power). Generally, the crown end of a piston is slightly smaller in diameter than the skirt end. The resulting slight taper allows for

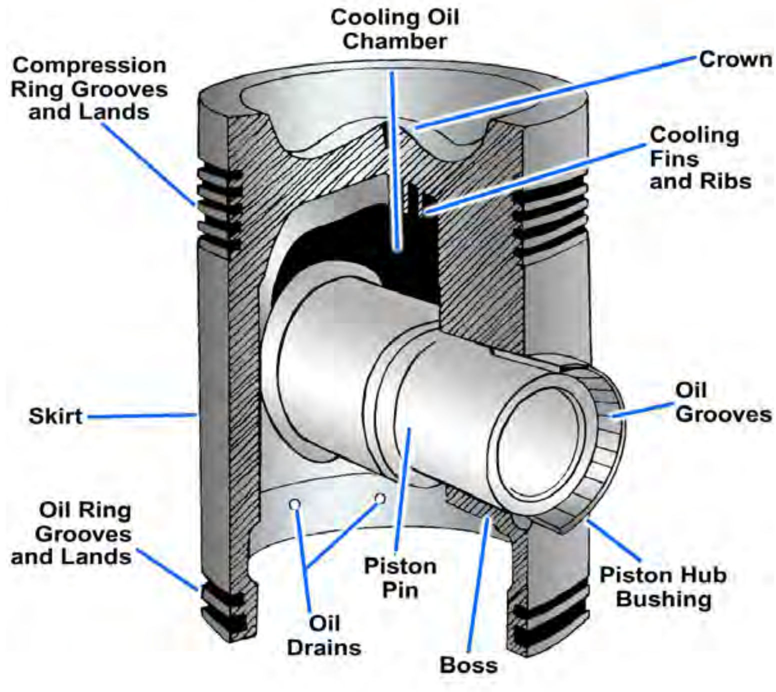


Figure 6-9 — Piston nomenclature for a trunk-type piston.

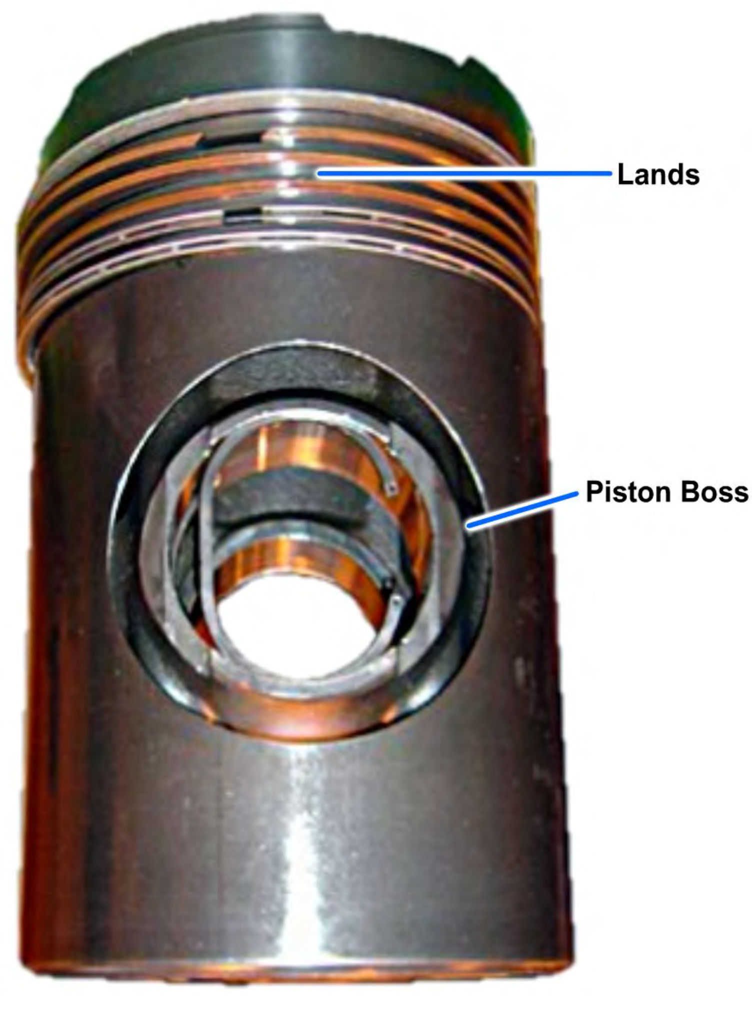


Figure 6-10 — Piston (Colt-Pielstick PC 2.5).

expansion of the metal at the combustion end. Even though slight, the taper is sufficient so that at normal operating temperatures, the diameter of the piston is the same throughout.

Manufacturers have produced a variety of crown designs—truncated, cone, recessed, dome or convex, concave or cup, and flat. Piston crowns of concave design are common in marine engines used by the Navy; however, other types may be encountered. An advantage of the concave shape is that it assists in creating air turbulence, which mixes the fuel with air during the last part of compression in diesel engines.

Some concave types of pistons have recesses in the crown to allow room for the parts that protrude into the combustion space. Examples of such parts are the exhaust and intake valves, the air starting valve, and the injection nozzle. In some 2-stroke cycle engines, piston crowns are shaped with irregular surfaces which deflect and direct the flow of gases.

The skirt of a trunk-type piston receives the side thrust created by the movement of the crank and connecting rod. In turn, the piston transmits the thrust to the cylinder wall. In addition to receiving thrust, the skirt aids in keeping the piston in proper alignment within the cylinder. Some pistons are plated with a protective coating of tin which permits close fitting, reduces scuffings, and prolongs piston life. Still other pistons may be given a phosphate treatment to aid skirt lubrication. This process etches the surface and provides a nonmetallic, oil-absorbent, antifriction coating that promotes rapid break-in and reduces subsequent wear.

Most trunk-type pistons are of one-piece construction. Some trunk pistons are made of two parts and two metals; the trunk or skirt is made of cast iron or an aluminum alloy, and the crown or head is made of steel. In some pistons of this type of construction, the crown is fitted to the trunk with a ground joint, while in others the parts are welded together. Without grooves and lands, the piston rings cannot be properly spaced or held in position. The number of grooves and lands on a piston will vary considerably, depending on such factors as the size and the type of the piston, See *Figures 6-9* and *6-10.*

Some pistons have oil drains (small holes) in the bottom of some of the grooves (*Figure 6-9*); some pistons have oil drains in the skirt of the piston or in the land. These holes serve as oil returns, permitting lubricating oil from the cylinder wall to pass through the piston into the crankcase.

Generally, the bosses (hubs) of a piston are heavily reinforced openings in the piston skirt, (*Figure 6-10*). Some bosses are a part of an insert which is secured to the inside of the piston. The principal function of the bosses is to serve as mounting places for the bushings or bearings which support the piston pin. The bosses provide a means of attaching the connecting rod to the piston. Generally, the diameter of the piston at the bosses is slightly less than the diameter of the rest of the piston. This difference serves to compensate for the expansion of the extra metal in the bosses.

Because of the intense heat generated in the combustion chamber, adequate cooling must be provided. The heat transmitted through the rings (approximately 30 percent of the heat absorbed by the piston) to the cylinder wall is not sufficient in many engines to keep the unit cooled within operating limits. Most pistons have fins or ribs and struts as internal parts (*Figure 6-9*). The additional surfaces of these parts help to dissipate heat; much of the heat is carried away by oil which may be pump-forced, sprayed, splashed, or thrown by centrifugal force onto the underside of the piston assembly. A different approach to cooling the piston head is with the use of drilled passages from the connecting rod through the piston pin to the piston bosses. Drilled passages in the piston direct the oil to cavities in the piston crown. Oil discharged from these cavities is controlled so a sizeable amount is retained at all times to cool the crown by “cocktail shaker” action as the piston moves up and down in the cylinder. A cutaway view of this type of design is shown in *Figure 6-17*. Oil is the principal means of cooling for most piston assemblies. Intake air is also used in the cooling of hot engine parts. In order to exhaust or scavenge a cylinder of burned gases and cool the engine parts, the intake and exhaust valves or ports are so timed that both are open for a short time at the end of the exhaust stroke. This action allows the intake air to enter the cylinder, clean out the hot gases, and, at the same time, cool the parts.

Crosshead Pistons

A type of crosshead piston is currently being used in some engines (*Figure 6-11*). The crosshead piston is a two-piece unit with a crown that can withstand the high heat and pressure of a turbocharged engine and a skirt specifically designed to absorb side thrust.

The crown and skirt are held together by the piston pin. The downward load on the crown pushes directly on the pin through a large slipper bearing (bushing). The separate skirt has less thermal distortion than the crown piece and is free of downward thrust loads. It specifically guides the piston in the cylinder, takes up side thrust, and carries the oil scraper rings. The crown carries the compression rings. Since the crown is separate, it takes only a slight amount of side thrust and is not forced to slide sideways under the compression rings when they are pressed hard against the bottoms of their grooves by combustion gas pressure. Lubricating oil is fed upward by pressure to cool the piston pins and piston crown.

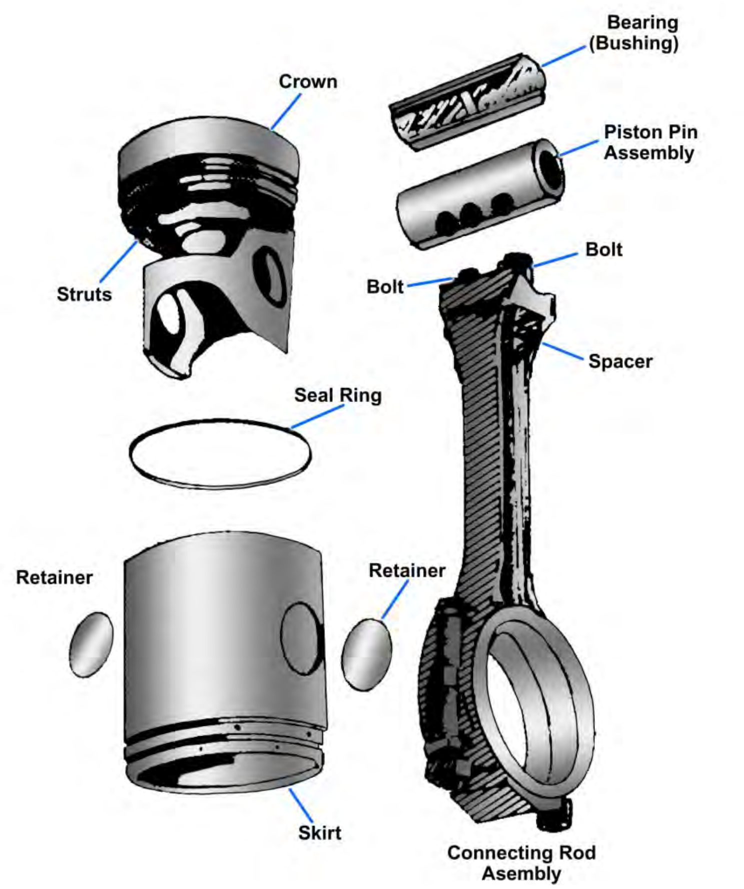


Figure 6-11 —Typical crosshead piston and connecting rod components.

Piston Rings

Piston rings are particularly vital to engine operation in that they must effectively perform three functions: seal the cylinder, distribute and control lubricating oil on the cylinder wall, and transfer heat from the piston to the cylinder wall. All rings on a piston perform the latter function, but two general types of rings—compression and oil—are required to perform the first two functions.

The number of rings and their location will also vary considerably with the type and size of the piston. In *Figures 6-9, 6-10, and 6-12* the compression rings are located toward the crown or combustion end of the piston. The ring closest to the crown is sometimes referred to as the firing ring. Two different examples of piston ring location are shown in *Figures 6-10 and 6-12*. In *Figure 6-10*, both compression and oil rings are located toward the crown above the pin bosses. In *Figure 6-12*, the compression rings are located above the bosses and the oil rings are located below the bosses.

The terms above and below adequately identify ring location when the crown of the piston is at the top, as it is in the in-line and V-type engines. These terms may lead to confusion, however, when reference is made to ring location on the upper pistons of opposed-piston engines. Piston ring location can be more accurately identified by reference to the crown or combustion end and to the skirt or crankshaft end of the piston. There are many variations in the design of compression and oil rings. Some common variations are illustrated in *Figure 6-13, frames 1-5.*

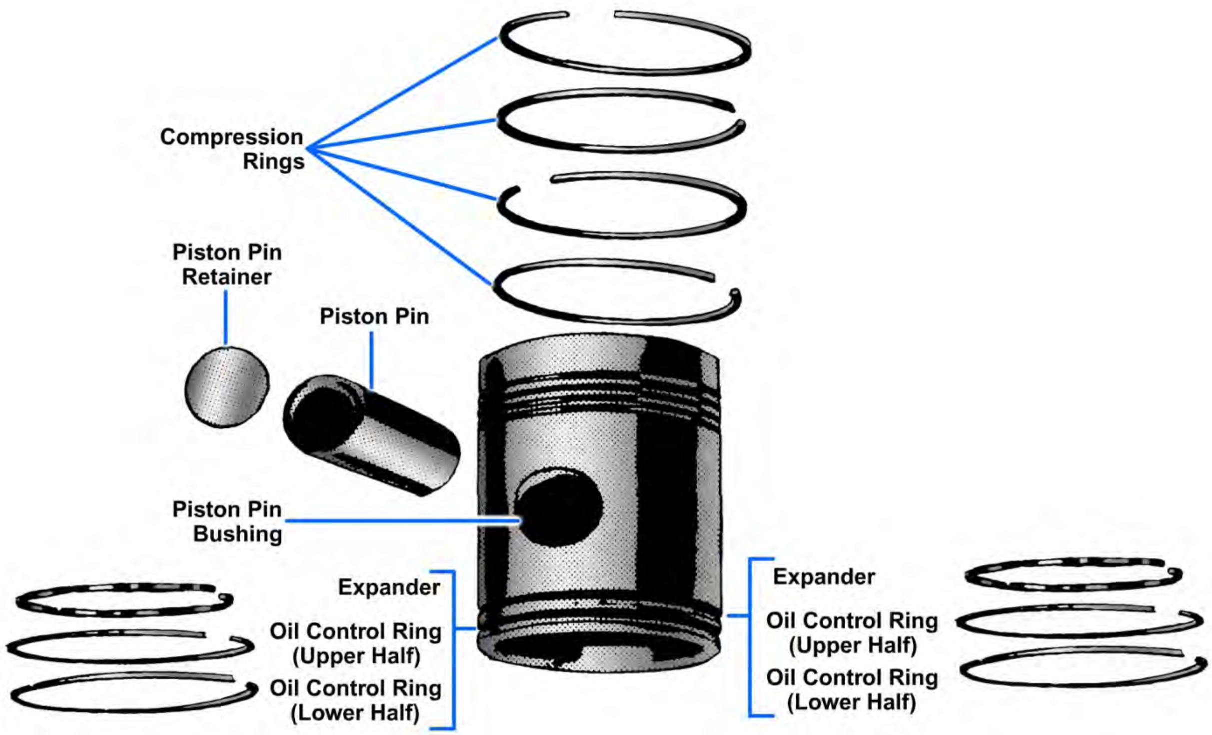


Figure 6-12 — Typical piston, piston rings, pin, and relative location of parts.

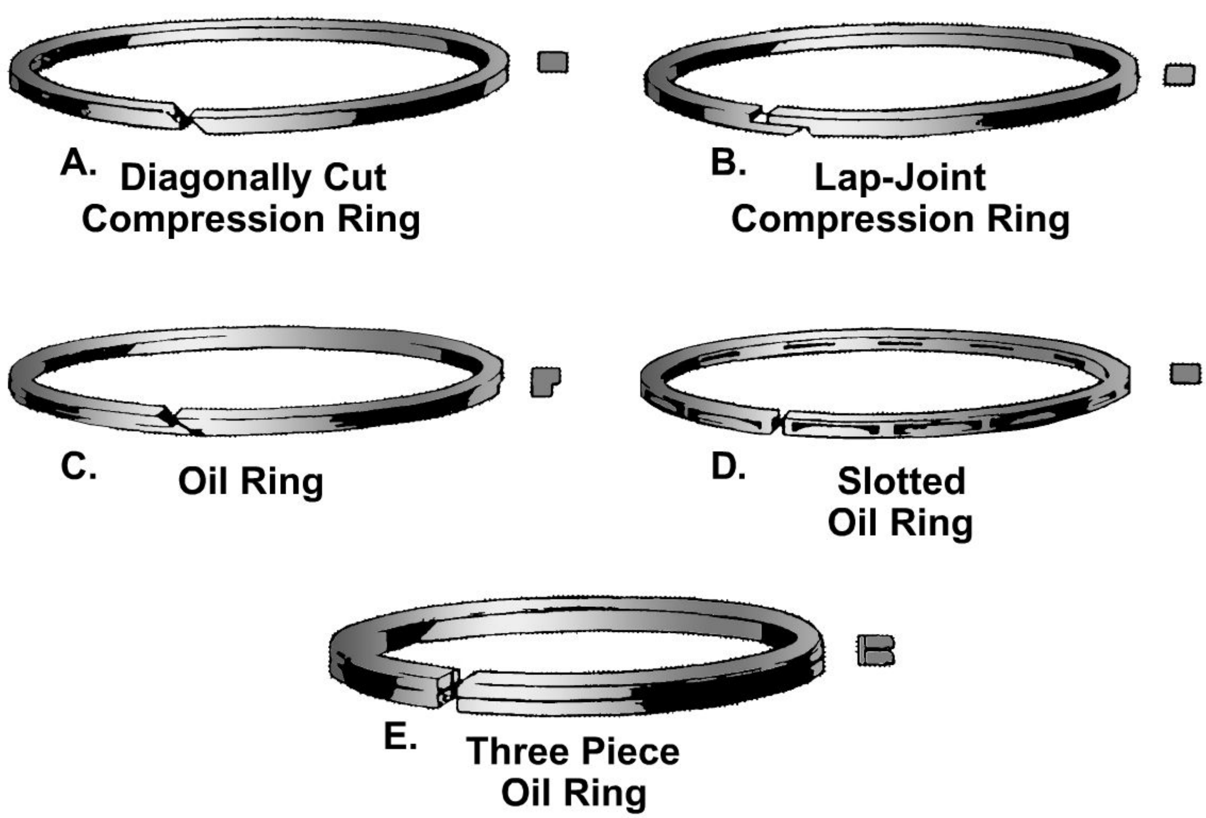


Figure 6-13 — Types of piston rings.

Compression Rings

The principal function of compression rings is to seal the cylinder and combustion space so that the gases within the space cannot escape until they have performed their function. Some oil is carried with the compression rings as they travel up and down the cylinder for lubrication.

Most compression rings are made of gray cast iron. Some types of compression rings, however, have special facings, such as bronze (inserted in a slot cut in the circumference of the ring) or a specially treated surface. Rings with the bronze inserts are sometimes called gold seal rings, while those with special facings are referred to as bimetal rings. The bimetal ring is composed of two layers of metal bonded together, the inner layer being steel and the outer layer being cast iron.

Compression rings come with a variety of cross sections; however, the rectangular cross section is the most common. Since piston rings contribute as much as any other one thing toward maintaining pressure in a cylinder, they must possess sufficient elasticity to press uniformly against the cylinder walls. The diameter of the ring, before installation, is slightly larger than the cylinder bore. Because of the joint, the ring can be compressed to enter the cylinder. The tension that is created when the ring is compressed and placed in a cylinder causes the ring to expand and produce pressure against the cylinder wall. The pressure exerted by rings closest to the combustion space is increased by the action of the confined gases during compression and combustion. The gases enter behind the top ring, through the clearance between the ring and groove, and force the ring out against the cylinder and down against the bottom of the groove. The gas pressure on the second ring and each successive compression ring is progressively lessened since the gas that reaches these rings is limited to that passing through the gap of each preceding ring. One can look at the compression rings and tell whether they have been functioning properly. If a ring has been working properly, the face (surface bearing against the cylinder wall) and the bottom of the ring will be bright and shiny because of contact with the cylinder wall and the groove. The top and back (inside surface) of the ring will be black, since they are exposed to the hot combustion gases. Black areas on sealing surfaces indicate that hot gases have been escaping.

Under normal operating conditions, with engine parts functioning properly, there will be very little leakage of gas because of the excellent sealing of the piston rings. The oil that prevents metal-to-metal contact between the rings and cylinder wall also helps, to a degree, in making the seal. When a proper seal is established, the only point at which gas can leak is through the piston ring gap. The gap of a piston ring is so small, compared to the total circumference of the ring, that the amount of leakage is negligible when rings are functioning properly.

Oil Rings

Although oil rings come in a large variety of designs, they must all do two things: (1) distribute enough oil to the cylinder wall to prevent metal-to-metal contact, and (2) control the amount of oil distributed.

Without an adequate oil film between the rings and the cylinder, undue friction occurs, resulting in excessive wear of the rings and the cylinder wall. On the other hand, too much oil is as undesirable as not enough oil. If too much oil is distributed by the rings, the oil may reach the combustion space and burn, wasting oil and causing smoky exhaust and excessive carbon deposits in the cylinder. Such carbon deposits may cause the rings to stick in their grooves. Sticking rings lead to a poor gas seal. Thus, oil rings provide an important function in proper control and distribution of the lubricating oil. Some types of oil rings are shown in *Figure 6-13, frames 3, 4, and 5.*

Most oil control rings use some type of expander to force them against the cylinder wall. This aids in wiping the excess oil from the cylinder wall. For example, a General Motors 6-71 piston has two sets of oil control rings placed on the skirt below the piston pin. Both sets are identical; each consisting of three pieces (two rings and an expander) (*Figure 6-12*). The ring illustrated in *Figure 6-13, frame 5,* is also a three-piece oil ring. In rings of this type, the two “scraping” pieces have very narrow faces bearing on the cylinder wall, which permit the ring assembly to conform rapidly to the shape of the cylinder wall. Since the ring tension is concentrated on a small area, the rings will cut through the oil film easily and remove the excess oil. The bevel on the upper edge of each ring face causes the ring to ride over the oil film as the piston moves toward top dead center (TDC), but as the piston moves downward for intake and power, the sharp, hook-like lower edge of each ring scrapes or wipes the oil from the cylinder wall.

Another example of differences in terminology and location is found in the Fairbanks-Morse (FM) 38D8 1/8. A piston in this type of engine has three oil rings all located on the skirt end. The two nearest the crankshaft end of the piston are called oil drain rings, while the ring nearest the pin bosses is referred to as the scraper. The drain rings are slotted to permit oil to pass through the ring and to continue on through the holes drilled in the ring grooves. *Figure 6-13, frame 4* shows one type of slotted oil ring. Additional information concerning pistons and piston rings can be found in Naval Ships' Technical Manual, Chapter 233.

Piston Pins and Piston Bearings

In trunk-type piston assemblies, the only connection between the piston and the connecting rod is the pin (sometimes referred to as the wrist pin) and its bearings. These parts must be of especially strong construction because the power developed in the cylinder is transmitted from the piston through the pin to the connecting rod. The pin is the pivot point where the straight-line, or reciprocating, motion of the piston changes to the reciprocating and rotating motion of the connecting rod. Thus, the pin is subjected to two principal forces—the forces created by combustion and the side thrust created by the change in direction of motion. Before discussing the pin further, let us consider the side thrust which occurs in a single-acting engine equipped with trunk-type pistons (*Figure 6-14, frames 1 and 2*).

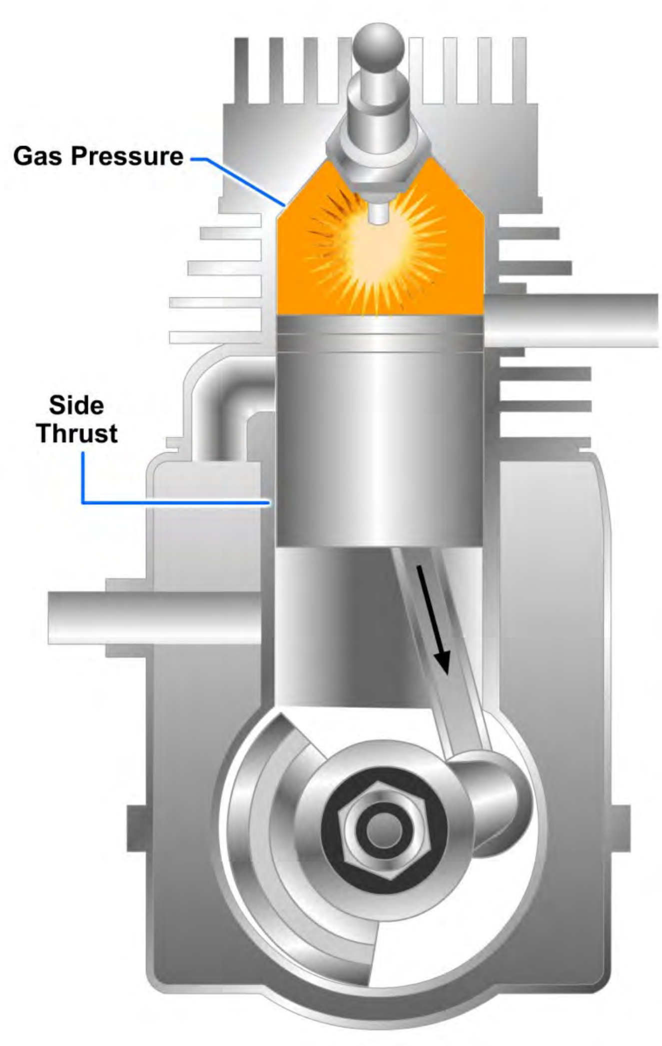


Figure 6-14 — Trunk-type piston in a single-action engine showing side trust.

Side thrust is exerted at all points during a stroke of a trunk-type piston, except at TDC and bottom dead center (BDC). The side thrust is absorbed by the cylinder wall. Thrust occurs first on one side of the cylinder and then on the other, depending on the position of the piston and the connecting rod and the direction of rotation of the crankshaft. In *Figure 6-14, frame 1,* gas pressure is forcing the piston downward (power). Since the crankshaft is rotating clockwise, the force of combustion and the resistance of the driven parts tend to push the piston to the left. The resulting side thrust is exerted on the cylinder wall. If the crankshaft were rotating counterclockwise, the situation would be reversed.

In *Figure 6-14*, *frame 2,* the piston is being pushed upward (compression) by the crankshaft and connecting rod. This causes the side thrust to be exerted on the opposite side of the cylinder. Thus, the side thrust alternates from side to side as the piston moves up and down. Side thrust in an engine cylinder makes proper lubrication and correct clearance essential. Without an oil film between the piston and the cylinder wall, metal-to-metal contact occurs and results in excessive wear. If the clearance between the piston and cylinder wall is excessive, a pounding noise, called PISTON SLAP, will occur as the thrust alternates from side to side.

Types of Piston Pins

Pins are usually hollow and made of alloy steel, machined, hardened, and precision-ground to fit the bearings. Their construction provides maximum strength with minimum weight. Some pins are chromium-plated to increase the wearing qualities. The pins are lubricated by splash from the crankcase, by oil forced through drilled passages in the connecting rods, or by the use of piston oil spray nozzles.

Piston pins must be secured in position so they do not protrude beyond the surface of the piston or have excessive end-to-end motion. Otherwise, the pin will tend to damage the cylinder wall. Piston pins may be secured in the connecting rod assembly in one of three ways: (1) rigidly fastened into the piston bosses, (2) clamped to the end of the rod, or (3) free to rotate in both piston and rod. When piston pins are secured by these methods, the pins are identified as (1) stationary (fixed), (2) semi-floating, and (3) full floating, respectively.

Stationary

The stationary pin is secured to the piston at the bosses, and the connecting rod oscillates on the pin. Since all movement is by the connecting rod, uneven wear may occur on the contacting surfaces in this type of installation. For this reason, use of this type of pin is not typical in Navy diesel engines.

Semifloating

Semifloating pins are secured in the middle to the connecting rod (*Figure 6-15*). The ends of the pin are free to move in the piston pin bearings in the bosses.

Full-Floating

Full-Floating pins are not secured to either the piston or the connecting rod. Pins of this type may be held in place by caps, plugs, and snap rings, or spring clips which are fitted in the bosses (*Figure 6-12*). The securing devices for a full-floating pin permit the pin to rotate in both the rod and piston pin bosses. Of the three types of piston pins, the full-floating piston pin is the most common.

Types of Piston Pin Bearings

The bearings used in connection with most piston pins are of the sleeve bearing or bushing type. These bearings may be further identified according to location—the piston boss piston pin bearings and the connecting rod piston bearings.

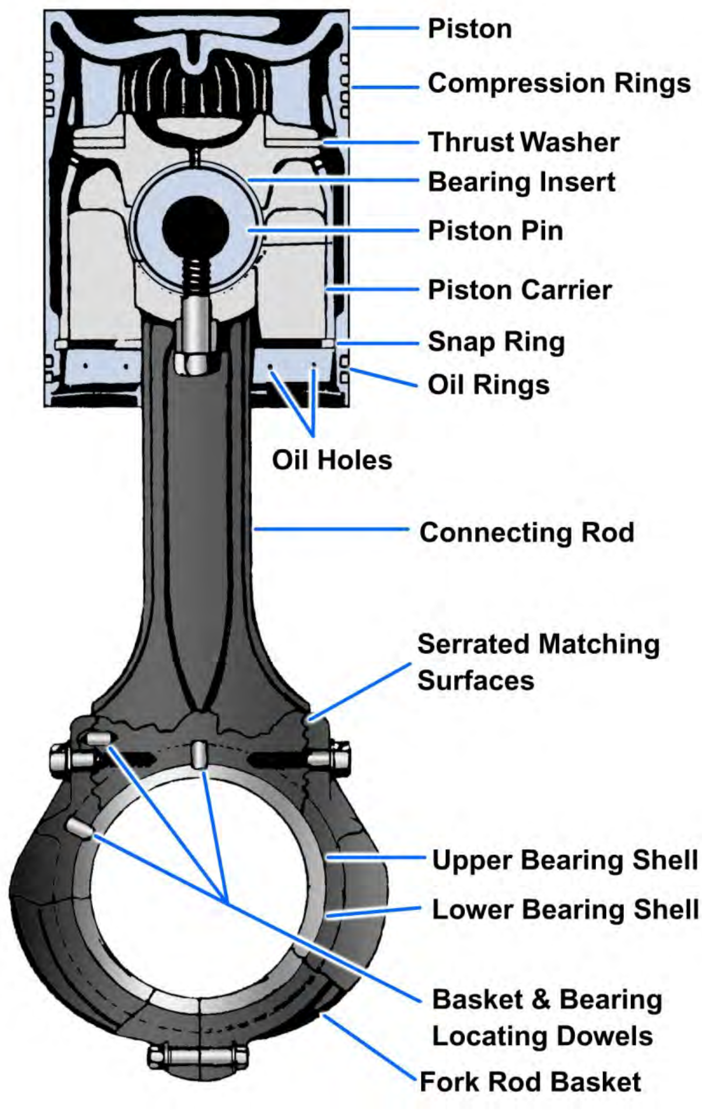


Figure 6-15 — Cross section of a semifloating piston and connecting rod assembly.

The bearings or bushings are made of bronze or similar material. Since the bushing material is a relatively hard-bearing metal, surface-hardened piston pins are required. The bore of the bushing is accurately ground in line for the close fit of the piston pin. Most bushings have a number of small grooves cut in their bore for lubrication purposes (*Figure 6-16*). Some sleeve bushings have a press fit, while others are “cold shrunk” into the bosses.

Bearings of the sleeve bushing type for both the bosses and the connecting rod are shown in *Figure 6-16.*

NOTE

The bosses are a part of an insert.

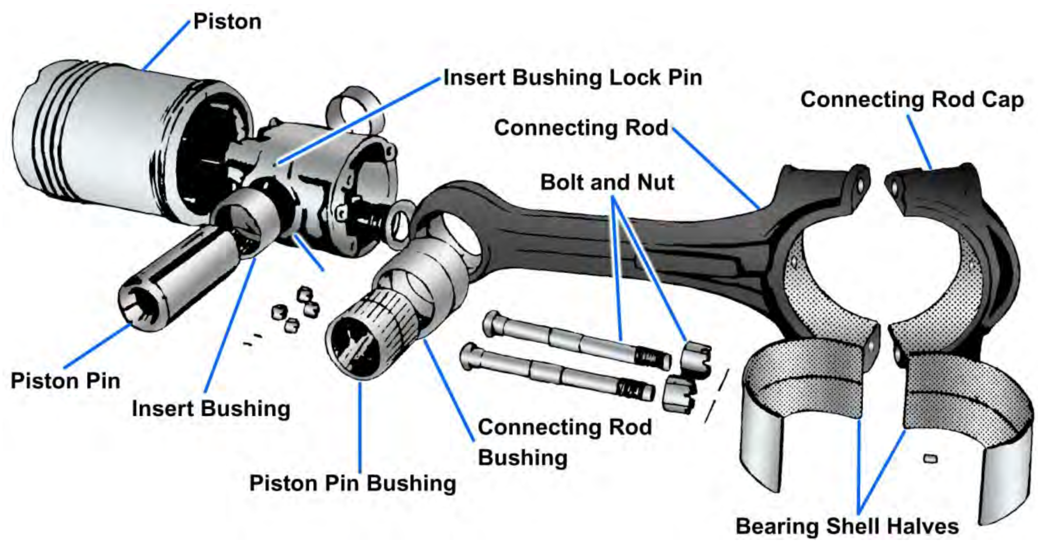


Figure 6-16 — Piston and connecting rod (Fairbanks-Morse).

If the piston pin is secured in the bosses of the piston (stationary) or if it floats (full-floating) in both the connecting rod and piston, the piston end of the rod must be fitted with a sleeve bushing. Pistons fitted with semifloating pins (*Figure 6-15*) require no bearing at the rod end.

Sleeve bushings used in the piston end of connecting rods are similar in design to those used in piston bosses. Generally, bronze makes up the bearing surface. Some bearing surfaces are backed with a case-hardened steel sleeve, and the bushing has a shrink fit in the rod bore. In other bushings, the bushing fit is such that a gradual rotation (creep) takes place in the eye of the connecting rod.

In another variation of the sleeve-type bushing, a cast bronze lining is pressed into a steel bushing in the connecting rod.

Connecting Rods

The connecting rod is the connecting link between the piston and the crankshaft. It is one of the most highly stressed parts of an engine in that the connecting rod transmits the forces of combustion to the crankshaft.

In general, the type of connecting rod used in an engine depends on the cylinder arrangement and the type of engine. Several types of connecting rods have been designed. Only two, however—the conventional rod and the fork and blade rod—are those likely to be found in marine engines used by the Navy and are the ones discussed here.

Conventional Rods

The conventional rod, illustrated in *Figure 6-16*, is typical of those used in many in-line and V-type engines. When used in V-type engines, two rods are mounted on a single crankpin. The two cylinders served are offset so that the rods can be operated side by side.

Rods are generally made of drop-forged, heat-treated carbon steel (alloy steel forging). Most rods have an I- or H-shaped cross section which provides maximum strength with minimum weight. The bore (hub, eye) at the piston end of the rod is generally forged as an integral part of the rod, (*Figure 6-16)*. The use of semifloating piston pins eliminates the need for the bore (*Figures 6-11 and 6-15).* The bore at the crankshaft end is formed by two parts; one an integral part of the rod and the other a removable cap (*Figure 6-16)*. Rods are generally drilled or bored to provide an oil passage from the crankshaft to the piston end of the rod.

The bore of the crankshaft end of a conventional rod is fitted with a precision bearing of the shell type, (*Figure 6-16)*. In design and materials, rod bearings are similar to the main journal bearings, which are discussed in connection with crankshafts later in this chapter. Connecting rod bearings of most engines are pressure-lubricated by oil from adjacent main bearings, through drilled passages. The oil is evenly distributed over the bearing surfaces by oil grooves in the shells. Bearing shells have drilled holes which line up with an oil groove in the rod bearing seat. Oil from this groove is forced to the piston pin through the drilled passage in the rod. *Figure 6-17* illustrates a drilled type of connecting rod, which in this example is used in conjunction with a "cocktail shaker" type of piston.

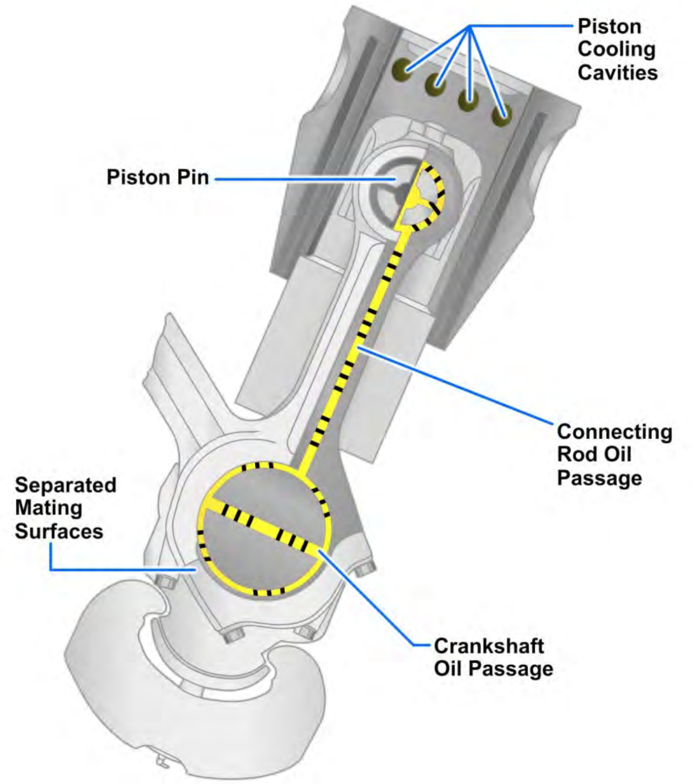


Figure 6-17 — Cutaway view of a connecting rod showing oil passages (Colt-Pielstick).

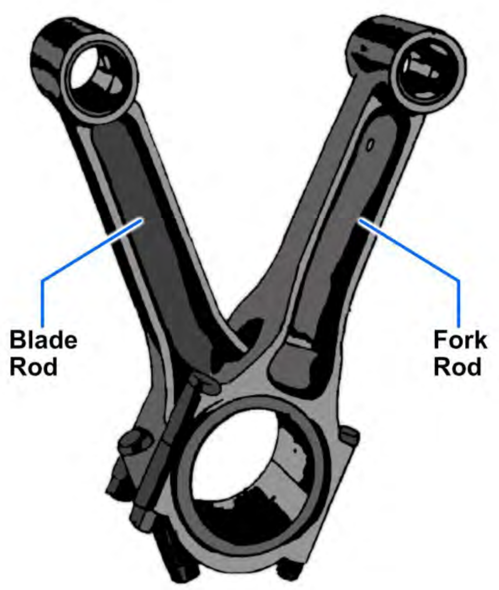


Figure 6-18 — Fork and blade connecting rod.

Fork and Blade (Plain) Connecting Rods

While two conventional rods are used to serve two cylinders in some V-type engines, a single assembly consisting of two rods is used in other engines of this type. As the name implies, one rod is fork-shaped at the crankshaft end to receive the blade rod. In general, fork and blade rods are similar to conventional rods in material and construction. However, design at the crankpin end (*Figure 6-18*) obviously differs from that of the conventional rods.

The bearings of fork and blade rods are similar to those already discussed, except that the upper shell must have a bearing surface on the outer surface to accommodate the blade rod.

Connecting Rod Bolts

Connecting rod bolts are the securing link between the piston assembly and the crankshaft. The rod bolts, because of the need for great strength, are generally made of heat-treated alloy steel. Fine threads with close pitch are used to give maximum strength and to permit secure tighten.

The majority of rod bolts used are machined to provide high fatigue resistance by having a large portion of the body of the bolt turned to a diameter of less than the root diameter of the thread. Thus, all the body, except the ends and the center portion (which acts as a dowel), is machined to the smaller diameter. Refer to the bolts in *Figure 6-16*. As an additional precaution in some connecting rods, the mating surfaces between the foot of the rod and the connecting rod cap are serrated to help the bolts resist side forces (*Figures 6-15 and 6-17).*

CRANKSHAFT

As one of the largest moving parts in an engine, the crankshaft changes the movement of the piston and the connecting rod into the rotating motion that is needed to drive such items as reduction gears, propeller shafts, generators, and pumps.

As the name implies, the crankshaft consists of a series of cranks (throws) formed as offsets in a shaft. The crankshaft is subjected to all the forces developed in an engine. Because of this, the shaft must be of especially strong construction. It is usually machined from forged alloy or high-carbon steel. The shafts of some engines are made of cast-iron alloy. Forged crankshafts are nitride (heat-treated) to increase the strength of the shafts and to minimize wear. While crankshafts of a few larger engines are of the built-up type (forged in separate sections and flanged together), the crankshafts of most modern engines are of one-piece construction (*Figure 6-19*).

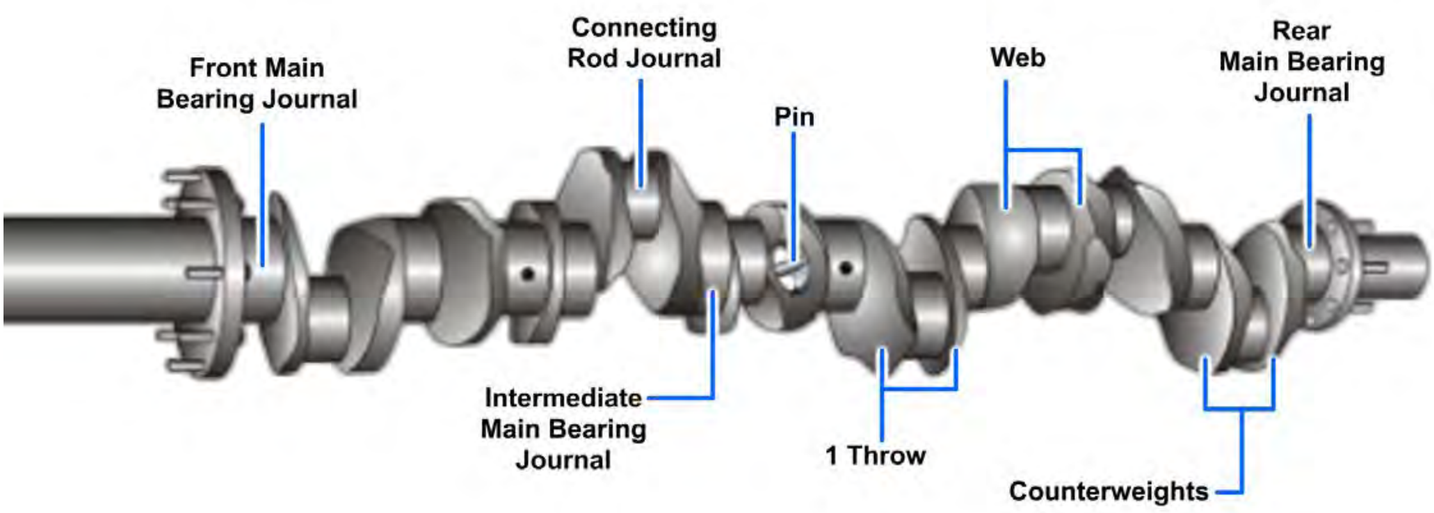


Figure 6-19 — One-piece crankshaft.

Crankshaft Terminology

The parts of a crankshaft may be identified by various words. However, the terms in *Figure 6-19* are the ones that are most commonly used in the Naval Sea Systems Command (NAVSEA) technical manuals for the engines used by the Navy.

The main journals serve as the points of support and as the center of rotation for the shaft. As bearing surfaces, the main journals and the connecting rod journals of crankshafts are surface-hardened so that a longer wearing, more durable bearing metal can be used without causing excessive wear of the shaft.

As illustrated in *Figure 6-19*, crankshafts have a main journal at each end of the shaft with an intermediate main journal between the cranks. Each crank (throw) of a shaft consists of three parts—two webs and a pin—as shown in *Figure 6-19*. Crank webs are sometimes called cheeks or arms. The cranks, or throws, provide points of attachment for the connecting rods, which are offset from the main journals.

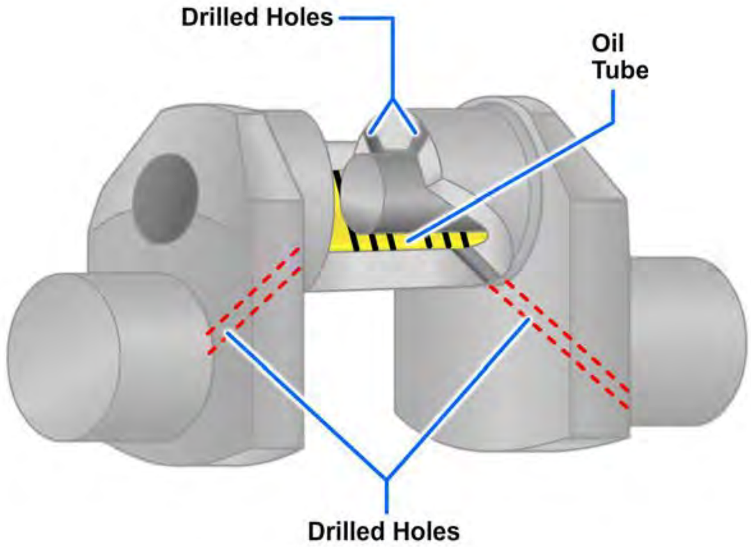


Figure 6-20 — An example of hollow connecting rod journal construction.

In many crankshafts, especially in large engines, the connecting rod journals and main journals are of hollow construction. Hollow construction not only reduces weight considerably but also increases torque capability of the crankshaft and provides a passage for the flow of lubricating oil (*Figure 6-20).*

The forces that turn the crankshaft of a diesel engine are produced and transmitted to the crankshaft in a pulsating manner. These pulsations create torsional vibrations, which are capable of severely damaging an engine if they are not reduced, or dampened, by opposing forces. Many engines require an extra dampening effect to ensure satisfactory operation. It is provided by a torsional vibration damper mounted on the free end of the crankshaft. Several types of torsional dampers are currently in use.

On some crankshafts, part of the web of the crankshaft extends beyond the main journal to form or support counterweights. These counterweights may be integral parts of the web (*Figure 6-19*) or may be separate units attached to the web by studs and nuts, or setscrews *(Figure 6-21*).

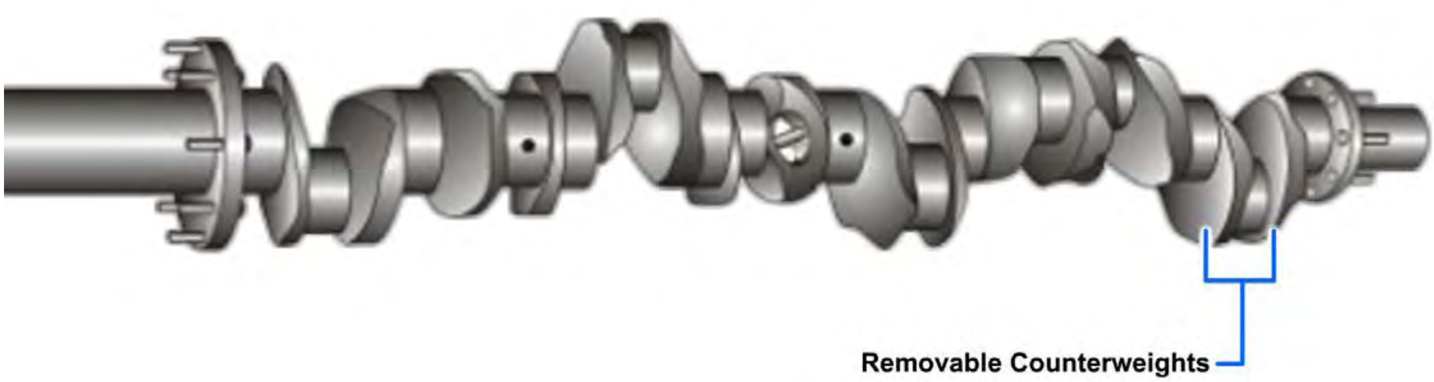


Figure 6-21 — Crankshaft with removable counterweights.

Counterweights balance the off-center weight of the individual crank throws and thereby compensate for centrifugal force generated by each rotating crank throw. If such vibrations are not controlled, the shaft would become damaged. Excessive vibration may lead to complete failure of the engine. Counterweights use inertia to reduce the pulsating effect of power impulses in the same manner as the flywheel. Flywheels are described later in this chapter.

Crankshafts and Lubrication

Whether a crankshaft is of solid construction *(Figure 6-19*) or of hollow construction (*Figure 6-20*), the main journals, the connecting rod journals, and the webs of most shafts have drilled passages for lubricating oil. Two other variations in the interior arrangement of oil passages in crankshafts are shown in *Figure-22, frames 1 and 2*. A study of these two oil passage arrangements will give you an idea of the part the crankshaft plays in engine lubrication. In the system illustrated in *Figure 6-22*, *frame 1,* each oil passage is drilled through from a main bearing journal to a connecting rod journal. The oil passages are in pairs that crisscross each other in such a way that the two oil holes for each journal are on opposite sides of the journal. These holes are in axial alignment with the oil grooves of the bearing shells when the shells are in place. Since the oil groove in a bearing goes at least halfway around the bearing, a part of the groove will always be aligned with at least one of the holes.

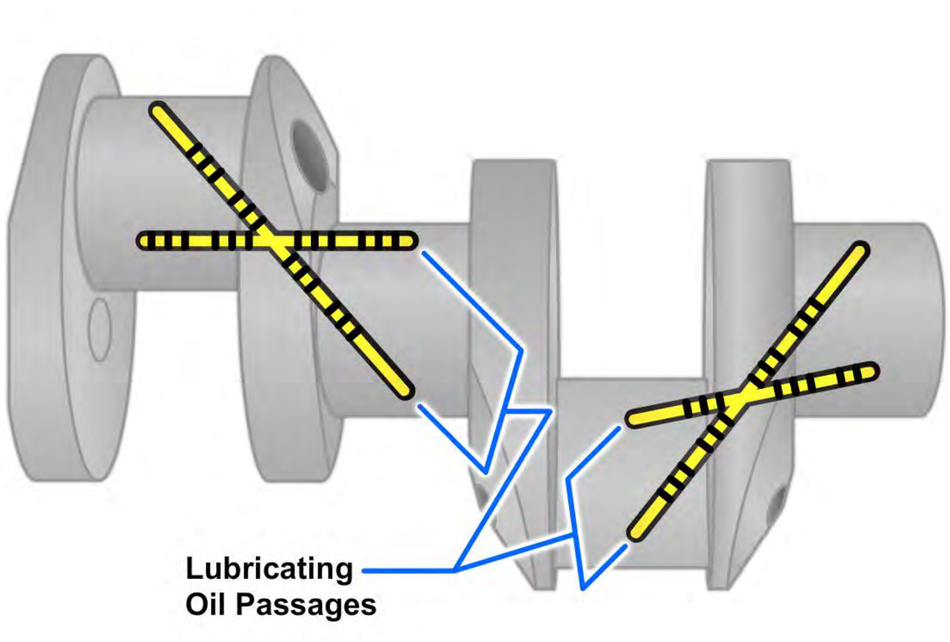


Figure 6-22 — Examples of crankshaft oil passage arrangement

In the oil passage arrangement shown in *Figure 6-22, frame 2,* (the shaft is shown in *Figure 6-19*), the passage is drilled straight through the diameter of each main and connecting rod journal. A single diagonal passage is drilled from the outside of a crankshaft web to the center of the next main journal. The diagonal passage connects the oil passages in the two adjoining connecting rod journals and main journals. The outer end of the diagonal passage is plugged. Lubricating oil under pressure enters the main bearing and is forced through the diagonal passage to lubricate the connecting rod bearing. From there it flows through the drilled connecting rod to lubricate the piston pin and cool the piston.

In engines that use crankshaft oil passage arrangements the connecting rods are drilled to carry the lubricating oil to the piston pins and piston. Not all engines have drilled connecting rods. In some V-type engines, drilled passages supply oil to the main and connecting rod bearings, but oil for the lubrication and cooling of the piston assembly may be supplied by centrifugal force or by separate supply lines.

Crankshaft Throw Arrangements

The smooth operation of an engine and its steady production of power depend, to a great extent, on the arrangement of the cranks on the shaft and on the firing order of the cylinders. For uniform rotation of the crankshaft in most multi-cylinder engines, the power impulses must be equally spaced with respect to the angle of crankshaft rotation. Whenever possible, they must also be placed so that successive explosions do not occur in adjacent cylinders.

Crankshafts may be classified according to the number of throws. The 6-throw shaft illustrated in *Figure 6-19* is for a 6-cylinder, in-line, and 2-stroke cycle engine. Shafts of similar design can be used in V-type engines.

The number of cranks and their arrangement on the shaft depend on a number of factors, such as the arrangement of the cylinders (in-line or V-type), the number of cylinders, and the operating cycle of the engine. How these factors influence throw arrangement and firing order can be seen in a comparison of *Figure 6-23, Examples a through e*. The arrangement of throws with respect to one another and with respect to the circumference of the main journals is generally expressed in degrees. In an in-line engine, the number of degrees between throws indicates the number of degrees the crankshaft must rotate to bring the pistons to TDC in firing order. This is not true in engines where each throw serves more than one cylinder. *Figure 6-23* lists the examples of throws with respect to cylinder arrangement, the number of cylinders served by each throw, and the firing order of the cylinders. (The sketches are not drawn to scale and do not indicate relative size, but are for illustrative purposes only.)

In studying the examples in *Figure 6-23*, remember that the crankshaft must make only one revolution (360°) in a 2-stroke cycle; whereas two revolutions are required in a 4-stroke cycle. Note the throw arrangement in *Example a* of a 4-stroke cycle engine. Since the 4-cylinder engine in *Example a* operates on the 4-stroke cycle, throws 1, 3, 4, and 2 (see firing order), must be 180° apart in order for the firing to be spaced evenly in 720° of crankshaft rotation. Note too, that in all the other examples, the throws are equally spaced, regardless of cylinder arrangement, cycle of operation, or number of cylinders.

In *Examples b and c,* the shaft design and the number of degrees between throws are the same. Yet the shaft in *Example c* fires twice as many cylinders. This is possible because one throw, through a fork and blade rod, serves two cylinders which are positioned in 60° banks. Thus, even though both engines operate on the 4-stroke cycle, the 12-cylinder engine requires only 60° shaft rotation between power impulses. There are six throws shown in *Examples b and d,* yet they are 120° apart in one and 60° apart in the other. Why? The cylinder arrangement, the total number of cylinders, and the number of cylinders served by each throw are the same. In *Examples b and d*, the operating cycle is the controlling factor in throw arrangement. In *Examples d and e,* other variations in shaft throw arrangement and firing order are shown. Note that the differences are governed to a great extent by the cylinder arrangement, the number of cylinders served by the shaft and by each throw, and the operating cycle of the engine.

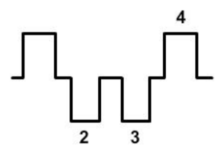
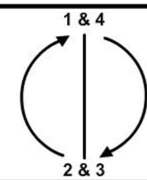
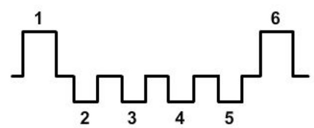
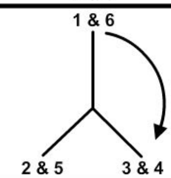
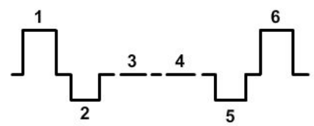
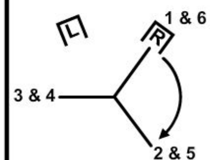
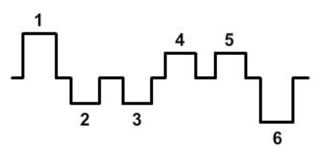
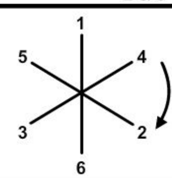
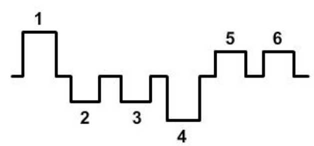
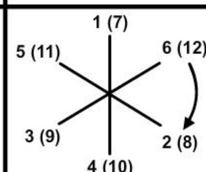
EXAMPLE	NUMBER CYLINDERS	CYLINDER ARRANGEMENT	CYCLE	NO CYL SERVED BY EACH THROW	THROW ARRANGEMENT (SIDE VIEW)	THROW ARRANGEMENT (END VIEW)	FIRING ORDER	NO DEGREES BETWEEN THROWS (SEE SKETCHES)	NO DEGREES SHAFT ROTATION BETWEEN FIRINGS
(a)	4	IN-LINE	4 - Stroke	1			1-3-4-2	4 THROWS 180° APART	180
(b)	6	IN-LINE	4 - Stroke	1			1-5-3-6-2	6 THROWS 120° APART	120
(c)	12	V	4 - Stroke	2			L 1 2 3 4 5 6 R 1 2 3 4 5 6 1R, 3L, 4R, 5L, 2R, 1L, 6R, 4L, 3R, 2L, 5R, 6L	6 THROWS 120° APART	60
(d)	6	IN-LINE	2 - Stroke	1			1-5-3-6-2-4	6 THROWS 60° APART	60
(e)	12	V	2 - Stroke	2			1 2 3 4 5 6 7 8 9 10 11 12 1-11-5-9-3-10-4-8-2-12-6-7	6 THROWS 60° APART	30

Figure 6-23 — Example of crankshaft arrangement.

BEARINGS

The bearings of an engine make up an important group of parts. Bearings serve to support rotating shafts and other moving parts and to transmit loads from one part of the engine to another. Engine bearings consist of two basic types: antifriction bearings and friction bearings. Both types are used in Navy diesel engines.

Antifriction Bearings

Antifriction bearings can be grouped into six general classifications: ball bearings, cylindrical roller bearings, and needle bearings, tapered roller bearings, self-aligning roller bearings, and thrust bearings. The use of antifriction bearings is mostly limited to the exterior areas of an engine. They are used in cooling pumps, fuel-injection pumps, governors, starters, flywheel pilot bearings, turbochargers, and blowers.

All antifriction bearings employ a rolling element (rollers, balls, or needles) between the inner and outer rings (races). Either the inner ring or the outer ring will remain stationary. See *Figure 6-24* for cutaway views of two types of antifriction bearings. Because of the small contact area between the rolling elements and the inner and outer rings and the necessity for the bearing to withstand the high compression stress, the material used for the construction of roller bearings is usually carbonized steel alloy. The material used for ball bearings is usually heat-treated chromium-alloy steel.

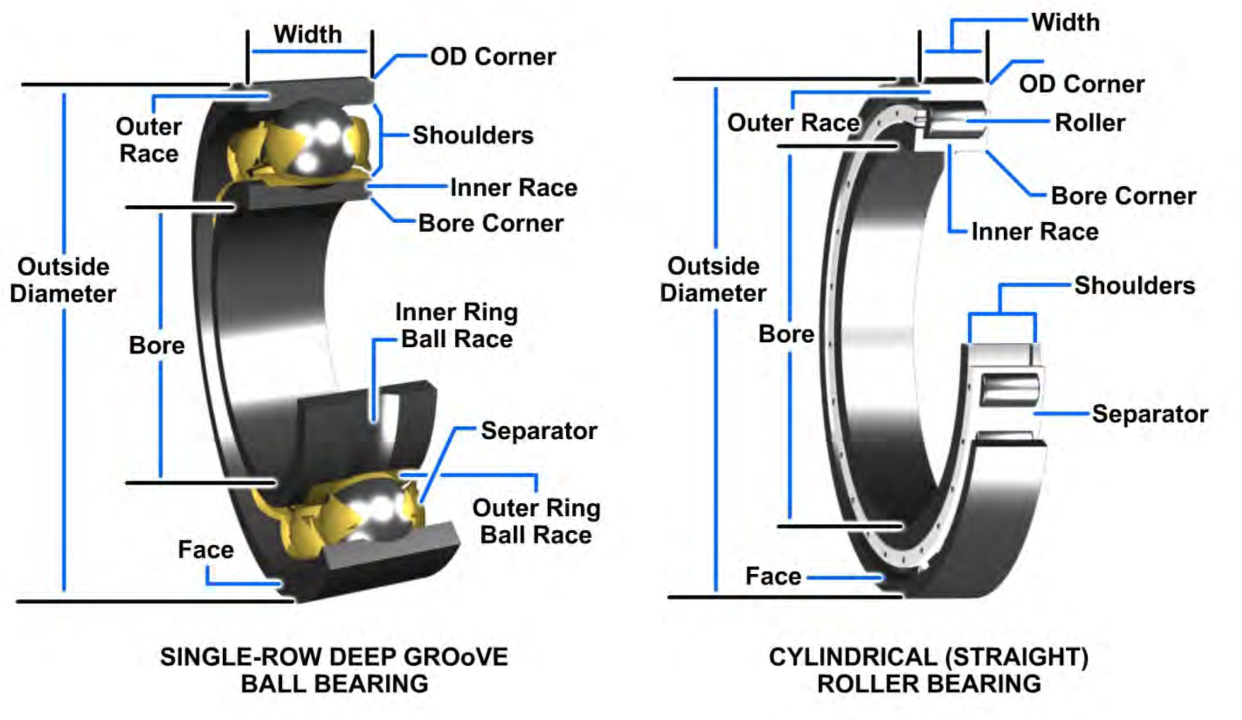


Figure 6-24 — Cutaway view of a ball bearing and roller bearing

As an Engineman, you will come into contact with various items of equipment that may require bearing replacement. Bearings that are similar in appearance may not be suitable as replacement bearings. Ball and roller bearings are identified by a numerical code which indicates the bore in millimeters or sixteenths of an inch. The internal fit, or tolerance, and any special characteristics are also coded by number. Letter codes indicate the type of bearing, the outside diameter (OD), the width of the cage, the seal or shield, the modification, and the required lubricant.

Friction Bearings

In diesel engines, friction bearings serve to support the crankshaft, connecting rod, camshaft, and gear train. In some engine applications, friction bearings also support the rocker arm shaft as well as various pumps.

A type of friction bearing that is representative of most of the bearings used in Navy diesel engines is the precision bearing. Precision-type bearings that act as supports for the crankshaft are referred to as main journal bearings. In our discussion of friction bearings, we will use the main journal bearing as a representative sample.

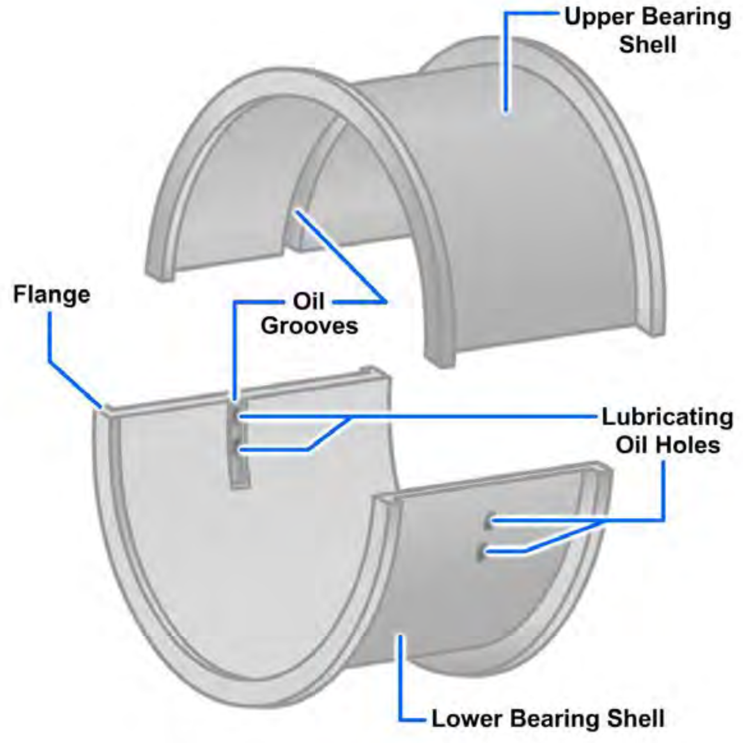


Figure 6-25 — Main bearing in a cylinder block.

Main journal bearings are of the sliding contact, or plain, type consisting of two halves, *Figure 6-25*. The location of main engine bearings in one type of block is shown in *Figure 6-26*. The main journal bearings of most marine engines used by the Navy are of aluminum, aluminum alloy, or trimetal construction. In the trimetal type of construction, the bearing has a steel back bonded with a layer of bronze to which is bonded a layer of bearing material. The bearing material is either lead-based babbitt or tin-based babbitt. Regardless of the construction materials, the function and performance of main journal bearings are basically the same, with the exception of bearings, which are constructed not only to support the crankshaft but also to hold the crankshaft in position axially. This is done by flanges, which are part of the bearings, as shown in *Figure 6-26*. Such flanges are on both halves of a bearing.

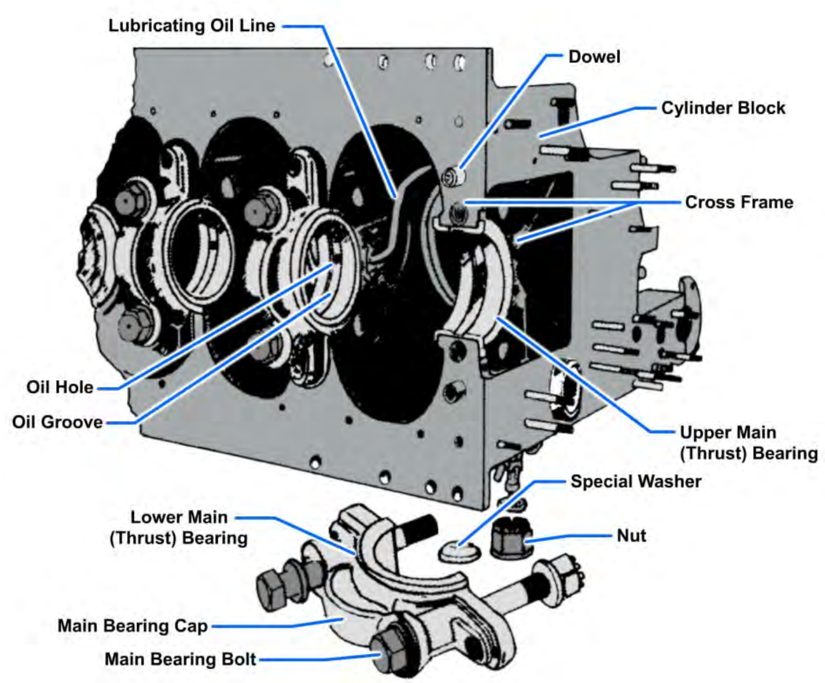


Figure 6-26 — Main bearing in a cylinder block.

These types of bearings are called thrust bearings. Some engines use separate flat thrust washers on each side of one main bearing to control the crankshaft thrust (back and forth movement).

Main bearings and their housing and caps are precision machined with a tolerance sufficiently close that, when properly installed, the bearings are in alignment with the journals and fit with a predetermined clearance. The clearance provides space for the thin film of lubricating oil which is forced, under pressure, between the journals and the bearing surfaces. Under normal operating conditions, the film of oil surrounds the journals at all engine load pressures. Lubricating oil enters the bearing shells from the engine lubricating system through oil grooves in the bearing shells, *Figures 6-25 and 6-26*. These inlets and grooves are located in the low-pressure area of the bearing.

Main bearings are subjected to a fluctuating load, as are the connecting rod bearings and the piston pin bearings. However, the manner in which main journal bearings are loaded depends on the type of engine in which they are used.

In a 2-stroke cycle engine, a load is always placed on the lower half of the main bearings and the upper half of the piston pin bearings. In the connecting rod, the load is placed upon the upper half of the connecting rod bearings at the crankshaft end of the rod. This is true because the forces of combustion are greater than the inertial forces created by the moving parts.

In a 4-stroke cycle engine, the load is applied first on one bearing shell and then on the other. The reversal of pressure is the result of the large forces of inertia imposed during the intake and exhaust strokes. In other words, inertia tends to lift the crankshaft in its bearings during the intake stroke and exhaust stroke. Additional information on bearings can be found in Naval Ships' Technical Manual, Chapter 244.

FLYWHEELS

The speed of rotation of the crankshaft increases each time the shaft receives a power impulse from one of the pistons. The speed then gradually decreases until another power impulse is received. If permitted to continue unchecked, these fluctuations in speed (their number depending upon the number of cylinders firing on one crankshaft revolution) would result in an undesirable situation with respect to the driven mechanism as well as to the engine. Therefore, some means must be provided so that shaft rotation can be stabilized. In most engines, this is accomplished by installation of a flywheel on the crankshaft. In other engines, the motion of such engine parts as the connecting rod journals, webs and lower ends of the connecting rods, and such driven units as the clutch and generator serves the purpose. The need for a flywheel decreases as the number of cylinders firing in one revolution of the crankshaft and the mass of moving parts attached to the crankshaft increase.

A flywheel stores up energy during the power event and releases it during the remaining events of the operating cycle. In other words, when the speed of the shaft tends to increase, the flywheel absorbs energy. When the speed tends to decrease, the flywheel gives up energy to the shaft in an effort to keep shaft rotation uniform. In doing this, a flywheel (1) keeps variations in speed within desired limits at all loads; (2) limits the increase or decrease in speed during sudden changes of load; (3) aids in forcing the piston through the compression event when an engine is running at low or idling speed; and (4) provides leverage or mechanical advantage for a starting motor.

Flywheels are generally made of cast iron, cast steel, or rolled steel. Strength of the material from which the flywheel is made is of prime importance because of the stresses created in the metal of the flywheel when the engine is operating at maximum designed speed.

In some engines, a flywheel is the point of attachment for items such as a starting ring gear or a turning ring gear, *Figure 6-27*. The rim of a flywheel may be marked in degrees. With a stationary pointer attached to the engine, the degree markings can be used for a determination of the position of the crankshaft when the engine is being timed.

JACKING GEARS

Diesel drive installations are equipped with a means of jacking, or barring, over. A great majority of diesel engines are jacked over by hand. One method of rotating the engine is with the use of a turning bar. In this installation, holes are provided around the circumference of the rim for insertion of the turning bar so that the crankshaft can be manually rotated, *Figure 6-27*. This is a very simple but effective means that allows for the precise positioning of the crankshaft when required for timing.

Still another method of rotating the crankshaft is the engine barring device consists of a pinion and a hex head drive shaft. The drive shaft is mounted in a housing containing an eccentric sleeve arrangement for engaging the pinion with the ring gear on the flywheel. The only maintenance required for the jacking gear is periodic inspection for wear and minor lubrication of the moving parts of the pinion assembly.

Figure 6-27 — Ring gear and coupling (flywheel).

The diesel engine lube oil system shall be primed before starting and before the engine is turned over (by hand or by a motor-driven jacking gear) prior to starting. Priming of the engine should continue only until a slight pressure is registered on the engine lube oil pressure gauge or until oil is observed at each main bearing. Continue priming until a slight pressure is registered on the engine lube oil pressure gauge or until oil flow is observed at each *site* flow indicator. Before starting the engine after a prolonged shutdown, inspect the air receiver and blower discharge passages and remove any accumulation of lube oil .When an engine room is secured and the ship is being towed, or is being propelled by units other than its main engines, the bearings of the shafts and machinery that are turned by propeller drag shall be adequately lubricated. If adequate lubrication is unavailable, the jacking gear shall be engaged and locked. Even with the jacking gear engaged and the brake set, oil shall be supplied to the bearings underway, if practical; to provide additional safety in case the jacking gear brakes should start to slip.

The barring device can also be operated by an air (motor) wrench placed over the hex head of the drive shaft. Main drive engines, as well as some auxiliaries, are usually equipped with safety devices that prevent the engine from starting while the jacking gear is engaged. The type of safety devices will depend on the type of starting system used.

SUMMARY

The valve-actuating mechanisms are those parts that transform the rotary motion of a drive mechanism into reciprocating motion. Reciprocating motion is used for the operation of engine cylinder valves. The camshaft is the principal part of a valve-actuating mechanism. Rotary motion of the cams on the camshaft is changed to reciprocating motion, and power is transmitted to the various cylinder valves (intake, exhaust, fuel injection, and air start) by means of rocker arm or tapped assemblies. These assemblies make contact with the cams by the use of cam followers.

The process of transmitting the power developed in an engine to useful energy involves the motion of many parts. The major parts are the piston, connecting rods, and crankshaft; however, many related parts must be considered in the process of changing reciprocating motion to rotary motion. For example, a piston, which may be of the trunk type or the crosshead type, receives the force of combustion and transmits it to the crankshaft through a connecting rod.

To accomplish their functions, pistons are fitted with piston rings, such as compression and oil control rings. Piston rings function to maintain a gastight seal between the piston and cylinder wall, to assist in cooling the piston, and to control cylinder wall lubrication.

Trunk-type pistons are fastened to the connecting rods by pins which may be stationary, semifloating, or full-floating. Side thrust created by combustion and the motion of the moving parts is received by the cylinder wall through a trunk-type piston. The crosshead assembly absorbs the side thrust in engines fitted with the crosshead-type piston.

The crankshaft, the largest of the moving parts of an engine, receives the power impulses from all cylinders of the engine, transforms the motion of the pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel or driven unit.

Other important parts which must be considered in connection with moving parts of an engine are bearings. Bearings may be of the antifriction type or friction type. Both types can be found on diesel installations. Antifriction bearings are commonly used in the engine accessories while friction bearings are commonly used within the internal structure of the engine.

As in the case of the principal stationary parts of the engine, you should be thoroughly familiar with all of the major moving and actuating components of an engine. You should know the functions and operating principles of these parts and how these parts are related to the stationary parts. You should be able to associate each component, as discussed separately, with other related components of the engine and how each part or assembly is related to the cycle of engine operation. If you are uncertain concerning any of these areas, go back and review this information before proceeding to the next chapter.

End of Chapter 6

Principal Moving and Related Components

Review Questions

6-1. What type of intake and exhaust valves are used on internal-combustion engines?

A. Gas-operated check
B. Spring-activated
C. Cone shaped seat
D. Poppet

6-2. In a 2-stroke cycle diesel engine, the camshaft does NOT carry a cam for actuating what component?

A. Exhaust valves
B. Intake valves
C. Unit injectors
D. Air start valves

6-3. What is the usual metallurgical makeup of valve bridge and serves to extend the life of valve seats?

A. Forged steel
B. Ground tempered steel
C. Annealed high-carbon steel
D. Chrome-plated alloy steel

6-4. Why is the crown of a piston smaller than a skirt?

A. It has more rings on it
B. It runs hotter
C. It absorbs no side thrust
D. It gets worn down faster

6-5. How are the pistons held in place on an engine?

A. Crowns
B. Bosses
C. Lands and grooves
D. Skirts

6-6. What is the maximum amount of combustion heat absorbed by the piston that is removed through the rings to the cylinder wall?

A. Approximately 20%
B. Approximately 30%
C. Approximately 40%
D. Approximately 50%

6-7. What are some of the ways that heat is transferred through the cylinder walls to cool a piston?

A. Intake air and lubricating oil
B. Intake air and exhaust
C. Piston speed and crankcase air
D. Lubricating oil and cooling fins

6-8. Which of the following characteristics does NOT apply to compression rings?

A. They commonly have a rectangular cross-section
B. Their diameter is slightly larger than the cylinder bores
C. Combustion gases act only on the combustion areas
D. They transfer heat to cylinder wall

6-9. How would you classify the shape of crankshaft?

A. Several flanges forged together
B. Several throws in a row formed as offsets
C. A shaft with a crank at the end
D. A series of bearing and weights

6-10. What is the function of the drilled passages in the crankshaft?

A. To relieve excess oil pressure at the connecting rods
B. To carry oil to the connecting rods
C. To carry lubricating oil to the piston pin and the piston
D. To lighten the crankshaft by the amount that offsets the weights of any counterweights used

6-11. Where does the oil travel after passing the crankshaft?

A. Through the main journal and the connecting rod journal
B. Through the connecting rod bearing and the piston pin
C. Through the connecting rod bearing and the connecting rod
D. Through the connecting rod and the piston crown

6-12. What is the purpose for main journals on a crankshaft?

A. Used to ensure balance of rotation
B. Used as the attach point for the connecting rod
C. Used as the point of support and the center of rotation of the shaft
D. Used as the attachment for the flywheel

6-13. In addition to reducing the weight considerably, why is a crankshaft hollow in construction?

A. Provide passage for lubricating oil
B. Ensure timing of the engine
C. To balance the crankshaft
D. To offset the weight of the flywheel

6-14. What components do NOT use antifriction bearing?

A. Starters
B. Camshafts
C. Governors
D. Blowers

6-15. What do the letter codes identify on the ball/roller bearing?

A. Outside diameter
B. Weight of the bearing
C. Material of the bearing
D. The depth of the bore

6-16. What type of bearing serves to hold the crankshaft in position axially?

A. Main
B. Thrust
C. Roller
D. Ball

6-17. What type of bearing is a precision bearing?

A. Fixed
B. Floating
C. Non-friction
D. Friction

6-18. What event during the combustion cycle does the flywheel store energy?

A. Intake
B. Compression
C. Power
D. Exhaust

6-19. What accessories are usually attached to an engine’s flywheel?

A. Lubricating oil pump
B. Governor
C. Water pump
D. Turning ring gear

6-20. When the engine’s speed decreases, the flywheel gives up energy to the crankshaft for uniform rotation, the flywheel will?

A. Keeps variation in speed within desired limits at all loads
B. Keeps variation in speed within desired limits different loads
C. Increases in speed during sudden change of load
D. Decreases in speed during sudden change of load

6-21. What measures are in place to ensure the engine doesn’t start while the jacking gear is engaged?

A. “DO NOT START” sign attached to gear
B. Area roped off
C. Engine safety devices
D. Engine can operate while engaged

6-22. What is the jacking gear used for on diesel engines?

A. To start the engine
B. To reverse the engine
C. Inspection of the crankshaft
D. To position the crankshaft for timing

6-23. What situation should the engine’s jacking gear be engaged and locked?

A. When adequate lubricating oil is unavailable
B. During trend analysis
C. During maintenance
D. During full power run

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CHAPTER 7

SPEED CONTROLLING DEVICES

This chapter contains general information about maintenance and repair of speed controlling devices, injection pumps known as governors, and how these devices control the engine's operations. Refer to the appropriate manufacturer's technical manuals and the maintenance requirements (3-M) for more specific information. Naval Ships' Technical Manual, Chapter 233, "Diesel Engines".

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the function and maintenance of machinery speed limiting devices, Governors.
2. Explain the removal and replacement of mechanical and hydraulic system components.

CONTROL DEVICES IN A DIESEL ENGINE

In this section of the chapter, we will discuss the methods and the devices that serve to control the output of injection pumps and injectors. By controlling the output of the fuel injector system, these devices ensure control of engine operation.

GOVERNORS

A governor is a speed-sensing device on an engine that serves to maintain constant speed in revolutions per minute (rpm) within the design power rating of a diesel engine. To control an engine means to keep it running at a desired speed, either with, or regardless of, the changes in the load carried by the engine. A governor may also serve to limit the high- and low-idle rpm of the engine. The degree of control required depends on the engine's performance characteristics and the type of load it drives. Without a governor, a diesel engine could reach maximum rpm and destroy itself quickly. An example of engine control without the use of a governor is in the conventional automobile—the engine speed and engine load changes are sensed by the driver. The driver's movement of the throttle is an extension of a conditioned reflex; in other words, the driver acts as the governor. However, a driver is not capable of reacting to load and speed changes quickly enough when operating a diesel engine. This is because diesel engines can maintain a constant speed better by using a governor. In diesel engines, the speed and power output is determined by varying the amount of fuel injected into the cylinders to control combustion. The governor acts through the fuel injection equipment to regulate the amount of fuel delivered to the cylinders. As a result, the governor holds engine speed reasonably constant during fluctuations in load. Hydraulic and mechanical are the two principal types of governors. To understand why different types of governors are needed for different jobs, you will need to know the meaning of several terms (*Table 7-1)* used in describing the action of the governor in regulating engine speed.

Table 7-1 — Terminology for Governors

CONDITION	DESCRIPTION
Speed Droop	The decrease in speed of the engine from a no-load condition to a full load condition. Speed droop is expressed in rpm or (more commonly) as a percentage of normal or average speed.
Isochronous Governing	Maintaining the speed of the engine truly constant, regardless of the load. This means governing with perfect speed regulation or zero speed droop.
Hunting	The continuous fluctuation (slowing down and speeding up) of the engine speed from the desired speed. Hunting is caused by over control by the governor. These fluctuations of speed can be eliminated by blocking the fuel linkage manually but will reappear when engine is returned to governor
Stability	The ability of the governor to maintain the desired engine speed without fluctuations or hunting.
Sensitivity	The change in speed required before the governor will make a corrective movement of the fuel control mechanism and is generally expressed as a percentage of the normal or average speed.
Promptness	The speed of action of the governor. It identifies the time interval required for the governor to move the fuel control mechanism from a no-load position to a full-load position. Promptness depends on the power of the governor; the greater the power, the shorter the time required to overcome the resistance.
Surges	Rhythmic variations of speed of large magnitude. They can be eliminated by blocking the fuel linkage manually and will not reappear when returned to governor control unless the speed adjustment of the load changes.
Jiggles	High-frequency vibrations of the governor fuel rod end or engine fuel linkage. Do not confuse jiggle with the normal regulating action of the governor.
Maximum No-Load Speed	The highest engine rpm obtainable when the throttle linkage is moved to its maximum position with no load applied to the engine.
Maximum Full-Load Speed	Indicates the engine rpm at which a particular engine will produce its maximum designed horsepower setting as stated by the manufacturer.
Idle Or Low-Idle Speed	Indicates the normal speed at which the engine will rotate with the throttle linkage in the released or closed position.
Work Capacity	Describes the amount of available work energy that can be produced to the output shaft of the governor.
Response Time	Normally the time taken in seconds for the fuel linkage to be moved from no-load to a full-load position.

Now that you have read the definitions of some of the terms associated with governors, we will proceed with our comparison between mechanical and hydraulic governors.

Classification of Governors

Governors for diesel engines used by the Navy can be divided into two general classes—mechanical and hydraulic. Both types of governors serve to regulate engine speed by controlling the fuel injected into the engine and are referred to as speed-regulating governors. The mechanical governor is usually simple in design, contains few parts, and is relatively inexpensive. It is frequently used as a speed-limiting device when extremely sensitive operation is not required.

The hydraulic governor is more complex in design and contains more parts than the mechanical governor. However, it is more sensitive to speed variations, more quickly acting, and more accurate because of the reduction of friction and the small mass of moving parts. Due to the forces exerted by the hydraulic system, a hydraulic governor can be smaller and more compact than a mechanical governor and still operate the fuel mechanism of a large engine.

Both mechanical and hydraulic governors will be discussed in greater detail later in this chapter. Governors may also be classified according to the function they perform (*Figure 7-1 frame 1 and 2*), the forces they use in operation, and the means by which they operate the fuel control mechanism. The function of a governor on a given engine is determined by the load on the engine and the degree of control required. Governors are classified according to their function as constant speed, variable-speed, speed-limiting, and load limiting.

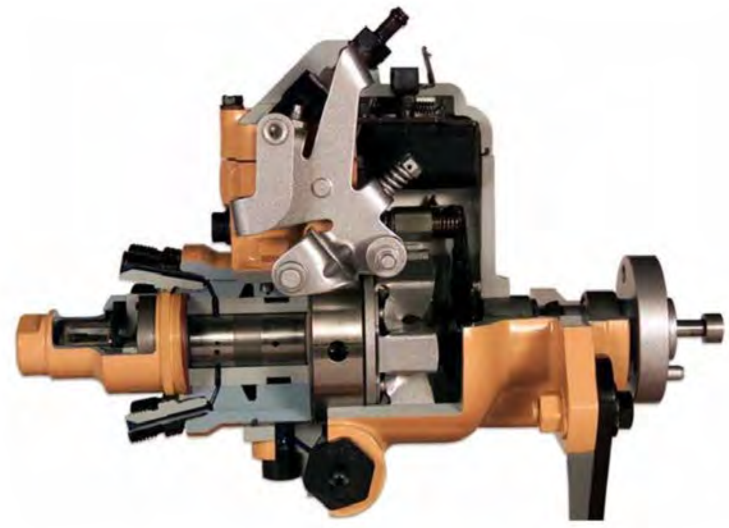

Figure 7-1 — Classification of governors.

Some installations require a constant engine speed from a no-load to a full-load condition. Governors that maintain one speed, regardless of load, are called constant-speed governors. Governors that maintain any desired engine speed over a wide speed range (low idle- maximum speed) and that can be set to maintain a desired speed in that range are classified as variable-speed governors. Speed-control devices that serve to keep an engine from exceeding a specified maximum speed (racing) and from dropping below a specified minimum speed are classified as speed-limiting governors. Some speed-limiting governors limit maximum speed only. Some engine installations need a control device to limit the load that the engine will handle at various speeds. Load –limiting governors are used to limit the load that the engine will handle at various speeds.

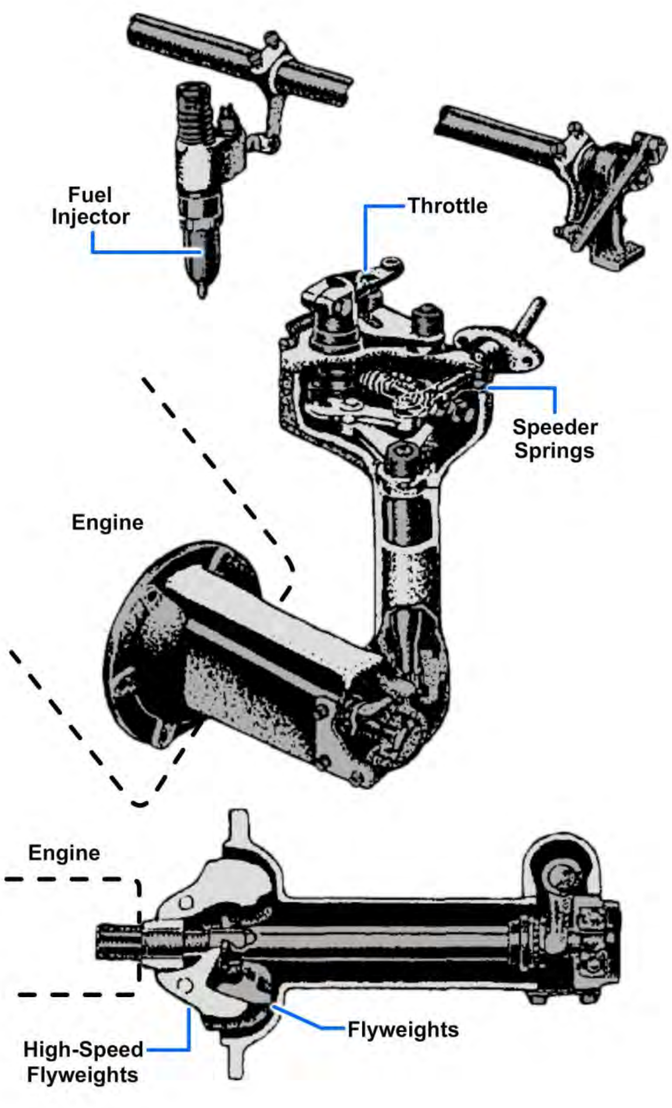

Figure 7-2 — Mechanical governor.

Mechanical Governors

A mechanical governor (*Figure 7-2 and 7-3*) controls the speed of the engine by controlling the spring balanced position of the flyweights. In a mechanical governor, the centrifugal force generated by the rotating flyweights, acts directly on the fuel control mechanism. The governor's spring tension is set to oppose the centrifugal force and will define the top engine limit or high idle speed. When the load is decreased or removed from the engine (such as when a clutch is disengaged) and the speed exceeds its former balanced setting, the increased speed of the flyweights develops a greater centrifugal force that upsets the former flyweight spring balance This means that as the load is increased at a constant throttle setting, the speed of the engine will drop or droop slightly rather than remain constant. Maximum speed control is affected by the action of the high-speed (small) flyweights acting against a heavy (high-speed) spring.

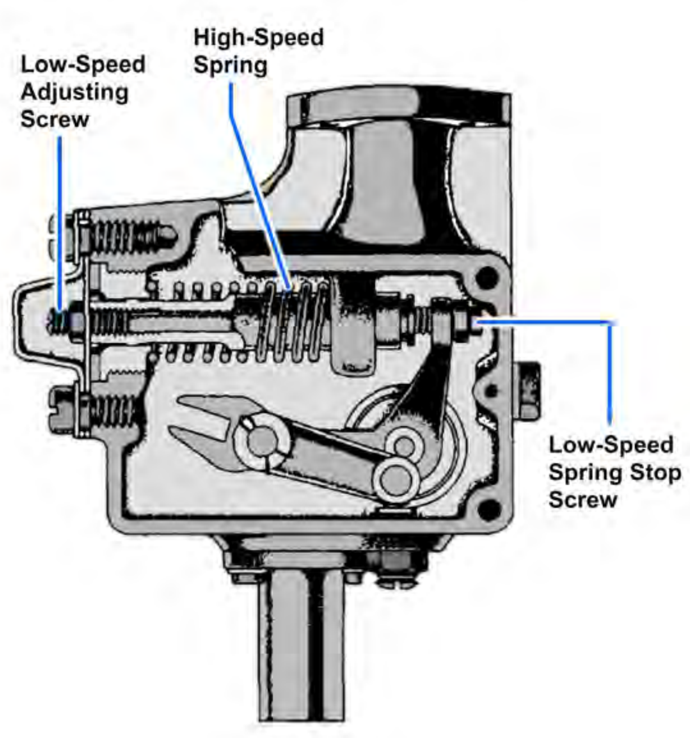

Figure 7-3 — Mechanical governor control mechanism.

The weights achieve new balance as they move outward and further compress the spring. Any movement of the flyweights is reflected in a vertical change in position of link A. When the load is increased on the engine, the fuel injected will be inadequate for the increased load and the engine will slow down. The centrifugal force of the flyweights will then decrease and permit the former balanced spring force to move link A down until the new flyweight position again is balanced by the spring. Note that the linkage movement causes an increase in fuel when the load is increased and a decreased supply of fuel as the load is reduced. From this discussion, it is evident that the mechanical governor controls the fuel supply by virtue of the flyweight position.

Mechanical governor faults are usually revealed in speed variations. But not all speed variations are faults of the governor. When abnormal speed variations appear, perform the following procedures:

1. Check the load to be sure the speed changes are not the result of load fluctuations.
2. If the load is steady, check the engine to make sure all the cylinders are firing properly.
3. Make sure there is no binding in the governor mechanism or operating linkage between the governor and the engine. There should be no binding in the injector control rack shaft or its mounting brackets. If you find no binding anywhere and the governor still fails to control the engine properly, you may assume that the governor is worn or inoperative.

If the governor is the cause of improper speed variations, it must be completely disassembled, inspected, and rebuilt or replaced. When it is necessary to disassemble and reassemble the governor, secure a copy of the manufacturer's instruction book and follow the instructions given. During reassembly of the governor, use only hard grease on the gasket. Under NO circumstances, use shellac on the gasket. Adjustment procedures for the replacement of any governor are listed in the manufacturer's instruction manual. Follow them with particular attention to the precautions listed.

Hydraulic Governors

Hydraulic governors are speed-sensitive elements; the hydraulic governor, as shown in *Figure7-4*, depends on a flyweight arrangement similar to that of the mechanical governor. However, the power supply that moves the fuel mechanism is operated hydraulically rather than through direct mechanical linkage with the flyweights. Hydraulic governors are used in many applications because they are more sensitive and have greater power to move the fuel control mechanism of the engine. The flyweights of the hydraulic governor are linked directly to a small pilot valve that opens and closes ported passages, admitting oil under pressure to either side of a power piston linked to the fuel control mechanism. Since the flyweights move only a lightweight pilot valve, the inherent design of the hydraulic governor is more sensitive to small speed changes than the design of the mechanical type of governor, which derives all of its working power from the flyweights. The larger and heavier the fuel control mechanism, the more important it is to employ a hydraulic governor. The fuel control mechanism is a piston that is acted upon by fluid pressure, generally oil, under the pressure of a pump. With appropriate piston size and oil pressure, the power of the governor at its output shaft (work capacity) can be made sufficient to operate the fuel-changing mechanism of the largest engines. The speed-measuring device, through its speeder rod, is attached to a small cylindrical valve, called a pilot valve. The pilot valve slides up and down in a bushing that contains ports that control the oil flow to and from the servomotor. The force needed to slide the pilot valve is very little; a small ball head is able to control a large amount of power at the servomotor.

The basic principle of a hydraulic governor is very simple. When the governor is operating at control speed or state of balance, the pilot valve closes the port and there is no oil flow. When the governor speed falls due to an increase in engine load, the flyweights move inward and the pilot valve moves down. This movement opens the port to the power piston and connects the oil supply of oil under pressure. The oil pressure acts on the power piston, forcing it upward to increase the fuel.

Manufacturers state that 50 percent of all governor troubles are caused by dirty oil. For this reason, take every precaution to prevent the oil from becoming contaminated. Most hydraulic governors use the same type of oil used in the engine crankcase provided it is absolutely clean and does not foam. Change the oil in the governor at regular intervals, depending upon the type of operation. But regardless of the operation or the preventive maintenance schedule, change it at least every 6 months. Make sure the oil containers used to fill the governors are clean and that only clean, new, or filtered oil is used. Also, check the oil level frequently to make sure the proper level is maintained and the oil does not foam. Foaming oil is usually an indication that water is present in the oil. Water in the oil will cause serious damage to the governor.

There is always a lag between a change in fuel setting and the time the engine reaches the new desired speed. The cause of this hunting is the unavoidable time lag between the moment the governor acts and the moment the engine responds. Even when the fuel controls are set as required during a speed change, hunting caused by overshooting will occur. As long as engine speed is above or below the desired new speed, the simple hydraulic governor will continuously adjust (overcorrect) the fuel setting to decrease or increase the delivery of fuel. The engine cannot come back to the speed called for by the governor. Most hydraulic governors use a speed droop to obtain stability. Speed droop gives stability because the engine throttle can take only one position for any speed. Therefore, when a load change causes a speed change, the resulting governor action ceases at the particular point that gives the amount of fuel needed for a new load. In this way speed droop prevents unnecessary governor movement and overcorrection (hunting). For this reason, a hydraulic governor must have a mechanism that will discontinue changing the fuel control setting slightly before the new setting has actually been reached. This mechanism, used in all modern hydraulic governors, is called a compensating device. One type of compensating device is illustrated in *Figure 7-5*. The buffer piston, buffer springs, and needle valve in the hydraulic circuit between the control land of the pilot valve plunger and the power piston comprise the buffer compensating system of the governor. Lowering the pilot valve plunger permits a flow of pressurized oil into the buffer cylinder and power cylinder.

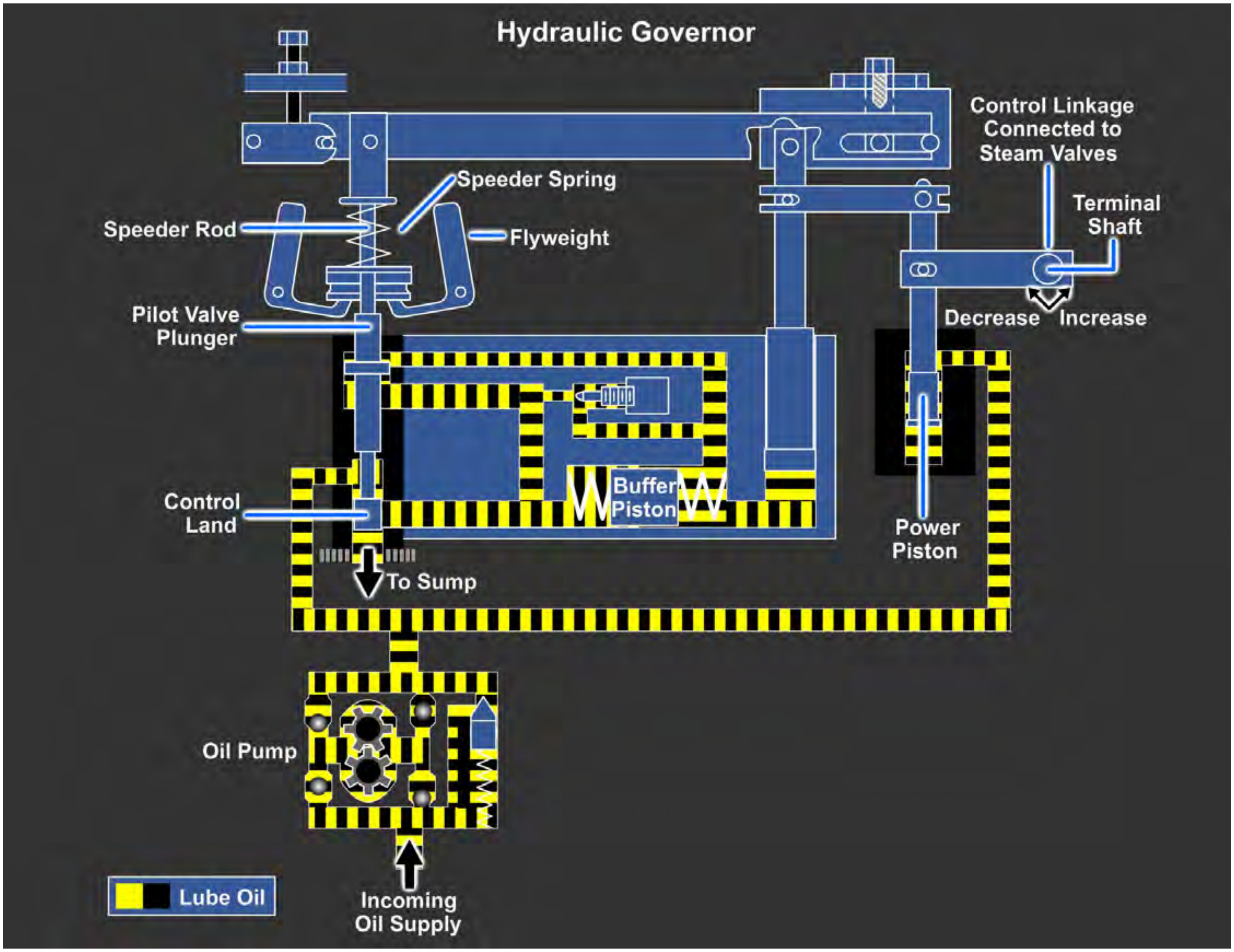

Figure 7-4 — Hydraulic governor with compensating device.

> **NOTE**
>
> When a governor problem is suspected, before performing any maintenance or adjustments, disconnect the governor fuel rod end from the fuel control rack and make sure there is no binding or sticking of the fuel control rack. This procedure will determine if the trouble is actually the governor

This flow of oil moves the power piston up to increase fuel. As the pilot valve plunger moves up, oil is permitted to flow from the buffer cylinder and power cylinder to the governor sump, and the power piston spring moves the power piston down to decrease fuel. The rate of compensation is adjusted by regulating the oil leakage through the compensating needle valve. If the compensating needle valve is adjusted correctly, only a slight amount of hunting will occur after a load change. This hunting will quickly be dampened out, resulting in stable operation through the operating range of the governor.

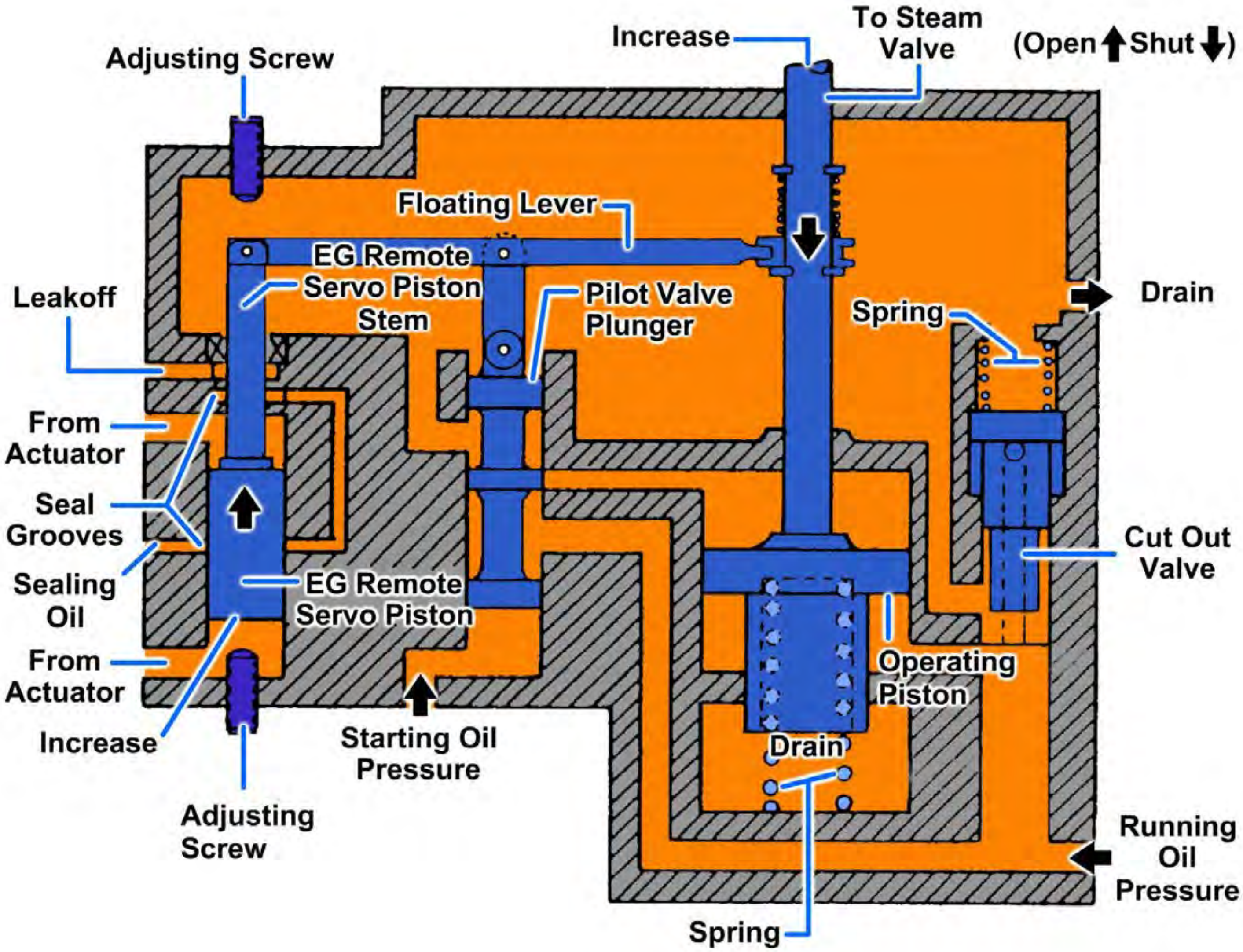

Figure 7-5 — Mechanical diagram of hydraulic governor.

When a new or overhauled governor is installed, adjust the governor compensating needle valve (even though it has been adjusted previously at the factory or repair facility). This adjustment is made with the governor controlling an engine with a load. If this adjustment is not made, high overspeeds and low underspeeds after load changes will result, and the return to normal speeds will be slowed. Follow the procedure listed in the manufacturer's maintenance manual and the PMS.

Overspeed Safety Devices

Engines that are maintained in proper operating condition seldom reach speeds above those for which they are designed. However, conditions may occur to cause excessively high operating speeds, such as when a ship's propeller comes out of the water in rough seas. Operation of a diesel engine at excessive speeds is extremely dangerous because of the relatively heavy construction of the engine's rotating parts. A high-speeding engine develops inertia and centrifugal forces that may seriously damage parts or even cause them to fly apart. You must know why an engine may reach a dangerously high speed and how to bring it under control when excessive speed occurs.

In some two-stroke cycle engines, lubricating oil may leak into the cylinders as a result of leaky blower seals or broken piping. Even though the fuel is shut off, the engine may continue to operate, or even "run away," as a result of the combustible material coming from the uncontrolled source.

Engines in which lubricating oil may accumulate in the cylinders generally have an automatic mechanism that shuts off the intake air at the inlet passage to the blower. If there is no air shutoff mechanism and if shutting off the fuel will not stop an engine that is overspeeding, place a cloth article such as a blanket or a pair of dungarees over the engine's intake to stop airflow. This action will subsequently stop the engine.

Excessive engine speeds are more commonly found where there is an improperly functioning regulating governor than where lubricating oil accumulates in the cylinders. To stop an engine that is overspeeding because of lubricating oil in the cylinders, stop the flow of intake air. To accomplish an emergency shutdown or reduction of engine speed when the regulating governor fails to function properly, shut off or decrease the fuel supply to the cylinders.

NOTE

If the engine overspeeds and exceeds its rated rpm trip settings, internal inspection of the engine must be accomplished before the engine is restarted.

NOTE

Overspeed safety devices must always be operative and must never be disconnected for any reason while the engine is operating. All overspeed safety devices should be tested under the Planned Maintenance System (PMS).

You can shut off the fuel supply to the cylinders of an engine in several ways, either manually or automatically:

1. Force the fuel control mechanism to the NO FUEL position.
2. Block the fuel line by closing a valve.
3. Prevent the mechanical movement of the injection pump.

Overspeed safety devices automatically operate the fuel and air control mechanisms. As emergency controls, these safety devices operate only when the regular speed governor fails to maintain engine speed within the maximum design limit. Devices that bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply are generally called overspeed trips. Devices that reduce the excessive speed of an engine, but allow the engine to operate at safe speeds, are more commonly called overspeed governors.

All overspeed governors and trips operate on a spring-loaded centrifugal governor element. In overspeed devices, the spring tension is great enough to overbalance the centrifugal force of the weights until the engine speed rises above the desired maximum. When the engine speed reaches the setting of the governor, the centrifugal force overcomes the spring tension and operates the mechanism that stops or limits the fuel or air supply. Overspeed governors are designed to prevent the engine from exceeding a specific maximum speed.

When a governor serves as a safety device, the fuel or air control mechanism is operated by the centrifugal force either directly, as in a mechanical governor, or indirectly, as in a hydraulic governor. In an overspeed trip, the shutoff control is operated by a power spring. The spring is placed under tension when the trip is manually set and is held in place by a latch. If the maximum speed limit is exceeded, a spring-loaded centrifugal weight will move out and trip the latch, allowing the power spring to operate the shutoff mechanism.

Mechanical overspeed trips depend upon the centrifugal forces developed by the engine and must be maintained in good working condition. A faulty overspeed device can endanger not only the engine but also the personnel. The engine could explode or fly apart because of the uncontrolled speed. The engine instruction manual contains information as to the speed at which the overspeed device is designed to function. Most overspeed trips are adjustable. Before making any changes in the adjustment of the overspeed trip, you must determine the cause. If the engine did not trip out, was it for some reason other than the action of the element of the overspeed trip? First check the accuracy of the tachometer and then test the overspeed trip. Remember that all spring tension and linkage adjustments to an overspeed are critical. Instructions for these adjustments are found in the manufacturer's instruction manual. You MUST follow these instructions.

Hydraulic overspeed trips are extremely sensitive to dirt. Dirt or lacquer-like deposits may cause the trip to bind internally. The speed-sensitive element and all parts of the linkage and mechanisms incorporated with the speed-sensitive element must be kept clean. When painting around the engine, you must avoid allowing paint to fall on joints, springs, pins, or other critical points in the linkage.

The overspeed trip will not function properly if parts are bent, badly worn, improperly installed, or dirty, or if their motion is restricted by some other part of the engine. In some situations the driveshaft of the overspeed trip may be broken; this would prevent rotation of the flyweight and the overspeed trip. Insufficient oil in the hydraulic trip may be another source of trouble. Maintain a proper oil level as specified by the instruction manual.

BASIC CARE OF THE GOVERNOR

Contaminants and foreign matter in the governor oil are the greatest single source of governor troubles. Use only new or filtered oil. Be sure that all containers used for the governor oil are clean. The time interval between governor oil changes depends upon many factors: type of service, operating temperature, quality of oil, and so forth. Anytime the governor oil appears to be dirty or breaking down from contaminants or excessive temperatures, drain the governor while it is hot; flush it with the lightest grade of the same oil, and refill it with fresh oil. In any event, follow the PMS for regular oil drain intervals.

A governor should operate several years before needing replacement if it is kept clean and if the drive from the engine is smooth and free from torsional oscillations. Except for isolated cases, so rare they can be almost disregarded, governors do not suddenly fail or break down (*Table 7-2*). Instead, they wear gradually and give an external indication of their condition in the form of slight hunting, sluggish operation, and so forth. Further deterioration is at a slow enough rates that an exchange governor may be ordered for installation and the governor changed out at a convenient downtime.

The following are some general procedures to keep the overspeed safety devices in proper operation:

- Keep the overspeed trip and its linkage clean.
- Remove the source of binding.
- Replace faulty parts.
- Maintain a proper oil level in the hydraulic overspeed trip.
- Adjust the speed-sensitive element according to the instruction manual.
- If the trip has been damaged, replace it with a spare and completely rebuild or overhaul the damaged one according to the instruction manual.

Table 7-2 — Common problems with governors

PROBLEM	CAUSE	CORRECTIVE ACTION
Engine hunts or surges.	Compensating needle valve adjustment incorrect.	Make needle valve adjustment; ensure that the opposite needle valve is closed.
	Dirty oil in governor.	Drain oil; flush governor; refill.
	Low oil level.	Fill to correct level with clean oil.
	Foamy oil in governor.	Drain oil; refill.
	Lost motion in engine governor linkage or fuel pumps.	Repair linkage and realign pumps.
	Governor worn or incorrectly adjusted.	Remove governor and make internal checks for clearances according to applicable instructions.
	Engine misfiring.	Test and replace injectors.
	External fuel linkage sticking or binding.	Disconnect fuel rack from governor and manually move linage and progressively disconnect fuel pump links until binding area is found (dirt, paint, and misalignment are the usual causes of binding.
Governor rod end jiggles	Rough engine drive.	Check alignment of gears; inspect for rough gear teeth; check backlash of gear.
	Governor base not bolted down evenly	Loosen bolts; realign and secure.

Test overspeed trips and governor mechanisms once each quarter and after each major engine overhaul. To verify if the safety device is in proper working order, overspeed the engine. When you are making this test, use a tachometer to check the speed at which the overspeed mechanism will operate. These safety devices should operate at the speed specified in the engine instruction manual. If this information is not available, use the following values for the test:

- For large, slow-speed engines, the value is 107 percent maximum-rated speed.
- For high-speed engines, the value is 110 percent maximum-rated speed.

If there is any irregularity during testing, stop the test, check the overspeed safety device, and correct the problem before continuing the test procedure.

SUMMARY

The control of the engine speed is dependent on speed-sensitive devices known as governors. There are two basic types of governors, mechanical and hydraulic. The mechanical governor is used when extremely sensitive operation is not required. The hydraulic governors are more sensitive to speed variations.

This chapter has presented several common facts in maintenance, repair, and overhaul of speed controlling devices. Maintenance personnel must secure the appropriate manufacturer's instruction manual. Do not make any repair, maintenance, or overhaul of these precision pieces of equipment until you obtain the appropriate manual. You must read, understand, and strictly follow the instructions from the manufacturer. Be sure to pay particular attention to any safety precautions in those instructions.

End of Chapter 7

Speed Controlling Devices

Review Questions

7-1. What term means the decrease in speed of the engine from no-load condition to a full load condition?

A. Jiggles
B. Isochronous governing
C. Hunting
D. Speed Droop

7-2. What term means the rhythmic variations of speed of large magnitude that can be eliminated by blocking the fuel linkage manually?

A. Hunting
B. Promptness
C. Surges
D. Stability

7-3. What controls the speed of a diesel engine that has mechanical governors?

A. Throttle setting
B. Spring pressure
C. Fuel delivery
D. Adjusting screw

7-4. How does the hydraulic oil reach the power piston of the hydraulic governor?

A. Through a small pilot valve
B. Oil leakage from the compensating needle
C. Through the buffer cylinder
D. Gravity from the oil sump

7-5. If an engine overspeeds and exceeds its rated revolutions per hour (RPM) trip setting, what must you do before restarting it?

A. Reset overspeed trips and restart engine
B. Able to restart engine immediately, no action required
C. Conduct internal inspection prior to restart engine
D. Get permission from ship’s Engineering Officer to restart engine

7-6. All of the following factors are considered when determining the time interval between governor oil changes EXCEPT which one?

A. Flashpoint of the oil
B. Type of service the oil is going to be used for
C. Operating temperature of the oil
D. Quality of the oil

7-7. What is the maximum rated speed percent for large, slow-speed engines' safety devices to operate at?

A. 10
B. 49
C. 107
D. 150

7-8. What would an incorrectly adjusted compensating needle valve cause in an engine?

A. Speed droop
B. Surges
C. Jiggles
D. Isochronous governing

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CHAPTER 8

ENGINE DRIVE MECHANISMS

Frequently, the source of power that operates one engine part is also the source of power for other parts and accessories of the engine. The source of power that operates engine valves may also be the source of power that operates such items as the governor; fuel, lubricating, and water pumps; and overspeed trips. Since mechanisms that transmit power to operate specific parts and accessories may be related to more than one engine system, we will discuss drive mechanisms before getting into the engine systems.

After reading the information in this chapter, you should be able to recognize the basic design, function, and arrangement of various parts associated with drive mechanisms of 2-stroke and 4-stroke cycle diesel engines.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify the drive mechanism for a 2-stroke cycle, in-line diesel engine.
2. Identify the drive mechanism for a 2-stroke, V-type diesel engine.
3. Identify the drive mechanism in an opposed-piston engine.
4. Identify the drive mechanism in a 4-stroke cycle diesel engine.

DRIVE MECHANISMS FOR A 2-STROKE CYCLE, IN-LINE DIESEL ENGINE

Drive mechanism identifies the group of parts that takes power from the crankshaft and transmits that power to various engine components and accessories. The drive mechanism does not change the type of motion, but it may change the direction of motion. For example, the impellers of a blower are driven or operated by a rotary motion from the crankshaft transmitted to the impellers by the drive mechanism, an arrangement of gears and shafts. While the type of motion (rotary) remains the same, the direction of motion of one impeller is opposite that of the other impeller as a result of the gear arrangement within the drive mechanism.

A drive mechanism may be a gear, chain, or belt type. The gear type is the most common. Some engines use chain assemblies or a combination of gears and chains as the driving mechanism. Belts are not common on marine engines, but are used as drive mechanisms on gasoline engines.

Some engines have a single-drive mechanism that transmits power to operate engine parts and accessories. In some engines, there may be two or more separate mechanisms. When separate assemblies are used, the one that transmits power to operate the accessories is called the accessory drive. Some engines have more than one accessory drive. A separate drive mechanism that serves to transmit power to operate engine valves is generally called the camshaft drive or timing mechanism. The camshaft drive, as the name implies, transmits power to the camshaft of the engine. The shaft, in turn, transmits the power through a combination of parts which causes the engine valves to operate. Since the valves of an engine must open and close at the proper moment (with respect to the position of the piston) and remain in the open and closed positions for definite periods of time, a fixed relationship must be maintained between the rotational speeds of the crankshaft and the camshaft. Camshaft drives are designed to maintain the proper relationship between the speeds of the two shafts. In maintaining this relationship, the drive causes the camshaft to rotate at crankshaft speed in a 2-stroke cycle engine and at one-half crankshaft speed in a 4-stroke cycle engine.

There is considerable variation in the design and arrangement of the parts of drive mechanisms found in different engines. The size of an engine, the cycle of operation, the cylinder arrangement, and other factors govern the design and arrangement of the components as well as the design and arrangement of the mechanisms. Some of the variations in drive mechanisms are considered in the descriptions and illustrations that follow. The arrangements of the drive mechanisms described in this chapter are represented of those commonly found in marine engines used by the Navy.

In some engines, the operating mechanisms consist of a single-drive mechanism. A complete assembly that transmits power from the driving part to the driven part, the operating mechanism consists of gears, shafts, and couplings.

Gears

When the driving mechanism of an engine consists only of gears, the mechanism is commonly called a gear train. In a gear train, the gears must be accurately cut and heat-treated to resist wear. Helical teeth (teeth placed at an angle) are frequently used in place of spur teeth (teeth placed straight) for greater quietness and more uniform transmission of power. Gears and shafts are used in various arrangements to drive the vital components and accessories of the engine.

The arrangement shown in *Figure 8-1* is designed for right-hand rotation, and it functions as both the camshaft drive and the accessory drive. The train consists of five helical gears completely enclosed at the rear end of the engine. Note that all gears are driven by the crankshaft gear through an idler gear. An idler gear is placed between two other gears to transfer motion from one gear to the other without changing their direction. In *Figure 8-1,* the idler gear may be located on either side of the engine, depending upon the direction of the crankshaft's rotation, (locate the spacer, or "dummy hub"). The use of a single idler gear is shown in *Figure 8-2.*

Since the engine operates on a 2-stroke cycle, the camshaft and balancer gears are driven at the same speed as the crankshaft gear. Either the camshaft gear or the balancer gear may be driven by the crankshaft gear through the idler gear; the drive arrangement depends on the model (right or left-hand rotation). The camshaft and balance shaft gears are counterweighted for balance purposes.

The accessories receive power from the blower drive gear, which is driven by the camshaft gear (*Figure 8-1*). Located on the blower side of the engine and supported by the rear end plate, the blower drive gear transmits power to the blower, governor, water pump, and fuel pump, as shown in *Figure 8-3*. *Figure 8-3* also shows the location of the various engine accessories and the shafts, gears, and couplings that transmit the power from the blower drive gear to each of the accessories.

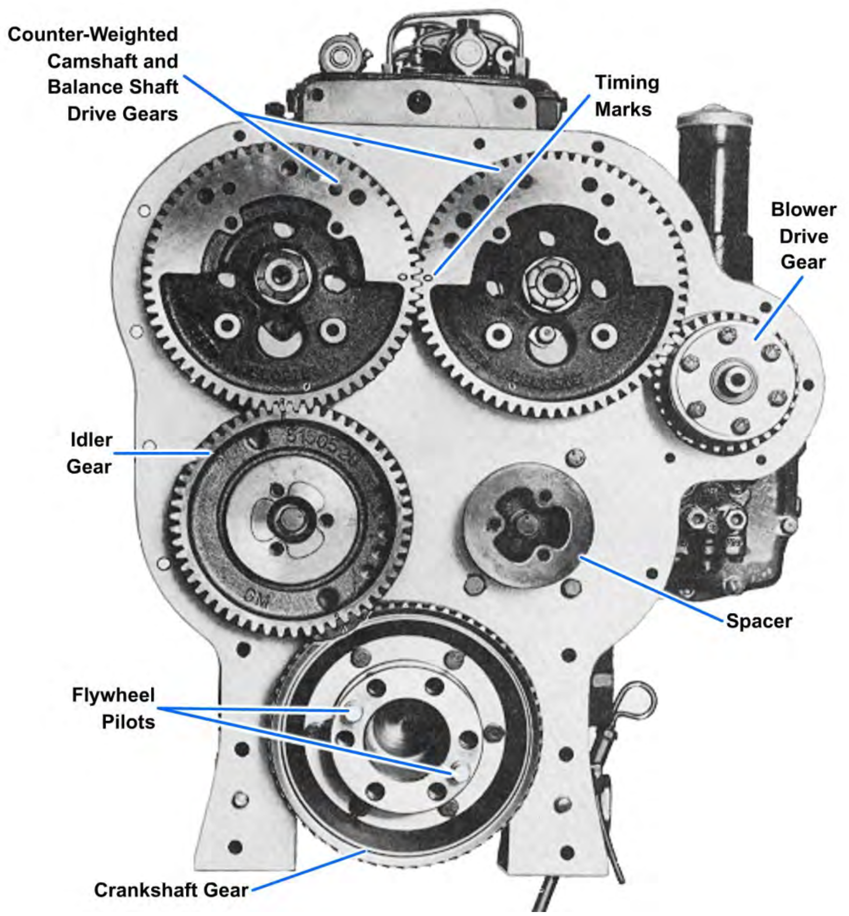

Figure 8-1 — Camshaft and accessory drive.

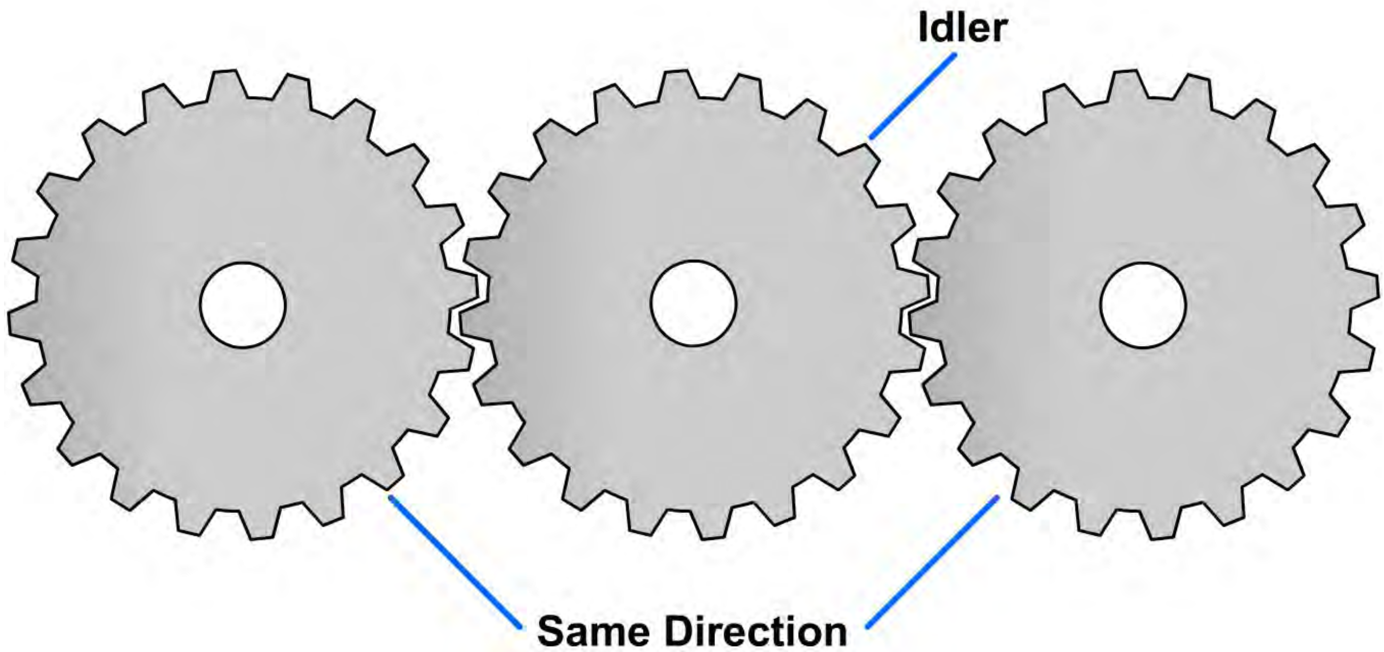

Figure 8-2 — Idler gear.

The blower end of the governor drive shaft is serrated or splined, and it engages with corresponding serrations or splines inside the upper blower shaft. The fuel pump is bolted to the rear cover of the blower and is driven from the lower blower rotor shaft through a device that acts as a universal joint. The water pump is mounted on the front end of the blower and is driven by the rotor shaft, through a coupling (*Figure 8-3).*

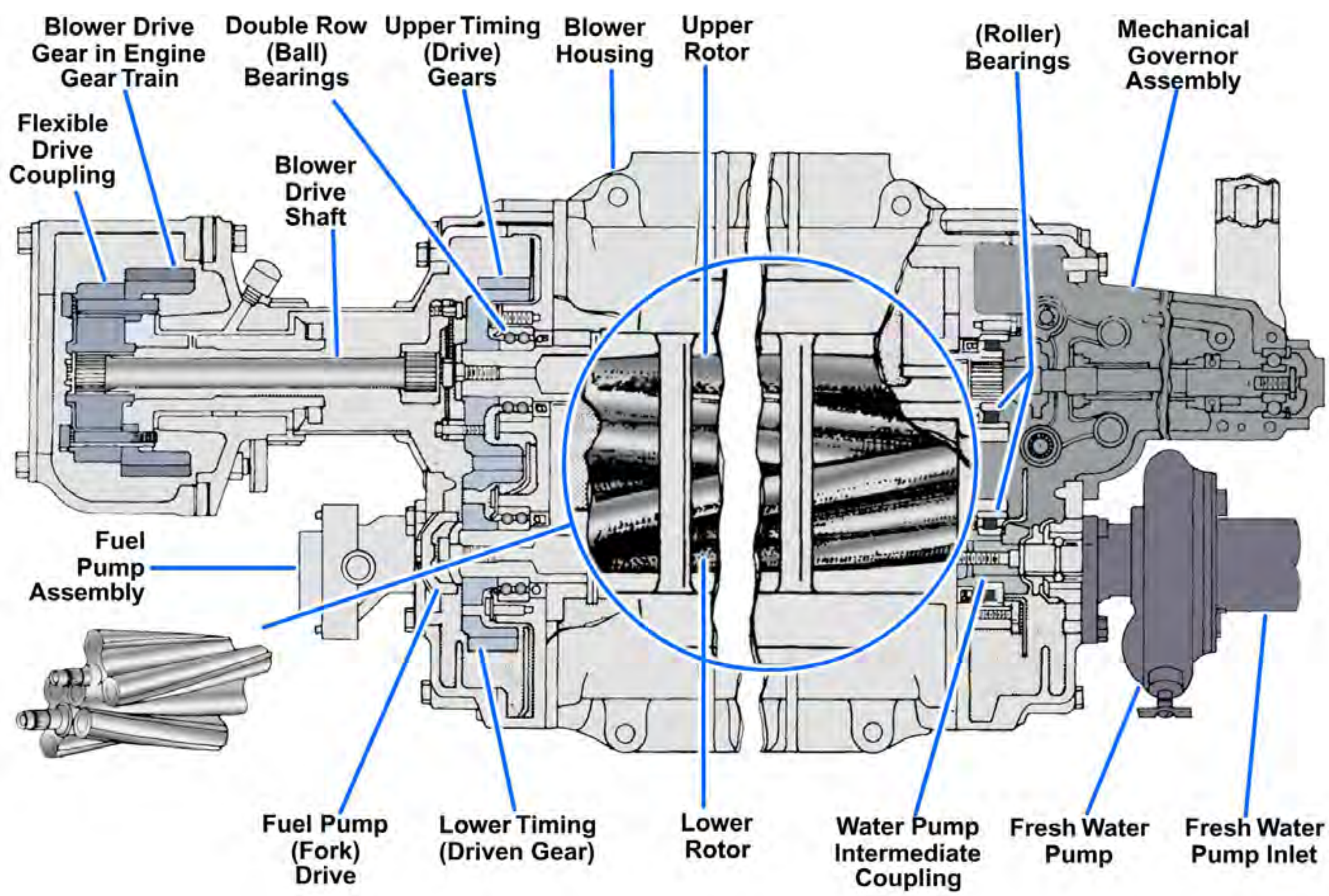

Figure 8-3 — Blower, drive assembly, and accessories. Mechanical governor attached.

DRIVE MECHANISMS FOR A 2-STROKE CYCLE, V-TYPE DIESEL ENGINE

The in-line engine discussed in the preceding section requires only one drive mechanism (gear train) to transmit power to the valve actuating gear and engine accessories. Our discussion will now cover an engine that uses two separate gear drives (gear trains), one at each end of the engine. The front gear train, shown in *Figure 8-4,* consists of a crankshaft gear and two idler gears. The idler gears serve to drive the water pump (not shown) and balance the engines. (See balance weights.) The rear gear train (*Figure 8-5)* consists of a crankshaft gear, three idler gears, and two camshaft gears. The rear idler gears, like the front, also serve to balance the engine. (See balance weights.) The two other gears that are mounted on the rear of the engine, as shown in *Figure 8-5*, are the accessory drive gear and the blower drive gear.

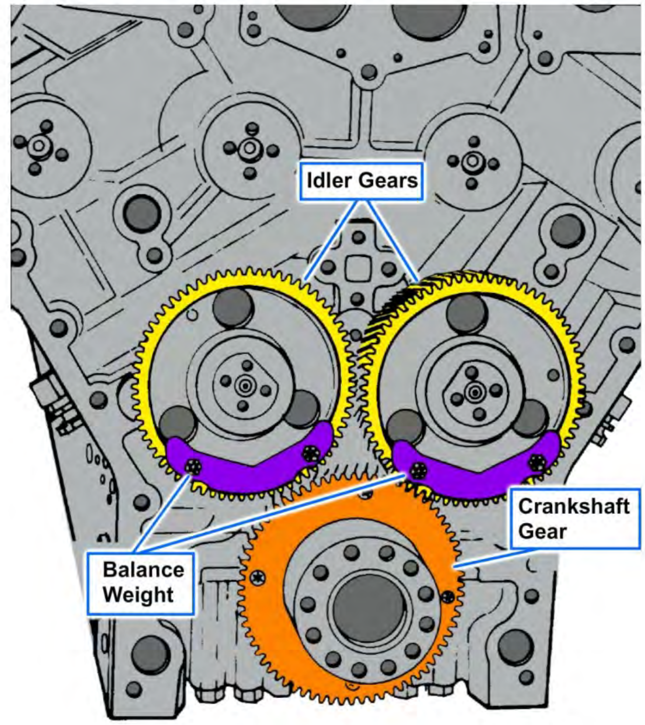

Figure 8-4 — Front gear train.

The correct relationship between the crankshaft and the two camshafts must be maintained so that the fuel injection, the opening and closing of exhaust valves, and the engine balance can be properly controlled. Since the camshaft must be in time with the crankshaft, timing marks are stamped on the face of the gears to facilitate correct gear train timing. The timing marks stamped on various gears are shown in *Figures 8-1 and 8-6*. When an engine is assembled, whether it is a 2-stroke or 4-stroke cycle engine, it is important that the appropriate timing marks be lined up on the gears as each gear is installed.

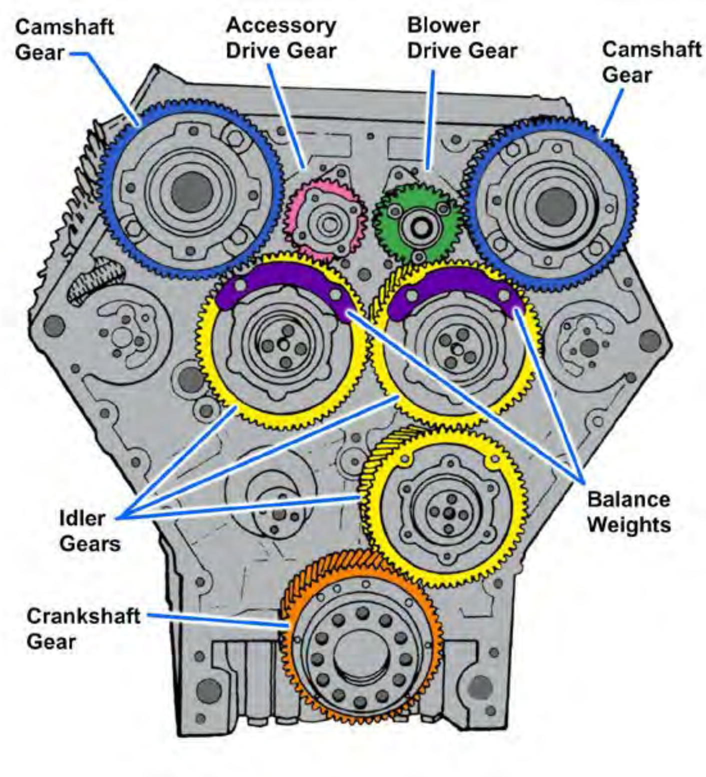

Figure 8-5 — Rear gear train.

DRIVE MECHANISMS IN AN OPPOSED-PISTON ENGINE

The drive mechanisms of an opposed-piston engine will obviously differ, to a degree, from those of single-acting engines because of design differences. Some of the differences are because:

- Power is supplied by two crankshafts in an opposed-piston engine, instead of one.
- The camshaft drives of the engines we have discussed thus far supply power to one or more accessories as well as to the valve-actuating gear. This is not true of the camshaft in an opposed piston engine, since ports are used instead of valves for both intake and exhaust.

Regardless of differences in mechanisms, the basic types of drives, gear and chain, are found in both single-acting and opposed piston engines. While the two engines described in preceding sections had only gear-type drive mechanisms, the opposed-piston engine used as an example in this section has chain assemblies as well as gear trains incorporated in the mechanisms that supply power to engine parts and accessories.

The Fairbanks-Morse (FM) opposed-piston engine has three separate drive mechanisms. The drive that furnishes power to the camshaft and fuel-injection equipment is the chain type. The blower and the accessories are operated by gear type drives. The location of each drive is shown in *Figure 8-7*.

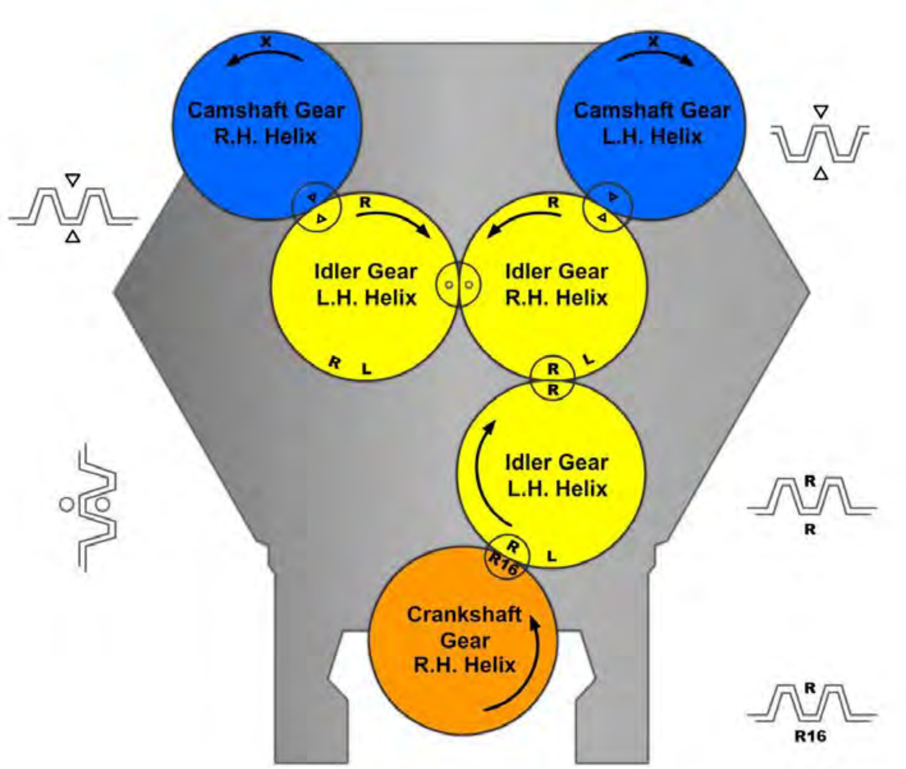

Figure 8-6 — Rear gear train timing marks.

Camshaft Drive-Actuating Gear

The opposed-piston engine does not have cylinder valves; since two other drives are provided to operate the accessories, the primary purpose of the camshaft drive is to transmit power for, and to time the operation of, the fuel injection pumps. The camshafts are located in the upper crankshaft compartment (*Figure 8-7).* The shafts turn at the same rate of speed as the crankshaft.

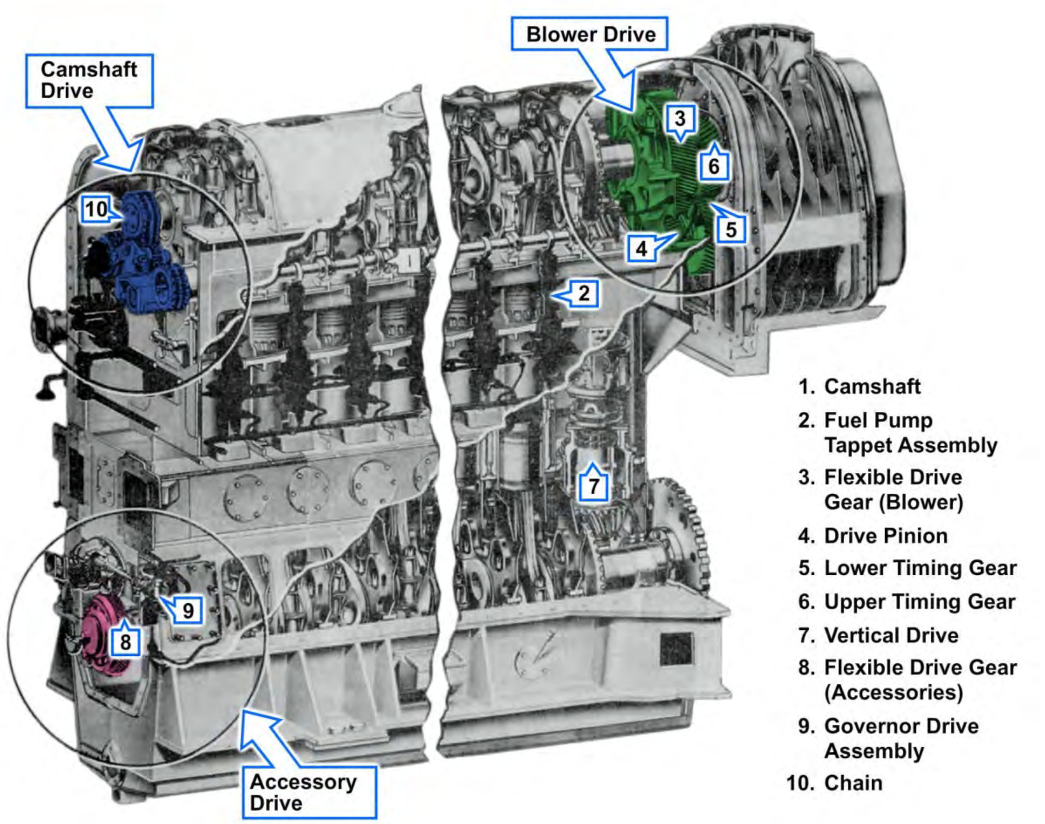

Figure 8-7 — Location of drive mechanisms in an opposed-piston engine (Fairbanks-Morse 38D8 1/8).

Chain Assembly

The power required to operate the fuel injection pumps at the proper instant during the cycle of operation is transmitted through the camshafts from the crankshaft by a chain drive (frequently called the timing mechanism). The names and arrangement of the components of the drive are shown in *Figure 8-8.* The drive sprocket is attached to the upper crankshaft at the control end of the engine. A sprocket is attached to the end of each camshaft, and there are three other sprockets for timing and adjustment purposes.

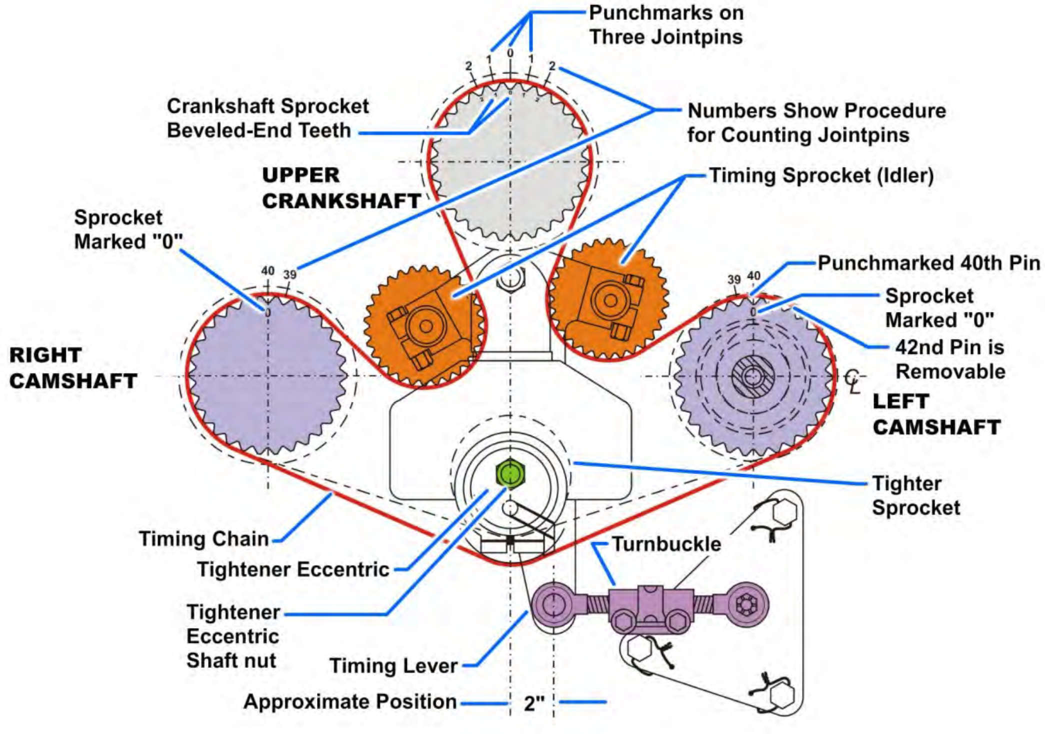

Figure 8-8 — Camshaft drive and timing mechanism.

The chain conveys the rotation of the upper crankshaft to the camshaft sprockets by passing over the crankshaft sprocket, under the two timing sprockets, over the two camshaft drive sprockets, and under the tightened sprockets. The timing sprockets are mounted on an adjustable bracket or lever. By moving the lever, the timing of the two camshafts can be adjusted. The adjustable tightened sprocket is used to obtain and maintain the proper slack in the chain.

Blower Drive Mechanism

The power to drive the blower is transmitted from the upper crankshaft, through a gear train (*Figure 8-7*). The train consists of a drive gear, a pinion gear, and the two timing (impeller) gears of the blower.

The drive gear is the flexible type (*Figure 8-7*). The principal parts of the flexible drive gear are a spider drive hub (which is keyed to the crankshaft), a gear (within which spring spacers are bolted), and springs (which absorb torsional oscillations transmitted by the crankshaft). The flexible drive gear with end plate removed and the spider drive hub is shown in *Figure 8-9*.

The flexible drive gear meshes with the drive pinion (*Figure 8-7*). The pinion is keyed to the lower impeller shaft and held in place by a locknut. The lower impeller driving (timing) gear meshes with the upper impeller driven gear (*Figure 8-7*).

Accessory Drive Mechanism

The majority of the accessories for the FM 38D8 are driven by a gear mechanism that receives power from the lower crankshaft at the control end of the engine (*Figure 8-7*). A more detailed view of the accessory drive is shown in *Figure 8-10*. Referring to both these figures as you read the following description will help you become familiar with the components of the drive and with the way that power is transmitted to the driven units.

The accessory drive transmits power to the water pumps, the fuel oil pump, the lubricating oil pump, and the governor. The drive gear (*Figure 8-7*) of the mechanism is bolted to a flange on the crankshaft. The drive gear is the flexible type; therefore, engine shocks transmitted by the crankshaft are absorbed by the drive springs of the gear.

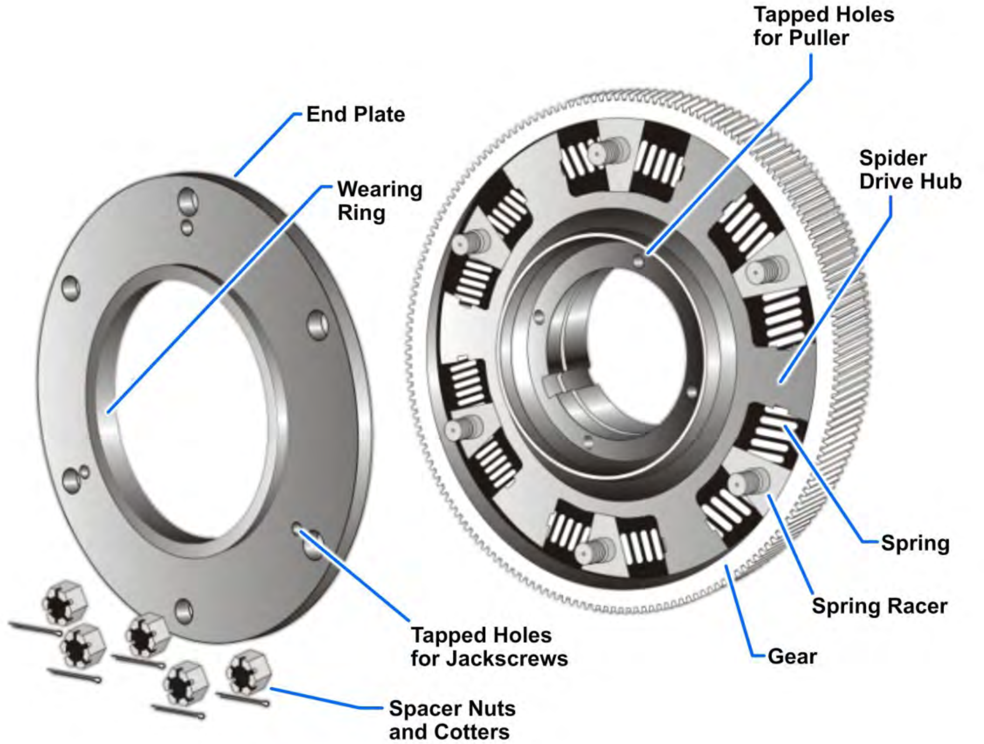

Figure 8-9 — Blower flexible drive gear.

The water pump drive gears mesh directly with the flexible drive gear. The fuel pump drive gear (attached to the flexible drive gear) transmits power to the fuel pump driven gear through an idler, the fuel pump driven gear on the mounting plate in *Figure 8-10*. The lubricating oil pump drive gear meshes directly with the flexible drive gear. Power is transmitted to the pump through a shaft and an internal gear coupling—the lubricating oil pump drive. The shaft of the lubricating oil pump drive also transmits power to the governor. A gear on the shaft meshes with a mating gear on the governor drive gear shaft. This shaft drives the governor coupling shaft which, in turn, drives the governor, through a beveled gear drive (*Figure 8-7*).

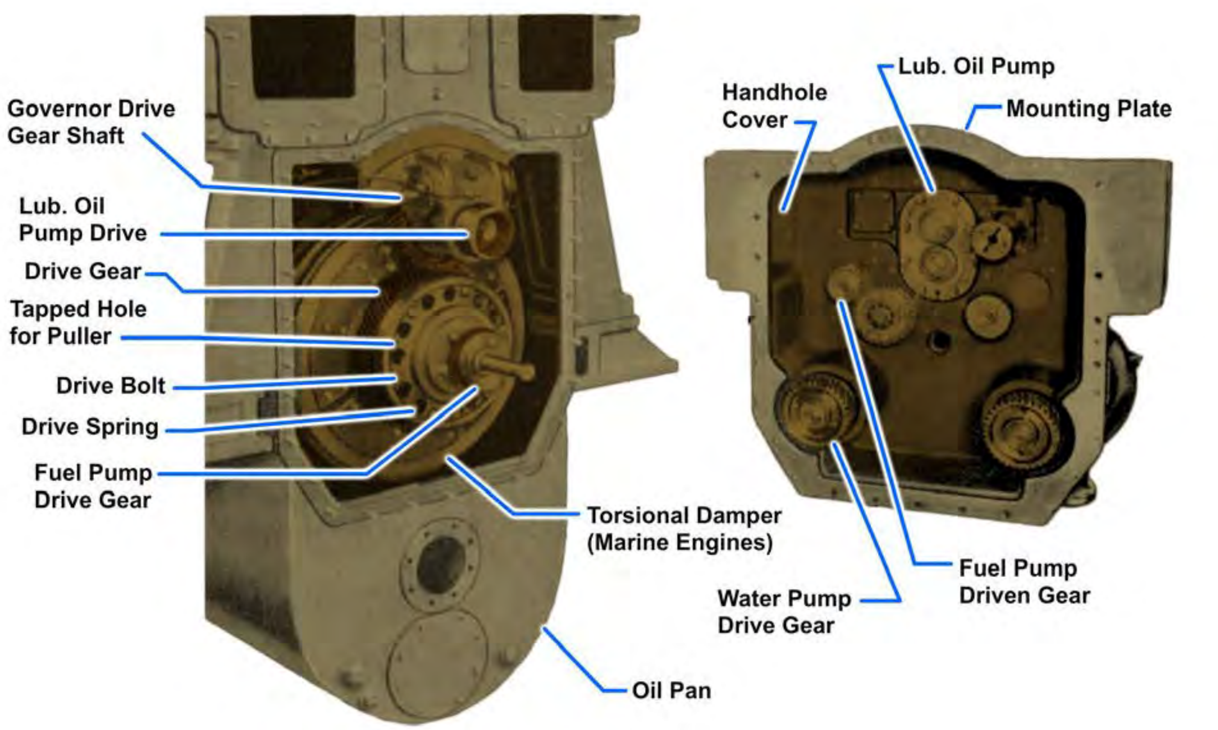

Figure 8-10 — Accessory drive (Fairbanks-Morse 38D8 1/8).

DRIVE MECHANISMS IN A 4-STROKE CYCLE DIESEL ENGINE

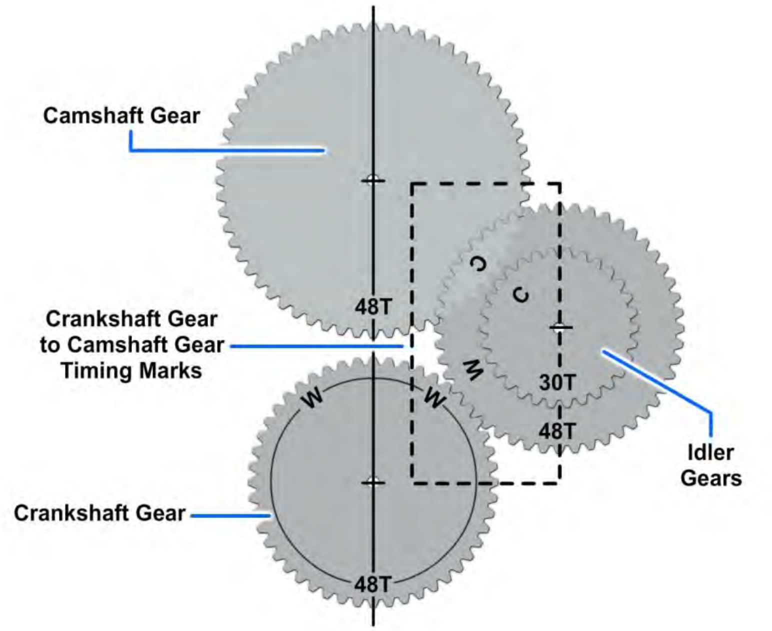

Figure 8-11 — Gear train of a 4-stoke cycle engine showing gear ratio.

The drive mechanisms we have discussed so far have applied to 2-stroke cycle engines. We will now take a look at a gear train of a 4-stroke cycle engine (*Figure 8-11*). The gear train for the 4-stroke cycle engine is different from that of the 2-stroke cycle engine for two reasons. The first reason is that there is no provision for the driving of a blower since 4-stroke cycle diesel engines are either naturally aspirated or are turbocharged. Turbocharging units are exhaust driven and require no mechanical drive. Another difference is the need for gear reduction in a 4-stroke cycle engine between the crankshaft and the camshaft. In a 4-stroke cycle engine, the camshaft speed must be exactly one-half the crankshaft speed. Remember, in a 4-stroke cycle engine, the crankshaft must rotate 720° for each power event per cylinder. The method by which the required 2:1 gear reduction is accomplished is by the use of one or more idler gears between the crankshaft gear and the camshaft gear. Refer to *Figure 8-11* as we explain how the 2:1 gear ratio is obtained in one type of engine. If the crankshaft were to revolve 360 degrees, it would move a total of 48 teeth. This movement is transmitted to the large idler gear, which will also revolve 360 degrees, or 48 teeth. As you can see in *Figure 8-11*, a smaller idler gear with 30 teeth is mounted to the larger idler gear. This smaller gear is where the gear ratio starts to change. As the small idler gear revolves 360 degrees, or 30 teeth, it drives the camshaft gear 180 degrees, or 30 teeth. (The gear with the greater number of teeth will always revolve more slowly than the gear with the smaller number of teeth.) Thus, we now have the 2:1 ratio between the crankshaft and camshaft that is required for a 4-stroke cycle engine to operate.

Now compare the gear train of the 4-stroke cycle engine in *Figure 8-11* to that of the 2-stroke cycle gear train in *Figures 8-1 and 8-5*. You should be able to recognize the difference in these drive mechanisms.

SUMMARY

The drive mechanisms of an engine are those assemblies that transmit power for the operation of engine accessories and certain engine parts. The drive mechanisms may be a chain assembly, gear train, belts, or a combination of any of these parts. Some engines have only one drive mechanism, which is generally called the camshaft drive. Other engines may have a second major drive mechanism called the accessory drive. In most engines, each drive is generally identified by the name of the principal part or the accessory drive, such as blower drive, camshaft drive, and governor drive.

The importance of these drive-transmitting devices is evident if you consider the function of the components to which power is transmitted. The valve–actuating mechanisms control the fuel, intake air, exhaust gases, and starting air (when applicable) in the cylinders. The engine accessories that are driven are those that circulate the cooling water and lubricating oil, supply air for scavenging and supercharging, supply fuel, and control engine speed. If you are unsure as to how these drive mechanisms function, we recommend you review this chapter again.

End of Chapter 8

Engine Drive Mechanism

Review Questions

8-1. What is the drive design for the camshaft to rotate at relative to the crankshaft speed on a 4-stroke cycle diesel engine?

A. Same speed as the crankshaft
B. Twice the speed of the crankshaft
C. Half the speed of the crankshaft
D. Three times the speed of the crankshaft

8-2. Of the following variation in design and arrangements of drive mechanisms found on diesel engines, which one is NOT considered?

A. Size of engine
B. Cycle of operation
C. Cylinder arrangement
D. Number of cylinders

8-3. What kind of teeth is frequently used for more uniform transmission of power in drive mechanisms?

A. Helical
B. Herring bone
C. Spur
D. Straight

8-4. Why do the camshaft and balance gear use counterweights in the drive mechanism on the 2-stroke in-line diesel engine?

A. Maintaining proper timing
B. Balancing the camshaft and balancer gear with the crankshaft
C. Balancing the camshaft with blower gear
D. Balancing the idler and accessories gears with the camshaft gear

8-5. What component in the drive mechanism of a 2-stroke cycle diesel engine transmits power to the blower, governor, water pump, and fuel pump?

A. Camshaft gear
B. Blower driver gear
C. Fuel pump gear
D. Lube oil pump gear

8-6. What component is driven by idler gear in the front gear train of 2-stroke cycle V-type engine?

A. Fuel pump
B. Lube oil pump
C. Start air solenoid
D. Water pump

8-7. How would someone know the correct way to place the gears on the gear train for the crankshaft and camshaft?

A. Wear patterns of old gears
B. Reading the technical manual
C. Timing marks
D. All gears are universal

8-8. Of what medium is the drive constructed that furnishes power to the camshaft and fuel injection equipment on an opposed-piston diesel engine?

A. Belts
B. Chains
C. Gears
D. Wire rope

8-9. Where does the power to drive the blower come from on an opposed-piston diesel engine drive mechanism?

A. Accessory drive
B. Camshaft
C. Lower crankshaft
D. Upper crankshaft

8-10. Which of following does NOT receive power from the accessory drive gear on an opposed-piston diesel engine drive mechanism?

A. Fuel pump
B. Governor
C. Start air solenoid
D. Water pump

8-11. What must a 4-stroke cycle engine's camshaft speed be, compared to the engines crankshaft's speed?

A. The same
B. Twice
C. Half
D. Four times

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CHAPTER 9

INTAKE AND EXHAUST SYSTEMS

Combustion requires air, fuel, and heat. Certain ratios of all three are necessary if an engine is to operate. This chapter discusses air as it is required to support combustion in the cylinder of an engine, the processes of scavenging and supercharging, and the group of parts involved in supplying the cylinders of an engine with air and in removing the waste gases after combustion and the power event are finished. The engine parts that accomplish these functions are commonly referred to as the intake and exhaust systems.

After reading the information in this chapter, you should be able to describe the purposes and principles of operation of air intake and exhaust systems as well as the functions of their associated components. You should also be able to trace the path of the intake air and exhaust gases through these systems and understand the significance of scavenging and supercharging and how these processes differ in the operating cycles of two- and four-stroke engines.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the function of the engine air-intake system.
2. Explain the function of the intake system components.
3. Explain the function of the engine exhaust system.

INTAKE SYSTEMS

This section deals with intake systems of diesel engines. Most of the parts are in similar systems of gasoline engines.

Although the primary function of a diesel engine intake system is to supply the air required for combustion, the system also cleans the air and reduces the noise created by the air as it enters the engine. An intake system may include an air silencer, an air cleaner and screen, an air box or header, intake valves or ports, a blower, an air heater, and an air cooler. Not all of these parts are common to every intake system. The differences will be explained as these systems are discussed.

Scavenging and Supercharging

In the intake systems of all two-stroke cycle diesel engines and some four-stroke cycle diesel engines, a device known as a blower is installed to increase the flow of air into the cylinders. The blower compresses the air and forces it into an air box or manifold, which surrounds or is attached to the cylinders of an engine. Thus, more air under constant pressure is available as required during the cycle of operation.

The increased amount of air, a result of blower action, fills the cylinder with a fresh charge of air. During the process, the increased amount of air helps to clear the cylinder of the gases of combustion. The process is called scavenging, and the intake system of some engines, especially those operating on the two-stroke cycle, is sometimes called the scavenging system. The air forced into the cylinder is called scavenge air, and the ports through which it enters are called scavenge ports.

Scavenging must take place in a relatively short portion of the operating cycle. The duration of the process differs in two- and four-stroke cycle engines. In a two-stroke cycle engine, the process takes place during the latter part of the downstroke (expansion) and the early part of the upstroke (compression). In a four-stroke cycle engine, scavenging takes place when the piston is nearing and passing top dead center (TDC) during the latter part of an upstroke (exhaust) and the early part of a downstroke (intake). The intake and exhaust openings are both open during this interval of time. The overlap of intake and exhaust permits the air from the blower to pass through the cylinder into the exhaust manifold, cleaning out the exhaust gases from the cylinder and, at the same time, cooling the hot engine parts.

When scavenging air enters the cylinder of an engine, it must be so directed that the waste gases are removed from the remote parts of the cylinder. The two principal methods by which removal is accomplished are referred to as port uniflow scavenging and valve uniflow scavenging. In the uniflow method of scavenging, both the air and the burned gases flow in the same direction. This action causes a minimum of turbulence and improves the effectiveness of the scavenging action. An example of a port uniflow system is shown in *Figure 9-1.*

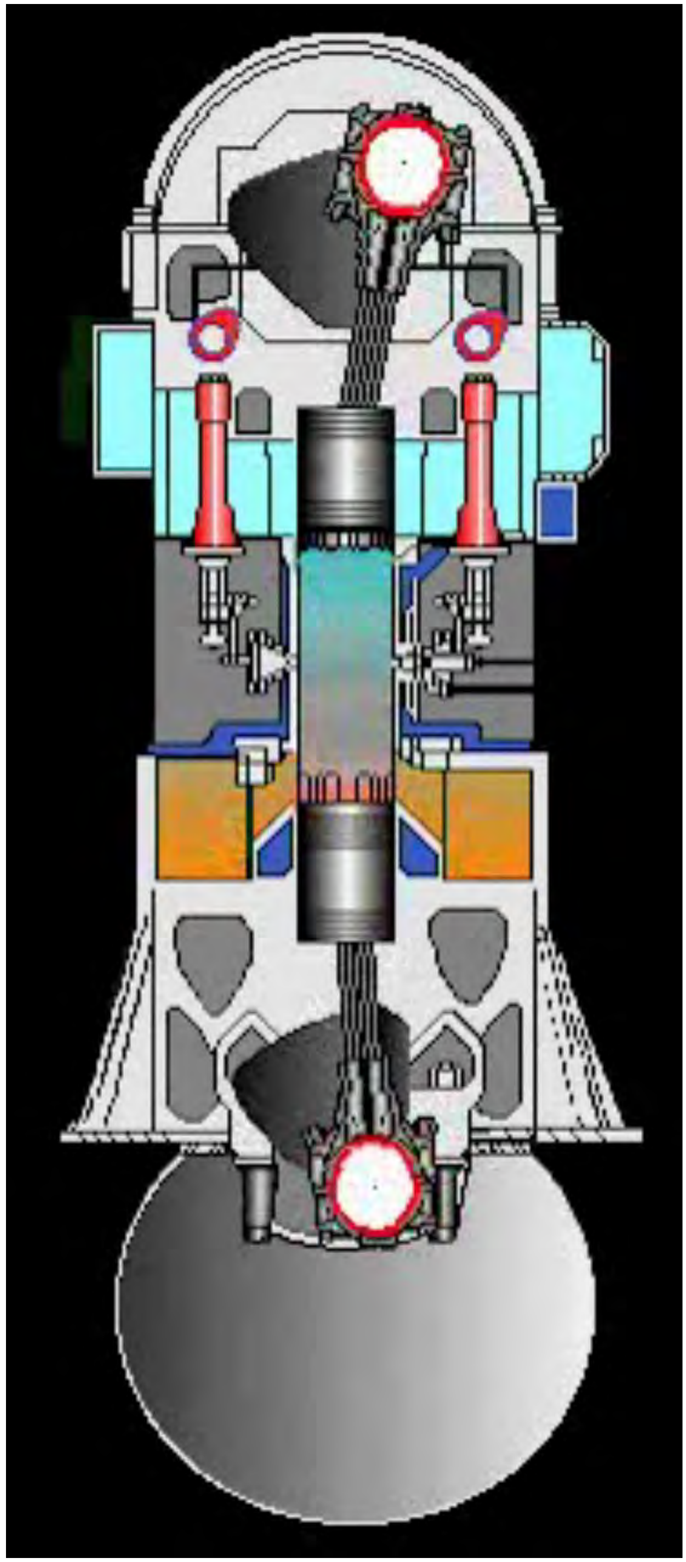

Figure 9-1 — Port uniflow system.

Valve uniflow (*Figure 9-2*) scavenging and supercharging are not common to all diesel engines For instance, in some four-stroke cycle engines, the air enters the cylinder as a result of a pressure difference created by the piston as it moves away from the combustion space during the intake event. This type of intake is sometimes referred to as the suction-type, or naturally aspirated, intake; however, the air is actually forced into the cylinder because of the greater pressure outside the cylinder. An increase in airflow into the cylinders of an engine can serve to increase power output, in addition to being used for scavenging. Because the power of an engine comes from the burning of fuel, an increase in power requires more fuel. The increased fuel, in turn, requires more air because each pound of fuel requires a certain amount of air for combustion The supplying of more air to the combustion spaces than can be supplied through the action of atmospheric pressure and piston action (in four-stroke cycle engines) or scavenging air (in two-stroke cycle engines) is called supercharging.

In some two-stroke cycle diesel engines, the cylinders are supercharged during the air intake simply by an increase in the pressure of scavenging air. The same blower is used for supercharging and scavenging. Scavenging is done when air is admitted under low pressure into the cylinder while the exhaust valves or ports are open. Supercharging is done with the exhaust ports or valves closed—a condition that enables the blower to force air under pressure into the cylinder and thereby increase the amount of air available for combustion. A supercharged engine occurs when the manifold pressure exceeds the atmospheric pressure. The increase in pressure, resulting from the compression action of the blower, will depend on the type of installation. With the increase in pressure and amount of air available for combustion, there is a corresponding increase in combustion efficiency within the cylinder. An engine of a given size that is supercharged can develop more power than an engine of the same size that is not supercharged.

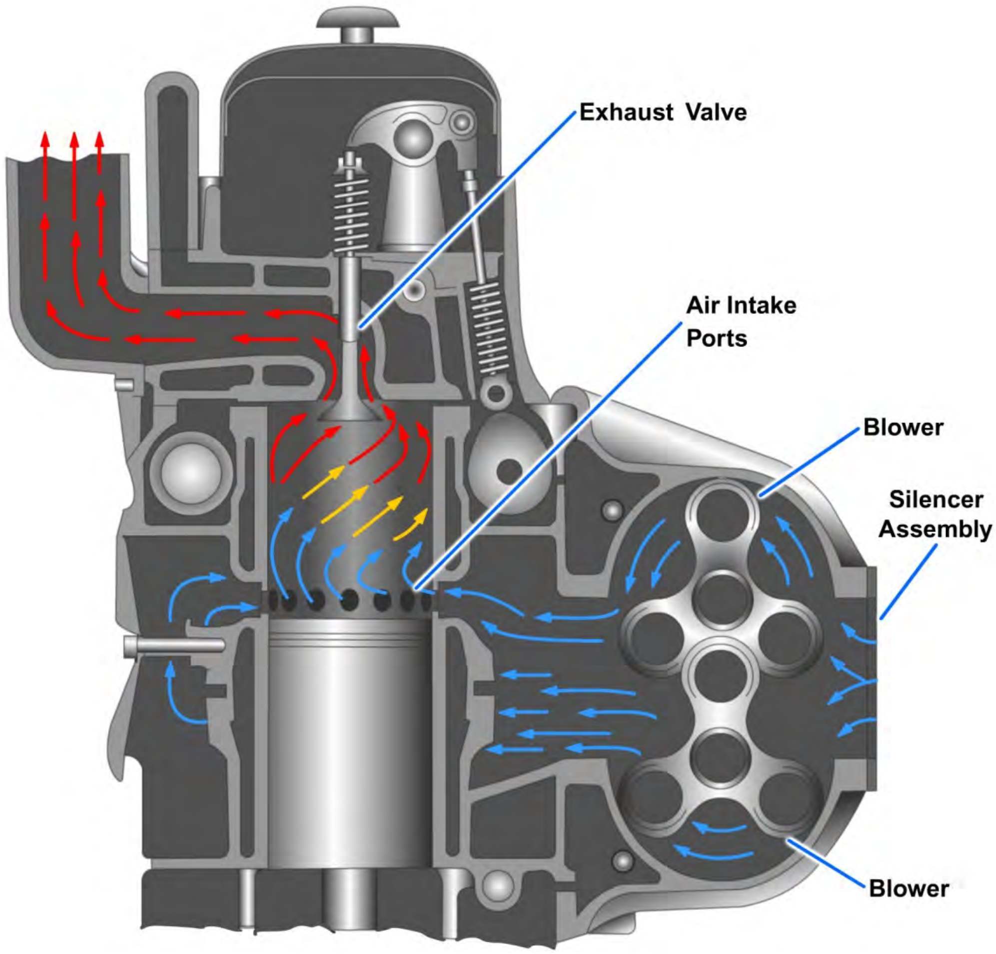

Figure 9-2 — Valve uniflow system in a two-stroke cycle diesel engine.

For a four-stroke diesel engine to be supercharged, a blower must be added to the intake system because exhaust and intake in an unsupercharged engine are performed by the action of the piston. The timing of the valves in a supercharged four-stroke cycle engine is also different from that in a similar engine that is not supercharged. In a supercharged engine, the closing of the intake valve is slowed down so that the intake valves or ports are open for a longer time after the exhaust valves close. The increased time that the intake valves are open (after the exhaust valves close) allows more air to be forced into the cylinder before the start of the compression event.

The amount of additional air that is forced into the cylinder and the resulting increase in horsepower depends on the pressure in the air box or intake manifold. The increased overlap of the valve openings also permits the air pressure created by the blower to remove gases from the cylinder during the exhaust event. Study *Figure 9-3, frames 1 and 2* so that you will understand how the opening and closing of the intake and exhaust valves, or ports, affect both scavenging and supercharging. Also, note the differences in these processes as they occur in supercharged two- and four-stroke cycle engines.

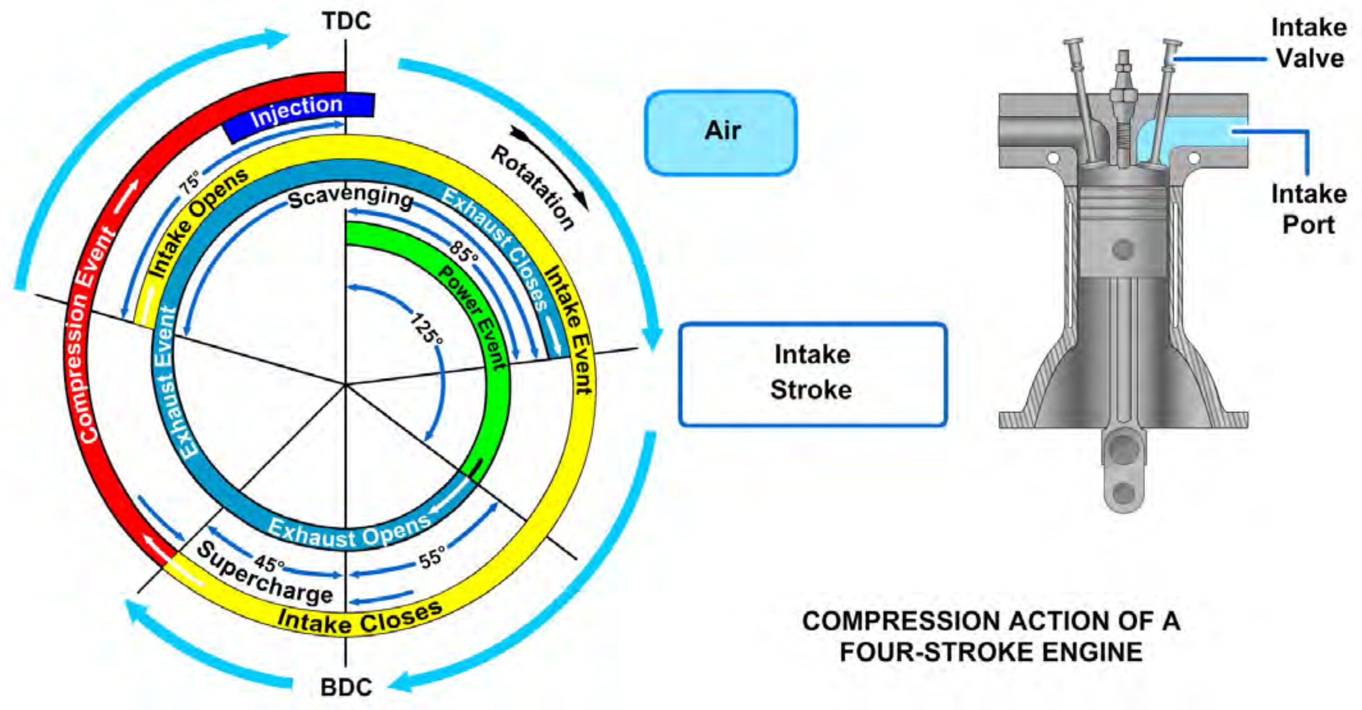

Figure 9-3 — Scavenging and supercharging in diesel engines.

In *Figure 9-3, frames 1 through 3,* the circular pattern represents crankshaft rotation. Some of the events occurring in the cycles are shown in degrees of shaft rotation for purposes of illustration and easier comparison only. (When working with the timing of a specific engine, check the appropriate instructions.)

When studying *Figure 9-3, frames 1 through 3,* keep in mind that the crankshaft of a four-stroke cycle engine makes two complete revolutions in one cycle of operation, while the shaft in a two-stroke cycle engine makes only one revolution per cycle. Also, keep in mind that the exhaust and intake events in a two-stroke engine do not involve complete piston strokes as they do in a four-stroke engine.

Four-Stroke Cycle Scavenging and Supercharging

Figure 9-3, frame 1and 2, is based on the operation of a four-stroke cycle engine that uses a centrifugal-type blower (turbocharger) to supply the cylinders with air under pressure.

In a supercharged four-stroke cycle engine, the duration of each event differs somewhat from the length of the same events in a non-supercharged four-stroke engine. The intake and exhaust valves are open much longer in a supercharged engine, and the compression and power events are shorter, permitting a longer period for scavenging. When the exhaust event is complete, the turbocharger fills the cylinder with fresh air under pressure before the compression event begins. The turbocharger supercharges the cylinders.

To understand the relationship of scavenging and supercharging to the events of the cycle, look again at *Figure 9-3, frame 1and 2,* and follow through the complete cycle. Start your study of the cycle at TDC, the beginning of the power event. At this point, peak compression has been reached, fuel injection is nearly completed, and combustion is in progress. Power is delivered during the downstroke of the piston for 125° of crankshaft rotation. At this point in the downstroke, at 55° before bottom dead center (BDC), the power event ends and the exhaust valves open

The exhaust valves remain open throughout the rest of the downstroke (55°), throughout all of the next upstroke (180°), and throughout 85° of the next downstroke; a total of 320° of shaft rotation. At a point 75° before the piston reaches TDC, the intake valves open and the turbocharger begins forcing fresh air into the cylinder. For 160° of shaft rotation, the air passes through the cylinder and out of the exhaust valves, clearing the waste gases from the cylinder. The rapid flow of gases escaping through the exhaust manifold drives the turbocharger. The process of scavenging continues until the exhaust valves close at 85° past TDC.

The intake valves remain open, after the exhaust valves close, for an additional 140° of shaft rotation (45° past BDC). From the time the exhaust valves close until the piston reaches approximately BDC, the cylinder is being filled with air from the turbocharger. During this interval, the increase in pressure is too small to be considered because of the increasing volume of the cylinder space. (The piston is in the downstroke.) When the piston reaches BDC and starts the upstroke, the volume of the space begins to decrease as the turbocharger continues to force air into the cylinder. The result is a supercharging effect. During the remainder of the upstroke (after the intake valves close), the supercharged air is compressed. Fuel injection begins several degrees before TDC and ends shortly after TDC. The actual length of the injection period in a specific engine depends on the speed and load of the engine. When the piston reaches TDC, a cycle (two complete crankshaft revolutions and four strokes of the piston) has taken place, and the engine is ready to repeat the cycle.

Two-Stroke Cycle Scavenging and Supercharging

When comparing *Figure 9-3, frames 1 through 3,* note that the length of the supercharging and scavenging periods in a two-stroke cycle engine is not the same as those in a four-stroke cycle engine. Also, there is considerable difference in piston location between the times when these processes take place in the two types of engines. In a four-stroke cycle, scavenging takes place while the piston is traveling through the latter part of the upstroke and the early part of the downstroke, and supercharging takes place when the piston is in the vicinity of BDC. In a two-stroke cycle, the processes of scavenging and supercharging both take place while the piston is in the lower part of the cylinder. In a four-stroke cycle engine, a piston does much of the work of intake and exhaust. In a two-stroke cycle engine, the piston does very little work in these two processes. Therefore, many two-stroke cycle engines use a blower to force air into the cylinder and to clear out the exhaust gases.

Figure 9-3, frame 3 is based on the two-stroke cycle of operation. If you compare *Figure 9-3, frames 1 through 3*, the differences in the scavenging and supercharging processes in two- and four-stroke cycle engines are more apparent. Start your study of the cycle with the piston at TDC in *Figure 9-3, frame 3*. Fuel has been injected, ignition has occurred, and combustion is taking place. The power developed forces the piston through the power event until the piston is 92 1/2° (as compared to 125° for the four-stroke cycle in *frames 1 and 2*) past TDC, just a little more than halfway through the downstroke. At this point, the exhaust valves open, gases escape through the manifold, and cylinder pressure drops rapidly.

When the piston reaches a point 48° before BDC, the intake ports are uncovered as the piston moves downward and scavenging begins. Compare this motion with the opening of the intake valves in a four-stroke cycle in *Figure 9-3, frame 1and 2*. The scavenging air, under blower pressure, swirls upward through the cylinder and clears the cylinder of exhaust gases. This situation in the cylinder when scavenging starts is approximately the same as that illustrated in *Figure 9-2*. Note the position of the piston, the open scavenging ports, the open exhaust valves, and the flow of air through the cylinder. The flow of scavenge air through the cylinder also helps to cool the parts, which are heated by combustion.

Study again *Figure 9-3, frame 3*. Scavenging continues until the piston is 44 1/2° past BDC (a total of 92 1/2° as compared with 160° in the four-stroke cycle in *Figure 9-3, frame 1and 2*), at which point the exhaust valves close. In a two-stroke cycle engine, the exhaust valves remain open during only 132°, as compared with the 320° in the four-stroke cycle. The scavenge ports remain open for another 3 1/2° of shaft rotation (45° in the four-stroke cycle), and the blower continues to force air into the cylinder. The ports are open for only a short interval after the exhaust valves close; enough time is available for the blower to create a supercharging effect before the compression event starts.

The piston closes the intake ports at 48° past BDC. The compression event takes place during the remainder of the upstroke, with injection and ignition occurring at TDC. At this point, one cycle is ended and another is ready to start.

INTAKE SYSTEM COMPONENTS

There are many variations in the designs of the engine parts, which function as a group to properly direct clean air to intake valves or ports. The function of each kind of part remains basically the same. We will discuss the common types and principal parts of engine air-intake systems.

Silencers, Screens, and Cleaners

Diesel engines use a great amount of air that enters from the intake system. This air must enter as quietly and clean as possible. Unless a silencer is installed, the air that rushes through the air-cleaning devices will sound like an extremely high-pitched whistle. Consequently, silencers are generally constructed as part of the air-cleaning components.

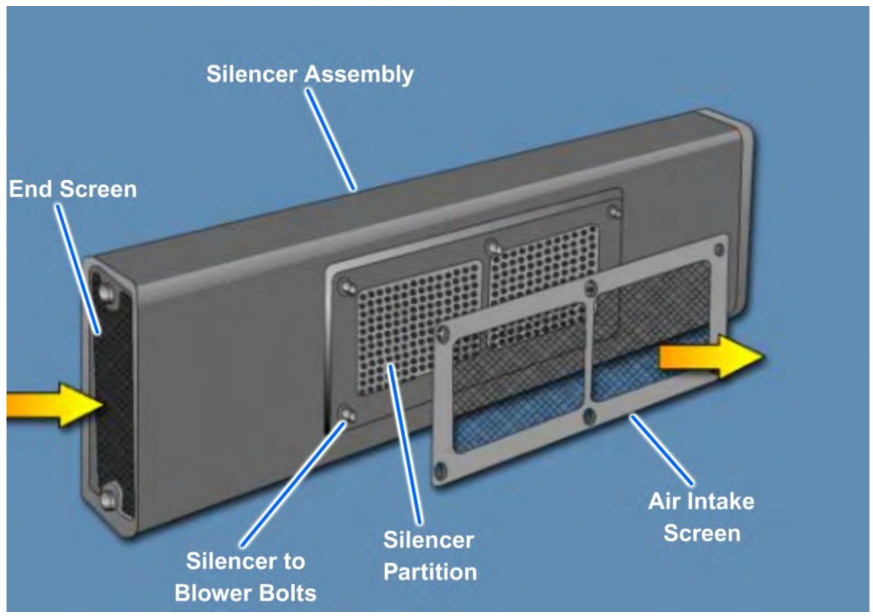

Figure 9-4 — Air-intake silencer assembly.

One type of air-intake silencer assembly is shown in *Figure 9-4*. The silencer assembly is bolted to the intake side of the blower (*Figure 9-2)*. A perforated steel partition divides the silencer lengthwise into two sections. Air enters the end of the silencer and passes through the inner section into the blower. The noise of the air passes through the silencer where it is reduced by a sound-absorbent, flameproof, felted cotton waste, which fills the outer section of the silencer. Upon leaving the silencer, the air enters the blower through an air-intake screen (*Figure 9-4*). The air-intake screen prevents particles of foreign material from entering the engine. Unless it is filtered from the intake air, foreign material might seriously damage the blower assembly and internal engine parts, such as pistons, piston rings, and liners.

The silencer-and-screen assembly just described is sometimes referred to as a dry-type cleaner and silencer. Another type of air cleaner and silencer is the viscous type. In both dry and viscous types, intake air is drawn through a fine mesh or screen, which filters the air. The mesh of such cleaners may consist of cotton fabric, wire screening, specially wound copper crimp, or metal wool. The principal difference between cleaners of the dry and viscous types is that the mesh of a viscous-type cleaner is wet, usually, with a medium-weight oil. An air cleaner and silencer assembly of the viscous type is shown in *Figure 9-5.* The filter and silencer of this unit form a cylinder silencing chamber, the ends of which are packed with sound-deadening material. Air enters the silencer through the circumferential surface of the silencing chamber. The filter element fits over the air inlet. The element of the filter consists of a series of oil-wetted wire baffles, which collect any airborne dirt entering the chamber.

Another type of intake-air cleaner and silencer includes an oil bath as part of the assembly. A cross section of an oil bath air cleaner is shown in *Figure 9-6*. This type of air cleaner is referred to as a heavy-duty oil bath air cleaner. In heavy-duty oil bath air cleaners, there are two cleaning elements. One is a removable separator screen; the other is a fixed metal-wool element (metal mesh). Follow along as we explain how the oil bath air cleaner functions.

The air is drawn into the cleaner through an opening in the center of the top. As the air reaches the bottom of this passage, it changes direction and flows up around the outside of the center passage through the metal-wool element. The centrifugal force, caused by the sudden change in direction, traps large particles of dirt in the oil in the bottom of the cleaner. Smaller particles of dirt in the oil picked up by the air are trapped in the metal-wool element. It is important not to overfill the oil reservoir during maintenance.

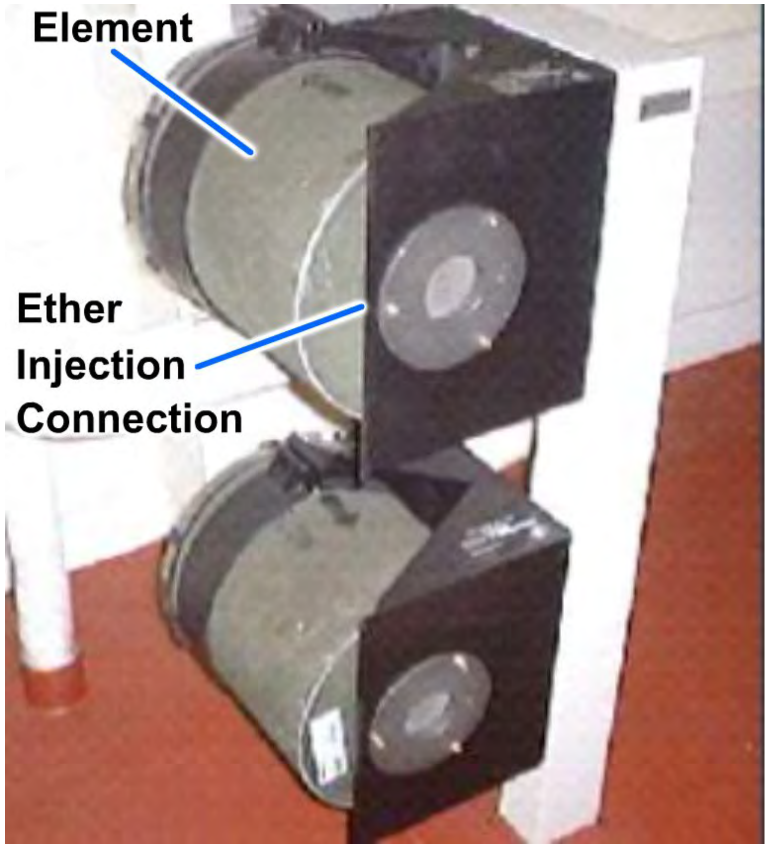

Figure 9-5 — Viscous type of air filter and silencer assembly.

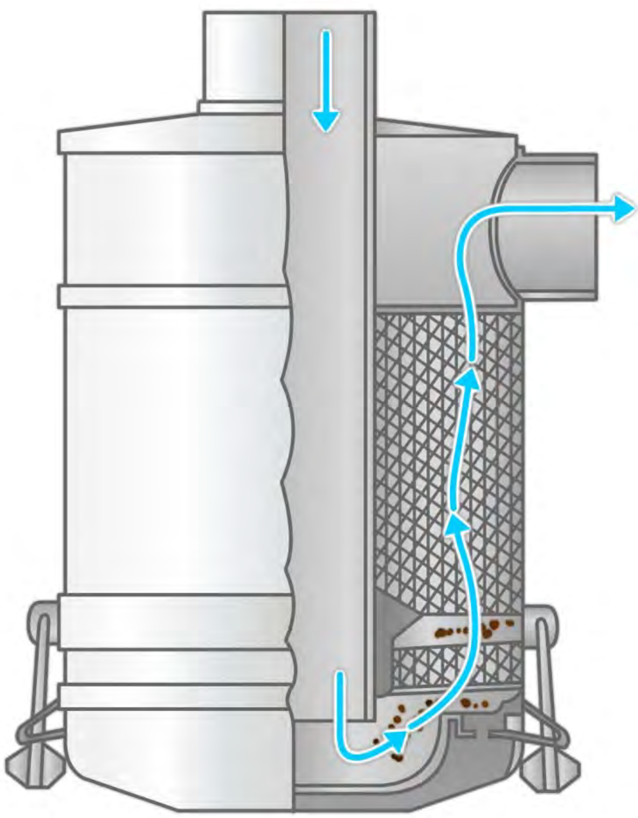

Figure 9-6 — Airflow through a heavy-duty oil bath air cleaner.

Overfilling will cause oil to be drawn into the engine. Light-duty oil bath air cleaners work in the same way, but because of their size, they are not capable of providing the same volume of air to the engine.

The silencer and cleaner assemblies described in the preceding paragraphs is representative of the devices that serve to clean intake air and to reduce the noise the air makes as it enters the engine. To ensure sufficient cleaning of the intake air, air filters should be cleaned as specified by the Planned Maintenance System (PMS).

Blowers

Blowers are necessary on most two-stroke cycle engines to force scavenging air through the cylinders. Supercharged engines, either two- or 4-stroke cycle, must have a blower to fill the cylinder with fresh air at a pressure above atmospheric pressure before the compression event starts. The primary function of an engine blower is to deliver a large volume of air at a low pressure.

There are two principal types of blowers, positive displacement and centrifugal. A positive displacement blower is usually gear driven directly by the engine, while a centrifugal blower is usually driven by an exhaust-gas turbine. Positive displacement blowers may be divided into two groups: the multiple-lobe type, commonly called the lobe, or roots, blower; and the axial-flow blower. Blowers are introduced briefly in *Fireman,* NAVEDTRA 14104. The roots blower is commonly used on many two-stroke cycle engines. Exhaust-driven centrifugal blowers (turbocharger) found in many four-stroke engine and some two-stroke engines will be discussed later.

Roots Blower

Designed for efficient diesel operation, the roots blower, shown in *Figure 9-7*, supplies the fresh air needed for combustion and scavenging. The air volume needed for the engine to perform scavenging is about 40 times greater than the cylinder volume. The location of the blower on the engine depends on the cylinder arrangement. *Figure 9-8* shows the location of the roots blower on a V-type engine. *Figure 9-2*, shows the blower location on an in-line engine. The operation of the blower is similar to that of a gear-type pump. Two hollow, three-lobe rotors revolve in opposite directions (*Figure 9-8*). When the rotors turn, air is drawn in the space between the lobes at the inlet, is trapped, and is carried around to the discharge side. The meshing lobes at the discharge side force the air out of the lobe pockets and into the air box, where the air is then available for use. A continuously uniform supply of air can be maintained. The rotor lobes are made with a helical (spiral) shape (*Figure 9-9)*. In the helical design, one discharge phase begins before the previous discharge phase is entirely completed, and the lobes are said to overlap. This overlapping tends to produce a smoother discharge of air than could be realized if the rotor lobes were of a straight design. Helical timing gears located on the drive end of the rotor shafts prevent the meshing rotor lobes from touching (*Figure 9-9*).

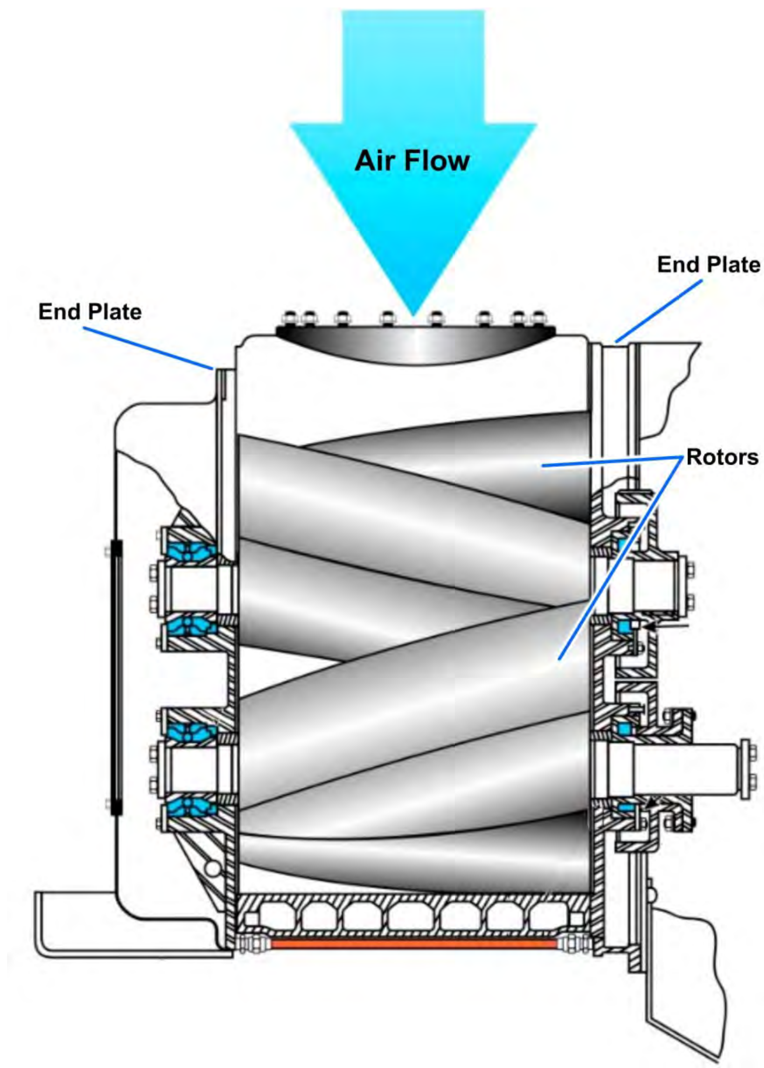

Figure 9-7 — Roots blower.

Each rotor is supported in the doweled end plates of the blower housing by a roller bearing at the front end and by a two-row radial and thrust ball bearing at the gear end.

Lubrication of the blower bearings, timing gears, and governor drive is provided through oil passages that lead from the main oil galleries of the engine to an oil passage in each end plate of the blower. The rotor lobes require no lubrication because they are prevented from touching by the timing gears.

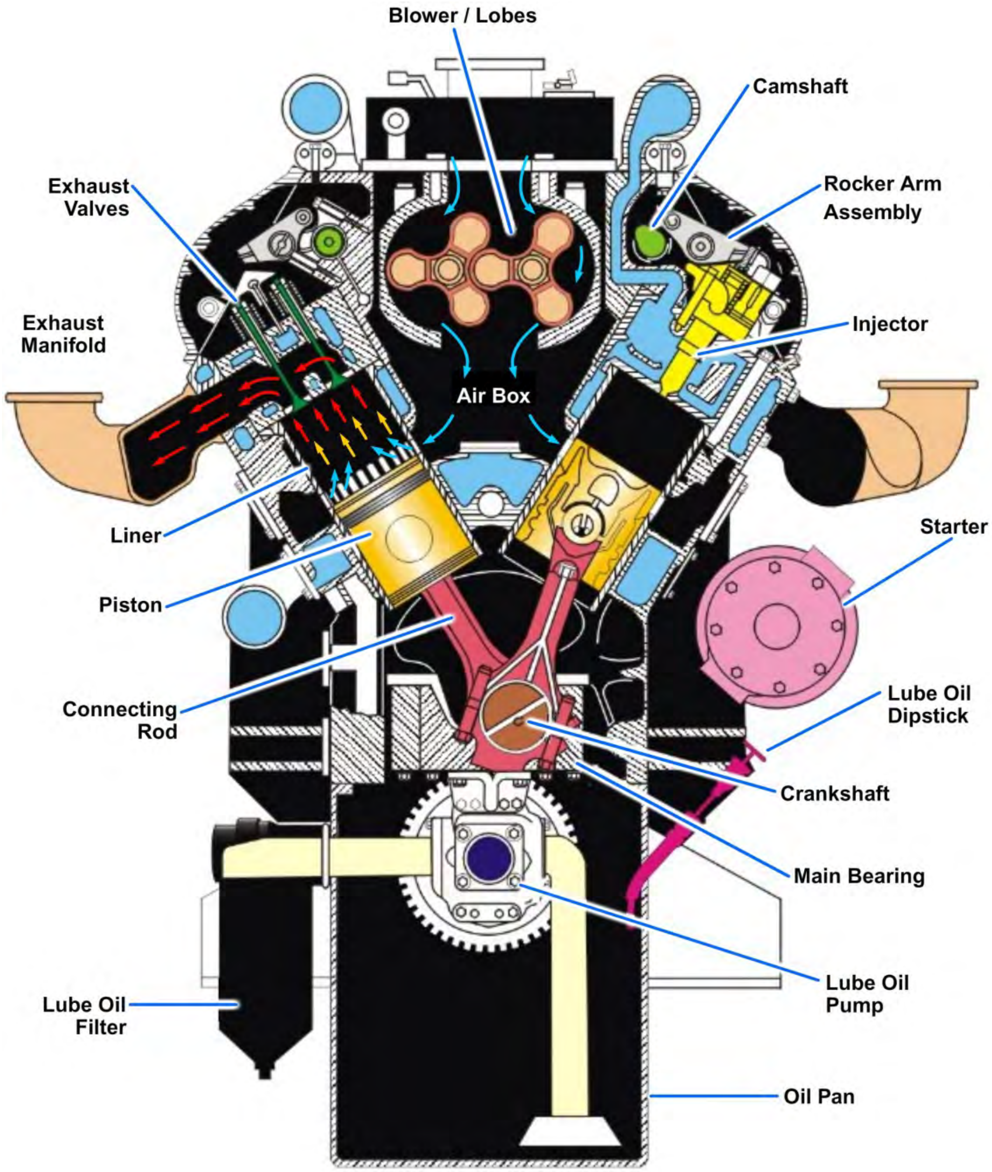

Figure 9-8 — Air-intake system through a root-type blower on a V-type engine.

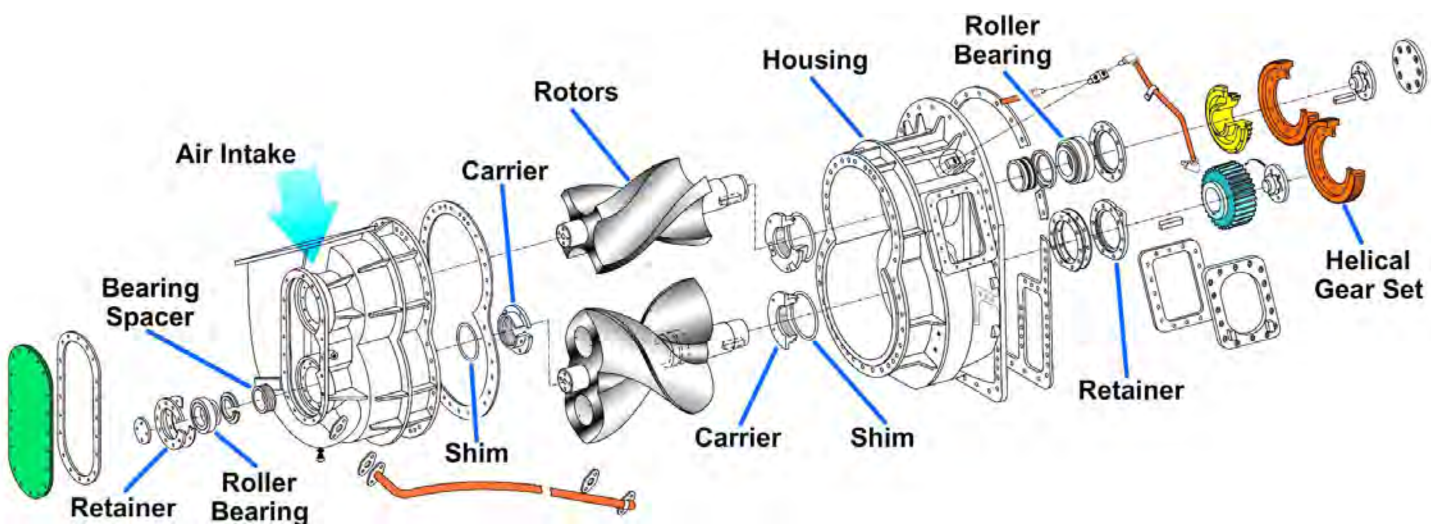

Figure 9-9 — Components of a root-type blower.

Turbocharger

Turbochargers are unlike positive displacement blowers, which are driven through a gear train by the engine crankshaft. Positive displacement blowers permit only modest power increases because most of the power developed must be returned to drive the blower. On the other hand, turbochargers produce higher net gains as they use the normally wasted exhaust gas energy for power. Turbocharging can produce power gains of over 50 percent compared to those of naturally aspirated engines. Several types of centrifugal blowers (turbochargers) are used in naval service. Although several types of centrifugal blowers (turbochargers) are used in naval service, they all operate on the same following principles of operation:

1. The gases from the exhaust manifold drive a turbine.
2. The turbine drives an impeller (on the same shaft), which supplies air to the cylinders for scavenging and supercharging.

Figure 9-10 provides an illustration of a turbocharger. The exhaust system of a turbocharger consists of a heat-resistant alloy casting that encloses the turbine wheel and provides an exhaust gas inlet and an exhaust gas outlet. The system furnishes the driving power for the turbocharger by using the high-temperature and high-velocity exhaust gases from the exhaust manifold. The gases enter the turbine casing, striking the turbine wheel and causing it to rotate at a high speed. The speed of the turbine is automatically controlled by the speed and the load of the engine. When the gases have turned the turbine, they are discharged through the exhaust outlet.

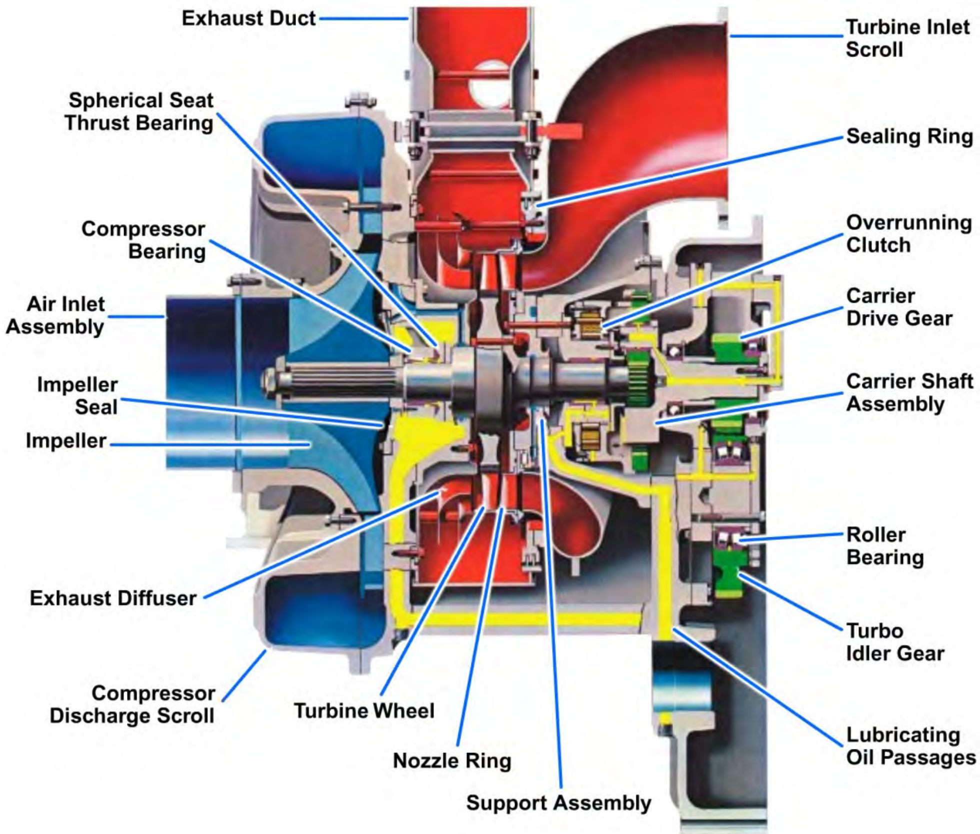

Figure 9-10 — Principles of operation for a turbocharger.

The air-intake system of a turbocharger consists of a compression housing and compressor wheel. During engine operation, exhaust gases flowing from the engine through the turbine housing cause the turbine wheel to rotate. The compressor wheel, which is mounted on the opposite end of the same shaft, rotates with the turbine. The compressor wheel draws ambient (fresh) air into the compressor housing and compresses the air. The turbocharger responds to engine load change by reacting to the flow of exhaust gases. As the power output of the engine increases, the flow of exhaust gases also increases. This action increases the speed and output of the rotating assembly proportionately, delivering more air to the intake system of the engine. *Figure 9-11* illustrates the air induction and exhaust system for one type of diesel that uses two turbochargers. Note the arrows that indicate the flow pattern of the exhaust, inlet air, and compressed air systems. The compressed air used (*Figure 9-11*) for combustion and scavenging is directed through an aftercooler. Most engines that are turbocharged use aftercoolers to cool the compressed air. Aftercoolers, also referred to as heat exchangers, are small radiators placed between the compressor housing and the intake manifold of the engine. As the compressed hot air passes through the aftercooler, the air is cooled to reduce its volume. Consequently, more air is able to enter the cylinder. The result is lower cylinder pressure, more effective cooling of the cylinder component, and a lower exhaust temperature.

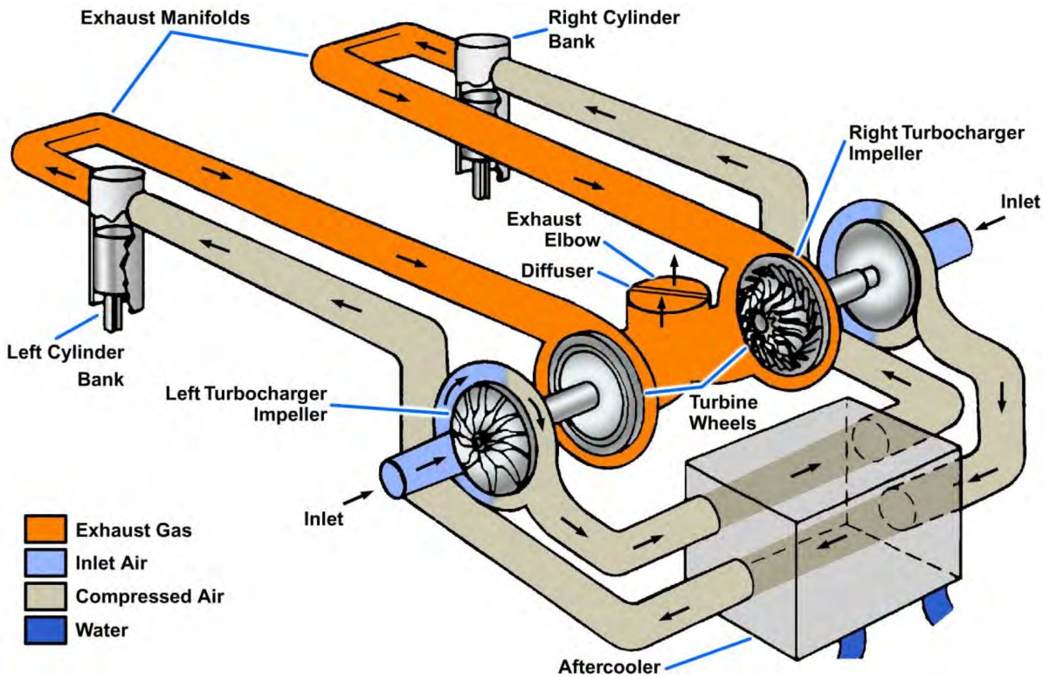

Figure 9-11 — Air induction and exhaust system.

Without the aftercooler, the air temperature entering the intake manifold will increase sharply because of the compression of the air and heat from the turbocharger. This undesirable condition can result in a loss of air density and power, a higher temperature within the cylinder, and a higher exhaust gas temperature.

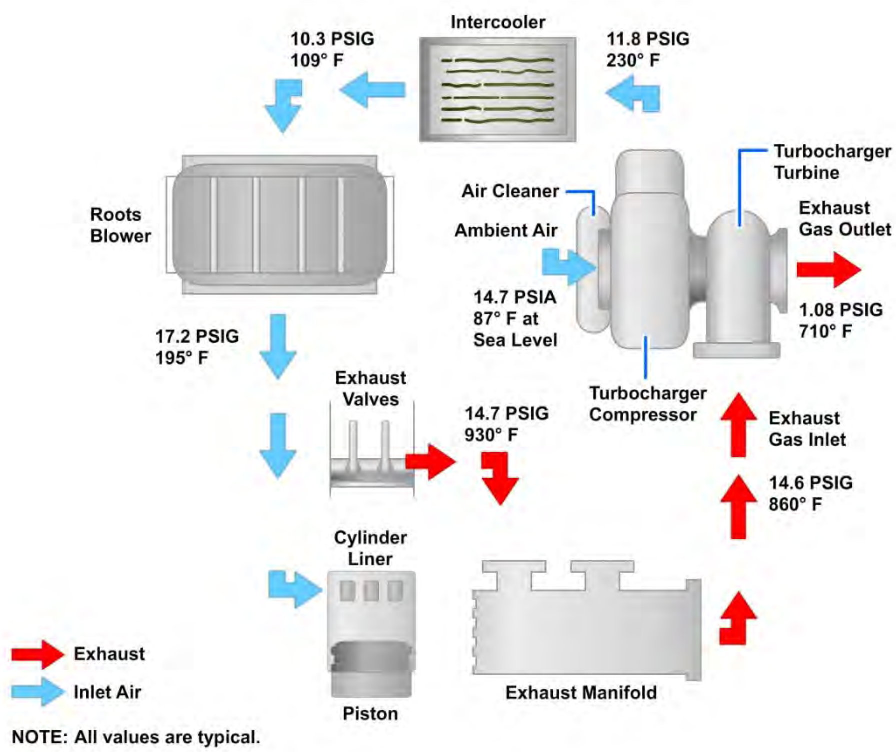

Figure 9-12 — Engine air system with roots blower and turbocharger assemblies.

In some installations, roots blowers and turbochargers are used together within one system. These two components serve to compress the air more efficiently than would be possible if only a blower or a turbocharger were to be used separately. As we discuss this type of system, refer to *Figure 9-12*. In operation, air is drawn into the blower section of the turbocharger through the air cleaner. Air is compressed, and the temperature is increased. The high-temperature compressed air is then delivered to the intercooler (heat exchanger), where the temperature is reduced. (Intercoolers are heat exchangers that are usually located between the compressor and the roots blower.) The cooled dense charge of air is then routed to the roots blower inlet. The roots blower further compresses the air and delivers it to the engine.

During the intake event, air is forced into the cylinders where it scavenges (cleans) out the combustion gases and fills the cylinder with a clean, dense air charge that is above atmospheric pressure. After the combustion and power event are completed, the exhaust valves open and the hot exhaust gases are discharged to the exhaust manifold. The hot, high-velocity exhaust gases are directed to the turbine section of the turbochargers, where they drive the turbine wheel at high speed. During this process, the pressure and the temperature of the exhaust gases are reduced and some of the energy that would otherwise be lost is used to drive the turbocharger. After the exhaust gases leave the turbocharger, they are routed to a muffler.

Intake Air Passages

Air must pass through a number of passages to reach the combustion spaces within an engine. From the blower or turbocharger, the air is discharged into a unit or passage that is directed to the intake valves or ports of the cylinders. In two-stroke cycle engines, the passages that conduct intake air to the cylinders are generally referred to as an air box. The air box surrounds the cylinders (*Figure 9-2)* and is built into the block. In two-stroke cycle, V-type diesel engines, the air box consists of the space (within the block) between the two banks of the V-construction and the open space between the upper and lower deckplates of each bank (*Figure 9-8)*. In some two-stroke cycle engines, the passage that serves as a reservoir for intake air from the blower is called an air header.

Drains are generally provided in air boxes, receivers, and headers to drain off any liquids that may accumulate. A slight amount of vapor from the air charge may condense and settle in the air box, or a small amount of lubricating oil may be blown into the air box as the piston passes the ports on the downstroke following the power event. On some engines, the drains are vented to the atmosphere. In others, a special drain tank collects the drainage from the air box. The purpose of the tank is to prevent drainage of oil into the engine room. Drains are of primary importance when the air cooler is installed between the blower (or turbocharger) discharge and air-intake manifold or receiver. The drains are usually left open during engine operation to prevent condensation or water from leaky coolers from being carried into the engine cylinders with the combustion air.

In four-stroke cycle diesel engines, the intake air passages from the blower to the cylinders differ from those in two-stroke cycle engines in that these passages are not an integral part of the block. Instead, a separate unit is attached to the block to conduct intake air to the engine cylinders. The attached unit is generally called an air-intake manifold.

Cylinder Ports and Valves

The amount of air that enters the cylinders from the air box or manifold is controlled by the opening and closing of the cylinder valves or ports. Whether air is admitted to the cylinders of engines through ports or by valves depends upon the type of engine. In four-stroke cycle engines, the amount of air that enters the cylinders is controlled by valves. Ports control the discharge of exhaust gases from some two-stroke cycle engines, and valves perform the same function in all four-stroke and many two-stroke cycle engines. We have made frequent reference in this chapter to ports and have illustrated their location in the cylinder liner. Intake ports (*Figures 9-1, 9-2, and 9-8*) are usually located in such a way that air enters the cylinder in a whirling motion. The turbulence created helps to increase the amount of intake air that is reached by the injected fuel particles. Thus, the power output of the engine is increased. Intake ports as well as exhaust ports are opened and closed by the piston as it moves back and forth in the cylinder. The valves of an engine are opened and closed at the proper point in the cycle of operation by the valve mechanisms.

Cylinder Test Valves and Safety or Relief Valves

In some large engines, each cylinder is equipped with valves that serve different purposes from those of the intake and exhaust valves. Instead of admitting air to the cylinder or permitting the exhaust gases to escape, these valves may be used for testing or safety purposes. Even though they are not a part of the air system of the engine, these valves are definitely related to the air system because they serve to test or relieve pressure that may develop with the combustion space. *Figure 9-13* illustrates a test valve (hand operated):

- To vent the cylinder of any accumulated water or oil before an engine is started.
- To relieve cylinder pressure when the engine is being turned by hand.
- To test compression and firing pressures.

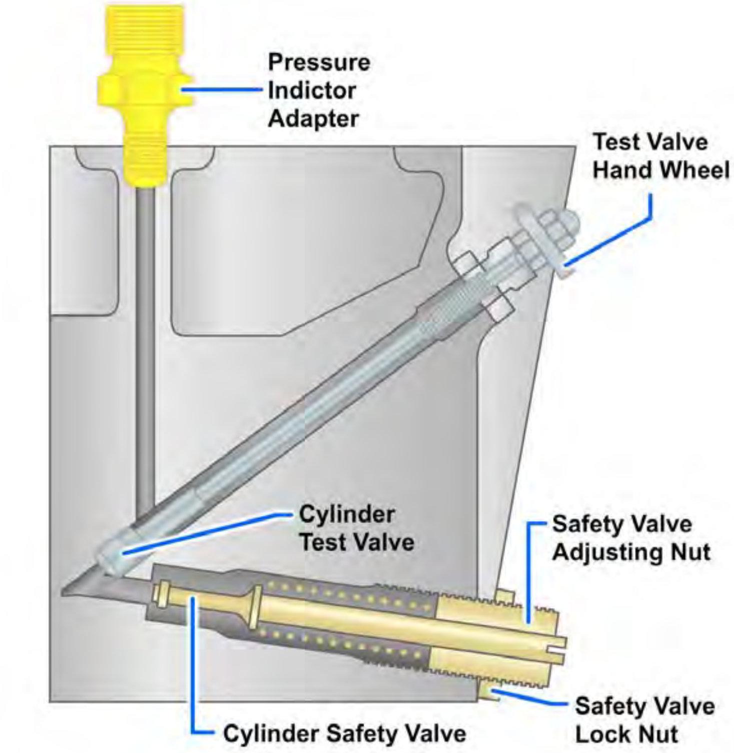

Figure 9-13 — Cylinder test and safety valves.

Manufacturers use the terms safety valves and relief valves to identify valves installed in cylinder heads or liners that serve to relieve excessive pressure that may develop when the engine is operating. These valves are of the spring-loaded poppet type. These valves are designed to open when the cylinder pressure exceeds a safe operating limit.

A sectional view of the safety valve and test valve arrangement is shown in *Figure 9-13*. Note the passage and adapter for a cylinder pressure indicator. Most test and relief valve arrangements have an adapter for the cylinder pressure measuring instrument. In *Figure 9-13*, the valves are fitted in passages within the cylinder head. In some engines, the relief valve is attached separately to the exterior of the head or liner

EXHAUST SYSTEMS

The parts of engine air systems considered so far have provided a passage for air into the cylinders and for the release of gases from the cylinders after combustion. The relationship of blowers, or turbochargers, to both the intake and exhaust systems has also been pointed out. The system that functions primarily to carry gases away from the cylinders of an engine is called the exhaust system. An exhaust system may be designed to perform one or more of the following functions: muffle exhaust noise, quench sparks, remove solid material from exhaust gases, and furnish energy to a turbine-driven supercharger. In the following sections, we will discuss the principal parts that may be used in combination to accomplish the functions of an engine exhaust system.

Exhaust Manifolds

When the gases of combustion are forced from the cylinders of an engine, the gases enter a unit that is generally referred to as the manifold. The exhaust manifold for a large diesel is shown in *Figure 9-14.* This exhaust manifold is made up of sections; called chamber assemblies, expansion joints, and adapter assemblies. The expansion joints, which are used between chamber assemblies, provide the necessary flexibility to compensate for expansion and contraction of the manifold resulting from temperature changes. Some manifolds are made of steel plate with welded joints and branch elbows of steel castings, while others are made of aluminum. The exhaust manifolds of most marine engines are generally cooled by water flowing through a water jacket surrounding the manifold. The exhaust manifold, shown in *Figure 9-14,* is for the passage of gases from the combustion spaces to the exhaust inlet of the turbocharger. Thus, the turbine end of the turbocharger is considered to be part of the exhaust system because it forms part of the passageway for the escape of gases to the exhaust outlet.

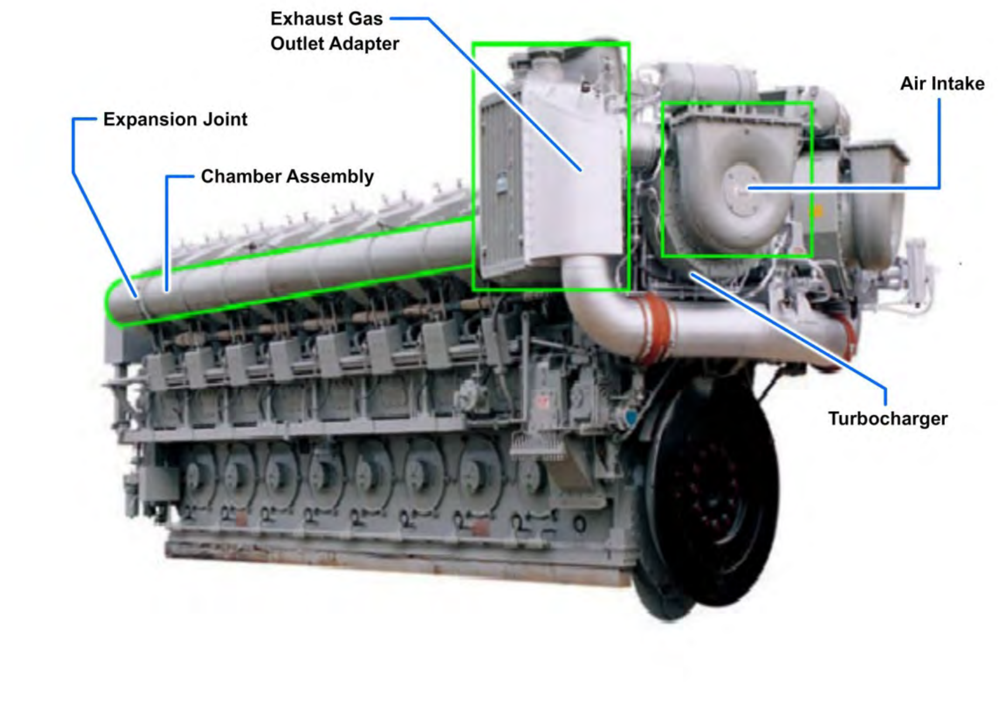

Figure 9-14 — Exhaust manifold of a turbocharged engine.

After passing through the turbine end of a turbocharged engine (or the exhaust manifold of a naturally aspirated four-stroke cycle engine) or being discharged from the exhaust manifold of a two-stroke cycle engine, the gases pass through the exhaust pipe (flexible or rigid) to the silencer, or muffler Silencers, or mufflers, are placed on internal combustion engines mainly to reduce the noise created by the exhaust gases as the exhaust valves or ports open. In addition to acting as silencers, most mufflers also act as spark arresters that trap the burning carbon particles and soot from the mufflers as the exhaust gases are directed to and discharged into the atmosphere.

Exhaust Pyrometers

As more fuel is burned in an engine, the exhaust gases will become hotter. The device that measures the temperature of these gases is called a pyrometer. By comparing the exhaust gas temperature of each cylinder, the operator can determine if the load is balanced throughout the engine.

Two types of pyrometers measure exhaust temperature readings: the fixed installation and the portable hand-recording instrument (*Figure 9-15), b*oth types use a thermocouple unit, such as the one in *Figure 9-16*, installed in the exhaust manifold.

Pyrometers of the fixed installation type, (*Figure 9-15)* have a thermostatically operated control spring, which makes the required temperature corrections automatically. A selector switch is used to

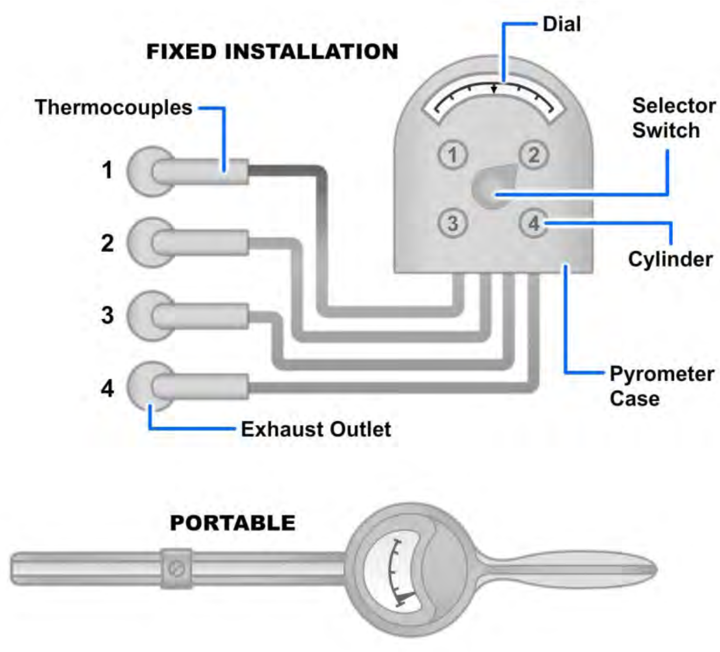

Figure 9-15 — Pyrometers used in diesel engine exhaust systems.

show the readings of one cylinder at a time. The portable hand pyrometer (*Figure 9-15),* has a zero adjuster, which must be set by hand and placed in contact temporarily with the terminals of each thermocouple.

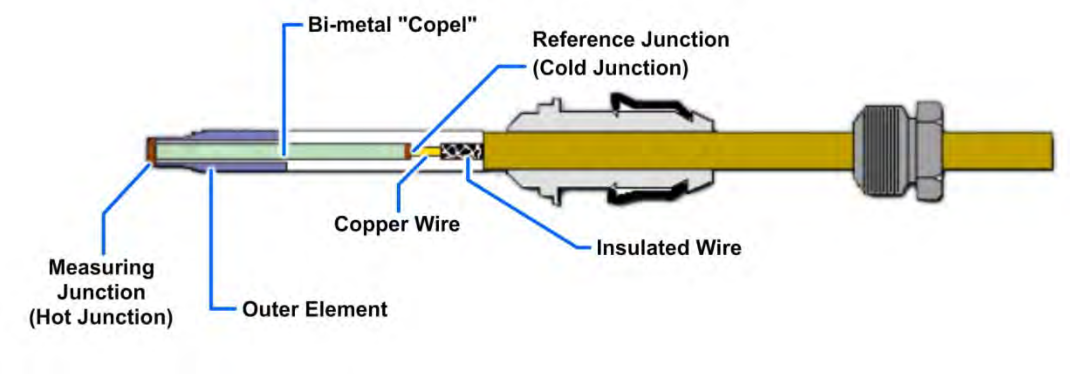

Figure 9-16 — Sectional view of a thermocouple.

The indicating unit of the pyrometer is calibrated to give a direct reading of temperature. However, the pyrometer actually measures the difference between the electric current produced by heat acting on dissimilar metals in the thermocouple hot junction and cold junction. The metals most commonly used in the thermocouple are iron and constantin, which are covered by an insulator. The thermocouple is placed so that the hot junction is in contact with the exhaust gases.

When the hot junction is heated by the exhaust gases, a small voltage develops in proportion to the temperature. This voltage is transferred by the wires to the pyrometer indicator. The pyrometer indicator is actually a sensitive voltmeter that has a scale that is graduated to show temperatures between the hot junction and the cold junction. Some variations in exhaust temperatures are normal and are to be expected when engines are operating at other than full power. The amount that exhaust temperatures may differ from cylinder to cylinder will depend on the type of engine. Refer to the appropriate manufacturer's technical manual for the allowable limits for your diesel.

Parts of Other Systems Related to Engine Intake and Exhaust Systems

The parts discussed in this chapter are those generally associated with the air systems of most engines. Some engines are equipped with parts that perform special functions. These parts, even though related to the engine air systems, are more frequently considered as parts of other engine systems.

Some engines are equipped with intake air heaters or use other methods to overcome the influence of low temperatures in cold weather starting. Many engines are equipped with devices or systems that provide crankcase ventilation. Blower action is necessary in many ventilation systems. The systems operate to prevent contamination of engine-room spaces by heated or fumeladen air to reduce the formation of sludge in lubricating oil and to prevent the accumulation of combustible gases in the crankcase and in the oil pan or sump. Devices that serve to ventilate engine crankcases are discussed with the lubricating systems.

SUMMARY

In diesel engines, the passageway for air into the combustion spaces and burnt gases from the combustion spaces is formed by the parts of two systems—the intake and exhaust systems. The combustion spaces serve as the dividing line between these two systems.

The primary purpose of an intake system is to supply to the cylinders a large volume of air for combustion and scavenging. The system must clean the air and reduce the noise created by the air as it enters the engine. When the air has served its purpose in the cylinder, the waste gases are expelled to the atmosphere by the exhaust system. In the turbocharged engine, the waste gases serve to drive the turbocharger prior to the expulsion of the gases to the atmosphere by way of the exhaust system.

After studying the information in this chapter, you should understand both the purposes and the principles of operation of the components of the air and exhaust systems in an engine and be able to trace the path of the intake air and exhaust gases through the systems.

You should also be able to understand the significance of scavenging and supercharging and how these processes differ in the operating cycles of two- and four-stroke cycle engines. If you are uncertain in any of these areas, go back and review those sections of this chapter before proceeding to the next chapter.

End of Chapter 9

Intake and Exhaust Systems

Review Questions

9-1. Which of the following components is part of the diesel engine air-intake system?

A. Muffler
B. Air box
C. Spark arrester
D. Silencer

9-2. What process involves using an increased amount of air to clear the cylinder of combustion exhaust gases?

A. Natural exhaust
B. Turbocharged
C. Supercharged
D. Scavenging

9-3. Supplying more air to the combustion space than can be supplied from atmospheric pressure or piston action, on a four-stroke diesel engine, is what process?

A. Supercharged
B. Turbocharged
C. Natural aspirated
D. Scavenging

9-4. Which of the following statements describes the timing difference between a supercharged and non-supercharged diesel engine compression and power events?

A. Longer in a supercharged engine
B. Shorter in a supercharged engine
C. No difference
D. Compression event longer, and power event shorter on a supercharged engine

9-5. What component is used on a diesel engine air-intake system to ensure the incoming air is as quiet and clean as possible?

A. Filter
B. Cleaner
C. Muffler
D. Silencer

9-6. What grade of oil is used on the viscous- type air cleaner?

A. Extra-duty weight
B. Heavy-duty weight
C. Light-duty weight
D. Medium-duty weight

9-7. What determines the location of the blower on a diesel engine?

A. Space allotment in the engine room
B. Cylinder arrangement
C. Placement of gears
D. Crankshaft web design

9-8. After the exhaust air leaves the turbocharger but before it enters the air-intake housing, the air passes through what component to compress its volume?

A. Strainer
B. Baffles
C. Aftercooler
D. Blower

9-9. Most marine engines exhaust manifolds are cooled by what method?

A. Force draft air
B. Shell and tube cooler
C. Water jacket surrounding manifold
D. Installed cooling coils

9-10. What instrument is used to measure exhaust gases?

A. Thermostat
B. Gasometer
C. Pyrometer
D. Thermometer

9-11. What action produces the minimum turbulence and improves the effectiveness of the scavenging action?

A. Direct line intake
B. Cross pattern intake
C. Steam line intake
D. Uniflow intake

9-12. From what source, if any, do the rotor lobes receive lubrication?

A. Main oil gallery
B. Governor drive assembly
C. Crankshaft oil passages
D. Lubrication not required

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CHAPTER 10

ENGINE COOLING SYSTEMS

In this chapter, we will primarily discuss closed cooling systems for internal-combustion engines. After reading the information in this chapter, you should recognize the purpose and function of an engine cooling system and the principal components of the basic cooling system design that is used in diesel engines. In the basic maintenance of engine cooling systems, you should understand the need for various chemical inhibitors and how they are used in an engine cooling system for the control of corrosion.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the importance of the cooling system.
2. Explain the different types of cooling systems (jacket and seawater).
3. Describe the principle components of the cooling system.
4. Explain the maintenance of heat exchanger tubes.
5. Explain the water and chemical requirements of a cooling system.

COOLING SYSTEM

A great amount of heat is generated within an engine during operation. The combustion process produces the greatest portion of this heat; compression of gases within the cylinders and friction between moving parts add to the total amount of heat developed within an engine. Since the temperature of combustion alone is about twice that at which iron melts, it is apparent that, without some means of dissipating heat, an engine could operate for only a very limited time.

When fuel burns in the cylinders of an engine, only about one-third of the heat energy from the fuel changes into mechanical energy and then leaves the engine in the form of brake horsepower (BHP). (Brake horsepower is a measure of the developed power of an engine in actual operation.) The rest of the heat energy shows up as unwanted heat in the form of:

- Hot exhaust gases.
- Frictional heat from the rubbing surfaces.
- Heating of the metal walls that form the combustion chamber, cylinder head, cylinder, and piston.

The job of the cooling system is to remove the unwanted heat from these parts so that the following problems can be prevented:

- Overheating and the resulting breakdown of the lubricating oil film that separates the rubbing surfaces of the engine.
- Overheating and the resulting loss of strength of the metal itself.
- Excessive stresses in or between the engine parts resulting from unequal temperatures.

Unwanted heat is transferred through the mediums of water, lubricating oil, air, and fuel. The water of the closed cooling system removes the greatest portion (approximately one-fourth) of the unwanted heat generated by combustion. The balance of the heat is carried away from the engine by the lubricating oil, the fuel, and the air. If the heat lost through cooling could be turned into work by the engine, the output of the engine would be almost doubled. However, the loss of valuable heat is necessary for an engine to operate.

Diesel engines must maintain a film of lubrication oil on pistons, cylinder walls, and the load-bearing surfaces of other moving parts to operate properly. The formation of such an oil film depends, to a large degree, on the viscosity of the oil. If the engine cooling system did not keep the engine temperature below a specified level, viscosity would decrease. This condition would result in inadequate lubrication, and metal-to-metal contact would occur with resulting excessive wear of the load-bearing parts. The heat absorbed by the lubricating oil (from the combustion process and from fluid friction in bearings) must be removed so that oxidation of the oil and formation of sludge can be kept to a minimum.

Prevention of overheating is generally thought of as the primary function of an engine cooling system. However, it is possible that a cooling system might remove too much heat. If an engine is operated at lower than normal temperatures, condensation takes place in the crankcase, causing acids and sludge to form in the lubricating oil. Also, cylinder temperatures must be maintained high enough to minimize the condensation of corrosive gases on the cylinder walls. Excessively low operating temperatures tend to increase ignition lag, a condition that causes detonation. The cooling system of an engine must maintain the operating temperatures within a specified range. These temperatures can be located in the applicable manufacturer's technical manuals.

Maintaining Clearances

Each engine is designed by the manufacturer to have specific clearances between the moving parts. If the engine is operated below the temperature range specified by the manufacturer, parts in the engine will fail to expand sufficiently to obtain the desired clearances. Excessive clearances between the reciprocating parts of the engine will cause pounding. Excessive clearances between the bearings and journals will allow the oil to escape before it can reach the areas that are distant from the oil inlet port. If the engine is operated above the specified temperature range, the parts will expand and insufficient clearances between the moving parts will result. As the clearances are reduced, the required space for the oil film is also reduced. Once the oil film is reduced, inadequate lubrication of the moving parts will occur. As mentioned earlier, inadequate lubrication will cause metal-to-metal contact, accelerated wear, and seizure to occur in the engine.

Retaining the Strength of Metals

High temperatures change the strength and physical properties of the various metals used in an engine. When a cylinder head is subjected to excessively high temperatures, the tensile strength of the metal is reduced. The probability of fracture or cracking is thereby increased. Such high temperatures also cause excessive expansion of the metal, which may result in shearing of the cylinder-head bolts. Overheating can "cook" the seal rings used on the water side of the cylinder liners, causing the sealing surface of the rings to harden. This condition will affect the ability of the material to prevent leakage of the coolant into the oil sump. Consequently, by removing heat from the engine, the cooling system helps to prevent deterioration of the engine parts. If the parts, such as liners, pistons, valves, and bearings, are allowed to overheat, the tensile strength will be materially reduced, thereby accelerating wear and increasing the probability of failure. If overheating is sufficiently severe, seizure of the engine will result.

TYPES OF COOLING SYSTEMS

The cooling system of a marine diesel engine functions to keep the engine parts and fluids at safe operating temperatures. In the open system, the engine is cooled directly by seawater. In the closed system, freshwater is circulated through the engine. The fresh (jacket) water is then cooled as it passes through a cooling device where heat is carried away by a constant flow of seawater or air.

The closed cooling system is the design that is most commonly used on marine internal-combustion engines.

The Open Cooling System

An open system means that the liquid that is used to carry heat away from the engine is drawn directly from the water in which the boat or ship operates. This liquid is moved through the system and then discharged overboard. In the open system, there is no freshwater circuit. The open cooling system is not used on most marine diesel engines for several reasons. The most important reason is that the open cooling system exposes the engine to scale formation, marine growth, and dirt deposits in the piping. You may find the open cooling system in use on some small gasoline engines, such as outboard motors. On engines such as these, you must flush the cooling system with freshwater to remove any traces of seawater that might cause corrosion and fouling. For the most part, our discussion of cooling systems throughout this chapter will be limited to closed cooling systems.

The Closed Cooling System

A cooling system is classified as closed if it has a freshwater circuit (system) that is self-contained and used continuously for the cooling of the engine. Closed cooling systems are normally operated at pressures greater than atmospheric pressure so that the boiling point of the coolant is raised to a temperature that is higher than 212 °F. Cooling of an internal-combustion engine is accomplished by the use of either a cooler (heat exchanger), keel cooler, or radiator and fan. We will continue our discussion of the closed type of cooling system with a general description of these three types of closed systems. We will then take a more detailed look at the components that make up the closed type of cooling system.

Heat Exchanger Cooling System

The heat exchanger cooling system combines two separate cooling systems—a jacket-water (freshwater) system and a raw-water (seawater) cooling system. The principal components that comprise the freshwater system are an engine coolant pump, one side of the heat exchanger, and the expansion tank and piping. In the jacket-water (freshwater) cooling circuit, the freshwater is reused continuously for cooling the engine. The order of the parts through which water flows in the freshwater circuit of a cooling system is not always the same. In the majority of installations, however, the coolant is circulated throughout the engine cooling spaces by an attached circulating freshwater pump. The direction of flow of engine coolant must always be such that the temperature of the freshwater will increase gradually as the freshwater passes through the engine. So that thermal shock of the hottest parts of the engine can be prevented, the coolant is directed to flow around the cylinder liners and cylinder head last, before it is directed out of the engine. The coolant then flows to a freshwater cooler (heat exchanger) where it is cooled by the seawater cooling circuit. After it leaves the cooler, the freshwater may or may not, depending on the installation, go through the lubricating oil cooler to act as a cooling agent for the lubricating oil. The coolant finally returns to the suction side of the freshwater pump, completing the circuit.

The seawater circuit of the heat exchanger cooling system consists of a centrifugal pump (usually similar to the freshwater pump). On most small engines, the seawater pump is attached. However, on large engines that are used for propulsion or power generation, the seawater pump is a motor-driven pump remote from the engine. The seawater cooling system for a large engine is often equipped with some means for providing emergency cooling water, such as from the firemain system. The centrifugal pump draws seawater through a sea chest, strainer, and sea valves. The pump then discharges the seawater through the freshwater cooler (heat exchanger). (In some installations, an additional strainer is located in the pump discharge.) From the freshwater cooler, the seawater is discharged overboard. The overboard discharge performs varying functions, depending on the individual installation. Normally, it serves to cool the engine exhaust piping and the silencer.

On some engine-generator units, the attached seawater pump furnishes seawater to the generator air coolers as well as to the freshwater coolers and returns the water to the overboard discharge. Throttling valves, or orifice plates, which are frequently placed in lines of the seawater cooling system and the outlet of a generator air cooler, serve to control the flow rate of the water that passes through these heat exchangers. For prevention of scale formations on heat transfer surfaces, the temperature must not exceed 130 °F with a minimum flow rate to reduce the effects of erosion.

The freshwater and seawater systems of an engine that employs the heat exchanger type of cooling system are shown in *Figures 10-1 and 10-2*. An aftercooler is part of this system because the engine is a turbocharged unit. In the system in *Figure 10-1,* part of the coolant flows through the cooler and is directed back to the lower passage of the flywheel housing. This coolant is then directed to the cylinder banks on each side of the cylinder block. The coolant (freshwater) circulates around the cylinder block, around the liners, and upward through the cylinder heads to the exhaust manifold. From the exhaust manifold, the coolant flows to the expansion tank where temperature regulators control the flow of coolant to the heat exchangers. When the temperature of the coolant is not high enough to open the regulators, coolant bypasses the heat exchangers to ensure quick warm-ups. A portion of the coolant is bypassed at all times. The jacketwater heater (*Figure 10-1*) is also commonly referred to as the keep-warm heater. This device is used on some engines prior to starting to preheat the engine by heating the jacketwater.

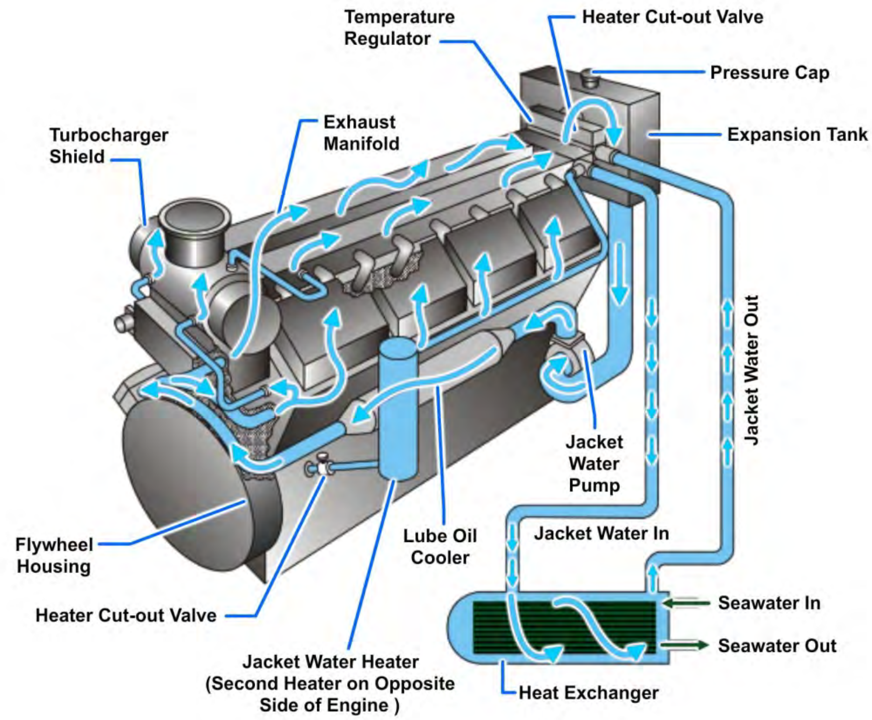

Figure 10-1 — Jacket-water (heat-exchanger) cooling system.

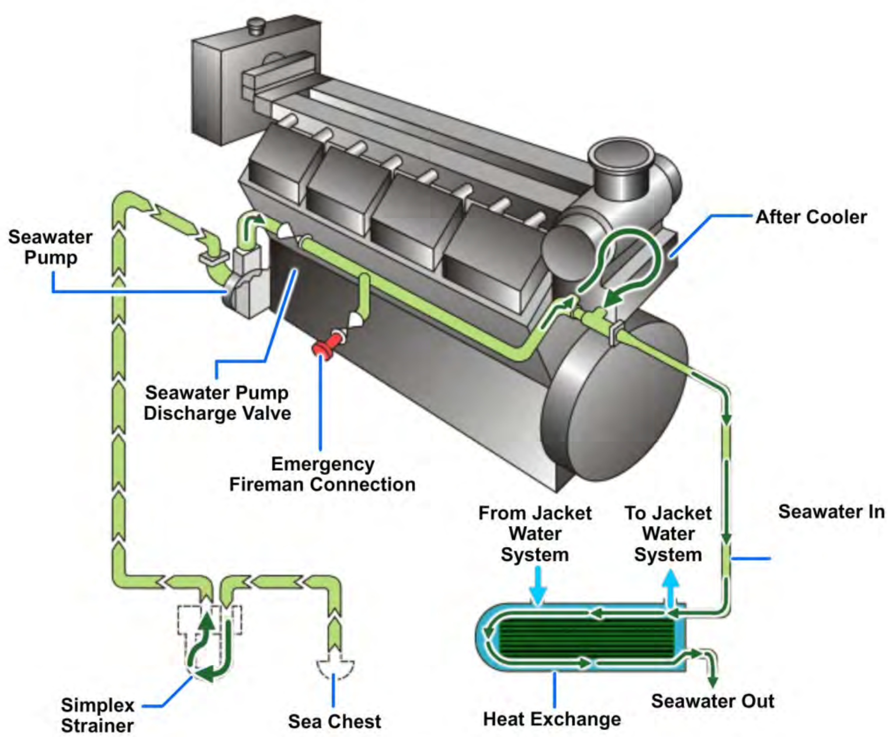

Figure 10-2 — Seawater cooling system.

In the seawater circuit shown in *Figure 10-2*, the seawater is drawn through the sea chest to a strainer by the seawater pump. The pump, through piping, directs the flow to the aftercooler for cooling the air and to the heat exchanger for cooling the freshwater.

Keel Cooling System

In the keel cooling system shown in *Figure 10-3*, which is used on small craft, heat transfer takes place in the keel cooling coil that is mounted on the hull of the vessel below the waterline. The coolant is moved by a high-capacity freshwater pump from the bottom of the expansion tank through the engine oil cooler and marine gear (transmission) oil cooler to the cylinder block. Openings in the water jacket around the cylinder bores connect with corresponding openings in the cylinder head through which the liquid passes to circulate around the valves and fuel injectors. A portion of the coolant is bypassed from the aft end of the water manifold into the aft end of the jacket surrounding the exhaust manifold and on to the expansion tank.

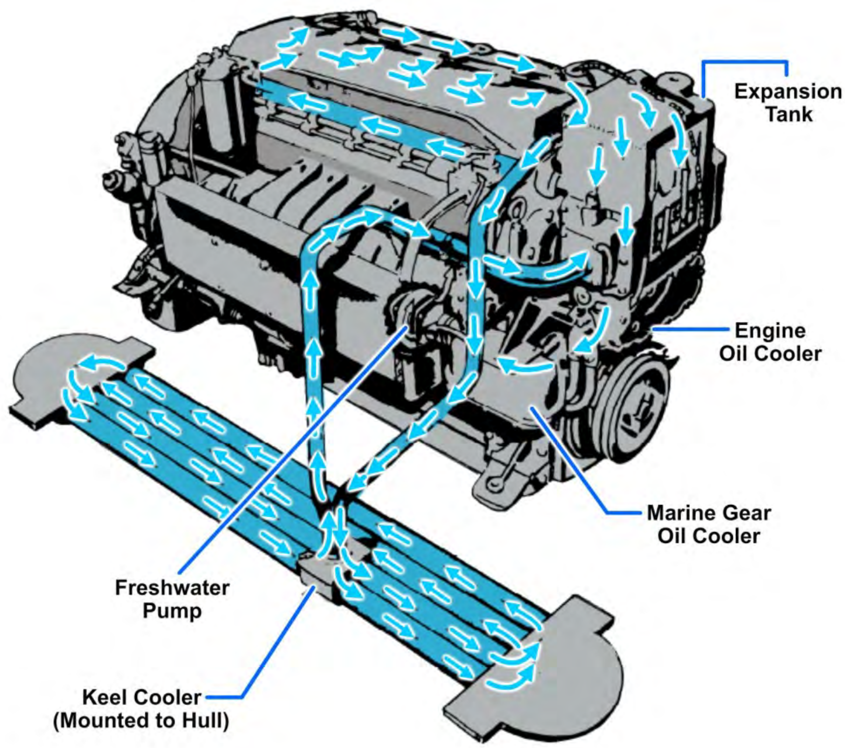

Figure 10-3 — Typical keel cooling system.

When the thermostat is open, the majority of the coolant in the water manifold passes through the thermostat housing and flows directly to and through the keel cooling coils. When the thermostat is closed, that portion of the coolant entering the thermostat housing is bypassed directly to the engine water pump inlet where it remixes with the coolant from the exhaust manifold jacket. The coolant is then circulated through the cylinder block and cylinder head. With the thermostat closed, a quick warm-up is assured since the circulating water does not pass through the keel cooling coils.

Radiator and Fan Cooling System

The radiator and fan cooling system is shown in *Figure 10-4*. In this system, the engine coolant is circulated through the radiator where it gives up its heat to the stream of air forced through the fins of the radiator by a fan. The

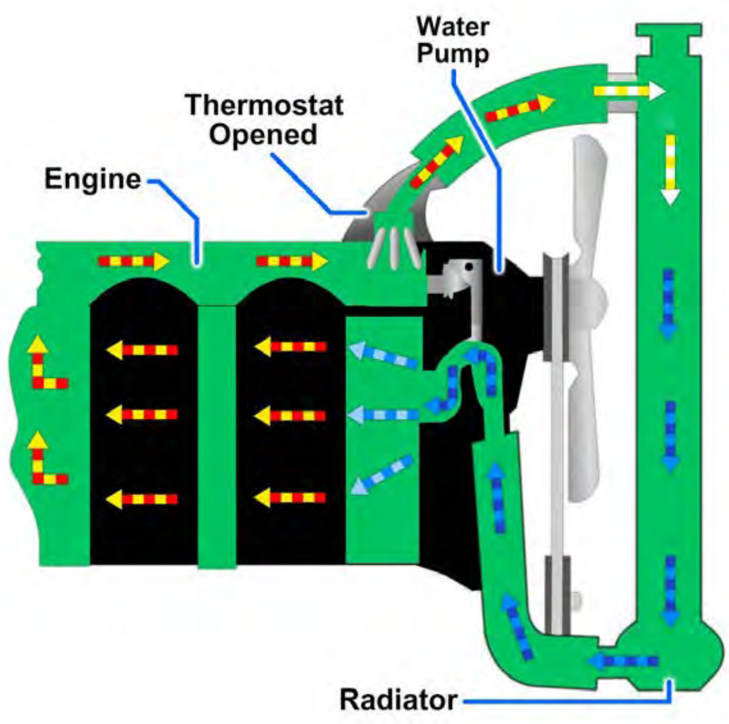

Figure 10-4 — Typical cooling system with radiator and fan.

fan is belt driven from the crankshaft. The water pump draws the cooling liquid through the oil cooler and discharges it into the lower part of the cylinder block. Openings in the water jacket around the cylinder bores connect with corresponding openings in the cylinder head through which the coolant rises to circulate around the valves and fuel injectors. The coolant then circulates through a water manifold that is bolted to the cylinder head. From the water manifold, the coolant discharges past the thermostat and into the radiator.

With the thermostat open, the coolant circulates through the radiator before returning to the water pump. With the thermostat closed, the coolant is bypassed from the water manifold directly to the pump and recirculated through the engine. A quick warm-up of the engine is assured since the circulating water does not pass through the radiator.

PRINCIPAL COMPONENTS OF A CLOSED COOLING SYSTEM

The cooling system of an engine may include such parts as pumps, coolers, radiators, water manifolds, valves, expansion tanks, piping, strainers, and instruments. Cooling systems used in the Navy include many of the same basic parts; the design and location of parts, however, may differ considerably from one engine to another.

Much of the information that follows is applicable to the cooling systems of both types of engines.

Pumps

All engine cooling systems have an attached freshwater pump. Some installations also have a detached auxiliary pump. The attached pump serves to keep the water circulating through the cooling system. Since attached pumps are engine driven, it is impossible for cooling water to be circulated in the engine after the engine has been stopped or in the event the attached pump fails. Some engines are equipped with electric-driven (detached) auxiliary pumps, which may be used if either the freshwater pump or the seawater pump fails. An auxiliary pump may also be used as an after-cooling pump when an engine has been secured.

The pumps used in the freshwater and seawater circuits of an engine cooling system may or may not be of the same type. In some systems, the pumps in both circuits are identical. In other systems, where pumps are of the same type but where variations exist, the principal differences between the pumps of the two circuits are in size and capacity. In the cooling system of some engines, the seawater pump has a capacity almost double that of the freshwater pump.

Centrifugal pumps are the principal type of pump used in engine cooling systems. On some engines, a rotary type of pump in which the impeller has flexible vanes is used in the seawater circuit. The basic principles of operation of these types of pumps are discussed in *Fireman,* NAVEDTRA 14104.

Centrifugal pumps are more common in engine cooling systems, particularly in large diesel engines, than pumps of other types. In centrifugal pumps, water is drawn into the center of the impeller and thrown at high velocity into the casing surrounding the impeller where the velocity decreases and the pressure increases correspondingly. Sealing devices, usually of the mechanical seal type, are provided to prevent leakage of water, oil, grease, or air around the impeller shaft. Pump location and method of drive will vary according to engine design.

Coolers (Heat Exchangers)

As a Fireman, you learned that devices that transfer heat from one fluid to another are called heat exchangers. You also learned that these devices are used as either heaters or coolers and that the same device may be used for both purposes. In internal-combustion engines, heat exchangers are used primarily for cooling. For this reason, the devices in engines that remove heat from a hot fluid (liquid or gas) by transferring the heat to a cooler fluid are commonly referred to as coolers.

Fluids Cooled

The primary function of heat exchangers that are used in diesel engines is to remove heat from the jacket water and the lubricating oil. Coolers are used to reduce the temperatures of engine intake air and generator cooling air and to cool engine exhaust gases. In most engine installations, the freshwater in the engine cooling system is cooled by seawater. Lubricating oil and air may be cooled by seawater or by freshwater, depending on the installation. On the basis of the fluids cooled, you will encounter freshwater coolers, lubricating oil coolers, and air coolers. All coolers operate on the same principle; in coolers used in various installations, the cooling of various fluids may differ in appearance and in details of design.

Classification of Coolers

Coolers may be classified in several ways: by the relative direction of flow of the two fluids (parallel flow, counterflow, and crossflow types); by the number of times either fluid passes the other fluid (single-pass and multipass types); by the path of heat (indirect-contact or surface type and direct-contact type); and by construction features of the unit (shell-and-tube type). The coolers used in cooling systems of engines are commonly identified on the basis of construction features.

Types of Coolers

The shell-and-tube type is a general classification that includes all coolers in which the two liquids are prevented from mixing by the thin walls of the tubes of the element. Modifications of the shell-and-tube cooler have resulted in two other types of coolers: the strut-tube cooler and the plate-tube cooler. These coolers are of the shell-and-tube type in that the fluids are prevented from mixing. Because of design features, however, the coolers used in engines are commonly identified as being either strut or plate-tube types.

Shell-And-Tube Coolers

The cooling systems of many engines are equipped with coolers of the shell-and-tube type. Shell-and-tube coolers serve to cool lubricating oil and freshwater. Coolers that are used for the cooling of lubricating oil are somewhat smaller than those that are used for the cooling of water. One model of a shell-and-tube cooler is shown in *Figure 10-5*. The shell-and-tube cooler consists principally of a bundle (also called a bank or nest) of tubes encased in a shell. The cooling liquid generally flows

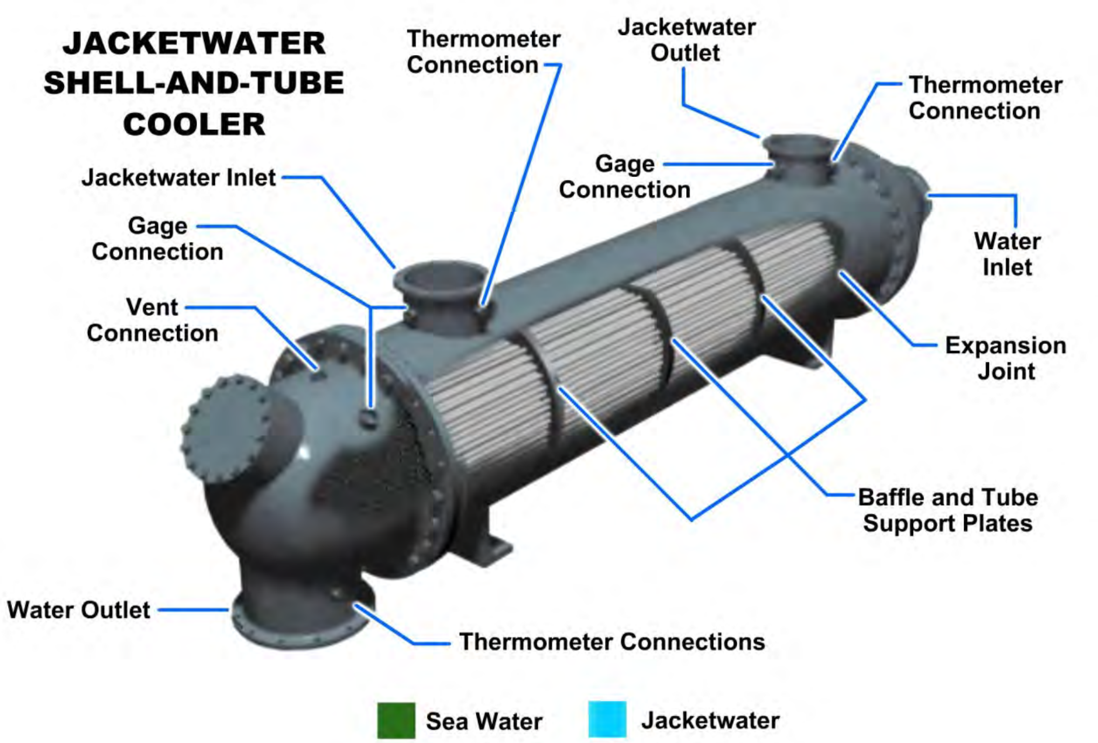

Figure 10-5 — Jacket-water shell-and-tube cooler.

through the tubes. The liquid to be cooled enters the shell at one end, is directed to pass over the tubes by baffles, and is discharged at the opposite end of the shell. In other coolers of this type, the cooling liquid flows through the shell and around the tubes; the liquid to be cooled passes through the tubes.

The tubes of the cooler are attached to the tube sheets at each end of the shell. This arrangement forms a tube bundle that can be removed as a unit from the shell. The ends of the tubes are expanded to fit tightly into the holes in the tube sheets; they are flared at their outer edges to prevent leakage. One tube sheet and a bonnet are bolted to the flange of the shell. This sheet is referred to as the stationary-end tube sheet. The tube sheet at the opposite end "floats" in the shell, a design that allows for expansion of the tube bundle. Packing rings, which prevent leakage past the floating-end tube sheet, are fitted at the floating end between the shell flange and the bonnet. The packing joint allows for expansion and prevents the mixing of the cooling liquid with the liquid to be cooled inside the shell by means of a leak-off, or lantern, gland that is vented to the atmosphere.

Transverse baffles are arranged around the tube bundle in such a manner that the liquid is directed from side to side as it flows around the tubes and through the shell. The deflection of the liquid ensures the maximum cooling effect. Several of the baffles serve as supports for the bank of tubes. These baffles are of heavier construction than those that only deflect the liquid. The flow of the liquid in the tubes is opposite the liquid flow in the shell. The cooler could be classified as the counterflow type, since heat transfer is through the walls of the tubes; the cooling liquid enters one end of the cooler, flows directly through the tubes, and leaves at the opposite end. The cooler, however, could be more precisely classified as a single-pass, indirect-type cooler.

Strut-Tube Coolers

Another design of cooler used in the cooling systems of marine engines is the strut-tube type. The strut-tube cooler has an advantage over the shell-and-tube cooler in that it provides considerable heat transfer in a smaller and more compact unit. On the other hand, the shell-and-tube cooler, while larger for an equivalent amount of heat transfer, has an advantage over the strut-tube cooler in that it is able to withstand a higher degree of scaling and larger foreign particles before the cooling system becomes clogged. Sometimes, the term radiator is used for coolers with strut-tube construction. There are many different designs of strut-tube coolers. The tube assemblies of two of these coolers, and the type of tube construction in each, are illustrated in *Figure 10-6, frames 1 and 2*.

Strut-tube coolers are used for the cooling of water and lubricating oil. Water coolers and oil coolers differ principally in design and in the size of the tubes. Each of the tubes (*Figure 10-6, frames 1 and 2*) in both the oil cooler and the water cooler is composed of two sections, or strips. In the strut-tube water cooler, both sections of each tube contain either a series of formed dimples or cross tubes brazed into the tubes. These struts (sometimes referred to as baffles) increase the inside and outside

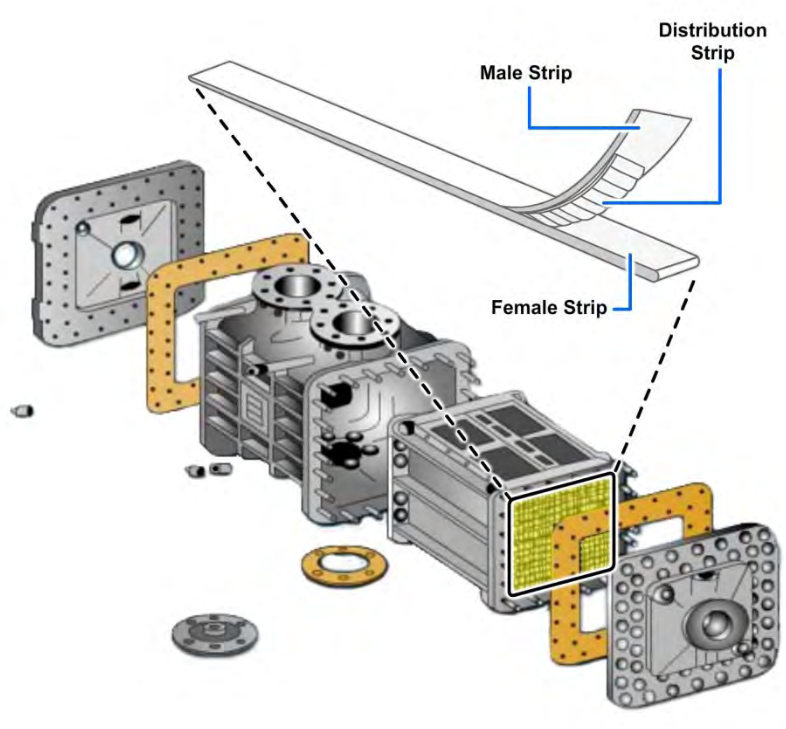

Figure 10-6 — Tube assembly of different strut-tube type coolers.

contact surfaces of each tube and create turbulence in the liquid flowing through the tube; thus, the heat transfer from the liquid being cooled to the cooling liquid is increased. The struts also increase the structural strength of the tube. In the oil cooler, the tubes are from one-half to one-third as large as the tubes of water coolers, and the sections of the tubes do not contain either dimples or cross tubes. Instead, a distributor strip, which serves the same purpose as the struts in the tubes of the water cooler, is enclosed in each tube.

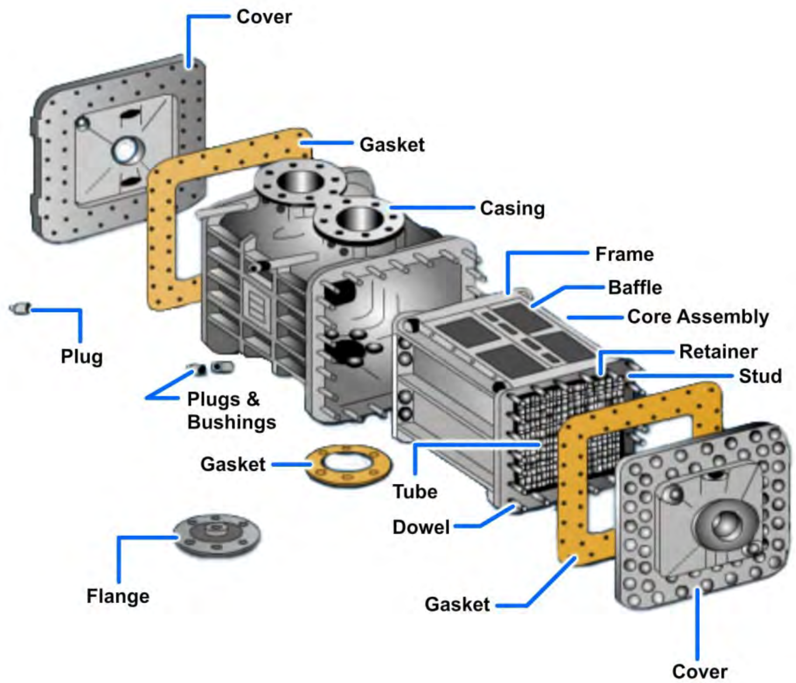

Figure 10-7 — Components of a strut-tube cooler.

The tubes of a strut-tube cooler are fastened in place with a header plate at each end and are further secured with an intermediate reinforcement plate. These plates are electroplated with tin to protect the iron parts of the cooler. The tube-and-plate assembly (sometimes called the tube bundle or the core assembly) is mounted in a bronze frame. The frame and the core assembly fit in the cast metal casing, or housing, and are held in place by the two end covers. The casing, core assembly, frame, covers, and other parts of one model of a strut-tube cooler are shown in *Figure 10-7*.

The header plates at the ends of the tubes separate the cooling-liquid space in the casing from the cooled-liquid ports in the end covers. The cooled liquid flows through the tubes in a straight path from the cover inlet port to the cover discharge port at the opposite end of the cooler. The intermediate tube plate acts as a baffle to create a U-shaped path for the cooling liquid, which flows around the outside of the tubes from the inlet opening of the casing to the discharge opening.

Plate-Tube Coolers

Shell-and-tube coolers and strut-tube coolers are used for cooling both oil and water, usually with seawater as a coolant; plate-tube coolers are used only for cooling oil. Seawater or freshwater may be used as the cooling liquid in plate-tube coolers, depending on the installation.

Figure 10-8 — Plate-tube cooler.

An exploded view of one model of a plate-tube cooler is shown in *Figure 10-8*. A plate-tube cooler consists of a stack of flat, oblong, plate-type tubes that are connected in parallel with the oil supply and enclosed in a cast metal housing. Each tube of a plate-tube cooler consists of two sections, or stampings, of copper-nickel. A distributor strip is enclosed in each tube. Several tubes are assembled to form the cooling element, or core, of the cooler.

In a plate-tube cooler, the cooling liquid flows through the casing and over the tubes. The heated oil flows through the tubes. The tubes in the core assembly are spaced so that the cooling water circulates freely over their external surfaces.

Location of Coolers

The location of coolers will vary, depending on the engine and the fluid cooled. Some coolers are attached; others are detached. Some freshwater coolers are located on the outside of the hull, well below the waterline. When so located, coolers are frequently referred to as outboard, keel, or hull coolers.

Figures 10-1 through 10-4, and 10-9, are example of variations in the locations of freshwater coolers and lubricating oil coolers, the location of the freshwater coolers and the lubricating oil coolers. *Figure 10-9* is representative of the location of the coolers in many small diesel engines. In this system of engine cooling, the hot coolant leaving the thermostat housing passes through the expansion tank, then through the cells of the cooling core. After leaving the heat exchanger, the engine coolant is picked up by the freshwater pump and circulated through the cylinder block and cylinder heads. The raw water (seawater) is forced horizontally between the cells of the core and serves to lower the temperature of the coolant as it passes through the cells. The location of the coolers in a medium-sized diesel differs from that in smaller engines.

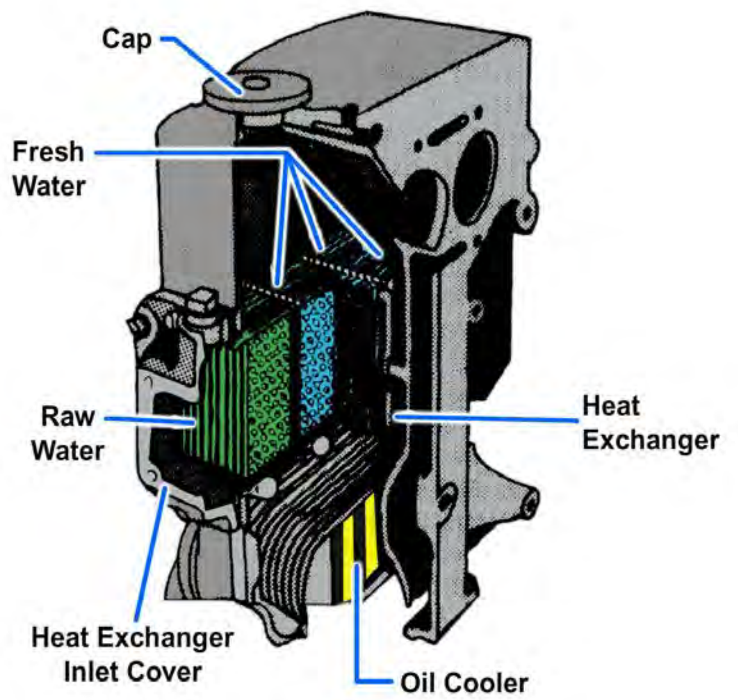

Figure 10-9 — Location of cooler and cooling system component on small engines.

The coolers discussed up to this point have been those that function to lower the temperature of freshwater and lubricating oil. In some engines, the temperature of the supercharged intake air is also reduced. If the temperature of this air, which is heated by compression within the supercharger, is reduced, then the amount of air charge entering the cylinder during each intake event will increase and the power output of the engine will be increased. Coolers that function to lower the temperature of the intake air are primarily of the radiator type and operate on the same principle as coolers that function to cool freshwater and lubricating oil. Air coolers that serve to cool intake air are referred to as intercoolers or after-coolers. The heated air from the supercharger passes around the tubes, where the heat is transferred to the cooling water that is flowing through the tubes. The cooling water is generally from the seawater circuit, but it may be from the freshwater circuit.

The engine cooling system also functions to cool the air around some engine-generator sets. Generators, unlike internal-combustion engines, cannot be directly cooled by liquids. If a generator develops more heat than can be removed by the surrounding air, a supply of cool air must be provided in a closed air circuit. The heated air from the generator is forced through the cooler, where the temperature is reduced. The air is then recirculated to the generator. Depending on the installation, either freshwater from the engine cooling system or seawater may serve as the cooling medium.

Engine Water Passages

The form, location, and number of cooling passages within an engine vary considerably in different engines. The form of cooling water passages and their locations are controlled by many factors, such as the size of the engine, the cycle of operation, and the cylinder arrangement. The examples we will use are for illustrative purposes and are not all-inclusive; however, the examples described are representative of the passages that are found in in-line, V-type, and opposed-piston engines.

The location and form of the water passages in a V-type engine are basically the same as those found in an in-line engine. Differences that exist are generally due to the cylinder arrangement. The location and form of these passages (*Figure 10-10, frames 1 and 2*) at one point in a V-type engine are shown in the cross-sectional view.

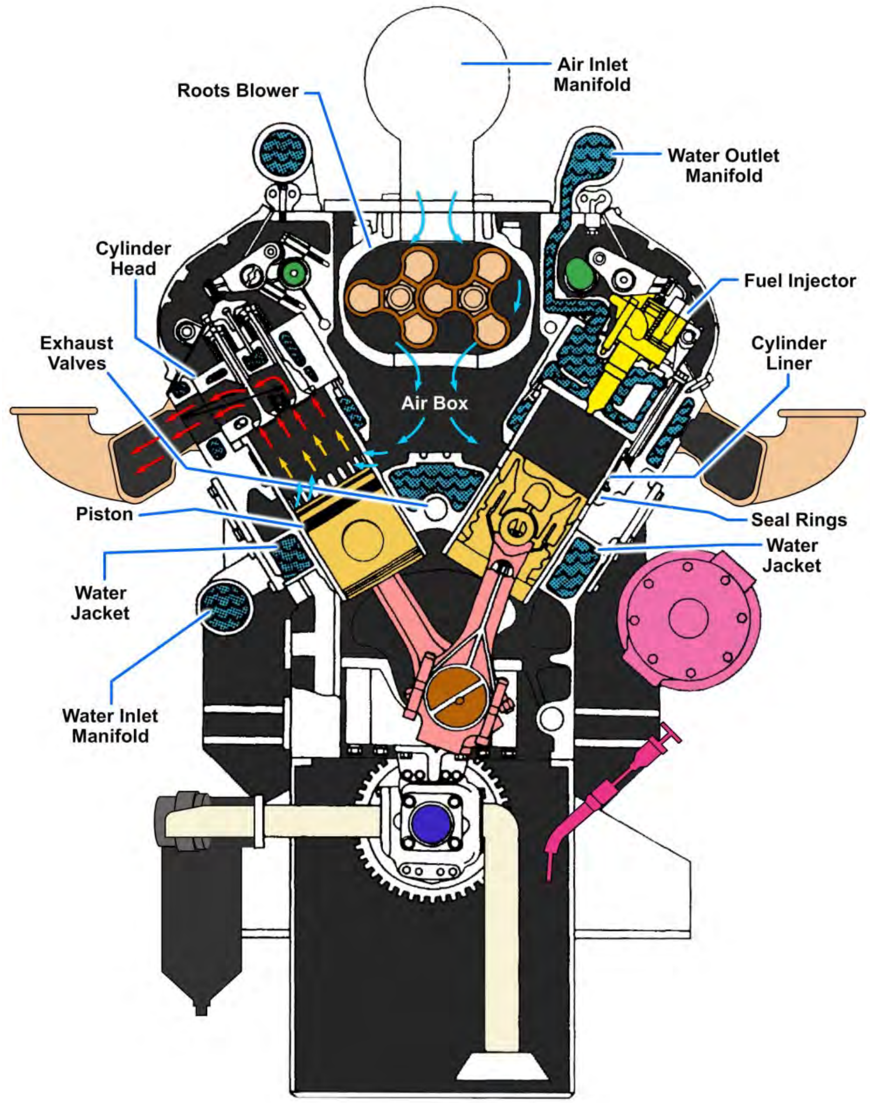

Figure 10-10 — Location of water passages in a V-block engine.

In operation, the water pump draws water from the off-engine system and pumps it into the cylinder block through the water jacket, around the cylinder liners, and through the cylinder heads to the water outlet manifolds. The flow of water (*Figure 10-10, frame 2*) divides in the water outlet manifolds goes to the exhaust manifolds, and through the jacket-water outlet. The majority of the water is discharged to the jacket-water outlet. From the jacket-water outlet, the water returns to the off-engine system for reuse after cooling. Water from the exhaust manifolds enters cored passages in the engine front cover and returns to the pump.

The location and form of the cooling passages in an opposed-piston engine will differ, to a degree, from those in other types of engines. The lack of cylinder heads eliminates some of the passages common to in-line and V-type engines. While differences of a minor nature exist in the passages of different types of engines, the cooling passages of all engines are similar in many respects. Some ways in which the passages of an opposed-piston engine are similar to those of other types of engines are shown in *Figure 10-11*.

The cooling water passages of the Fairbanks Morse (FM) 38D8 1/8 shown in *Figure 10-11* are similar to those found in other types of engines. The location of the water header (manifold), however, differs in various engines. In the FM 38D8 1/8, the water from the pump usually enters the engine through the water jackets of the exhaust elbows and the exhaust manifolds. Water enters the cylinder liner through a nozzle-adapter. In the usual arrangement, the water header or manifold in the FM 38D8 1/8 receives water from the cylinder-liner water passages. The water header of an FM 38D8 1/8 is the last passage in the engine through which water flows before it goes through the cooler and back to the pump.

Cylinder Heads

Most engines have cooling-water passages within the cylinder head. In the cylinder head, these passages generally surround the valves. In diesels, the water passages also surround the injectors. Usually, the passages are cast or drilled as an integral part of the head. In some cylinder heads, (*Figure 10-12*) each injector is inserted into a thin-walled copper tube that passes through the water space in the cylinder head. This design serves to ensure sufficient cooling. The lower end of the copper tube is pressed into the cylinder head and is flared over; the upper end is flanged and sealed with a neoprene seal. The flared lower end and sealed upper end prevent any leaks around the copper tube. The exhaust passages exhaust valve inserts, and injector tubes are completely surrounded by cooling water. Cooling of these areas of the cylinder head is further assured by the use of nozzles installed in the water inlet ports of the head. Nozzle holes (*Figure 10-12)* are so positioned in the cylinder head that the comparatively cool water that enters the head is directed at high velocity against the sections of the head that are subjected to the greatest heat.

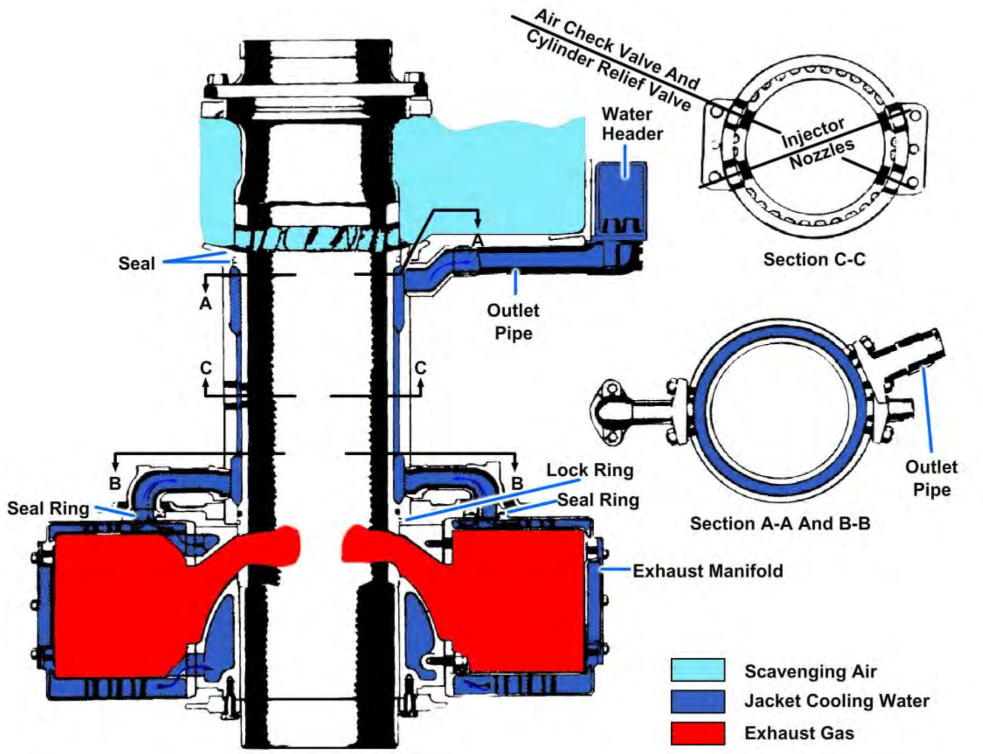

Figure 10-11 — Cooling water passages for opposed-piston engines.

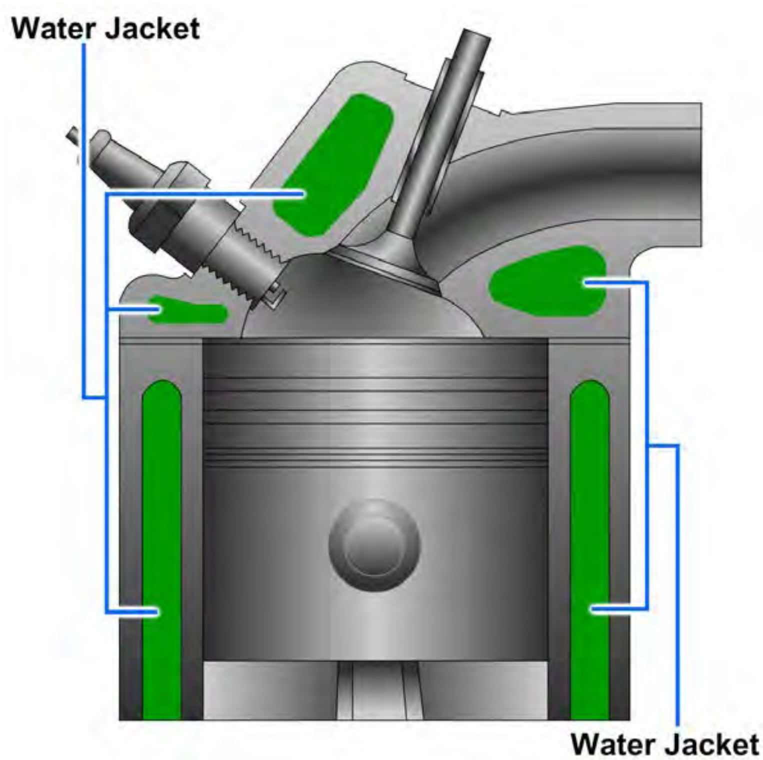

Figure 10-12 — Liquid cooling around valves and injectors in the cylinder head.

The passages in the cylinder head receive water from a jacket or from passages, either of which may be an integral part of the cylinder liners or the cylinder block. Water flow to the cylinder head is almost always upward from the liner or block.

Freshwater (Expansion) Tanks

The freshwater circuit of an engine cooling system includes a tank that is commonly referred to as the expansion tank. Some expansion tanks are identified as the surge tank or supply tank.

The freshwater tank provides a place where water may be added to the system when necessary and provides a space to accommodate changes in water volume that result from expansion and contraction when the water is heated and cooled. The piping arrangement to and from the expansion tank provides for three basic functions:

1. Permits excess water in the system to pass back to the tank as the water becomes warm and expands.
2. Permits water from the tank to flow into the system when the water becomes cool and contracts.
3. Allows for the resupply of water from the expansion tank in the event of leaks in the system.

Figures 10-1 and 10-3 are examples of tank locations; even though the exact locations of expansion tanks vary in different engines, the tank is always located at or near the highest point in the circuit.

The manner in which venting is accomplished in the freshwater circuit of a cooling system will vary, depending on the engine.

Venting generally involves the expansion tank. In some expansion tanks, particularly in the systems of larger engines, a vent pipe from the high point of the circuit carries to the tank any steam or air bubbles that may form in the system. When steam comes in contact with the cooler water in the tank, the steam condenses back into water. The condensation keeps the system free from steam or air pockets. The expansion tank is vented to the atmosphere. A gauge glass, located on the side of the tank, reveals the water level.

In many small engines, the freshwater circuit has no vent and operates under a slight pressure; this arrangement confines the water vapor, thus preventing the loss of water. The only escape for water vapor from a circuit that operates under pressure is through a small overflow pipe.

Temperature Regulation

The temperature of a liquid in the cooling system of an engine must be regulated to maintain normal operating conditions. One of the principal factors affecting the cooling of an engine is the rate of flow of water through the cooling system. The high flow rate of the water causes the heat to be carried away more quickly. As the velocity of the circulating water is reduced, the discharge temperature of the cooling water becomes higher and more heat is carried away by each gallon of cooling water circulated. As the rate of circulation is increased, each gallon of cooling water carries away less heat and the discharge temperature of the cooling water drops. Our discussion will now cover the devices that control the engine coolant direction of flow and, therefore, the temperature. These devices can be manually operated or thermostatically operated.

⚠ CAUTION ⚠

The throttling valve in the seawater circuit should be adjusted so that it regulates the minimum flow of seawater through the cooler while not exceeding a discharge temperature of 130 °F to reduce the effects of erosion and to prevent scale formation on heat transfer surfaces.

Manually Operated Throttling Valves

Throttling valves used in the seawater circuit will regulate the amount of water passing through the seawater side of the freshwater cooler. The throttling valve in the seawater circuit should be adjusted so that it regulates the minimum flow of seawater through the cooler while not exceeding a discharge temperature of 130 °F to reduce the effects of erosion and to prevent scale formation on heat transfer surfaces. Where throttling valves are incorporated in the seawater circuit and a thermostatically operated valve is included in the freshwater circuit, the throttling valves serve only to provide a constant flow of seawater or to close the circuit completely. Temperature is then controlled by direction of flow by the action of the thermostatically operated valve in the freshwater circuit.

Thermostatically Operated Bypass Valves

In marine diesel engine installations, automatic temperature control by means of thermostatically operated bypass valves is more common than control by means of throttling valves in the seawater circuit. When used in the jacket-water system, these valves are located between the point where the jacket water leaves the engine block and the component that cools the water. The thermostatic valves used in the cooling systems of engines are of two types: the conventional type, shown in *Figure 10-13, frames 1 through 4* which are also used in automotive engines, and the three-way proportioning type, shown in *Figures 10-14*. Valves of the latter type are commonly called automatic temperature regulators. Conventional thermostatic valves are generally used in small engines; the automatic temperature regulators are commonly used in medium and large engines.

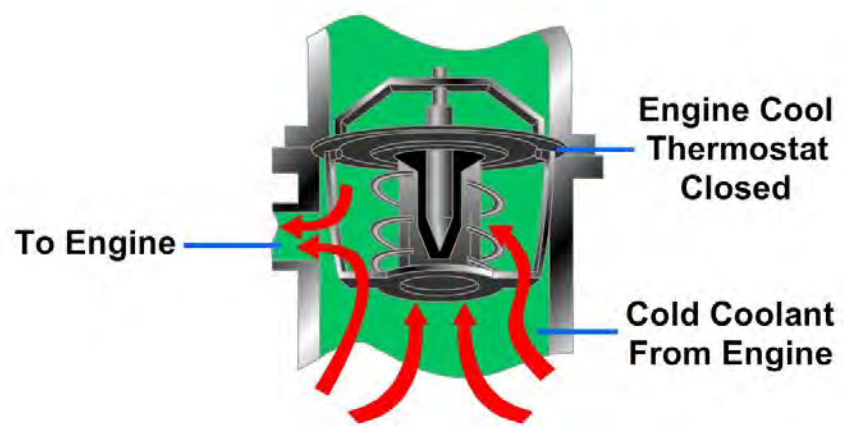

Figure 10-13 — Conventional type valve operation.

Conventional Thermostatic Valves

A typical thermostatically controlled system, as shown in *Figure 10-4*, is designed to open at a specified temperature. This temperature is known as the rating of the thermostat and is usually stamped on the thermostat. Most thermostats begin to open at their rated temperatures and are fully open at about 20 °F above their rated temperatures. For example, a thermostat with a rated temperature of 165 °F will start to open at that temperature. At 185 °F, the thermostat will be fully open. The conventional type of thermostatic valve is not adjustable. If a higher or lower operating temperature is desired, the valve must be replaced with a valve of a different rating.

Figure 10-13 illustrates the operation of a thermostatic valve. A spring holds the valve shut when the coolant is cold *(Figure 10-13*, *frames 1 and 2)*. Thus, the coolant is stopped from circulating through the cooling medium and is directed to the bypass line where it is forced back to the water pump to be recirculated. As the coolant starts to heat up, a special plastic wax-like substance within the temperature-sensing bulb of the thermostat starts to liquefy and expand *(Figure 10-13*, *frames 3 and 4)*. This expansion process begins to force the valve open. As the valve starts to open, some of the coolant will begin to enter the cooling medium. When the temperature of the coolant reaches the operating temperature of the engine, the wax-like substance within the bulb becomes totally liquefied and fully expanded. At this point, the valve is completely open and directs most of the coolant through the cooling medium.

Automatic Regulating Valves

The temperature of the freshwater is regulated automatically by a three-way control valve that maintains the temperature of the freshwater at any desired value by bypassing a portion of the water around the freshwater cooler. Even though these regulators are automatic or self-operated, provisions are included for manual operation in the event that the automatic feature fails.

Shown in *Figure 10-14* is one type of three-way, temperature-sensitive valve for changing the path of water flow. This valve has a temperature-sensitive element that is placed in the engine jacket-water discharge line. The element contains a liquid (a mixture of ether and alcohol) that gives off a vapor when heated by the jacket water that produces a pressure that is proportional to the temperature to which the bulb is exposed. The pressure is transmitted through liquid-filled flexible tubing (capillary tube) to a bellows in the head of the valve. The movable end of the bellows is connected to the valve stem. When the bellows expands or contracts, the valve will open or close accordingly. The action of the bellows is opposed by a spring. The compression of the spring can be adjusted so that the specified operating temperature can be readily set.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range *(Figure 10-15)*. The setting is controlled by the range-adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale that is attached to the regulator frame. The scale is graduated from 0 to 9, representing the total operating range of the regulator.

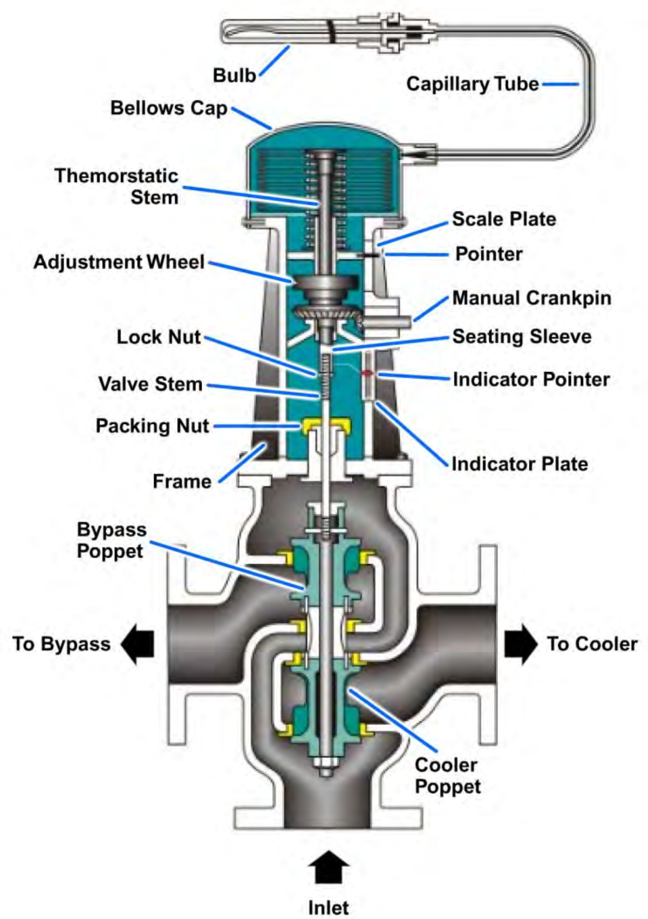

Figure 10-14 — Automatic temperature regulator.

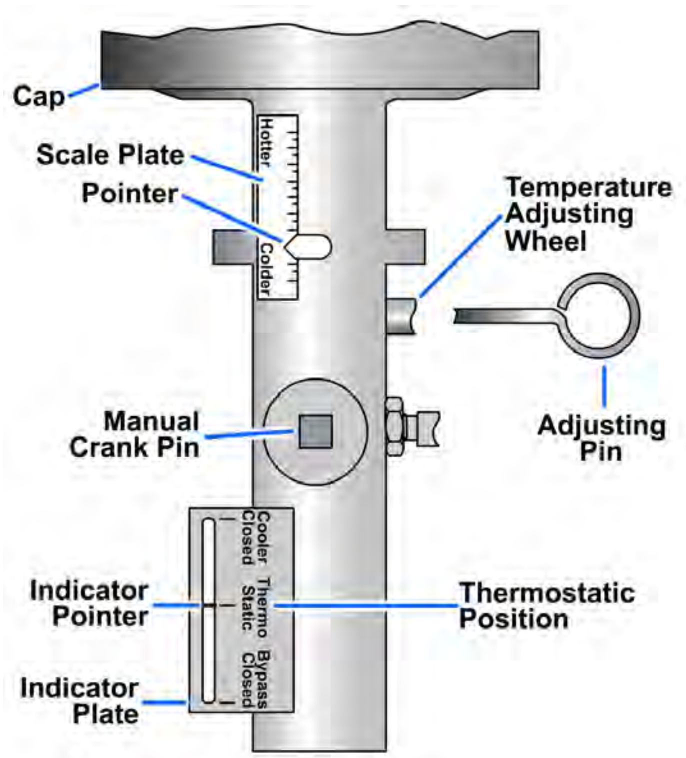

Figure 10-15 — Scale and indicator plate of an automatic temperature regulator.

In contrast to the valve illustrated in *Figure 10-16*, the three-way automatic regulating valve does not use a gas or liquid as a sensing or activating element. The sensing or activating element in this valve is a “power pellet.” The power pellet contains a special wax material (similar to that in the conventional thermostatic valve) that expands with tremendous force as it changes from a solid to a liquid when heat is applied. In this valve (as in the conventional thermostatic valve), the important characteristic of the sensing element is that when the wax material is fully liquefied, expansion stops. The manufacturer uses a different formulation to establish a suitable operating range and limiting action for each three-way automatic regulating valve. The sensing element for each of these valves is set at the normal temperature rating by the manufacturer and cannot be altered once the rating has been set. If a different rating is required, a new valve must be used.

The three-way temperature regulating (control) valve that is located in the freshwater circuit automatically regulates jacket-water flow to the jacket-water cooler to maintain optimum water temperature. These valves are arranged so that flow is normally through the recirculating line which bypasses the cooler and permits the jacket water to be recirculated through the engine. As shown in *Figure 10-16, view A*, the temperature of the jacket water rises and the valve starts to open. When the jacket water in contact with the valve element starts to exceed normal operating temperature, the valve fully opens to permit full flow to the jacket-water cooler where the excessive heat is given up (*Figure 10-16, view B).* It should be noted that the applications of conventional thermostatic valves or automatic regulating valves we have discussed do not control the rate of water flow through the cylinder jackets but vary the flow through whatever cooling medium is used. This design provides for the control of the temperature of the jacket water without a reduction in the rate of flow in the engine that might cause localized hot spots.

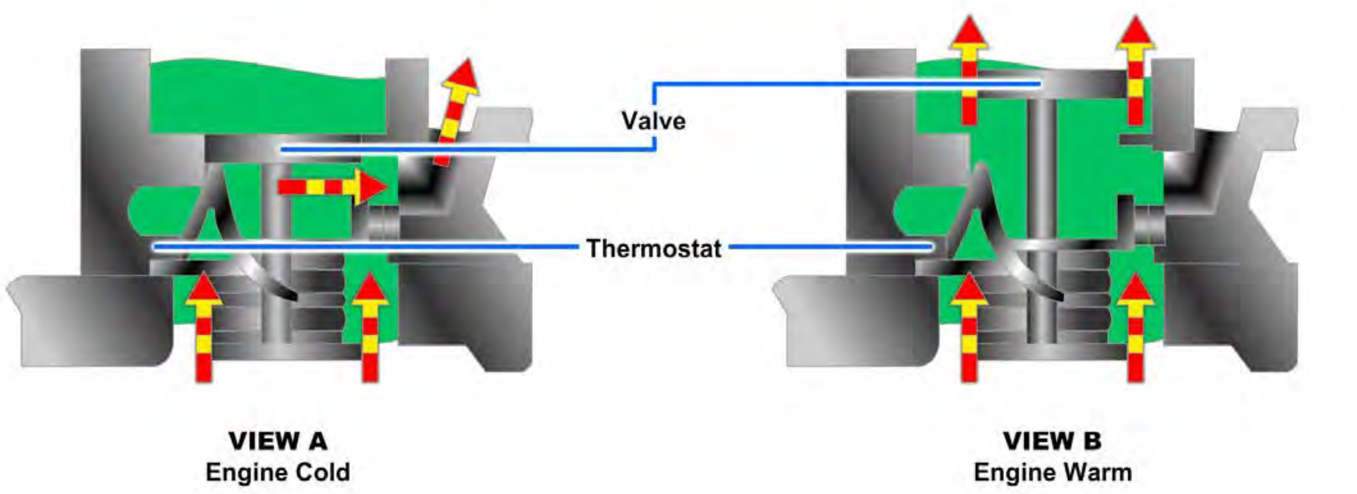

Figure 10-16 — Three-way temperature regulating valve operation.

When located in the seawater circuit, the regulator controls the amount of seawater flowing through the coolers. When the temperature of the freshwater becomes greater than the temperature for which the regulator is set, the regulator actuates a valve to increase the flow of seawater through the coolers. When the temperature of the freshwater is below the temperature for which the regulator is set, the regulator actuates a valve to decrease the flow of seawater through the coolers.

Temperature regulators are used not only to control the temperature of the freshwater but also to control indirectly the temperature of the oil discharge from the lubricating oil cooler. Control of lubricating oil temperature is possible because the water that is passed through the regulator and the freshwater cooler is the cooling agent in the lubricating oil cooler.

MAINTENANCE OF THE HEAT EXCHANGER TUBES

Shipyard, repair ship, or tender personnel are usually responsible for such repair work as re-tubing heat exchangers. However, you should have a good understanding of the procedures involved. You should also be qualified to act as a ship's inspector to see that all work is being performed satisfactorily. Enginemen will inspect and clean heat exchangers, check for leaks and plugged tubes, and operate the units. Proper maintenance of heat exchangers is necessary to ensure continuous ship operation and equipment longevity. Conduct preventative maintenance according to the maintenance and material management (3-M) system.

Foreign matter can clog condenser tubes and degrade condenser tubes service life and reliability. Air vents are provided at the top of heat exchangers so sufficient cooling water flow and pressure are maintained under all operating conditions. Foreign matter, grease, and dirt will reduce the rate of heat flow from the circulating water in the tubes. This, in turn, will reduce the maximum transfer that can be obtained and lower the efficiency of the plant.

For single-tube sheet heat exchangers, remove blocked tubes that cannot be cleared from service. This is done by plugging the tube ends with tapered phenolic plugs. For double tube sheet heat exchangers, replace or permanently plug blocked tubes that cannot be cleared. If there is insufficient time for replacing or permanently plugging them, temporarily plug the blocked tubes with tapered phenol plugs. Replace with permanent ones at the first opportunity available.

Replace plugged tubes whenever the number of plugged tubes in a heat exchanger approaches 10 percent of the total amount of tubes. At that point, the effect of the plugged tubes on the operation of the unit should become noticeable.

CAUTION

Heat exchanger tubes are made of corrosion-resistant material that forms a protective oxide film on the seawater side. A scratch in this film can cause surface pitting. Never use abrasive or metal tools or wire brushes for cleaning tubes. Use all cleaning equipment carefully to avoid damaging the protective film.

Conditions may arise that call for more frequent inspections of main condensers. The ship may operate in shallow water or in waters where there are large amounts of seaweed, schools of small fish, or large amounts of oil. When any of these conditions occur, open the condenser for inspection and cleaning. Before opening the heat exchanger, read and observer all the precautions listed in *Naval Ships' Technical Manual* (NSTM), Chapter 254.

Remove material lodged in the tubes with air, water lance, water gun, high pressure water jet, or non-metallic rod or scraper.

Nonmetallic bristle brushes or rubber plugs can be blown through tubes using a water or lance, followed by water flush.

WATER AND CHEMICAL REQUIREMENTS OF A COOLING SYSTEM

Since the purpose of an engine cooling system is to keep engine parts and working fluids at safe operating temperatures, you must take preventive actions to keep corrosion and scale formation to a minimum. To help prevent undesirable operating conditions in an engine, you must meet two basic requirements. First, you must use an acceptable type of water for the cooling system. Second, you must chemically treat the water with the proper corrosion inhibitor.

Water

When you fill the freshwater cooling system of an engine, you must use an acceptable type of water. An important part of a coolant treatment program for any engine is the use of water that contains minimum amounts of hardness, chloride, and sulfate. The water you must use for filling or topping off cooling systems or for mixing treatment chemicals is indicated by the following categories:

1. Shore-source water that meets the requirements of NSTM, Chapter 220, volume 2, for shore-source feedwater.
2. Shipboard boiler feedwater or condensate that meets the requirements of NSTM, Chapter 220, volume 2.
3. Water produced by shipboard distilling plants, demineralizers, or reverse osmosis units.
4. Water produced by shore-based distilling plants, demineralizers, or reverse osmosis units.

If water indicated by these categories is not available, use clean, freshwater. Clean, freshwater includes shipboard potable water or city water.

Chemicals

The chemicals you will use for treating freshwater in engine cooling systems will vary according to the composition of the metal you are trying to protect, the application of the engine, and the climate to which the engine is subjected. Because of these variations, our discussion of engine cooling system treatments will be general. Complete information on this subject can be obtained in the NSTM, Chapter 233.

Our discussion will cover some of the chemicals that are authorized for the treatment of freshwater systems in engines. Remember, however, that the water treatment methods that will be discussed in this chapter are preventive treatments only. These treatments will not remove scale that has already formed in the cooling system.

A corrosion inhibitor is a water-soluble chemical compound that protects the metallic surfaces of the cooling system against corrosive attack. Depletion of all types of inhibitors occurs through normal operation; strength levels must be maintained by addition of inhibitors as required after the coolant is tested.

The importance of a properly inhibited coolant cannot be overstressed. A coolant that has insufficient inhibitors, the wrong inhibitors, or no inhibitors at all invites the formation of rust and scale deposits within the cooling system. Rust, scale, and mineral deposits can wear out water pump seals and coat the walls of the cylinder block water passages and the outside walls of the cylinder liners. As these deposits build up, they insulate the metal and reduce the rate of heat transfer. A 1/16-inch deposit of rust or scale on 1 inch of cast iron is equivalent to 4 1/4 inches of cast iron in heat transferability (*Figure 10-17*).

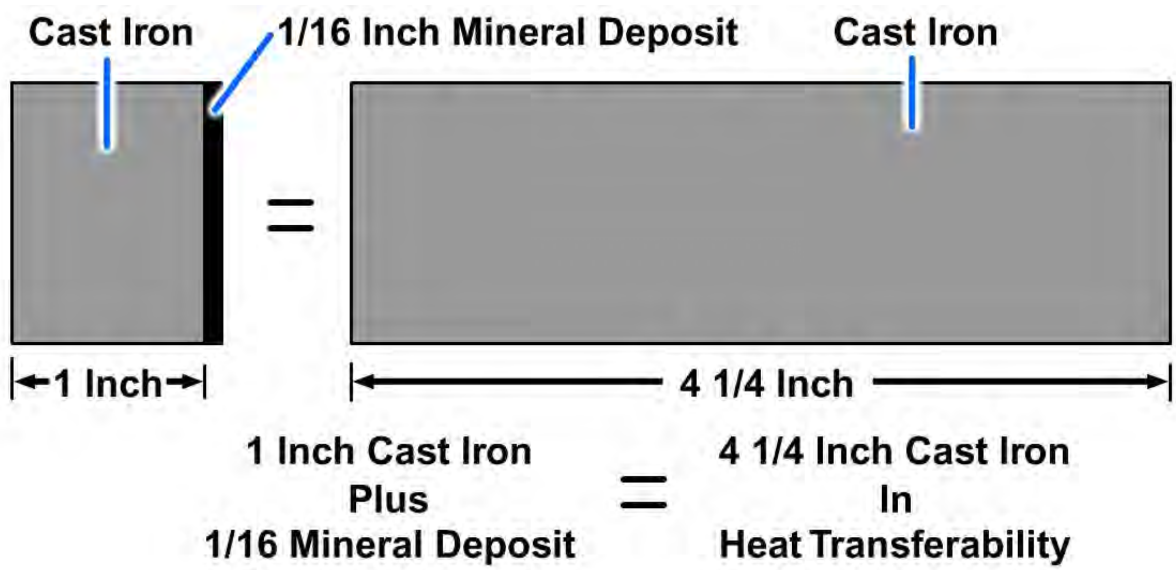

Figure 10-17 — Reduction of heat transfer capacity from rust or scale deposits.

An engine affected in this manner overheats gradually—over a period of weeks or months. Liner scuffing, scoring, piston seizure and cylinder head cracking are the inevitable results. An improperly inhibited coolant may also become corrosive enough to “eat away” coolant passages, erode seal ring grooves, and cause leaks to develop. If sufficient coolant accumulates on top of a piston, a hydrostatic lock can occur while the engine is being started. This, in turn, can result in a bent connecting rod. As a precaution against these possibilities, an engine should be barred over by hand before being started.

An improperly inhibited coolant can also contribute to cavitation erosion. Cavitation erosion is caused by the collapse of bubbles (vapor pockets) that form on the coolant side of an engine component. The collapse results from a pressure differential in the liquid caused by the vibration of the engine part. As bubbles collapse, they form pinpoints of very high pressure. Over a period of time, the rapid succession of millions of tiny bursting bubbles can wear away (erode) internal engine surfaces.

Components such as freshwater pump impellers and the water sides of wetted cylinder liners are especially susceptible to cavitation erosion. In extreme cases their surfaces can become so deeply pitted that they appear to be spongy, and holes can develop completely through them.

When this training manual was written, there were five types of corrosion-inhibitor treatments authorized for use in naval engine cooling systems. These treatments include:

1. MIL-A-53009 inhibitor
2. NALCOOL 2000
3. Inhibited antifreeze (A-A-52624, Type I)
4. Soluble oil (MIL-I-24453)
5. Nalfleet 9-111

MIL-A-53009 Inhibitor

MIL-A-53009 inhibitor is authorized for any system not specially assigned to another treatment. This treatment does not provide any freezing protection. Ships authorized to use MIL-A-53009 treatment which requires freezing protection shall use A-A-52624 Type I Antifreeze in place of MIL-A-53009 inhibitor. The chemical additive MIL-A-53009 consists of a blend of inhibitor chemicals in a liquid solution. The inhibitors neutralize the acidic byproducts that result from the combustion blow-by gases that leak into the coolant. To prevent corrosion, the inhibitors form protective layers on the metal surfaces of the cooling system.

> ⚠ **CAUTION** ⚠
>
> Do not use MIL-A-53009 and inhibited antifreeze together in the same engine cooling system. Overtreatment with MIL-A-53009 and inhibited antifreeze can result in the formation of deposits in heat exchangers. This condition can cause overheating. Refer to NSTM, Chapter 233, for information concerning the required conversion procedures.

NALCOOL 2000 Proprietary Treatment

NALCOOL 2000 is authorized for systems prone to cavitation corrosion, such as the FFG-7 Class Detroit Ship Service Diesel Generators, for Virginia Class Submarines, and for certain Caterpillar engines. This treatment does not provide and freezing protection. Ships authorized to use NALCOOL 2000 which requires freezing protection shall use A-A- 52624 Type I Antifreeze in place of NALCOOL

2000. NALCOOL 3000 is an authorized substitute for NALCOOL 2000. NALCOOL 2000 stops cavitation in three ways:

1. By forming a physical barrier (a chemical film).
2. By preventing corrosion of the metal surface, thus strengthening its resistance to cavitation.
3. By reducing foaming, which means less air entrapment, a major cause of cavitation?

NOTE

When you are making the conversion from NALCOOL 2000 to the required inhibited antifreeze/NALCOOL 2000 combination, you must first dump the cooling system. You must dilute the antifreeze with water in the cooling system before adding the NALCOOL 2000. Do not combine concentrated antifreeze and NALCOOL 2000, as the inhibitor chemicals will become insoluble and separate from the solution.

A-A-52624 Type I Inhibitor Antifreeze.

A-A-52624 Type I replace MIL-A-46153, which was cancelled. Antifreeze is authorized for use by all small craft except those for which another treatment is specified *(Table 10-1);* it is also used for any cooling system requiring freezing protection except where a proprietary brand of antifreeze is specified. A-A-52624 Type I Inhibitor Antifreeze provides better corrosion protection than MIL-A-46153, so it may be used for ships authorized to use NALCOOL 2000 when freezing protection is required, without any special procedures.

Table 10-1 — Inhibitor Treatments Authorized for Various Ship Classes

TREATMENT	SHIPS/CLASS	NOTES
MIL-A-53009	ATS-1, LSD-41, LST 1182, YTB, YTM, MTS, Submarines, all diesel engines and generators on ships not listed below	1
NALCOOL 2000	AOE Class, ARS Class, FFG-7 Class, Virginia Class Submarines, LCC Class, PB Mk III, PB Mk IV, PBR Mk II	2
Inhibited Antifreeze (A-A-52624 Type I)	All small craft and small boat not listed elsewhere in this table	3
Soluble Oil (MIL-I-24453)	MSO Class, MCMC 1,2	4
Nalfleet 9-111	MCM 3-14, MHC Class	5
Paxcool and DEAC ("Catcool")	PC-1 Class	6
Glysacor G93 and Glysantin G05	PB MK V	

NOTES

1. Ships authorized to use MIL-A-53009 shall use inhibited antifreeze when freezing protection is required.
2. NALCOOL 3000 is equivalent to NALCOOL; ships authorized to NALCOOL 2000 shall use inhibited antifreeze when freezing protection is required.
3. A-A-52624 Type I replace MIL-A-46153, which was cancelled.
4. Ships authorized to use soluble oil shall use inhibited antifreeze when freezing protection is required.
5. Ships using Nalfleet 9-111 do not use antifreeze.
6. Paxcool is used in PC-1 Class Paxman engines. DEAC ("Catcool") is used in PC-I Class Caterpillar engines.

MIL-I-24453 Soluble Oil

Soluble oil treatment is authorized for use in engines with aluminum block (or large amount of aluminum heat-rejecting surfaces) and single-loop waste heat distilling plants. Heat-rejecting aluminum is particularly prone to corrosion. Ships with single-loop waste heat distilling plants are vulnerable to contamination of distillate and potable water by engine coolant. Soluble oil is considered safe to use where there is a possibility of contaminating drinking water, and is effective at protecting aluminum heat-rejecting surfaces. This treatment does not provide any freezing protection; if freezing protecting is required by these engines, A-A-52624 Type I antifreeze must be used in place of soluble oil, and precautions must be taken to prevent and detect possible contamination of distillate.

Nafleet 9-111

Nafleet 9-111 is authorized for use in Isotta Fraschini engines on MCM and MHC class ships. These engines contain heat-rejecting aluminum plus a variety of other metals, and are particularity prone to corrosion, which results in the formation of heavy deposits in the cooling system internals and overheating. Nafleet 9-111 does not provide freezing protection.

Safety Precautions

A number of safety precautions shall be observed when treating engine coolants. Many of the chemicals employed are bases (alkalies); some are acids. All are skin irritants and are poisons when ingested. Protective equipment shall be worn when handling the chemicals. Do not handle the chemicals directly. Immediate medical attention shall be obtained if eye contact or ingestion of any kind occurs. Contaminated clothing shall be laundered prior to reuse. Do not store, carry, or consume food or tobacco in areas where the chemicals are stored, handled, or dispensed.

Bases (Alkalies)

Concentrated coolant treatments are nearly all bases (alkalies); MIL-A-53009, inhibited antifreeze, NALCOOL 2000, and Nalfleet 9-111 all contains strong bases (are strongly alkaline). Coolant treated with these chemicals is somewhat alkaline. The following precautions should be taken:

1. Do not mix bases directly with acids because the heat generated may cause the chemicals to spatter. All bases shall be stored separately from acids.
2. If bases contact the skin, flush the affected skin with cold water until the slippery feeling disappears. If a burning or itching sensation persists, seek medical attention.
3. If bases come in contact with the eyes, flush with large amount of potable water and seek immediate medical attention.

Acids

Do not mix acids directly with bases because the heat generated may cause the chemicals to spatter. All bases shall be stored separately from acids.

1. If acids contact the skin, flush the affected skin area with cold water. If burning or itching sensation persists or a skin rash develops, seek medical attention.
2. If acids come in contact with the eyes, flush with large amount of potable water and seek immediate medical attention.

Poisons

1. Isopropyl alcohol (rubbing alcohol) is very different from ethyl alcohol. Small amounts of isopropyl alcohol, if swallowed, can cause serious illness.
2. Sodium chromate is very poisonous if taken in by ingestion, inhalation, or skin absorption and is irritating to the eyes, skin, and mucous membranes. Sodium chromate is a carcinogen.
3. A-A-52624 Type I Inhibited Antifreeze, Paxcool, DEAC (“Catcool”), and Glysantin consist primarily of ethylene glycol, which is toxic by ingestion. Ethylene glycol vapors from hot antifreeze are also toxic.
4. MIL-A-53009 inhibitor and NALCOOL 2000 are both toxic by ingestion, and may be irritating to the eyes and skin.
5. Cupric sulfuric acid is toxic and is irritating to the eyes, skin, and mucous membranes.
6. Phenolphthalein is used medicinally in extremely small amounts but in larger amounts it is poison.
7. Soluble oil, although relatively low in toxicity, can irritate the eyes and skin. In addition, soluble oil shall be ingested.

Flammables

Isopropyl alcohol is a Category I flammable material, with a flash point of 59 °F (15 °C), a boiling point of 180 °F (82 °C) and a Hazard Characteristics Code (HCC) of F2. Isopropyl alcohol shall be stored in a flammable storage locker per NSTM Chapter 670.

Oxidizers

Sodium chromate is an oxidizing material and shall not be stored with or allowed to come in contact with reducing material.

You must always take precautions to prevent contamination of the ship's potable freshwater system. You must prevent backflow of the engine cooling water through the filling connection. Remember, specifications require that an air gap remain between the freshwater supply and the fill connection. This design must not be altered.

Corrosion-inhibitor-treated coolants must be disposed of according to the procedures in the *Environmental and Natural Resources Protection Manual,* OPNAVINST 5090.1(series) and NSTM Chapter 593.

SUMMARY

In this chapter, we have covered three types of closed cooling systems: (1) heat exchanger, (2) keel cooler, and (3) radiator and fan. The heat exchanger and keel cooling systems use freshwater to cool the engine and seawater to cool the freshwater. In the heat exchanger system, seawater is pumped from the sea, through a sea chest and strainer, to the heat exchanger, and overboard. In the keel cooling system, freshwater is circulated to the keel cooler, which is in direct contact with the seawater. The radiator and fan cooling system uses a stream of air that passes through the radiator to cool the freshwater.

In our discussion of engine cooling systems, we identified the need for freshwater treatment and use of the five corrosion-inhibitor treatments approved for naval service: (1) MIL-A-53009 inhibitor, (2) NALCOOL 2000, (3) inhibited antifreeze (A-A-52624, Type I), (4) soluble oil (MIL-I-24453), (5) Nalfleet 9-111.These chemicals present health hazards when they come in contact with the skin or eyes or are taken internally.

End of Chapter 10

Engine Cooling System

Review Questions

10-1. How much heat energy from the fuel changed into mechanical energy leaves the engine in the form of brake horsepower?

A. One half
B. One third
C. One fourth
D. One fifth

10-2. What medium would be a suitable solution for removing heat from a diesel engine?

A. Lubricating oil
B. Heat resistant wool
C. Vacuum tubes
D. Paper filters

10-3. What condition will be occurring if the diesel engines cooling system reduces the temperature of the lubricating oil too low?

A. Oxidation
B. Knocking
C. Ignition lag
D. Governor overspeeding

10-4. Where is the water being drawn from and discharged to in an open loop cooling system?

A. Jacket water system
B. Main raw water system
C. Potable water system
D. Operational waters

10-5. What is the minimum boiling point of the coolant in a closed cooling system?

A. 32 °F
B. 100 °F
C. 212 °F
D. 250 °F

10-6. On larger diesel engines that provide propulsion, what is the means for emergency cooling?

A. Potable water
B. Firemain
C. Distillate
D. Jacket water

10-7. What component drives the fan in the radiator and fan cooling system?

A. Crankshaft
B. Camshaft
C. Governor drive
D. Accessories drive

10-8. What is the most common type of pump used in the diesel engine cooling system?

A. Worm gear drive
B. Positive displacement
C. Centrifugal
D. Lobe gear

10-9. What is use in a shell-and-tube cooler to keep the mixing of cooling medium and the liquid being cooled from happening?

A. Baffles
B. Seals
C. Gaskets
D. Packing joints

10-10. What function does NOT involve the freshwater expansion tank?

A. Provide room for expansion when water is warm
B. Provide room for contraction when water is cool
C. Adding water to the engine
D. Washing the engine

10-11. What is the maximum seawater cooling temperature needed on the discharge side of a seawater cooler, to prevent scale formation and erosion?

A. 100 °F
B. 130 °F
C. 160 °F
D. 190 °F

10-12. What inhibitor treatment is authorized for use on MCM ship?

A. MIL-A-53009
B. NALCOOL 2000
C. Nalfleet 9-111
D. Paxcool

10-13. In what *Naval Ships' Technical Manual* (NSTM) chapter can you find the listing of chemicals to correctly protect diesel engine against corrosion and scale formation?

A. Chapter 090
B. Chapter 220 volume 3
C. Chapter 220 volume 1
D. Chapter 233

10-14. What is the maximum percentage of plugged tubes a heat exchanger can have before replacement of the tubes is required?

A. 5%
B. 10%
C. 15%
D. 20%

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CHAPTER 11

ENGINE LUBRICATING OIL SYSTEMS

After studying the information in this chapter, you should be able to understand the basic theories of lubrication, the factors affecting lubrication, the functions and characteristics of greases, lubricating oils used aboard ship, and the design and function of components in various lubricating oil systems, including tanks, pumps, coolers, and filtering devices, that you, as an engineman, may be required to operate or maintain. You should be able to understand the importance of standards and procedures and how they are established and enforced through the Lube Oil Quality Management Program.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the concept of the lubrication theory.
2. Explain the classifications of lube oil (LO).
3. Explain the classifications of grease.
4. Explain the maintenance and operation of the lube oil (LO) systems.
5. Explain the importance for ventilation for internal spaces.
6. Explain the maintenance and operation of oil purification systems.
7. Explain the goals of the Lube Oil Quality Management (LOQM) Program.

THEORY OF LUBRICATION

Lubrication is important for reliable engine operation as air, fuel, and heat are to combustion. Lubrication is considered to be one of the most important factors in the operating life of an internal combustion engine. The lubrication requirements of shipboard machinery are met in various ways, depending on the design of the machinery. It is important not only that the proper type of lubricant be used, but also that the lubricant be supplied to the engine parts at the specified flow rate and temperature and those provisions be made for removal of any impurities that enter the system.

is the natural resistance to motion caused by surfaces that are in contact with each other. The purpose of lubrication is to reduce the harmful effects of friction by changing sliding friction to fluid friction. Before discussing the characteristics of sliding and fluid friction, we must first define the two main categories of friction: static and kinetic. The friction that exists between a body at rest and the surface upon which it is resting is called static friction. The friction that exists between the surfaces of moving bodies (or between one moving body and a fixed body) is called kinetic friction. Static friction uses more force than kinetic friction. To put a body in motion, you must overcome static friction and inertia. To keep a body in motion, you must overcome kinetic friction.

There are three types of kinetic friction: sliding, rolling, and fluid. Sliding friction occurs when the surface of one solid body slides across the surface of another solid body. Rolling friction occurs when the surface of a curved body, such as a cylinder or a sphere, rolls across another surface. Fluid friction is the internal resistance to motion exhibited by a fluid.

Fluid friction occurs because of two properties of a lubricant: cohesion and adhesion. Cohesion is the attraction between the molecules of a substance that tends to hold the substance together. Adhesion is the attraction between molecules that tends to cause unlike surfaces to stick together. Consider a paddle, for example, that is being used to stir a liquid. Cohesion between the molecules of the liquid tends to hold the liquid together. This tendency retards the motion of the liquid. Adhesion between the molecules of the liquid and those of the paddle cause the liquid to stick to the paddle. This tendency further causes friction between the paddle and the liquid. In the theory of lubrication, cohesion and adhesion are important properties of a liquid. Adhesion is the property of a lubricant that, in liquid form, causes the lubricant to stick to the parts being lubricated. Cohesion is the property that holds the lubricant together and enables it to resist breakdown under extreme pressure. For proper operation of an engine, the contacting surfaces of all moving parts of the engine must be prevented from touching each other so that friction and wear can be reduced to a minimum. Sliding contact between two dry metal surfaces under load will cause excessive friction, heat, and wear. Friction, heat, and wear can be reduced greatly, of course, if metal-to metal contact is prevented. When a clean film of lubricant is used between the metal surfaces, metal-to-metal contact is automatically reduced. The lubricating film used between load-bearing surfaces in machinery is provided by a specified oil or grease. Different materials have varying degrees of cohesion and adhesion. Solid bodies are highly cohesive but only slightly adhesive; most liquids are highly adhesive but only slightly cohesive.

Fluid Lubrication

One of the properties of a liquid is that it cannot be forced into a smaller space than it already occupies. A liquid is, for all practical purposes, incompressible. This fact allows for moving metal surfaces to be kept separated from each other by fluid lubrication. Because of this, liquid is used for most lubrication. As long as the lubricant film remains unbroken, fluid friction is able to replace sliding friction and rolling friction.

In any process involving friction, some power is always consumed, and some heat is always produced. Overcoming sliding friction consumes the greatest amount of power and produces the greatest amount of heat. Overcoming fluid friction consumes the least amount of power and produces the least amount of heat.

Langmuir Theory

A presently accepted theory of lubrication is based on the Langmuir Theory regarding the action of the fluid films or layers of oil between two surfaces, one or both of which are in motion. According to this theory, at least three layers of oil exist between two lubricated bearing surfaces. Shown in *Figure 11-1*, *view A,* two of the oil films shown are boundary films and are indicated by Roman numerals I and V. A boundary film is a condition in which the oil film is neither so thin as to cause seizure nor so thick as to create a full film of oil between the shaft and the bearing. As shown in view A, one of the boundary films (I) clings to the surface of the rotating journal. The other boundary film (V) clings to the stationary lining of the bearing. Boundary film lubrication alone is not sufficient to protect metal surfaces from friction and wear. Between the two boundary films are one or more fluid films that slide layer upon layer. These fluid films are indicated in *Figure 11-1, views A* and *B* by Roman numerals II, III, and IV. Refer to *Figure 11-1, view B*. When the rotating journal is set in motion, a wedge of oil (W) is formed. Contact between the two metal surfaces is prevented when oil films II, III, and IV slide between boundary films I and V.

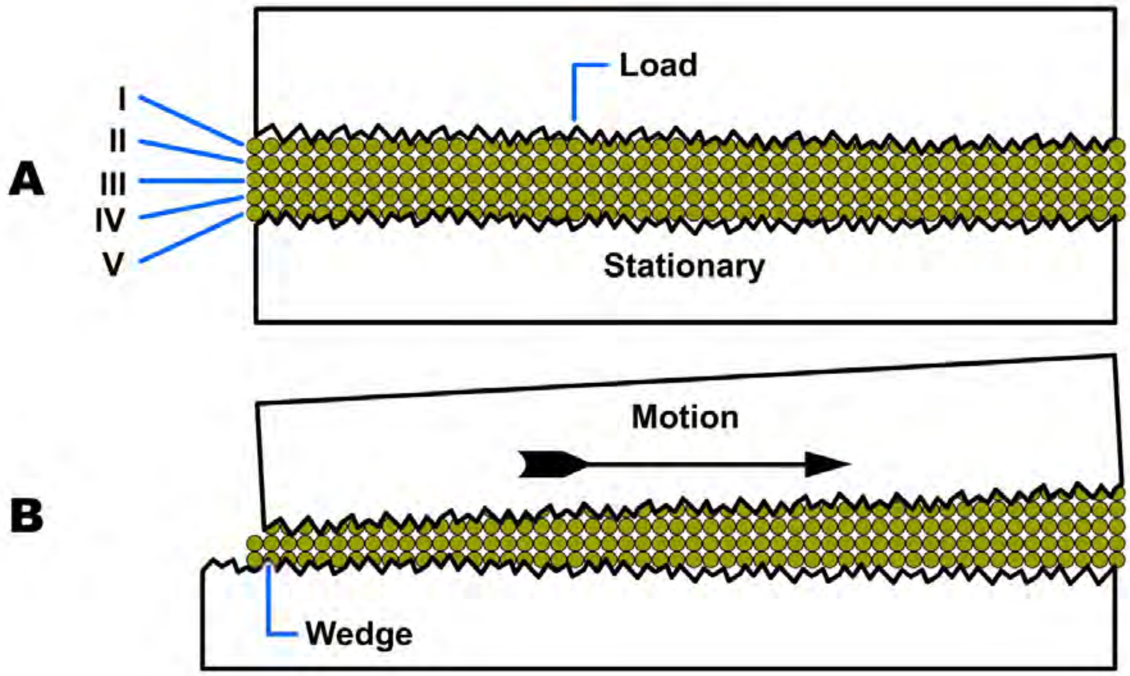

Figure 11-1 — Theory of oil film lubrication showing boundary and fluid oil films.

Figure 11-2, views A, B, and C, represents a journal or shaft rotating in a solid bearing. The clearances are enlarged in each view to show the formation of the oil film. The shaded portion in each view represents the clearance filled with oil. The position of the oil wedge (W) is shown with respect to the position of the journal as the journal starts and continues in motion.

Figure 11-2, view A, shows the oil film is in the process of being squeezed out while the journal is at rest (stationary). As the journal begins to turn (*Figure 11-2, view B*), the oil adhering to the surface of the journal is carried into a space between the journal and the bearing*. Figure 11-2, view B,* (starting), shows the oil film increases in thickness and tends to lift the journal away from the bearing. Remember, a liquid is incompressible. As the shaft speed increases, the journal takes a position similar to that in *Figure 11-2, view C* (running). It is estimated that in a diesel engine the pressure in

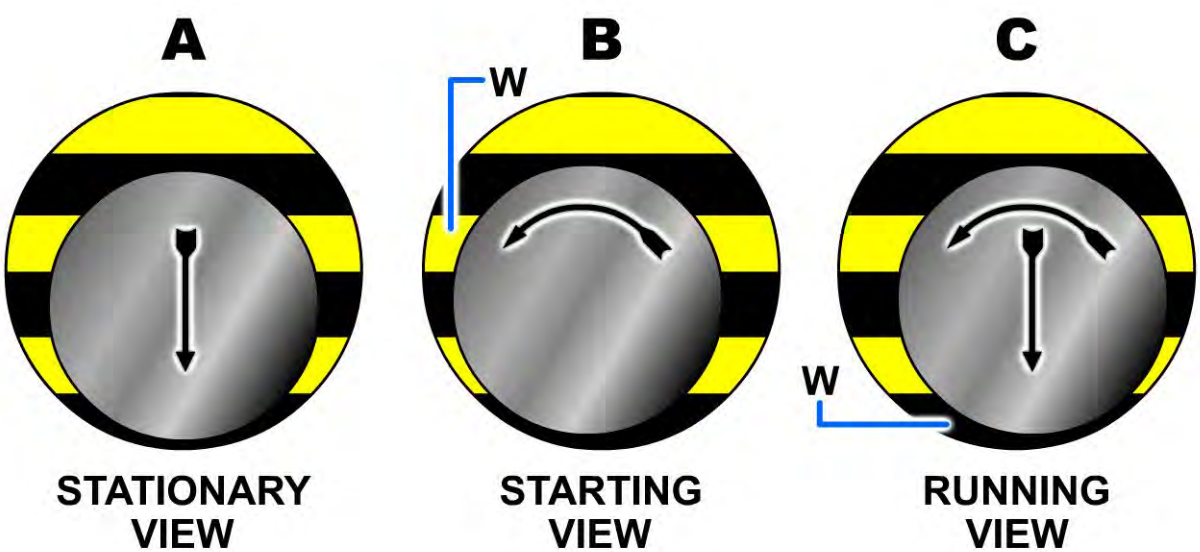

Figure 11-2 — Journal rotation in a solid bearing showing the distribution of the oil film.

the oil wedge can build up to several hundred pounds per square inch (psi). This pressure, along with the correct viscosity of the oil, is necessary so that the fluid films can slide into place and prevent metal-to-metal contact. Without this protection, boundary line lubrication alone cannot prevent the damage to metal surfaces that would result from sliding and rolling friction.

Factors Affecting Lubrication

A number of factors determine the effectiveness of oil film lubrication. They include load, temperature, viscosity, and flow rate, speed, and alignment, condition of the bearing surfaces, running clearances, and purity of the lubricant. Many of these factors, of course, are interrelated and interdependent. The viscosity of any given oil is affected by temperature, and the temperature is affected by running speed; therefore, the viscosity is partially dependent on the running speed.

A lubricant must stick to the bearing surfaces and support the load at operating speeds. More adhesiveness is required to make a lubricant stick to bearing surfaces at high speeds than at low speeds. At low speeds, greater cohesiveness is required to keep the lubricant from being squeezed out from between the bearing surfaces.

Large clearances between bearing surfaces require the use of a lubricant with a high viscosity and cohesiveness that will provide an adequate lubricating oil film. The larger the clearances, the greater resistance the lubricant must have so it will not be pounded out. If the lubricant is pounded out, the lubricating oil film will be destroyed. High unit loading of a bearing will also require the use of a lubricant with a high viscosity. A lubricant that is subjected to high loading must be sufficiently cohesive to hold together and maintain the oil film.

CLASSIFICATION OF LUBRICATING OILS

Lubricating oils approved for shipboard use are limited to those grades and types necessary to provide proper lubrication under all anticipated operating conditions.

For general lubrication and in hydraulic systems that use petroleum-based lubricants, the Navy must use certain oils. These special viscosity series of oils are strengthened with oxidation and corrosion inhibitors and antifoam additives. Deck machinery uses compounded oils, which are mineral oils with additives.

Special lubricating oils are available for a wide variety of services. The Federal Supply Catalog has a list of these oils. Among the most important specialty oils are those used for lubricating refrigerant compressors. These oils must have a very low pour point and must be maintained with a high degree of freedom from moisture.

Lubricants for reciprocating internal combustion engines are commonly known as detergent or dispersive oils. These lubricants contain additives that keep combustion products such as fuel, soot (unburned carbon), and oxidation (acid-forming) products in suspension, thereby reducing the amount of contaminants deposited on engine parts. These engine oils also contain additives that reduce wear and inhibit rusting, foaming, and oxidation. These advantages are particularly important in modern, high-speed, turbocharged marine diesel engines.

Diesel engines use a detergent-dispersant type of additive oil to keep the engines clean. These lubrication oils must be fortified with oxidation and corrosion inhibitors. This allows long periods between oil changes and prevents corrosion of bearing materials. Shipboard diesels operate satisfactorily on a single viscosity grade, MIL-L-9000 (military symbol 9250). However, for engines that may be operated in an environment of 0°C (32°F) or below, MIL-L-2104, OEHDO-10 oil is recommended. For standardization, engine oil is generally used in reduction gears associated with shipboard diesels. Although 9250 oil is not formulated as gear oil, it performs well in such applications. For additional information on lubricating oils, refer to the *Naval Ships Technical Manual* (NSTM), Chapter 262.

The Navy identifies lubricating oils by number symbols. Each identifying symbol consists of four digits and, in some cases, appended letters as shown in *Table 11-1*. The first digit shows the series of oil according to type and use; the last three digits show the viscosity of the oil. The viscosity digits indicate the number of seconds required for a 60-milliliter (mL) sample of oil to flow through a standard orifice at a certain temperature. Symbol 9250, for example, shows that the oil is series 9 oil which is specified for use in diesel engines. It also shows that a 60-mL sample should flow through a standard orifice in 250 seconds when the temperature of the oil is 210°F. Another example is symbol 2135 TH. This symbol shows that the oil is a series 2 oil, which is suitable for use as a force-feed lubricant or as a hydraulic fluid. It also shows that a 60-mL sample should flow through a standard orifice in 135 seconds when the oil is at a certain temperature (130°F, in this case). The letters H, T, TH, or TEP added to a basic number indicate a primary specific usage within the general category.

Table 11-1 — Classification of lubrication oils

9250	2135TH
9; series of oil (diesel engine)	2; series of oil (force-feed lubricant) hydraulic fluid
250; 60-mL sample should flow through a standard orifice in 250 seconds when the temperature of the oil is 210°F	135; 60-mL sample should flow through a standard orifice in 135 seconds when the temperature of the oil is (130°F in this case)
	TH; added to a basic number to indicate a primary specific usage within the general category

Properties of Lubricating Oils

Lubricating oils used by the Navy are tested for a number of properties.

Standard test methods are used for each test. The properties of lube oil are briefly explained in the following paragraphs.

Viscosity

The viscosity of oil is its tendency to resist flow or change shape. A liquid of high viscosity flows very slowly. In variable climates, automobile owners change oil according to prevailing seasons. Oil changes are necessary because heavy oil becomes too thick or sluggish in cold weather, and light oil becomes too thin in hot weather. The higher the temperature of oil, the lower its viscosity becomes; lowering the temperature increases the viscosity. On a cold morning, it is the high viscosity or stiffness of the lube oil that makes an automobile engine difficult to start. The viscosity must always be high enough to keep a good oil film between the moving parts. Otherwise, friction will increase, resulting in power loss and rapid wear on the parts.

Oils are graded by their viscosities at a certain temperature. Grading is set up by noting the number of seconds required for a given quantity (60 ml) of the oil at the given temperature to flow through a standard orifice. The right grade of oil, therefore, means oil of the proper viscosity.

Every oil has a viscosity index based on the slope of the temperature-viscosity curve. The viscosity index depends on the rate of change in viscosity of given oil with a change in temperature. A low index figure means a steep slope of the curve or a great variation of viscosity with a change in temperature; a high index figure means a flatter slope or lesser variation of viscosity with the same changes in temperatures. If you are using an oil with a high viscosity index, its viscosity or body will change less when the temperature of the engine increases.

Pour Point

The pour point of oil is the lowest temperature at which the oil will barely flow from a container. At a temperature below the pour point, oil congeals or solidifies. Lube oils used in cold weather operations must have a low pour point. The pour point is closely related to the viscosity of the oil. In general, an oil of high viscosity will have a higher pour point than an oil of low viscosity.

Flash Point

The flash point of oil is the temperature at which enough vapor is given off to flash when a flame or spark is present. The minimum flash points allowed for Navy lube oils are all above 300°F. However, the temperatures of the oils are always far below 300°F under normal operating conditions.

Fire Point

The fire point of oil is the temperature at which the oil will continue to burn when it is ignited.

Autoignition Point

The autoignition point of oil is the temperature at which the flammable vapors given off from the oil will burn. This kind of burning will occur without the application of a spark or flame. For most lubricating oils, this temperature is in the range of 465° to 815°F.

Demulsibility

The demulsibility, or emulsion characteristic, of an oil is its ability to separate cleanly from any water present, an important factor in forced-feed systems. You should keep water (fresh or salt) out of oils.

Neutralization Number

The neutralization number of oil indicates its acid content and is defined as the number of milligrams of potassium hydroxide (KOH) required neutralizing 1 gram of the oil. The increase in acidity with use is an index of deterioration and is measured as a part of the work factor test. This test is not applicable to 9250 oil. All petroleum products deteriorate (oxidize) in air and heat. Oxidation produces organic acids which, if present in sufficient concentrations, will cause deterioration of alloy bearing at elevated temperatures.

1. Galvanized surfaces.
2. Demulsibility of the oil with respect to fresh and/ or salt water. The increase in acidity with use is an index of deterioration and is measured as a part of the work factor test. This test is not applicable to 9250 oil.

Precipitation Number

The precipitation number of oil is a measure of the amount of solids classified as asphalts or carbon residue contained in the oil. The number is reached when a known amount of oil is diluted with naphtha and the precipitate is separated by centrifuging—the volume of separated solids equals the precipitation number. This test detects the presence of foreign materials in used oils. Oil with a high precipitation number may cause trouble in an engine. It could leave deposits or plug up valves and pumps.

CLASSIFICATION OF LUBRICATING GREASES

Some lubricating greases (*Figure 11-3*) are simple mixtures of soaps and lubricating oils. Others are more unusual, such as silicones and dibasic acids, which are exotic liquids. These may be thickened with metals or inert materials so that enough lubrication is provided. Requirements for oxidation inhibition, corrosion prevention, and extreme pressure performance are met by the addition of special substances (additives).

Lubricating greases are supplied in three grades: soft, medium, and hard. The soft greases are used for high speeds and low pressures (light loads); the medium greases are used for medium speeds and medium pressures (medium loads); the hard greases are used for slow speeds and high pressures (heavy loads).

Figure 11-3 — Lubricating greases.

Classification of Lubricating Greases

Navy specifications have been drawn to cover the several grades of lubricating greases. The grades most common in use in engine rooms are ball and roller bearing grease and extreme pressure grease.

Ball and Roller Bearing Grease (MIL-G-24508A)

Ball and roller bearing grease is for general use in equipment designated to operate at temperatures up to 300°F. For temperature applications above 300°F, high-temperature, electric-motor, ball and roller bearing grease (MIL-L-15719 insulated silicone for electric motors with heated- stabilized ball bearing) must be used.

CAUTION

Under no circumstance should it be applied to bearings in which the main action involves the shifting of metal-to-metal contact as in journal bearing, spiral gear, gear train, and similar applications.

Extreme Pressure Grease (MIL-G-17740)

Extreme pressure grease has antirust properties and is suitable for lubrication of semi-enclosed gears, or any sliding or rolling metal surfaces where the load may be high and where the equipment may be exposed to salt spray or moisture. It is intended for use in temperature ranges within 0° to 140°F.

Graphite Grease (VV-G-671)

Graphite grease may be applied with compression grease cups to bearings operating at temperatures that do not exceed 150°F. The three grades of graphite grease are as follows:

- Grade 1 Soft, for light pressures and high speeds
- Grade 2 Medium, for medium pressures and medium speeds
- Grade 3 Medium Hard, for high pressures and slow speeds

Grease Cup Lubrication

Dirt in lube oil will generally settle out, but dirt in grease will remain mixed within the grease and will become abrasive. For this reason, you must be particularly careful to prevent contamination, especially where grease cups are used. Before you open the container, carefully remove all dirt from the exterior. Do NOT allow any dirt to enter either the opening or the grease cups. You should frequently empty, clean, and refill the cups with fresh grease.

Pressure Greasing

Pressure fittings provide an easy means for lubricating numerous low-speeds, lightly loaded, or widely separated bearings. They are not good for use on electric generators and motors, as pressure fittings used on these units may force grease out of the bearing and onto the windings. Pressure fittings are similar to those on an automobile where grease guns are used for lubrication. Before using the grease gun, you should clean the pressure fittings and gun tip. Apply pressure to the fitting until grease comes out around the edges of the bearing. In bearings fitted with felt or other seals, you must be careful to avoid breaking the seals by over-pressure. If you use excessive pressure while you are lubricating the needle type of roller bearings, you may unseat the needles.

NOTE

You must use only one type of grease to fill a grease gun. You should mark the grease gun to identify the type of grease it contains so that you will not use the wrong lubricant.

Ball and Roller Bearing Lubrication

The oil or grease used to lubricate ball and roller bearings (roller contact bearings) serves many important functions. It provides a lubricating film among the balls, rollers, and retainers and between the surfaces of the ends of the rollers and the races. The oil or grease disperses heat caused by rolling friction and prevents corrosion of highly polished parts. It also helps keep dirt, water, and other foreign matter out of the parts. You must use the lubricant recommended for each machine, and you should avoid too much lubrication. Information about greases is given in the NSTM, Chapter 262.

⚠ **CAUTION** ⚠

All lubricants are hazardous materials. All lubricants, especially synthetics, are toxic and hazardous to health. You should avoid prolonged skin and eye contact. Remove lubricant-soaked clothing promptly and wash skin thoroughly with soap and water. The Material Safety Data Sheet (MSDS) for each item includes precautions, disposal information, and hazards. If you need an MSDS, ask your supervisor.

LUBRICATING OIL SYSTEMS

The reliability and performance of modern diesel engines are directly dependent on the effectiveness of their lubricating systems. To be effective, an engine-lubricating system must successfully perform the functions of minimizing friction between the bearing surfaces of moving parts, dissipating heat, and keeping the engine parts clean by removing carbon and other foreign matter. In almost all modern internal combustion engines, the system that provides the oil for these functions is the forced-lubrication type of design. Although there are many variations in lubricating systems for internal combustion engines, the components and method of operation are basically the same for all designs.

Components of a Lubricating Oil System

The lubricating system of an internal combustion engine consists of two main divisions:

1. One that is inside the engine. The internal system consists mainly of passages and piping.
2. One that is outside the engine. The external system includes several components that aid in supplying the oil in the proper quantity, at the proper temperature, and free of impurities. In the majority of lubricating oil systems for internal combustion engines, the external system includes such parts as tanks and sumps, pumps, coolers, strainers, and filters.

Tanks and Sumps

The lubricating systems of propulsion installations use tanks to collect, store, and recirculate oil after it has been used for lubrication and cooling. Some installations have a sump or drain tank under the engine to collect the oil as it drains from the engine crankcase. Separate storage and sump tanks are not common in auxiliary engines; these engines generally contain the oil supply directly within the engine oil pan.

Pumps

Positive displacement, rotary gear pumps deliver oil under pressure to the various parts of the engine. Since the pumps are gear driven by the engine camshaft or, in some engines, directly by the crankshaft, the oil is supplied at flow rates adjusted to the needs of the engine. Changes in engine speed will cause corresponding changes in pump output.

The operating pressure is normally controlled by one or more pressure-regulating valves, which open or close as necessary to maintain the specified flow rate to various load-bearing parts of the engine. These spring-actuated devices divert excess oil directly to the engine sump or back to the inlet of the lubricating oil pump.

Detached lubricating pumps on large diesel engines fill the sump tanks from the storage tanks and flush and prime the lubricating oil system. You should be thoroughly familiar with these components before attempting to transfer oil or to flush and prime the engine. When priming or flushing the engine, you should know that prolonged flushing or priming of the lubricating oil system on any engine may cause oil to accumulate in the air intake passages and cause overspeeding upon starting. To prevent this, you must observe the following precautions:

1. Prime the engine-lubricating oil system before the engine is turned over by hand or by motor-driven jacking gear. This ensures that a film of oil is deposited to prevent friction when parts start to move.
2. Continue to prime the engine ONLY until the engine-lubricating oil pressure gauge registers a slight pressure or until you see oil at each main bearing.
3. Before starting the engine after a prolonged shutdown, inspect the air receiver and blower discharge passages and remove any accumulation of lubricating oil.

Coolers

The lubricating oil systems of most engines use coolers (heat exchangers) to maintain the oil temperature within the most efficient operating range. Oil, passing through the operating engine, absorbs heat from the metal parts. Since engine oil is recirculated and used over and over, it is continually absorbing additional heat. Unless the heat is removed, the oil temperature will rise to excessive values. At extremely high temperatures, oil tends to oxidize rapidly and form carbon deposits. Excessive engine operating temperatures also cause an increase in the rate of oil consumption. Consequently, oil coolers are required to remove excess heat from the oil so that the oil will retain its lubricating qualities.

The coolers used to remove heat from lubricating oil are of the same type as those used to remove heat from other fluids common to internal combustion engines. These coolers are referred to as shell and tube, strut tube, or plate tube coolers.

Filtering Devices

Oil must be clean before it goes into the lubricating system of an engine. Oil must also be cleaned regularly while it is being recirculated through the engine. Dust and dirt particles from the intake air get into the oil system. Flakes of metal from the engine parts are also picked up and carried in the oil. Carbon particles from incomplete combustion in the cylinders work into the oil. Heat causes the oil to deteriorate and form sludge and gummy material that may coat load-bearing or heat-transfer surfaces or circulate through the oil system. Some water will get into the oil, even when precautions are taken.

The lubricating oil system of an engine uses strainers and filters to remove abrasives and foreign materials which tend to increase wear of engine parts and cause the lubricating oil to deteriorate. A variety of strainers and filters are used in Navy installations. According to Navy terminology, all metal-edge and wire-mesh devices are classed as strainers. Devices that have replaceable, absorbent cartridges are called filters. Filters remove smaller particles than strainers. The location and number of strainers and filters will vary, depending on the type of installation.

Strainers

Lubricating oil strainers may be either simplex or duplex. A duplex strainer is two strainer elements in one assembly. A manual valve directs the flow of oil through either of the elements. When duplex strainers are used, one element can be bypassed, and the element can be removed and cleaned without disturbing the flow of oil through the other element to the engine.

Every approved lubricating oil strainer has a built-in, spring-loaded or differential area, pressure-relief valve. The valve must be sufficiently large to bypass all of the oil around a clogged strainer to maintain an uninterrupted flow of oil to the engine.

Metal-edge strainers consist of a strainer element surrounded by a case that serves as a sump to collect foreign material and water. The element has an edge-wound metal ribbon or a series (stack) of edge-type disks. Most strainers have devices for manually rotating the strainer element against metallic scrapers, which remove the material caught by the element. Strainers usually have vents for releasing air from the system.

Edge-Wound Metal Ribbon Strainer

An edge-wound metal ribbon strainer is shown in *Figure 11-4*. This strainer cleans the oil required by the engine except when the element is removed for cleaning or servicing. Under normal operating conditions, the oil comes into the strainer at the top and descends to surround the ribbon element. The oil then passes through the element, into the center, and then upward to the outlet passage.

To remove the element, turn the control valve handle to the BYPASS position. This position will divert the oil flow through the strainer head and will allow you to remove the element without interrupting the oil flow to the engine.

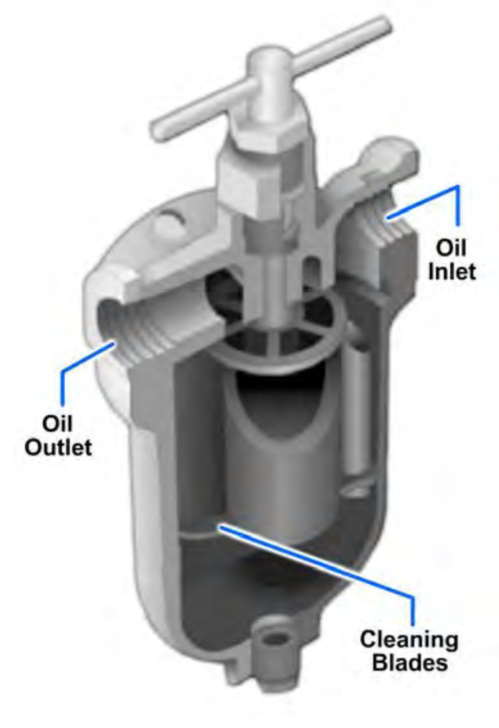

Figure 11-4 — Edge-wound metal ribbon lube oil strainer.

Another type of element consists of a closely compressed coil of stainless steel wire. The wire has been passed between rollers so that it is a wedge-shaped wire or ribbon with one edge thicker than the other. On one side of the wire, projections are spaced at definite intervals. The other side of the wire is smooth. The projections on one side of the wire touch the smooth side of the wire on the adjacent coil to provide appropriate spacing between adjacent coils. The thick edge of the wire is on the outside of the coil. A tapered slot is therefore formed from the outside to the inside of the coil, with the narrowest part of the slot on the outside. With this arrangement, dirt particles small enough to pass through the outside, or narrowest, portion of the slot will not become stuck halfway through the slot and clog the oil flow. The dirt removed from the oil remains on the outside of the element and can be readily removed when the element is rotated with the cleaning handle. As the element rotates, the cleaning blade scrapes foreign material from the element.

The control valve handle on the strainer operates the bypass valve. When the handle is in the ON position, the lubricating oil is flowing through the strainer. When the handle is in the BYPASS position, the oil is flowing directly through the head of the unit, and the strainer case and element can be removed and cleaned. The ON and BYPASS positions are indicated on the strainer head.

Edge-Disk Strainer

A duplex strainer of the edge-disk type is shown in *Figure 11-5.* The strainer consists of two sections, each of which contains two strainer elements. A control valve between the two sections secures one section while the other remains in operation. The secured section acts as a standby unit; it may be opened for cleaning and inspection without interrupting the straining operation.

A strainer element of the edge-disk type consists of an assembly of thin disks separated slightly by spacer disks. The assembly of an edge-disk strainer element is illustrated in *Figure 11-6.* The lower end of the disk assembly is closed; the upper end is open to the strainer discharge. Oil enters the strainer assembly and is forced down between the casing and disk assembly and then through the disks into the center of the disk assembly. The oil then passes up through the assembly and out through the discharge outlet. In passing through the strainer, the oil passes through the slots between the strainer disks. A relief valve at the bottom of the strainer element relieves pressure which builds up if the slots become filled with foreign matter. The relief valve bypasses the oil up through the center of the strainer element and out through the strainer discharge when a predetermined pressure is reached.

When the assembly is turned by the external handle, the solids which have lodged against or between the disks are carried around until they meet the stationary cleaner blades. The stationary cleaner blades clean the solids from the strainer surface. The solids are compacted by the cleaner blades and fall into the sump of the strainer.

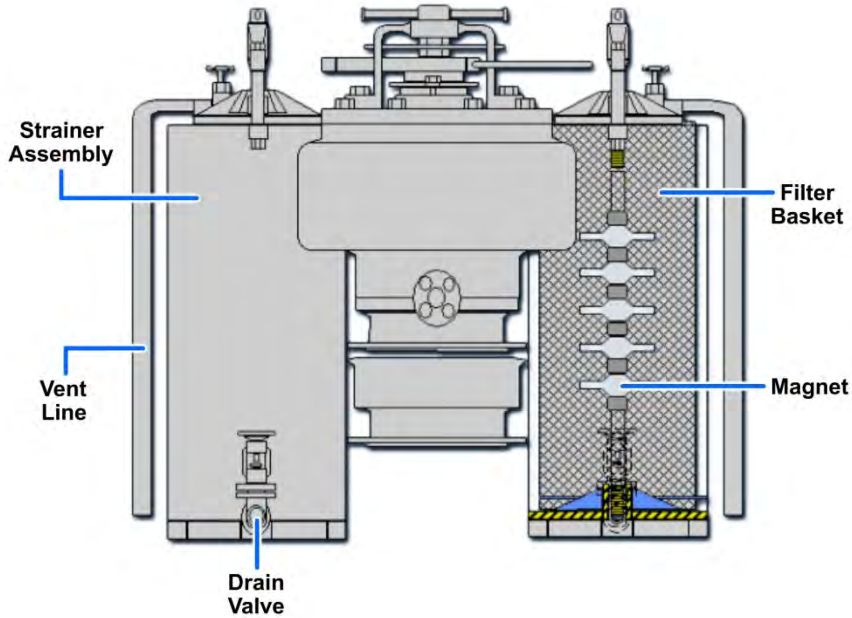

Figure 11-5 — Edge-disk lube oil strainer.

To keep the strainer in a clean, free-filtering condition, give the wing handle on the element that is not in use one or more complete turns in a clockwise direction, then shift the flow to the element you have cleaned. If the handle turns hard, then the strainer surfaces have heavy deposits of solids on them. You must then remove the head and disk assembly and soak it in a solvent until the solids are removed.

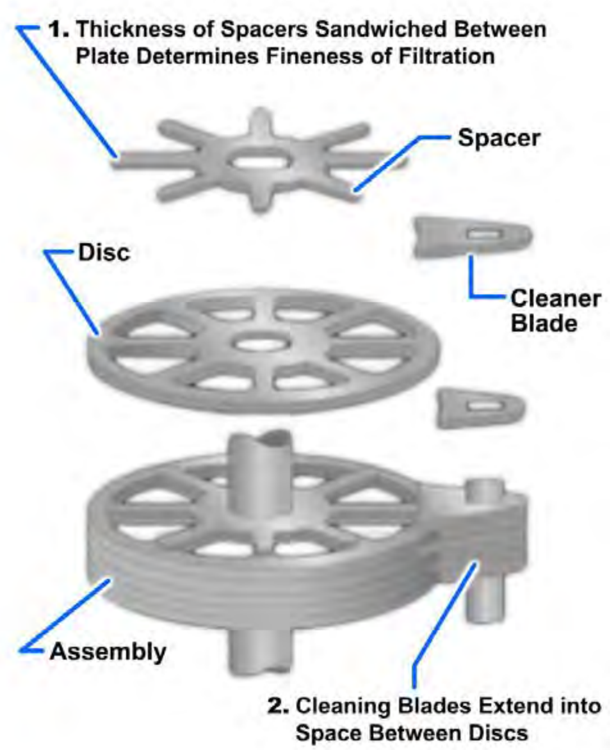

Figure 11-6 — Edge-disk strainer element assembly.

Wire-Mesh (Screen) Strainer

Strainers installed on the suction or intake side of the pressure pumps are generally of the wire-mesh (screen) type and are referred to as coarse strainers. Some screen-type strainers are located in the oil pan or sump.

Filters

In filters approved by the Navy, the absorbent material is composed of such substances as cellulose, cotton yarn, and paper disks. Filters may be located directly in the pressure-lubricating oil system, or they may be installed as bypass filters. When installed in the pressure system, a filter must contain a built-in, spring-loaded, pressure-relief valve. The valve must be large enough to bypass all oil to the engine in case the filter element becomes restricted.

A bypass filter has an orifice plate in the line to the filter. This component controls the amount of oil removed from the lubricating oil pressure system. (The amount of oil that flows through a bypass filter is only a small percentage of the oil that flows through the pressure system.) The oil from a bypass filter is returned to the sump tank. Examples of some of the filters with which you will come into contact are shown in *Figure 11-7.*

Tank-Type Filter

Figure 11-7 illustrates the basic design of a tank-type filter and consists of a single tank that holds several filter elements. In some tank-type filters, each filter element holder has a relief valve to protect the element against excessive pressure. Other tank-type filters are constructed to withstand pressure greater than that of the relief valve setting on any of the pumps in the lubricating oil filtering system.

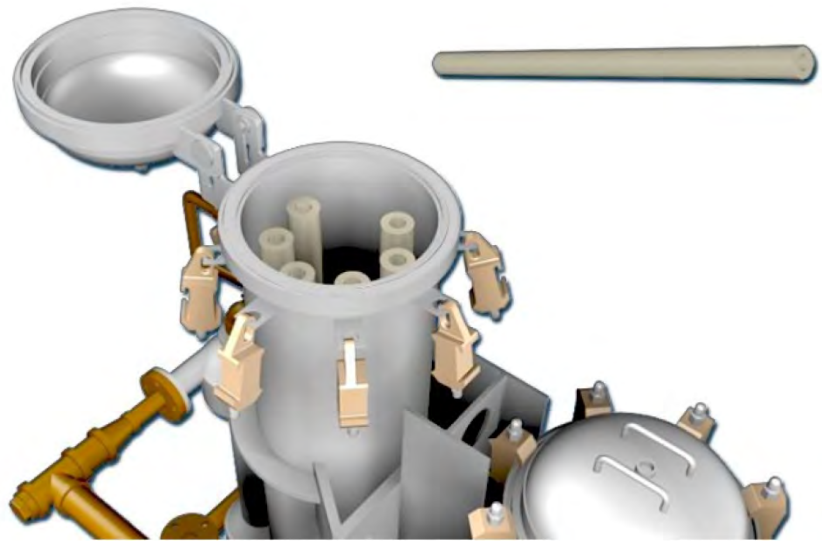

Figure 11-7 — Tank-type lube oil filter.

Spin-On Filter

The spin-on filter is not unlike the filter you would find on an automobile engine. The spin-on filter consists of a shell, an element, and a gasket combined into a unitized assembly. An oil filter adapter that contains a bypass valve assembly provides the support for each pair of oil filters.

Canister-Type Filter

The canister-type filter assembly consists of a replaceable element closed within a shell which is mounted in an adapter or base. When the filter shell is in place, the element is restrained from movement by a coil spring. The bypass valve assembly contained in the adapters will be explained in the next section of this chapter.

Up to this point in the chapter, we have discussed only the main components of an engine lubricating system. You should also be familiar with the piping and gauges, thermometers, and other instruments essential for safe, reliable operation of the system. In the remainder of this chapter, we will deal with the types of lubricating oil filtering systems, the flow of oil through a lubricating oil filtering system (including the internal or engine part of the system), how and why lubricating oil systems are ventilated, and the requirements for testing.

Functions of Lubricating Oil in an Engine

A lubricating oil with the necessary properties and characteristics will (1) provide a film of proper thickness between the bearing surfaces under all conditions of operation, (2) remain stable under changing temperature conditions, and (3) not corrode the metal surfaces. If the lubricating oil is to meet these requirements, the engine operating temperature must NOT exceed a specified limit.

In internal combustion engines, lubricating oil serves six functions:

1. Controls friction between load-bearing surfaces
2. Reduces wear by preventing metal-to-metal contact between moving parts
3. Limits the temperature by carrying away heat from fluid friction and combustion of fuel
4. Reduces corrosion by coating metal parts and by flushing debris from between moving parts
5. Dampers mechanical shock in gears
6. Forms a seal on the walls of the cylinders

Some of these functions and characteristics are discussed in the sections that follow.

Protective Film

Direct metal-to-metal contact of load-bearing surfaces is similar to the action of a file as it wears away metal. The filing action is a result of very small irregularities in the metal surfaces. The severity of the filing action depends on the finish of the surfaces, the force with which the surfaces are brought into contact, and the relative hardness of the materials. Lubricating oil fills the tiny cavities in bearing surfaces and forms a film between the sliding surfaces to prevent high friction losses and rapid wear of engine parts. The lack of a proper oil film will result in a seized (frozen) piston, wiped bearings, and stuck piston rings.

Cooling

Lubricating oil assists in cooling the engine because the constant flow of oil carries heat away from localized “hot spots.” The principal parts from which oil absorbs heat are the bearings, the journal surfaces, and the pistons. In some engines, the oil carries the heat to the sump where the heat dissipates in the mass of oil. Most modern internal combustion engines use a centralized pressure-feed lubrication system. This type of system has an oil cooler (heat exchanger) where the heat in the oil is transferred to the water circulating in the jacket-water cooling system.

Sludge Control

Gummy or carbonaceous material that accumulates in lubricating oil is called sludge. Most engine lubricating oils have some natural ability for preventing conditions that may cause sludge to form and for carrying sludge that does form in a finely suspended state until it is removed by filtering equipment. Chemicals are added to some oils to improve the ability of the oils to prevent the formation of sludge.

The formation of sludge is greatly reduced when the lubricating oil has the proper stability. Stability is defined as the ability of the oil to resist oxidation and deterioration for long periods. Proper stability is essential for a strong oil film to be maintained throughout the normal temperature ranges of an operating engine. A good oil film will provide the required the film strength, to form a seal between the piston and the cylinder wall. With the oil seal in place, burned fuel and exhaust gases cannot get by the piston rings to form sludge.

Various factors tend to cause sludge to form in an engine. Carbon from the combustion chambers or from the evaporation of oil on a hot surface, such as the underside of a piston, will cause sludge to form. Gummy, partially burned fuel, which gets past the piston rings, or an emulsion of lubricating oil and water, which may enter the lubricating oil system, will also tend to form sludge.

Sludge in the lubricating oil system of an engine is harmful for several reasons. Sludge may contain abrasive ingredients, such as dust from the atmosphere, rust as a result of water condensation in the engine, and metallic particles resulting from wear of engine parts. Sludge in engine lubricating oil causes premature wear of parts and eventual breakdown of the engine. Sludge may clog the oil pump screen or collect at the end of the oil passage leading to a bearing, preventing sufficient oil from reaching the parts to be lubricated. Sludge may coat the inside of the crankcase, act as an insulator, and blanket the heat inside the engine. This condition will cause the oil temperature to increase and induce oxidation. Sludge may accumulate on the underside of the pistons and prevent proper heat transfer, raising piston temperatures. Sludge in lubricating oil also contributes to sticking piston rings, a condition that will affect the ability of the rings to seal the cylinder.

General Motors Series 71 Diesel Engine

Figure 11-8 illustrates a typical lubricating oil system in a General Motors series 71 in-line diesel engine. Refer to *Figure 11-9* as you trace the flow of oil through this type of lubricating oil system.

NOTE

Note the directional arrows as we continue our discussion.

Flow of Lubricating Oil

The lubricating oil is circulated by a gear-type pump mounted on the No. 1 and No. 2 main bearing caps. The pump is gear driven by the crankshaft. All the oil leaving the pump is forced through the full-flow oil filter to the cooler and then into the oil gallery in the cylinder block. From the oil gallery, the oil is distributed to the various engine bearings. The drains from the cylinder head and other engine parts lead back to the oil pan.

When the pressure in the engine oil gallery exceeds approximately 100 psi, a spring-loaded integral plunger relief valve (A), located in the oil pump body, bypasses excess oil from the discharge to the inlet side of the pump. If the oil cooler should become clogged, the oil will flow from the pump through a spring-loaded bypass valve (B) directly into the oil gallery.

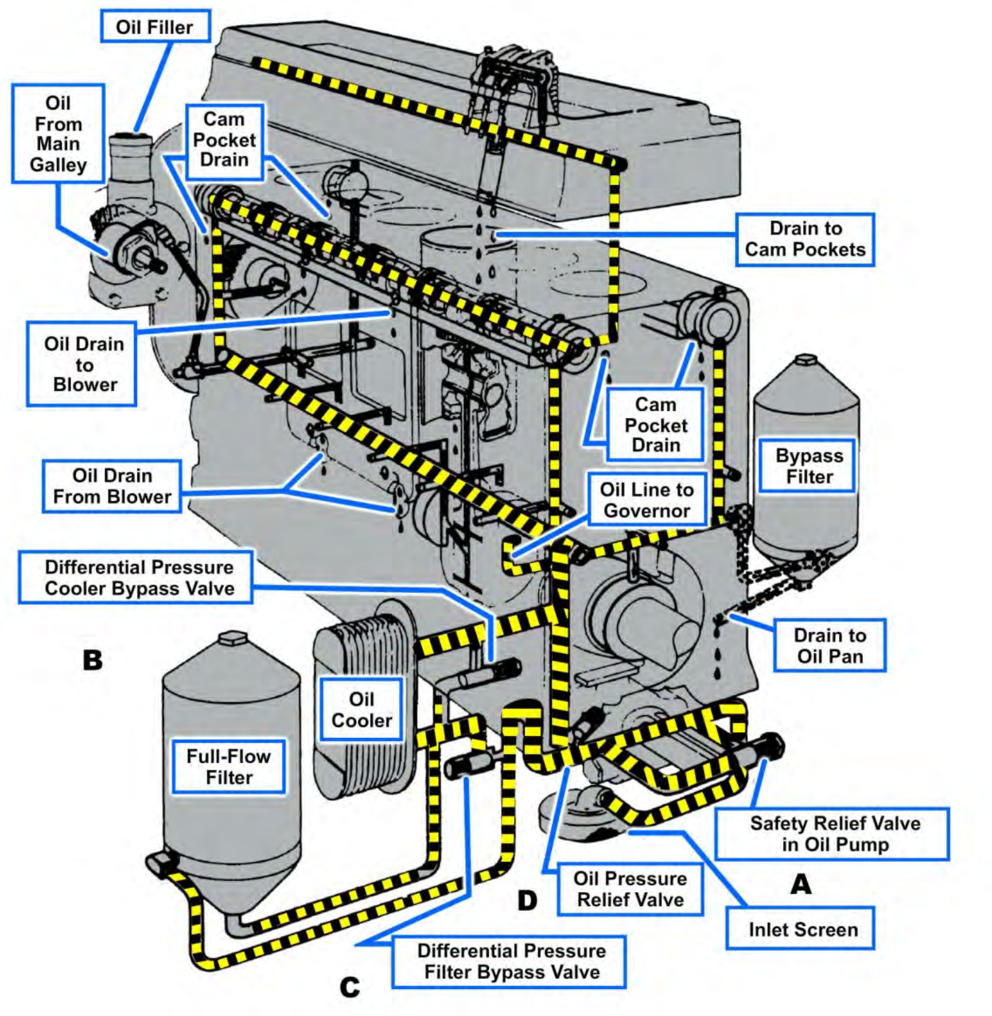

Figure 11-8 — Schematic of General Motors series 71 diesel engine, typical lube oil system.

Clean engine oil is assured at all times by the use of a replaceable element type of full-flow oil filter that is incorporated in the lubricating oil system. This filter is installed between the pump and the cooler, and it filters all the lubricating oil before it enters the engine. As mentioned before, there are two conditions under which oil will NOT pass directly through the filtering elements to the engine:

1. When the oil is cold (high viscosity)
2. When the filters are clogged

When one of these conditions exists, a bypass valve (C) opens and the filter elements are bypassed. A regulator (relief) valve (D) that is located between the pump outlet and the inlet to the cylinder block works to maintain stabilized lubricating oil pressure within the engine when the engine is operating at all speeds. This valve stabilizes the lubricating oil flow rate regardless of the temperature of the oil. When the oil pressure at the regulator valve exceeds 45 psi, the valve opens and remains open until the pressure falls below the operating pressure.

As an optional feature, a bypass type of filter with a replaceable element may also be used. In this design, a portion of the lubricating oil is continually bypassed through the filter. The filtered oil is then returned to the engine oil pan.

Distribution of Lubricating Oil

Oil from the cooler is directed by a vertical passage to the main gallery of the cylinder block. (As shown in *Figure 11-8*, this gallery distributes the oil to the main bearings and to a horizontal passage at each end of the cylinder block. From each of these two horizontal passages, oil flows to the end bearings of the camshaft and balancer shaft. Oil is forced through an oil passage in the camshaft which lubricates the camshaft intermediate bearings. Oil to lubricate the connecting rod bearings and piston pins, and to cool the piston head, is provided through the drilled crankshaft from the adjacent main bearings. The gear train is lubricated by the overflow of oil from the camshaft pocket. The blower drive gear bearing is lubricated through an external pipe from the rear horizontal oil passage of the cylinder block.

Valve and injector operating mechanisms are lubricated from a longitudinal oil passage on the camshaft side of the cylinder block which connects to the main oil gallery. Oil from this passage enters the drilled rocker arm shafts through the lower end of the rocker shaft bolts and rocker shaft brackets. Excess oil from the rocker arms lubricates the exhaust valves and cam followers.

Caterpillar Diesel Engine

The main caterpillar lubricating oil system is illustrated in *Figure 11-9*. Under normal operating conditions, lubricant from the oil pan base is pumped through the oil cooler, through the filter housing, and to the lube oil distribution gallery. A pressure-regulating valve (A) mounted on the oil pan base limits the maximum value of oil pressure. Bypass valves (B) in each filter divert the oil to the oil distribution gallery whenever the flow is momentarily restricted because of cold oil. When the oil is warm, only filtered oil is furnished to the engine bearings unless the

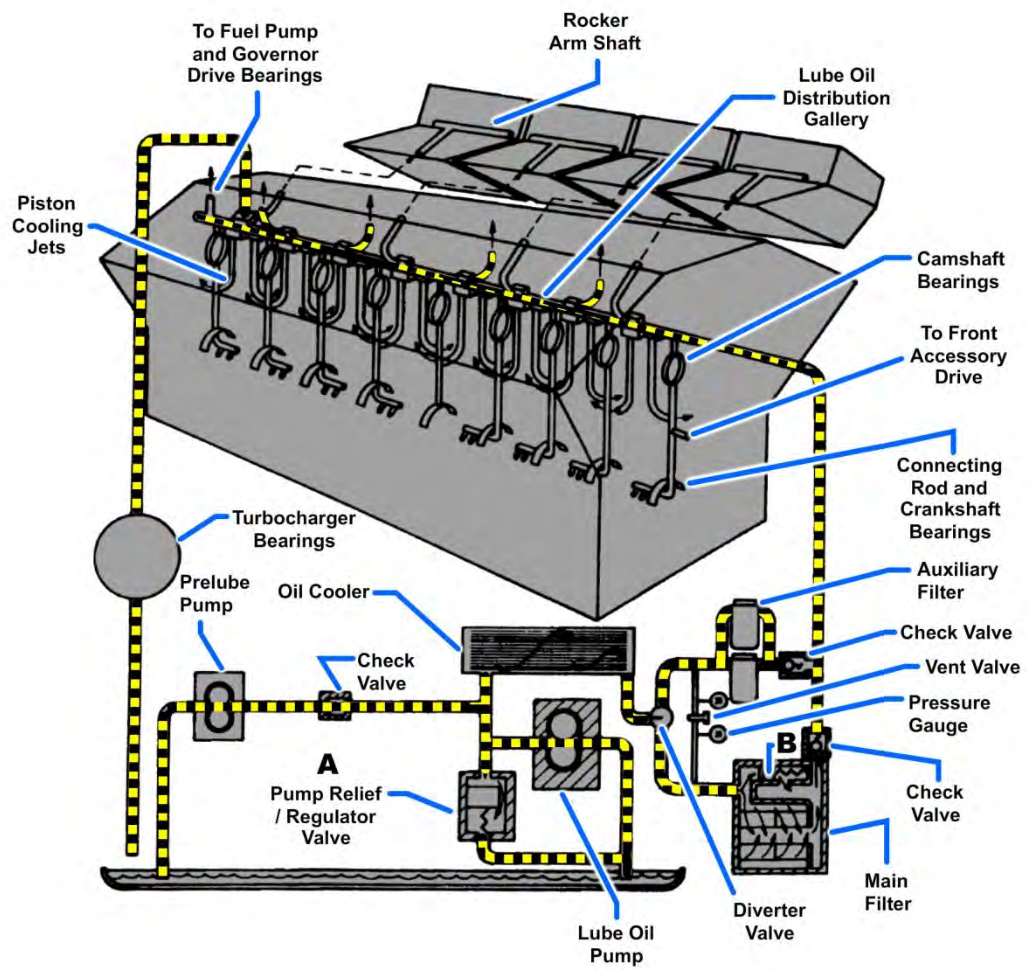

Figure 11-9 — Caterpillar diesel engine, typical lube oil system.

oil filter elements become restricted. If the filter should become restricted, the bypass valves would open and the oil would flow directly to the lube oil distribution gallery. The lube oil distribution gallery would then direct the oil through the connecting passages to the internal and external components of the engine, the timing gear, and the front accessory drive.

The strainers and filters used with Navy diesel engines are a part of what is generally referred to as the lubricating oil filtering system. Currently, engines use a system known as the full-flow filtering system. You should refer to *Figures 11-8 and 11-9* as you read the descriptions of this system.

In the full-flow filtering system, all the oil supplied to the engine by the oil pump normally passes through the filter elements, which remove impurities of 25 microns and larger.

NOTE

One micron is one millionth of a meter, or thirty-nine millionths of an inch. An ordinary grain of table salt is about 100 microns, and 25 microns is approximately one thousandth of an inch.

There are only two conditions where unfiltered lubricating oil is supplied to the engine:

- When the lubricating oil is cold (high viscosity)
- When the filter element is clogged

When one of these conditions exists, a bypass valve opens and a portion of the oil is bypassed around the filter element. The action of the bypass valve results from the resistance of the filter element to allow the oil to pass through it. The resistance creates enough back pressure for the spring-loaded bypass valve to open.

A secondary filtering system, which operates independently of the primary system, is currently being installed on various marine diesel engines.

The secondary system will filter impurities from the lubricating oil through a 5-micron filter, which is a much finer medium than the 25-micron filter used in the primary system.

External Components

In the lubrication of the external components of the Caterpillar diesel engine, the turbocharger governor, fuel injection pump housing, and fuel pump driveshaft receive lubricant from the fuel pump and governor drive housing oil manifold, see *Figure 11-9*. Any drain-back oil from these components returns to the oil pan base.

Internal Components

In the lubrication of the internal components, the oil distribution manifold directs the filtered lubricant through passages and tubes to the piston oil spray orifices, valve rocker mechanism, camshaft bearings, crankshaft bearings, connecting rod bearings, fuel pump, and governor drive housing oil manifold.

In the lubrication of the timing gear mechanism, the timing gears are lubricated by the drain-back of oil from the turbocharger, camshaft, and crankshaft. Oil, under pressure, also flows to the camshaft bearings.

In the lubrication of the front accessory drive, the oil distribution manifold delivers oil through a drilled passage to the front main bearing and the front accessory drive.

The information provided in this section is intended to show you that a lubrication system for any engine is an intricate system that must not only supply oil to the components but also supply the correct flow rate of oil at the specified temperature and pressure. Whenever you need information about a specific diesel engine, you should refer to the *Naval Sea Systems Command* (NAVSEA) technical manual for your engine.

VENTILATION OF INTERNAL SPACES

Most engines have some means to ventilate the internal cavities, or spaces, which are related to the lubricating oil system. Systems may be vented directly to the atmosphere or through the engine intake air system. The latter method is preferred in marine installations where the engine is located in an engine room or other compartment. Venting of heated, fume-laden air directly to the atmosphere in a machinery space will seriously contaminate the air in the space and may create a fire hazard. If the lubricating oil system is not vented in some manner, combustible gases may accumulate in the crankcase and oil pan, under certain conditions, these gases may explode.

During normal operating conditions, the mixture of oil vapor and air within an engine crankcase is not readily explosive. If moving parts, such as a bearing or a piston, becomes overheated as a result of inadequate lubrication or clearances, additional oil will vaporize, and an explosive mixture will be created. An explosion may occur if the temperature of the overheated part is high to cause ignition or if a damaged part strikes another part, which produces a spark.

In addition to the vapor created when lubricating oil contacts extremely hot surfaces, vapor may accumulate in the crankcase as a result of blow-by past the pistons. Blow-by occurs when the piston is compressing the air and during the power event.

There is little danger of a crankcase explosion or other troubles caused by vapors within the engine if the engine is kept in condition according to the prescribed maintenance program. The ventilation system of an engine greatly reduces the possibility of troubles that might occur because of an accumulation of vapors in the crankcase. Nevertheless, even when an engine is maintained according to prescribed procedures, casualties may occur, or conditions may be created which will lead to an explosion in the crankcase of the engine. When such casualties or conditions occur, they are generally due to abnormal operating circumstances or to the failure of a part.

You should be familiar with the possible causes of crankcase explosions so that you can learn how to prevent their occurrence. The importance of knowing what may cause a crankcase explosion and knowing the precautionary or preventive steps required are apparent when the aftereffects of an explosion are considered. A crankcase explosion may cause serious injury to personnel and extensive damage to the engine. Engine-room fires of a serious nature may occur after a crankcase explosion. Some of the mechanical defects which may lead to a crankcase explosion are crankshaft bearing failure, damaged or excessively worn liners or piston rings, and cracked or seized pistons.

Overheated Lubricating Oil

The formation of explosive vapor from lubricating oil is greatly accelerated by a rise in the temperature of the lubricating oil. A rise in temperature may be due to such factors as insufficient circulation of the oil, inadequate cooling of the oil, a faulty temperature-regulating valve, overloading of the engine, or damaged or excessively worn parts. In addition to creating explosive vapors, overheated lubricating oil can have other serious effects. The viscosity of the lubricating oil will be greatly reduced, and the tendency to form acids will be increased.

As an engineman, you must take immediate steps to correct any problem associated with overheated lubricating oil. You must maintain the temperature of the lubricating oil within the range of values specified in the NAVSEA technical manual for your engine.

Diluted Lubricating Oil

Dilution of engine lubricating oil with diesel fuel or jet propulsion (JP-5) increases the tendency toward vapor formation in the crankcase because both of these fuels have lower flash points than lubricating oil. Petroleum products vary greatly in their flash points. (Gasoline gives off sufficient vapor to ignite all temperatures well below freezing.) Diesel fuel gives off vapor in sufficient quantities to ignite when it is heated to approximately 140°F. Lubricating oil must be heated to a much higher temperature (325° to 510°F, depending on the series and symbol of the oil) before it reaches its flash point. You should remember that dilution alone cannot cause a crankcase explosion. It may, however, contribute to making an explosion possible.

Dilution of engine lubricating oil may be caused by a variety of troubles. Dilution of the lubricating oil in diesel engines may result from worn or stuck rings, worn liners or pistons, fuel leaks, or leaky nozzles or injectors. You should also remember that, even though an engine is in good condition, dilution will occur during continuous engine operation at low speeds and under idling conditions. Under these conditions of operation, dilution occurs as a result of the blow-by of unburned fuel particles that accumulate in the combustion spaces. As determined by tests, any diesel lubricating oil that is contaminated by more than 5 percent fuel should be discarded.

LUBE OIL PURIFICATION

The forced-feed lubrication systems in modern naval ships rely on pure oil. Oil that stays pure can be used for a long time. LUBE OIL DOES NOT WEAR OUT—it is merely robbed of its lubricating properties by foreign substances.

Contaminants interfere with the ability of the oil to maintain a good lubricating film between metal surfaces. These contaminants must be removed or the oil will not meet lubrication requirements. Dirt, sludge, and other contaminants will act as abrasives to score and scratch the rubbing metal surfaces within engines, generators, pumps, and blowers. Water is the greatest source of contamination. Strainers, filters, settling tanks, and centrifugal purifiers are used in lubrication systems to keep the oil pure. Filters and strainers were discussed earlier in the chapter. This section will deal with settling tanks and centrifugal purifiers.

Lubricating oil piping is generally arranged to permit two methods of purification: batch purification and continuous purification. The batch process uses settling tanks while the continuous process uses centrifugal purifiers.

Settling Tanks

In the batch process, the lube oil is transferred from the sump to a settling tank by a purifier or transfer pump. Settling tanks permit oil to stand while water and other impurities settle out. Settling is caused by the force of gravity. A number of layers of contaminants may form in the bottom of the tank. The number of layers depends on the specific gravity of the various contaminating substances. For example, a layer of metal may form on the bottom, followed by a layer of sludge, a layer of water, and then the clean oil on top. Settling tanks are normally used when the ship is in port. After the oil is heated and allowed to settle for several hours, water and other impurities that have accumulated in the settling tanks are removed. The oil that is left in the tanks is then centrifuged and returned to the sump or storage tank.

Centrifugal Purifiers

When a ship is at sea or when time does not permit batch purification in the settling tanks, the continuous purification process is used. Centrifugal purifiers are used in this process. The purifier takes the oil from the sump in a continuous cycle. Before entering the purifier, the oil is heated to help remove the impurities.

Detailed instructions on constructing, operating, and maintaining purifiers are furnished by manufacturers' technical manuals, PMS, and the Engineering Operation Sequencing System (EOSS). Carefully follow these documents when you are operating or performing maintenance on purifiers. The following general information will help you understand the purification and the purposes and principles of purifier operation.

A purifier may be used to remove water and/or sediment from oil. When water must be removed, the purifier is called a separator. When the main source of contamination is sediment, the purifier is used as a clarifier. When used to purify lubricating oil, a purifier may be used as either a separator or a clarifier. Aboard ship, a purifier is almost always operated as a separator.

Types of Centrifugal Purifiers and Their Operating Characteristics

Two types of purifiers are used in Navy installations. Both types operate on the same principle. The principal difference is in the design of the rotating units. In one type, the rotating element is a bowl-like container which encases a stack of disks. This is the disk-type DeLaval purifier. In the other type, the rotating element is a hollow, tubular rotor and is the tubular-type Sharples purifier.

Disk-Type Purifier

A view of a disk-type centrifugal purifier is shown in *Figure 11-10, frames 1 through 4*. The bowl is mounted on the upper end of the vertical bowl spindle, which is driven by means of a worm wheel and friction clutch assembly. A radial thrust bearing at the lower end of the bowl spindle carries the weight of the bowl spindle and absorbs any thrust created by the driving action.

The flow of oil through the bowl and additional parts is shown in *Figure 11-10, frame 4.* Contaminated oil enters the top of the revolving bowl through the regulating tube. The oil then passes down the inside of the tubular shaft and out the bottom into the stack of disks. As the dirty oil flows up through the distribution holes in the disks, the high centrifugal force exerted by the revolving bowl causes the dirt, sludge, and water to move outward. The purified oil flows inward and upward, discharging from the neck of the top disk. The water forms a seal between the top disk and the bowl top. (The top disk is the dividing line between the water and the oil.) The disks divide the space within the bowl into many separate narrow passages or spaces. The liquid confined within each passage is restricted so that it can flow only along that passage. This arrangement minimizes agitation of the liquid as it passes through the bowl. It also makes shallow settling distances between the disks.

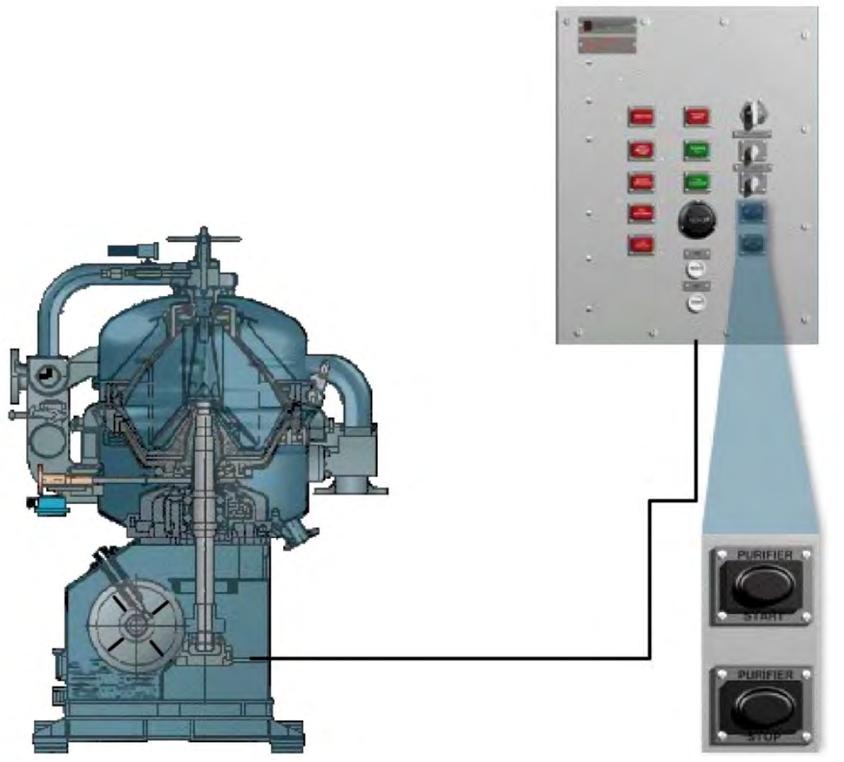

Figure 11-10 — Disk- type lube oil centrifugal purifier.

Most of the dirt and sludge remains in the bowl and collects in a more or less uniform layer on the inside vertical surface of the bowl shell. Any water, along with some dirt and sludge, separated from the oil, is discharged through the discharge ring at the top of the bowl.

Tubular-Type Purifier

A cross section of a tubular-type centrifugal purifier is shown in *Figure 11-11*. This type of purifier consists essentially of a bowl which rotates at high speeds. The bowl has an opening in the bottom to allow the dirty lube oil to enter. It also has two sets of openings at the top to allow the oil and water (separator) or the oil by itself (clarifier) to discharge (*Figure 11-11*). The bowl, of the purifier is connected by a coupling unit to a spindle. The spindle is suspended from a ball-bearing assembly. The bowl is belt driven by an electric motor mounted on the frame of the purifier.

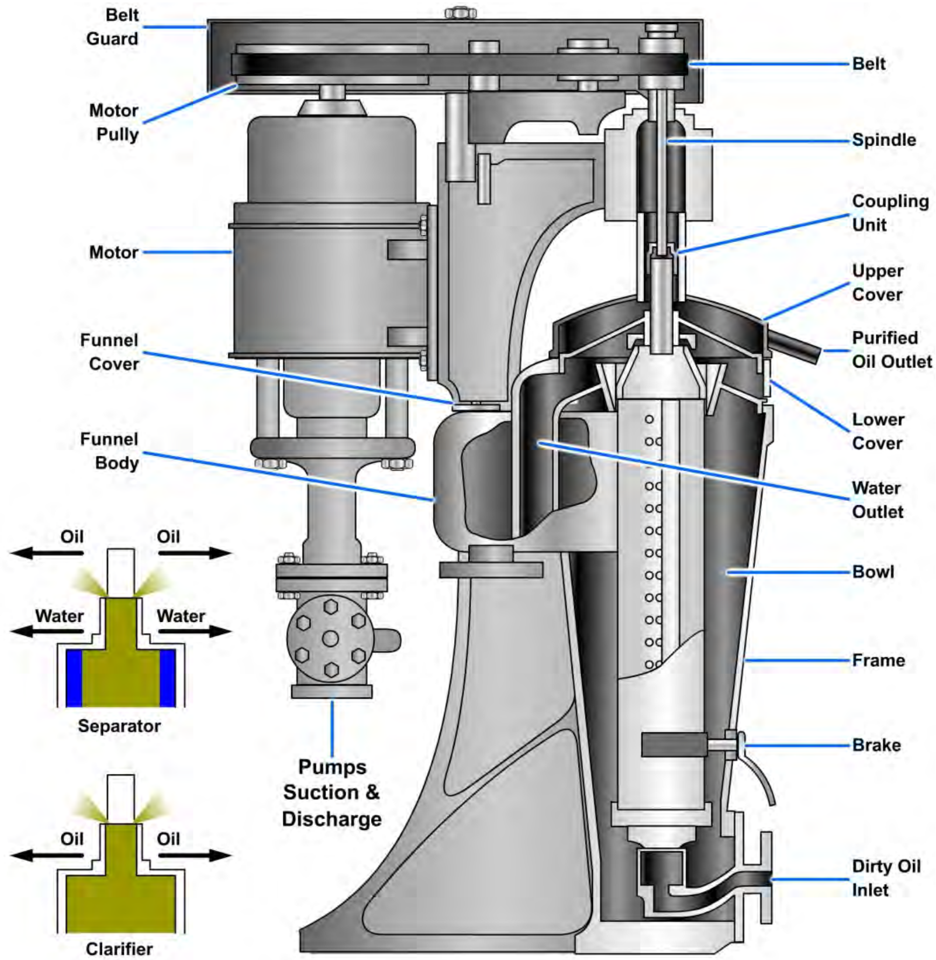

Figure 11-11 — Tubular-type centrifugal purifier.

The lower end of the bowl extends into a flexibly mounted guide bushing. The assembly restrains movement of the bottom of the bowl, but is also allows the bowl enough movement to center itself during operation. Inside the bowl is a device consisting of three flat plates equally spaced radially. This device is commonly referred to as the three-wing device, or just the three-wing. The three-wing rotates with the bowl and forces the liquid in the bowl to rotate at the same speed as the bowl. The liquid to be centrifuged is fed, under pressure, into the bottom of the bowl through the feed nozzle.

When the purifier is used as a lube oil clarifier, the three-wing has a cone on the bottom. The feed jet strikes against this cone in order to bring the liquid smoothly up to bowl speed without making an emulsion. This type of three-wing device is shown in *Figure 11-12*

Separation is basically the same in the tubular-type purifier as in the disk-type purifier. In both types, the separated oil assumes the innermost position, and the separated water moves outward. Both liquids are discharged separately from the bowls, and the solids separated from the liquid remain in the bowl (*Figure 11-13).*

General Notes on Purifier Operations

Specific details are found in the instructions provided for operating a given purifier. The information provided here is general and is applied to both types of purifiers.

For maximum efficiency, purifiers should be run at maximum designed speed and rated capacity. Since turbine oils are always contaminated with water from condensation, the purifier should be operated as a separator and not as a clarifier. However, a purifier must not be run at designed rated capacity when a unit is used as a separator of 9000 series (compounded- or additive-type heavy-duty lube oils) detergent oil. Some engine installations using oils of the 9000 series are exposed to large quantities of water. If the oil becomes contaminated with water, the oil has a tendency to emulsify. The tendency is greater when the oil is new. This condition decreases during the first 50 to 75 hours of engine operation. When an emulsion appears, the purifier should be lowered to 80 percent of the rated capacity and this operation continued as long as a noticeable amount of free water discharges along with the emulsion. When a purifier is run as a separator, the bowl should be primed with fresh water before opening the suction valve. The water serves to seal the bowl and make the liquid layers equal. If the bowl is not primed, oil will be lost through the water discharge ports.

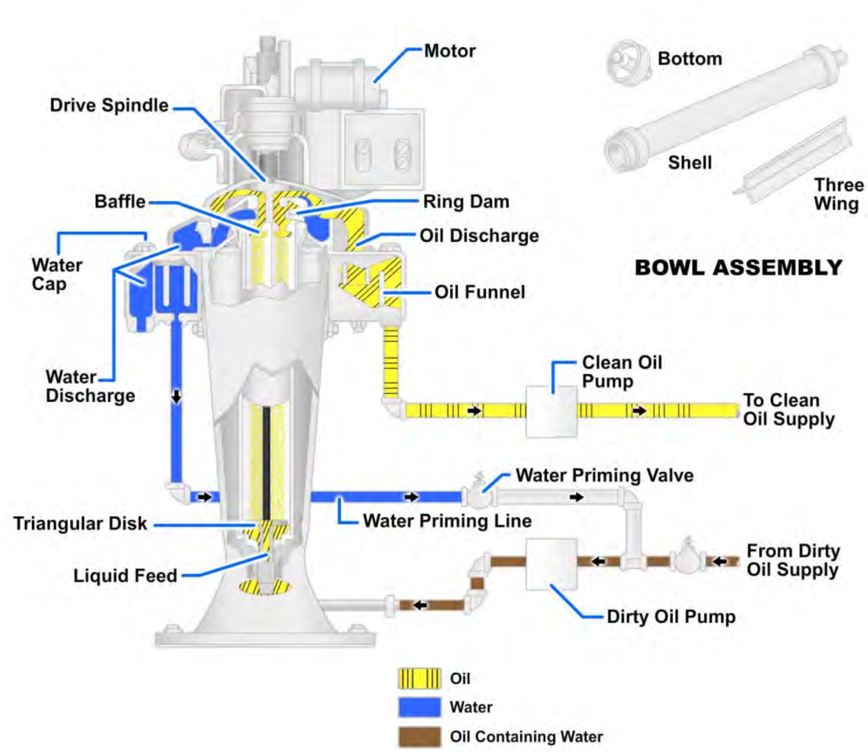

Figure 11-12 — Principles of a centrifugal purifier.

Influencing Factors in Purifier Operation

The time required for purification and the output of a purifier depend on many factors. The viscosity of the oil and the pressure applied to the oil are such factors. Two other important factors are the size of the sediment particles and the difference in the specific gravity of the oil.

The viscosity of the oil determines to a great extent the length of time required to purify lube oil. The more viscous the oil, the longer the time required to purify it to a given degree of purity. Decreasing the viscosity of the oil by heating will help purification.

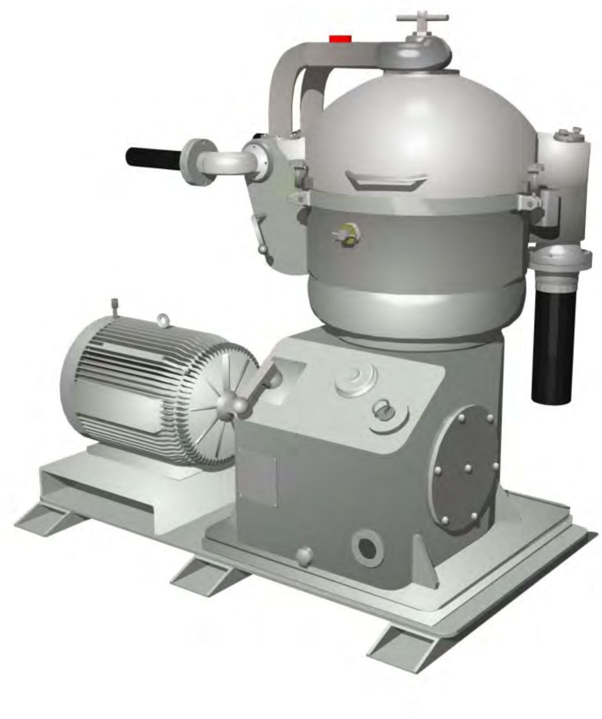

Figure 11-13 — Path of oil through the bowl-type purifier.

Even though certain oils may be properly purified at operating temperatures, greater purification is created by heating the oil to a higher temperature. To do this, the oil is passed through a heater. The oil reaches the proper temperature in the heater before it enters the purifier bowl.

Oils used in naval installations may be heated to specified temperatures without adverse effects. Prolonged heating at higher temperatures, however, is not recommended because of the tendency of such oils to oxidize. In general, oil should be heated enough to produce a viscosity of about 90 seconds, Saybolt Universal (90 SSU).

Pressure should not be increased above normal in order to force high viscosity oil through the purifier. Instead, viscosity should be decreased by heating the oil. The use of excess pressure to force oil through the purifier will result in poor purification. But if the pressure of the oil is reduced as it is forced into the purifier, purification will improve. This happens because the length of time the oil is under the influence of centrifugal force has increased.

For clean oil to be discharged from a purifier and for the water discharged to be free of oil, the proper size discharge ring (RING DAM) must be used. The size of the discharge ring depends on the specific gravity of the oil being purified. All discharge rings have the same outside diameter, but they have inside diameters of different sizes. Ring sizes are shown by even numbers; the smaller the number, the smaller the ring size. The size, in millimeters, of the inside diameter is stamped on each ring. Sizes vary by 2-mL steps. Charts provided in manufacturers' technical manuals show the proper ring size to be used with an oil of a specific gravity. Generally, the ring size shown on a chart will produce good results. However, the recommended ring may not produce good purification. In that case, the correct size must be determined by trial and error. In general, purification is best when the ring of the largest possible size is used to prevent loss of oil.

Maintenance of Purifiers

Proper care of an oil purifier requires that the bowl be cleaned often and that all sediment be carefully removed. How often a purifier is cleaned depends on the amount of foreign matter in the oil to be purified. If the amount of foreign matter in oil is not known, the machine should be shut down and checked. The amount of sediment found in the bowl at this time will indicate how often the purifier should be cleaned. The bowl assembly should be thoroughly cleaned each time lube oil is run through for batch purification from the settling tank.

While the purifier is operating on a sump of an operating unit, checks should be made to ensure the purifier has not lost its seal. A casualty caused by a loss of lube oil can occur fairly rapidly. This happens if all the lube oil from a sump is dumped to the bilge or drain tank by an improperly operating purifier.

In the remainder of this chapter, we will touch briefly on the Navy's Lube Oil Quality Management (LOQM) Program, shipboard testing of diesel engine lube oil, and environmental pollution control.

LUBE OIL QUALITY MANAGEMENT PROGRAM

Because of the importance of lubricating oils to the reliability and operating life of machinery, the LOQM Program was established. The policies of this program have been set forth in the form of an instruction. Although the procedures of the program may vary from place to place, the objectives are the same. Some of the major points are as follows:

1. How often you should take samples
2. What equipment you should use to take samples
3. The types of tests you must perform on the samples
4. The required logs and records you must maintain
5. The actions you should take based on the tests

The Joint Oil Analysis Program (JOAP) provides spectrographic analyses of your ship's lube oil at a designated laboratory. This program serves to detect accelerated wear in machinery. Oil testing is performed without disassembly of the machinery, and the results of the tests are available long before any other trouble is indicated. Lube oil samples are submitted to the laboratory for examination on a periodic basis. The testing activity advises the ship of the test results and provides recommendations. The ship is then responsible for maintaining accurate records of operating hours after major overhauls, oil changes, and completed repairs.

For additional information on the required shipboard tests and procedures you must use to maintain the quality of lubricating oils, refer to the NSTM, Chapter 262.

Shipboard Testing of Diesel Engine Lube Oil

In addition to submitting the required samples to the JOAP laboratories, you can use the shipboard diesel engine lubricating oil test kit to take samples and perform tests on your ship's diesel engine lube oil (9250). The kit provides a quick and accurate means you can use to check used oil for fuel dilution, viscosity, and acidity to determine if the oil is within the specified limits.

Oil color change is common in diesel engine lube oil after a few hours of use. The change in color is due to the suspension of fine particles of unburned carbon (soot) that accumulate in the oil. Darkening is not a definite indication that the oil has lost its lubricating properties. Diesel engine lube oil should not be drained solely because of color change.

Water in lubricating oil can usually be detected by the cloudy appearance of an oil sample taken from an operating engine or by small droplets of water that may separate in a sample bottle. A small quantity of free water in the lube oil in a diesel engine should cause no difficulty because it will change to steam and pass into the exhaust system as the engine reaches normal operating temperatures. Any salt accumulation in the oil will be monitored through JOAP. When serious water contamination exits, such as freestanding water in the bottom of the sample bottle or if the oil has a cloudy appearance, the oil should be drained and replaced with fresh oil after the source of the leak has been repaired.

The effectiveness of any lubricating system depends on the quality of the lubricant and the condition of the principal parts of the engine. The life of a diesel engine is remarkably long provided the engine is adequately lubricated. Effective lubrication, in turn, depends on timely completion of required checks, inspections, and maintenance procedures. For additional information, refer to the NSTMs, Chapters 233 and 262.

Safety Precautions

All lubricated equipment and the lube oil systems shall be protected from damage by observance of the following precautions:

1. If the oil supply is interrupted, stop the affected machinery immediately; determine cause and correct; restore oil supply before resuming operation.
2. If a sudden increase of pressure at the pumps is noted, inspect the flow of oil at the bearings immediately. The pressure increase is usually attributable to a clogged strainer.
3. The lubrication system shall be operated as an independent system. The standby and emergency lube oil pump shall be kept ready for immediate use.
4. Take every precaution to prevent water from entering the lube oil system; if water level exceeds system contamination limits, remove it as quickly as possible.
5. Do not permit the oil level in gear casings to rise to the point that gear teeth are immersed; such immersion causes churning, foaming, emulsification, and a sudden increase in temperature.

6. At the first sign that the temperature of the lube oil leaving a bearing or other unit is higher than normal, check oil cooler operation and investigate the cause of increased bearing temperature.
7. Operate oil coolers when oil temperature at the cooler outlet reaches system temperature specified by Naval Sea Systems Command (NAVSEA), and continue to operate as long as the oil temperature at the cooler outlet exceeds that temperature. Any rise above normal operating temperature shall be satisfactorily accounted for; the bearing condition shall be watched carefully. Any problem discovered shall be remedied immediately. Until corrected, the machinery shall be slowed or stopped to avoid exceeding the safe bearing temperature.
8. When oil coolers are unused for more than 24 hours while in port, keep the seawater side drained.
9. Use only manufacturer-recommended oils that appear on the applicable Military Specification (MILSPEC) Qualified Products List (QPL). The addition of commercial after-market or NON-MILSPEC additives to MILSPEC products is prohibited.
10. When an engine room is secured and the ship is being towed, or is being propelled by units other than its main engines, the bearings of the shafts and machinery that are turned by propeller drag shall be adequately lubricated. If adequate lubrication is unavailable, the jacking gear shall be engaged and locked. Even with the jacking gear engaged and the brake set, oil shall be supplied to the bearings underway, if practical; to provide additional safety in case the jacking gear brakes should start to slip.
11. Circulate clean oil through an idle system weekly for at least 15 minutes. Jack the main engines at the same time. This precaution is not applicable to diesel engine or gas turbine installations.
12. The lube oil purifiers shall be operated each day while underway until there is no indication of water in the oil. When the main propulsion machinery is secured, the lube oil shall be purified until no water is discharged from the purifiers.
13. To prevent emulsification or acidity, oil in the drain tank shall be routed to the settling tanks, heated, and run through the purifiers as soon as the oil becomes emulsified or contaminated by water or other impurities.
14. Diesel lube oil contaminated by more than 5 percent fuel or 40 percent thickening shall be discarded.
15. Whenever any part of the lube oil system is open, however briefly, the openings shall be covered to prevent the entry of foreign matter.
16. Waste rags shall never be used to wipe the inside of a tank, a bearing, or other lubrication system part. Use lint-free wiping cloths only.
17. The oil reservoir of blowers and other independent machinery shall be monitored frequently and kept filled with clean oil of the proper quality.
18. Lube oil shall be discarded, the system cleaned, and new oil introduced when testing indicates that allowable use limits have been exceeded or when reasonable operation of the purification facilities will not remove emulsion and sludge. The addition of new oil to used oil to enhance or ″sweeten″ its properties is prohibited.
19. To ensure that the proper grade of oil has been delivered and is free from contamination, all newly received oil shall be carefully examined before being taken on board.
20. Keep covers on oil cups of secured machinery.
21. Keep bearing inspection opening covers closed except when openings are in use for bearing examination.

22. Do not cut in coolers until after oil pumps have been started. Secure coolers before securing oil pumps. The pressure on the oil side of the cooler shall always be kept greater than that on the water side.
23. Lube oil in the bilges shall not be reclaimed nor added to the lubrication system.

SUMMARY

Lubricating systems of the pressure type are found in marine diesel engines. Pressure lubricating systems generally include pumps, strainers, pressure-regulating valves, filters, bypass valves, and coolers, in addition to the necessary piping and passages.

Even though the lubricating systems of various engines differ in some aspects of design, all the systems are quite similar with respect to oil flow. In general, the pump draws oil from the source of supply (oil pan, sump, or separate tank) and forces the oil through a strainer, a filter, and a cooler before the oil enters the engine. Upon entering the engine, the oil generally flows into a main oil header, which may be either a passage in the block or a separate line suspended in the block. The main oil gallery supplies oil to the various parts of the engine that require lubrication.

Ventilation of the engine crankcase is essential for efficient and safe engine operation. Unless the crankcase of an engine is properly ventilated, harmful vapors will accumulate in the crankcase. These vapors come primarily from two sources. Some of the vapors are formed when the lubricating oil comes in contact with the hot internal surfaces of the engine these vapors can create an explosion. These vapors must be removed from the crankcase; otherwise, a local hot spot within the engine might ignite the charge. Vapors may also accumulate in the crankcase because of the blow-by between the pistons and the cylinder liners. Blow-by occurs when the piston is compressing the air or the fuel-air charge during the power event. In all engines, products of combustion escape past the piston rings and into the crankcase during the power event. Products of combustion contain water vapor which condenses when it comes in contact with a cool surface. Such condensation causes corrosion and contaminates the lubricating oil.

Because of the importance of lubricating oil, LOQM Program was established. By following this program, you should be able to identify problems before they create a breakdown. Remember, planned maintenance of your ship’s diesel engine is always preferred over breakdown maintenance.

If you are uncertain concerning any of the information in this chapter on engine lubricating systems, we recommend that you reread the sections in which you are having problems before you proceed to the next chapter.

End of Chapter 11

Engine Lubricating Oil System

Review Questions

11-1. What is the friction between a body at rest and the surface upon which it is resting?

A. Kinetic
B. Immobile
C. Static
D. Motile

11-2. What is a presently accepted theory on lubrication?

A. Boyles
B. Einstein
C. Newton
D. Langmuir

11-3. What is the property of lubrication which holds the lubricants together and enables it to resist breakdown under extreme pressure?

A. Cohesion
B. Viscosity
C. Demusibility
D. Adhesion

11-4. Why do diesel engines' lubricating oils contain additives?

A. Increase the foaming of the lubricating oil
B. Reduce wear to engine parts
C. Increase the oxidation of metal surfaces
D. Increase the heat insulation in the combustion chamber

11-5. What determines the viscosity digits in the classification of lubricating material?

A. Standard code from the manufactory
B. Number of minutes required for a 60 milliliter (mL) sample of oil to flow through a standard orifice at a certain temperature
C. Number of seconds required for a 60 mL sample of oil to flow through a standard orifice at a certain temperature
D. The size of the orifice that is used during the viscosity test

11-6. What lubricating oil property is the oils tendency to resist flow or change shape?

A. Viscosity
B. Pour point
C. Neutralization number
D. Precipitation number

11-7. What lubricating oil property is a measure of the amount of solids classified as asphalts or carbon residue contained in the oil?

A. Viscosity
B. Pour point
C. Neutralization number
D. Precipitation number

11-8. What are simple mixtures of soaps and lubricating oils called?

A. Petroleum
B. Lubricating greases
C. Synthetic oil
D. Penetrating oil

11-9. What is the maximum operating temperature of ball and roller bearing grease?

A. 100°F
B. 200°F
C. 300°F
D. 400°F

11-10. When filling a grease cup with lubricating grease, what must be kept out of the cup?

A. Fresh grease
B. Dirt
C. Moisture
D. Air

11-11. Which of the following function is NOT an indication that a diesel engine lubricating oil system is effective?

A. Smooth starting of the diesel engine
B. Minimizes friction between bearing surfaces and moving parts
C. Removes heat from the surface area where friction is present
D. Keeps diesel engine parts clean

11-12. What must every approved lubricating oil strainer have built in?

A. Vent valve
B. Fill tube
C. Spring-loaded differential area
D. Sight glass

11-13. Where does the lubricating oil go from the bypass filter?

A. To the engine
B. Recirculated through the lubricating oil cooler
C. Returned to the sump tank
D. Bypassed to the settling tank

11-14. Where could combustible gases accumulate in the diesel engine if there was no way to vent the gases?

A. In the attached lubricating oil pump
B. In the emergency lubricating pump
C. On the sides of the combustion chamber
D. In the diesel engines crankcase

11-15. What would happen to the lubricating oil if it became overheated?

A. Formation of acids
B. Formation of sludge
C. The lubricating oil flash point would increase
D. The lubricating oil flash point would decrease

11-16. What is the normal temperature range for lubricating oil to prevent dilution?

A. 100°- 200°F
B. 200°- 300°F
C. 300°- 400°F
D. 600°- 700°F

11-17. What is the biggest source of contamination in lubricating oil?

A. Diesel fuel
B. Jet propulsion 5 (JP5) fuel
C. Sediments
D. Water

11-18. What oil is used in modern naval ships with forced-feed lubrication systems?

A. Hydraulic oil
B. Pure oil
C. Penetrating oil
D. Synthetic oil

11-19. When water must be removed from the lubricating oil, the purifier is called?

A. Clarifier
B. Separator
C. Filter
D. Strainer

11-20. What *Naval Ships Technical Manual* (NSTM) would you refer to for additional shipboard tests and procedures to maintain the quality of lubricating oil?

A. Chapter 150
B. Chapter 220
C. Chapter 262
D. Chapter 358

11-21. What determines the size of the discharge rings on a purifier?

A. Viscosity
B. Pour point
C. Flash point
D. Specific gravity

11-22. What program is used by the Navy to ensure the properties of the lubricating oil are reliable and proper for use on naval equipment?

A. Lube Oil Quality Management (LOQM)
B. Navy Oil Analysis Program (NOAP)
C. Joint Oil Analysis Program (JOAP)
D. Engineering Operating Procedures (EOP)

11-23. What condition is NOT caused by a high lubricating oil level in a gear casing?

A. Churning
B. Demulsibility
C. Foaming
D. Emulsification

11-24. What must be done to newly received oil?

A. Store in storage tank
B. Store in settling tank
C. Carefully examine before bringing onboard
D. Send for Joint Oil Analysis Program (JOAP) testing

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CHAPTER 12

DIESEL FUEL SYSTEMS

In this chapter, we will discuss the common types of fuels and the hardware systems that store, clean, transfer, and finally inject the fuel into the engine for burning. After studying the information in this chapter, you will be able to identify the characteristics of engine fuels in terms of properties, combustion, volatility, and turbulence. You will also be able to identify diesel engine fuel systems in terms of external fuel systems and fuel injection systems. You will be able to describe the design, function of components, and methods of operation of the jerk-type, distributor-type, and unit fuel injector systems.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Identify the diesel engine fuel oil (FO) requirements.
2. Explain the maintenance and operation of the fuel oil (FO) systems.
3. Explain the purpose and operation of the fuel oil (FO) purifier.
4. List and discuss the different fuel injection systems for diesel engines.

DIESEL ENGINE FUEL REQUIREMENTS

The fuels burned in the internal-combustion engines used by the Navy must meet the specifications prescribed by the Naval Sea Systems Command (NAVSEA). Thus, selecting a fuel with the required properties is not your responsibility. Your primary responsibility is to follow the rules and regulations dealing with the proper use of fuels. You must strictly adhere to all prescribed safety precautions. You must also take every possible precaution to keep fuel as free as possible from impurities. Even though proper handling and use are your prime responsibilities with respect to fuel, knowing the characteristics of fuels will help you understand some of the problems in engine operation and maintenance.

At the time of manufacture, fuels are generally clean and free from impurities. The processes of transferring, storing, and handling fuel tend to increase the danger of contamination with foreign materials, a condition that can interfere with engine performance. Sediment and water in fuel can cause engine wear, gumming, and corrosion in the fuel system. Foreign materials in fuel can also cause an engine to operate erratically with a loss in power. For these reasons, periodic inspection, cleaning, and maintenance of fuel handling and filtering equipment are necessary.

Because of the differences in the combustion processes and in the fuel systems of diesel and gasoline engines, the fuels for these engines must be refined to meet different requirements. Diesel engines require a particularly clean fuel; the closely fitted parts of the injection equipment will wear rapidly and the small passages that create the fuel spray within the cylinders will become clogged. The diesel fuel must have a composition that permits it to be injected into the cylinders in a fine mist or fog. Diesel fuel must also have ignition qualities that permit the fuel to ignite properly and burn rapidly when it is injected into the cylinders.

Volatility and Engine Operation

The ability of a liquid to change to vapor is known as volatility. All liquids tend to vaporize at atmospheric temperatures, but their rates of vaporization vary. The rate of vaporization increases as the temperature increases and as the pressure decreases (Temperature is more important than pressure). For a given temperature, a highly volatile fuel will vaporize more readily and at a faster rate than a fuel with a lower volatility. The volatility of fuel affects engine starting, length of warm-up period, fuel distribution, and engine performance. High volatility, however, can also result in fuel dilution of the lube oil in the crankcase.

Injection, Ignition, and Combustion

The self-ignition point of a fuel is a function of temperature, pressure, and time. In a properly operating diesel engine, the intake air is compressed to a high pressure (increases the temperature), and the injection of fuel starts a few degrees before the piston reaches top dead center (TDC). The fuel is ignited by the heat of compression shortly after fuel injection starts and combustion continues throughout the injection period. Combustion in a diesel engine is much slower than it is in a gasoline engine, and the rate of pressure rise is relatively small.

Immediately after injection, the atomized fuel partially evaporates with a resultant chilling of the air in the immediate vicinity of each fuel particle. However, the extreme heat of compression rapidly heats and vaporizes the fuel droplets to the self-ignition point and combustion begins. The fuel particles burn as they mix with the air. The smaller particles burn rapidly, but the larger particles take more time to ignite because heat must be transferred into them to bring them to the self-ignition point.

There is always some delay between the time fuel is injected and the time it reaches the self-ignition point. This delay is commonly referred to as ignition delay or lag. The duration of the ignition delay depends on the characteristics of the fuel, the temperature and pressure of the compressed air in the combustion space, the average size of the fuel particles, and the amount of turbulence present in the space. As combustion progresses, the temperature and pressure within the space rise rapidly, the ignition delay of fuel particles injected later in the combustion process is less than in those injected earlier. In a diesel engine, the delay period between the start of injection and the start of self-ignition is the first phase of combustion. The second phase of combustion is ignition of the fuel injected during the first phase and the rapid spread of the flame through the combustion space as injection continues. The resulting increases in temperature and pressure reduce the ignition lag for the fuel particles entering the combustion space during the remainder of the injection period.

Remember, only a portion of the fuel has been injected during the first and second phases. As the remainder of the fuel is injected, the third or final phase of combustion takes place. The increase in temperature and pressure during the second phase is sufficient to cause most of the remaining fuel particles to ignite with practically no delay as they come from the injection equipment in the third phase. The rapid burning during the final phase of combustion causes an additional, rapid increase in pressure.

Do not confuse the knock that occurs during the normal operation of a diesel engine with detonation. Generally, detonation in a diesel engine is caused by a simultaneous combustion of all particles of the fuel spray in the cylinder. Combustion (Diesel) knock in a diesel engine is directly related to the amount of ignition delay and will take place at the end of the second phase. Diesel knock occurs from the rapid burning of large amounts of fuel (gathered in the cylinder before combustion begins). The amount of fuel that is ignited instantaneously determines whether combustion is normal or detonation occurs.

Detonation in a diesel engine is generally caused by too much delay in ignition. When the ignition point of the excess fuel is reached, all of this fuel ignites simultaneously, causing extremely high pressures in the cylinder and an undesirable knock. Thus, detonation in a diesel generally occurs at the start of the second phase of combustion. Detonation in a diesel may occur when the engine is not warmed up sufficiently or when fuel injection equipment is not operating properly. These conditions may allow excessive fuel to accumulate in the cylinder.

Even though diesel fuel must have the ability to resist detonation, it must ignite spontaneously at the proper time under the pressure and temperature conditions existing in the cylinder. The ease with which a diesel fuel ignites and the manner in which it burns determines the ignition quality of the fuel. The ignition quality of a diesel fuel is determined by its cetane rating, which is identified by its cetane number. The higher the cetane number, the less lag there is between the time the fuel enters the cylinder and the time it begins to burn.

The cetane number of diesel fuel is the numerical result of an engine test designed to evaluate fuel ignition delay. To establish the cetane number scale, two reference fuels are used, cetane and heptamethylnonane. Cetane has an excellent ignition quality (100), and heptamethylnonane has a very poor ignition quality (15). The cetane rating of a fuel in which the ignition quality is unknown can be determined by a comparison of the performance of the fuel with that of a reference fuel. The cetane number represents the percentage of pure cetane in a reference fuel that will just match the ignition quality of the fuel being tested. A higher cetane number means a quicker burning of the fuel, a condition that tends to result in easier engine starting, particularly in cold weather.

Turbulence and Combustion in Diesel Engines

In both gasoline and diesel engines, the fuel and air must be properly mixed to obtain efficient combustion. In gasoline engines, mixing of the fuel and air takes place outside the cylinder. Depending upon the design of the system, mixing will occur in one of two places: (1) within the carburetor in the carburetor-type system or (2) at the intake ports in the fuel injection-type systems. In both designs the proper mixture is forced into the cylinder to be compressed. In the diesel engine, however, fuel in the form of small particles is sprayed into the cylinder after the air has been compressed, thus mixing takes place within the cylinder. If each particle of fuel is to be surrounded by sufficient air to burn it completely (that is, if proper air-fuel mixture is to be obtained), the air in the combustion space must be in motion. This air motion is called turbulence. Various means are used to create turbulence. The design of the engine and a process called pre-combustion create proper turbulence.

Methods of Creating Turbulence

Fuel is distributed in the cylinders of a diesel engine by injection nozzles, which atomize the fuel and direct it to the desired portions of the combustion space. Fuel injection creates some turbulence, but not enough for efficient combustion.

In 2-stroke cycle engines, scavenging-air ports are designed and located so that the intake air enters the cylinder with a whirling or circular movement. The movement of the air continues through the compression event and aids in mixing the air and fuel when injection occurs.

While fuel injection and the ports in 2-stroke cycle engines aid in creating air movement, special shapes in the combustion space create additional turbulence is created in most engines. These shapes may include the piston crown and that portion of the cylinder head that forms part of the main combustion space. In some engines, auxiliary combustion chambers are provided as part of the combustion space to aid in mixing the fuel and air.

Even though there are many types of combustion chambers, all are designed to produce one effect, to bring sufficient air in contact with the injected fuel particles to provide complete combustion at a constant rate. Combustion chambers may be broadly classified under four types: open, pre-combustion, turbulence, and divided chamber. The last three terms more commonly refer to auxiliary combustion chambers, which use a process called pre-combustion.

Of the three types of chambers, the open combustion chamber is the simplest in design. The fuel is injected directly into the top of the combustion space. The piston crown and the cylinder head are shaped to cause a swirling motion of the air as the piston moves toward TDC during the compression event. There are no special chambers to aid in creating turbulence. Open combustion chambers require higher injection pressures and a greater degree of atomization than other types to obtain the same degree of turbulence and mixing.

Pre-combustion and Turbulence

Some diesel engines have an auxiliary space or chamber at or near the top of each main combustion space. These chambers receive all or part of the injection fuel and condition it for final combustion in the main combustion chamber of the cylinder. This conditioning, called pre-combustion, involves a partial burning of the fuel before it enters the main combustion space. Pre-combustion helps to create the turbulence needed for the fuel and air to properly mix. Because of differences in designs, the manner in which pre-combustion aids in creating turbulence differs from one type of auxiliary combustion chamber to another. For this reason, we will discuss three types of auxiliary chambers by their common names—pre-combustion chambers, turbulence chambers, and air or energy cells.

Look at *Figure 12-1*, to see how the pre-combustion chamber creates turbulence. The pre-combustion chamber, spherical in shape, is located in the cylinder head directly over the center of the piston crown. The pre-combustion chamber is connected to the main combustion space of the cylinder by a multiple orifice called a burner. During the compression event, a relatively small volume of compression-heated air is forced through the burner into the pre-combustion chamber. Heat stored by the burner increases the temperature of the compressed air and facilitates initial ignition.

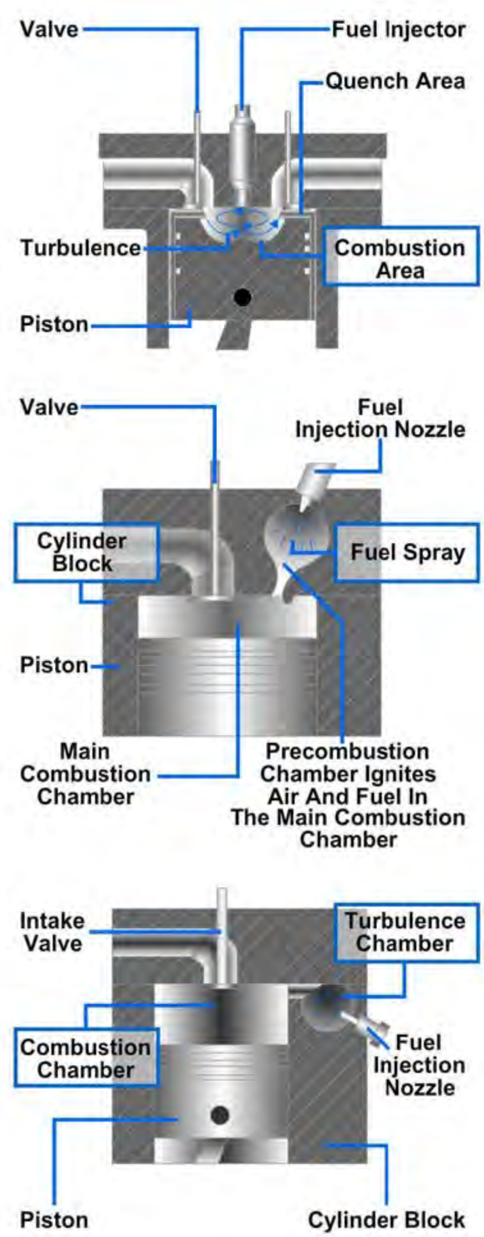

Figure 12-1 — Pre-combustion chamber.

Fuel is atomized and sprayed into the hot air in the pre-combustion chamber, and combustion begins. Only a small part of the fuel burns in the pre-combustion chamber because of the limited amount of oxygen. The fuel that does burn in the chamber creates enough heat and pressure to force the fuel, as injection continues, into the cylinder at great velocity. The velocity of the fuel entering the main combustion space and the shape of the piston crown help to create the necessary turbulence within the cylinder.

Engines that have pre-combustion chambers do not require fuel injection pressures as great as engines that have open-type chambers. The spray of injected fuel can be coarser, since the pre-combustion chamber functions to atomize the fuel further before the fuel enters the cylinder.

Some engines have auxiliary combustion chambers. They differ from pre-combustion chambers in that nearly all of the air supplied to the cylinder during the intake event is forced into the auxiliary chamber during the compression event. Auxiliary chambers in which this occurs are sometimes referred to as turbulence chambers. There are several variations of turbulence chambers, one of which is illustrated in *Figure 12-2.*

In *Figure 12-2*, v*iews A through C*, notice that turbulence, indicated by the arrows, is created in the auxiliary chamber as compression (*Figure 12-2, view A*), injection (*Figure 12-2, view B*), and combustion (*Figure 12-2,view C*) take place. In engines with turbulence chambers, there is very little clearance between the top of the piston and the head when the piston reaches TDC (*Figure 12-2, view B*). For this reason, a high percentage of the air in the cylinder is forced into the turbulence chamber during the compression event. The shape of the chamber (usually spherical) and the size of the opening through which the air must pass help to create turbulence. The opening to the turbulence chamber becomes smaller as the piston reaches TDC, thereby increasing the velocity of the air. Velocity plus deflection of the air as it enters the auxiliary chamber creates considerable turbulence. Fuel injection (*Figure 12-2, view B*) is timed to occur when the turbulence in the chamber is the greatest. This timing ensures a thorough mixing of the air and fuel. The greater part of combustion takes place within the turbulence chamber and is completed as the burning gases expand and force the piston down in the power event.

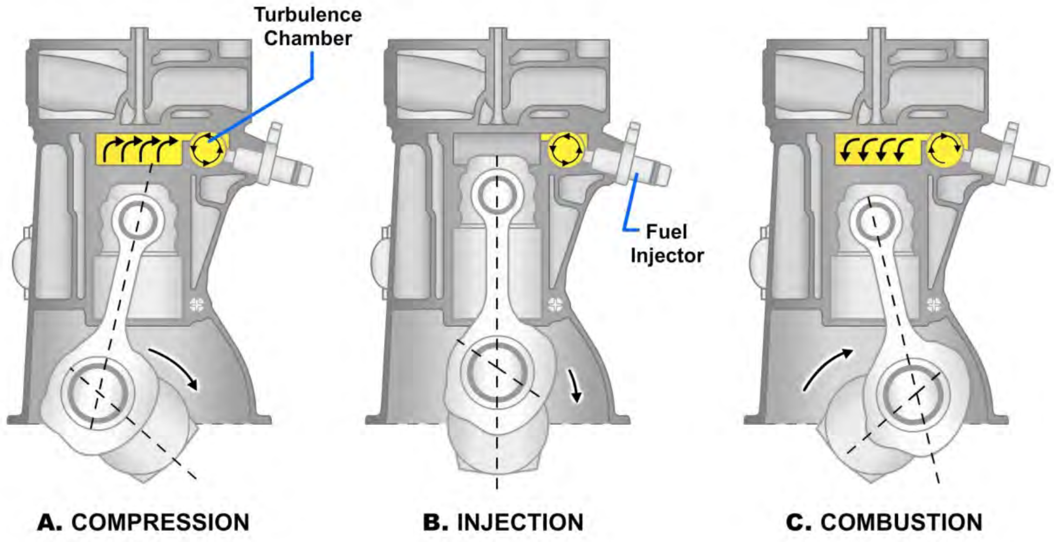

Figure 12-2 — Turbulence chamber.

In some high-speed diesel engines, turbulence is created by an auxiliary chamber referred to as an energy (air) cell. Energy cells differ in design and location. In most engines, the cells are located in the cylinder heads. One type of energy cell that is located in the cylinder head is a divided cell and is divided into two chambers. The Lanova cell is the divided chamber type. *Figure 12-3*, shows cross-sectional top and side views of a divided auxiliary combustion chamber.

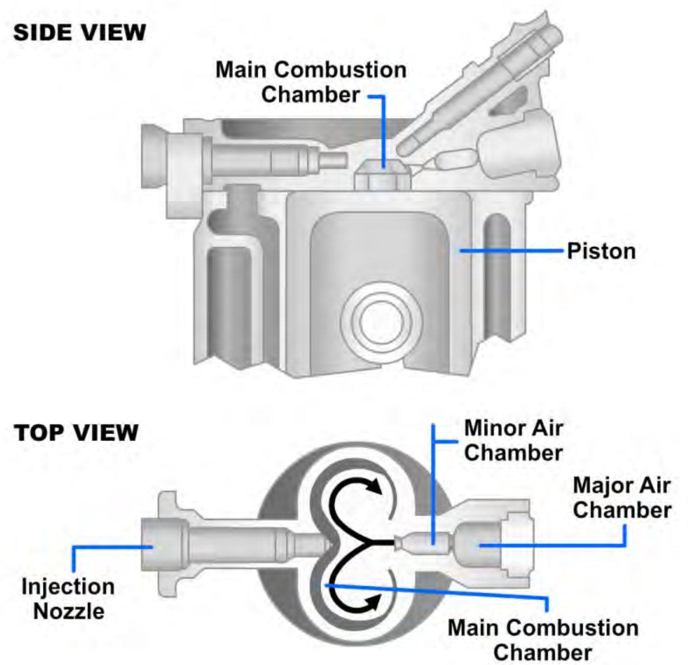

Figure 12-3 — Divided combustion chamber.

Study the construction and operation of a typical system, the Lanova design, shown in *Figure 12-3*. It employs a combustion chamber consisting of two rounded spaces cast in the cylinder head. The inlet and exhaust valves open into the main combustion chamber. The fuel-injection nozzle lies horizontally, pointing across the narrow section where the lobes join. Opposite the nozzle is the two-part energy cell, which contains less than 20 percent of the main-chamber volume.

During the compression stroke, the piston forces air into the energy cell. Near the end of the stroke, the nozzle sprays fuel across the main chamber in the direction of the mouth of the energy cell. While the fuel charge is traveling across the center of the main chamber, between a third and a half of the fuel mixes with the hot air and burns at once. The remainder of the fuel enters the energy cell and starts to burn there, ignited from the fuel already burning in the main chamber.

The cell pressure rises sharply, causing the products of combustion to flow at high velocity back into the main combustion space. This flow sets up a rapid swirling movement of fuel and air in each lobe of the main chamber, promoting the final fuel-air mixing and ensuring complete combustion. The two restricted openings of the energy cell control the time and rate of expulsion of the turbulence-creating blast from the energy cell into the main combustion space. The rate of pressure rise on the piston is gradual, resulting in smooth engine operation.

The divided combustion chamber is similar, in some respects, to other types of chambers. It is similar to an open combustion chamber in that the main volume of air remains in the main combustion chamber and principal combustion takes place there. Both the divided chamber and the turbulence chamber depend on a high degree of turbulence to ensure thorough mixing and distribution of the fuel and air. Turbulence in a divided combustion chamber is dependent on thermal expansion caused by combustion in the energy cell and not on engine speed as in other types of auxiliary combustion chambers.

NAVAL DISTILLATE DIESEL FUEL

The Navy normally uses naval distillate North Atlantic Treaty Organization (NATO) symbol F-76 in diesel engines, but also uses other fuels such as jet propulsion JP-5 (NATO symbol F-44) and naval distillate lower pour point (NATO symbol F-75). Code F-76 and F-75 fuels are compatible and can be mixed in all proportions. Code F-44 and F-75 fuels are authorized for use in diesel engines where there is a logistic advantage for use. At present, most ships carry naval distillate fuel (F-76) for boilers and for diesel engines.

Shipboard Fuel Testing

Normally, ships procure fuel through the military supply system. It is reasonable to assume that fuel received from the military supply system will meet the requirements of the applicable military fuel specification because of the extensive quality surveillance procedures this system uses. However, when fleet oilers deliver fuel to ships, it can become contaminated by solids and water. The receiving ship must remove solids and water through settling and stripping or by use of purification equipment.

The fuel testing equipment items described in this section will help you identify the solids and water that must be removed by stripping and determine whether the purification equipment is functioning adequately to remove the solids and the water.

Required shipboard fuel testing equipment items (*Table 12-1*) for all ships are as follows:

Table 12-1 — Fuel oil (FO) tests and equipment

NAME OF TEST	EQUIPMENT (METHODS)
Visual	Glass sample bottle
Bottom sediment and water (BS&W)	Laboratory centrifuge
Flashpoint	Pensky-Martens closed-cup tester
API gravity	Hydrometer range: 29-41 and 39-51

In addition to these four tests, if you are an Engineman assigned to a ship with gas turbine propulsion plants or helicopter in-flight refueling (HIFR) capability, you will be required to have the following testing equipment:

1. Allowable Equitable List (A.E.L.) free water detector Mk II
2. A.E.L. contaminated fuel detector Mk III

For detailed information on shipboard testing, consult the *Naval Ships' Technical Manual (NSTM)*, Chapters 541 and 542.

External Fuel Systems

The fuel system in a diesel-powered naval vessel must be installed, operated, and maintained with the same care and supervision as the ship's engines. Inspections, maintenance, and operation of fuel tanks and fuel-handling equipment must be carried out according to the Ships' Maintenance and Material Management (3-M) system and the NSTM, Chapters 541 and 542.

The fuel is pumped from the storage tank to the service or day tank, and from there it is delivered to the fuel injection equipment on the engine. Removing sediment and water from the fuel before it enters the service tank is good practice. This is usually done with a centrifugal purifier. The fuel is transferred from the service tank by an engine-driven pump (also called a booster, transfer, or primary pump) through a metal-edge strainer and a cartridge-type replaceable element filter to a header at the inlet of the fuel injection equipment installed on the engine. Excess fuel (that is NOT used for combustion) is returned to the service tank.

Storage Tanks/Ballast

Fuel oil (FO) storage tanks (*Figure 12-4*) hold fuel as it is loaded onto the ship, before it is purified for use by propulsion and auxiliary equipment. The three kinds of FO storage tanks differ in the way seawater ballasting is related to fuel storage and ship stability.

With separate fuel and ballasting tanks, seawater is never introduced into a fuel tank and fuel never enters a ballast tank. This arrangement keeps the fuel free of seawater and keeps the ballast seawater clean.

On ships using combination fuel or ballast tanks, there are no separate seawater ballast tanks. Empty fuel storage tanks may be ballasted with seawater to aid in ship stability.

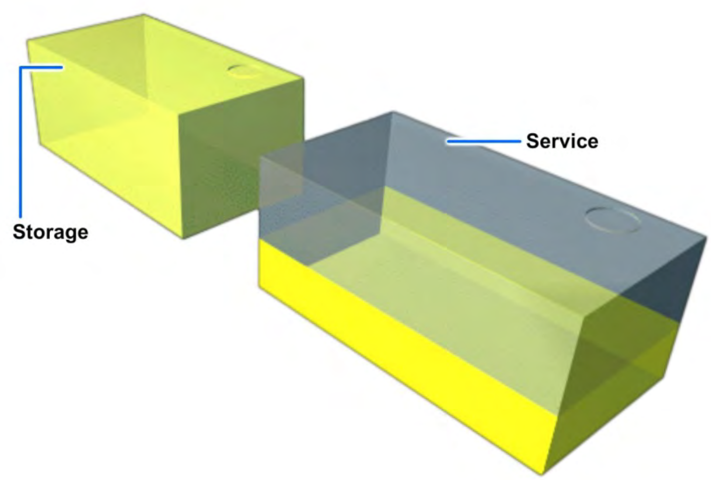

Figure 12-4 — Fuel oil (FO) tanks.

Seawater-compensated FO storage tanks are always completely full of liquid. Ballast seawater enters the tank as fuel is removed and is displaced overboard as fuel is added. The fuel and seawater in a tank tend to remain separate because of differing specific gravities. The types of fuels stored on naval vessels are lighter than seawater; thus, fuel floats on seawater.

Service Tanks

The service or day tank is usually vented to the atmosphere and mounted at a high point in the fuel system, which allows the weight of the fuel to pressurize the external system and prevent air from leaking into the system. The presence of air in the fuel will interfere with proper operation of the fuel injection equipment. Propulsion or auxiliary equipment is usually served by two FO service tanks. Fill fuel service tanks to a maximum of 95 percent at sea and 80 percent in port.

Use the online service tank it is 50 percent full, and then place the standby service tank online. If for any reason the standby tank is not ready, a 50 percent reserve capacity is still available in the online service tank. When the service tank in use is changed, fill the new standby tank as soon as possible to give the fuel the maximum amount of time for contaminants to naturally settle out or for tank recirculation.

The engine-driven fuel transfer pump is the positive-displacement type. Usually the fuel transfer pump is equipped with a built-in relief valve to ensure constant pressure to the injection equipment. The fuel strainer is located on the suction side of the transfer pump, and the filter is connected into the system on the discharge side of the pump. The pressure drop across these filters and strainers increases with time. Some systems have a relief valve in the line before the cartridge filter so that the bypassed fuel can be returned directly to the supply tank. The relief valve provides a more constant fuel supply pressure.

Fuel Oil (FO) Service Pumps

Essential to the operation of the FO fill and transfer system are the FO service pumps (*Figure 12-5*). Most FO service pumps are rotary, positive displacement pumps, either motor- or steam turbine-driven.

The most common kinds are screw pumps and sliding vane pumps. Positive displacement pumps usually have a good suction lift capability and some tolerance for solid particles in the fluid. Even so, the pump will last longer if it is aligned with the shortest suction runs and pumps the cleanest fuel possible.

Figure 12-5 — Fuel oil (FO) service pump.

Figure 12-6 — Fuel oil (FO) transfer pump.

Fuel Oil (FO) Transfer/Stripping Pumps

Other pumps essential to the operation of the FO fill and transfer system are the FO transfer (*Figure 12-6*), and stripping pumps.

An FO transfer pump takes suction from any storage tank or contaminated oil settling tank and delivers fuel, usually through filtration equipment, to a service tank. Fuel is transferred immediately whenever service tanks require refilling. The transfer system is also designed to allow transfer of fuel between storage tanks. Most ships also have FO stripping pumps installed.

The primary metal-edge fuel strainer used in Navy installations is a duplex type, which is actually two complete strainers connected by a suitable header or piping. This arrangement allows either strainer to be completely cut out of the system for cleaning or repair while all of the fuel flows through the other strainer. *Figure 12-7*, shows a typical metal-edge strainer. A magnified view of a portion of the element is shown in *Figure 12-8*. The fuel flows from the outside to the inside. In Navy-approved strainers, the spaces between the leaves, or ribbons, which act as fuel passages, are between 0.001 and 0.0025 inch. Do not allow the pressure drop across these strainers to exceed 1.5 pounds per square inch (psi) when a fuel flow is equal to the full capacity of the fuel pump. In some engines, a duplex strainer is placed between the fuel supply tank and the transfer pump and, during operation, may be working under a vacuum.

The secondary, cartridge-type, fuel filter contains elements that must conform to Navy specifications. Do not allow the pressure drop across clean and new elements to exceed 4.5 psi. Change the elements when the pressure drop reaches the value specified in the manufacturer's instruction book. Drain the sump of the filters and strainers as often as practicable, preferably when the fuel is flowing.

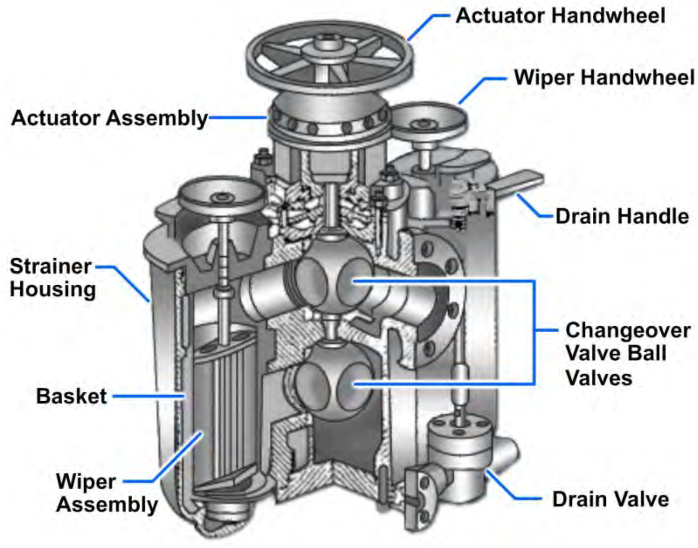

Figure 12-7 — Primary fuel metal-edge strainer.

CENTRIFUGAL PURIFIERS

Detailed instructions are furnished with each purifier concerning its construction, operation, and maintenance. When you are responsible for the operation and maintenance of a purifier, study the appropriate NAVSEA technical manual and follow the instructions carefully. The following sections will provide general information on the methods of purification and the principles of operation of centrifugal purifiers.

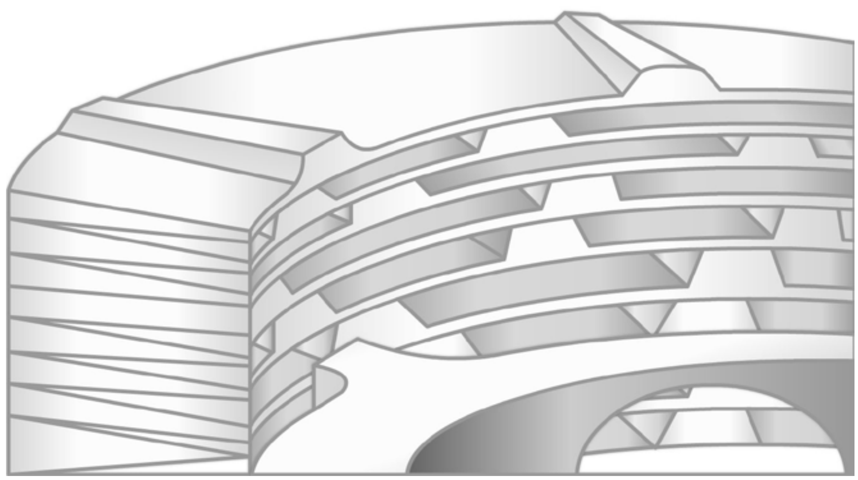

Figure 12-8 — Enlarged section of ribbon in strainer.

Centrifugal purifiers are used for purification of both fuel and lubricating oil. A purifier may remove both water and sediment, or it may remove sediment only. When water is involved in the purification process, the purifier is usually called a separator. When the principal contaminant is dirt or sediment, the purifier is used as a clarifier. Purifiers are generally use d as separators for the purification of fuel. Whether a purifier is used as a separator or a clarifier depends on the water content of the oil that is being purified.

The following general information will help you understand the purification process, the purposes and principles of purifier operation, and the basic types of centrifugal purifiers in use in naval service.

Principles of Operation

In the purification of fuel, centrifugal force is the fundamental principle of operation. Centrifugal force is force exerted upon a body or substance by rotation. Centrifugal force impels the body or substance outward from the axis of rotation.

A centrifugal purifier is essentially a container that is rotated at high speed while contaminated fuel is forced through, and rotates with, the container. However, only materials insoluble in the fuel can be separated by centrifugal force. For example, JP-5 or naval distillate cannot be separated from lubricating oil, nor can salt be removed from seawater by centrifugal force. Water, however, can be separated from fuel because water and fuel do not form a true solution when mixed. There must be a difference in the specific gravities of the materials as it separates from the fuel into three major components based on differences in relative densities. These components are described as (water) the heavy phase, (purified fuel) the light phase, and solids/sludge before they can be separated by centrifugal force. The purifier is basically a motor-driven centrifuge. Rotation at high revolutions, within the bowl assembly, provides the centrifugal force necessary for the purification process. During normal operation, the purifier constantly discharges the heavy phase (water) and light phase (purified fuel). *Figure 12-9* demonstrates the normal operation of a FO purifier.

When a mixture of fuel, water, and sediment stands undisturbed, gravity tends to form an upper layer of fuel, an intermediate layer of water, and a lower layer of sediment. The layers form because of the specific gravities of the materials in the mixture. If the fuel, water, and sediment are placed in a container which is revolving rapidly around a vertical axis, the effect of gravity is negligible in comparison with that of the centrifugal force. Since centrifugal force acts at right angles to the axis of rotation of the container, the sediment with its greater specific gravity assumes the outermost position, forming a layer on the inner surface of the container. Water, being heavier than fuel, forms an intermediate layer between the layer of sediment and the fuel, which forms the innermost layer. The separated water is discharged as waste, and the fuel is discharged to the service tank or the day tank. The solids remain in the rotating unit.

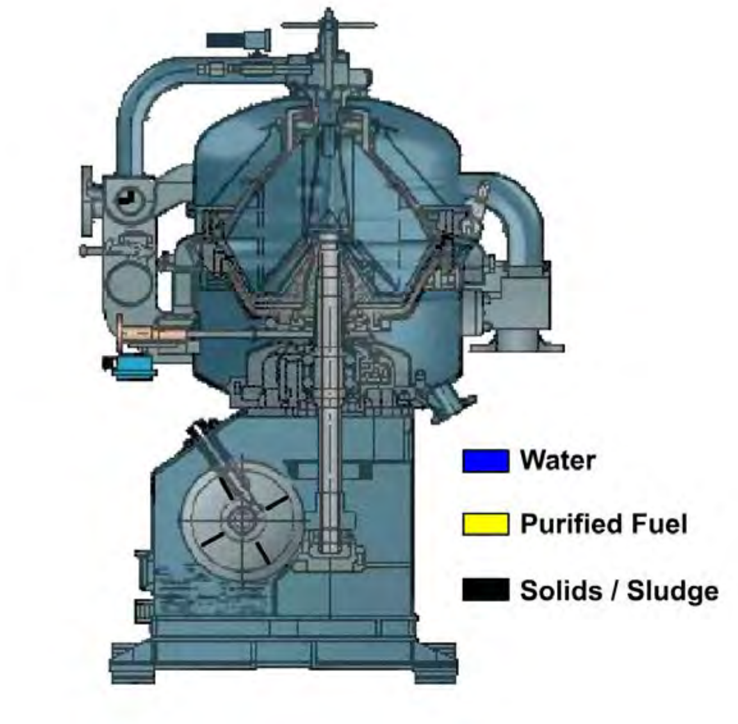

Figure 12-9 — Fuel oil (FO) purifier.

Separation by centrifugal force is further affected by the size of the particles, the viscosity of the fluids, and the time during which the materials are subjected to the centrifugal force. The greater the difference in specific gravity between the substances to be separated and the lower the viscosity of the fuel, the greater will be the rate of separation.

Types of Centrifugal Purifiers

Navy installations use two basic types of purifiers. Both use centrifugal force. Principal differences in these two types are the design of the equipment and the operating speed of the rotating elements. In one type, the rotating element is a bowl-like container that encases a stack of discs. This is the disc-type DeLaval purifier, which has a bowl operating speed of about 7,200 revolutions per minute (rpm). In the other type, the rotating element is a hollow cylinder. This machine is the tubular-type Sharples purifier, which has an operating speed of 15,000 rpm.

Disc-Type Purifier

A sectional view of a disc-type centrifugal purifier is shown in *Figure 12-10*. The bowl is mounted on the upper end of the vertical bowl spindle, which is driven by means of a worm wheel and friction clutch assembly. A radial thrust bearing at the lower end of the bowl spindle carries the weight of the bowl spindle and absorbs any thrust created by the driving action. The parts of a disc-type bowl are shown in *Figure 12-11*.

The flow of fuel through the bowl and additional parts is shown in *Figure 12-9* contaminated fuel enters the top of the revolving bowl through the regulating tube. The fuel then passes down the inside of the tubular shaft, out the bottom, and up into the stack of discs. As the dirty fuel flows up through the distribution holes in the discs, the high centrifugal force exerted by the revolving bowl causes the dirt, sludge, and water to move outward. The purified fuel is forced inward and upward, discharging from the neck of the top disc. The water forms a seal between the top disc and the bowl top it is the dividing line between the water and the fuel. The discs divide the space within the bowl into many separate narrow passages or spaces. The liquid confined within each passage is restricted so that it can flow only along that passage. This arrangement minimizes agitation of the liquid as it passes through the bowl. It also forms shallow settling distances between the discs.

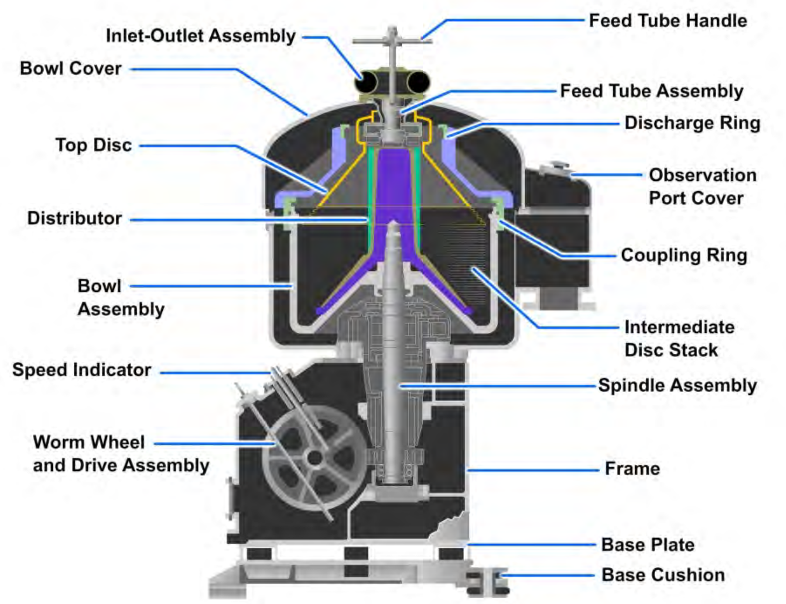

Figure 12-10 — Disc-type centrifugal purifier (DeLaval).

Any water, along with some dirt and sludge, separated from the fuel, is discharged through the discharge ring at the top of the bowl. However, most of the dirt and sludge remains in the bowl and collects in a more or less uniform layer on the inside vertical surface of the bowl shell.

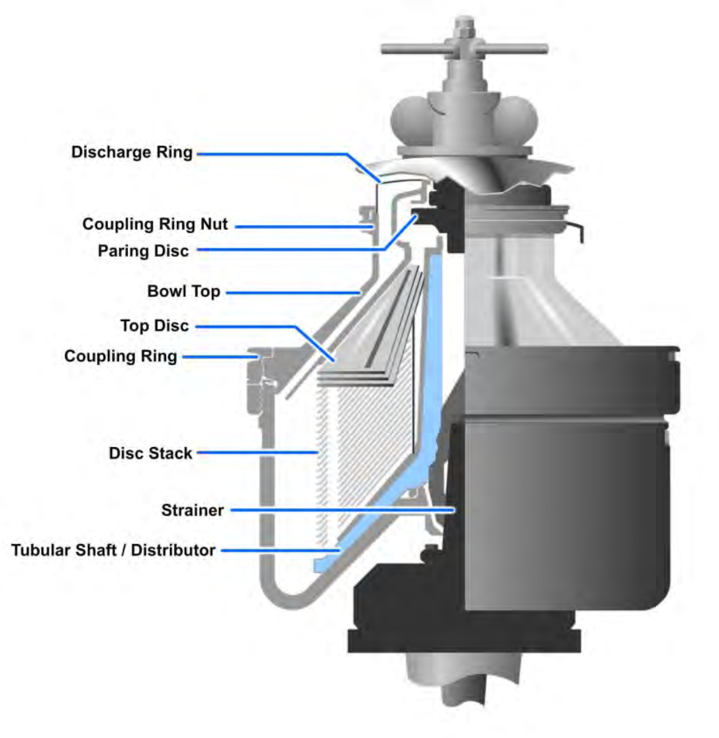

Figure 12-11 — Components of a disc-type purifier bowl (DeLaval).

Tubular-Type Purifier

Figure 12-12 shows a cross section of a tubular-type centrifugal purifier. This type of purifier consists essentially of a hollow rotor or bowl that rotates at high speeds. The rotor has an opening in the bottom to allow the dirty fuel to enter. It also has two sets of openings at the top to allow the fuel and water to discharge. The bowl, or hollow rotor, of the purifier is connected by a coupling unit to a spindle. The spindle is suspended from a ball bearing assembly. The bowl is belt-driven by an electric motor mounted on the frame of the purifier.

The lower end of the bowl extends into a flexibly mounted guide bushing. The assembly restrains movement of the bottom of the bowl, but it also allows the bowl enough movement to center itself during operation. Inside the bowl is a device consisting of three flat plates that are equally spaced radially. This device is commonly referred to as the three-wing device, or just the three-wing. The three-wing rotates with the bowl and forces the liquid in the bowl to rotate at the same speed as the bowl. The liquid to be centrifuged is fed, under pressure, into the bottom of the bowl through the feed nozzle.

After the bowl has been primed with water, separation is basically the same as it is in the disc type purifier. Centrifugal force causes clean fuel, which has the lowest specific gravity, to assume the innermost position, and the higher density water and dirt are forced outward towards the sides of the bowl. Fuel and water are discharged from separate openings at the top of the bowl. The location of the fuel-water interface within the bowl is determined by the size of a metal ring called a ring dam, or by the setting of a discharge screw. The ring dam or discharge screw is also located at the top of the bowl. Any solid contamination separated from the liquid remains inside the bowl all around the inner surface.

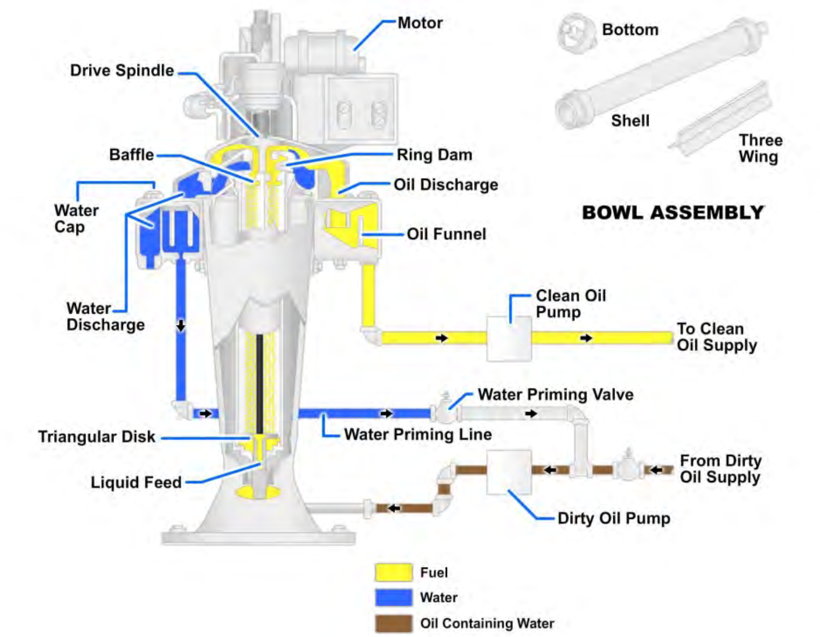

Figure 12-12 — Flow of fuel through a tubular-type purifier (Sharpie's).

Obtain specific instructions for the operation of a purifier from the NAVSEA technical manual provided with the unit. The following general information applies to the basic operation of purifiers in naval service.

When operating a purifier as a separator, prime the bowl with fresh water before admitting any fuel to the purifier. The water seals the bowl, and the spinning bowl creates an initial equilibrium of layers of liquid according to specific gravities. If the bowl is not primed, the fuel will be lost through the water discharge ports.

The time required for purification and the output of a purifier depends on many factors. Two important factors are the size of the sediment particles and the temperature of the incoming dirty fuel. In order for any purifier to operate at its rated capacity in gallons per hour, the fuel must be heated to a specified temperature to reduce the viscosity of the fuel. A lower viscosity does two things:

1. It lowers the specific gravity.
2. It enables the fuel more easily to give up any water which may be entrained.

The viscosity of the fuel determines to a great extent the length of time required for purification. The more viscous the fuel, the more time is required for the fuel to be subjected to centrifugal force. Decreasing the viscosity of the fuel by heating will speed up the purification process and increase the capacity of the purifier. To reach a higher temperature, the fuel must pass through a heater. The fuel will reach the proper temperature in the heater before it enters the purifier bowl.

Proper care of any fuel purifier requires that the bowl be cleaned as required and that all sediment be carefully removed. How often you clean a purifier depends on the amount of foreign matter in the fuel to be purified. If the amount of foreign matter in a fuel is not known, shut down the machine and check it. The amount of sediment found in the bowl at this time will indicate how often to clean the purifier.

Detailed procedures for operating and maintaining purifiers are furnished by NAVSEA technical manuals, Planned Maintenance System (PMS), and the Engineering Operational Sequencing System (EOSS). Carefully follow these written procedures when you are operating or performing maintenance on purifiers.

It should be obvious from the preceding information that the purpose of the external fuel system is to store and deliver clean fuel to the fuel injection equipment.

FUEL INJECTION SYSTEMS

The fuel injection equipment used on Navy diesel engines is the mechanical type. Some engine manufacturers make and install their own fuel injection equipment. Others rely on other manufacturers who specialize in fuel injection equipment and who design and modify their products to meet the requirements of the engine manufacturer. This equipment will vary in construction and method of forcing fuel into the combustion chamber; however, in every case, the fuel injection equipment for any diesel engine must accomplish several basic functions.

Functions

The five general functions that fuel injection equipment must accomplish are metering the fuel, injecting the fuel, timing the injection process, atomizing the liquid fuel, and creating pressure for dispersion of the fuel. You can easily recall these functions by remembering the initials MITAC. All five functions are required for effective combustion of fuel in the cylinders of a diesel engine. Now we will discuss the role of each of these factors and how they all work together.

Metering

Accurate metering, or measuring, of fuel means that for a given engine speed, setting, and load, the same quantity of fuel must be delivered to each cylinder just before each power stroke of the engine. If this does not happen, engine speed will be erratic and the horsepower output of the engine will not be uniform. Smooth engine operation and even distribution of the load between cylinders requires that the same amount (volume) of fuel is delivered to a particular cylinder each time it fires and that equal volumes of fuel are delivered to all cylinders of the engine.

Injecting

The fuel system on the engine must control the rate of injection, which, in turn, determines the rate of combustion. The rate of fuel injection at the start must be low enough so that excessive fuel does not accumulate in the cylinder during the first phase (physical) of injection delay (before combustion begins). Injection should then proceed at such a rate that the rise in pressure in the combustion chamber is not too great.

The rate of fuel injection must be such that the fuel is introduced as rapidly as possible to obtain complete burning of the fuel-air mixture. An incorrect rate of injection affects engine operation in the same way as improper timing. When the rate of injection is too high, the symptoms are similar to those caused when fuel injection is too early. When the fuel injection rate is too low, the symptoms are similar to those caused when fuel injection is too late.

Timing

In addition to measuring the amount of fuel and rate of fuel injection, the fuel injection equipment must cause these events to occur at the proper time. Correct timing is vital to ensure that complete combustion takes place and that maximum energy is obtained from the fuel. (The engine develops rated horsepower for each pound of fuel burned.) When fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air charge in the cylinder is not high enough, late injection results in rough, noisy operation of the engine.

Noisy engine operation occurs when the engine cannot convert as much energy from the fuel into the horsepower required moving the load. Late injection permits some fuel to be wasted by wetting of the cylinder walls and piston crown. This condition, of course, results in poor fuel economy, higher than normal exhaust gas temperatures, and smoky exhaust.

Atomizing

Shortly before the top of the compression stroke, at a point controlled by the mechanical injection timing arrangement, one or more jets of fuel are introduced into the combustion chamber. As explained previously, ignition of fuel does NOT occur immediately on injection. The fuel droplets absorb heat from the compressed air swirling around the combustion chamber. This process is necessary because it causes the liquid fuel to vaporize so it can burn! The duration of the second phase (chemical) of ignition delay is controlled by the design (shape) of the combustion chamber, fuel and air inlet temperatures, degree of atomization of the fuel, and the quality of the fuel. When the fuel-air mixture reaches a temperature at which self-ignition occurs, the flame begins to spread. Injection of the remaining volume of fuel for the cylinder continues during this time. The ignition delay period must be short to avoid diesel knock can be avoided.

Once the flame has been completely initiated, the fuel delivered to the cylinder is injected into the burning mixture. This fuel vaporizes and burns almost instantaneously. This process is the third phase of fuel injection. Liquid fuel must be injected into each cylinder in the form of a fine spray. Proper atomization increases the surface area of the fuel, which must be exposed to oxygen molecules in the air so that complete burning of the fuel can take place and the rated horsepower can be developed. To avoid simultaneous combustion of all droplets of the fuel spray (detonation), the injected spray is usually in the form of fine droplets to start ignition (beginning of second phase) and larger droplets later in the phase. The degree of atomization of the fuel is controlled by the diameter and shape of the nozzle orifice(s) or opening(s), injection pressure, and the density of the air charge in the combustion chamber.

Creating Pressure

The quality (volume) of fuel, and the rate at which the fuel is injected into the cylinders of an engine is controlled by fuel injection equipment. The fuel injection equipment also controls the timing and duration of the injection event. At the beginning of injection, fuel pressure may be from as low as 1800 psi to as high as 30,000 psi, depending upon the design of the equipment. The fuel injection equipment must raise the pressure of the fuel enough to overcome the force of the compressed air charge in the combustion chamber and ensure proper dispersion (distribution) of the fuel being injected into the combustion space. Proper dispersion of the atomized fuel in the air charge is an important factor for complete combustion to take place. Dispersion of the fuel is affected, in part, by the atomization process and the penetration of the fuel, which determines the distance through which the fuel droplets travel after leaving the injector tip or nozzle. If the atomizing process results in fuel droplets that are too small, they will not have sufficient weight to penetrate very far into the air charge. Too little penetration results in the fuel igniting and burning before it is properly dispersed through the air charge in the combustion space. Since penetration and atomization tend to oppose each other, a compromise in the degree of each is necessary in the design of the fuel injection equipment.

Fuel Injection Equipment

Three methods are commonly used for the mechanical injection of fuel (at the proper amount, time, and duration) into the cylinders of a diesel engine.

1. Jerk pump fuel injection system
2. Distributor fuel injection system
3. Unit fuel injector system

Jerk Pump Fuel Injection System

Jerk pump fuel injection systems consist of high pressure pumps and pressure-operated spray valves or nozzles that are separate components. In some engines, there is only one pump and one nozzle for each cylinder. In other engines, each cylinder has two pumps and two nozzles. The pump itself carries out most of the injection event. The pump raises pressure, meters the fuel, and times the injection. The nozzle is simply a spring-loaded check valve that reacts to the pressure supplied from the high pressure pump.

> **NOTE**
>
> A major manufacturer of jerk pump fuel injection systems is the American Bosch company. The system may use either of two different types of pumps, designated APF or APE. The letter F in APF identifies a pump that does not have its own drive, and the letter E in APE indicates a pump with a self-contained drive.

Bosch APF Pump

Type APF pumps are of the single-cylinder design with the plunger pump for each cylinder contained in separate housing *Figure 12-13*. In a 6-cylinder engine, there are six separate APF pumps. Each pump is cam driven and fuel volume is regulated by the setting of the control rack.

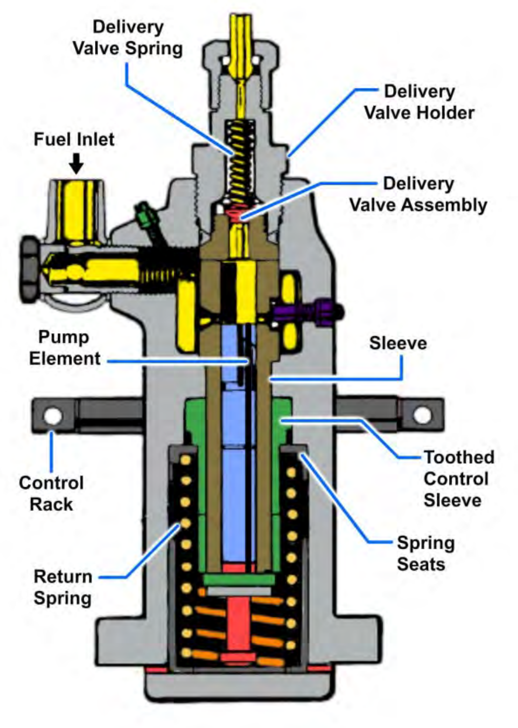

Figure 12-13 — Type APF single cylinder, fuel injection pump.

Bosch APE Pump

Figure 12-14, view A and B, illustrate a typical Bosch APE fuel injection pump. Type APE pumps are assembled with all the individual cylinder plungers in a single housing. *Figure 12-14, view A*, shows a typical fuel supply system. *Figure 12-14, view B*, shows the pump assembly for a 6-cylinder engine. The injection pumps are operated from a single camshaft in the bottom part of the housing. The cam lobes are arranged so that the firing order is consistent with the engine firing order. Each revolution of the camshaft provides one fuel charge from each outlet.

Although our discussion will be on the APE pump system, the APF pump operates on the same principles. The information on the pumping principle, metering principle, and delivery valve operation also applies to the APF pump.

General Operating Principles

Figure 12-14, views A and B, refer to the operating principles of the APE pump system. Refer to *Figure 12-14, view A and B*; follow the letters in parenthesis in the explanation of the operation of the system.

The supply pump (C) is a plunger-type, cam activated pump that is equipped with inlet and outlet check valves and a hand-priming pump (D). The supply pump draws fuel from the fuel tank (A) through a primary filter (B) and discharges the fuel to a final stage filter (E). An arrow is stamped on the supply pump housing to indicate the direction of fuel flow. From the final stage filter, the fuel then flows into the injection pump sump (fuel gallery) which provides all six plunger and barrel assemblies with fuel. An overflow valve assembly (H), which regulates and maintains the pump sump (gallery) pressure, is attached to the injection pump housing (G). The overflow valve assembly also permits any air in the system to work its way out and return to the fuel tank.

When the pump plunger is in its lowest position, fuel from the sump (gallery) enters the barrel ports and fills the volume above the plunger. The upward movement of the plunger (through cam action) seals off the barrel ports and forces fuel (now under high pressure) through the delivery valve assembly and high pressure tubing (J) to the holder and nozzle assembly (K).

Fuel enters the nozzle holder inlet flows through passages to the nozzle which contains a spring-loaded valve. Fuel pressure exerts a force against the lower end of the valve, which is opposed by the spring force. At a preset pressure, the spring force is overcome and the valve rises, thus permitting the fuel to flow through the nozzle spray holes (orifices) and into the combustion chamber.

The slight fuel leakage between the nozzle valve and body (required for nozzle lubrication) is returned to the fuel tank through a leak-off line. Normally, the nozzle leak-off line is connected to the pump return line; thus both are returned to the fuel tank in a single line.

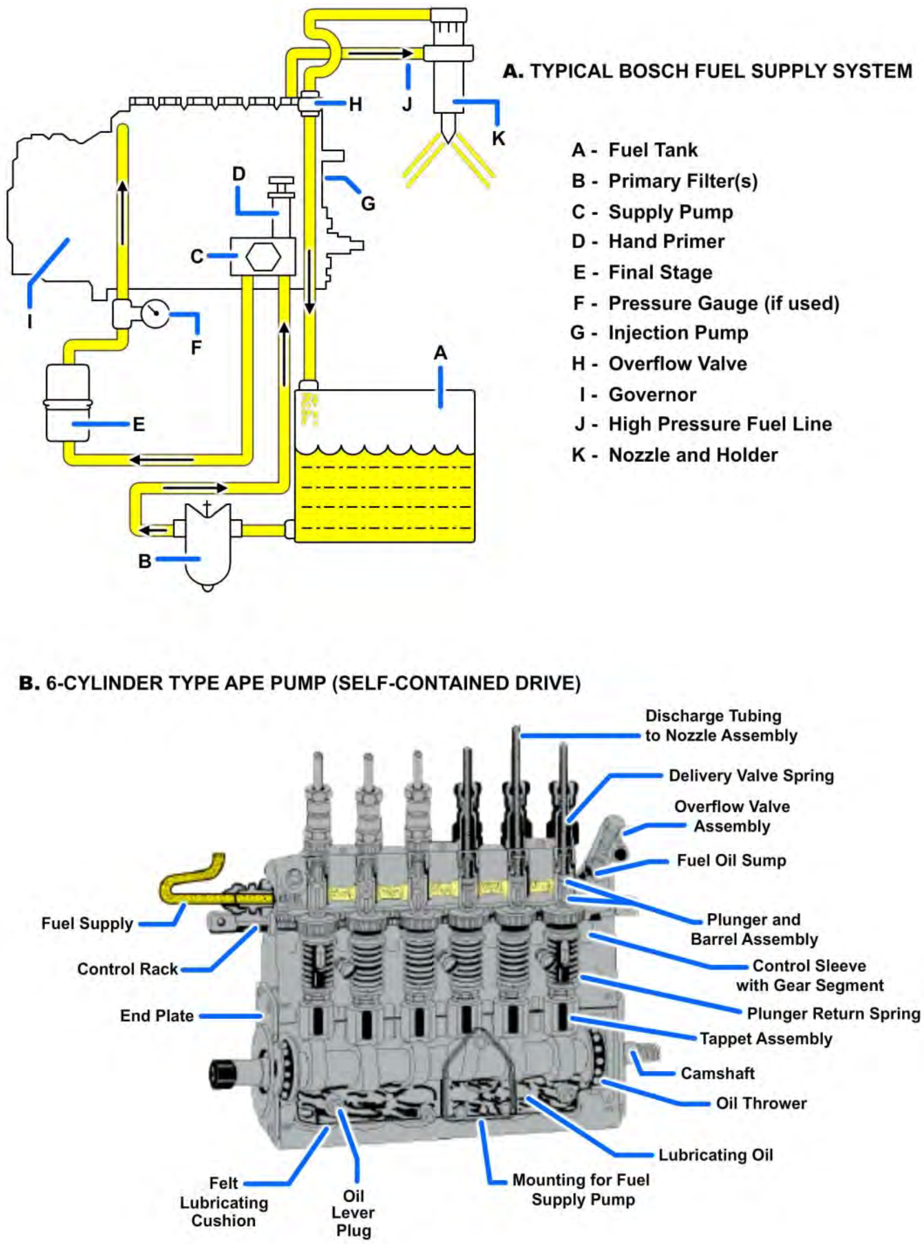

Figure 12-14 — Bosch APE fuel supply system and fuel injection pump.

Pumping Principle

We will first discuss the pumping principle behind the action of the APE fuel pump, *Figure 12-15, frames 1 through 4*. Refer to *Figure 12-15, frame1, w*hen the plunger is at the bottom of its stroke, fuel from the pump sump flows through the barrel ports and fills the volume above the plunger. The sump fuel initially fills the vertical slots and connecting cutaway areas of the plunger.

Upward movement of the plunger seals off the barrel ports, trapping fuel in the barrel (*Figure 12-15, frame 2)*. The additional upward movement of the plunger, *(Figure 12-15, frame 3*) forces fuel through the delivery valve and finally to the combustion chamber. Fuel delivery will stop when the plunger helix uncovers the barrel port (*Figure 12-15, frame 4*). This action releases the trapped fuel through the slot in the plunger and out through the barrel ports.

Metering Principle

Refer to *Figure 12-16, views A through C*, as you read how the fuel is metered and controlled. Movement of the speed governor output shaft, which is attached to the rear of the pump housing, automatically controls the positioning of the helix. The governor, through linkages, positions the control racks that rotate the segment gears and control sleeves, which, in turn, radially position the plunger flange and helix. The fuel control rod (rack) teeth engage the plunger gear teeth to control fuel metering. Lateral movement of the fuel rack causes the plungers to rotate. This action, in turn, determines the effective stroke of the plunger by the plunger helix position in relation to the barrel port.

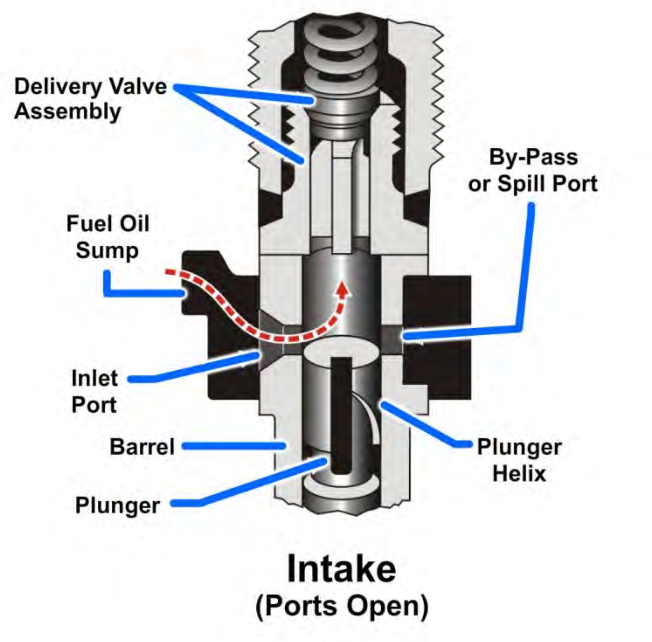

Figure 12-15 — Pumping principles of an APE pump.

The position of the plunger helix controls the amount of fuel delivered. When the plunger is rotated to the position illustrated in *Figure 12-16, view A*, the effective part of the stroke (that position of the stroke from the closing of the barrel ports by the top of the plunger to the point where the edge of the helix raises above the barrel ports) is long, and fuel delivery is at a maximum. When the plunger is rotated to the position shown in *Figure 12-16, view B*, the effective part of the stroke is reduced since the helix will uncover the barrel ports sooner (at a lower position). This action reduces the volume of fuel delivered to the cylinder. When the vertical slot on the plunger is in line with one of the barrel ports, as illustrated in *Figure 12-16, view C*, there is no effective stroke and therefore no fuel delivery.

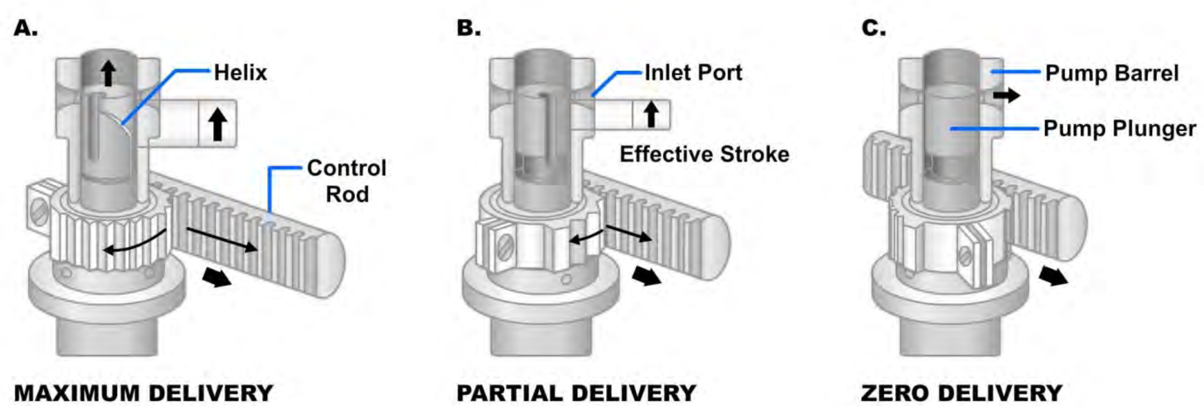

Figure 12-16 — Effects of plunger rotation on fuel delivery (metering principle).

Delivery Valve Operation

As we discuss the delivery valve operation of the APE pump, refer to *Figure 12-17.* The delivery valve assembly is located directly above the plunger. The delivery valve assembly assists the injection function by preventing irregular losses of fuel from the delivery to the supply side of the system between pumping strokes.

The delivery valve assembly consists of a valve with a conical seat and a valve body with a corresponding mating seat. Opening pressure is controlled by the force of the delivery valve spring that engages the top of the valve.

Since liquid fuel trapped in the barrel is essentially incompressible, pressure is created after the plunger, on its upward stroke, closes off the barrel ports. When this hydraulic pressure overcomes the force of the delivery valve spring, the valve opens and fuel passes through it into the injection tubing.

When the edge of the plunger helix passes the lower edge of the barrel port, there is a rapid drop in fuel pressure below the delivery valve (*Figure 12-17, view A*), and the force of the valve spring, combined with the high differential in pressure, begins to return the valve to its seat.

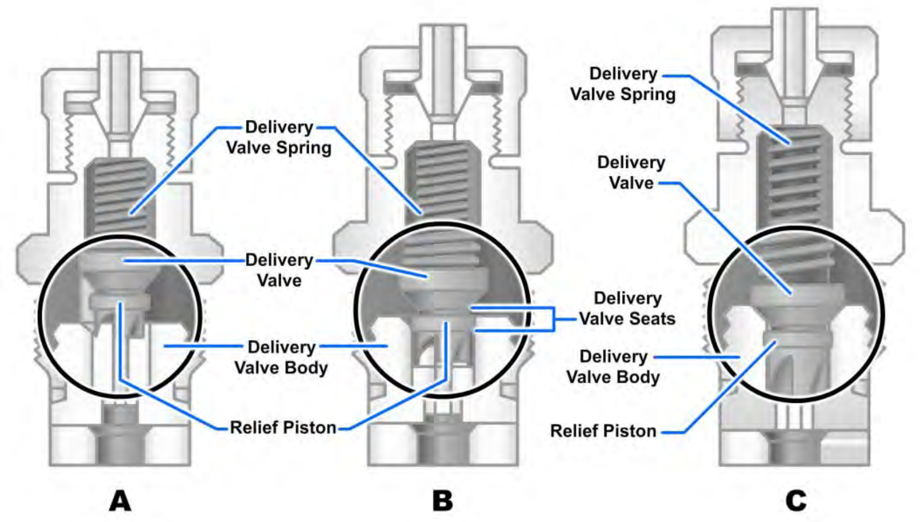

Figure 12-17 — Delivery valve in three positions.

As the valve starts downward into the valve body (*Figure 12-17, view B)* the lower edge of its retraction piston enters the valve bore. At that moment, the flow of fuel by the delivery valve stops. In *Figure 12-17, view C*, the continued downward movement of the valve (retraction piston) increases the volume on the high pressure side by the amount of the piston retraction (its displacement volume) and, consequently, reduces the residual pressure in the injection tubing and nozzle holder. This lower pressure promotes rapid closing of the injection nozzle valve and diminishes the effect of hydraulic pressure waves that exist in the tubing between injections, thereby minimizing the possibility of the nozzle reopening (a secondary injection) before the next regular delivery cycle.

Plungers

Plungers include three different types of helixes: a lower helix, an upper helix, and both an upper and a lower helix. (The shape and the position of the helix governs the fuel delivery curve, the beginning or ending of injection, or both the beginning and ending of injection.) For the lower helix plunger (*Figure 12-18, frame 1*) the effective stroke (injection) always begins at the same time, regardless of where the plunger is rotated because the top end that closes the ports is flat. The end of injection can be varied because of the sloping design of the helix. Injection has a constant beginning and a variable ending. This type of plunger is used in pumps marked “timed for port closing”.

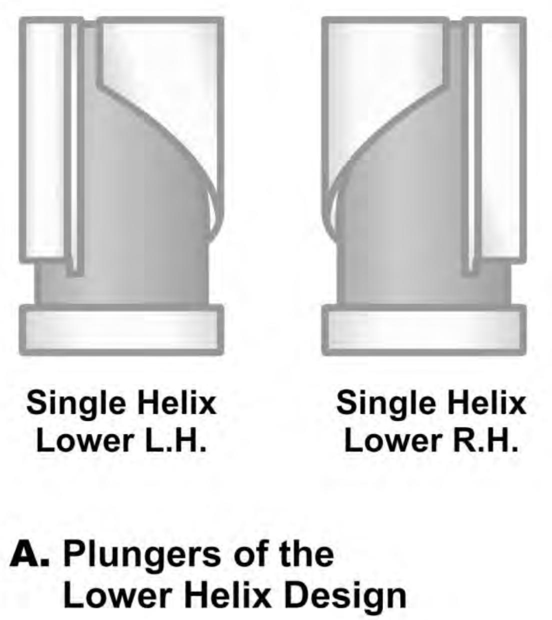

Figure 12-18 — Plunger types.

For the upper helix plunger (*Figure 12-18, frame 2*) the beginning of the effective stroke varies as the plunger is rotated because the top edge, which closes the ports, is sloping. Thus, the beginning of delivery is variable and the ending is constant. Plungers of this type are used in pumps marked “timed for port opening”.

Third type of plunger (*Figure 12-18, frame 3*) has a variable beginning (upper helix) and a variable ending (lower helix) design. Rotation of this type of plunger varies both the beginning and the ending of delivery of the fuel.

Distributor Fuel Injection System

In our discussion of the distributor fuel injection system, we will use the DPA type for our example because of its wide use on Navy small craft. The DPA pump is a compact unit that is lubricated throughout by fuel and requires no separate lubrication system. It contains no ball or roller bearings, gears, or highly stressed springs. Sensitive speed control is maintained by governor that is either mechanically or hydraulically operated within the pump itself.

Design and Components

In the DPA distributor type of injection pump, the fuel is pumped by a single element. The fuel charges are distributed in the correct firing order by a rotary distributor integral with the pump. Equality of delivery to each nozzle is an inherent feature of the pump. Since the timing interval between injection strokes is determined by the accurate spacing of the distribution ports and the operating cams do not have to be adjusted, accurate timing of delivery is also an inherent feature of the pump.

There is a central rotating steel member known as the pumping and distributing rotor. The rotor is a close fit in a stationary steel cylindrical body, called the hydraulic head. The pumping section of the rotor has a transverse bore containing two opposed pump plungers. These components rotate inside a cam ring in the pump housing and operate through rollers and shoes sliding in the rotor. The cam ring has as many internal lobes as the engine has cylinders. The opposed plungers have no springs but are moved outward hydraulically by fuel pressure.

The pumping and distributing rotor is driven by splines from a drive shaft. At its outer end, the rotor carries a vane-type fuel transfer pump. With a piston-type regulating valve housed in the end plate, the transfer pump serves to raise the pressure of the fuel to an intermediate level, known as the transfer pressure.

Operation

The DPA pump is driven at half engine speed. As the rotor turns, a charging port in the rotor aligns with the metering port in the hydraulic head. Fuel at metered pressure then flows into the central passage in the rotor and forces the plungers apart. The amount of plunger displacement is determined by the amount of fuel that can flow into the element while the ports are aligned. The fuel inlet port closes as rotation continues. As the rotor turns, the fuel remains isolated into the rotor. As the single distributor port in the rotor comes into alignment with one of the outlet ports in the hydraulic head, the action of the cam forces the plungers quickly together. At this point, high pressure is generated, and the pressurized fuel passes via a high pressure line to an injector. From the injector, the fuel passes to the engine combustion chamber. This entire cycle of operation is repeated once for each engine cylinder per pump revolution.

Injection Nozzles

An injection nozzle assembly serves to position the nozzle accurately in the engine cylinder. An injection nozzle assembly will contain the necessary spring and pressure adjustment means to provide for the proper action of the nozzle valve. An injection nozzle assembly will also provide a means by which fuel can be conducted the nozzle and the combustion chamber of the engine. Although manufacturers produce a wide variety of nozzles to meet the requirements of several different combustion systems and engine sizes. There are essentially two basic groups of injection nozzles: the pintle nozzles and the hole nozzles.

Refer to the cutaway sectional view of a Bosch injection nozzle assembly in *Figure 12-19*. Notice the details of the nozzle holder and the pintle-type nozzle. The high pressure fuel from the injection pump enters the nozzle holder body through a metal-edge strainer. From the strainer, the fuel goes through a drilled fuel passage that extends to the bottom of the nozzle holder body. The nozzle, with its spray tip, is held against the bottom of the nozzle holder by the cap nut. A groove in the top of the nozzle forms a circular passage for the fuel between the nozzle and the holder (*Figure 12-20*).

Several vertical ducts (*Figure 12-19),* carry the fuel from the circular passage to the fuel cavity, near the bottom of the nozzle. The nozzle valve cuts in sharply to a narrower diameter in the fuel cavity, providing a surface against which the high pressure fuel in the fuel cavity can act to raise the valve from its seat in the spray tip. When the valve is raised from its seat, the fuel sprays out to the combustion chamber through a ring of small holes (hole nozzle), or around the pintle and out through the single hole (pintle nozzle).

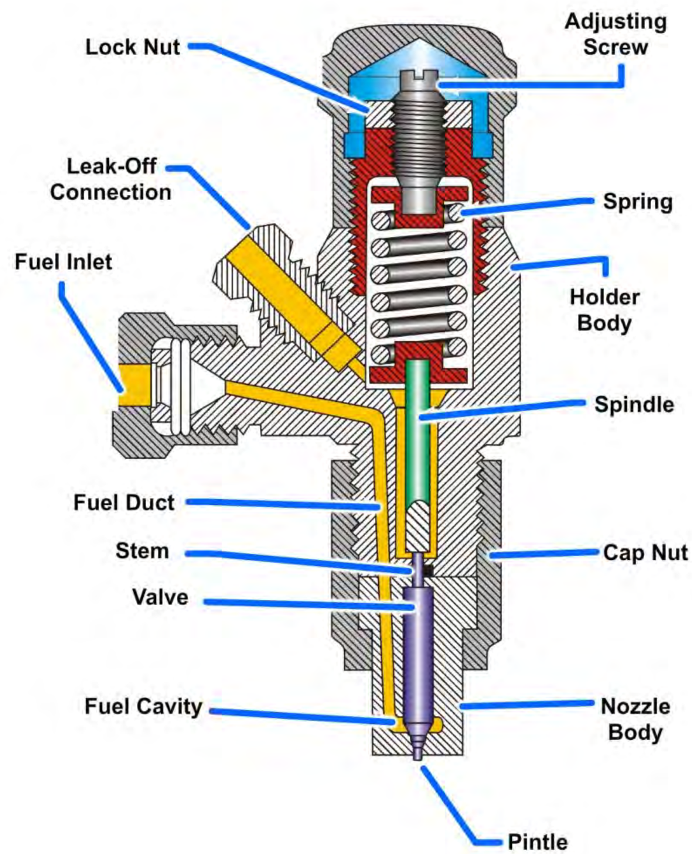

Figure 12-19 — Sectional view of a Bosch injection pintle-type nozzle assembly.

The valve has a narrow stem that projects into the central bore of the nozzle holder where it bears against the bottom of the spindle. The spindle is held down by the pressure-adjusting spring. Whenever the upward force of the high pressure fuel acting on the needle valve exceeds the downward force of the spring, the valve can rise. The moment the spring force is greater, the valve will snap back to its seat. The spring tension is regulated by a pressure-adjusting screw or shims.

Regardless of the close-lapped fit of the valve, some fuel will leak past the valve and rise through the central bore of the nozzle holder. This fuel lubricates the moving parts and carries away heat from the injector. The bypassed fuel then drains off through the fuel drain connection to a drip tank. There is a bleeder screw that can serve to bypass fuel to the nozzle, sending the fuel directly to the fuel drain.

The pintle nozzle and the hole nozzle are compared in *Figure 12-20, views A and B.*

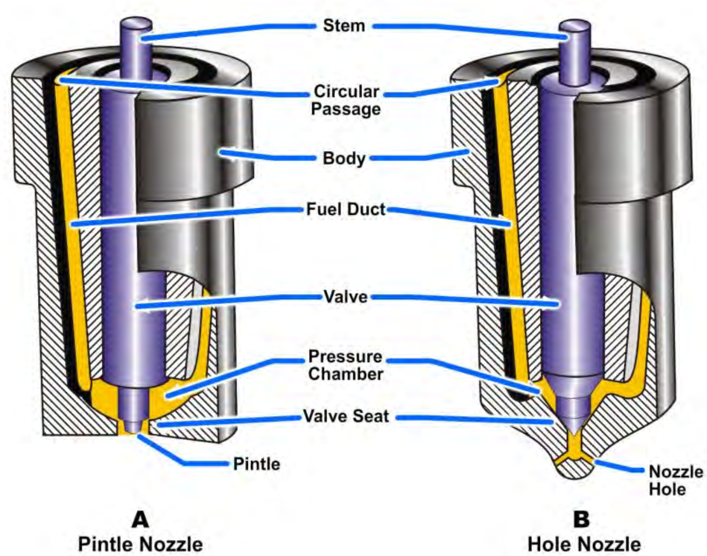

Figure 12-20 — Pintle nozzle and hole nozzle.

Pintle Nozzle

As illustrated in *Figure 12-20, view A*, the valve of the pintle nozzle has an extension that protrudes through the hole in the bottom of the nozzle body and produces a hollow cone-shaped spray. The included angle of the spray cone may be up to a maximum of 60 degrees, depending on the type of combustion chamber in which it is used. A pintle nozzle generally opens at a lower pressure than the pressure at which the hole nozzle opens because fuel flows more readily from the large hole of the pintle nozzle. Although atomization of the fuel is not as complete in the pintle nozzle as it is in the whole nozzle, penetration into the combustion space is greater. Pintle -type nozzles are used in engines having pre-combustion, divided, air cell, or energy-cell combustion chambers, in which mixing of fuel and air is largely dependent on combustion reaction or turbulence. The motion of the pintle tends to inhibit the formation of carbon crust on the tip of the nozzle.

Multiple-Hole Nozzle

The multiple-hole nozzle (*Figure 12-20, view B),* provides good atomization but less penetration than the pintle nozzle. The multiple-hole nozzle is used with the open type of combustion chamber, in which high atomization is more important than penetration. The spray pattern of the hole nozzle is dependent on the number and placement of the holes or orifices.

Spray openings, or orifices, are from 0.006 inch to about 0.033 inch in diameter, and their number may vary from 3 to as many as 18 for large bore engines. Regardless of design, all nozzles and tips function to direct the fuel into the cylinder in a pattern that will bring about the most efficient combustion. Obviously, the slightest defect in nozzles and tips will have an adverse effect on engine operation.

Unit Fuel Injector System

Unlike the design of the other two fuel injection systems, the unit injector provides each cylinder with its own high pressure pump. The unit injector design eliminates the need for a remotely located high pressure pump and high pressure external fuel lines, such as those used in the systems we have covered in the preceding sections. The unit fuel injector (UFI) is complete with pumping and timing element, fuel control, and injection valve spray tip assembly to control the quantity, rate, and timing of fuel delivery. The UFI is used on all General Motors engines; therefore, there are various models available to meet the needs of the engines. Our discussion will cover the two most commonly used types:

- Crown valve
- Needle valve injector

The crown valve injector shown in *Figure 12-21* was placed in service in 1953 and is still in use within the Navy. In 1962, the needle valve injector incorporating a new tip design was introduced (*Figure 12-22*). The needle valve injector provides for improved economy and emissions by increased pop pressure (2300 to 3300 psi for the needle valve injector compared with 450 to 850 psi for the crown valve injector) and a more precise method of fuel control than the crown valve type of unit injector.

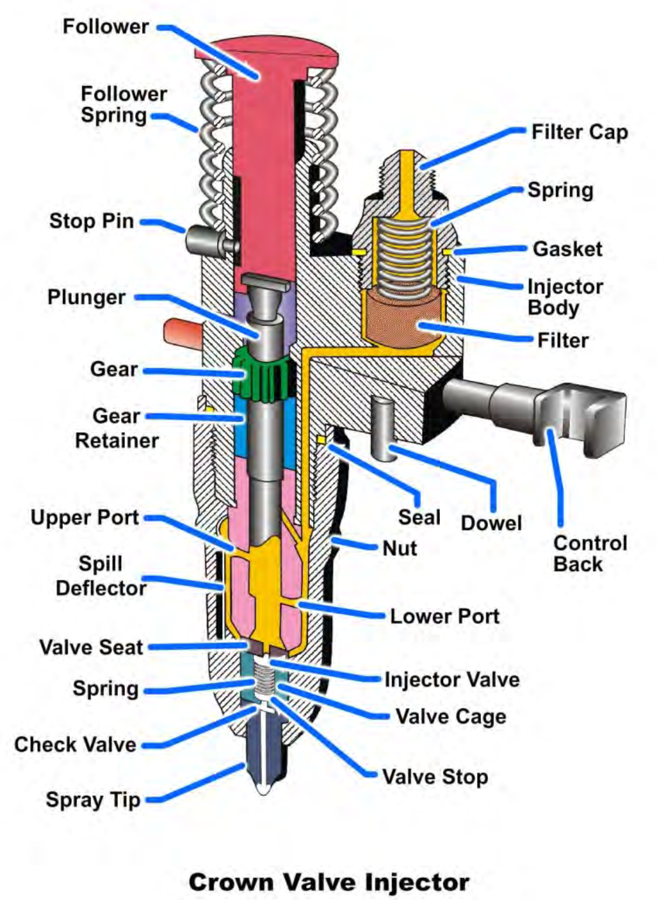

Figure 12-21 — Cutaway view of a crown valve injector.

Design and Components

The unit injector is installed in the cylinder head, as shown in *Figure 12-23*. It is held in place by an injector clamp. The cylinder head has a copper tube into which the injector fits snugly with the spray tip projecting slightly into the cylinder clearance space. Water circulates around the copper tube and cools the lower part of the injector. Two fuel lines are connected to each injector; one carries fuel to the injector and the other carries away the fuel that is bypassed. The injector is operated by a rocker arm and push rod assembly, which work off the camshaft. The amount of fuel injected is regulated by the control rack, which is operated by a lever secured to the control tube.

Operation

Fuel, under pressure, enters the injector at the inlet side through a filter cap and filter. From the filter, the fuel passes through a drilled passage into the supply chamber, the area between the plunger bushing and the spill deflector, in addition to that area under the injector plunger within the bushing. The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the annular ring-shaped chamber by two funnel-shaped ports in the plunger bushing.

The motion caused by the injector rocker arm is transmitted to the plunger by the follower, which bears against the follower spring (*Figure 12-22*). The reciprocating up-and down motion of the plunger can also rotate around its own axis by the gear, which meshes with the control rack. For the metering of the fuel, an upper helix and a lower helix are machined in the lower part of the plunger. The relation of the helices to the two fuel ports will change as the rotation of the plunger changes.

As the plunger moves downward (due to the force of the injector rocker arm), a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port. This action will occur until the port is closed off by the lower end of the plunger. A portion of the fuel trapped below the plunger is then forced up through a central passage in the plunger into the fuel metering recess and into the supply chamber through the upper port until that port is closed off by the upper helix of the plunger. As seen in

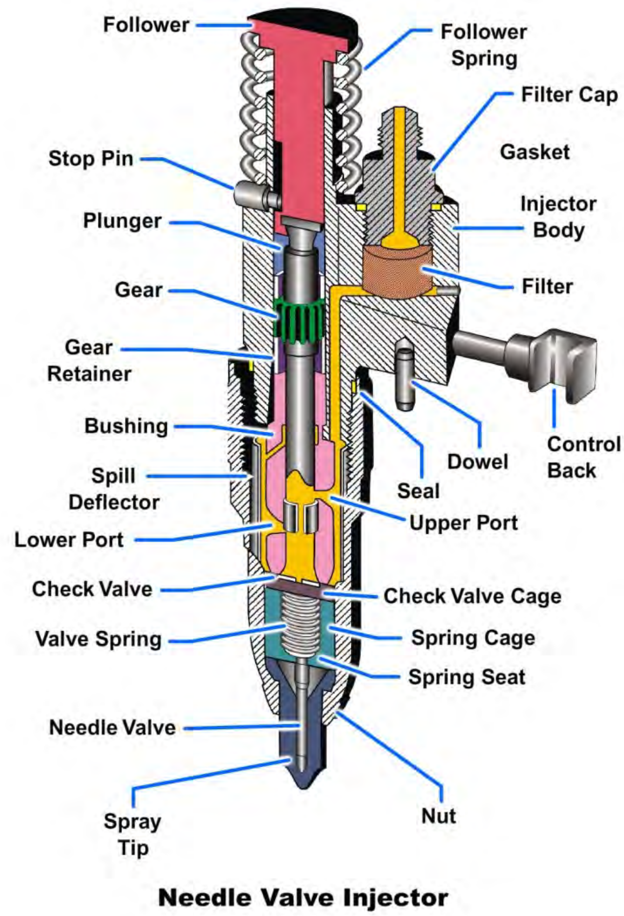

Figure 12-22 — Cutaway view of a needle valve injector.

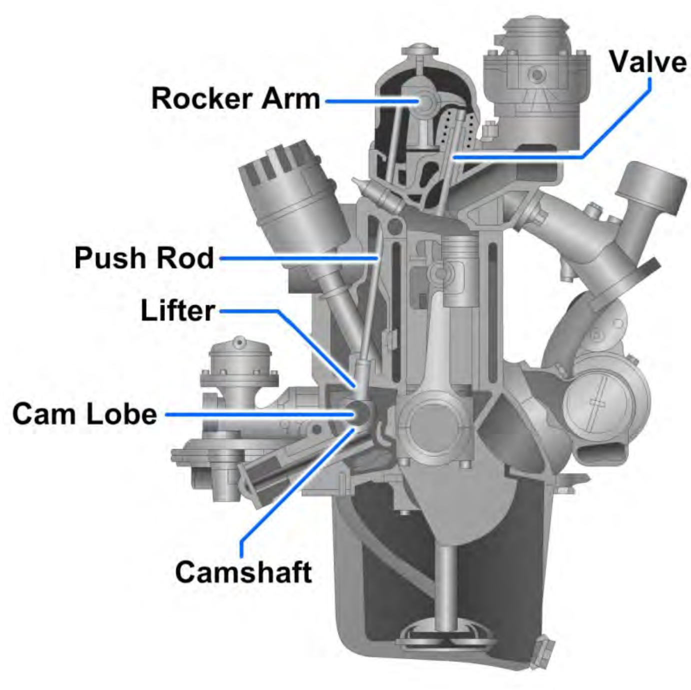

Figure 12-23 — Fuel injector mounting.

Figure 12-22, with the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to increased pressure by the continuing downward movement of the plunger.

When sufficient pressure builds up, the flat check valve opens. The fuel in the check valve cage, spring cage, tip passages, and tip fuel cavity is compressed until the force of the pressure acting upward on the needle valve is sufficient to open the valve against the downward force of the valve spring. As soon as the needle valve lifts off its seat, as illustrated in *Figure 12-22,* (or as soon as the injector valve is lifted off its seat, as illustrated in *Figure 12-21*), the fuel is forced through the small orifices in the spray tip and atomized into the combustion chamber. When the lower land of the plunger uncovers the lower port in the bushing, the fuel pressure below the plunger is relieved. The valve spring then closes the needle valve (or injector valve), and injection stops. A pressure relief passage is provided in the spring cage. This passage permits any bleed-off of fuel that may leak past the needle pilot in the tip assembly. The check valve, located directly below the bushing (the needle valve in *Figure 12-22*), or mounted in the spray tip (the crown valve in *Figure 12-21*), prevents leakage from the combustion chamber into the fuel injector in case the valve is accidently held open by a small particle of dirt. The injector plunger is then returned to its original position by the injector follower spring.

Figure 12-24 shows the various phases of injector operation indicated by vertical travel of the injector plunger. On the return upward movement of the plunger, the high pressure cylinder within the bushing is again filled with fuel through the ports. The constant circulation of fresh, cooler fuel through the injector renews the fuel supply in the chamber, helps carry heat from the injector, and effectively removes all traces of air that might otherwise accumulate in the system and interfere with accurate metering of the fuel. The fuel injector outlet opening, through which the excess fuel returns to the fuel return manifold and then back to the fuel tank, is directly adjacent to the inlet opening.

A change in the position of the helices by rotation of the plunger retards or advances the closing of the ports and the beginning and ending of the injection period. At the same time, a change in the position of the helices increases or decreases the amount of fuel injected into the cylinder. With the control rack pulled out all the way (no injection, as shown in *Figure 12-24, view A)*, the upper port is not closed by the helix until after the lower port is uncovered. Consequently with the rack in this position, all of the fuel is forced back into the supply chamber and no injection of fuel takes place. With the control rack pushed all the way in (full injection), the upper port is closed shortly after the lower port has been covered, and a maximum effective stroke and maximum injection is produced. From this no injection position *Figure 12-24, view A* to the full injection position (full rack movement *Figure 12-24, view D)*, the contour of the upper helix advances the closing of the ports and the beginning of injection.

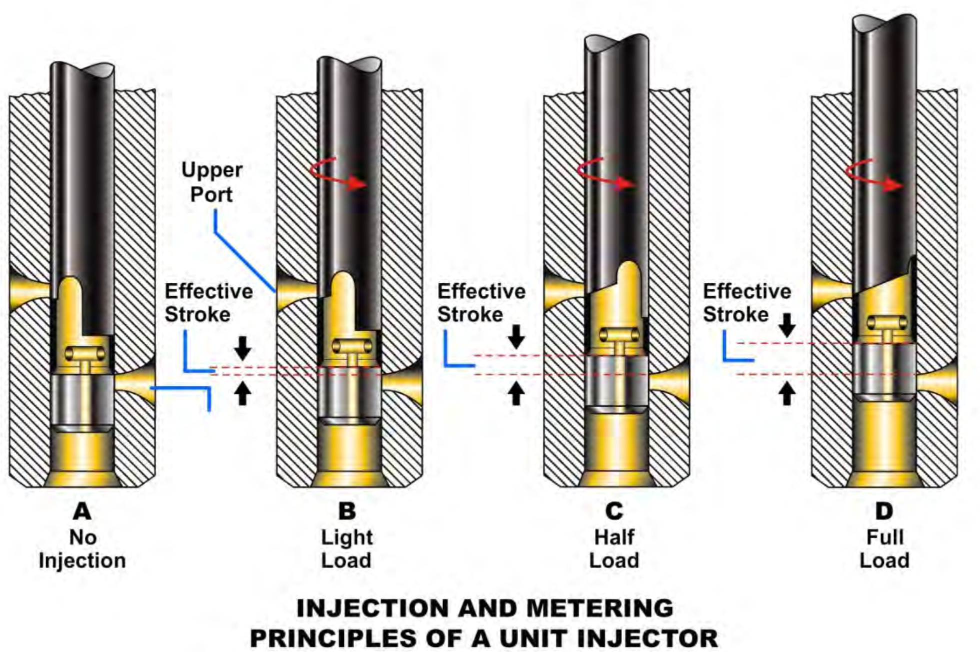

Figure 12-24 — Injection and metering principle of a unit injector.

The importance of fuel purity in any injection system cannot be overstated. The unit injectors have spray tip holes as small as 0.005 inch. Pressures of approximately 20,000 psi are developed by a combination of spray hole area restriction and plunger/bushing design. Typically, the plunger and bushing are matched to a diametrical clearance of 60 millionths of an inch to prevent leakage during the injection cycle. As you can see, impurities of any kind can damage the unit.

Purging the Diesel Engine Fuel Injection System

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high pressure pumps and fuel lines. Unlike liquid fuel, which is incompressible, when air is present in the system, compression and expansion of air will occur and the injector valves will either fail to open or will not open at the proper time.

Determine the presence of air in a fuel system by bleeding a small amount of fuel from the top of the fuel filter or by slightly loosening an air bleeder screw or plug. If the fuel appears quite cloudy, it is likely that there are small bubbles of air in the fuel.

When working with fuel systems, remember that if air is entering a fuel line, the pressure within the fuel line must be lower than atmospheric pressure. The smallest of holes in the transfer pump suction piping will allow enough air to flow into the system to air bind the high pressure pumps. Carefully inspect all fittings in the suction piping. A loose fitting or a damaged thread condition will allow air to enter the system. On installations that use flanged connections, be sure to check the condition of the gaskets. Inspect tubing (especially copper) and flexible hose assemblies carefully for cracks that may result from constant vibration or rubbing.

The use of tubing and flexible hose assemblies on diesel engine fuel systems is common. Flexible hose assemblies are used more on the supply or low pressure side of the injection equipment, while tubing is more commonly used on the high pressure side of the injection equipment. The use of tubing and flexible hose assemblies is also the means by which all pressure gauges of a diesel may be located on a central gauge board away from the system the gauges are monitoring. Additional information concerning the fabrication and fitting of flexible hose assemblies and tubing can be found in *Tools and Their Uses*, NAVEDTRA 14256, and in *Fluid Power*, NAVEDTRA 14105.

If an engine is allowed to run out of fuel, you can expect trouble from air that enters the fuel system. If there is a considerable amount of air in the filter, a quick method of purging the system of air is to remove the filling plugs on top of the filter and pour in clean fuel until all air is displaced. Remove any air remaining in the system by using the hand priming pump. Open the system between the pump and the filter. Operate the hand priming pump until all air is removed and only clear fuel flows from the line. Then close the line. Repeat the same procedure at other points in the system, such as between strainers and the filters, between the filters and the high pressure pumps, and at the overflow line connection (excess fuel return line) on the high pressure pump housing. In small, high-speed diesel engines, you may need to prime only at the overflow connection. Since priming high pressure lines is time-consuming, attempt to start the engine before purging these lines. However, do not crank the engine for more than the specified interval of time. If the engine still fails to start, you should prime the high pressure lines. Since the procedure necessary to prime high pressure lines will vary considerably with different installations, follow the NAVSEA technical manual instructions for the proper procedure.

SUMMARY

You should be familiar with factors related to combustion and how these factors affect diesel engines. Know the meaning of turbulence and pre-combustion and the significance of each to the combustion process of a diesel engine.

In our discussion of fuel systems, we can never overstress the importance of clean fuel. Devices that help maintain the quality of fuel and oil are known as purifiers. Purifiers may be of the disc or tubular type. These purifiers differ in construction and method; however, both operate to remove water and dirt from fuel by centrifugal force. As you can see from the information you have read in this chapter, a great deal of importance is placed on keeping the fuel system in a high state of purity.

From reading our discussion of fuel injection systems, you should be aware of three types of mechanical diesel fuel injection systems:

- Jerk type
- Distributor-type
- Unit fuel injector type

How these three systems differ in construction and the methods by which fuel injection is achieved.

A complete understanding of fuel injection and engine control is a must if you are to operate a diesel engine in a safe and effective manner. If you are uncertain about any of the information in this chapter, we recommend you reread the sections that are giving you trouble.

End of Chapter 12

Diesel Fuel Systems

Review Questions

12-1. What is the ability of a liquid to change to vapor known as?

A. Gas
B. Volatility
C. Consternation
D. Motile

12-2. What is the fuel ignition quality, and the ease at which diesel fuel burns called?

A. Cetene number
B. Cetene index
C. Octane number
D. Octane index

12-3. What is the difference in fuel injection pressure on an engine with a pre-combustion chamber and an engine without a pre-combustion chamber?

A. Pre-combustion chamber engines require greater injection pressure.
B. Pre-combustion chamber engines require less injection pressure.
C. There is no difference in either engine.
D. Engines without pre-combustion chambers will naturally create more pressure.

12-4. In what *Naval Ship's Technical Manuals* (NSTM) chapters would you find detailed information on shipboard fuel testing?

A. 100, and 101
B. 250, and 251
C. 541, and 542
D. 754, and 755

12-5. What kind of pumps are most fuel service pumps?

A. Centrifugal
B. Vane
C. Variable-stroke
D. Rotary, positive displacement

12-6. What is the maximum allowable pressure drop, in pounds per square inch (psi), across a clean new fuel filter element?

A. 1.0
B. 3.5
C. 4.5
D. 6 .0

12-7. What purification phase is the heavy phase?

A. Solids
B. Salt
C. Water
D. Purified fuel

12-8. What form(s) a seal between the top disc and the bowl top on the disc-type purifier?

A. Water
B. Fuel
C. Solids
D. Air

12-9. What happens when you decrease the viscosity of the fuel by heating it and speeding up the purification process?

A. The capacity of the purifier decreases.
B. The need for the purifier is removed.
C. The capacity of the purifier increases.
D. The purifier must be purged more.

12-10. What is NOT part of the jerk pump fuel injection system?

A. Rack and pinion control rack
B. High pressure pump
C. Pressure operated spray valves
D. Nozzles

12-11. What kind of nozzle injection system is used with the open type of combustion chamber?

A. Pintle
B. Unit
C. Crossfire
D. Multiple-hole

12-12. What is the corrective action when the diesel engine runs out of fuel?

A. Fill with fresh fuel
B. Purge air from engine
C. Use either to start engine
D. Pour fuel directly into the piston and crank engine

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CHAPTER 13

ENGINE STARTING SYSTEMS

In this chapter, we will discuss the operating principles of the air-pilot-operated diaphragm control valves, and the operating principles of starting systems used with internal combustion engines. As an Engineman, you will be concerned with four types of starting systems: electric, hydraulic, air motor, and compressed air admission.

Electric starting systems are used with diesel engines in small craft (boats) and gasoline engines. The hydraulic starting system is used where nonmagnetic or lightweight characteristics are required. The air motor and compressed air admission systems are used on many larger engines. For a diesel engine to start, it must turn over fast enough to obtain sufficient heat to ignite the fuel-air mixture. If the engine turns over too slowly, the unavoidable small leaks past the piston rings and past the intake and exhaust valves (4-stroke cycle engines) will allow a substantial amount of the air to escape during the compression stroke. The heat loss from the compressed air to the cylinder walls will be greater at low speed because of the longer exposure.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the air-pilot-operated diaphragm control valve maintenance.
2. List the similarities, differences, and functions of the starting systems.
3. Name the different types of ignition aids and give the purpose of each.

AIR-PILOT-OPERATED DIAPHRAGM CONTROL VALVES

Air-pilot-operated diaphragm control valves are used extensively on naval ships. The valves and their control pilots are available in several designs to meet different requirements. They may be used as unloading valves to reduce pressure or to provide continuous regulation of pressure and temperature. They may also be used for the control of liquid levels.

The air-operated control pilot may be either direct acting or reverse acting. A direct-acting pilot is shown in *Figure 13-1*. In this type of pilot, the controlled pressure, the pressure from the discharge side of the diaphragm control valve, acts on top of a diaphragm in the control pilot. This pressure is balanced by the pressure exerted by the pilot adjusting spring. When the controlled pressure increases and overcomes the pressure exerted by the pilot adjusting spring, the pilot valve stem is forced downward. This action opens the pilot valve to increase the amount of operating air pressure going from the pilot to the diaphragm control valve. A reverse-acting pilot has a lever that reverses the pilot action. In a reverse-acting pilot, an increase in

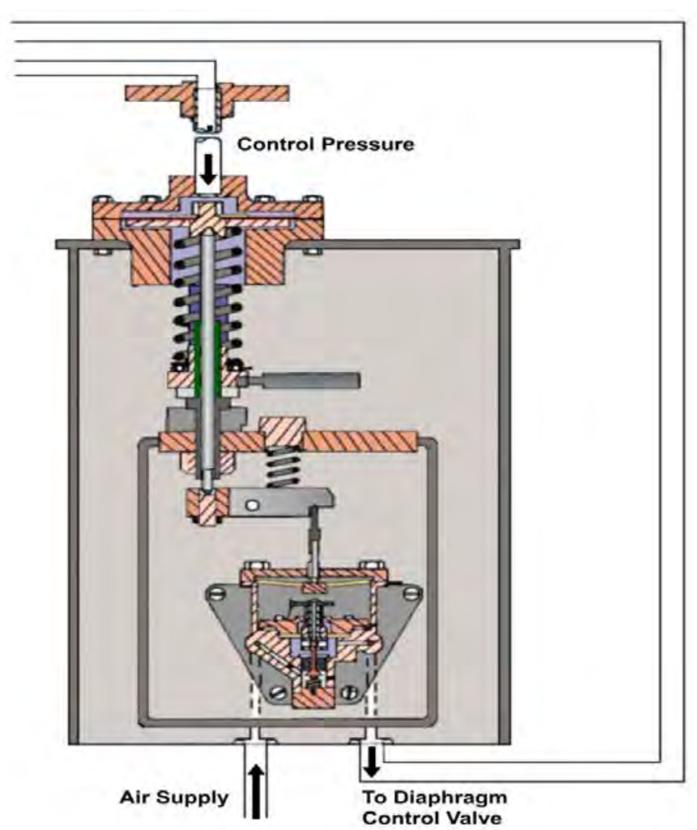

Figure 13-1 — Air-operated control valve.

controlled pressure produces a decrease in operating air pressure. In the diaphragm control valve, operating air from the pilot acts on a diaphragm contained in the superstructure of the valve operator or positioner.

The pilot air is direct-acting in some valves and reverse-acting in others *(Figure 13-2, frames 1 through 3).* If the valve operator is direct-acting, the operating air pressure from the control pilot is applied to the top of the valve diaphragm. When the valve operator is reverse-acting, the operating air pressure from the pilot is applied to the underside of the valve diaphragm.

A very simple type of direct-acting diaphragm control valve is shown in *Figure 13-2, frame 2*. The operating air pressure from the control pilot is applied to the top of the valve diaphragm. The valve in the figure is a downward-seating valve. Increase in operating air pressure pushes the valve stem downward, which will close the valve. The operating air pressure from the control pilot is applied to the top of the valve diaphragm (*Figure 13-2, frame 2*). But the valve shown in *Figure 13-2 frame 3* is more complicated than the one shown in *Figure 13-2, frame 2*. The valve shown in *Figure 13-2, frame 3* is an upward-seating valve rather than a downward-seating valve. Any increase in operating air pressure from the control pilot tends to open this valve rather than to close it.

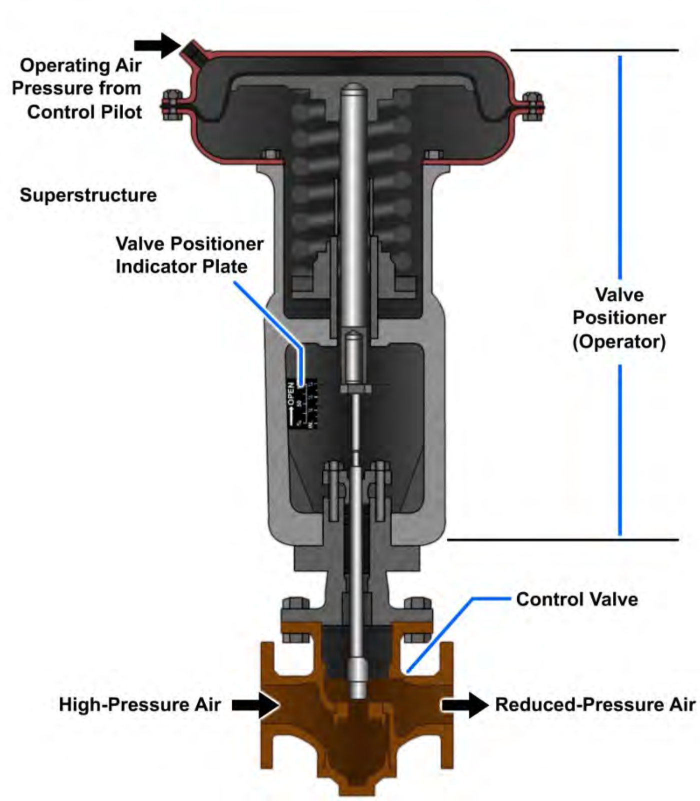

Figure 13-2 — Diaphragm control valve.

As we have seen, the air-operated control pilot and the positioner of the diaphragm control valve may be either direct-acting or reverse-acting. The diaphragm control valve may be either upward-seating or downward-seating. These factors, as well as the purpose of the installation, determine how the diaphragm control valve and its air-operated control pilot are installed in relation to each other.

To see how these factors are related, a diaphragm control valve and its air-operated control pilot are used to supply reduced steam pressure.

ELECTRIC STARTING SYSTEMS

As an Engineman, you may be required to perform basic maintenance on an electrical starting system for a small boat engine when an electrician is not available.

Electric starting systems use direct current (dc) because electrical energy in this form can be stored in batteries and can be drawn upon when needed. The battery's electrical energy is restored when the battery is charged with an engine-driven generator or alternator.

WARNING

Operate exhaust fan for at least 4 minutes before starting engines, and check bilge compartment for gasoline vapors.

The main components of the electric starting system are a storage battery, starting motor and associated control and protective devices. A typical cranking system is shown in *Figure 13-3*.

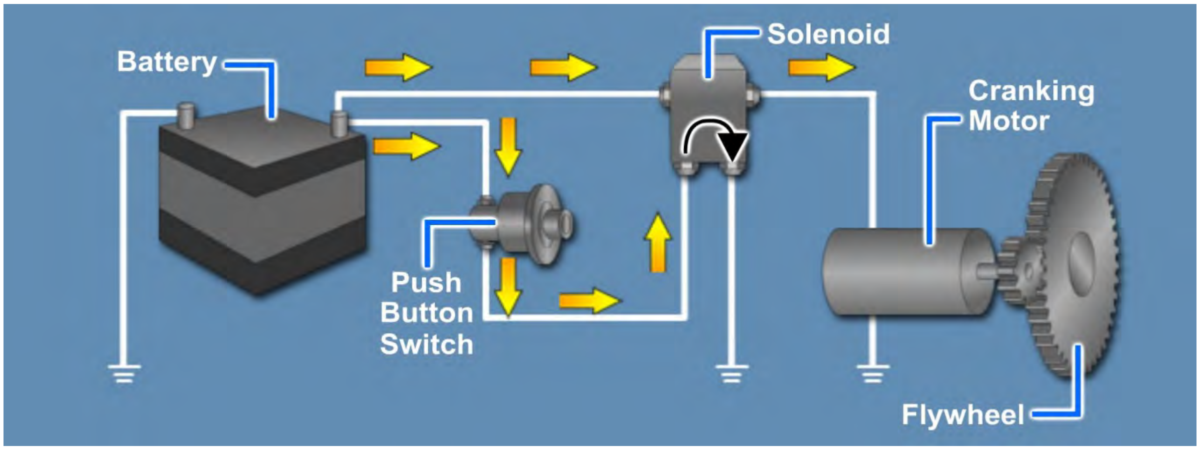

Figure 13-3 — Electrical cranking system and gear reduction single transfer switch.

Batteries

The lead acid storage battery provides the power source for starting small boat engines and other types of small and medium size engines. Most starting motors for the engines in small craft are rated for 24 to 28 volts. To supply the required current for starting, four individual 6-volt batteries are connected in series.

For maximum efficiency and long life of the storage battery, periodic inspections are essential. Batteries that serve to start boat engines are subjected to moderately heavy use and may require frequent independent charging in addition to the charging provided by the engine generator or alternator.

Monitoring the Charging System

As an operator, you should be aware of the condition of the charging system of the engine. You can use the ammeter to monitor the charging system. An ammeter is a device that is wired into the electrical circuit to show the current flow to and from the battery and is mounted on the gauge board (panel) along with the other monitoring gauges. After the engine is started, the ammeter should register a high charge rate at the rated engine speed. This is the rate of charge received by the battery to replenish the current the battery has used to start the engine. As the engine continues to operate, the ammeter should show a decline in the charge rate to the battery. The ammeter will not show a zero charge rate since the regulator voltage is set higher than the battery voltage. The small current registered prevents rapid brush wear in the battery-charging generator. If lights or other electrical equipment are connected into the circuit, the ammeter should show discharge when these items are operating and the engine speed is reduced.

Electronic/Computer

An electronic or computer-controlled spark advance system uses engine sensors, an ignition control module, and/or a computer to adjust ignition timing. A distributor may or may not be used in this type of system; if it is used it will not contain centrifugal or vacuum advance mechanisms.

Engine sensors check various operating conditions and send electrical data representing these conditions to the computer. The computer can then analyze the data and change the timing for maximum engine efficiency. Sensors that are used in this system are:

- Crankshaft position sensor—reports engine revolution per minute (rpm) to the computer
- Camshaft position sensor—tells the computer which cylinder is on its power stroke

- Manifold absolute pressure sensor—measures engine intake manifold vacuum, an indicator of load
- Intake air temperature sensor—checks temperature of air entering the engine
- Engine coolant temperature sensor—measures the operating temperature of the engine
- Knock sensor—allows the computer to retard timing when the engine pings or knocks
- Throttle position sensor—notes the position of the throttle

The computer receives inputs signals from these sensors, and it is programmed to adjust ignition timing to meet different engine operation conditions.

Starting Motors and Drives

The starting motor for a diesel or a gasoline engine operates on the same principle as a direct current electric motor. The motor is designed to turn extremely heavy loads but tends to overheat quickly because it draws a high current (300 to 665 amperes). To avoid overheating, NEVER allow the motor to run for more than the specified amount of time. Then allow it to cool for 2 or 3 minutes before using it again. Refer to the *Naval Sea System Command* (NAVSEA) technical manual for your engine for the recommended cranking and cooling periods.

The starting motor is located near the flywheel (*Figure 13-3).* The drive gear on the starter is arranged so that it can mesh with the teeth on the flywheel when the starting switch is closed. The drive mechanism has two functions:

1. To transmit the turning force to the engine when the starting motor runs, disconnecting the starting motor from the engine immediately after the engine has started.
2. To provide a gear reduction ratio between the starting motor and the engine (the gear ratio between the driven pinion and the flywheel is usually about 15 to 1).

The drive mechanism must disengage the pinion from the flywheel immediately after the engine starts. After the engine starts, the engine speed may increase rapidly to approximately 1500 rpm. If the drive pinion were to remain meshed with the flywheel and locked with the shaft of the starting motor, at a normal engine speed (1500 rpm) the shaft would spin at a rapid rate of speed (between 22,500 and 30,000 rpm). At such a rate of speed, the starting motor would be badly damaged.

Bendix Drive Mechanisms

A starting motor equipped with a Bendix drive friction-clutch mechanism is illustrated in *Figure 13-4*. The drive mechanism moves the drive pinion so that it meshes with the ring gear on the flywheel.

The pinion of the Bendix drive is mounted on a spiral-threaded sleeve so that when the shaft of the motor turns, the threaded sleeve rotates within the pinion, moving the pinion outward, causing it to mesh with the flywheel ring gear and crank the engine. A friction clutch absorbs the sudden shock when the gear meshes with the flywheel.

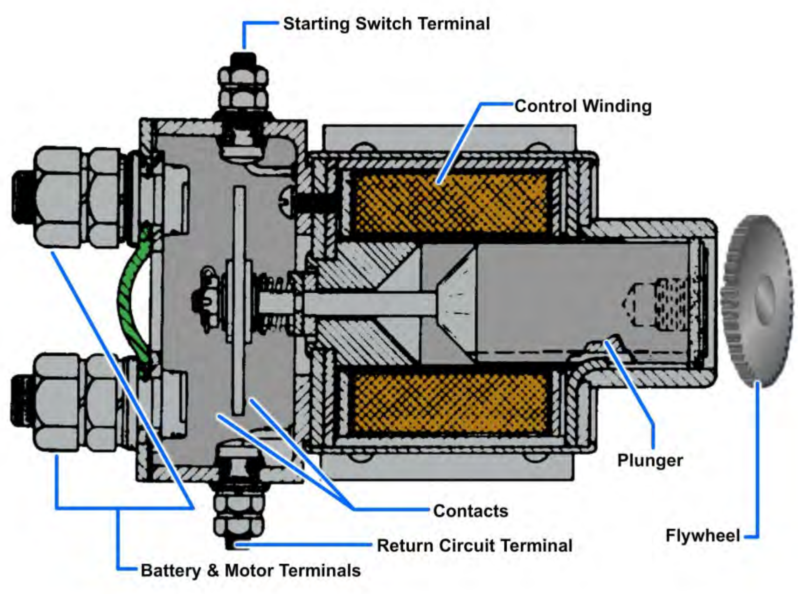

Figure 13-4 — Bendix drive friction-clutch mechanism.

As soon as the engine runs under its own power, the flywheel drives the Bendix gear at a higher speed than that at which the shaft of the starting motor is rotating. This action causes the drive pinion to rotate in the opposite direction on the shaft spiral and automatically disengages the drive pinion from the flywheel as soon as the engine starts.

Special switches are needed to carry the heavy current drawn by starting motors. Starting motors that have a Bendix drive use a heavy-duty solenoid switch (relay switch) to open and close the motor-to-battery circuit and a hand-operated starting switch to operate the solenoid switch. The starting switch is on the instrument panel and may be a pushbutton or a lever type. The solenoid switch (*Figure 13-4*), is mounted on and grounded to the starting motor housing so that the wires that must carry the heavy current required by the motor may be as short as possible to prevent voltage droop and overheating resulting from current draw. When the solenoid is energized by the starting switch, the plunger is drawn into the core and completes the circuit between the battery and the starting motor.

Operating precautions on the Bendix drive must be strictly followed. There are times when the engine may start, throw the drive pinion out of mesh, and then stop. When the engine is coming to rest, it may often rock back part of a revolution. If at that moment the pinion is engaged, the drive mechanism may be seriously damaged. Therefore, you must wait several seconds to be sure that the engine is completely stopped before you use the starting switch again.

Sometimes the pinion will fail to engage immediately after the starting motor has been energized. When this happens, you will not hear the engine turning over and the starting motor will develop a high-pitched whine. You should immediately de-energize the starting motor to prevent overspeeding. An electric starting motor operating under no-load conditions can quickly overspeed and can be seriously damaged.

If the pinion is to engage and disengage freely, the sleeve and the pinion threads should be free from grease and dirt. The Bendix drive should be lubricated according to instructions in the NAVSEA technical manual.

Dyer Drive Mechanism

A starting motor assembly with a Dyer drive mechanism is shown in *Figure 13-5*. An exploded view of the drive assembly is shown in *Figure 13-6*.

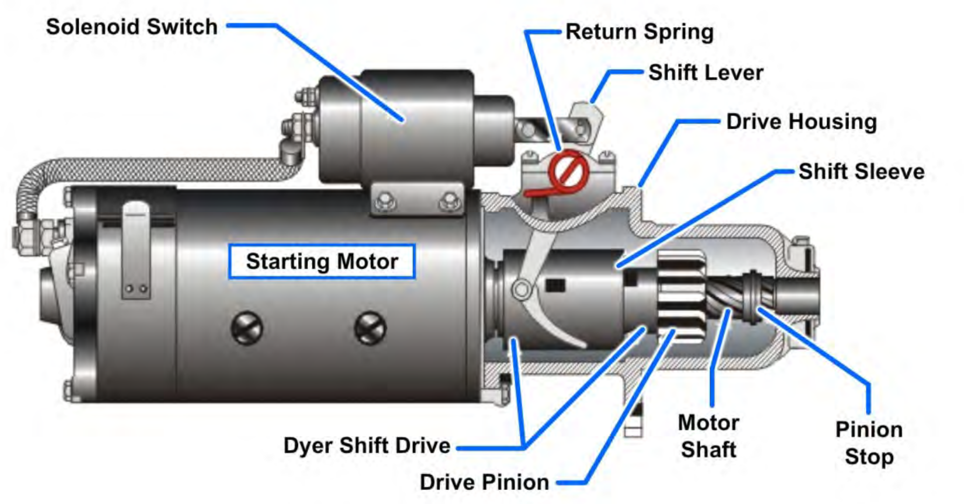

Figure 13-5 — Cross section of starting motor with a Dyer driver.

The starting motor is equipped with a Dyer shift drive, which is operated through a solenoid starting shift and switch. The solenoid assembly is mounted on the starting motor and is connected to the battery and motor. Remote control starting is accomplished by a starter switch on the instrument panel that, upon being closed, energizes the starter solenoid. A heavy-duty plunger inside the solenoid is connected by linkage to the pinion shift lever that operates the Dyer drive. When the starter switch is closed, the battery energizes the coil of the solenoid switch, which pulls the pinion gear into mesh with the ring gear on the flywheel. Continuation of the plunger movement closes the solenoid switch contacts, removing the coil from the circuit and permitting the cranking motor to crank the engine.

The Dyer drive consists of a splined section on the armature shaft, a shift sleeve, pinion, gear pinion guide, pinion stop, thrust washers, and springs. The thrust washers furnish a thrust bearing for the shift sleeve (*Figure 13-7)* when it is in the returned position. The springs aid in the lock operation and in the engagement action.

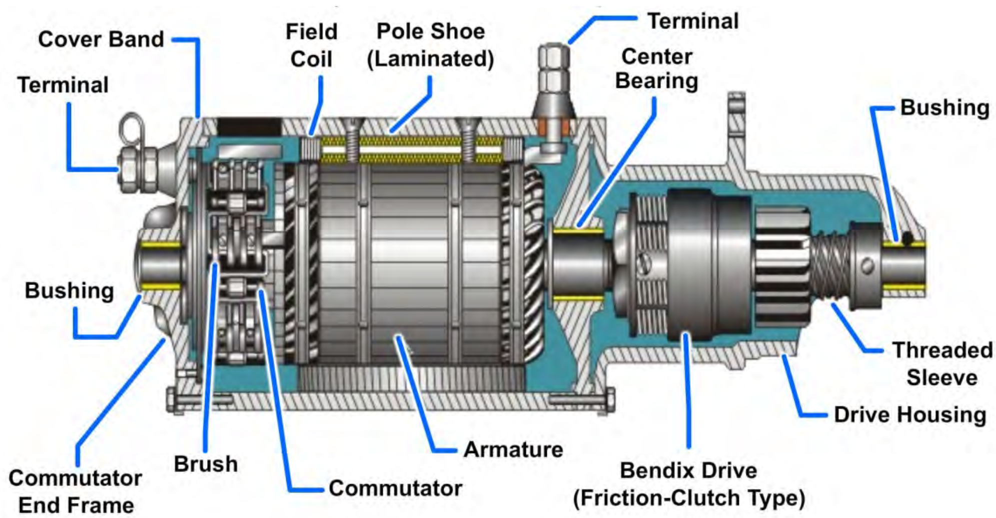

Figure 13-6 — A starting motor with a Dyer drive.

The entire drive is contained in the starting motor drive housing. The movement of the pinion is controlled by a shift lever which is connected directly to the shift sleeve.

The Dyer drive provides a positive engagement of the cranking motor pinion gear with the engine flywheel (*Figure 13-8, frames 1 through 4)* before the cranking motor switch contacts are closed or the armature is rotated. This design prevents the pinion gear teeth from clashing with the flywheel ring gear. It also prevents the possibility of broken or burred teeth on either the ring gear or the drive pinion gear. The pinion gear is thrown out of mesh with the flywheel by the reversal of torque as the engine starts. The operation of the Dyer drive mechanism is similar to that of the Bendix drive. As shown in *Figure 13-8, frame 1*, the mechanism begins in the disengaged position. The starting switch energizes and the solenoid pulls its plunger in and begins to move the pinion gear toward the ring gear (*Figure 13-8, frame 2).* The pinion gear fully meshes with the ring gear before the motor shaft begins to rotate (*Figure 13-8, frame 3)*. The motor shaft rotates and the shift sleeve returns to its original position *(Figure 13-8*, *frame 4)*. The drive pinion moves the flywheel ring gear which cranks the engine.

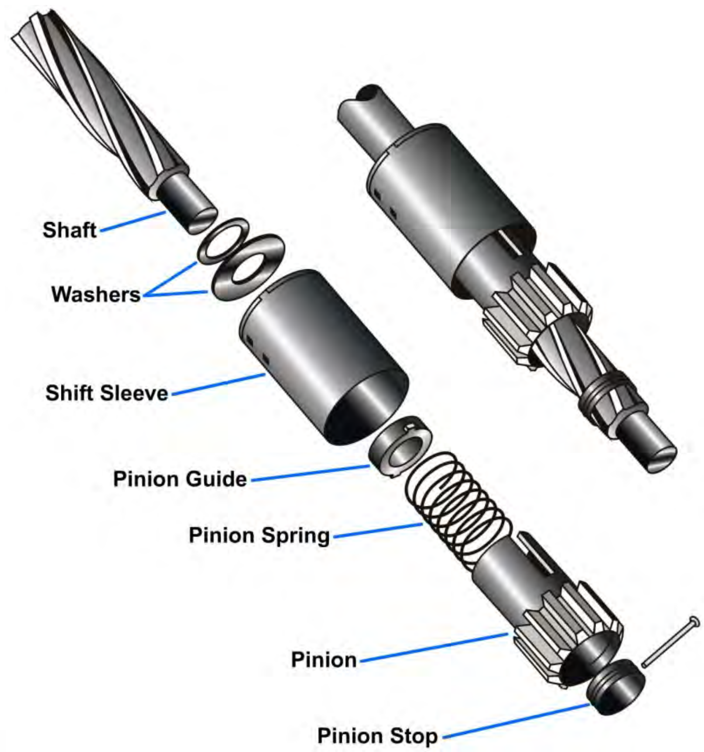

Figure 13-7 — Dyer shift drive mechanism.

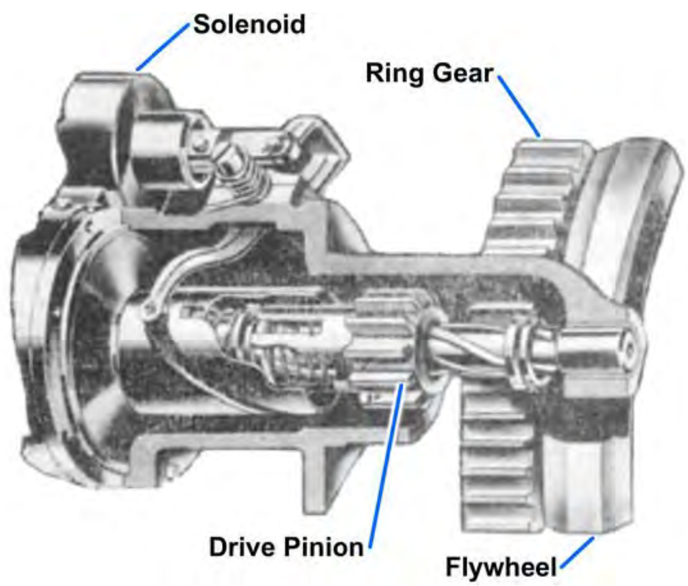

Figure 13-8 — Dryer drive operation.

Sprag Overrunning Clutch Drive

Another type of drive mechanism used by the Navy is the Sprag overrunning clutch. This type of drive is similar to the Dyer drive in that the pinion is engaged by the action of a lever attached to the solenoid plunger. Once engaged, the pinion will stay in mesh with the ring gear on the flywheel until the engine starts or the solenoid switch disengages. To protect the starter armature from excessive speed when the engine starts, the clutch "overruns" or turns faster than the armature, which permits the starter pinion to disengage itself from the ring gear.

The solenoid plunger and shift lever, unlike those in the Dyer drive, are completely enclosed in a housing to protect them from water, dirt, and other foreign matter. An oil seal, installed between the shaft and lever housing, and a linkage seal, installed around the solenoid plunger, prevent transmission oil from entering the starter frame or solenoid case. The nose housing of the drive mechanism can be rotated so that a number of solenoid positions can be obtained with respect to the mounting flange.

HYDRAULIC STARTING SYSTEMS

Hydraulic starting systems are used on various small diesel engines. The hydro-starter system, as illustrated in *Figure 13-9,* is a complete hydraulic system used for the cranking of internal-combustion engines. The system is automatically recharged by the engine-driven hydraulic pump after each engine start. The starting potential of this system does not deteriorate during long periods of inactivity Continuous exposure to hot or cold climates also has no detrimental effect upon the hydro-starter system. Engine starting torque for a given pressure will remain fairly constant regardless of the ambient temperature.

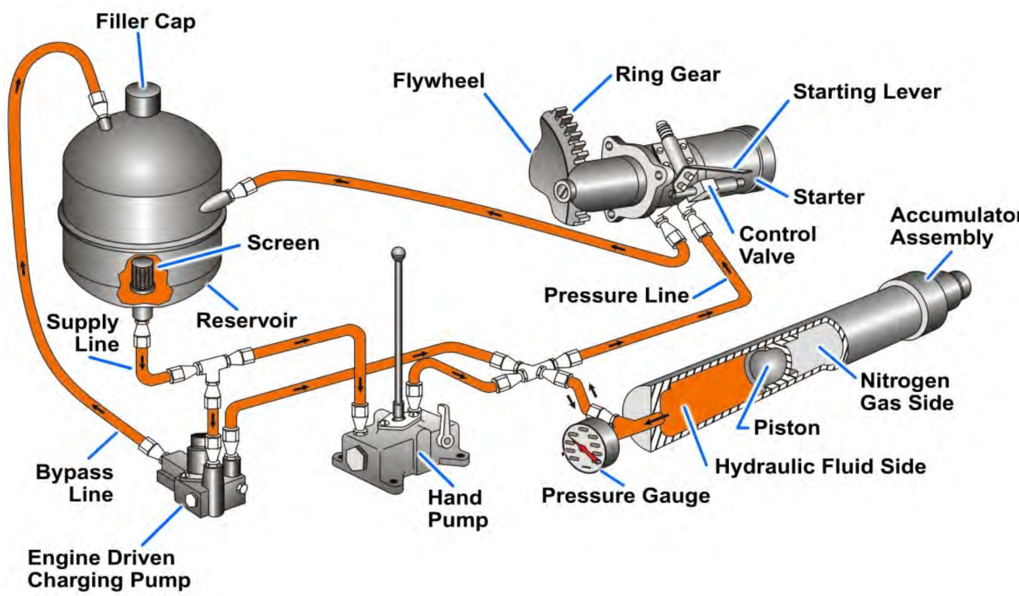

Figure 13-9 — Hydraulic starting system.

The hydro-starter system consists of a reservoir, an engine-driven charging pump, a manually operated pump, a piston-type accumulator (with a fluid side and a nitrogen side), a hydraulic vane-type starting motor, and connecting lines and fittings. Hydraulic fluid oil flows by gravity (or by a slight vacuum) from the reservoir to the inlet of either the engine-driven pump or the hand pump. Fluid discharged by either pump is forced at high pressure into the accumulator and is stored at approximately 3250 pounds per square inch (psi) under the pressure of compressed nitrogen gas. Nitrogen is used instead of compressed air because nitrogen will not explode if seal leakage permits oil to enter the nitrogen side of the accumulator.

When the starter is engaged with the ring gear on the flywheel of the engine, and the control valve is opened, high pressure fluid is forced out of the accumulator by the action of the piston from the expanding nitrogen gas. The fluid flows into the starting motor, which rapidly accelerates the engine to a high cranking speed. When the starting lever is released, the spring action disengages the starting pinion and closes the control valve. This action stops the flow of hydraulic oil from the accumulator. The used fluid returns from the starter directly to the reservoir (see the directional arrows in *Figure 13-9*).

During engine operation, the engine-driven charging pump runs continuously and automatically recharges the accumulator. When the required pressure is attained in the accumulator, a valve within the pump body opens and the fluid discharged by the pump is bypassed to the reservoir. When the system is shut down, the pressure in the accumulator will be maintained.

The hand pump of the hydro-starter system is a double-action piston pump. It serves to pump fluid into the accumulator for initial cranking when the accumulator has exhausted all the fluid stored in it. The starter is protected from high speeds of the engine by the action of an overrunning clutch.

The hydraulic starting system may be used with most small engines now in service without modification other than the clutch and pinion assembly, which must be changed when a conversion from a left-hand to a right-hand rotation is made.

AIR MOTOR STARTING SYSTEMS

Starting air comes directly from the ship's medium pressure (MP) or high pressure (HP) air service line or from starting air flasks, which are included in some systems for the purpose of storing starting air. From either source, the air, on its way to the starting system, must pass through a pressure-reducing valve, which reduces the higher pressure to the operating pressure required to start a particular engine.

A relief valve is installed in the line between the reducing valve and the starting system. The relief valve is normally set to open at 12 percent above the required starting air pressure. If the air pressure leaving the reducing valve is too high, the relief valve will protect the system by releasing air in excess of a preset value and permit air only at safe pressure to reach the starting system of the engine.

In the following sections, we will discuss two common types of systems that use air as a power source for starting diesel engines—the air starting motor system and the compressed air admission system.

Some larger engines and several small engines are cranked over by starting motors that use compressed air. Air starting motors are usually driven by air pressures varying from 90 to 200 psi. *Figure 13-10* shows an exploded view of an air starting motor with the major components identified.

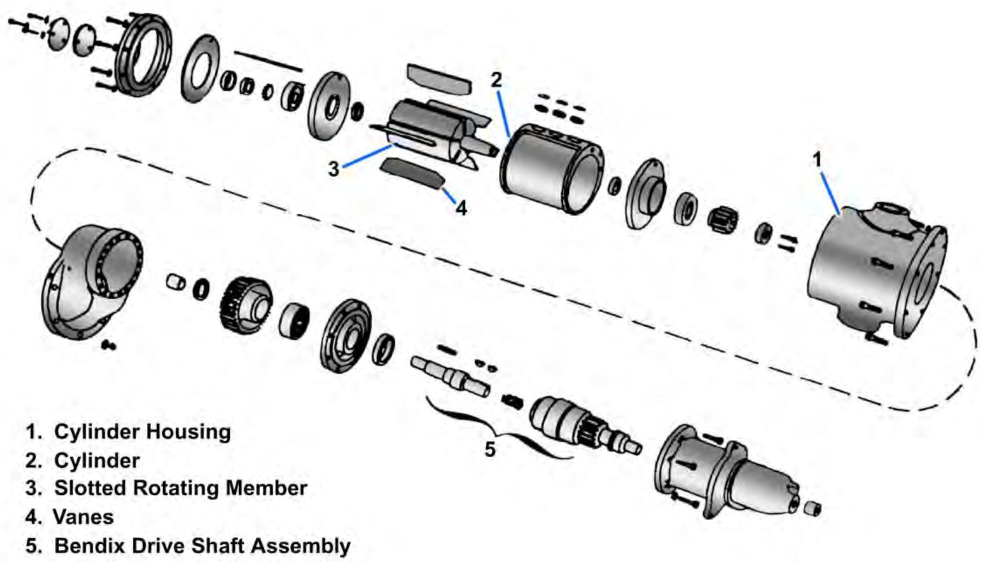

Figure 13-10 — Air starting motor (exploded view).

Figure 13-11 shows the principles by which the air starting motor functions. As you read the following discussion on the flow of air through the starting motor, refer to *Figure13-11* for the relative position of the principal components. In *Figure 13-11*, starting air enters through piping into the top of the air starter housing (1) and flows into the top of the cylinder (2). The bore (3) of the cylinder has a larger diameter than the rotor. The rotor (4) inside the cylinder is a slotted rotating member which is offset with the bore of the cylinder. The rotor carries the vanes (5) in slots, allowing the vanes to maintain contact with the bore of the cylinder. The pressure of the starting air against the vanes forces the rotating member to turn approximately halfway around the core of the cylinder, where exhaust ports (6) allow the air to escape to the atmosphere. A shaft and a reduction gear connect the rotating member to a Bendix drive, which engages the ring gear of the flywheel to crank the engine.

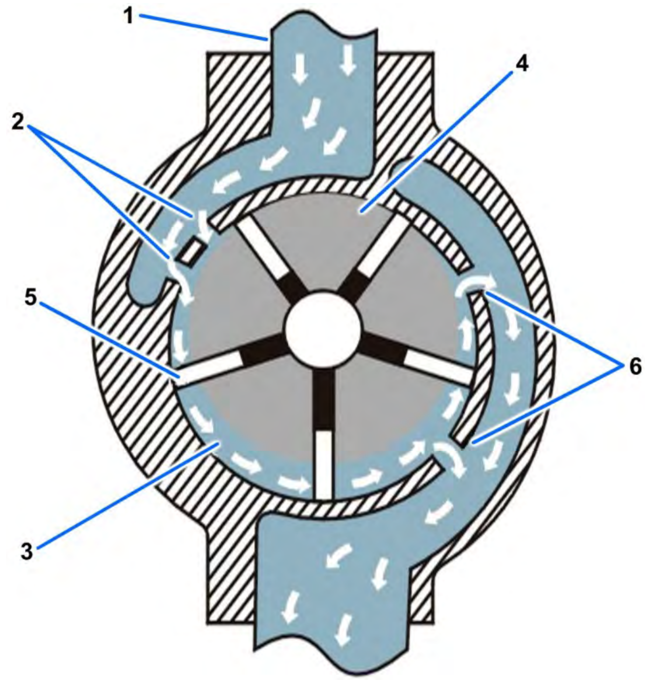

Figure 13-11 — Flow of air through an air starting motor.

COMPRESSED AIR ADMISSION SYSTEM

Most large diesel engines are started when compressed air is admitted directly into the engine cylinders. Compressed air at approximately 200 to 300 psi is directed into the cylinders to force the pistons down and thereby turn the crankshaft of the engine. This air admission process continues until the pistons are able to build up sufficient heat from compression to cause combustion to start the engine (*Figure 13-11).* The engine is started by the admitting of compressed air into the right hand bank of cylinders. Control valves and devices that permit compressed air to flow to the cylinders are actuated by control air that is directed through the engine control system.

The air start manifold runs parallel to the right bank of cylinders. Jumper lines are connected only to the right bank of cylinders because only one bank of cylinders needs to be attached to the air starting system. The jumper lines connect the air start manifold to the air start check valves in the cylinder head and supply the required air pressure to the cylinders *(Figure 13-11).* The heart of the engine control system is the main air start control valve. A cutaway view of this valve is shown in *Figure 13-12.* Except when the engine is being cranked, this component acts as a simple stop valve. A small amount of air is routed through the air supply port (A) to the spring side of the starting air valve. This air pressure, along with the force of the main spring, holds the main

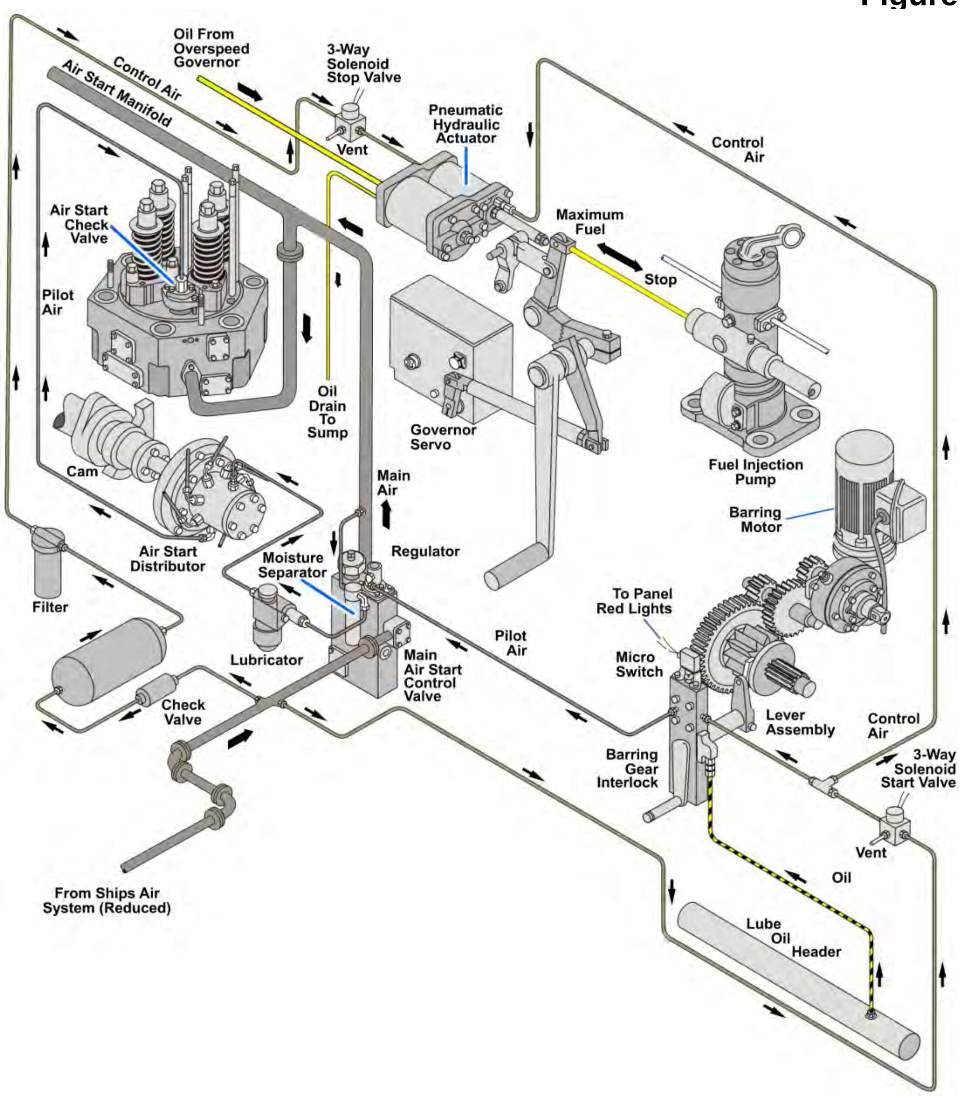

Figure 13-12 — Compressed air admission starting system.

starting air valve; however, the surface area inside the piston (at the bottom) is less than the bottom area outside the valve against its seat. Air pressure is the same on both sides of the piston inside the valve body piston, so the spring is required to hold the piston down against the seat. When air pressure acting on the piston becomes unbalanced, such as when air pressure on the inside of the piston is reduced, air pressure acting on the larger surface area on the outside of the piston will force the piston up off the seat of the starting air valve. As long as the main starting air valve remains seated, starting air cannot pass through the control valve and enter the air start manifold. However, when compressed air is needed for the engine to start, the drain valve is forced downward, either by air that is brought in through the control air inlet by pilot air or by the pin attached to the manual start lever.

The pressurized air above the main spring in the start control valve escapes through the vent ports at the top of the valve body, when the drain valve is in the proper position. The resulting release of pressure allows the main starting valve to overcome the spring force and to lift off its seat. In turn, compressed starting air is permitted to pass through the control valve and into the air start manifold. Starting air will continue to pass through the main air start control valve until the drain valve is closed. When the drain valve closes, the area above the piston depressurizes and forces the main starting valve back on its seat. This reseating action shuts off starting air through the control valve.

The entry of starting air into the cylinders is controlled by pilot air. Pilot air leaves the main air start control valve, passes through an air filter and an oiler, and enters the air start distributor. The air distributor is directly driven by the right camshaft. As the camshaft rotates, pilot air is allowed to pass through a line to the appropriate air start check valve in the firing sequence. Pilot air opens each check valve to allow high-pressure starting air to enter the cylinder from the jumper line, force the piston downward, and rotate the crankshaft. The air start check valve functions as a pilot actuated air admission valve until the cylinders begin to fire. As the cylinders fire, pressure created by combustion exceeds the pressure of the starting air, this condition forces the air start check valves to close, preventing combustion gases from entering the air start manifold.

At the same time that starting air is delivered to the cylinders, control air at 200 psi is supplied to the forward end of the pneumatic auxiliary start/stop relay and the fuel rack activator piston. The control air cases the piston to pull the fuel racks toward the full-fuel position. Once the engine is started, its speed is controlled by a hydraulic governor with a pneumatic speed mechanism attached for remote engine control. The governor is also equipped with a dial that can be used for local control of engine speed during maintenance, or in an emergency.

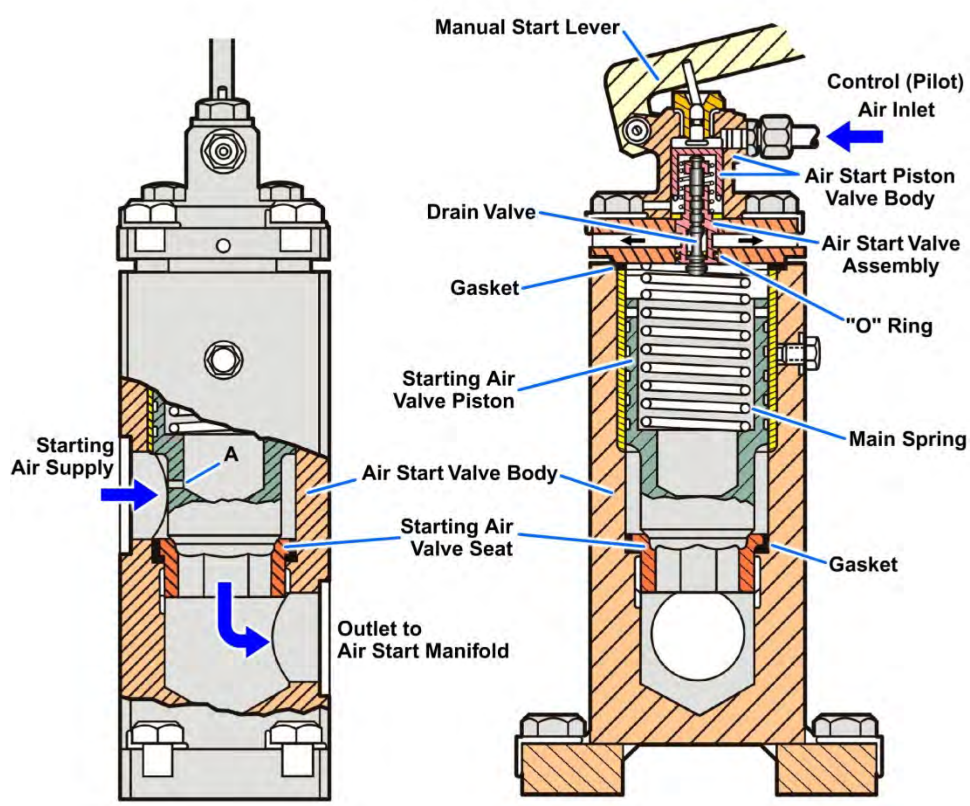

Figure 13-13 — Main air start control valve.

The control air that operates the main air start control valve passes through a primary safety device, the barring gear interlock (*Figure 13-13*). The barring gear interlock prevents the engine from accidentally starting or rotating and also prevents the barring gear from being engaged when the engine is running. The safety feature is provided by the barring lever assembly. When the barring lever assembly is in place, the interlock will not allow control air to reach the main air start control valve, and compressed air will not be admitted to the cylinders.

Basically, all air starting systems operate similarly and contain components that are similar in function to those used in the two types of air starting systems we have discussed.

COLD WEATHER STARTING AIDS

Ignition in a diesel engine is accomplished by a combination of fuel injection and compression of intake air. Diesel engines normally require longer cranking periods than gasoline engines. At low ambient temperatures, a diesel engine is extremely difficult or impossible to start without adequate accessories to assist in the starting process. As the outside temperature drops, battery efficiency is reduced and cranking load becomes high. The increased load results from higher oil viscosity. The cold cylinder walls also chill the incoming air, and the air cannot reach the temperature required for combustion. The methods used for helping an engine start in cold weather include:

1. Heating the air in the cylinder (glow plugs)
2. Heating the intake air (grid resistor)
3. Adding a volatile, easily combustible fluid (ether) to the intake air
4. Heating the coolant and/or lubricating oil (heaters)

Glow Plugs

Deriving its power from the battery, the glow plug is a low-voltage heating element that is inserted in the combustion chamber of each cylinder. The glow plug is used briefly before the cold engine is cranked. In general, the time limit for the use of the glow plug is dependent upon the ambient temperature and the design of the engine. The operating temperature of a glow plug is between 1652 and 1832 °F. Glow plugs are common on pre-combustion chamber engines, but not on direct injection diesel, because they use shaped piston crowns that produce a very effective turbulence to the air in the cylinder. A glow plug is used for each cylinder located just below the injection nozzle and threaded into the cylinder head. Specifications for different glow plugs vary according to the manufacturer; be sure and check the manufacturer’s service manual for the correct ohms resistance valve.

Grid Resistors

The grid resistor usually consists of an electrical resistance grid mounted on a frame and supported by insulating blocks in the engine air intake manifold. The grid is preheated by current from the starting battery before the engine is cranked, and is operated during the cranking period until the engine has reached operating speed.

The basic drawback in the use of glow plugs or the grid resistor as starting aids is that they require battery power that is also needed for cranking. The cranking power of a battery is already reduced at low temperatures. In the following examples (*Table 13-1),* note how the cranking power of a battery is reduced as the ambient temperature drops:

Table 13-1 — Ambient Temperature vs. Cranking Power Loss

AMBIENT TEMPERATURE	PERCENTAGE OF CRANKING POWER OF BATTERY
80 °F	100 percent
32 °F	65 percent
0 °F	45 percent

Ether Primers

A widely used cold weather starting aid for engines of small craft is the ether capsule. The ether capsule serves to inject a highly volatile fluid into the air intake system to assist ignition of the fuel.

WARNING

Ether must not be used in connection with the grid resistor or glow plug methods. With the high volatility of ether, additional heat could cause ignition in the intake manifold or pre-ignition in the combustion chamber.

An ether capsule primer (*Figure 13-14)* consists of a discharge cell, discharge nozzle, and pressure primer capsule, which contains a liquid ether mixture. The discharge cell and the discharge nozzle are connected together by a suitable length of tubing. The discharge cell is a metal enclosure containing a piercing pin and a removable cap for insertion of the pressure primer capsule. When the lever is operated, it forces the capsule against the piercing pin.

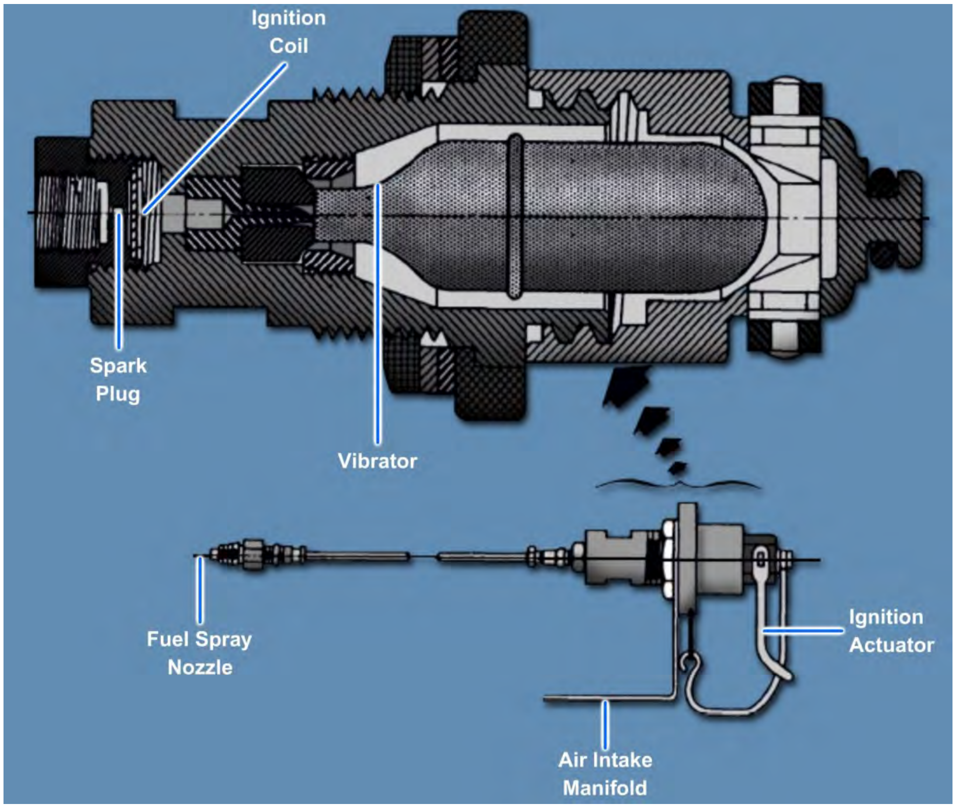

Figure 13-14 — Ether capsule primer.

WARNING

Explosion will occur if steel pressure primer bulb is heated above 600 °F.

The discharge cell is installed at the control station in a vertical position so that the neck of the capsule is always down toward the piercing pin. The discharge nozzle is installed through a pipe connection at the forward end of the intake manifold. When you are using the ether capsule primer, press the engine starter switch. As soon as the starting motor brings the engine up to cranking speed, operate the discharger lever to discharge the capsule. Continue cranking while the ether mixture is being forced rapidly through the connecting tube to the intake manifold where it is sucked into the cylinders. The capsule requires approximately 15 seconds to discharge, and the diesel engine should start during this interval.

NOTE

Starting aids are not intended to correct deficiencies, such as a weak battery or a poorly tuned engine. They are intended for use when other conditions are normal but the air temperature is too low for the heat of compression to ignite the fuel-air mixture in the cylinders. For additional information on starting aids refer to *Naval Ships' Technical Manual,* chapter 233.

Heaters

Two other types of starting aids are the cylinder-block jacket-water heater and the engine-oil heater. When fuel enters a cold combustion chamber and the intake air is also cold, the fuel fails to evaporate. Instead, it collects in the cylinders, washes the lubrication from the cylinder walls, and dilutes the crankcase oil. These problems are corrected when the coolant or lubricating oil is heated.

These heaters function to keep the engine components warm at all times. Moreover, they minimize engine component wear during starting and warm-up. The heaters may use steam or electricity as a heat source for the coolant or lubricating oil.

SUMMARY

As an Engineman, you must know the purpose and principles of operation of the air-pilot-operated diaphragm control valves, and the operating principles of the four types of starting systems used in Navy diesel engines: (1) electric, (2) hydraulic, (3) air motor, and (4) compressed air admission.

You should be aware of the various devices that aid the starting of an engine in cold temperatures. Starting an engine in cold weather may require the use of starting aids that (1) heat the air in the cylinder, (2) heat the intake air, (3) inject a highly volatile fluid into the air intake, or (4) heat the lubricating oil and/or the coolant. A commonly used starting aid is the ether capsule. The basic reason for its use is that it will not take away battery power that is needed for cranking.

End of Chapter 13

Engine Starting Systems

Review Questions

13-1. What kind of valve is used as an unloading valve to reduce pressure or to provide continuous regulation of pressure and temperature?

A. Hydraulic-pilot-operated diaphragm control
B. Air-pilot-operated diaphragm control
C. Steam-pilot-operated diaphragm control
D. Water-pilot-operated diaphragm control

13-2. Where does the pressure come from on the diaphragm control valve that acts on top of a diaphragm in the control pilot?

A. The inlet side
B. The bottom side
C. The discharge side
D. The top side

13-3. What voltage are most starting motors for small craft engines rated at?

A. 24-28 volts
B. 48-52 volts
C. 64-68 volts
D. 72-80 volts

13-4. What do starting motors that have Bendix drive use to open and close the motor-to-battery circuit?

A. Light-duty capacitor
B. Heavy-duty capacitor
C. Light-duty solenoid switch
D. Heavy-duty solenoid switch

13-5. What is connected by a linkage inside the solenoid to the pinion shift level that operates the Dyer drive?

A. Gear drive
B. Rack and pinion
C. Belt drive
D. Heavy-duty plunger

13-6. How is the pinion gear thrown out of mesh with the flywheel as the engine is started?

A. Reversing the torque
B. Reversing the rotation of the flywheel
C. Reversing the rotation of the engine
D. Reversing the rotation of the pinion gear

13-7. What kind of gas is used to actuate the piston that forces high pressure fluid out of the accumulator when the starter is engaged with the ring gear on the flywheel of the engine, and the control valve is opened?

- A. Argon
- B. Helium
- C. Nitrogen
- D. Oxygen

13-8. How does starting air enter into the cylinders?

- A. Blowers
- B. Fans
- C. Controlled air
- D. Pilot air

13-9. What is the operating range of glow plugs?

- A. 1400-1600 °F
- B. 1652-1832 °F
- C. 1950-2150 °F
- D. 2234-2434 °F

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CHAPTER 14

DIESEL ENGINE OPERATING PRACTICES

In this chapter we will apply the material in the preceding chapters to the practical problems of operating diesel engines. Since the diesel engines used by the Navy differ widely in design, size, and application, the procedures we will discuss apply only to general types of installations. Descriptions will apply generally to the various auxiliary and propulsion diesel installations in Navy ships. Detailed and specific information and operating instructions are provided in the manufacturers' manuals for specific installations, in *Naval Sea System Command* (NAVSEA) technical manuals, and in ship's doctrine such as the *Engineering Operational Sequencing System* (EOSS). You should also be able to recognize the fundamental starting, operating, and stopping procedures for a diesel engine under normal operating conditions.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the importance of inspection and maintenance.
2. List the operating instructions of diesel engines.
3. Explain the importance and purpose of an emergency diesel generator.
4. Discuss the factors influencing Engineering Casualty Control.
5. Explain the purpose of correction and prevention of casualties.
6. List different Engine Room Casualties.

INSPECTION AND MAINTENANCE

Inspection and maintenance are vital to successful casualty control; they minimize casualties caused by material failures. Through continuous and detailed inspection procedures, you can discover damaged parts, which may fail at a critical time, and eliminate underlying conditions, which will lead to early failure of parts.

Underlying conditions will generally include maladjustment, improper lubrication, corrosion, erosion, and other causes of machinery damage.

You must pay particular and continuous attention to the following symptoms of malfunctioning equipment:

1. Unusual noises.
2. Vibrations.
3. Abnormal temperatures.
4. Abnormal pressures.
5. Abnormal operating speeds.

You must thoroughly familiarize yourself with the specific temperatures, pressures, and operating speeds of equipment required for normal operation so that you will detect any departure from normal operation.

If a gauge or other instrument for recording operating conditions of machinery gives an abnormal reading, you must fully investigate the cause. The installation of a spare instrument or a calibration test will quickly indicate whether the abnormal reading is from instrument error. You must trace any other cause to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external symptoms are apparent. You should be suspicious of any changes in the operating speeds (those normal for the existing load) of pressure-governor-controlled equipment. Variations from normal pressures, lubricating oil temperatures, and system pressures often indicate either improper operation or poor condition of machinery.

When a material failure occurs in any unit, promptly inspect all similar units to determine whether there is any danger that a similar failure might occur. Prompt inspection may eliminate a wave of repeated casualties.

Pay strict attention to the proper lubrication of all equipment, including frequent inspection and sampling to determine that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Allow samples to stand long enough for any water to settle. When auxiliaries have been idle for several hours, you should drain a sufficient sample from the lowest part of the oil sump to remove all settled water. Replenish with fresh oil to the normal level.

Symptoms of Engine Trouble

When learning to recognize the symptoms that may help you locate the causes of engine trouble, you will find that experience is the best teacher. Even though written instructions are essential for efficient troubleshooting, the information usually given will serve you only as a guide. It is very difficult to describe the sensation you should feel when you are checking the temperature of a bearing by hand; the specific color of exhaust smoke when pistons and rings are worn excessively; and, for some engines, the sound you will hear if the crankshaft counterweights come loose. You must actually work with the equipment before you can associate a particular symptom with a particular problem. Written information, however, can save you a great deal of time and can help you eliminate unnecessary work. Written instructions will make your detection of problems much easier in practical situations.

Symptoms that indicate trouble may be in the form of an unusual noise or instrument indication, smoke, excessive consumption of lube oil, or contamination of the lube oil, fuel, or engine coolant. *Table 14-1* provides a general listing of various trouble symptoms the operator of an engine may encounter. For additional information, you should consult the *Naval Ships' Technical Manual (NSTM)*, Chapters 079 and 233.

Noises

Unusual noises that may indicate that a trouble exists (or is impending) are classified as pounding, knocking, clicking, and rattling. You must be able to associate each type of noise with certain engine parts or systems that might be the source of the trouble.

Pounding or hammering is a mechanical knock (and should not be confused with a fuel knock). Pounding or hammering may be caused by a loose, excessively worn, or broken engine part. Generally, troubles of this nature will require major repairs. Detonation (knocking) is caused by the presence of fuel or lubricating oil in the air charge of the cylinders during the compression stroke. Excessive cylinder pressures accompany detonation. If detonation is occurring in one or more cylinders, you should stop the engine immediately to prevent possible damage.

Table 14-1 — Symptoms of engine trouble

NOISE	INSTRUMENT INDICATIONS			SMOKE	CONTAMINATION OF LUBE OIL, FUEL, OR WATER
	PRESSURE	TEMPERATURE	SPEED		
Pounding (*mechanical*)	Low lube oil pressure High lube oil pressure	Low lube oil temperature High lube oil temperature	Idling speed hot normal maximum hot normal	Black exhaust Bluish-white	Fuel oil in the lube oil Water in the lube oil
Knocking (*detonation*)	Low fuel oil pressure (in low pressure fuel supply system)	Low cooling water temperature (*fresh)*		smoke arising from crankcase	Oil or grease in the water Water in the fuel oil
Clicking (*metallic)*	Low cooling water pressure (*fresh*)	High cooling water temperature *(fresh*)		Smoke arising from cylinder head	Air or gas in the water
	Low cooling water pressure *(salt*)	Low cylinder exhaust temperature		Smoke from engine auxiliary equipment (*blowers, pumps, etc.*)	Metal particles in lube oil
Rattling	High cooling water pressure (*salt)* Low compression pressure Low firing pressure High firing pressure Low scavenging air receiver pressure(*super-charge engine*) High exhaust rack pressure	High exhaust temperature in one cylinder			

Clicking noises are generally associated with an improperly functioning valve mechanism or timing gear. If the cylinder or valve mechanism is the source of metallic clicking, the trouble may be due to a loose valve stem and guide, insufficient or excessive valve tappet clearances, a loose cam follower or guide, broken valve springs, or a valve that is stuck open. A clicking in the timing gear usually indicates that there are some damaged or broken gear teeth.

Rattling noises are generally caused by vibration of loose engine parts. An improperly functioning vibration damper, a failed antifriction bearing, or a gear-type pump that is operating without prime are also possible sources of trouble when rattling noises occur.

When you hear a noise, first make sure that it is a symptom of trouble. Each diesel engine has a characteristic noise at any specific speed and load. The noise will change with a change in speed or load. As an operator you must become familiar with the normal sounds of an engine. You must investigate all abnormal sounds promptly. You can detect and locate knocks that indicate trouble by using special instruments, such as an engineer’s stethoscope, or a “sounding bar,” such as a solid metal screwdriver or bar.

Instrument Indicators

An engine operator probably relies more on the instruments to detect impending troubles than on all the other trouble symptoms combined. Regardless of the type of instruments you use, the indications are of no value if inaccuracies exist. Be sure an instrument is accurate and is operating properly. All instruments must be tested at specified intervals or whenever they are suspected of being inaccurate.

As an Engineman, you will assist in scheduling and performing various tests on your equipment. They are used to determine how your equipment is performing and if there are any equipment malfunctions. These tests are performed at various times, such as (1) before the ship goes to the shipyard for overhaul, (2) after post-deployment, (3) during a tender availability, or (4) as required by Planned Maintenance System (PMS).

The tests are performed by the ship's force, intermediate maintenance activity (IMA) personnel, shipyard personnel, or an inspection team (such as a Board of Inspection and Survey [INSURV]). Detailed types of inspections are described in *COMNAVSURFLANT Maintenance Manual,* COMNAVSURFLANTINST 9000.1C *or COMNAVSURFPAC Ship and Craft Maintenance Manual, Volumes 1 and 2, Planned Maintenance,* COMNAVSURFPACINST 4700.1B. Two types of inspections and tests that can be used to "spot" impending trouble in an internal combustion engine are called trend and spectrographic analyses.

Smoke

Smoke is a useful aid for locating some types of trouble, especially if you associate smoke in conjunction with other trouble symptoms. The color of exhaust smoke can also provide you with clues in troubleshooting.

The color of engine exhaust is a good, general indication of engine performance. The exhaust of an engine that is in good condition and operating under normal load has little or no color. A dark, smoky exhaust at normal load indicates incomplete combustion; the darker the color, the greater the amount of unburned fuel in the exhaust. Incomplete combustion may be due to a number of troubles. Some manufacturers associate a particular type of trouble with the color of the exhaust. The more serious troubles are identified below:

1. Bluish-white smoke.
   a. Worn or stuck piston rings
   b. Worn cylinder liners
   c. Worn valve guides
   d. Cracked pistons
   e. Leaking injectors
2. Black or gray smoke.
   a. Incompletely burned fuel
   b. High exhaust back pressure (clogged exhaust ports, piping, or muffler)
   c. Restricted air inlet (clogged inlet ports, air cleaner, blower inlet screen)
   d. Malfunctioning turbocharger
   e. Improperly timed or faulty injectors
   f. Engine overload (cylinders not balanced)
   g. Low compression (burned valves or stuck piston rings)

Excessive Consumption of Lube Oil, Fuel, or Water

An operator should be aware of engine trouble whenever excessive consumption of any of these vital liquids occurs. The possible troubles indicated by excessive consumption will depend on the system in question. Leakage, however, is one trouble that may be common to all systems. Before starting any disassembly, check for a misaligned system or for leaks in the system in which any excessive consumption is occurring.

Electrical Systems

Since most small boat crews do not include an electrician, it will be the responsibility of the boat engineer to troubleshoot and repair any problems in the electrical ignition and lighting systems. The ignition systems have been discussed earlier in this manual, so most of the information here will apply to auxiliary systems.

The electrical system on a typical small boat consists of the following equipment and devices:

1. A battery-charging generator or alternator driven by the propulsion engine.
2. An engine starting system.
3. A battery used both for starting the engine and for supplying auxiliary loads when the engine is secured.
4. A control and distribution panel having switches and fuses for the control and protection of circuits to auxiliary loads.
5. Cables for interconnecting the above.
6. A voltage regulator.

Ungrounded, Two-Wire, 24-Volt System

The electrical system used on Navy small boats is generally a two-wire, ungrounded, 24-volt system. The two-wire system is a necessity on a nonconducting boat hull of wood or plastic. The steel boat hull makes a good electrical conductor and permits the use of a single-wire electrical system with a grounded or hull return. There are certain reasons, however, for the use of an ungrounded, two-wire system on steel hull boats instead of the single-wire installation.

Because of environmental conditions (such as exposure to saltwater spray), an unwanted ground sometimes occurs on boat electrical systems. Experience has shown that fewer shutdowns occur on ungrounded, two-wire systems than on the single-wire systems. As a result, every effort has been made to provide a two-wire, ungrounded system, and the Electrician's Mate must maintain that system in good condition. An ungrounded system can tolerate the temporary situation of any single grounded condition, regardless of its location, because no function is affected. A variety of troubles, however, may result when two places in the same system become grounded. The more common troubles include blown fuses, failure of the starting system to energize, or faulty operation of any device, such as horns, voltage regulator, lights, and miscellaneous auxiliary loads.

Protection of Circuits

Fuses are normally provided only in the circuits supplying auxiliary loads, such as horns, running lights, cabin lights, spotlights, and communications equipment.

All other circuits, such as the starting motor circuit, solenoid switch control circuit, battery charging circuit, and power supply to the distribution panel, are unfused. This is because the possibility of short circuits or leakage currents is reduced by use of the following equipment, components, and systems:

1. Two-wire, ungrounded electrical system instead of single-wire, grounded.

2. Two-wire, ungrounded electrical components of such rugged construction as to make grounding of internal wiring or terminals difficult under normal service conditions.
3. Watertight components, such as battery connection boxes, a distribution and control panel, and a starting motor solenoid switch.
4. Cables between batteries and starting motor of sufficient size to carry high inrush currents and provided with terminal lugs and end sealing to prevent penetration of moisture.
5. Splash guards for attached generators/alternators.
6. Sealed meters or transparent splash shields to protect instruments such as battery charging ammeters.
7. Fusing of auxiliary load circuits so that faults in these circuits can be isolated.

When you are working around an engine or boat, it will be to your advantage to pay particular attention to how a unit is wired and what type of wiring is used. These observations will make your job of finding and repairing troubles much easier.

When you are on a small boat away from the ship, it will be rather difficult for you to check out a system completely because all the required test equipment will not be available. However, you can check for such things as loose or corroded connections, broken wiring, faulty switches, and burned out lamps or fuses. You can obtain detailed information pertaining to a particular installation from the appropriate NAVSEA technical manual.

OPERATING INSTRUCTIONS FOR DIESEL ENGINES

There may be occasions when a diesel engine must be started, operated, and secured under a variety of demanding conditions, such as emergencies and casualties in engine supporting systems. Operation under such unusual conditions requires that you know and understand the engine installation, the function of supporting systems, and the reasons for the procedures used in normal and emergency operations.

The procedures we will discuss in the following sections are basic steps of engine operation. These procedures do NOT contain every step that must be taken. Remember, circumstances and conditions concerning engine operation will vary. When you are starting or operating an engine or combating casualties in the engineering plant, use your *Engineering Operating Sequencing System* (EOSS).

Starting Procedures

Diesel engines are started either by hydraulic, electric, compressed air admission, or air-powered starting motors. The general starting procedure for all types of systems consists of (1) making pre-operational checks, (2) aligning supporting systems, and (3) cranking the engine with the starting equipment until ignition occurs and the engine is running.

The steps of the starting procedure will differ depending on whether you are starting the engine after routine securing, after a brief period of idleness, or after a long period of idleness. We will first list the basic steps you should follow for starting an engine that has been routinely secured under normal conditions.

After Routine Securing

To start an engine that has been routinely secured, you should first make ready the supporting systems—cooling, lubrication, and fuel—as follows:

1. Check all valves in the seawater cooling system to ensure that the system is lined up for normal operation.

2. Start the separate motor-driven seawater pump (if it is provided). If an auxiliary engine is cooled from the ship's seawater circulating system, ensure that adequate pressure and flow will be available.
3. Vent seawater coolers, using the vent cocks or vent valves on the heat exchanger shells. (If this is not done, air or gas can accumulate, reducing the effective cooling surface area of a heat exchanger).
4. Check the level in the freshwater expansion tank. Remember that a cold expansion tank will need a lower fluid level than one that is hot, so leave room for expansion.
5. Check the freshwater cooling system: Set all valves in their operating positions; start the motor-driven circulating pump (if it is provided); vent the system; and check the freshwater level in the expansion tank again. The freshwater level may have dropped if air or gas were vented elsewhere from the system.
6. Check the lubricating system: Check the oil level in the sump; add oil if necessary to bring it to the proper level. Ensure that adequate grease is applied to bearings that require grease lubrication. If oil sump heaters are installed, raise the lubricating oil temperature to 100 °F.
7. In idle engines, the lube oil film can be lost from the cylinder walls. It is desirable for you to restore this film before you actually start the engine. (Large diesel engines will restore the film by pressurizing the lube oil system and jacking the engine over without starting it. The pressure in the lube oil system will oil the cylinders, and the pistons will distribute the oil film). To pressurize the lubricating system, either start the motor-driven lubricating oil pump, or air-driven pre-lube pump (if installed), or operate a hand-operated lubricating oil pump. If the lubricating oil pump is driven by the engine, it will develop pressure when the engine is jacked over. To reduce the load on the jacking gear and prevent an accidental start, open any cylinder test valves or indicator cocks. Then, turn the engine over using the jacking gear, which may be motor-driven or hand-operated. As the engine turns over, observe the indicator cocks for excessive moisture. The presence of excessive moisture indicates water or fuel accumulation in the cylinders.
8. When you have performed the preceding operation, disengage the jacking gear and restore the cylinder test valves or indicator cocks to their operating positions.
9. Line up and prime the fuel systems. Check to ensure that there is sufficient clean fuel for the anticipated engine operation.
10. Test the alarm panel for power by manually operating such alarms as the low pressure lubricating oil alarm and the freshwater high-temperature alarm.
11. Now start the engine with the starting system. Follow the approved written procedures for the type of starting system in use.

NOTE

If the lube oil pressure does not rise immediately to the operating pressure, STOP the engine and determine the cause of the low pressure.

12. Once the engine is running, energize the low-pressure lube oil alarm and the water temperature alarm. Pay careful attention to all gauges and other indications of engine condition and performance.
13. Idle the engine until the lube oil temperature reaches 100 °F. Next, apply a light load of 20 to 30 percent. When the lube oil temperature reaches 120 °F, apply the normal load (50 to 80

percent). If possible, avoid placing a load on the engine until the engine has reached operating temperature.

> **NOTE**
>
> Normal or high loading of a cold engine will produce carbon in the cylinder heads, cause excessive engine wear, and dilute the lubricating oil. The procedures for placing the engine “on the line” will depend on the type of installation. In general, it is best to bring the engine up to speed gradually, while being alert for symptoms of trouble when you are initially loading the engine and while the engine is approaching normal range.

After a Brief Period of Idleness

Starting a warm engine, after it was recently secured and if no unusual conditions are suspected, consists of aligning the systems that may have been secured (such as circulating water), disconnecting the engine from the load, and cranking the engine up to starting speed.

Carefully observe the lubricating oil pressure. The temperature of coolant may exceed normal operating temperatures for a minute or so until the heat accumulated in the secured engine is removed.

After Overhaul or a Long Period of Idleness

You should make additional checks and inspections when the engine you are starting has been idle for a long period of time or has been recently overhauled. You should perform the following checks:

1. Inspect the parts of the engine system that have been worked on to ensure that the work is complete, that the covers have been replaced, and that it is safe to operate any valves or equipment that have been tagged out of service. (All danger tags must have been removed).
2. Check all pipe connections to see whether the connections are tight and whether the systems have been properly connected.
3. Fill the freshwater cooling system with treated water if it has been drained. Be sure coolant is flowing through all parts and components of the system. Vent the system.
4. Make a thorough check of the lubricating system. Check the sump level and fill the sump if necessary. If a separate oil pump is installed, pre-lube the engine. You can consider the system to be pre-lubed when a slight pressure registers on the engine oil pressure gauge. Then, make a visual check, with inspection plates removed, to see whether oil is present at all points of the system and in each main bearing. Examine pipes and fittings for leaks. If lubricators are installed, be sure they are filled.
5. Inspect the air receiver, the filter, and the discharge passages of the blower for cleanliness, and remove any oil accumulations.
6. If the engine has a hydraulic governor, inspect the governor oil level. If an overspeed trip is installed, be sure it is in proper operating condition and position.
7. Examine all moving parts of the engine to see that they are clear for running. Check the valve assemblies, including the intake, exhaust, and air-starting valves; and the fuel control linkage for freedom of movement.
8. Inspect the fuel service tank for the presence of water and sediment. Fill the tank with clean fuel if necessary. Start the auxiliary fuel pump (if one is installed) and see whether the fuel

pressure gauges are registering properly. Examine the fuel piping and fittings for leaks, especially the fittings and lines inside the engine. Thoroughly vent all air from the fuel system, using the vent cocks. Be sure that the fuel strainers have been cleaned and that new filter elements have been installed.

9. If the engine has an air-starting system, open the lines on the system and blow them out. Reconnect the lines and pressurize the starting air banks (flasks).
10. Make a final check to ensure that all parts are in place, then open all scavenging-air header and exhaust header manifold drains.
11. Now start the engine, using the procedures for a routinely secured engine.

Normal Operating Procedures

Operation of a diesel engine cannot be separated from the operation of the equipment the engine is driving. Each type of engine and installation has its special operating routine. A systematic procedure has already been established, based on these special requirements and on the experience of the engine operators with the particular installation. You must respect and follow this procedure, Engineering Operating Procedure (EOP), *Figure 14-1*. The following information is general and should be considered as incomplete in terms of operation of any specific plant. While an engine is operating, its performance is monitored and observed for two purposes:

1. To recognize any unsatisfactory operation or impending malfunctions early so that immediate casualty control procedures can be started.
2. To recognize any unsatisfactory operation or impending malfunctions early so that immediate casualty control procedures can be started.

You must keep a complete log of all operating conditions. Observe and record the operating pressures and temperatures in the log at hourly intervals. Compare the entries over a period of time and note any deviations from normal conditions. An example of an engine operating record is provided in *Figure 14-2*.

You must be alert to changing or unusual noises made by the operating machinery. Gradually changing sounds are difficult to detect, especially if you are inexperienced. Often an oncoming watch will detect a new sound that the present watch was not aware of. When unusual operating conditions occur, load, lubrication, cooling, engine speed, or fuel supply problems are usually responsible, either directly or indirectly. You must be alert to changes in any of these areas. In the next sections, we will provide you with some general guidelines.

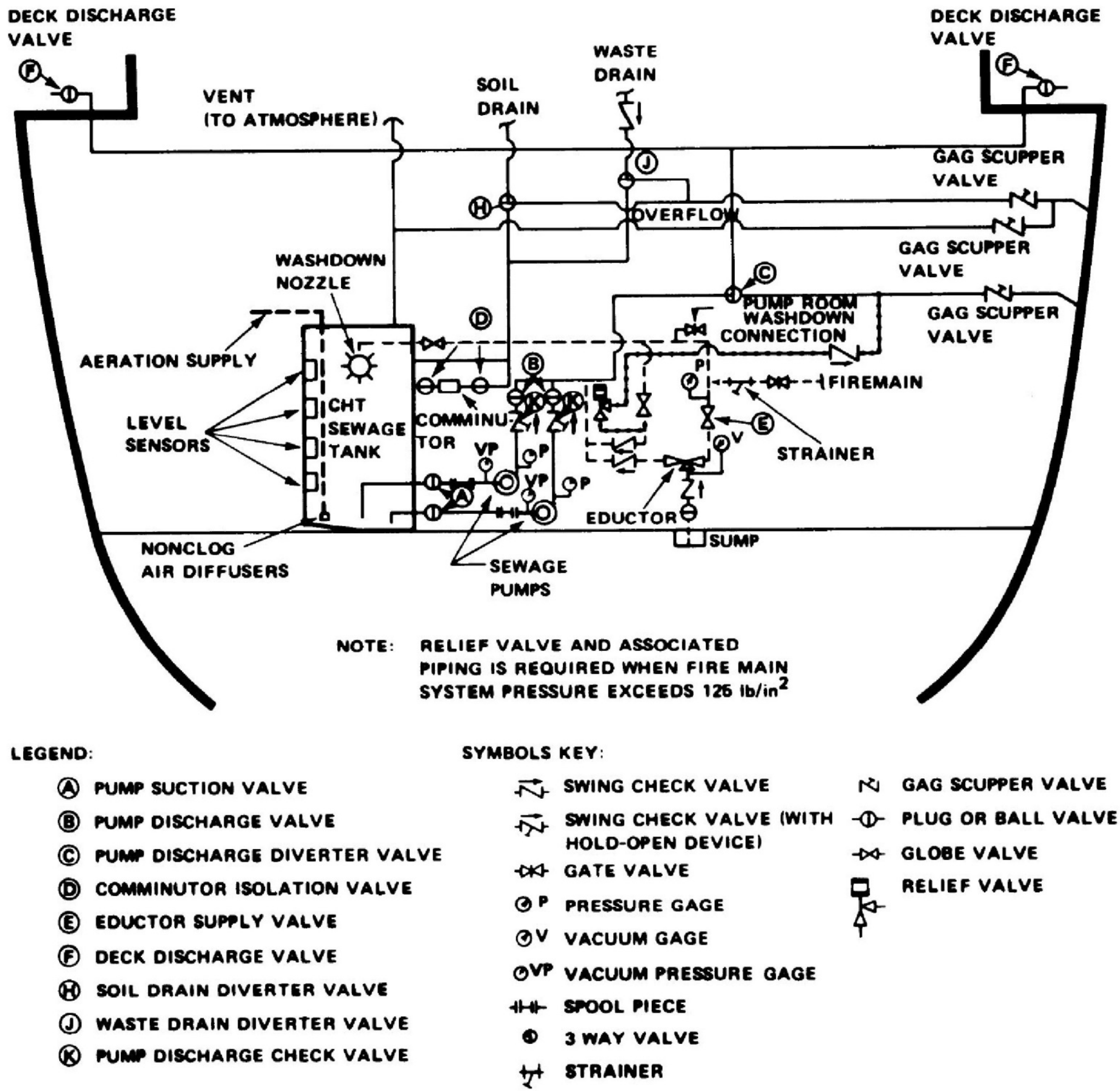

Figure 14-1 — Engineering Operating Procedure (EOP).

DIESEL ENGINE OPERATING RECORD-ALL SHIPS

NAVSEA 9231/2 (9-78)(FORMERLY NAVSEC 9410/2) S/N 0116-lf-092-3110 RETAIN 2 YEARS - THEN DISPOSE ACCORDING TO CURRENT DISPOSAL INSTRUCTIONS

U.S.S.	TIME ZONE DESCRIPTION	CLOCKS SET-BACK OR AHEAD HRS. MINUTES AT	LOCATION ☐ AT SEA ☐ IN PORT	DATE

CHECK ONE ☐ PROPULSION ☐ AUXILIARY ENGINE NO. ________ *Preferred to 30" Barometer

DISREGARD WHEN NOT REQUIRED

TIME	TACHOMETER	GENERATOR					TEMPERATURES										PRESSURES										
		ELECTRIC LOAD		TEMPERATURE			SALT WATER		FRESH WATER			LUBE OIL		HOTTEST CYLINDER		SCAV-ENG-ING AIR	SEA WATER AT PUMP	FRESH WATER TO ENG.	LUBE OIL		FUEL OIL		SCAV-ENG-ING AIR	BACK PRES-SURE (IN.)	VAC.* UUM (IN.)	CRANK CASE MA-NOM-ETER (IN.)	LUBE-OIL SUMP (GAL.)
		AMPS.	VOLTS	AIR TO CLR.	FWD. BRG.	AFT. BRG.	INJEC-TION	OVER-BD.	TO ENG.	FROM ENG.	TO OIL CLR.	TO. ENG.	FROM ENG.	NO.	TEMP.				AT PUMP	AT ENG.	TO FILT.	FROM FILT.					
0100																											
0200																											
0300																											
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TIME	CLUTCH AND REDUCTION GEAR					
	L.O. IN CLUTCH (°F)	L.O. OUT CLUTCH (°F)	L.O. IN R. GEAR (°F)	L.O. OUT R.GEAR (°f)	L.O. OR AIR IN CLUTCH (°F)	L.O. IN R. GEAR (P.S.I.)
0100						
0200						
0300						
0400						
0500						
0600						
0700						
0800						
0900						
1000						
1100						
1200						
1300						
1400						
1500						
1600						
1700						
1800						
1900						
2000						
2100						
2200						
2300						
2400						

ENGINE HOURS	THIS COMMISSION	TOTAL TODAY	BROUGHT FWD.	TOTAL	SINCE OVERHAUL	TOTAL TODAY	BROUGHT FWD.	TOTAL	SNORKEL	TOTAL TODAY	BROUGHT FWD.	TOTAL

0000-0400	0400-0800	0800-1200

Figure 14-2—Diesel engine operating record.

Load

The manner of applying a load to an engine and the regulation of the load will depend on the type of load and the design of the system. The procedures for loading an engine, or placing it on the line, are established by the EOSS.

Whenever you are starting a cold engine, allow ample time to build the load up gradually.

NEVER fully load an engine before it has been warmed up. Gradual application of the load will prevent damage to the engine from such conditions as uneven rates of expansion and inadequate lubrication at low temperatures. (An exception to this rule is the use of emergency generators, set up for automatic mode, in which the engines must take on rated loads as soon as they are started).

Never operate a diesel engine for prolonged periods with less than one-third of its rated load. Combustion at low load is incomplete, so partially burned fuel and lubricating oil may cause heavy carbon deposits which will foul the valve stems, injector tips, piston rings, and exhaust systems.

In addition to these problems, prolonged operation at low-load conditions may cause the exhaust valves to stick and burn, dilute the lubricating oil, scuff the cylinder liners, increase fuel consumption, and cause excessive smoke when the load is increased. If you must operate an engine at less than 30 percent power for more than 30 minutes, you should increase the load to above 50 percent power at the first opportunity.

Diesel engines are designed to operate up to full-load conditions for prolonged periods. However, diesel engines should NEVER be operated at an overload except in an emergency. This includes both excessive torque and engine speed. Overload may be indicated by excessive firing pressures and exhaust temperatures. When conditions indicate an overload, reduce the load immediately.

Lubrication

The performance of the lubrication system is one of the most important factors of engine operation you can monitor. Indicators continuously show oil temperature and pressure in key parts of the system. While the engine is operating, you should monitor the indicators and sight glasses on a regular basis. An alarm (horn or siren) will usually warn you of low pressure. If an alarm is not installed, you must continuously monitor the oil pressure and check the oil level.

Under typical operating conditions, you should be able to estimate the rate at which the engine burns its lubricating oil and to predict when replenishment will be needed.

The condition and cleanliness of the lubricating oil is critical for long engine life. Therefore, you should clear the metal-edge type of lubricating oil strainers by rotating the cleaning handle. This procedure should be performed during each watch. The condition of filters is often indicated by the amount of pressure drop from the inlet to the outlet.

Pressures and Temperatures

You must ensure that all pressures and temperatures are maintained within the normal operating ranges. If this is not possible, secure the engine. You must also check all instruments frequently. The NAVSEA technical manual will provide you with detailed information concerning the proper operating pressures and temperatures. When this information is not available, maintain the temperature of the lubricating oil as it leaves the engine between 160 and 200 °F, and maintain the temperature of the freshwater as it leaves the engine at not less than 155 °F or more than 185 °F. Do not allow the temperatures in the seawater cooling system to exceed 130 °F. Higher temperatures will cause deposits of salt and other solids in the coolers and piping and will aggravate corrosion. Make frequent checks of the cooling system to detect any leaks. Vent coolers and heat exchangers at least once each watch. Check the level of the freshwater in the expansion tank frequently and add freshwater as necessary. If the freshwater level gets low enough to cause overheating of the engine, NEVER add cold water until after the engine has cooled.

Critical Speeds

The vibrations resulting from operation at destructive critical speeds will cause serious damage to an engine. All moving parts of machinery have critical speeds. Critical speed means there are certain ranges of speed during which excessive vibration in the engine will be created. Every part of the engine has a natural period of vibration, or frequency. When impulses set up a vibration that coincides with the natural frequency of the body, each impulse adds to the magnitude of the previous vibration. Finally, the vibration becomes great enough to damage the engine structure.

Vibration may be set up by linear impulses from reciprocating parts or by torsional impulses from rotating members. The crankshaft is the part that causes torsional vibration, because pressure impulses on the piston cause the crankshaft to twist. When the pressure acting on the piston in each cylinder decreases, the shaft untwists. If pressure impulses, which are timed to the natural period of the shaft, are permitted to continue, the amplitude of vibration will become so great that the shaft can break. If the speed of such an engine is changed, the pressure impulses will no longer coincide with the natural period of the shaft and the excessive vibration will stop. Since each engine has a natural period of vibration, the only control you have is to avoid operating the engine at critical speeds. If critical speeds exist below the normal speed of the engine, you should pass through the critical ranges as quickly as possible when you are changing engine speed.

Detailed information concerning critical speed ranges is provided with each installation. Tachometers should be marked to show any critical speed ranges to make it easier for you to keep the engine out of the critical ranges. Remember, tachometers sometimes get out of adjustment. Consequently, you should frequently compare each tachometer with a calibrated mechanical counter.

Fuel

You must maintain an adequate supply of clean fuel. Check the fuel system frequently for leaks. Clean all fuel strainers at periodic intervals. Replace fuel filter elements whenever necessary. When diesel fuel purifiers are provided, purify all fuel before you transfer it to the service or day tanks. Frequently check the service tanks for water and other settled impurities by sampling through the drain valve at the bottom of the tank. Drain off water and impurities.

Stopping and Securing Procedures

You can stop a diesel engine by shutting off the fuel or air supply. You can shut off the fuel supply by placing the throttle or the throttle control in the STOP position. If the engine installation permits, it is a good idea to allow the engine to idle, without load, for a short time before you stop it. This practice will permit engine temperature to reduce gradually. It is also good practice to operate the manual overspeed trip when you are stopping the engine so that you can check the operating condition of the device.

Before tripping the overspeed trip, reduce the engine speed to the specified idling speed. Some overspeed trips reset automatically. In some installations, however, you must reset the overspeed trip manually before the engine can be started again.

In addition to the detailed procedures listed in various EOSS checklists and NAVSEA technical manuals, you should take the following steps after an engine has stopped:

1. Open the drain cocks on the exhaust lines and on the scavenging-air inlet headers (if they are provided).

2. Leave open the specified number of indicator cocks, cylinder test valves, or hand-operated relief valves so you can detect any water accumulation in the cylinders prior to starting the engine.
3. Secure the air pressure. If starting air is left on, the possibility of a serious accident will increase.
4. Close all sea valves.
5. Allow the engine to cool.
6. Clean the engine thoroughly by wiping it down before it cools. Clean the deck plates and see that the bilges are dry.
7. Arrange to have any casualties repaired. No matter how minor casualties may appear, repairs must be made and troubles must be corrected promptly.

Precautions in Diesel Engine Operation

You must obtain the specific safety precautions for a given engine from the appropriate NAVSEA technical manual. In addition to the guidelines in the NAVSEA technical manual, you should observe the following precautions when operating or maintaining a diesel engine.

Relief Valves

If a relief valve on an engine cylinder lifts (pops) several times, stop the engine immediately. Determine the cause of the trouble and decide upon the correct solution. Except in an emergency, NEVER lock a relief valve in the closed position. Pressure-relief mechanisms are fitted on enclosures in which excessive pressures may develop.

Fuel

When fuel reaches the injection system, it should be absolutely free of water and foreign matter. You must thoroughly centrifuge the fuel before using it, and you must keep the filters clean and intact. Remember, fuel leakage into the lubricating oil system will cause dilution of the lubricating oil with a consequent reduction in viscosity and lubricating properties.

Cooling Water

Do NOT allow a large amount of cold water, under any circumstances, to enter a hot engine suddenly. Rapid cooling may crack a cylinder liner and head or may cause a piston to seize within a cylinder. Reduce the load or, when ordered to do so, stop the engine when the volume of circulating water cannot be increased and the temperatures are too high. In freezing weather, you must carefully drain all passages and pockets in the engine that contain freshwater and that are subject to freezing, unless an antifreeze solution has been added to the water.

Starting Air

When engines are stopped, you must vent all starting-air lines. Serious accidents may result if pressure is left on. Intake air must be kept as clean as possible. Accordingly, you must keep all air ducts and passages clean.

Cleanliness

Cleanliness is essential to efficient operation and maintenance of diesel engines. You must maintain clean fuel, clean coolants, clean lubricants, and a clear exhaust. You must also keep the engines clean at all times, and take steps to prevent oil or fuel from accumulating in the bilges or in other areas to prevent fire hazards.

EMERGENCY DIESEL GENERATORS

Most naval ships are equipped with diesel driven emergency generators. (Diesel engines are most suitable for this application because of their quick-starting ability). Emergency generators furnish power directly to vital electrical auxiliaries, such as the steering gear and the ship's gyro. Emergency generators may serve as a source of power for the casualty power distribution system. All engineering personnel should become familiar with the emergency and casualty power systems aboard their ship.

Emergency diesel generator sets must be ready at all times for immediate use. You should complete the following checks to ensure that the support systems and control system are aligned and that the emergency generator is ready for operation.

1. Fuel service tank filled, with all water drained.
2. Fuel system valves correctly aligned.
3. Air flask(s) charged.
4. Air-starting system valves correctly aligned.
5. "Keep warm" system(s) (if used) activated.
6. Switchboard set to AUTOMATIC position (The green light should be on).

A typical shipboard plant may consist of two emergency diesel generators, one forward (near the bow and above the waterline) and one aft (near the stern), in spaces outside the main machinery spaces. Each emergency generator has its individual switchboard and switching arrangement for control of the generator and for distribution of power to certain vital auxiliaries and to a minimum number of lighting fixtures in vital spaces.

The capacity of the emergency unit varies with the size of the ship in which it is installed. Regardless of the size of the installation, the principle of operation of the engine is basically the same as it is for any diesel engine.

Emergency diesel engines are started either by compressed air or by a starting motor and develop full-rated load power within 10 seconds of starting. In a typical installation, the starting mechanism is actuated when the ship's normal supply voltage on the bus falls to approximately 80 percent. The generators are not designed for parallel operation. When the ship's supply voltage fails, a transfer switch automatically disconnects the emergency switchboard from the main distribution switchboard and connects the emergency generator to the emergency switchboard. With this arrangement, transfer from the emergency switchboard back to the main distribution switchboard is accomplished manually. Then, the emergency generator must be manually stopped and reset for automatic starting. Since emergency diesel generators are of limited capacity, only certain circuits can be supplied from the emergency bus. These include such circuits as the steering gear and the interior communications switchboard. If some vital circuit is secured, another circuit may then be cut in, up to the capacity of the generator.

Operating Instructions

Normally, the emergency diesel generator will start automatically, but for test purposes and under other conditions it may be started and operated manually. The following guidelines are for testing the operation of an air-started emergency diesel generator set.

The engine is started automatically when the ship's normal supply fails and causes the solenoid air valve (located between the starting-air flask and the engine) to open, admitting starting air to the engine. The engine then turns over on air until firing begins. As the engine speed increases, the air cutoff governor valve closes and shuts off the starting air. As soon as the normal operating speed is reached and the generator develops normal voltage, the solenoid air valve also closes to shut off the starting-air supply. (The starting-air flask is charged from the high-pressure air system, through a reducing valve. The air stored in the starting-air flask varies in pressure from 300 to 600 psi, depending on the installation).

To start the engine manually, de-energize the solenoid valve. If the ship's supply current is not broken, you must open the switch in the solenoid circuit. Then, admit starting air to the engine by opening the valve manually with the handwheel.

After firing begins, turn the handwheel to close the valve and cut off the starting air. (The handwheel must be turned to the open position of the valve whenever you must leave the generator set available for emergency service). If the lubricating oil pressure does not build up immediately after the engine starts, shut down the engine and determine the cause of the trouble. NEVER operate the engine without lubricating oil pressure. At regular intervals, check the lube oil pressure, fuel pressure, cooling water temperature, and exhaust temperature. (In addition, clean the fuel and lubricating oil filters regularly).

To SHUT DOWN or STOP the engine, move the fuel-control lever to the STOP position. After the lever is released, it will automatically return to the running position to permit the engine to be restarted.

Operating Precautions

You must observe the following operating precautions and inspections:

1. Do NOT operate the engine without lubricating oil pressure; this will cause serious damage.
2. Do NOT operate the engine in an overloaded or unbalanced condition. An overload condition on one or more cylinders may be indicated by an increase in the exhaust temperature or by smoky exhaust.
3. Do NOT operate the engine with an abnormal water outlet temperature.
4. Do NOT operate the engine after an unusual noise develops; the noise might be an indication of pending trouble. Investigate the noise and correct any trouble, particularly if the condition may prove harmful to the engine.
5. If the overspeed device trips and shuts down the engine, investigate the cause of the trouble before you restart the engine.
6. Make certain that the fittings of the ventilation system that serve the compartment in which the engine is located are open. If you start a diesel engine while the vent system is secured, the engine will consume the air in the compartment.

   Under these conditions, the engine may continue to operate long enough to suffocate you. This precaution applies to installations where the engine does not have a direct air supply from the outside to the intake manifold. These precautions also apply to emergency diesel fire pumps.

FACTORS INFLUENCING ENGINEERING CASUALTY CONTROL

Casualty prevention is the most effective form of casualty control. The primary instructions and guidelines you should use to handle any engineering casualty to your ship are as follows:

1. Engineering Operational Casualty Control (EOCC) procedures.
2. Ship's casualty control manual (for ships without EOCC).
3. Ship's damage control manual.
4. Ship's damage control bills (part of the ship's Watch, Quarters, and Station Bill).

5. *Ship's Organization and Regulation Manual* **(**SORM)

The following are just examples of instructions and guidelines that could be used to handles specific engineering plant casualties.

INOPERATIVE SPEED GOVERNOR

1. Control the engine manually, if possible.
2. Notify the engineering officer and the bridge and request permission for engine repairs.
3. When permissions have been obtained, check the governor control mechanism.
4. Check the linkage for binding or sticking.
5. Check the lubrication; flush and refill with proper oil.
6. Check setting of needle valve.
7. Make repairs. When they are complete, start the engine and check the operation. When it is operating properly, notify the engineering officer and the bridge.

ABNORMALLY HIGH LUBE OIL TEMPERATURE

1. Check the lube oil pressure.
2. Check the saltwater pump discharge and the temperature of the cooling water.
3. Check the freshwater level in the expansion tank and the temperature of the freshwater.
4. Check the sea suction and the overboard valves.
5. Vent the freshwater and the saltwater pumps.
6. Check the operation of the thermostat control valve to the lube oil and freshwater heat exchanger.
7. Report any trouble found to the engineering officer and the bridge. Request permission to secure the engine for repair.
8. When permission is received, make repairs.
9. After all repairs are complete, check the engine for proper operation, report it to the engineering officer and the bridge.

INOPERATIVE DIESEL FUEL OIL TRANSFER PUMP

1. Line up the diesel fuel to supply the tank as quickly as possible.
2. Notify the engineering officer and the bridge of the casualty.
3. In an emergency, line up and use the hand- operated pump in order to operate.
4. At the earliest possible time, inspect and repair the fuel oil transfer pump.
5. Report the results of the investigation and the repairs to engineering officer and the bridge.

INOPERATIVE COUPLING LUBE OIL REGULATING VALVE

1. Maintain the correct operating pressure by manually operating the clutch dump valve.
2. Report to the engineering officer and the bridge. Request permission to secure the engine to affect repair.
3. When permission is granted, replace or repair the valve.
4. Test for proper operation.
5. If the valve is operating properly, report to the engineering officer and the bridge.

COUPLING THROWING OIL

1. Check the system. Attempt to repair the leak.
2. Report to the engineering officer and the bridge. If the leak is not repaired, request permission to secure the engine for repairs.
3. When permission is granted, secure the engine, conduct an investigation, and make necessary repairs.
4. Upon completion of repairs, test the coupling.
5. Report to the engineering officer and the bridge

Design

Sound design influences the effectiveness of casualty control in two ways: (1) it eliminates weaknesses which may lead to material failure, and (2) it installs alternate or standby means for supplying vital services in the event of a casualty to the primary means. Both of these factors are considered in the design of naval ships.

Individual plants on board ship are equipped with duplicate vital auxiliaries, loop systems, and cross-connections. Complete propulsion plants are also designed to operate as isolated units (split-plant design).

Communications

As a provision for sufficient means of communication to be available, several different systems are installed aboard ship. The normal means of communications are the battle telephone (sound-powered) circuits, interstation 2-way systems (intercoms), ship's service telephones, ship's loudspeaker (1-MC), and voice tubes. Messengers are used in some situations when other methods of communication are not available or when written reports are required.

Transmission of correct information regarding a casualty and the speed with which the report is made are the principal values of any method of communication.

Control of all communication circuits must be established by the control station. The circuits must never be allowed to get out of control from "cross talk" caused by more than one station.

Casualty control communications must be incorporated into casualty control training. The control station or engineering control must be promptly notified of a casualty so that other casualties (which could be more serious than the original casualty) can be prevented.

Training

Casualty control training must be a continuous step-by-step procedure with constant refresher drills. Realistic simulation of casualties requires adequate preparation. The amount of advance preparation required is not always readily apparent. You must carefully visualize the full consequences of any error that could be made in handling simulated casualties that were originally intended to be of a relatively minor nature. There must be a complete analysis and all participants must be carefully instructed before simulation of major casualties and battle damage. A new crew must have an opportunity to become familiar with the ship's piping systems and equipment before simulation of any casualty that may have other than purely local effects.

In the preliminary phases of training, a "dry run" is useful for imparting knowledge of casualty control procedures without endangering the ship's equipment by a too realistic simulation of a casualty. Under this procedure, a casualty is announced, and all individuals are required to report as though action were taken. (An indication must be made that the action is simulated). Definite corrective actions can be taken, and with careful supervision the timing of individual actions can appear to be very realistic.

Regardless of the state of training, dry runs should always be held before actual simulation of any involved casualty. Similar rehearsals should be held before simulation of relatively simple casualties whenever new personnel are involved and particularly after an interruption (such as a naval shipyard overhaul period) of regularly conducted casualty training has occurred.

CORRECTION AND PREVENTION OF CASUALTIES

The speed with which corrective action is taken to control an engineering casualty is of paramount importance. This is particularly true for casualties that affect the ship's propulsion power plant, steering system, and electrical power generation and distribution. If casualties associated with these functions are allowed to accumulate, they may lead to serious damage to the engineering installation—damage that often cannot be repaired without loss of the ship's operating availability.

When risk of possible permanent damage exists, the commanding officer has the responsibility of deciding whether to continue operation of the equipment under casualty conditions. Such action can be justified only when the risk of even greater damage, or loss of the ship, may be incurred if the affected unit is immediately secured.

Whenever there is no probability of greater risk, the proper procedure is to secure the malfunctioning unit as quickly as possible even though considerable disturbance to the ship's operations may occur. Although speed in controlling a casualty is essential, action should never be undertaken without accurate information; otherwise, the casualty may be mishandled and cause irreparable damage and possible loss of the ship. War experience has shown that the cross-connecting of intact systems with a partly damaged one must be delayed until it is certain that such action will not jeopardize the intact systems. Speed in handling casualties can be achieved only by thorough knowledge of the equipment and associated systems and by thorough and repeated practice in performing the routines required to control specific, predictable casualties.

Phases of Casualty Control

The handling of any casualty by shipboard personnel can usually be divided into three phases:

1. Limiting of the effects of the damage.
2. Emergency restoration.
3. Complete repair.

The first phase is concerned with immediate control of a casualty to prevent further damage to the affected unit and to prevent the casualty from spreading through secondary effects, commonly known as “cascading.” (One fault leads to another).

The second phase requires the use of EOPs and involves restoring, as far as practicable, the services that were interrupted as a result of a casualty. For many casualties, the completion of this phase will eliminate all operational handicaps, except for the temporary loss of standby units, which will lessen the ability of the machinery to withstand additional failure. If no damage to, or failure of, machinery has occurred, this phase usually completes the operation.

The third phase of casualty control consists of making any repairs required to completely restore the installation to its original condition.

Split-Plant Operation

A primary method of casualty prevention and control is use of the split-plant mode of operation. The purpose of the split-plant design is to minimize battle damage that might result from a single hit.

Most naval ships that were built primarily as warships have at least two engineering plants. Larger combatant ships have four individual engineering plants. Split-plant operation means aligning support systems, engines, pumps, and other machinery so that two or more propulsion plants and/or electrical generating plants are available, each complete in itself. Each main engine installation has its own piping systems and other auxiliaries. Each propulsion plant operates its own propeller shaft. If one plant were to be put out of action by explosion, shellfire, or flooding, the other plant could continue to drive the ship ahead, though at somewhat reduced speed.

Split-plant operation is not absolute insurance against damage that might immobilize the entire engineering plant, but it does reduce the chances of such a casualty. It prevents transmission of damage from one plant to another or possible serious effect on the operation of the other plant or plants. It is the first step in the prevention of major engineering casualties.

The fuel system is generally arranged so that fuel transfer pumps can take suction from any fuel tank in the ship and can pump to any other fuel tank. Fuel service pumps supply fuel from the service tanks to the main engines. In split-plant operations, the forward fuel service pumps of a ship are lined up with the forward service tanks, and the after service pumps are lined up with the after service tanks. The cross-connect valves in the fuel transfer line must be closed except when fuel is being transferred.

Diesel propulsion plants are designed for split-plant operation only; however, some of the auxiliary and main systems may be run cross-connected or split. Among these auxiliaries are the starting-air systems, cooling-water systems, firemain systems, and, in some plants, the fuel and lube oil systems.

In diesel-electric installations, the diesel elements are split, but the generator elements can be run split or cross-connected. The advantages of this type of installation will depend on operating procedures as well as design.

Locking Main Shaft

An engineering casualty may be such that continued rotation of the main shaft will cause further damage. The main shaft should be locked until necessary repairs can be made since, except at very low speeds, movement of the ship through the water will cause the shaft to turn. Turning of the shaft will occur whether the ship is proceeding on its own power or being towed.

For locking a main shaft, there are no standard procedures applicable to all types of diesel-driven ships. For ships that have main reduction gears, shaft locking of the turning gear is permissible, provided it is designed for this purpose. Some ships have brakes that are used to hold the shaft stationary. On diesel-electric drive ships, no attempt should be made to hold the shaft stationary by energizing the electrical propulsion circuits.

Emergency Procedures

Under certain circumstances, you may be ordered to start additional engines. Time may not permit you to follow the normal, routine procedures. You may have to use emergency procedures. Because emergency procedures will differ, depending on the installation, you must be familiar with the specific procedures established for your ship.

ENGINE ROOM CASUALTIES

In the event of a casualty to a component of the propulsion plant, the principal objective is to prevent additional or major casualties. Where practicable, the propulsion plant should be kept in operation with standby pumps, auxiliary machinery, and piping systems. The important thing for you to remember is to prevent minor casualties from becoming major casualties, even if it means suspending the operation of the propulsion plant. It is better to stop the main engines for a few minutes than to risk putting them completely out of commission, a condition that will require major repairs.

When a casualty occurs, the engineering officer of the watch (EOOW) must be notified immediately. The EOOW will notify the officer of the deck (OOD) and the engineer officer. Main engine control must keep the bridge informed as to the nature of the casualty, the ship’s ability to answer bells, the maximum speed available, and the probable duration of the casualty.

General Safety Precautions

In addition to following the specific safety precautions listed in the operating instructions for an engine, you must continuously exercise good judgment and common sense when taking steps to prevent damage to material and injury to personnel.

In general, you can help to prevent damage to machinery by operating engines according to prescribed instructions, by using practices such as “bagging and tagging” parts that were removed from an engine during maintenance or overhaul, by having a thorough knowledge of your duties, and by being totally familiar with the parts and functions of the machinery you are operating and maintaining.

By maintaining machinery so the engines will be ready for full-power service in the event of an emergency and by taking steps to prevent conditions that are likely to constitute fire or explosion hazards, you can also help to prevent any damage that might occur outside of the ship. (This type of damage may take the form of damage to piers or other external structures or to other marine craft whenever a loss of control over the ship occurs).

Remember, personnel work most safely when they thoroughly know how to perform their duties, how to use their machines, how to take reasonable precautions around moving parts, and when they are consistently careful and thoughtful while performing their duties.

Emergency Starting and Securing Procedures

There may be times when an engine must be started, operated, or secured under emergency conditions. Before this becomes necessary, operating personnel should learn the procedures in the ship's EOCC. These procedures should be posted at the engine control station or operating position. Operators should be drilled in casualty control procedures at regular intervals. There is a definite hazard to starting a diesel engine under emergency conditions because personnel are rushed and tend to be careless.

There is always time for you to ensure that personnel are clear of external moving parts, such as belt drives and shafts, before actuating the starting gear. If emergency repairs have been made, be sure that all tools are accounted for before you close up the engine and that all essential parts have been replaced before you start the engine. An engine can be started and run briefly if it has air and fuel and if the starting system will operate. It will run much longer if it has functional lubrication and cooling systems.

With the exception of some boat engines that can be started by towing, there is no backup for the starting system. Usually sufficient spare parts and resources are available for you to restore any casualty to the starting system. Remember, however, if the repair is rushed, the danger resulting from careless work will increase.

In an emergency, you can start an engine by lining up the fuel system and actuating the starter. Before you do this, however, make certain that there is a supply of air to the engine and engine compartment and that the lubricating system will operate. After starting, establish cooling-water flow and review all the normal pre-starting checks as quickly as possible.

If an operating engine suffers a casualty, the decision of whether to continue operating or to secure the unit must be made immediately. The condition of the ship's operation is an important factor in this decision. In some instances, when risk of possible permanent damage exists, the commanding officer has responsibility for deciding whether to continue operation of equipment under casualty conditions.

Such action can only be justified when the risk of greater damage, or loss of the ship, may be incurred if the affected unit is secured. Risk to the ship is present in actual combat situations, severe weather conditions, narrow channels, and potential collision situations, which include close-formation maneuvering with other ships.

Engines can be operated with casualties to vital auxiliaries if the function of the auxiliary unit can be produced by other means. For instance, cooling-water flow can be reestablished from a firemain, and an engine can operate for some time with seawater in its cooling system as long as the cooling system is rinsed well afterward.

If the decision is made to secure an engine that has suffered a casualty, the general rule is to stop the engine as soon as possible. In the case of a propulsion engine, it will usually be necessary to stop the shaft also. This may require slowing the ship until the shaft is stopped and locked with the turning gear, shaft brake, or other means.

You can almost always stop an engine by securing the flow of fuel. Occasionally, this method will not work since a blower seal leak or a similar situation may permit the engine to run on its own lubricating oil. If you cannot brake the engine to stop it or slow it by increasing the load, you must find some means to stop the airflow to it.

To stop the airflow, you can activate engine shutdown devices (such as air intake flappers) to cover the air intake or you can find some way of securing the air to the blower intake. If you try to secure the air to the blower intake, make certain that the covering will not be sucked into the blower, as this would cause an additional casualty.

NOTE

Do not attempt to use a portable carbon dioxide (CO_2) fire extinguisher to secure a diesel engine. The CO_2 in the portable extinguisher will have little or no effect on the diesel engine. This is because the volume of air consumed by the diesel engine will be far greater than the volume of CO_2 contained in the extinguisher bottle.

SUMMARY

In this chapter, we have discussed some basic operating procedures that you may be able to apply to the type of unit to which you will be assigned. Our intent in this chapter was to provide you with general knowledge in regard to engine room operations and to direct you in handling the engineering room and equipment in unusual conditions. You should also be able to recognize the fundamental starting, operating, and stopping procedures you should use for a diesel engine under normal operating conditions and some of the emergency and casualty prevention procedures you may have to use under adverse circumstances.

End of Chapter 14

Diesel Engine Operating Practices

Review Questions

14-1. Why must you familiarize yourself with the specific temperatures, pressures, and operating speeds of equipment required for normal operations?

A. Easier to stand watch
B. Training new personnel
C. Detect any departure from normal operating conditions
D. Better training on aligning the systems

14-2. What should be done when collecting a lubricating oil sample from a piece of equipment that has been idle for some time?

A. Start the engine to warm the lubricating oil
B. Take the sample and wipe the area down
C. Drain a sufficient sample from the lowest part to remove all of the settled water
D. Tag out equipment and take the sample

14-3. What noise is associated with an improperly functioning valve mechanism or timing gear?

A. Clicking
B. Knocking
C. Pounding
D. Rattling

14-4. What does bluish-white exhaust smoke indicate from a diesel engine?

A. High exhaust back pressure (clogged exhaust ports, piping, or muffler)
B. Improperly timed or faulty injector
C. Low compression (burned valves or stuck piston rings)
D. Cracked pistons

14-5. What electrical system is necessary on a non-conducting boat hull of wood or plastic?

A. Grounded
B. Balanced
C. Two-wire
D. Three-wire

14-6. When you are starting or operating an engine or combating casualties in the engineering plant, what documentation should be used?

A. *Naval Ship's Technical Manual* (NSTM)
B. *Engineering Operating Sequencing System (*EOSS)
C. *Naval Sea System Command* (NAVSEA) technical manual
D. *Engineering Operating Procedures* (EOP)

14-7. What is the minimum temperature of the lubricating oil on a diesel engine that has been routinely secure that needs to be started?

A. 50 °F
B. 75 °F
C. 100 °F
D. 125 °F

14-8. What is the range of a normal load if applied to a diesel engine when the lubricating oil temperature reaches 120 °F?

A. 40 percent
B. 70 percent
C. 90 percent
D. 100 percent

14-9. When should a diesel engine be operated in an overload condition?

A. Emergency
B. Never
C. Break away
D. Exiting ports

14-10. What is a good indication that there is an unusual condition in the lubricating oil system on an operating diesel engine?

A. Clear smoke
B. Normal temperature
C. Normal pressures
D. Alarms going off

14-11. When securing a diesel engine you want to leave a specified number of indicator cocks open for what reason?

A. Assist in cooling the diesel engine down
B. Inspect cylinder after shutdown
C. Clean cylinder after shutdown
D. Detect any water accumulation in the cylinder prior to starting the diesel engine

14-12. While an emergency generator furnishes power, what electrical auxiliary is NOT considered a vital source?

A. The internet
B. Steering gear
C. Ship's gyro
D. Casualty distribution system

14-13. How is communication established during Engineering Casualty Control drills?

A. From damage control
B. From the control station
C. From the bridge
D. From repair five

14-14. What system is NOT designed for split-plant operation?

A. Fuel
B. Oily waste
C. Starting air
D. Cooling-water

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CHAPTER 15

TRANSMISSION OF ENGINE POWER

If the power developed by an engine is to be used to perform useful work, there must be some way to transmit the power from the engine (driving unit) to such loads as the propeller of a ship or boat, or the drive shaft of a generator, a compressor, or a pump. This chapter provides general information on how the force available at the crankshaft of an engine is transmitted to a point where it will perform useful work. The combination of devices used to transmit engine power to a driven unit is commonly called a drive mechanism.

After reading the information in this chapter, you should be able to identify various components associated with the drive mechanism, such as clutches, gears, couplings, and bearings, in terms of the ways in which they function to transmit the power from the engine to the driven unit. You should also be able to recognize the more common problems associated with these drive mechanisms, and some general procedures you should perform for preventive maintenance.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the function and maintenance of machinery transmissions.
2. Explain the function and maintenance of machinery clutches, reversing gears, and reduction gears.
3. Discuss the operation and maintenance of main shaft components.
4. Explain the procedures for replacing flexible couplings.
5. Discuss the operation and maintenance of the controllable pitch propeller (CPP).

FACTORS RELATED TO THE TRANSMISSION OF ENGINE POWER

The basic characteristics of an internal combustion engine make it necessary, in many cases, for the drive mechanism to change both the speed and the direction of shaft rotation in the driven mechanism. There are various methods for making required changes in speed and direction during the transmission of power from the driving unit to the driven unit. In most of the installations with which you will be working, the power is transmitted by a drive mechanism consisting principally of gears and shafts.

The process of transmitting engine power to a point where it can be used in performing useful work involves a number of factors. Two of these factors are torque and speed.

Torque

Torque, or turning force, is the force that tends to cause rotational movement of an object. The crankshaft of an engine supplies a turning force to the gears and shafts which transmit power to the driven unit. Gears serve to increase or decrease torque. For example, an engine may not produce enough torque to turn the shaft of a driven machine if the connection between the driving and driven units is direct, or solid. If the right combination of gears is installed between the engine and the driven unit, however, torque can be increased, and the turning force would then be sufficient to operate the driven unit.

Speed

Another factor related to torque and to the transmission of engine power is engine speed. If maximum efficiency is to be obtained, an engine must operate at a certain speed. To obtain efficient engine operation in some installations, the engine may need to operate at a higher speed than that required for operation of the driven unit. In other installations, the speed of the engine may need to be lower than the speed of the driven unit. Through a combination of gears, the speed of the driven unit can be increased or decreased so that both the driving and the driven units operate at their most efficient speeds; that is, so that the proper speed ratio exists between the units.

Speed Ratio and Gear Ratio

The terms speed ratio and gear ratio are frequently used in descriptions of gear-type mechanisms. Both ratios are determined by dividing the number of teeth on the driven gear by the number of teeth on the driving gear. For example, assume that the crankshaft of a particular engine is fitted with a driving gear that is half as large as the meshing, driven gear. If the driving gear has 10 teeth and the driven gear has 20 teeth, the gear ratio is 2 to 1. Every revolution of the driving gear will cause the driven gear to revolve through only half a turn. Thus, if the engine is operating at 2,000 revolutions per minute (rpm), the speed of the driven gear will be only 1,000 rpm; the speed ratio is then 2 to 1. This arrangement doubles the torque on the shaft of the driven unit. The speed of the driven unit, however, is only half that of the engine.

On the other hand, if the driving gear has 20 teeth and the driven gear has 10 teeth, the speed ratio is 1 to 2, and the speed of the driven gear is doubled. The rule applies equally well when an odd number of teeth is involved. If the ratio of the teeth is 37 to 15, the speed ratio is slightly less than 2.47 to 1. In other words, the driving gear will turn through almost two and a half revolutions while the driven gear makes one revolution.

The gear with the greater number of teeth, which will always revolve more slowly than the gear with the smaller number of teeth, will produce the greater torque. Gear trains that change speed always change torque. When speed increases, the torque decreases proportionally.

NOTE

The mechanical force of any driven unit will always be somewhat LESS than that of the driving unit due to power losses caused by such things as friction and lost motion. Therefore, output horsepower will always be equal to input horsepower minus any losses.

Types of Drive Mechanisms

You have just learned that the torque or the speed of an engine may need to be changed to satisfy the torque and speed requirements of the driven mechanism. The term indirect drive, as used in this chapter, describes a drive mechanism that changes both speed and torque. Drives of this type are common to many marine engine installations.

When the speed and the torque of an engine do NOT need to be changed to drive a machine satisfactorily, the mechanism used is a direct drive. Drives of this type are commonly used when the engine furnishes power for the operation of auxiliaries, such as generators and pumps.

Indirect Drives

The drive mechanisms of most engine-powered ships and of many boats are the indirect type. With this drive, the power developed by the engine(s) is transmitted to the propeller(s) indirectly, through an intermediate mechanism that reduces the shaft speed. Speed may be reduced mechanically, by a combination of gears, or by electrical means (for example, a diesel electric drive).

Mechanical Drives

The mechanical drives discussed in this chapter include devices that reduce the shaft speed of the driven unit, provide a means for reversing the direction of shaft rotation in the driven unit, and permit quick-disconnect of the driving unit from the driven unit.

Propellers operate most efficiently in a relatively low rpm range. The most efficient designs of diesel engines operate in a relatively high rpm range. In order that both the engine and the propeller may operate efficiently, the drive mechanism in many installations includes a device that permits a speed reduction from engine crankshaft to propeller shaft. The combination of gears that brings about the speed reduction is called a reduction gear. In most diesel engine installations, the reduction ratio does not exceed 3 to 1. There are some units, however, that have reductions as high as 6 to 1.

The propelling equipment of a ship or a boat must provide astern power as well as forward power. In some ships, backing down is accomplished by reversing the pitch of the controllable pitch propeller; in other ships and boats, however, backing down is accomplished by reversing the direction of rotation of the propeller shaft. In mechanical drives, the direction of rotation of the propeller shaft is reversed by use of reverse gears.

The drive mechanism of a ship or boat must do more than reduce speed and change direction of rotation. Most drive mechanisms have a clutch. The clutch disconnects the drive mechanism from the propeller shaft and permits the engine to be operated without turning the propeller shaft.

The arrangement of the components in an indirect drive varies depending upon the type and size of the installation. In some small installations, the clutch, the reverse gear, and the reduction gear may be combined into a single unit. In other installations, the clutch and the reverse gear may be in one housing and the reduction gear in a separate housing attached to the reverse-gear housing. Drive mechanisms arranged in either manner are usually called transmissions. In large engine installations, the clutch and the reverse gear may be combined; they may be separate units, located between the engine and a separate reduction gear; or the clutch may be separate and the reverse gear and the reduction gear may be combined.

In most geared-drive multiple propeller shaft ships, the propulsion units and their drive mechanisms are independent of each other. In some, however, the drive mechanism is arranged so that two or more engines can drive a single propeller.

Electric Drives

In the propulsion plants of some diesel-driven ships, there are no mechanical connections between the engine(s) and the propeller(s). In such plants, the diesel engines are connected directly to generators. The electricity produced by such an engine-driven generator is transmitted through cables to a motor, which is connected to the propeller shaft directly, or indirectly, through a reduction gear. When a speed reduction gear is included in a diesel-electric drive, the gear is located between the motor and the propeller.

The generator and the motor of a diesel-electric drive may be of the direct current (dc) type or the alternating current (ac) type. Since the speed of a dc motor varies directly with the voltage furnished by the generator, the control system of an electric drive is arranged so that the generator voltage can be changed at any time. An increase or decrease in generator voltage is used to control the speed of the propeller. Generator voltage may be changed electrically, by changes in engine speed, or by a combination of these methods. The controls of an electric drive may be located remotely from the engine, such as in the pilot house.

In an electric drive, the direction of rotation of the propeller is not reversed by a reverse gear. The electrical system is arranged so that the flow of current through the motor can be reversed. This reversal of current flow causes the motor to turn in the opposite direction. Thus, the direction of rotation of the motor and of the propeller can be controlled by manipulation of the electrical controls.

Direct Drives

In some marine engine installations, power from the engine is transmitted to the drive unit without a change in shaft speed; that is, by a direct drive. In a direct drive, the connection between the engine and the driven unit may consist of a solid coupling, a flexible coupling, or a combination of both. There may or may not be a clutch in a direct drive, depending upon the type of installation. Some installations have a reverse gear.

Solid Couplings

Solid couplings vary considerably in design. Some direct drives use solid couplings that consist of two flanges bolted together (*Figure 15-1)*. In other direct drives, the driven unit is attached directly to the engine crankshaft by a nut.

Solid couplings offer a positive means of transmitting torque from the crankshaft of an engine; a solid connection does not allow for any misalignment between the input and output shafts, nor does it absorb any of the torsional vibration transmitted from the engine crankshaft.

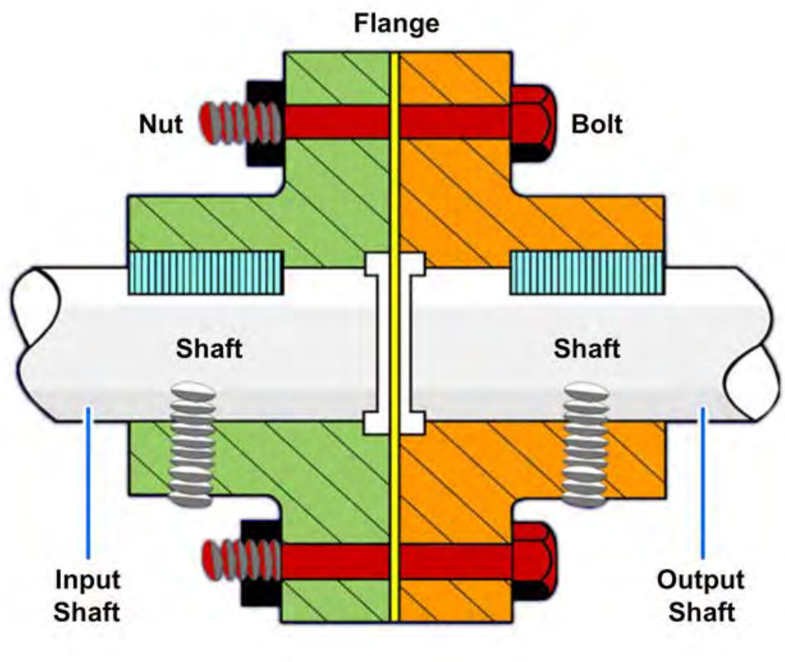

Figure 15-1 — Flange-type solid coupling.

Flexible Couplings

Since solid couplings do not absorb vibration and do not permit any misalignment, most direct drives employ a flexible coupling, which uses a flexible member or element to connect two flanges or hubs together. Connections of the flexible type are common to the drives of many auxiliaries, such as engine-generator sets. Flexible couplings are also used in indirect drives to connect the engine to the drive mechanism.

The two solid halves of a flexible coupling are joined by a flexible element (*Figure 15-2, frame 1 and 2)*. The flexible element may be made of rubber, neoprene, a steel spring, or gears. An example of a grid-type flexible coupling that uses a steel spring is shown in *Figure 15-2, frames 1 and 2,* and a gear-type coupling in *Figure 15-2, frame 3).*

Figure 15-2 — Flexible couplings.

CLUTCHES, REVERSE GEARS, AND REDUCTION GEARS

Clutches may be used on Navy direct-drive propulsion engines to disconnect the engine from the propeller shaft. With small engines, clutches are usually combined with reverse gears and are used for maneuvering boats. In large engines, special types of clutches are used to obtain required coupling or control characteristics and to prevent torsional vibration.

Clutches are used on marine engines to reverse the direction or rotation of the propeller shaft for maneuvering the ship, without changing the direction of rotation of the engine. Reverse gears are used principally with relatively small engines.

Reduction gears are used to obtain low propeller-shaft speed with a high engine speed. Speed reduction gears resolve two conflicting requirements:

1. For minimum weight and size for a given power output, engines must have a relatively high crankshaft speed.
2. For maximum efficiency, propellers must rotate at a relatively low speed, particularly where high thrust capacity is desired.

There are many types of transmissions used by the Navy. This chapter covers, in general, the operation of transmissions that use friction, pneumatic, hydraulic, and electromagnetic clutches, which may be found on Navy marine installations. You will find additional information on a particular unit in the *Naval Sea System Command* (NAVSEA) technical manual for that specific installation.

Friction Clutches and Gear Assemblies

Friction clutches are most commonly used with smaller high-speed engines. Pneumatic clutches, with cylindrical friction surfaces, are used with engines up to 2,000 horse power (hp).

There are two general types of friction clutches: disk and band.

Disk-type clutches are classified as either mechanical or hydraulic. Because of the wide use of the disk-type clutch on small craft, our discussion in the sections that follow will include both the mechanical and the hydraulic types.

Friction clutches are engaged when two friction surfaces are mechanically forced into contact with each other by toggle-action linkage through stiff springs or through the use of hydraulic or pneumatic pressure.

Twin-Disk Clutch and Gear Mechanism (Mechanical)

One of several types of transmissions used by the Navy on small craft is the twin-disk. The twin-disk transmission is equipped with a duplex clutch and a reverse and reduction gear unit, all contained in a housing at the after end of the engine. As shown in *Figure 15-3,* back plate (A), floating pressure plate (B), and front plate (C) of the clutch assembly are bolted to the flywheel on the crankshaft of the engine and rotate at the same speed as the engine.

The clutch assembly is contained in the part of the housing nearest the engine. It is a dry-type, twin-disk clutch with two friction disks or clutch plates. Each disk is connected to a separate reduction gear train in the after-part of the housing. The disk (D) and the gear train for forward rotation are connected by a hollow shaft (F). The disk (E) and the gear train for reverse rotation are connected by a shaft (G), which runs through the center of shaft (F). Since the gears for forward and reverse rotation of the twin-disk clutch and gear mechanism remain in mesh at all times, there is no shifting of gears. When the mechanism is shifted, only the (B), located between the forward and reverse disks, is moved.

Operation of the Twin-Disk Transmission

The forward rotating components are color coded green; the reverse rotating components are color coded red (*Figure 15-3)*. The clutch has a positive neutral that is set when the operating lever (M), which operates the throw-out fork (L), is placed in the middle position. Then the sliding sleeve (K) is also in a middle position, and the floating pressure plate (C) rotates freely between the two clutch disks (D and E). The only control the operator has is to cause the floating plate to bear heavily against either the forward disk or the reverse disk, or to put the floating plate in the positive neutral position so that it rotates freely between the two disks.

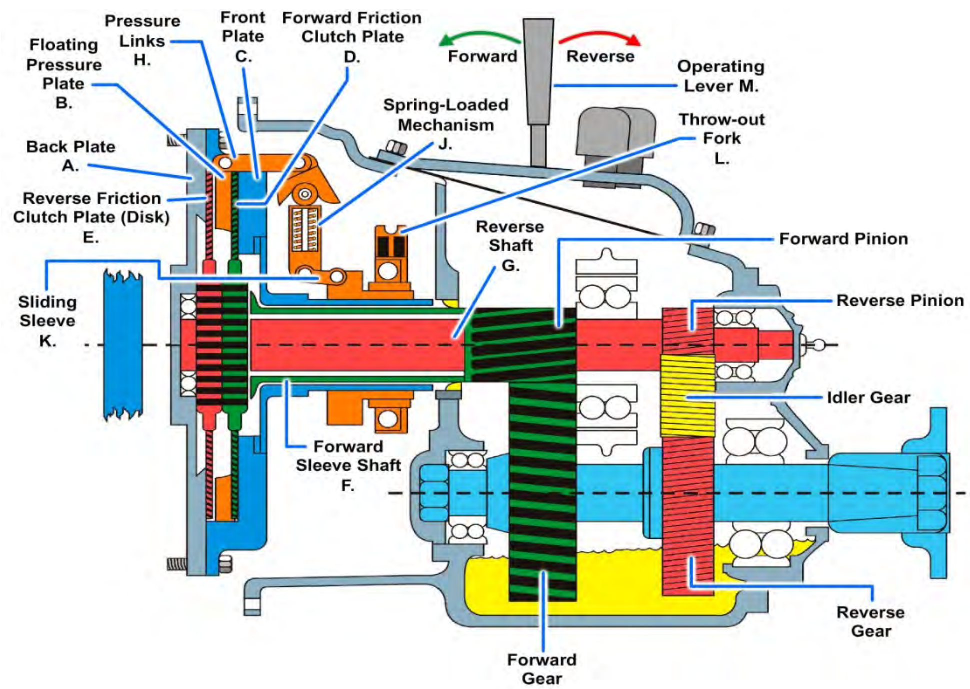

Figure 15-3 — Mechanical transmission (twin-disk).

Forward Rotation

When the operating lever (M) is pushed forward, the sliding sleeve (K) is forced backward. In this position, the pressure link (H) of the spring-loaded mechanism (J) pulls the floating pressure plate (C) against the forward clutch disk (D). The forward clutch friction disk, in turn, is pressed against the front plate (B), which is bolted to and rotates with the engine flywheel. The friction disk immediately begins to rotate with the front plate at engine speed because the forward friction disk has internal teeth that are in mesh with the external gear teeth on the left end of the forward sleeve (F). The forward sleeve shaft (F) transmits the rotation to the propeller shaft through the two-gear train (forward pinion and forward gear). Note the directional arrow for forward rotation.

NOTE

Several links must be used around the perimeter of the floating pressure plate to equalize the force against either of the two clutch plates.

Reverse Rotation

When the operating lever (M) is pulled back as far as it can go, the sliding sleeve (K) is pushed forward. In this position, the floating pressure plate (C) is forced against the reverse friction clutch plate (E). In turn, the reverse disk is pressed against the back plate (A), which is also bolted to the engine flywheel. At engine speed, the reverse friction clutch plate begins to rotate with the back plate because the reverse friction disk has internal teeth that are in mesh with the external gear teeth on the left end of the inner reverse shaft (G). The reverse shaft transmits the rotation through the three-gear train (reverse pinion gear, idler gear, and reverse gear). Notice the idler gear. This gear transmits motion from the reverse pinion gear to the reverse gear without a change in direction between the two. Note the directional arrow for reverse rotation.

Mechanical Clutch Problems

Malfunctions of friction clutches will vary, depending upon the type of clutch. The troubles discussed in this section—slippage and wear, freezing, and noise—are common to twin-disk clutches.

Slippage and Wear

Slippage and wear of mechanical clutches must be considered together, since each can be the cause of the other and each intensifies the other's effect. Slippage generally occurs at a high engine speed when the engine is delivering the greatest torque. Slippage causes lower efficiency, loss of power, and rapid wear of the clutch friction surfaces. There are several possible causes of clutch slippage: wear, insufficient pressure, overload, and fouling. Over a period of operation, extended engaging and disengaging of the surfaces will cause a normal amount of wear. If the surfaces are rough, wear will be excessive. Do not engage the clutch while the engine is racing. It may cause excessive wear, and it will strain the entire drive system.

When an engine is overloaded, torque may be increased to such an extent that slippage will occur. Obviously, you can prevent this trouble by keeping the load within specified limits. Whenever an engine is fully loaded, watch for symptoms that indicate slippage.

The clutch may slip when the lining surfaces become fouled with oil, grease, or water. Oil or grease on the clutch surfaces is usually the result of careless maintenance practices, such as forcing too much grease into the bearings or overfilling the gear case with oil. When oil in a gear case foams, there will probably be leakage from the shaft bearings. Foaming may result from overfilling. When foaming occurs, check for the proper oil level.

When filling a reduction gear case, add only enough oil to bring the level up to the full mark. Do not add or measure oil when the unit is in operation, because you will not get an accurate oil reading.

In a twin-disk clutch installation, an oil leak at the rear main bearing of the engine may cause oil to appear on the clutch surfaces. The leakage may be caused by excessive bearing clearance, overfilling of the engine crankcase, a plugged crankcase breather cap, or excessive crankcase pressure due to piston blow-by. The crankcase breather cap must be cleaned periodically so that it will not become clogged.

Another source of fouling is grease that may get on the linings of a dry-type clutch during overhaul. Do not handle the parts with greasy hands, and remove any grease deposits with an approved cleaner. For pneumatically operated friction clutches where rubber parts are used, use only a clean, dry cloth to wipe off clutch faces and linings.

When there is clutch slippage, immediately take steps to correct the trouble. The clutch surfaces are probably worn, so measure the thickness of the clutch linings. When a lining is worn excessively, replace it; tightening the adjusting device (installed on some units) will not correct for excessive wear of the linings. Instead, such adjustments may lead to scoring of the mating clutch surfaces, particularly when the linings are fastened to the clutch faces with rivets.

The spring-loaded clutch-operating mechanism of the twin disk is pressure set at the factory. It should not be necessary to adjust the mechanism, as it is designed to follow up and compensate for wear of the friction surfaces on the clutch plates. The simplest way to determine when the disks need to be replaced is to check the position of the plungers of the spring-loaded mechanisms in the engaged position. The plungers are permitted to travel a specified amount according to the specifications listed in the NAVSEA technical manual.

Frozen Clutch

When a clutch fails to disengage, it is frozen. Failure of the clutch to disengage may be caused by a defective clutch mechanism or by water absorbed in the material that lines the clutch plates.

When a clutch becomes frozen, inspect the operating mechanism. Check the control rods for obstructions or loose connections, and check for excessive clearances in the throw-out bearing pressure plate, the pivots, and the toggles. In a twin-disk clutch, warped disks will cause the clutch to freeze. (Warped disks are caused by extended running in neutral position).

If a clutch has molded clutch linings, moisture will cause the linings to swell and become soft. When this occurs, many linings tend to stick to the mating surfaces. Every effort should be made to prevent moisture from getting to the clutch linings. If a molded lining becomes wet, let it dry in the disengaged position. Allowing the linings to dry in the engaged position increases the possibility of sticking.

Clutch Noise

Dry-type clutches may produce a chattering noise when the clutch is being engaged. Excessive clutch chatter may cause damage to the reverse and reduction gears and may cause the clutch linings to break loose, resulting in complete clutch failure.

The principal cause of clutch chatter is oil, grease, or water on the linings. You should take every possible precaution to keep oil, grease, or water out of the unit, because replacement of the linings is the only satisfactory means of repair. All metal parts of the clutch may be cleaned according to instructions in the appropriate NAVSEA technical manuals.

Hydraulic Clutch and Gear Mechanism (Transmission)

Like the twin-disk transmission we have just discussed, the hydraulic transmission uses two friction plates to transfer drive torque to the gear mechanism. However, the hydraulic transmission does not use a floating plate to engage or disengage the clutches. The clutches are engaged or disengaged when either the forward or the reverse clutch disk is locked between a hydraulically operated piston and a drive plate.

Another difference between the two types of transmissions is the use of planetary gears in the hydraulic transmission, rather than a second shaft and an idler gear, to reverse rotation of the drive shaft. This method of reversing direction will be explained later in detail. One other difference is the method by which the transmissions are lubricated. The twin-disk transmission is splash lubricated by the action of the forward gear and the reverse gear as they pick up oil from the sump and throw the oil as they rotate. The hydraulic transmission is lubricated by both pressure oil and splash oil. A central passage is open to oil pump pressure at all times when the engine is running. All moving parts inside the transmission are lubricated from this source. A nozzle at the top of the housing provides a spray of oil for lubricating the drive (pinion) gear, the driven gear, and the bearings.

The hydraulic transmission consists of a forward drive clutch assembly, a reverse clutch and reduction gear assembly, an oil pump that supplies oil under pressure for operation of the clutches, a control (selector) valve that admits oil to the clutches, an oil strainer, and oil cooler. Although there are several designs of hydraulic transmissions, if you clearly understand the operating principles of the Torqmatic design you should be able to understand the operating principles of other types of hydraulic transmissions.

The hydraulic transmission receives input torque through the forward clutch plate which is bolted to the aft face of the engine flywheel. Torque for forward motion is transferred from the clutch plate to the forward clutch disk. Torque for reverse motion is transferred from the forward clutch disk to the planetary gears by the sun gear.

Neutral Operation

We will discuss the neutral operation of the transmission first because the selector valve lever should always be in the neutral position whenever you start the engine.

When the selector valve is in the neutral position, oil flows along one path. No pressure is applied against any of the hydraulic components. Therefore, the forward clutch disk rotates without turning any of the parts inside the transmission. This allows the transmission output shaft to remain stationary.

Forward Operation

When the lever of the selector valve is moved to the forward position, oil is admitted under pressure from the pump to the passage in the transmission and into an orifice in the pinion shaft. Oil then flows through a radial passage in the flywheel to an intersecting horizontal passage leading to the cavity between the flywheel and the forward clutch piston.

A piston-type dump valve, located at the outer diameter of the flywheel, controls the buildup and release of pressure against the piston. When the flywheel is rotating, the force exerted by the piston backup spring tends to push the valve out toward the periphery of the flywheel. When the selector control valve is opened and admits oil to operate the forward piston, the pressurized oil overrides the force of the dump valve spring and pushes the valve in toward the center of the flywheel. When the valve is pushed in, it uncovers a port in the flywheel leading to the piston and admits pressurized oil into the cavity at the front of the piston.

The pressurized oil moves the piston toward the back plate, locking the clutch plate between the piston and the back plate and causing the clutch plate to rotate with the back plate. Since the pinion shaft is splined through the center of the clutch plate, the shaft rotates in the same direction and at the same speed as the clutch plate. This is the same speed at which the engine flywheel is rotating because the flywheel and the shaft are locked together hydraulically into one assembly. During this operation, oil has also been flowing along the path to provide lubrication.

Reverse Operation

When the selector control valve lever is moved to the reverse position, oil is admitted from the pump to oil passages. The oil in the piston's passage flows under pressure to the cavity on the face of the rear piston. The oil pressure against the piston moves the piston, causing it to lock the rear clutch plate between the piston and the stationary back plate. This locking action engages the reverse clutch and provides torque to the planetary gear assembly (*Figure 15-4, frames 1 and 2*).

The planetary gear assembly (*Figure 15-4, frame 1*) is installed in the transmission to provide reverse motion of the output shaft. The planetary gear assembly contains the following parts: a sun gear, a ring gear with internal teeth, planet gears, and a planet carrier. In the planetary gear set (*Figure 15-4, frame 1*), the teeth of a gear are in mesh with the teeth of at least one other

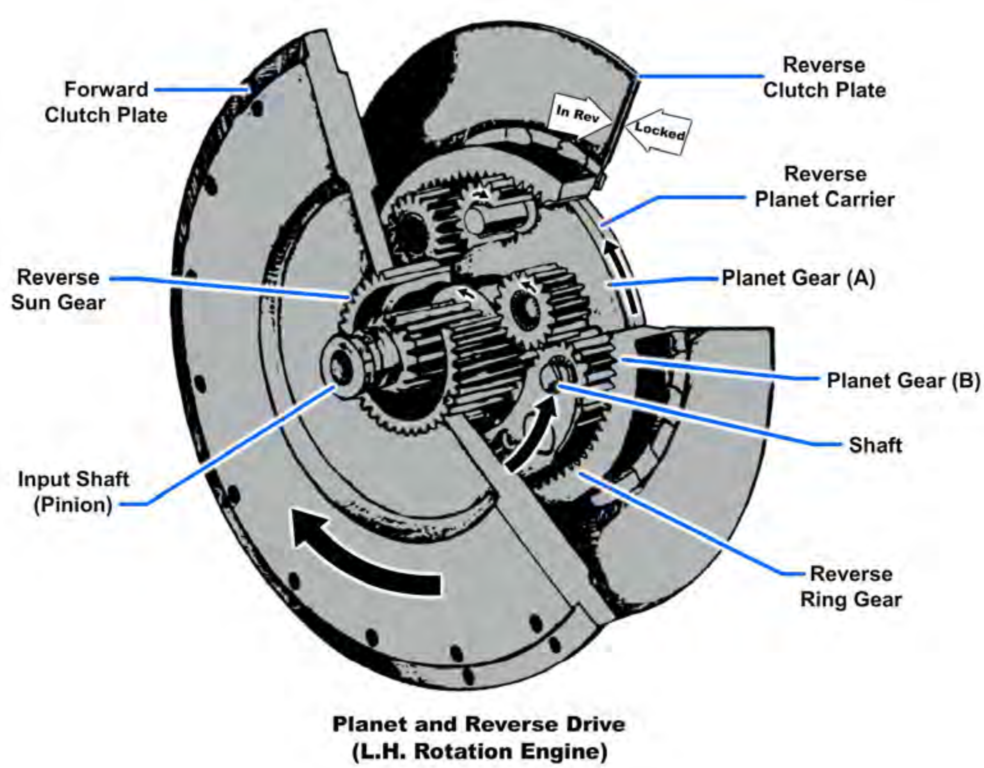

Figure 15-4 — Operation of planetary gear assembly.

gear at all times. Whenever one part of the gear set is turned, all other parts in the gear set are affected. The planetary gear set can be separated into three major parts, each with its own function.

To transmit power through a gear set, one gear turns as the drive member (sun gear). Another part, called the reaction member (reverse ring gear), is held and prevented from moving. A third part, the driven member or the output member (reverse planet carrier), is free to turn inside the reverse ring gear.

To understand how the planetary gear set provides reverse motion, you must keep in mind how the major parts are mounted. The sun gear is splined to the drive plate (forward clutch plate), which is bolted to the flywheel. Consequently, when the engine is running, the sun gear is revolving. The carrier to which the planet gears are mounted is attached by splines to the transmission pinion shaft. The ring gear is attached to the reverse clutch disk.

When the selector valve is in the forward position, the reverse clutch is disengaged, allowing the rear clutch disk to rotate freely. As the clutch disk rotates freely, the ring gear attached to the disk offers no resistance to the motion of the planet gears. In operation, a planetary gear set (*Figure 15-4, frame 2*) resembles the solar system. Planet gears orbit, or circle, the sun gear. Planet gears are held in place by the planet carrier and the ring gear. The ring gear surrounds and meshes with the planet gears. When the selector valve is put in the reverse position, hydraulic pressure stops and locks the rear clutch disk and the attached ring gear, resulting in the gear motion (*Figure 15-4, frame 2*) As the sun gear rotates clockwise, planet gear A rotates counterclockwise and planet gear B rotates clockwise. Since the ring gear is locked, gear B must move in a counterclockwise direction. The counterclockwise motion of gear B turns the carrier (on which the gear is mounted) and the pinion shaft (to which the carrier is mounted) in a counterclockwise direction. Thus, the planetary gear set has converted the clockwise motion of the input shaft into the counterclockwise motion of the pinion shaft. This change in direction of the pinion shaft also changes the direction of the drive shaft.

General Maintenance Procedures

This section describes some routine procedures you can use to maintain the hydraulic transmission in good operating condition and to identify the overall condition of the transmission. These guidelines include the care of the oil system and minor adjustments you can make to the transmission and control linkage. In the maintenance of the oil system, the proper oil level is very important. The transmission oil provides the pressure to apply clutches and the lubrication to cool components. Consequently, transmission performance will be affected if the oil becomes aerated. The primary cause of aeration or foaming is either low oil or too much oil in the sump. A low oil level can cause the input pump to cavitate. Too much oil in the sump can introduce oil into the gearing and clutches. This condition can cause aeration, which will overheat the transmission. Aeration can also change the viscosity and color of the oil to a thin milky liquid. These conditions will all cause irregular operation of the unit.

The oil level should be checked daily after the engine has been running for at least 1 hour. The oil level should be maintained at the FULL mark on the dipstick. Every 150 hours (or sooner, depending on the type of duty and environment), the oil and oil filters should be changed. You should refer to the appropriate Planned Maintenance System (PMS) for the specific procedures and intervals you should use for your unit. Heavy sludge deposits on the oil filter element indicate that the detergency of the oil has been exhausted. When this occurs, the oil change interval should be shortened. The oil filter should always be replaced at the time of the oil change so that any abrasive dust and metal particles can be removed.

When you must change the oil and filter, follow these general procedures:

1. Make sure the transmission has been warmed up to operating temperature.
2. Remove the oil drain plugs from the sump and oil filters and drain the oil. Replace the plugs.

3. Thoroughly clean the transmission strainer assembly. Use a new gasket when you are replacing the cover of the strainer.
4. Replace the filter elements. Thoroughly clean the filter shells and use new gaskets (seal rings) with the new filter elements.
5. Before starting the engine, remove the breather and refill the transmission with clean oil (from a clean container) to prevent contamination.
6. When refilling the system, pour enough oil into the transmission to bring the oil level up to the FULL mark on the dipstick. Start the engine and let it idle for 2 or 3 minutes with the transmission in neutral. Recheck the oil level and add oil (if necessary) to bring the oil up to the FULL mark on the dipstick. Do not overfill the transmission.
7. Carefully inspect the filter components and cover for oil leakage while the engine is running.

At each oil change, examine the used oil for evidence of dirt or water. If there is evidence of free water, check the cooler for leakage between the water and oil areas. Oil in the water side of the cooler is another sign of leakage. This, however, usually indicates leakage from the engine oil system. If coolant leaks into the transmission oil system, you must take immediate action to prevent malfunction and possible serious damage.

Ethylene glycol antifreeze will attack the material that lines the clutch plates. You must immediately disassemble, inspect, and clean the transmission and flywheel assembly. If antifreeze is present, both forward and reverse friction clutch plates must be replaced. The cooler should be repaired or replaced prior to installation of the new or rebuilt transmission.

Metal particles in the oil (except for the minute particles normally trapped in the oil filter) indicate damage has occurred in the transmission. When these particles are found, the transmission and flywheel assembly should be completely disassembled, and all internal and external oil circuits and all other areas where particles could lodge should be cleaned.

In the selector valve linkage assembly, the manual selector lever should move easily and give a crisp detent feel in the forward, neutral, and reverse positions. You should adjust the linkage so that the stops in the shift tower match the detents in the transmission.

Make periodic inspections for bent or worn parts, loose threaded connections, loose bolts, or accumulations of grease and dirt. All moving joints must be kept clean and well lubricated.

Airflex Clutch and Gear Assembly

On large diesel-propelled ships, the clutch, reverse gear, and reduction gear unit has to transmit an enormous amount of power. So that the weight and size of the mechanism can be minimized, special clutches have been designed for large diesel installations. One of these is the airflex clutch and gear assembly.

The airflex clutch and gear assembly, shown in *Figure 15-5, views A and B*, consists of two clutches—one for forward rotation (*Figure 15-5, view A*), and one for reverse rotation (*Figure 15-5, view B*).

The clutches are bolted to the engine flywheel, (*Figure 15-6*), by a steel spacer, so that they both rotate with the engine at all times at any engine speed. Each clutch has a flexible tube (gland) on the inner side of a steel shell (*Figure 15-5, view A)*. Before the tubes are inflated, they will rotate out of contact with the drums, which are keyed to the forward and reverse drive shafts. When air under pressure 100 psi is forced into one of the tubes the inside diameter of the clutch decreases. This causes the friction blocks on the inner tube surface to come in contact with the clutch drum, locking the drive shaft with the engine (*Figure 15-6)*.

Forward Rotation

The parts of the airflex clutch that give the propeller shaft ahead rotation are shown in *Figure 15-5, view A.* The clutch tube nearest the engine (forward clutch) is inflated to contact and drive the forward drum with the engine. The forward drum is keyed to the forward drive shaft, which carries the double helical forward pinion at the after end of the gear box. The forward pinion is in constant mesh with the double helical main gear, which is keyed to the propeller shaft. By following through the gear train, you can see that, for ahead motion, the propeller must rotate in a direction opposite to the rotation of the engine. (See the directional arrows).

Reverse Rotation

The parts of the airflex clutch that give the propeller shaft astern rotation are shown in *Figure 15-5, view B.* The reverse clutch is inflated to engage the reverse drum, which is then driven by the engine. The reverse drum is keyed to the short reverse shaft, which surrounds the forward drive shaft. A large reverse step-up pinion transmits the motion to the large reverse step-up gear on the upper shaft. The upper shaft rotation is opposite to the rotation of the engine. (Note the directional arrows in *Figure 15-5, view B*). The main reverse pinion on the upper shaft is in constant mesh with the main gear. By tracing through the gear train, you should see that, for reverse rotation, the propeller rotates in the same direction as the engine. The diameter of the main gear of the airflex clutch is approximately 2 1/2 times as great as that of the forward and reverse pinions. Thus, there is a speed reduction of 2 1/2 to 1 from either pinion to the propeller shaft. Since the forward and main reverse pinions are in constant mesh with the main gear, the set of gears that is not clutched in will rotate as idlers driven from the main gear. The idling gears rotate in a direction opposite to their rotation when carrying the load. For example, with the forward clutch engaged, the main reverse pinion rotates in a direction opposite to its rotation for astern motion. (Note the dotted arrow in *Figure 15-5, view A*). Since the drums rotate in opposite directions, a control mechanism is installed to prevent the engagement of both clutches simultaneously.

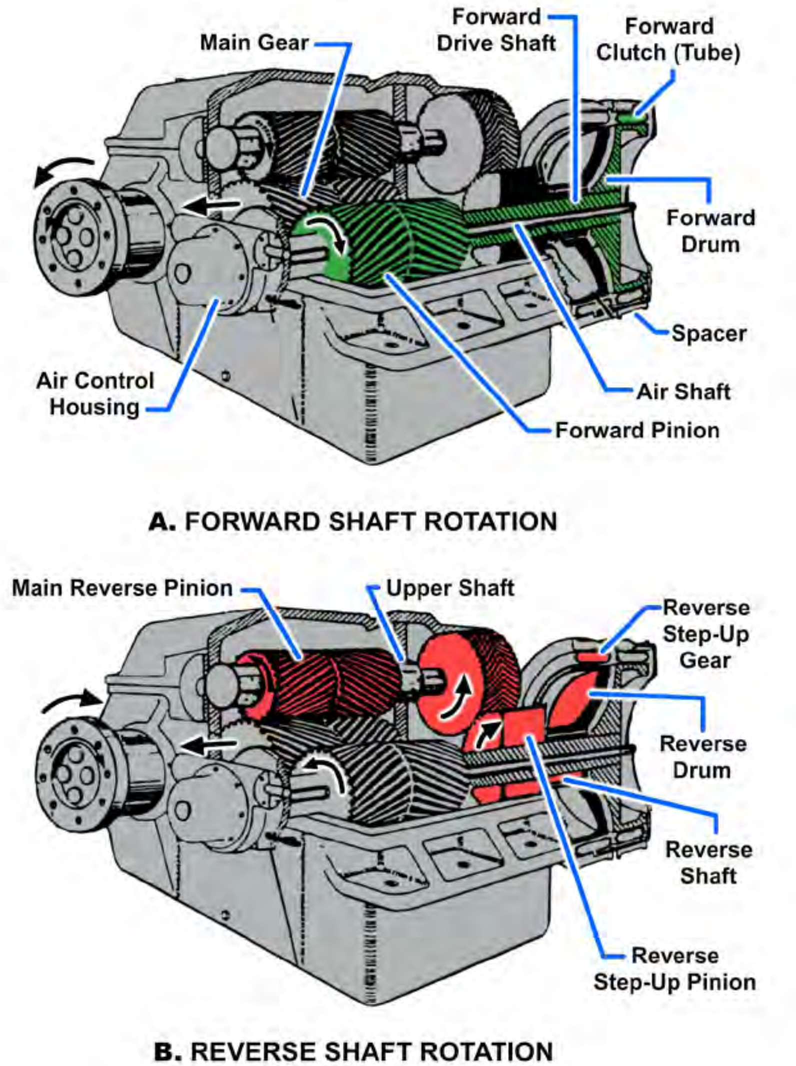

Figure 15-5 — Airflex clutch and gear assembly.

Airflex Clutch Control Mechanism

The airflex clutch is controlled by an operating lever that works the air control housing, located at the after end of the forward pinion shaft. The control mechanism *(Figure 15-7)*, directs the air into the proper paths to inflate the clutch glands (tubes). The air shaft, which connects the control mechanism to the clutches, passes through the forward drive shaft.

The supply air enters the control housing through the air check valve and must pass through the small air orifice. The restricted orifice delays the inflation of the clutch to be engaged during shifting from one direction of rotation to the other. The delay is necessary to allow the other clutch to be fully deflated and out of contact with its drum before the inflating clutch can make contact with its drum.

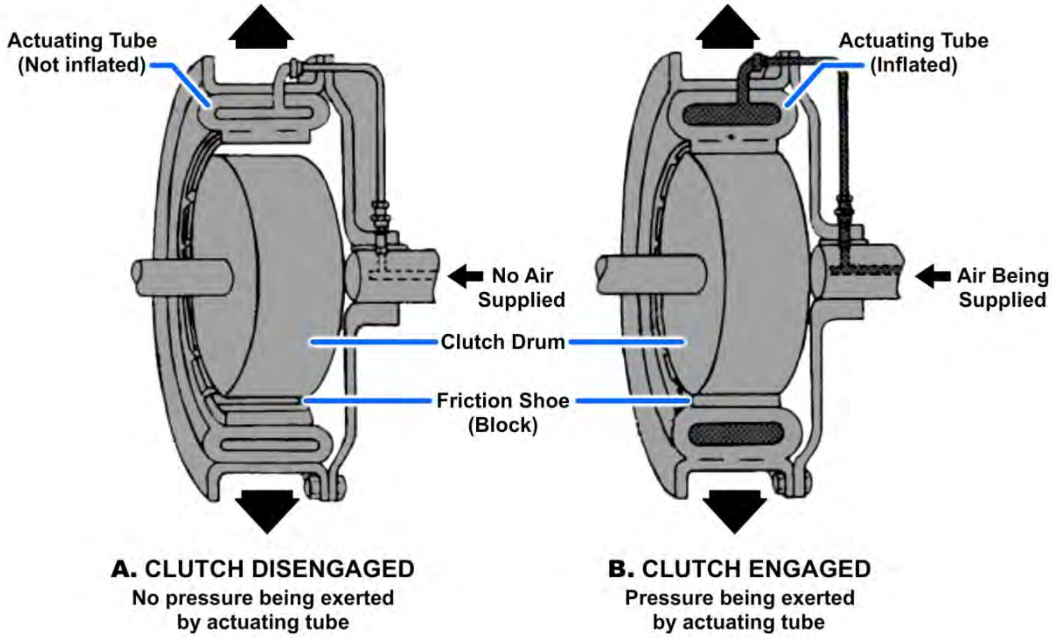

Figure 15-6 — Clutch operation.

The supply air goes to the rotary air joints in which a hollow carbon cylinder is held to the valve shaft by spring tension, preventing leakage between the stationary carbon seal and rotating air valve shaft. The air goes from the rotary joint to the four-way air valve. The sliding-sleeve assembly of the four-way valve can be shifted endwise along the valve shaft by operation of the control lever.

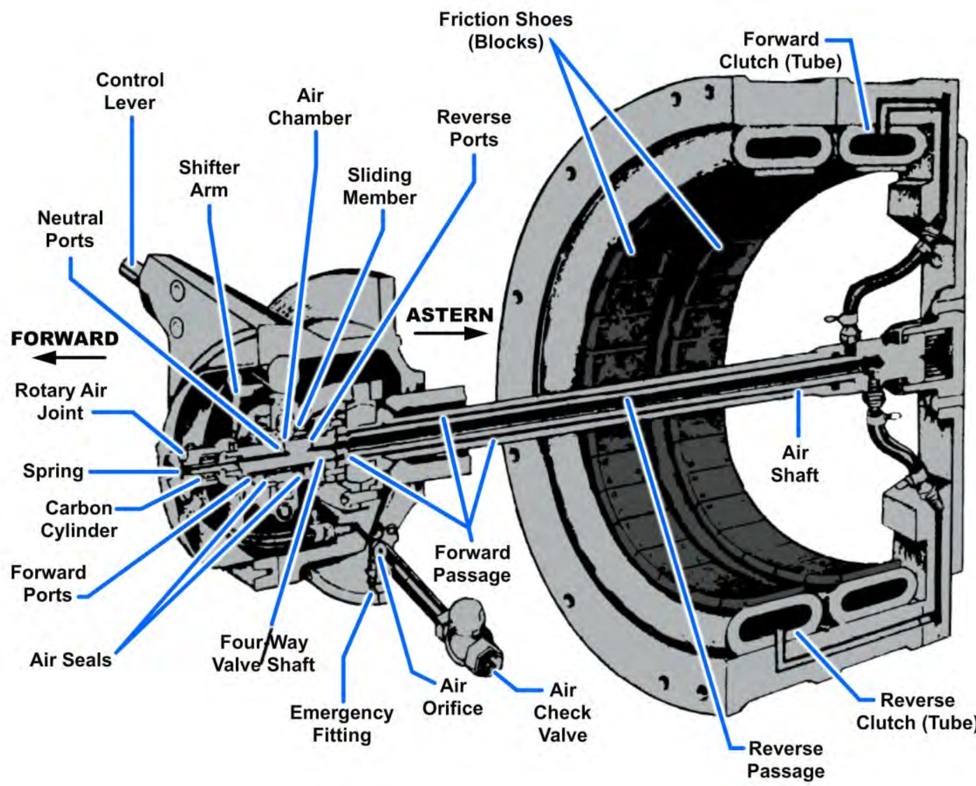

Figure 15-7 — Airflex clutch and control valves.

When the shifter arm on the control lever slides the valve assembly away from the engine, air is directed to the forward clutch. The four-way valve makes the connection between the air supply and the forward clutch. There are eight neutral ports that connect the central air supply passage in the valve shaft with the sealed air chamber in the sliding member. In the neutral position of the four-way valve shown in *Figure 15-7*, the air chamber is a dead end for the supply air. With the shifter arm in the forward position, the sliding member uncovers eight forward ports that connect with the forward passages that conduct the air to the forward clutch. The air now flows through the neutral ports, air chamber, forward ports, and forward passages to inflate the forward clutch gland. As long as the shifter arm is in the forward position, the forward clutch will remain inflated, and the entire forward air system will remain at a pressure of 100 psi.

At this point, let us assume that the bridge signals you to reverse the propeller. You should pull the operating lever back to the neutral position and hold it there for 2 or 3 seconds (as a safety factor). Then pull the lever to the reverse idling position and wait about 7 seconds, after which the reverse clutch is fully engaged. Then you can increase the reverse speed to whatever the bridge has ordered.

Why was it necessary to pause at the neutral and the reverse idling positions? What has happened in the air control and clutch mechanism? When you shift to neutral, the forward ports are uncovered, and the compressed air from the forward clutch and passage vents to the atmosphere. When you deflate either clutch, the air is vented through eight ports approximately the same size as the air orifice, so that deflating either clutch actually requires 1 to 2 seconds. Pausing for 2 or 3 seconds at neutral allows enough time for the forward clutch to deflate and disengage before you start inflating the reverse clutch.

When you shift to reverse idling, the air chamber comes over the eight reverse ports which open to the central reverse passage in the air shaft. The compressed air begins to inflate the reverse clutch immediately; the inflating air must pass through the single air orifice in the supply line, causing a delay of about 7 seconds to fully inflate a clutch. When the clutch is in the reverse idling position, wait until the reverse clutch is fully engaged before increasing the speed to prevent damaging the clutch (by slippage). It is impossible to have both clutches engaged at the same time.

MAIN PROPULSION SHAFT BEARINGS COMPONENTS

You will be required to monitor the operation of the propeller shaft bearings and to maintain them in good condition. These bearings support and hold the propulsion shafting in alignment. Three kinds of bearings are used for a main propulsion shaft: line shaft bearings (or spring bearings), stern tube bearings, and strut bearings. We will briefly discuss each of these bearings; refer to *Figure 15-8,* for the general location of the bearings on main shafting.

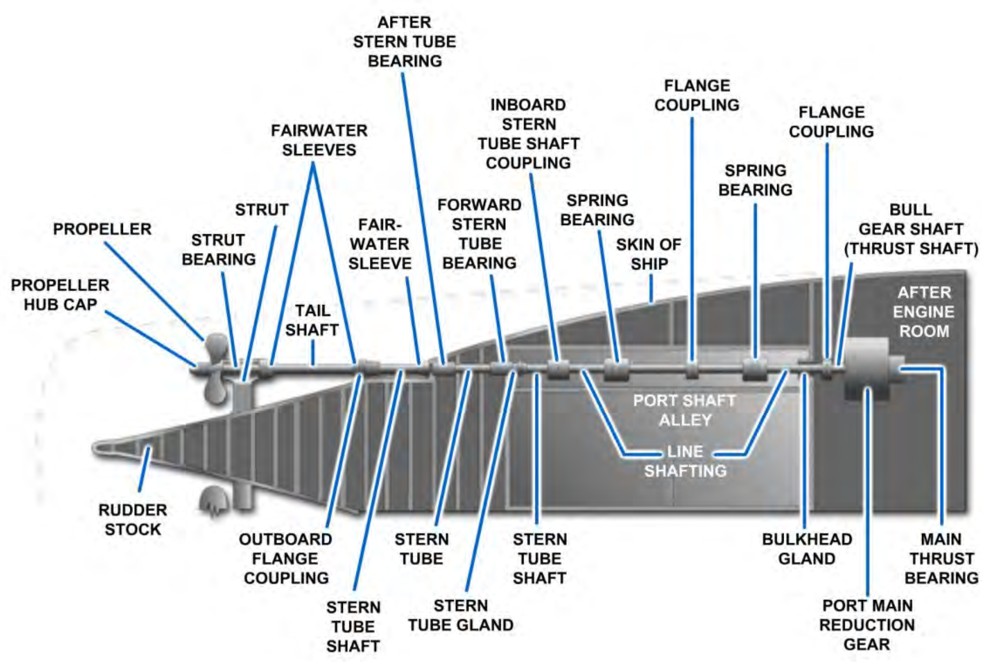

Figure 15-8 — Main shafting.

Bearings

Bearings in main propulsion units vary in size, composition, and lubrication requirements, but their purposes are the same. Bearings guide and support rotating elements, prevent free radial movement, and limit the axial movement of these elements. Radial or journal bearings carry loads applied in a plane that is at a right angle to the axis of the shaft. Thrust bearings carry loads applied in the same direction as the axis of the shaft and restrict axial movement.

Lubrication of bearings differs according to type. Babbitt-lined bearings are lubricated by a constant flow of lubricating oil. Stern tube and strut bearings, which are lined with hardwood, phenolic, or a rubber composition, are lubricated by a constant flow of seawater. Bearings operate with a small lubricant clearance. (The lubricant clearance is the difference between the outside diameter of the journal and the inside diameter of the bearing.) This clearance must always be maintained within specified limits. With proper clearances and proper lubrication, bearings will last for many years.

The information in this training manual is of a general nature. You can find additional information in *Naval Ships' Technical Manual* (NSTM) Chapters 243, 244, and 245. For details concerning a particular unit, consult the applicable NAVSEA technical manual and current Maintenance Requirement Cards (MRCs).

Line Shaft Bearings or Spring Bearings

Most of the line shaft bearings or spring bearings are the ring- or disc-oiled, babbitt-faced, spherical seat, or shell type. This type of bearing (*Figure 15-9*) is designed primarily to align itself to support the weight of the shafting. The brass oiler rings, shown in *Figure 15-9*, are a loose fit. The rings are retained in an axial position by guides or grooves in the outer bearing shell. As the shaft rotates, friction between the rings and the shaft is enough to cause the rings to rotate with the shaft. The rings dip into the oil in the sump. Oil is retained on the inside diameter of the rings and is carried to the upper bearings. The action of the oil ring guides and the contact of the rings on the upper shaft cause the oil to be removed from the rings and to lubricate the bearings.

The disc-oiled spring bearing (*Figure 15-10*) is basically the same as the ring-oil type except it uses an oil disc to lubricate the bearing. The oil disc is attached to, and rotates with, the shaft.

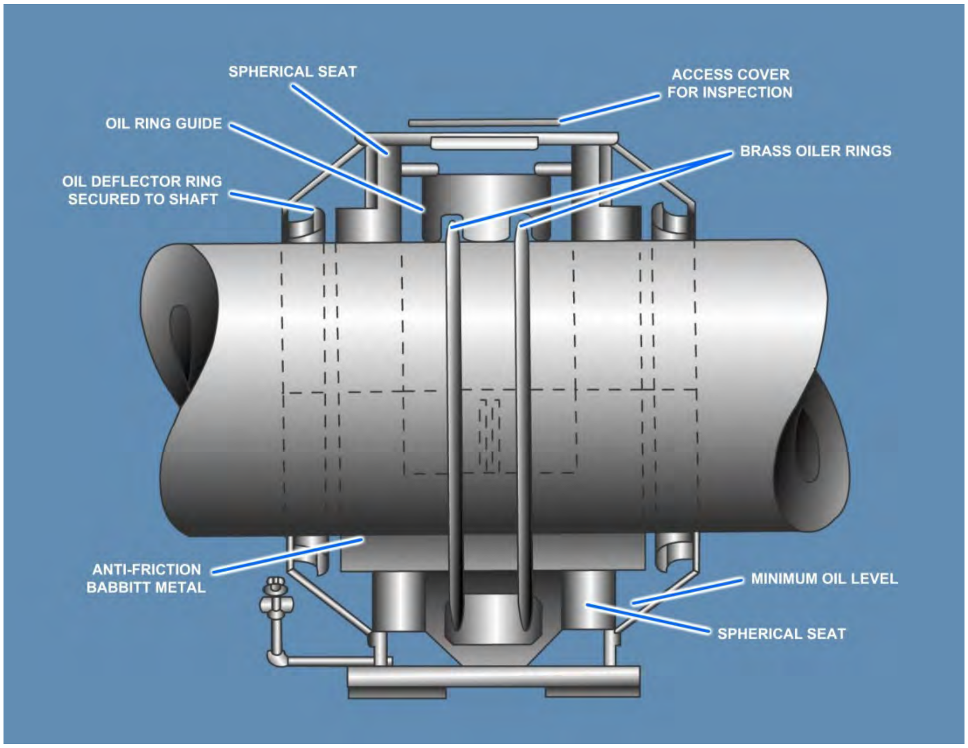

Figure 15-9 — Main line shaft bearing (ring-oiled).

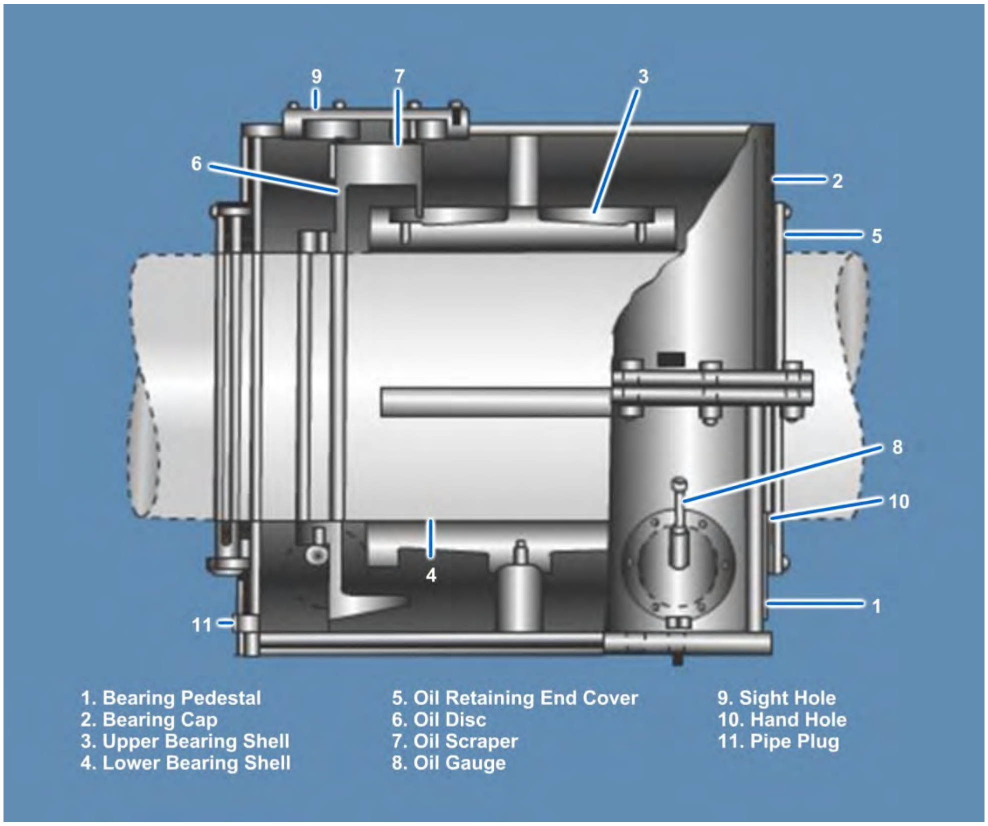

Figure 15-10 — Main line shaft bearing (disc-oiled).

Oil is removed from the disc by a scraper, located at the top of the bearing. The oil then runs into a pocket at the top of the upper bearing shell (*Figure 15-11)*. From here, the oil enters the bearing through drilled holes.

Tests have shown that the disc delivers more oil at all speeds than the ring discussed earlier, especially at turning gear speeds. The disc is also more reliable than the ring. Some ships have line shaft bearings that are force lubricated by a pump. You should check the line shaft bearing temperatures and oil levels at least once an hour. Inspection and maintenance should be done according to PMS requirements.

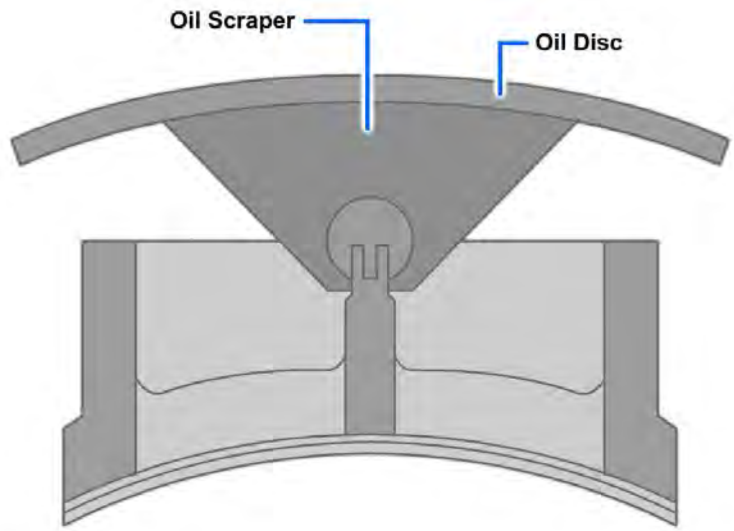

Figure 15-11 — Disc-oiled line shaft bearing scraper arrangement.

Stern Tubes and Stern Tube Bearings

The stem tube is located where the shaft passes through the hull of the ship. The shaft is supported within the stern tube by two stern tube bearings: one on the inner side, and one on the outer side of the hull. The construction of the stern tube bearing is basically the same as that of the strut bearing, which is described later in this chapter. The point where the shaft passes through the hull must be sealed to prevent seawater from entering the ship. This is accomplished primarily by use of either packing or mechanical seals. Stem tube packing (*Figure 15-12*) is used only on older ships as a primary sealer.

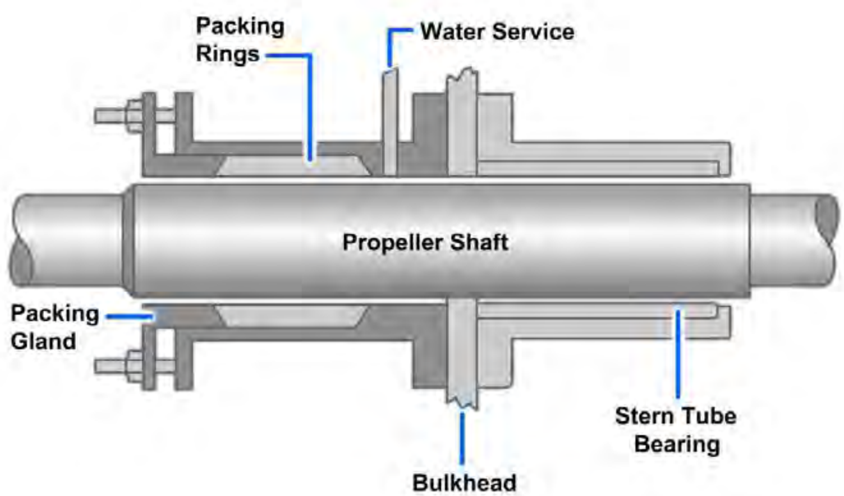

Figure 15-12 — Stern tube stuffing box and gland.

This packing method uses a stuffing box that is flanged and bolted to the stern tube. The after space contains a flushing connection to provide a constant flow of water through the stem tube (from inside the ship to outside the ship) to lubricate, cool, and flush the bearings. This flushing connection is supplied by the firemain. A drain connection is provided both to test the presence of cooling water in the bearing and to allow seawater to flow through the stern tube to lubricate the packing when the ship is underway. This is done where natural seawater circulation is used.

The gland for the stuffing box is divided longitudinally into two parts.

Gland leakage is required to prevent packing from heating up, crystallizing, and scoring the shaft sealing surface within the gland. Usually, the gland is tightened and the flushing connection is closed to eliminate leakage when the ship is in port. It is loosened just enough to permit a slight trickle of water for cooling purposes when the ship is underway. Whenever packing is added to a stern tube, be sure that the gland is drawn up evenly by using a rule to measure the distance between the gland and the stuffing box.

In some installations, mechanical seals are used to seal the stern tube. Two of the major advances of these seals are (1) they will operate maintenance free for extended periods, and (2) there is no leakage into the shaft alley.

Inflatable Sealing Ring

The split inflatable rubber seal ring is widely used in Navy ships. It is installed aft of the prime seal assembly rig (packing box or mechanical seal). It is used when it is necessary to repair or replace the prime sealing elements when the ship is waterborne.

When the seal is needed, it is inflated with nitrogen and expands against the shaft to form a watertight seal. Nitrogen is used because it is dry and will not deteriorate the seal as rapidly as compressed air, which often contains moisture, oil, and dirt.

The operation and testing of the split inflatable ring seal should be done according to ship's instructions and the applicable MRC. Never exceed the maximum pressure designated for inflating the seal. You can find the specified pressure designations in the NSTM, Chapter 243. Over-pressurization can rupture the seal.

Strut Bearings

Strut bearings, as well as the stern tube bearings, are equipped with composition bushings that are split longitudinally into two halves (*Figure 15-13, views A through C)*. The outer surface of the bushing is machined with steps to bear on matching lands in the bore of the strut. One end is bolted to the strut.

Since it is usually not practical to use oil or grease as a lubricant for underwater bearings, some other frictionless material must be used. There are certain materials that become slippery when wet. They include synthetic rubber; lignum vitae, a hard tropical wood with excellent wearing qualities; and laminated phenolic material consisting of layers of cotton fabric impregnated and bonded with phenolic resin. Strips made from any of these materials are fitted inside the bearing. Most Navy installations use rubber composition strips (*Figure 15-13, view C*).

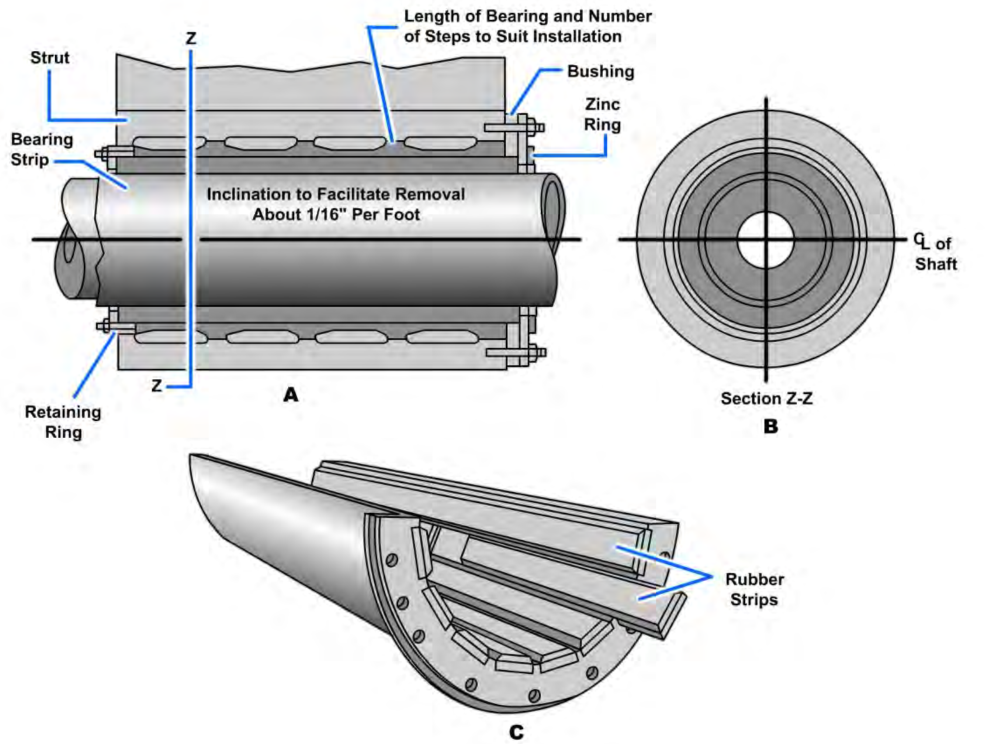

Figure 15-13 — Details of a strut bearing.

HYDRAULIC CLUTCHES (COUPLINGS)

The fluid clutch (coupling) is used in some Navy ships. A hydraulic coupling eliminates the need for a mechanical connection between the engine and the reduction gears. Power is transmitted through hydraulic couplings very efficiently (97 percent) without the transmission of torsional vibrations or load shocks from the engine to the reduction gear. The power loss from the small amount of slippage is transformed into heat, which is absorbed by the oil in the system. Some slippage is necessary for operation of the hydraulic coupling, since torque transmission depends on relative motion between the two rotors.

Hydraulic Coupling Assemblies

The two rotors and the oil-sealing cover of a typical hydraulic coupling for a large propulsion unit are shown in *Figure 15-14*. The primary rotor (impeller) is attached to the engine crankshaft. The secondary rotor (runner) is attached to the reduction gear pinion shaft. The cover is bolted to the secondary rotor and surrounds the primary rotor.

Before proceeding with the assembly of the rotors and the shafts in the coupling housing, study the structure of the rotors themselves. Each rotor has a concave shape with radial partitions. A shallow trough is welded into the partitions around the inner surface of the rotor (*Figure 15-14*); the arrows indicate the radial passages tunnels under this trough.

When the coupling halves are assembled, the two rotors are placed facing each other to form a series of circular chambers *(Figure 15-15).* The rotors do not quite touch each other; the clearance between them is 1/4 to 5/8 inch, depending on the size of the coupling. The curved radial passages of the two rotors are opposite each other, so that the outer passages combine to make a circular passage except for the small gaps between the rotors.

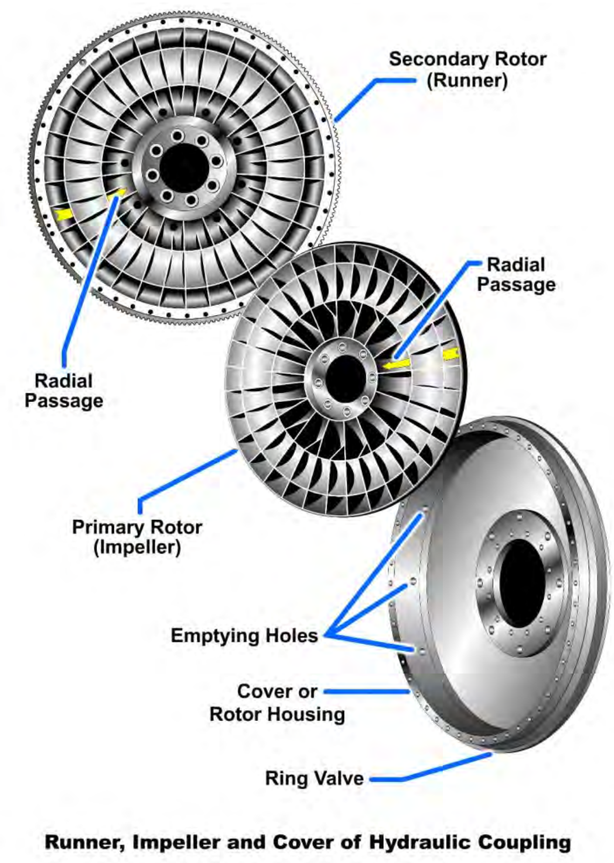

Figure 15-14 — Runner, impeller, and cover of hydraulic coupling.

In the hydraulic coupling assembly *(Figure 15-15)*, the driving shaft is secured to the engine crankshaft and the driven shaft goes to the reduction gear box. The oil inlet admits oil directly to the rotor cavities, which become completely filled. The rotor housing is bolted to the secondary rotor and has an oil-sealed joint with the driving shaft. A ring valve, going entirely around the rotor housing, can be operated by the ring valve mechanism to open or close a series of emptying holes in the rotor housing. When the ring valve is opened, the oil will fly out the rotor housing into the coupling housing, draining the coupling completely in 2 or 3 seconds. Even when the ring valve is closed, some oil leaks out into the coupling housing, and additional oil enters through the inlet. From the coupling housing, the oil is drawn by a pump to a cooler, and then sent back to the coupling.

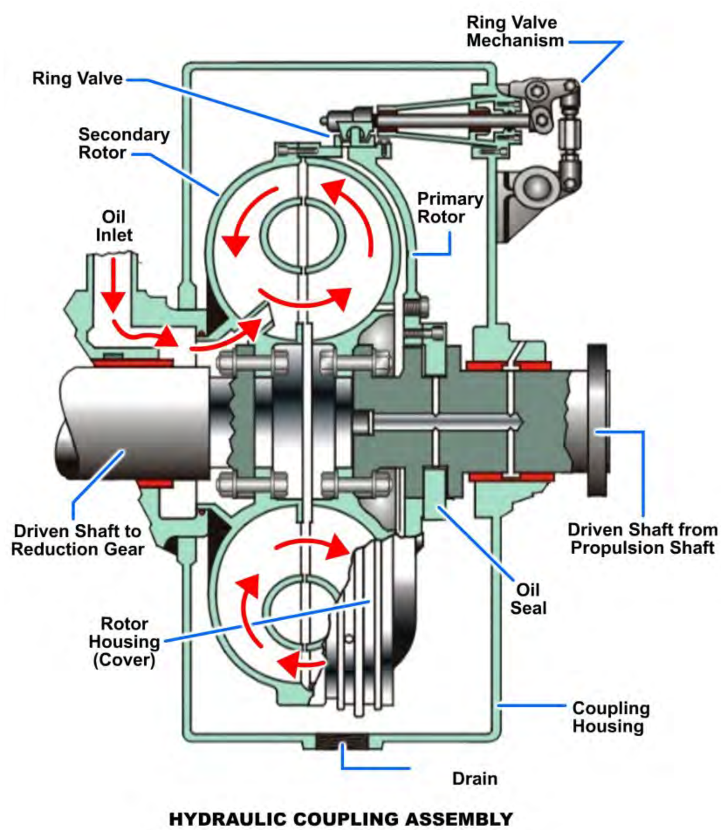

Figure 15-15 — Hydraulic coupling assembly.

Another coupling assembly used in Navy ships is the hydraulic coupling with piston-type quick-dumping valves. The operation of this coupling is similar to the one previously described. A series of piston valves are located around the periphery of the rotor housing. The piston valves are normally held in the closed position by springs. When air or oil pressure is admitted to the valves, the pistons are moved axially to uncover drain ports, allowing the coupling to empty. A hydraulic coupling with piston-type quick-dumping valves is used when extremely rapid declutching is not required. It offers greater simplicity and lower cost than a hydraulic coupling with a ring valve mechanism. Another type of self-contained unit for certain diesel-engine drives is the scoop control coupling shown in *Figure 15-16.*

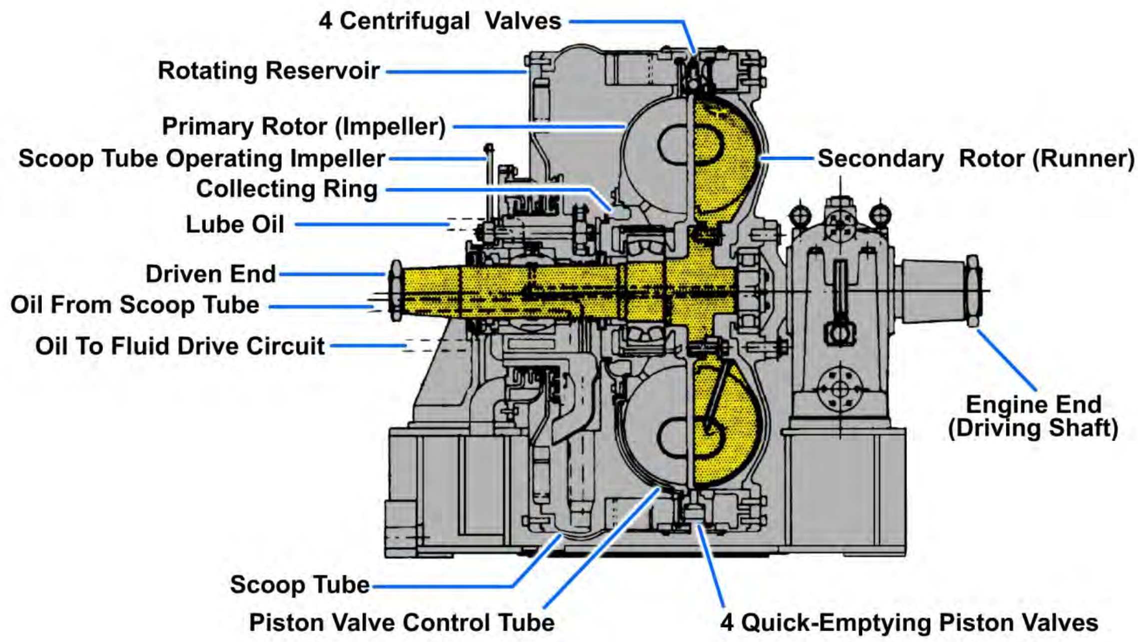

Figure 15-16 — Scoop control hydraulic coupling.

In couplings of this type, the oil is picked up by one of two scoop tubes (one tube for each direction of rotation), mounted on the external manifold. Each scoop tube contains two passages: a smaller one (outermost), which handles the normal flow of oil for cooling and lubrication, and a larger one, which rapidly transfers oil from the reservoir directly to the working circuit. The scoop tubes are mechanically operated from the control station through a system of linkages. As one tube moves outward from the shaft center line and into the oil annulus, the other tube is being retracted.

Four spring-loaded valves are mounted on the primary rotor. These valves, which are operated by centrifugal force, are arranged to open progressively as the speed of the primary rotor decreases. The arrangement provides the necessary oil flow for cooling as it is required. Quick emptying piston valves are provided to empty the circuit rapidly when the scoop tube is withdrawn from contact with the rotating oil annulus.

Under normal circulating conditions, oil fed into the collector ring passes into the piston valve control tubes. These tubes and connecting passages conduct oil to the outer end of the pistons. The centrifugal force of the oil in the control tube holds the piston against the valve port, thus sealing off the circuit. When the scoop tube is withdrawn from the oil annulus in the reservoir, the circulation of oil will be interrupted, and the oil in the control tubes will be discharged through the orifice in the outer end of the piston housing. This releases the pressure on the piston and allows it to move outward, thus opening the port for rapid discharge of oil. Resumption of oil flow from the scoop tube will fill the control tubes, and the pressure will move the piston to the closed position.

Principles of Operation

You can see what happens in the coupling when the engine is started and the coupling is filled with oil. The primary rotor turns with the engine crankshaft. As the primary rotor turns, the oil in the radial passages is forced to flow outward by centrifugal force. It forces oil across the gap at the outer edge of the rotor and into the radial passages of the secondary rotor, where the oil flows inward. The oil in the primary rotor not only is flowing outward, but also is rotating. As the oil flows over and into the secondary rotor, it strikes the radial blades in the rotor.

The secondary rotor soon begins to rotate and pick up speed, but it will always rotate more slowly than the primary rotor because of drag on the secondary rotor. Therefore, the centrifugal force of the oil in the primary rotor will always be greater than that of the oil in the secondary rotor. This causes a constant flow from the primary rotor to the secondary rotor at the outer ends of the radial passages and from the secondary rotor to the primary rotor at the inner ends.

Hydraulic Coupling Problems

With the quick-dumping hydraulic coupling, you may encounter the problem of dumping while under load or of excessive slippage. Either of these malfunctions may be caused by plugging of the pressure relief nozzles located in the periphery of the secondary (piston type) rotors. These nozzles consist of drilled allen setscrews, mounted in the secondary rotor at the ends of the radial tubes that feed air or oil to the dumping valves. The nozzles permit the feeder tubes to drain when the air or oil supply valve is closed, thus allowing the dumping valve to return to the closed position. The nozzles also permit the draining of any oil that has leaked past the control valve when shut.

There are also leak-off nozzles in the periphery of the secondary rotor at the base of the dumping valves. The leak-off nozzles serve as flushing exits for the valves and allow a continual flow of oil past the inlet port of the dumping valves. The oil washes away any particles of foreign matter that may collect as a result of the centrifugal force acting on the oil.

The best way to prevent a hydraulic coupling from dumping while under load is to keep the oil system free from foreign matter. Gasket compound and shreds of copper from oil tube packings often cause trouble. Every possible precaution must be taken to keep the oil system clean from foreign material.

To aid in this, the system has a strainer that effectively catches, or traps, most of the foreign matter that may reach the nozzles. All nozzles must be blown out during each overhaul.

If nozzles become clogged during operation, it is possible to clear them by operating the dumping control several times. This action may blow the obstruction through the nozzle opening. If this method fails, it will be necessary for you to secure the engine and remove and clean the nozzles.

Induction Couplings

Couplings of the induction type are used in some ships in the Navy (*Figure 15-17).* These couplings use the force of magnetism to “couple” the outer shaft to the input shaft. The inner cage is very similar in construction to the rotor of an electric motor. When the outer member is energized through the collector rings, a magnetic field is produced which will “lock in” the inner rotor. An instant disconnect of the driver from the driven shaft is accomplished by de-energizing the coupling excitation circuit.

The induction coupling limits maximum torque by pulling out of step when excessive torque is applied. The induction coupling also allows for a small amount of misalignment. In operating equipment that has induction couplings, observe the following directions and precautions:

1. Do NOT attempt to alter plant performance by changing control settings to settings other than those recommended in the NAVSEA technical manual for the equipment.
2. Ensure the coupling does not overheat because of insufficient ventilation when the fields rotate at slow speeds.
3. Ensure proper alignment is maintained (although most clutches of this type are capable of operating satisfactorily with a limited amount of misalignment).
4. Be thoroughly familiar with the means to permit the rotating members to be mechanically coupled in the event of total failure of the coupling excitation system.

5. Be thoroughly familiar with any interlocks that serve to PREVENT the following:
   a. Operation at reduced excitation EXCEPT when the prime mover is operating at specified reduced speeds.
   b. Excitation of the field windings UNLESS the throttle control is in the proper position.
   c. Excitation of the field windings UNLESS the shaft turning gear and shaft-locking devices are disengaged.
   d. Excitation of the field windings at a time when the clutch would turn the driven gear counter to the direction in which it is already being driven by another coupling or clutch.

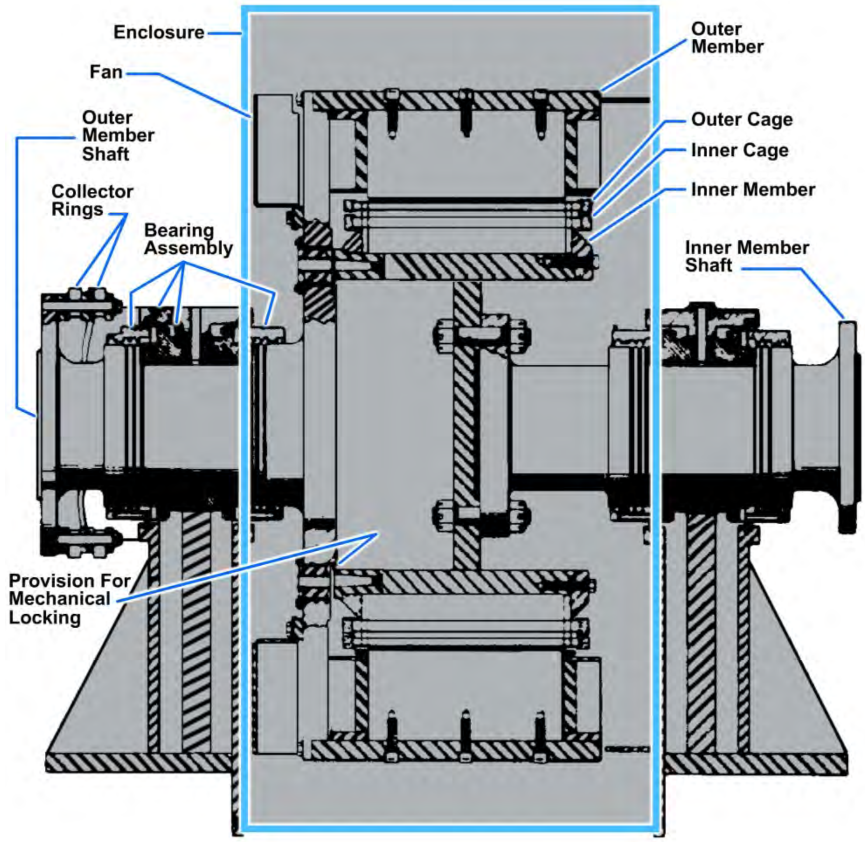

Figure 15-17 — Induction coupling.

CONTROLLABLE PITCH PROPELLERS

Controllable pitch propellers *(Figure 15-18)* are used in some naval ships. Controllable pitch propellers give a ship excellent maneuverability and allow the propellers to develop maximum thrust at any given shaft rpm. Ships with controllable pitch propellers require no reversing gear since the direction of the propeller thrust can be changed without changing the direction of shaft rotation. Controllable pitch systems are widely used on diesel-driven ships. Controllable pitch propeller systems may be controlled from the bridge or from the engine room through piping inside a hollow propulsion shaft to the propeller hub. Hydraulic or mechanical controls are used to apply the actuating force required to change the position, or angle of the pitch, of the propeller blades. A hydraulic system is the most widely used means of providing the force required to change the pitch of a controllable pitch propeller. In this type of system, a valve-positioning mechanism actuates an oil control valve. The oil control valve permits hydraulic oil, under pressure, to be introduced to either side of a piston (which is connected to the propeller blade) and at the same time allows for the controlled discharge of hydraulic oil from the other side of the piston. This action repositions the piston and thus changes the pitch of the propeller blades.

Some controllable pitch propellers have mechanical means for providing the blade actuating force necessary to change the pitch of the blades. In these designs, a worm screw and crosshead nut are used instead of the hydraulic devices for transmitting the actuating force. The torque required for rotating the worm screw is supplied either by an electric motor or by the main propulsion plant through pneumatic brakes.

In most installations, propeller pitch and engine power are controlled through a single lever. Movement of the lever causes both engine speed and pitch to change to suit the powering condition ordered. In emergencies, and in ships without single lever control, the propeller pitch may be changed independently of the engine power setting. Under this condition, overspeeding of the engine can result if the pitch is set too low, or over torqueing of the engine can result if the pitch is set too high.

In most ships with propulsion control systems, the machinery can be operated from three different locations. Local control is usually from a panel mounted on or near the machinery to be operated. The local control station is used for the operation of a single unit, for setting pitch on one propeller. The enclosed operating station (EOS) has a console for the operation of the complete propeller shaft, including main engines, propeller pitch control unit, clutches, and other machinery required for propulsion. On large ships, there may one EOS for each propeller shaft. The third operating station is the pilot-house console, which controls propeller shaft speed, and pitch, or direction. Generally this station cannot control the starting or stopping of main engines, operate clutches, or control other individual pieces of propulsion machinery. Both the EOS console and pilot-house console will have instruments that indicate shaft rpm, and other indicators required for the monitoring of the propulsion plant.

The worst enemy of any hydraulic system is dirt. Dirt that is allowed to enter the system, either when oil is being added or when other work is being performed, will create problems. Dirt will cause the extremely close clearances of parts in hydraulic components to become damaged. Also, dirt will cause the valves in the system to malfunction.

Instructions regarding the limitations of engine speeds at different propeller pitches have been issued to all ships equipped with controllable pitch propellers. In addition, the special operating and maintenance instructions for these propellers should be consulted before any overhaul or repairs are undertaken.

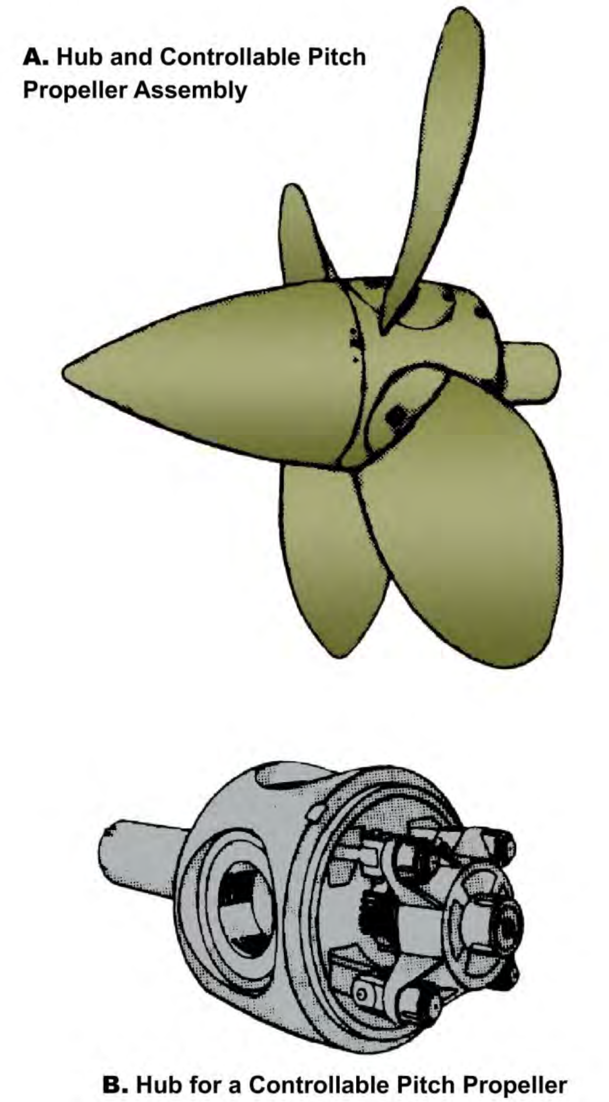

Figure 15-18 — Controllable pitch propeller components.

SUMMARY

In this chapter, we have discussed the various devices that transmit the power developed by the engine to the propeller of a vessel. In general, these devices consist of clutches, reverse gears, reduction gears, and the related shafting and bearings. A transmission requires an activating force to engage or disengage the clutch. This force may be in the form of mechanical, hydraulic, pneumatic, or electromagnetic energy. Some vessels are provided with controllable pitch propellers. With this arrangement, no reversing gear is required because the direction of propeller thrust can be changed without changing the direction of shaft rotation.

Learning to recognize various symptoms will help you to identify the abnormal conditions that may occur in clutches, couplings, and various associated gears. You should become familiar with the causes of gear, clutch, and coupling problems. By recognizing the causes of these problems, you can learn to prevent their reoccurrence through the application of correct operating procedures and proper upkeep and maintenance.

End of Chapter 15

Transmission of Engine Power

Review Questions

15-1. How is power transmitted from the drive mechanism on most Navy installations?

A. Fuel, and oil
B. Fuel and gears
C. Gears and shafts
D. Shafts and oil

15-2. What drive mechanism is used by common marine engines?

A. Attached
B. Indirect
C. Direct
D. Detached

15-3. What component is used in indirect drives to connect the engine to the drive mechanism?

A. Flexible coupling
B. Solid coupling
C. Spring coupling
D. Rigid coupling

15-4. What is the condition called when the clutch fails to disengage because of water absorbed in the material that lines the clutch plates?

A. Wear
B. Slippage
C. Squealing
D. Frozen

15-5. What linkage on friction clutches engages when two friction surfaces are mechanically forced into contact with each other?

A. Toggle-action
B. Spring
C. Hydraulic
D. Pneumatic

15-6. What component on the airflex clutch control mechanism delays the inflation of the clutch to be engaged during the shifting from one direction of rotation to the other?

A. Time delay switch
B. Restricted plates
C. Restricted orifice
D. Pressure switch

15-7. What component of the main shaft ensures the proper guide and support of rotating elements, prevents free radial movement, and limits the axial movement of the shaft?

A. Foundations
B. Supports
C. Bearings
D. Hangers

15-8. Where is the stern tube located on the main shaft?

A. Through the hull of the ship
B. Between the bulkheads between spaces
C. Under the rudder
D. Before the propeller

15-9. A hydraulic coupling eliminates the need for a mechanical connection between the engine and which part?

A. Main shaft
B. Flywheel
C. Propeller
D. Reduction gear

15-10. How is the outer rotor of the induction coupling energized to lock in with the inner rotor?

A. Contact switch
B. Pressure switch
C. Pressure contact
D. Collector rings

15-11. What is the worst enemy of any hydraulic system?

A. Dirt
B. Grease
C. Water
D. Fuel

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CHAPTER 16

PUMPS AND VALVES

As an Engineman, you will operate various types of pumps and valves. You will also be responsible for routine maintenance of this equipment in your spaces and possibly throughout the ship. The machinery of a system cannot work properly unless the pumps and valves are in good working order. In this chapter, we will discuss basic types of pumps and valves. Our discussion will also include the need for flange safety. The information in this chapter is general. You should refer to the appropriate *Naval Sea System Command* (NAVSEA) technical manual for specific information about various pumps and valves used on your ship.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the maintenance and operation of system pumps.
2. Explain the maintenance and operation of system valves.
3. Explain the maintenance and operation of special purpose valves (reducing, relief, and control valves).
4. Explain the general maintenance procedures of valves.

TYPES OF PUMPS

Pumps are by far the most numerous units of auxiliary machinery aboard ship. The types or classes of pumps used aboard ship include:

- Rotary pumps
- Centrifugal pumps
- Variable stroke reciprocating pumps
- Jet pumps

You can find straightforward explanations and illustrations of the basic principles of each type of pump in *Fireman*, NAVEDTRA 14104.This manual also discusses how the characteristics of each pump make it adaptable to a particular service in various engineering systems. We recommend that you review the information on pumps in *Fireman,* NAVEDTRA 14104, before you begin to study the information in this chapter.

Rotary Pumps

The operation of a positive-displacement rotary pump depends upon the principle that rotating gears, vanes, screws, or lobes trap liquid in the inlet side of the pump casing and move it to the outlet connection—thus producing flow. (Positive displacement means that a definite quantity of liquid is moved from the inlet to the outlet side on each revolution). In a positive displacement pump, pressure is the result of resistance to flow in the system to which it discharges. Pressure is limited only by the bursting strength and available power of the pump. For this reason, relief valves are always fitted on the pump discharge. Positive-displacement rotary pumps have largely replaced reciprocating pumps for pumping viscous liquids in naval ships, as they have a greater capacity for their weight and occupy less space.

Rotary pumps have very small clearances between rotating parts to minimize slippage (leakage) from the discharge side back to the inlet of the pump. With close clearances, these pumps must be operated at relatively low speeds to obtain reliable operation and maintain capacity over an extended period of time.

Types of Rotary Pumps

There are several types of positive-displacement rotary pumps, including the simple gear, herringbone gear, helical gear, and vane, lobe, and screw types. The main features of gear and screw pumps will be discussed briefly in the following paragraphs.

Simple Gear Pump

The simple gear pump *(Figure 16-1)* has two spur gears which mesh and revolve in opposite directions. One is the driving gear, and the other is the driven gear. Clearances between the gear teeth (the outside diameter of the gear) and the casing, and between the end face and the casing, are only a few thousandths of an inch. As they turn, the gears unmesh and liquid flows into the pockets that are vacated by the meshing gear teeth. This creates the suction that draws the liquid into the pump. The liquid is then carried around in the pockets formed by the gear teeth and the casing. At the outlet, or discharge side, the liquid is pushed out (displaced) by the meshing of the gear teeth and is forced to flow through the outlet connection of the pump.

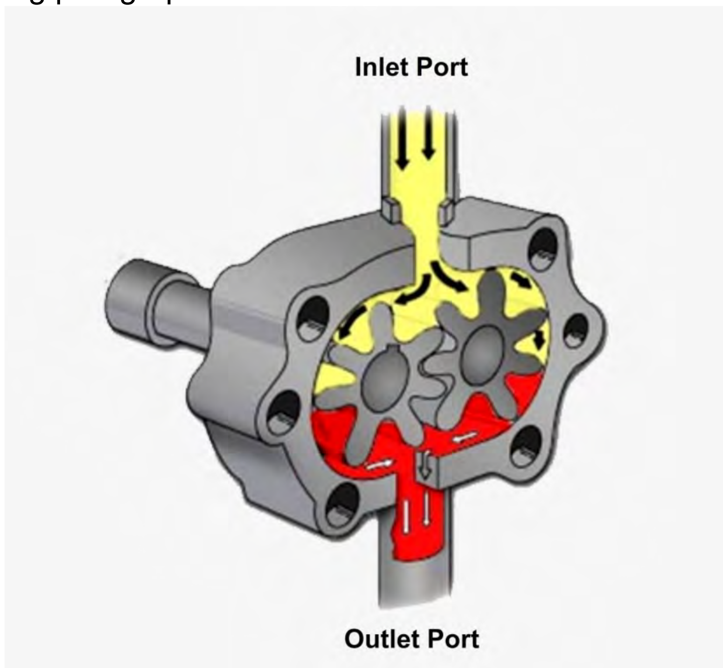

Figure 16-1 — Simple gear rotary pump.

Herringbone Gear Pump

In the herringbone gear pump *(Figure 16-2)* a modification of the simple gear pump, one discharge phase begins before the previous discharge phase is entirely complete. This overlapping tends to give a steadier discharge pressure than is found in the simple gear pump. Power-driven pumps of this type are sometimes used for low pressure lubricating oil service and fuel service.

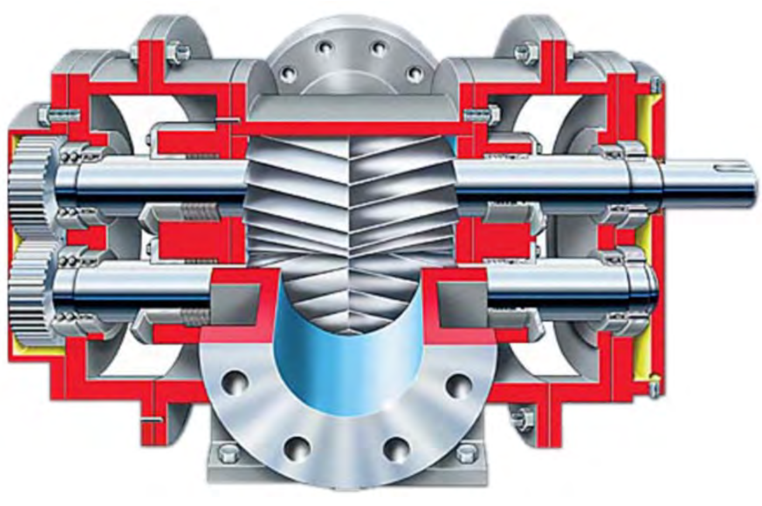

Figure 16-2 — Herringbone gear pump.

Helical Gear Pump

The helical gear pump (*Figure 16-3)* is still another modification of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump. The discharge flow is, accordingly, even smoother. Since the discharge flow is smooth in the helical gear pump, the gears can be designed with a small number of large teeth. This design allows for increased capacity without sacrificing smoothness of flow.

The pumping gears in this type of pump are driven by a set of timing and driving gears, which also function to maintain the required close clearances while preventing actual metal-to-metal contact between the pumping gears. Metallic contact between the teeth of the pumping gears would provide a tighter seal against leakage; however, it would cause rapid wear of the teeth because foreign matter in the pumped liquid would act like an abrasive on the contact surfaces.

Roller bearings at both ends of the gear shafts maintain proper alignment, thereby minimizing the friction loss in the transmission of power. Stuffing boxes prevent leakage at the shafts. The helical gear pump can pump nonviscous liquids and light oils at high speed. At lower speed, it can pump heavy viscous materials.

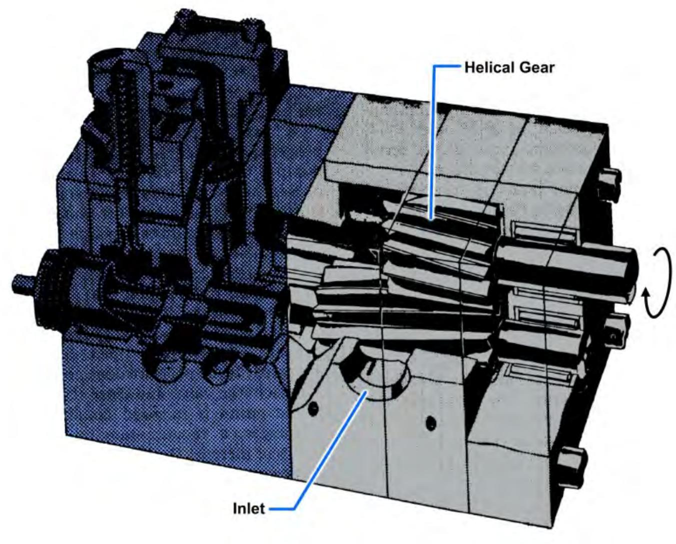

Figure 16-3 — Helical gear pump.

Lobe Pump

The lobe pump is still another variation of the simple gear pump. A lobe pump (heliquad type) is illustrated in *Figure 16-4*. The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The rotors are driven by external spur gears on the rotor shafts. Some lobe pumps are made with replaceable inserts (gibs) at the extremities of the lobes. These inserts take up the wear that would otherwise be sustained by the ends of the lobes. They maintain a tight seal between the lobe ends and the casing. The inserts are usually seated on a spring. They automatically compensate for considerable wear of both the gibs and the casing. Replaceable cover plates (liner plates) are fitted at each end of the casing where the lobe faces wear.

Figure 16-4 — Lobe pump (heliquad type).

Screw Pump

There are several types of screw pumps. The main differences are the number of intermeshing screws and the pitch of the screws. *Figure 16-5;* show a positive displacement, double-screw, and low-pitch pump. (In a low-pitch pump, the threads form a small angle with respect to the center line of the

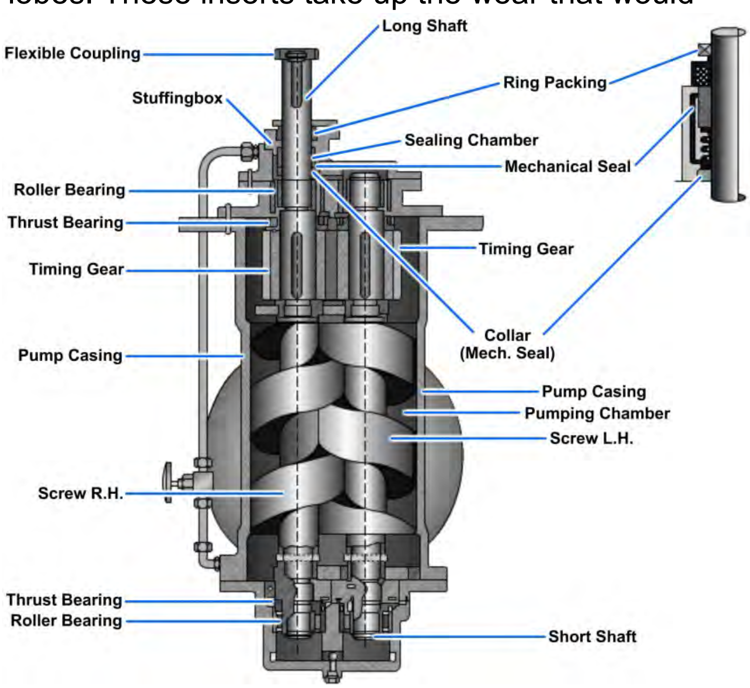

Figure 16-5 — Positive-displacement, double-screw, low-pitch pump.

pumping element.) Screw pumps are used primarily for pumping viscous fluids, such as F-76 and F-44. Hydraulic systems on some ships use the screw pump to supply pressure for the system.

In the screw pump, liquid is trapped and forced through the pump by the action of rotating screws. As the rotor turns, the liquid is trapped between the threads at the outer end of each pair of screws. The threads carry the liquid along within the housing to the center of the pump casing, where it is discharged.

Operating Troubles

From time to time you are likely to have some troubles with rotary pumps. The most common causes of trouble are (1) the system fails to build up the required pressure, or (2) the pump fails to discharge fluid. When these troubles occur, proceed as follows:

1. Stop the unit.
2. See that all valves in the pump suction lines are open.
3. Check the packing of all inlet valves and manifold valve stems to ensure that no air is being drawn into the suction piping.
4. Check the pump shaft packing for air leakage into the pump.
5. Check the spring case and the inlet and outlet connections of the discharge relief valve to ensure that no air is leaking into the pump suction.
6. Start the pump again. When it is up to the proper speed, read the suction gauge to see if the pump is pulling a vacuum. If a low vacuum (5 or 6 inches of mercury, or less) is indicated, air is probably leaking into the pump casing. If no vacuum is shown on the suction pressure gauge, it is possible that the pump is not “primed.” (This should rarely occur once the pump casing has once been filled.) If the system still does not build up pressure, close the discharge valve gradually, and note the pressure gauge at the same time. If the pressure increases, an open discharge line is indicated. If the pressure does not increase, open the discharge valve and close the suction valve. If the pump is in good condition with close clearances, a vacuum ranging from 15 to 25 inches of mercury (Hg) should be indicated by a vacuum gauge connected to the inlet of the pump.

⚠ CAUTION ⚠

Do not operate the pump any longer than necessary to get a gauge reading; the pumping elements depend on a constant flow for lubrication.

Centrifugal Pumps

Ships use centrifugal pumps for fire and flushing systems. Internal-combustion engines use centrifugal pumps to circulate cooling water. There are many types of centrifugal pumps, but all operate on the same principle.

The centrifugal pump uses the throwing force of a rapidly revolving impeller. The rotating impeller creates an empty space at the center hole (eye). The pressure at this point is less than atmospheric pressure (because of the mechanically displaced liquid). This causes atmospheric pressure to act on the surface of the liquid being pumped, forcing it into the pump casing and through the hole in the center of the impeller. It is then discharged from the outer rim of the impeller.

By the time the liquid reaches the outer rim of the impeller, it has acquired considerable velocity (kinetic energy). The flow of liquid then slows down as it moves through a volute or series of diffusing passages. As the velocity of the liquid decreases, its pressure increases, thus its kinetic energy is transformed into potential energy.

Types of Centrifugal Pumps

There are many different types of centrifugal pumps, but the two you are most likely to encounter onboard ship are the volute pump and the diffuser pump.

Volute Pump

In the volute pump (*Figure 16-6, views A and B*), the impeller discharges into a volute (a gradually widening spiral channel in the pump casing). As the liquid passes through the volute and into the discharge nozzle, a great part of its kinetic energy (velocity head) is converted into potential energy (pressure head).

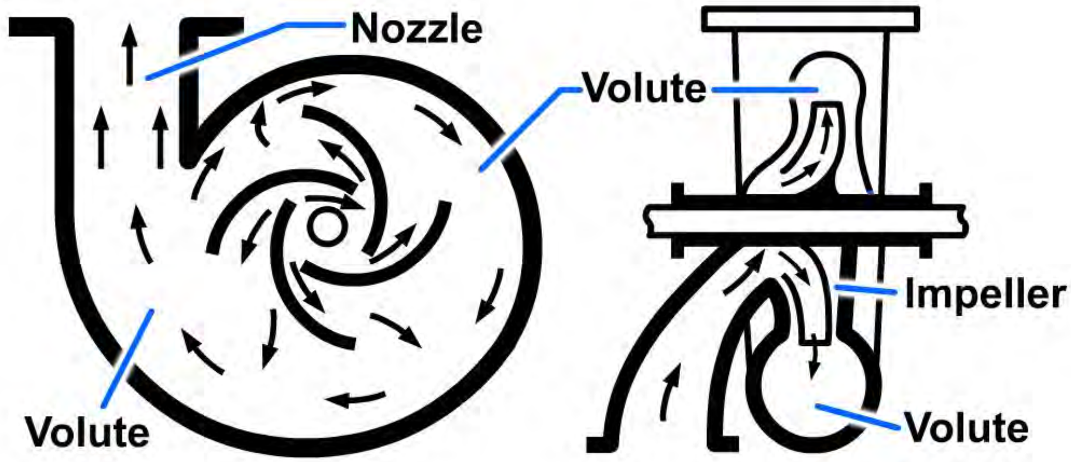

Figure 16-6 — Simple volute pump.

Diffuser Pump

In the diffuser pump *(Figure 16-7),* the liquid leaving the impeller is first slowed down by the stationary diffuser vanes that surround the impeller. The liquid is forced through gradually widening passages in the diffuser ring and into the volute (casing). Since both the diffuser vanes and the volute reduce the velocity of the liquid, there is an almost complete conversion of kinetic energy to potential energy.

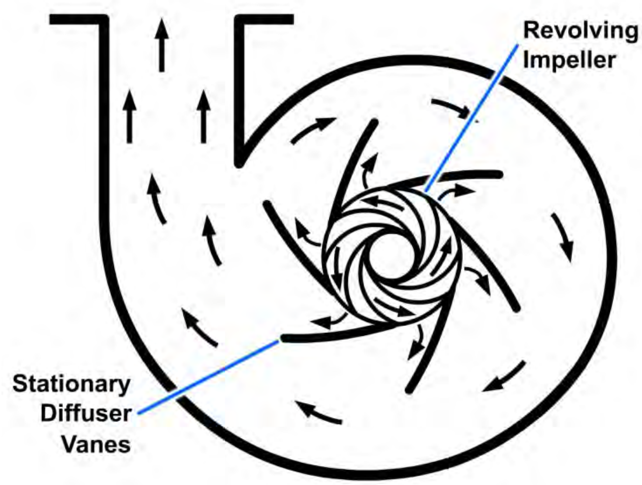

Figure 16-7 — Diffuser pump.

Classification of Centrifugal Pumps

Centrifugal pumps may be classified in several ways. For example, they may be either single stage or multistage. A single-stage pump has only one impeller. A multistage pump has two or more impellers housed together in one casing. As a rule, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as horizontal or vertical, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as single suction or double suction. The single-suction impeller allows liquid to enter the eye from one side only. The double-suction impeller allows liquid to enter the eye from two directions.

Impellers are also classified as closed or open. Closed impellers have side walls that extend from the eye to the outer edge of the vane tips. Open impellers do not have these side walls. Most centrifugal pumps used in the Navy have closed impellers.

Construction of Centrifugal Pumps

The following information applies in general to most of the centrifugal pumps used in naval service. Centrifugal pumps, illustrated in *Figure 16-8,* are used to supply cooling water to diesel engines. A cutaway view of a fire and flushing pump is shown *(Figure 16-9),* for the relative location of components.

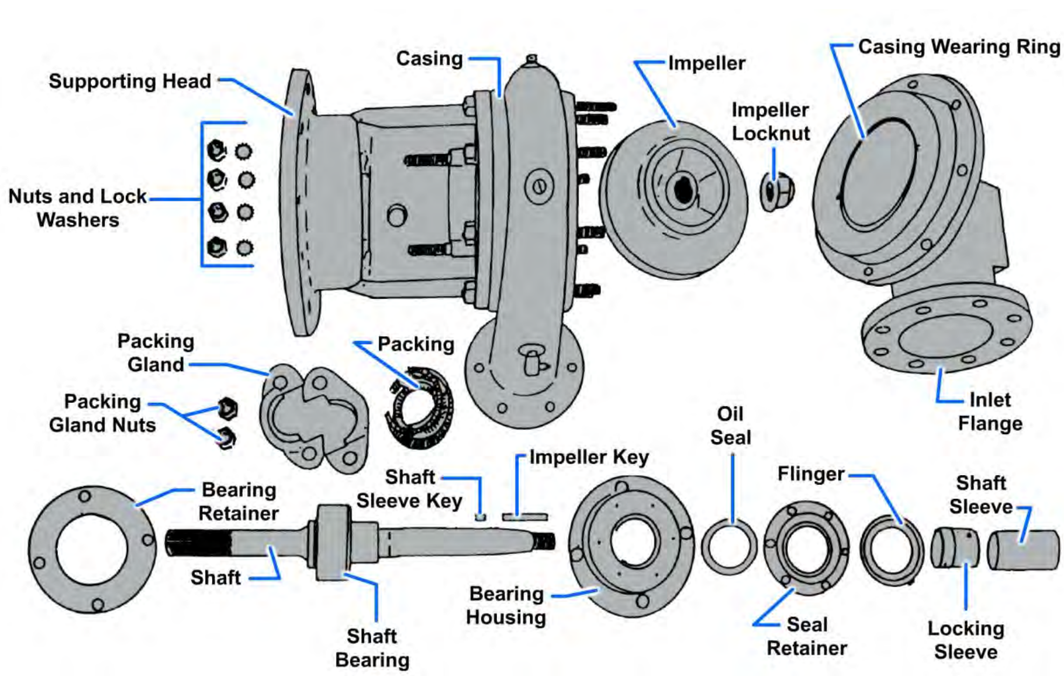

Figure 16-8 — Exploded view of a centrifugal water pump.

The shaft is protected from excessive wear and corrosion by a Monel or corrosion-resistant steel sleeve wherever the shaft comes in contact with the liquid being pumped or with the shaft packing. The advantage of using a shaft sleeve is that it can be replaced more economically than the entire shaft.

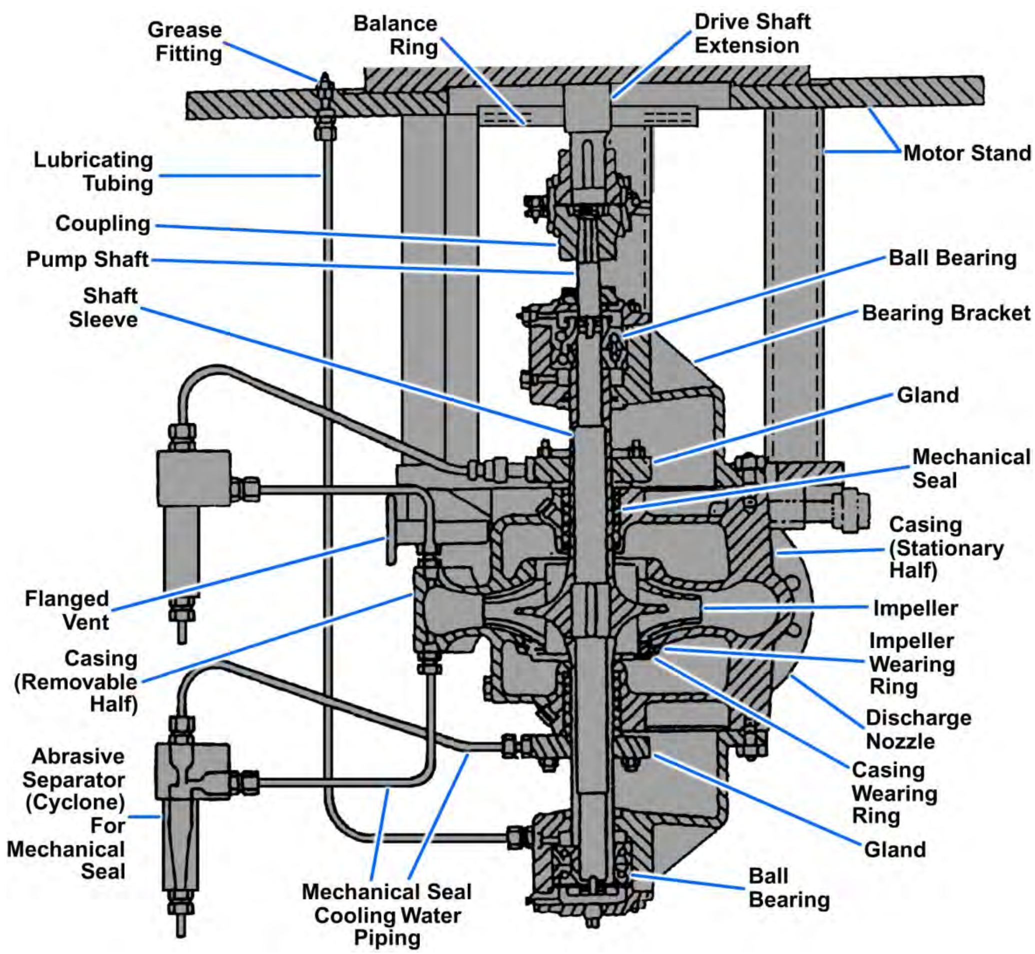

Figure 16-9 — Fire pump (vertical, double-suction impeller).

The impellers are carefully machined and balanced to reduce vibration and wear since they rotate at very high speeds. To prevent corrosion of pumps that handle seawater, the components of these pumps are made of nonferrous materials such as bronze or Monel.

A close radial clearance must be maintained between the outer hub of the impeller and that part of the pump casing in which the hub rotates to minimize leakage from the discharge side of the pump casing to the inlet side. Because of the close clearances at the hub and the high rotational speed of the impeller, the running surfaces of both the impeller hub and the casing at that point are subject to wear. Wear results from erosion as the liquid passes between the close spacing (clearance) of the wearing rings, from the high pressure side of the impeller, and back to the low pressure side of the pump *(Figure 16-10).*

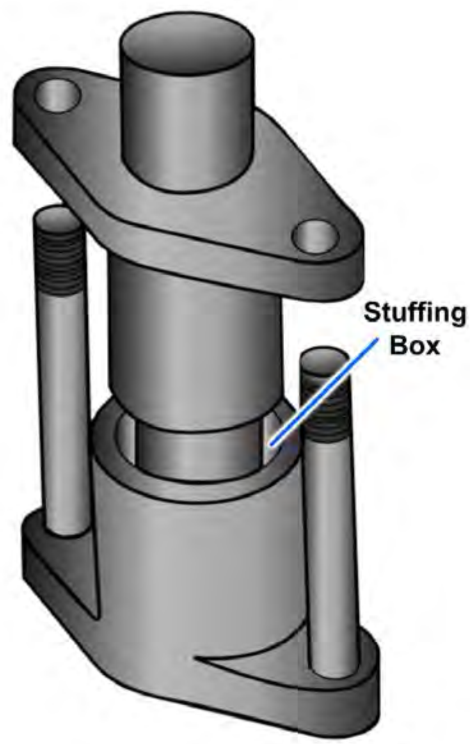

Figure 16-10 — Stuffing box on a centrifugal pump.

Centrifugal pumps are provided with replaceable wearing rings to eliminate the need for renewing an entire impeller and pump casing because of wear. One ring is attached to each outer hub of the impeller. This ring is called the impeller wearing ring. The other ring, which is stationary and attached to the casing, is called the casing wearing ring (*Figure 16-11, views A and B*). Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring. In this type of pump, the casing wearing ring is fitted into the end plate.

Recirculating lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods. Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the rotating joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box. Seal piping *(Figure 16-10)* leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft (between the shaft and the packing). Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water from the stuffing box from flowing along the shaft and entering the bearing housing.

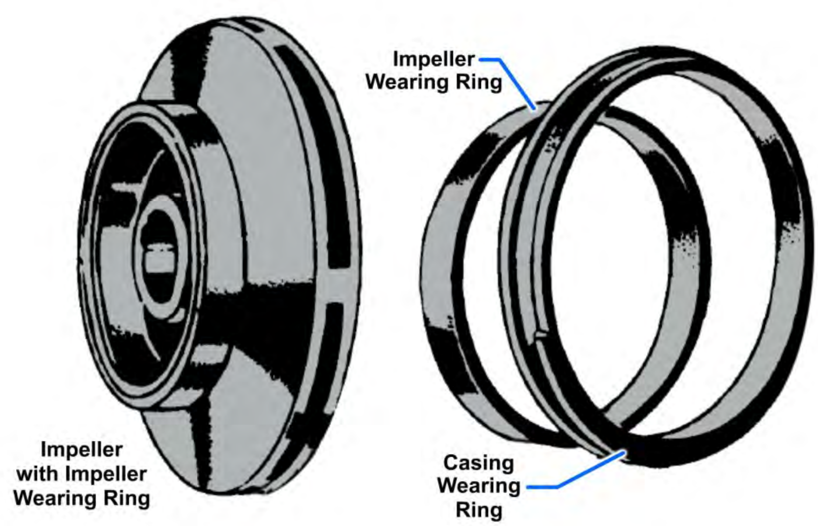

Figure 16-11 — Impeller and wearing rings for a centrifugal pump.

During pump operation, a certain amount of leakage around the shafts and casings normally takes place. This leakage must be controlled for two reasons: (1) to prevent excessive fluid loss from the pump, and (2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure. The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings, which causes the rings to deform and seal around the pump shaft and casing. The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely since a certain amount of leakage is necessary during operation.

Mechanical seals are rapidly replacing conventional packing on centrifugal pumps *(Figure 16-12).* Some of the reasons for the use of mechanical seals are as follows:

1. Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.
2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings. Leakoff causes two types of seal leakage:
   a. Water contamination of the engine lubrication oil.
   b. Loss of treated freshwater which causes scale buildup in the cooling system.

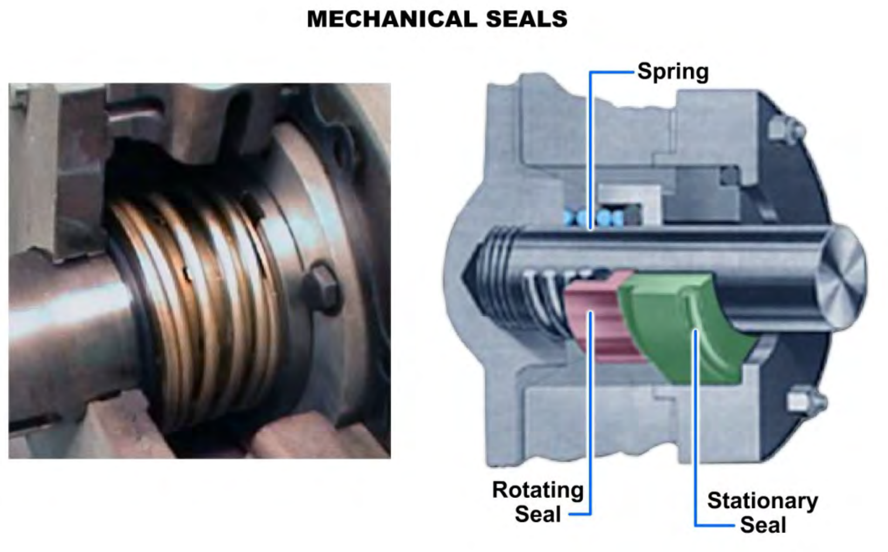

Figure 16-12 — Type-1 mechanical seal.

In regard to the use of mechanical seals, there are two important safety considerations:

1. Flammable liquids must be contained in the system.
2. Pumps in the vicinity of electrical or electronic gear where moisture can be a major problem must have zero leakoff.

Fire pumps and seawater pumps that are provided with mechanical shaft seals may also have cyclone separators. These separators use centrifugal force to prevent abrasive material (such as sand) in the seawater from passing between the sealing surfaces of the mechanical seal. The abrasive separator has no moving parts; liquid from the high pressure side of a pump is directed through tubing to the opening in the sides of the separator device, which is offset from the center line. As the liquid enters, it is given a swirling motion (cyclone effect) which causes heavier abrasive materials to be forced to the walls of the center tube, which is shaped to form a venturi. There is an opening at each end of the separator. The opening at the top is for “clean” water, which is directed through tubing to the mechanical seals in the pump. The high-velocity “dirty” water is directed through the bottom of the separator, back to the inlet piping for the pump.

Shaft and thrust bearings support the weight of the impeller and maintain the position of the rotor, both radially and axially. (Radial bearings may be sleeve or ball type. Thrust bearings may be ball or pivoted segmental type).

The power end of a centrifugal pump may be a steam turbine, an electric motor, or a diesel engine. Pumps used for continuous service can be either turbine or motor driven. Smaller pumps, such as those used for in-port or cruising operations, are generally motor driven. Pumps used for emergency firemain service are generally diesel driven.

Operating Troubles

Some of the operating troubles you, as an Engineman, may encounter with centrifugal pumps, together with the probable causes, are discussed in the following paragraphs. If a centrifugal pump DOES NOT DELIVER ANY LIQUID, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation (this may occur after motor overhaul); (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at INSUFFICIENT CAPACITY, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure; (3) insufficient pump speed; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (three-phase electric motor driven pumps).

If a pump WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump DRAWS TOO MUCH POWER, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids.

If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

1. Shut the pump discharge valve.
2. Secure the pump.
3. Open all valves in the pump suction line.
4. Prime the pump (fill casing with the liquid being pumped) and be sure that all air is expelled through the air cocks on the pump casing.
5. Restart the pump. If the pump is electrically driven, be sure the pump is rotating in the correct direction.
6. Open the discharge valve to “load” the pump. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump and continue troubleshooting according to the technical manual for that unit.

Maintenance of Centrifugal Pumps

When properly installed, maintained by use of the Planned Maintenance System (PMS), and operated, centrifugal pumps are usually trouble-free. Some of the most common corrective maintenance actions that you may be required to perform are discussed in the following sections.

Repacking

Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the stuffing box or seal.

How often the packing in a centrifugal pump should be renewed depends on several factors, such as the type of pump, condition of the shaft sleeve, and hours in use.

To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed. It is absolutely necessary to use the correct packing. When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, YOU ARE NOT USING THE RIGHT SIZE.

Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure. Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off. This gives the packing time to run-in and swell. You may then begin to adjust the packing gland. Tighten the adjusting nuts one flat at a time. Wait about 30 minutes between adjustments. Be sure to tighten the same amount on both adjusting nuts. If you pull up the packing gland unevenly (or cocked), it will cause the packing to overheat and score the shaft sleeves. Once you have the desired leak-off, check it regularly to make certain that sufficient flow is maintained.

Mechanical Seals

Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings. Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, sonar, radar, and other electronic cooling systems). They not only conserve the fluid being pumped but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

You should replace a mechanical seal whenever the seal is removed from the shaft for any reason or whenever leakage causes undesirable effects on equipment or surrounding spaces.

WARNING

Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on outboard ends for easy mechanical seal mounting.

Mechanical shaft seals serve to ensure that position liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

Variable-Stroke Pumps

Variable-stroke reciprocating pumps (also called variable-displacement pumps) are most commonly used on naval ships as part of an electrohydraulic transmission system. They are used on anchor windlasses, cranes, winches, steering engines, and other equipment. You will have to maintain and make minor repairs to hydraulic and related equipment outside your ship's engineering spaces. The information that follows is in addition to that found in *Fireman,* NAVEDTRA 14104. Two general types of variable-stroke pumps are in common use: the axial-piston pump and the radial-piston pump. In the axial-piston pump *(Figure 16-13),* the pistons are arranged parallel to each other and to the pump shaft. In the radial-piston pump *(Figure 16-14),* the pistons are arranged radially from the shaft.

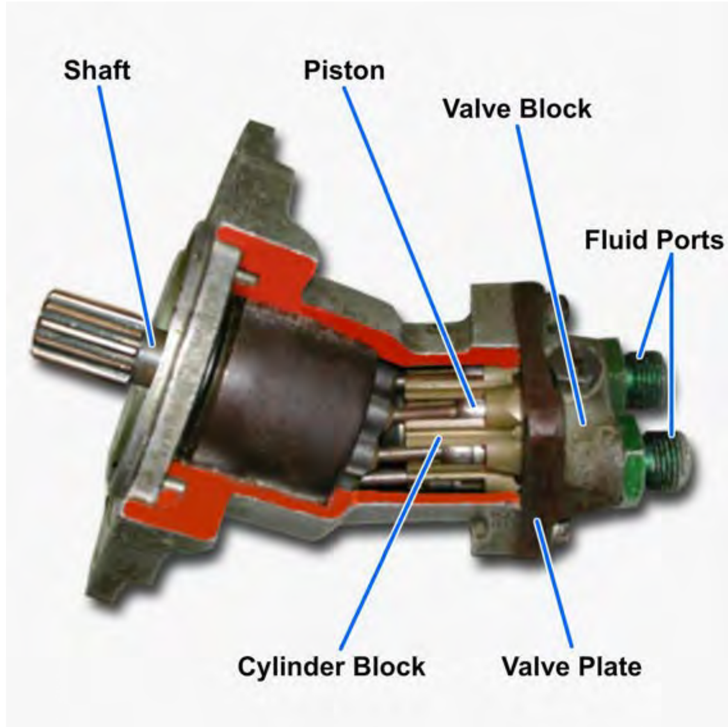

Figure 16-13 — Axial-piston hydraulic speed gear.

Variable-Stroke Axial-Piston Pump

The variable-stroke axial-piston pump usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. (Note that the term cylinder barrel, as used here, actually refers to a cylinder block that holds all the cylinders). An uneven number of pistons are always used so that pulsations in the discharge flow can be avoided. The piston rods make a ball-and-socket connection with a socket ring. The socket ring rides on a thrust bearing carried by a casting called the tilting box or tilting block.

When the tilting box is at a right angle to the shaft, and the pump is rotating, the pistons do not reciprocate; no pumping takes place. When the box is tilted away from a right angle, the pistons reciprocate and the liquid is pumped.

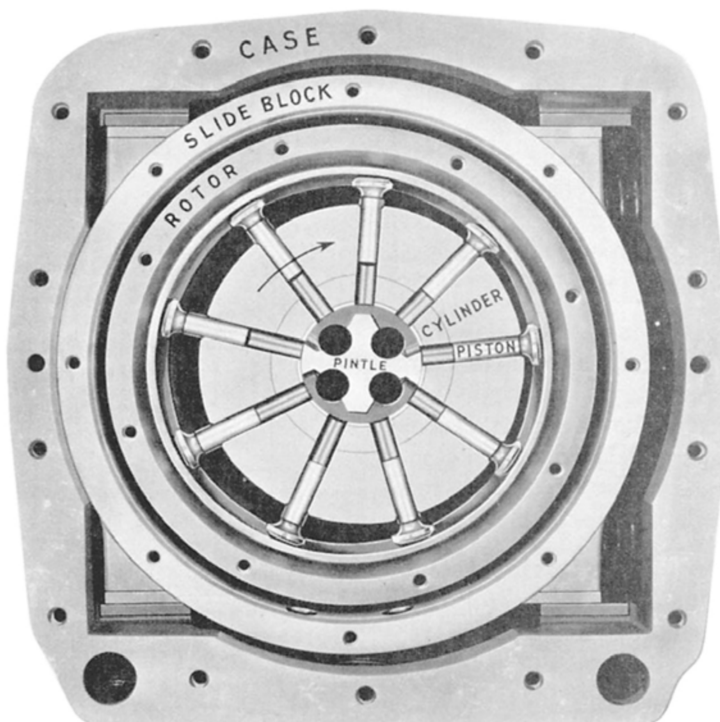

Figure 16-14 — Nine-piston (radial-piston) pump.

The variable-stroke axial-piston pump is often used as a part of a variable-speed gear, for forward and reverse rotation, such as electrohydraulic anchor windlasses, cranes, winches, and the power transmitting unit in electrohydraulic steering engines. In those cases, the tilting box is arranged so that it may be tilted in either direction. Thus it may be used to transmit power hydraulically to pistons or rams, or it may be used to drive a hydraulic motor. In the latter use, the pump is driven by a constant-speed electric motor and is called the A-end of the variable speed gear. The hydraulic motor is called the B-end.

The B-end unit of the hydraulic speed gear is exactly the same as the A-end of the variable stroke pump mentioned previously. It generally does not have a variable-stroke feature; the tilting box is installed at a permanently fixed angle. Thus, the B-end becomes a fixed-stroke axial-piston pump. *Figure 16-13* illustrates an axial-piston hydraulic gear with the A-end and B-end as a single unit. It is used in gun turrets for horizontal and vertical drive and for elevation driving units. For electrohydraulic winches and cranes, the A-end and B-end are in separate housings connected by hydraulic piping.

Hydraulic fluid introduced under pressure to a cylinder causes the piston to be pushed out. In being pushed out, the piston, through its connecting rod, will seek the point of greatest distance between the cylinder barrel and the socket ring. The resultant pressure of the piston against the socket ring will cause the cylinder barrel and the socket ring to rotate. This action occurs during the half revolution while the piston is passing the intake port of the motor (which is connected to the pressure port of the pump).

After the cylinder of the motor has taken all the hydraulic fluid it can from the pump, the piston passes the valve plate land and starts to discharge oil through the outlet ports of the motor to the suction inlet of the pump, and from there to suction pistons of the pump. The pump is constantly putting pressure on one side of the motor while it is constantly receiving hydraulic fluid from the other side. The fluid is merely circulated from pump to motor and back again.

Variable-Stroke Radial-Piston Pump

The variable-stroke radial-piston pump *(Figure 16-14)* is similar in general principle to the axial piston pump, but the arrangement of components is different. In the radial-piston pump, the cylinders are arranged radially in a cylinder body which rotates around a nonrotating central cylindrical valve. Each cylinder communicates with horizontal ports in the central cylindrical valve. Plungers or pistons, which extend outward from each cylinder, are pinned at their outer ends to slippers which slide around the inside of a rotating floating ring or housing.

The floating ring is constructed so that it can be shifted off-center from the pump shaft. When it is centered, or in the neutral position, the pistons do not reciprocate and the pump does not function, even though the electric motor is still causing the pump shaft to rotate. When the floating ring is forced off-center to one side of the pump shaft, the pistons reciprocate and the pump operates. If the floating ring is forced off-center to the other side, the pump also operates but the direction of the flow is reversed. Therefore, the direction of flow and the amount of flow are both determined by the position of the cylinder body relative to the position of the floating ring.

For further information, refer to *Naval Ships' Technical Manual (NSTM),* Chapter 503, and the NAVSEA technical manual for your unit.

Jet Pumps (Eductors)

An eductor is a type of jet pump. Unlike other pumps, a jet pump has no moving parts. A simple jet pump (*Figure 16-15)* consists of a jet supply line, a jet or nozzle, a suction line, a suction chamber, a diffuser, and a discharge line.

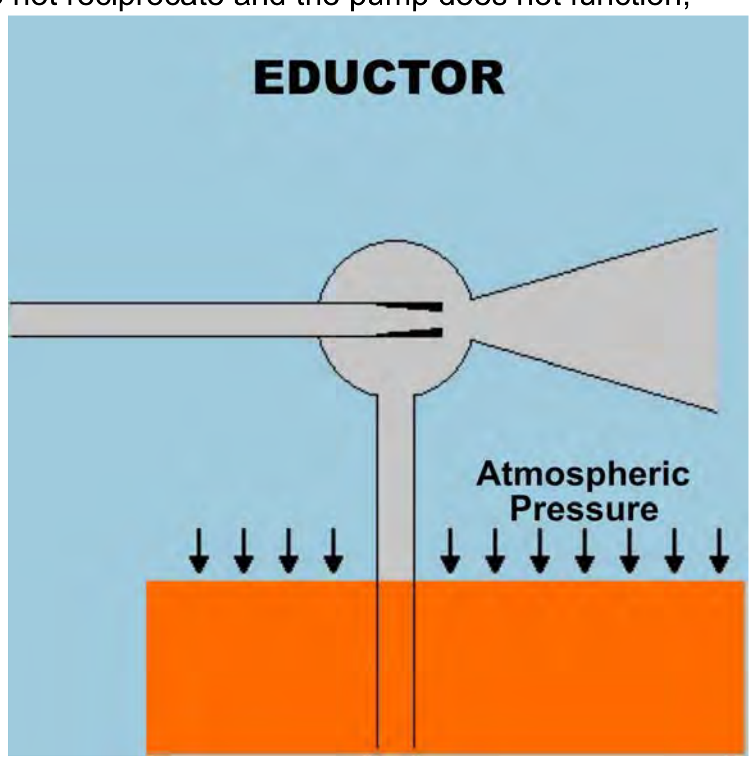

Figure 16-15 — Simple jet pump.

In a jet pump, pumping action is created as a fluid (water, steam, or air) passes at a high pressure and velocity through a nozzle and into a chamber that has an inlet and outlet opening.

The operating principle of a jet pump is as follows: Upon starting up, the rapidly moving jet fluid pushes on and gives sufficient motion to the air (or whatever substance may be in the suction chamber) to carry it out through the discharge line. Displacement of the air from the suction chamber creates a partial vacuum within the suction chamber, causing fluid to flow through the suction line. The fluid entering the chamber from the suction line is picked up by the high-velocity fluid, thus providing continuous pumping action.

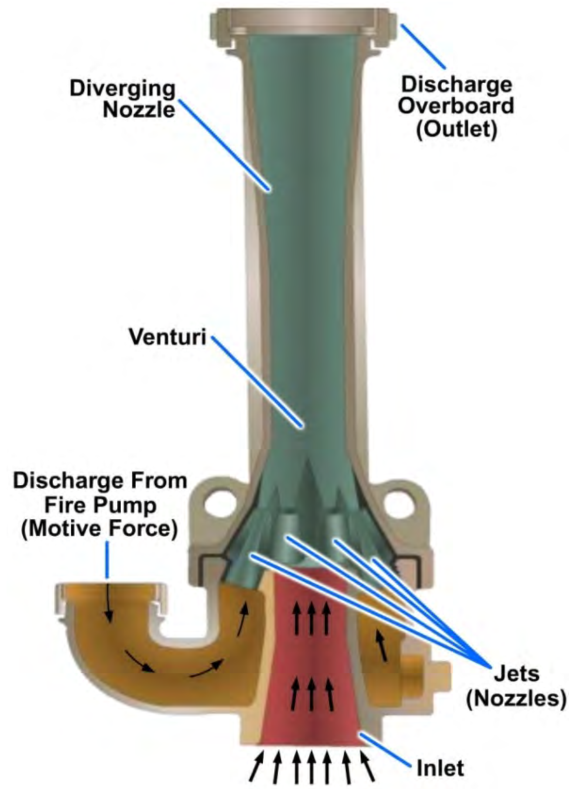

Figure 16-16 — Portable eductor.

Eductors are designed to pump large volumes of water. *Figure 16-16* illustrates a portable eductor used for emergency dewatering of a flooded compartment. In modern ships, fixed eductors have replaced fire and bilge pumps as a primary means for pumping bilges, deballasting, and dewatering compartments. Eductors allow centrifugal fire pumps to serve indirectly as drainage pumps without the risk of becoming fouled with debris from the bilges. The centrifugal pumps pressurize the firemain, and water from the firemain actuates the eductors. The eductors in modern combat ships have a much larger pumping capacity than fire and bilge pumps. They are installed as part of the piping in the drainage system and are flanged to permit easy removal and disassembly when repairs are necessary.

Because of their simplicity, jet pumps generally require very little maintenance. Since there are no moving parts, only the nozzles will show wear. The erosion action will cause the nozzles to become enlarged; in this case they are generally renewed. Occasionally the nozzles are removed; the strainers, if fitted, are cleaned; and a special reamer is inserted in the nozzles to clean out any rust or scale that may have accumulated.

Pump Care and Operation

You should carry out pump operation and safety precautions according to the engineering operational procedures (EOPs), a subsystem of the engineering operational sequencing system (EOSS), if your ship has EOSS, or the NSTM and the instructions posted on or near each individual pump. Follow the NAVSEA technical manual or maintenance requirement cards (MRCs) for PMS-related maintenance for all maintenance work.

⚠ CAUTION ⚠

Improper starting or securing of an eductor can cause rapid flooding of the space being pumped. Always follow the procedure on the posted operating card.

VALVES

Every piping system must have some means to control the amount and direction of the flow of a liquid or a gas through the lines. This is accomplished by the use of valves, which can be opened or closed as required. All valves can be grouped in two general classifications: (1) manually operated valves and (2) automatic valves.

Manually operated valves include all valves that are adjusted by hand. Automatic valves include check valves, thermostatic valves, and pressure-regulating valves. This section contains general information only. You should refer to the appropriate NAVSEA valve manuals if you should require more specific information.

Valves are usually made of bronze or steel. Steel valves are either cast or forged and are made of either plain steel or alloy steel. Alloy steel valves are used in high pressure, high-temperature systems. The disks and seats (internal sealing surfaces) of valves used in steam piping systems are usually coated with a chromium-cobalt alloy known as Stellite, which is an extremely hard metal.

Bronze valves are never used in systems where temperatures exceed 550 °F. Steel valves are used for all services above 550 °F. Bronze valves are used almost exclusively in systems that carry salt water. The seats and disks of these valves are usually made of Monel, a metal that has excellent corrosion- and erosion-resistant qualities.

Stop Valves

Stop valves are used to shut off or, in some cases, control the flow of fluid. They are controlled by the movement of the valve stem. Stop valves can be divided into four general categories: globe, gate, butterfly, and ball. (Plug valves and needle valves are also considered to be stop valves, but they are covered in more detail in *Fireman,* NAVEDTRA 14104).

Globe Valves

Globe valves are probably the most common valves in existence. They are used throughout the engineering plant and other parts of the ship. The globe valve gets its name from the globular shape of the valve body. However, you have to look inside the valve for a positive identification, because other valve types may also have globular bodies. Globe valve inlet and outlet openings are arranged in several ways to suit varying requirements of flow (*Figure 16-17, views A through C)*; straight flow, angle flow, and cross flow. The common type of globe valves are, *Figure 16-18,frames 1 and 2,* shows a cutaway view of a straight-flow globe valve.

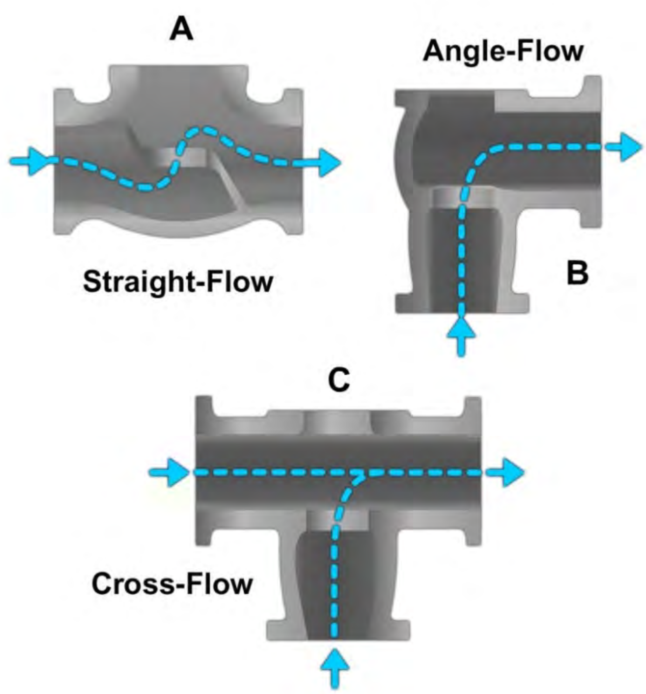

Figure 16-17 — Types of globe valves bodies.

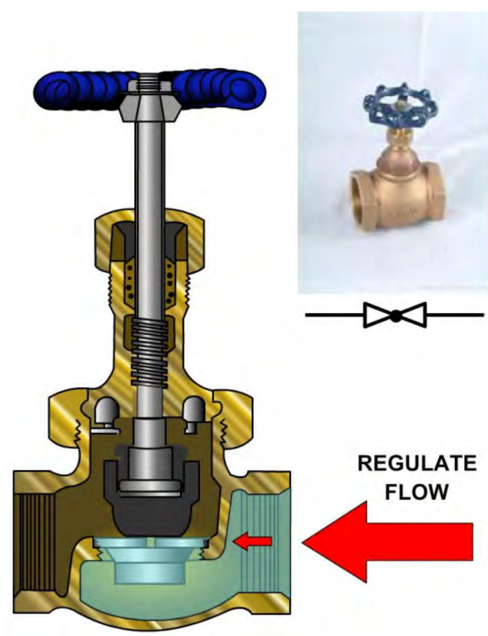

Figure 16-18 — Cutaway view of a straight-flow globe valve.

Gate Valves

Gate valves are used when a straight line flow of fluid and minimum flow restriction are needed, such as in the inlet piping for a centrifugal pump. Gate valves are so named because the part that either stops or allows flow through the valve acts somewhat like the opening or closing of a gate. The gate is usually wedge-shaped. When the valve is wide open the gate is fully drawn up into the valve bonnet. This leaves an opening for flow through the valve the same size as the pipe in which the valve is installed. There is little pressure drop or flow restriction through the valve. Gate valves are not suitable for throttling purposes. The control of flow would be difficult because of valve design, and the flow of fluid slapping against a partially open gate can cause extensive damage to the valve.

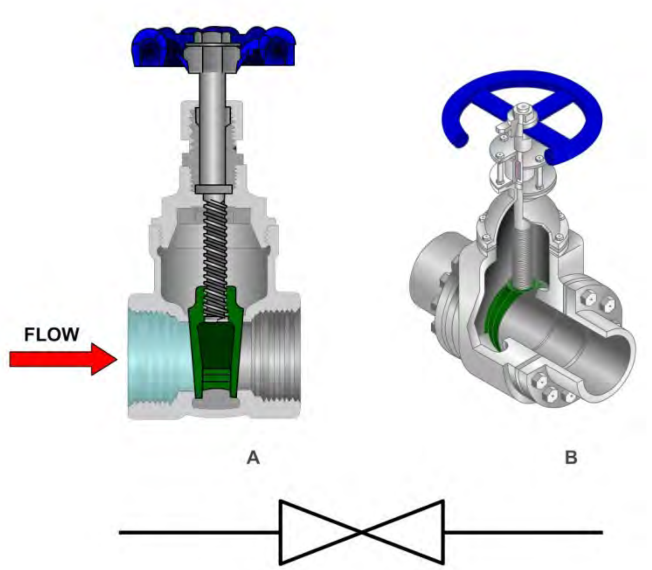

Figure 16-19 — Cutaway view of a gate stop valve (rising stem).

Gate valves are classified as either rising-stem or non-rising-stem valve *(Figure 16-19, frames 1 through 3).* In the design of the rising-stem valve, the stem is attached to the gate. The gate and stem rise and sink together as the valve is operated.

NOTE

Except as specifically authorized, gate valves should not be used for throttling.

In the design of the non-rising-stem gate valve, the stem is threaded on the lower end into the gate. As the handwheel on the stem is rotated, the gate travels up or down the stem on the threads while the stem remains vertically stationary. This type of valve will almost always have a pointer type of indicator threaded onto the upper end of the stem to indicate the position of the gate inside the valve.

Butterfly Valves

The butterfly valve is light in weight and is relatively small and quick acting. Butterfly valves are used in freshwater, fuel, lube oil, and chilled water systems where quick action and positive flow control are required *(Figure 16-20).* Butterfly valves operate in the same manner as the throttle valves and the choke valves in carburetors. A disk attached to a shaft pivots between the open and closed positions as the shaft is turned.

This older design of the butterfly valve is still widely used. This valve provides for positive shutoff, but it should not be used for throttling as standard practice. It consists of a body, a resilient seat, a butterfly-type disk, a stem, packing, a notched positioning plate, and a handle. The seat is under compression when it is installed in the valve body. This design provides a seal for the disk and the upper and lower points where the stem passes

Figure 16-20 — Butterfly valve.

through the seat. The packing provides a positive seal around the stem for added protection in case the seal formed by the seat becomes damaged. To gain access to the seat for replacement, you must first remove the stem and valve disk.

A newer, high-performance butterfly valve is shown in *Figure 16-21.* This improved design has higher pressure capabilities and allows for a full range of throttling positions not offered in the older design of butterfly valve shown in *Figure 16-20*. The newer design of butterfly valve has been introduced into the fleet and is gradually replacing the older design. Unlike the older style of butterfly valve, the new style has a removable retaining ring that holds the seat in place. To change the seat, all you must do is remove the retaining ring, remove the old seat, place a new seat into its groove, and reinstall the retainer ring.

To open or close a butterfly valve, turn the handle only one quarter of a turn to rotate the disk 90 degrees. Some larger butterfly valves may have handwheels or actuators that are driven by pneumatic, electric, or hydraulic means through a gearing arrangement *(Figure 16-22).*

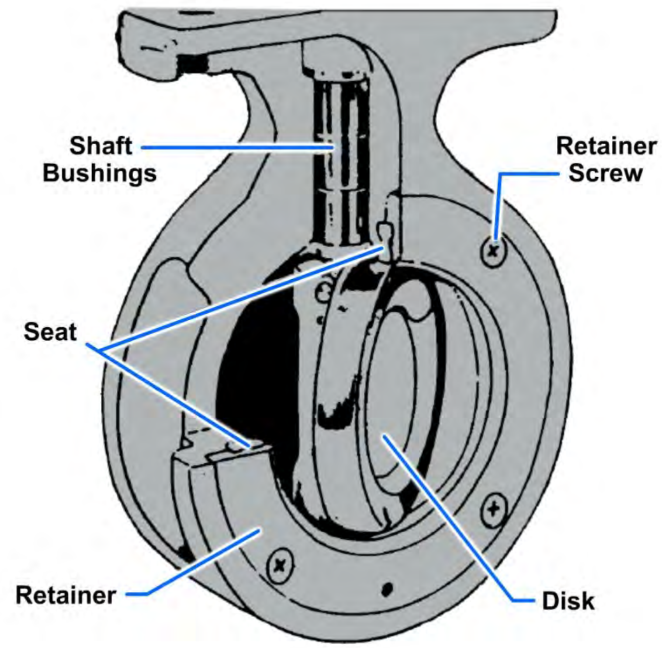

Figure 16-21 — Cutaway view of a high-performance butterfly valve.

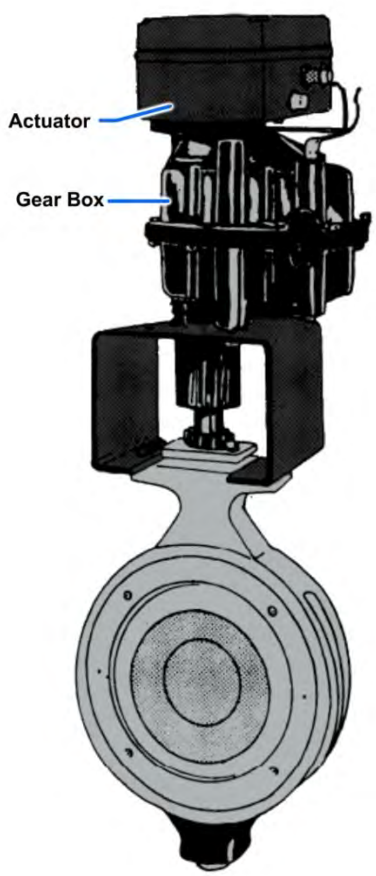

Figure 16-22 — Automatically operated butterfly valve.

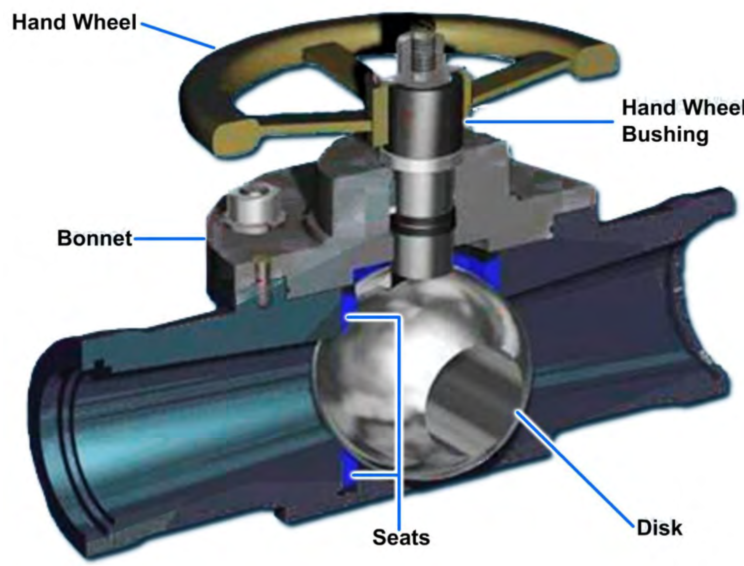

Figure 16-23 — Ball valve.

Ball Valves

Ball valves, as the name implies, are stop valves that use a ball to stop or start the flow of fluid. Most ball valves are the quick-acting type. They require only a 90-degree turn to completely open or close the valve. The ball *(Figure 16-23)* performs the same function as the disk in the globe valve. When the valve handle is operated to open the valve, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet, and flow is permitted. When the ball is rotated so the hole is perpendicular to the openings of the valve body, flow is stopped.

Check Valves

Check valves allow fluid to flow in a system in only one direction *(Figure 16-24, views A and B).* They are operated by the flow of fluid in the piping. A check valve may be of the swing type, lift type, or ball type. Check valves may also be built into globe valves or ball valves.

SPECIAL-PURPOSE VALVES (RELIEF, REDUCING, AND CONTROL VALVES)

There are many types of automatic pressure control valves. Some of them merely provide an escape for excessive pressures. Others reduce or regulate fluid pressure.

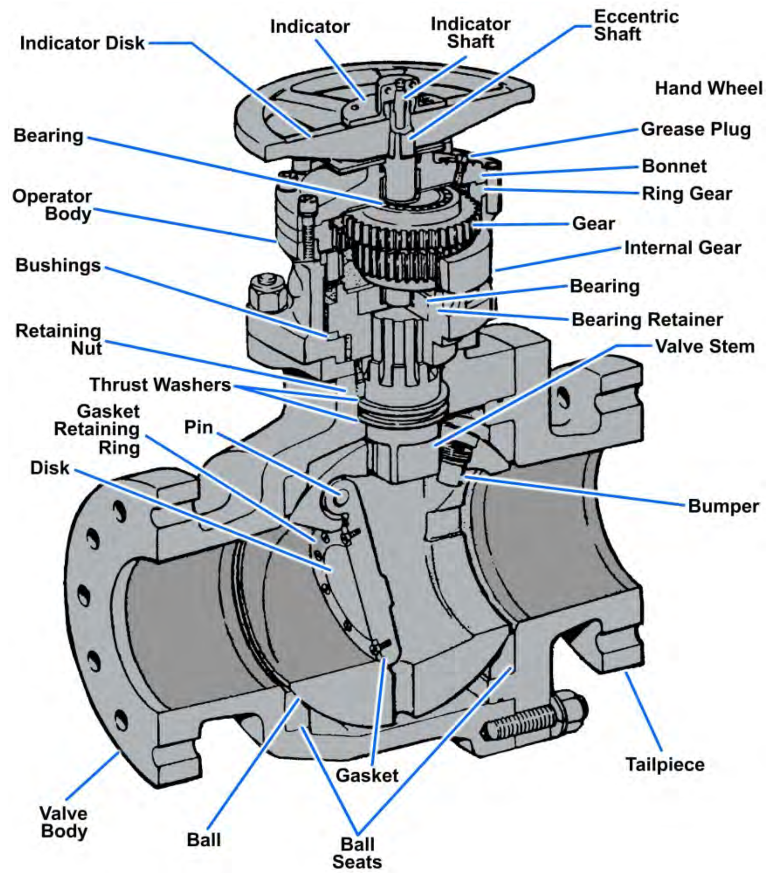

Figure 16-24 — Check valves.

NOTE

When a pressure-reducing station is lined up in the manual mode, the operator should use the indication on the outlet pressure gauge to adjust the bypass valve for the proper setting. The watch stander must check this setting periodically to ensure that the downstream pressure setting is within the specified value.

Relief Valves

Relief valves are installed in piping systems to protect them from excessive pressure. These valves have an adjusting screw, a spring, and a disk. The force exerted on the disk by the spring sets the relieving pressure. Most relief valves simply open when the preset pressure is reached and close when the pressure drops slightly below the lifting pressure *(Figure 16-25).* Many relief valves will also have a lever so the valve can be opened by hand for test purposes.

Pressure-Reducing Valves

Reducing valves are automatic valves that provide a steady pressure into a system that is at a lower pressure than the supply system. Reducing valves of one type or another are found in steam, air, lube oil, seawater, and other systems. A reducing valve can normally be set for any desired downstream pressure within the design limits of the valve. Once the valve is set, the reduced pressure will be maintained. This is true regardless of changes in the supply pressure; however, the supply pressure must be at least as high as the reduced pressure desired. It is also true regardless of the amount of reduced pressure fluid that is used.

Pressure-reducing valves for piping systems are usually installed in reducing stations, like the one shown in schematic form in *Figure 16-26*. In addition to a pressure-reducing valve, a reducing station should contain at least four other valves. Two of these are stop valves, located in the inlet piping and outlet piping for the reducing valve. These valves (V1 and V2) are shut to isolate the pressure-reducing valve from the piping system, in the event the valve needs repair. Some reducing valves may also have a stop valve in the downstream sensing line (V3). There should be a bypass valve (V4), used for throttling service, to manually control downstream pressure when the reducing valve is inoperative. The bypass valve is normally shut. Finally, there should be a relief valve (V5) to prevent over-pressurization of the piping system downstream of the reducing station in the event the reducing valve fails open (or the manual bypass valve is misadjusted).

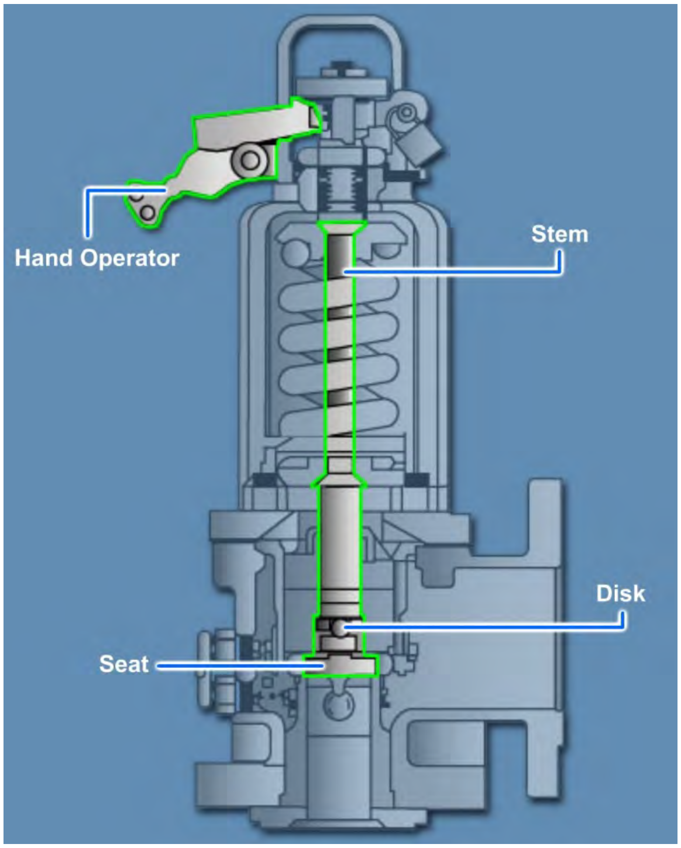

Figure 16-25 — Relief valves.

There are three basic designs of pressure-reducing valves in use. They are spring-loaded reducing valves, pneumatic-pressure-controlled (gas-loaded) reducing valves, and air-pilot-operated diaphragm-type reducing valves. There are many different styles within these three types. We will discuss a few of these variations.

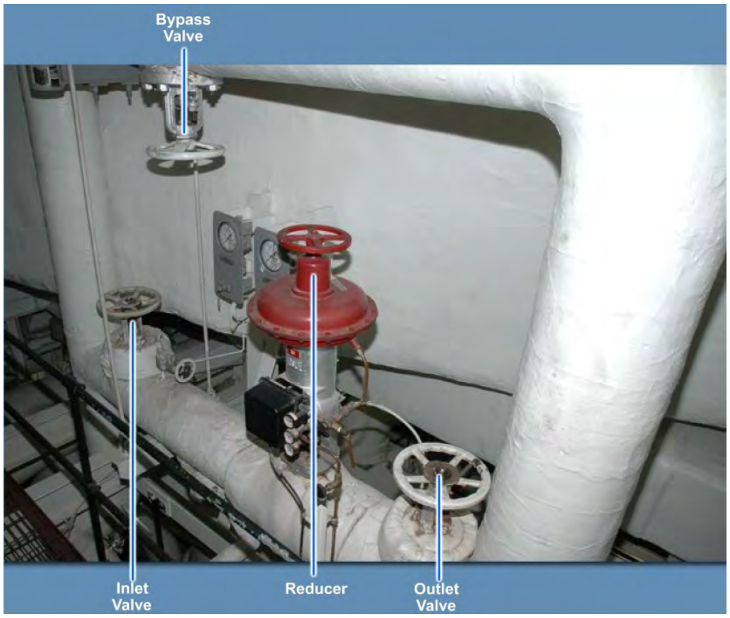

Figure 16-26 — Pressure-reducing station.

Spring-Loaded Reducing Valves

One type of spring-loaded reducing valve is shown in *Figure 16-27*. These valves are used in a wide variety of applications. Low pressure air reducers, auxiliary machinery cooling-water reducing stations, and some reduced-steam system reducers are of this type. The valve simply uses spring pressure against a diaphragm to open the valve. On the bottom of the diaphragm, the outlet pressure (the pressure in the reduced-pressure system) of the valve forces the disk upward to shut the valve. When the outlet pressure drops below the set point of the valve, spring pressure overcomes the outlet pressure and forces the valve stem downward, opening the valve. As outlet pressure increases, approaching the desired value, the pressure under the diaphragm begins to overcome spring pressure. This forces the valve stem upward, shutting the valve. Downstream pressure can be adjusted by removing the valve cap and turning the adjusting screw, which varies the spring pressure against the diaphragm. This particular spring-loaded valve will fail In the open position in the case of a diaphragm rupture.

Internal Pilot-Actuated Pressure-Reducing Valves

The internal pilot-actuated pressure-reducing valve *(Figure 16-28)* uses a pilot valve to control the main valve. The pilot valve controls the flow of upstream fluid, which is ported from the pilot valve, to the operating piston, which operates the main valve. The main valve is opened by the operating piston and closed by the main valve spring. The pilot valve opens when the adjusting spring pushes downward on the pilot diaphragm. It closes when downstream pressure exerts a force that exceeds the force of the adjusting spring. When the pilot valve shuts off or throttles the flow of upstream fluid to the operating piston, the main valve then pushes the valve and stem upward to throttle or close the main valve. When downstream pressure falls below the set point, the adjusting spring force acts downward on the diaphragm. This action overcomes the force of the downstream system pressure, which is acting upward on the diaphragm. This opens the pilot valve, allowing upstream pressure to the top of the operating piston to open the main valve.

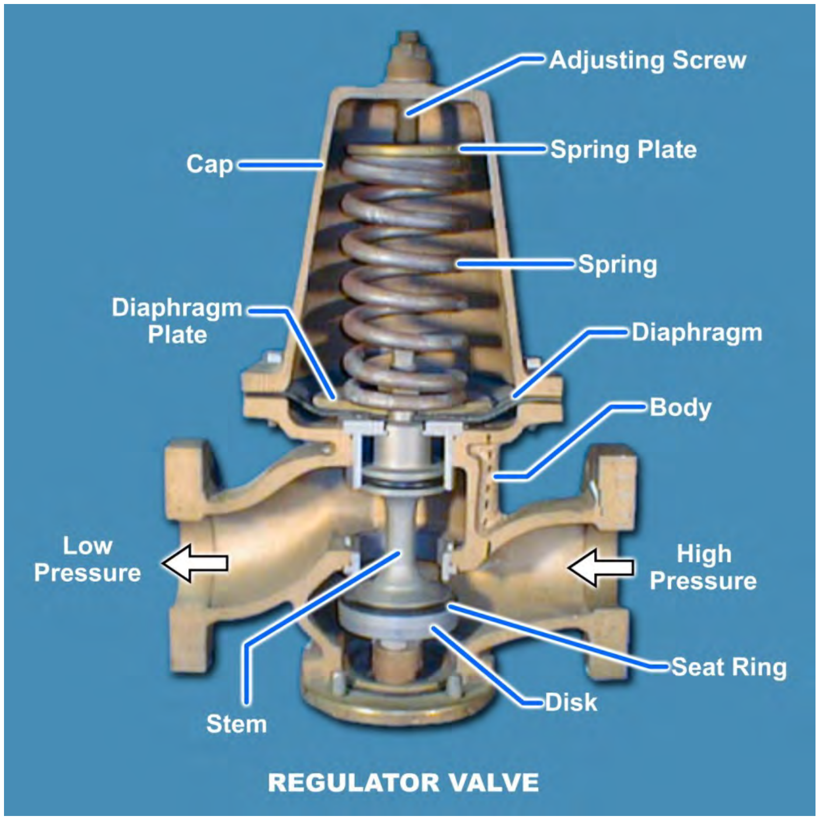

Figure 16-27 — Pressure-reducing (spring-loaded) valve.

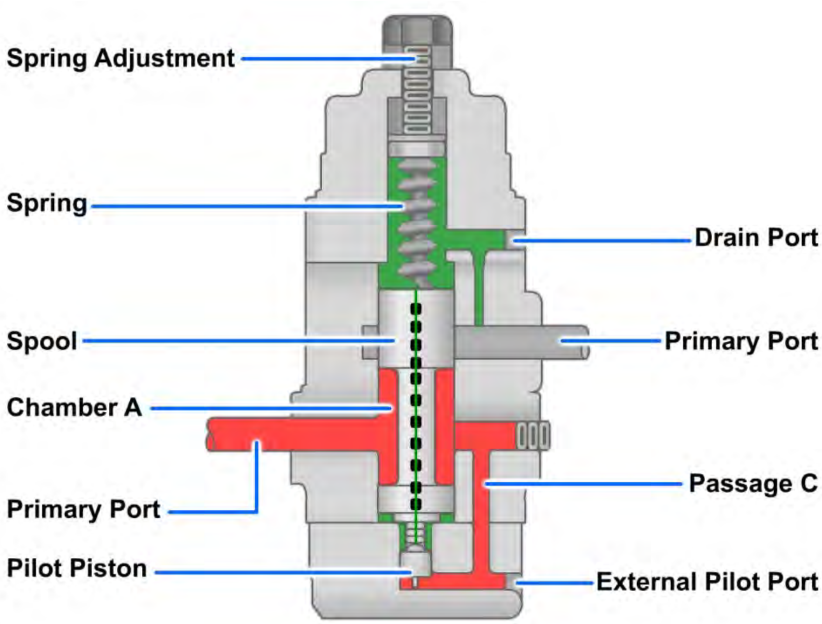

Figure 16-28 — Internal pilot-actuated pressure-reducing valve.

Pneumatic-Pressure-Controlled Reducing Valves

For engines that use compressed air as a power source, starting air comes directly from the ship's medium or high pressure air service line or from starting air flasks, which are included in some systems for the purpose of storing starting air. From either source, the air, on its way to the engine, must pass through a pressure reducing valve, which reduces the higher pressure to the operating pressure required to start a particular engine.

One type of pressure-reducing valve is the regulator *(Figure 16-29),* in which compressed air, sealed in a dome, furnishes the regulating pressure that actuates the valve. The compressed air in the dome performs the same function as a spring used in a more common type of regulating valve.

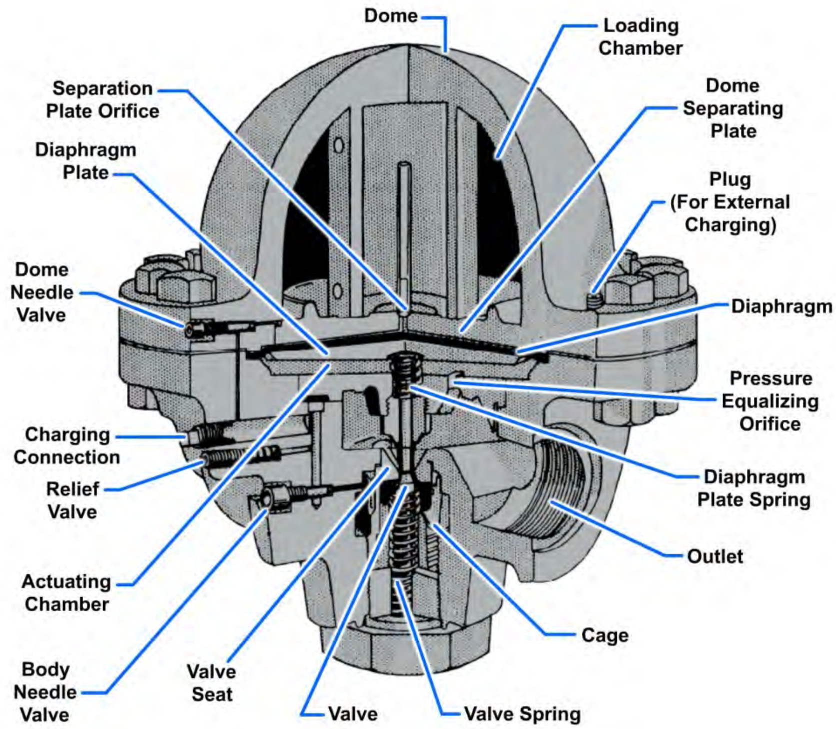

Figure 16-29 — Pressure-reducing (regulator) valve.

The dome is tightly secured to the valve body, which is separated into an upper (low pressure outlet) and a lower (high pressure inlet) chamber by the main valve. At the top of the valve stem is another chamber, which contains a rubber diaphragm and a metal diaphragm plate. This chamber has an opening leading to the low pressure outlet chamber. When the outlet pressure drops below the pressure in the dome, air in the dome forces the diaphragm and the diaphragm plate down on the valve stem. This partially opens the valve and permits high pressure air to pass the valve seat into the low pressure outlet and into the space under the diaphragm. As soon as the pressure under the diaphragm is equal to that in the dome, the diaphragm returns to its normal position, and the valve is forced shut by the high pressure air acting on the valve head.

When the dome-type regulator is used in the air start system for a diesel engine during the starting event, the regulator valve continuously and rapidly adjusts for changes in air pressure by partially opening and partially closing to maintain a safe, constant starting pressure. When the engine starts and there is no longer a demand for air, pressure builds up in a low pressure chamber to equal the pressure in the dome, and the valve closes completely.

Air-Pilot-Operated Diaphragm Control Valves

These valves are used extensively on naval ships. The valves and their control pilots are available in several designs to meet different requirements. They may be used as unloading valves to reduce pressure or to provide continuous regulation of pressure and temperature. They may also be used for the control of liquid levels.

The air-operated control pilot may be either direct acting or reverse acting. A direct-acting pilot is shown in *Figure 16-30.* In this type of pilot, the controlled pressure—that is, the pressure from the discharge side of the diaphragm control valve—acts on top of a diaphragm in the control pilot. This pressure is balanced by the pressure exerted by the pilot adjusting spring. When the controlled pressure increases and overcomes the pressure exerted by the pilot adjusting spring, the pilot valve stem is forced downward. This action opens the pilot valve to increase the amount of operating air pressure going from the pilot to the diaphragm control valve. A reverse acting pilot has a lever that

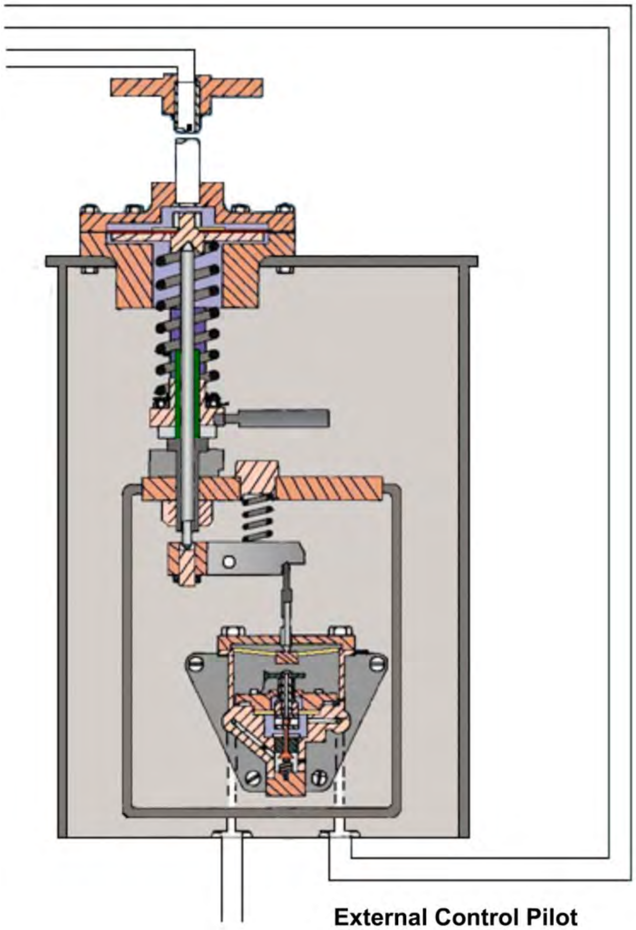

Figure 16-30 — Air-operated control pilot.

Now look at *Figure 16-31, frame 2,* this is also a direct-acting valve. The operating air pressure from the control pilot is applied to the top of the valve diaphragm. But the valve is more complicated than the one shown in *Figure 16-31, frame1.* The valve in *view B* is an upward-seating valve rather than a downward-seating valve. Therefore, any increase in operating air pressure from the control pilot tends to OPEN this valve rather than to close it.

As we have seen, the air-operated control pilot and the positioner of the diaphragm control valve may be either direct-acting or reverse-acting. In addition, the diaphragm control valve may be either upward-seating or downward-seating. These factors, as well as the purpose of the installation, determine how the diaphragm control valve and its air-operated control pilot are installed in relation to each other.

reverses the pilot action. In a reverse-acting pilot, an increase in controlled pressure produces a decrease in operating air pressure.

In the diaphragm control valve, operating air from the pilot acts on a diaphragm contained in the superstructure of the valve operator or positioner *(Figure 16-31).* It is direct-acting in some valves and reverse-acting in others. If the valve operator is direct-acting, the operating air pressure from the control pilot is applied to the TOP of the valve diaphragm. When the valve operator

is reverse-acting, the operating air pressure from the pilot is applied to the UNDERSIDE of the valve diaphragm.

A very simple type of direct-acting diaphragm control valve is shown in *Figure 16-31, frames 1 and 2*. The operating air pressure from the control pilot is applied to the top of the valve diaphragm. The valve in the figure is a downward-seating valve. Any increase in operating air pressure pushes the valve stem downward. This tends to close the valve.

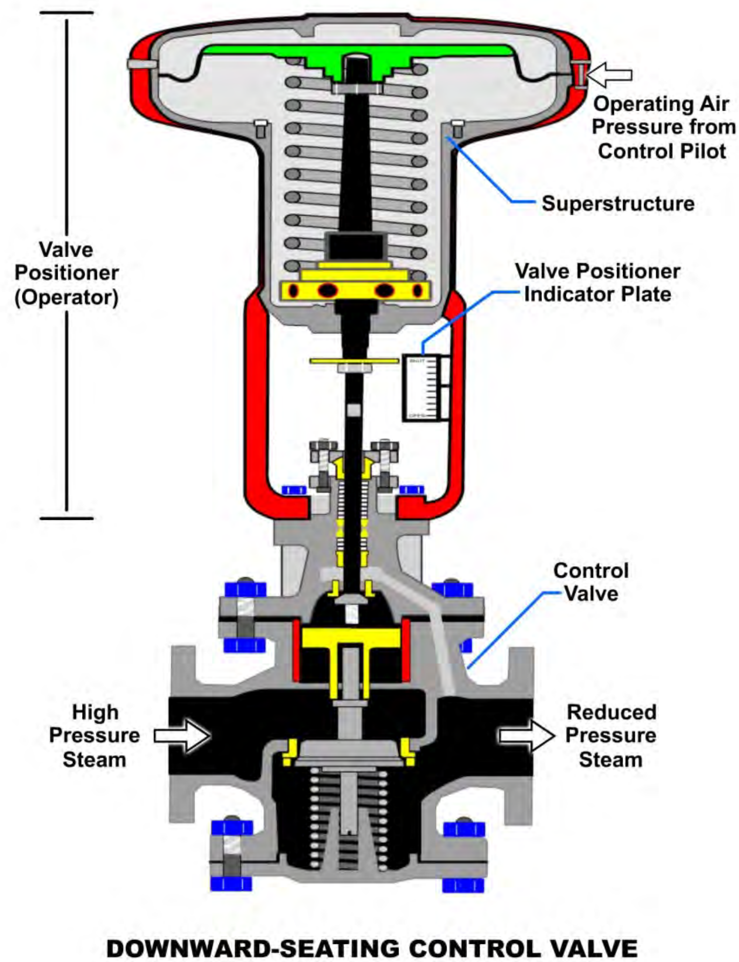

Figure 16-31 — Diaphragm control valves.

To see how these factors are related, let's consider an installation; a diaphragm control valve and its air-operated control pilot are used to supply reduced steam pressure *(Figure 16-32).* We will assume that the service requirements indicate the need for a direct-acting, upward-seating, diaphragm control valve. Can you figure out which kind of a control pilot—direct-acting or reverse-acting— should be used in this installation?

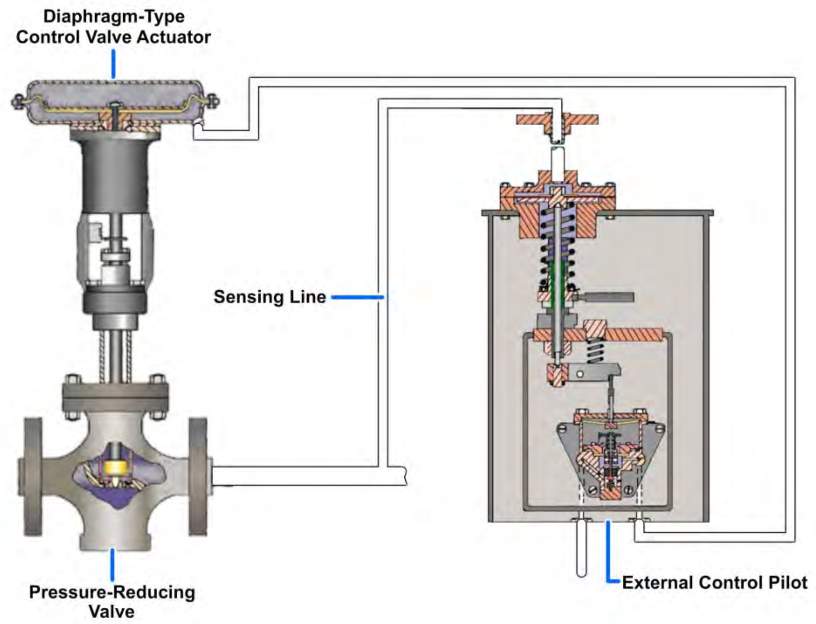

Figure 16-32 — Arrangement of control pilot and diagram control valve for supplying reduced steam pressure.

Let's try it first with a direct-acting control pilot. The controlled pressure (discharge pressure from the diaphragm control valve) increases. When that happens, increased pressure is applied to the diaphragm of the direct-acting control pilot. The valve stem is pushed downward and the valve in the control pilot is opened. This sends an increased amount of operating air pressure from the control pilot to the top of the diaphragm control valve. The increased operating air pressure acting on the diaphragm of the valve pushes the stem downward. Since this is an upward-seating valve, this action OPENS the diaphragm control valve still wider. Obviously, this won't work—for this application, an INCREASE in controlled pressure must result in a DECREASE in operating air pressure. Therefore, we made a mistake in choosing the direct-acting control pilot. For this particular pressure-reducing application, we should choose a REVERSE-ACTING control pilot.

You will probably not need to decide which type of control pilot and diaphragm control valve are needed in any particular installation. But you must know how and why they are selected so that you will not make mistakes in repairing or replacing these units.

Remote-Operated Valves

Remote-operating gear provides a means of operating certain valves from distant stations. Remote-operating gear may be mechanical, hydraulic, pneumatic, or electric. A reach rod or series of reach rods and gears may be used to operate engine-room valves in instances where valves are difficult to reach.

Other remote-operating gear is installed as emergency equipment. Some split-plant valves, main drainage system valves, and overboard valves are equipped with remote-operating gear. These valves can be operated normally or, in an emergency, they may be operated from remote stations. Remote-operating gear also includes a valve position indicator to show whether the valve is open or closed.

GENERAL MAINTENANCE FOR VALVES

For some system in the engineering plant the valve need to have special equipment to ensure that all the connection in the system are mated securely, and the medium being carried through is directed away from heat sources.

Packing and Gasket Materials

You will use gasket materials to seal fixed joints in steam, water, fuel, air, lube oil, and other piping systems. You will use packing materials to seal joints that slide or rotate under operating conditions (moving joints). There are many commercial types and forms of packing and gasket material. The Navy has simplified the selection of packing and gasket materials commonly used in naval service. NAVSEA has prepared a packing and gasket chart (Mechanical Standard Drawing B0153). This chart shows the symbol numbers and the recommended applications of all types and kinds of packing and gasket materials. A copy of the chart should be located in all engineering spaces.

A four-digit symbol number identifies each type of packing and gasket. The first digit indicates the class of service with respect to fixed and moving joints. For example, if the first digit is 1, it indicates a moving joint (moving rods, shafts, valve stems, and so forth). If the first digit is 2, it indicates a fixed joint (such as a flange or a bonnet). The second digit indicates the material of which the packing or gasket is primarily composed. This may be vegetable fiber, rubber, metal, and so on. The third and fourth digits indicate the different styles or forms of the packing or gaskets made from the material. To find the right packing material, check the MRC or the NAVSEA packing and gasket chart. The MRC lists the symbol numbers and the size and number or rings required. The NAVSEA packing and gasket chart lists symbol numbers and includes a list of materials. For additional information concerning packing and gasket material, refer to NSTM, Chapter 078.

Packing

Corrugated ribbon packing (CRP) is a relatively new packing material; it is a 100-percent graphite material expressly suited for installation in steam, feed, and condensate valves. CRP contains no binders, resins, fillers, lubricants, or other additives. It has the lubricating quality typical of pure graphite with the capability for rapid heat dissipation, thus reducing wear. Unlike conventional graphite, which is brittle, CRP is flexible and highly resilient. When CRP is formed in a valve stuffing box, it restructures.

This restructuring capability allows CRP to be wrapped around the valve stem in any size valve stuffing box and to be formed into a solid endless packing ring by compression

CRP is easily cut to a predetermined length. It does not turn rock-hard or shrink at any temperature. Once installed and after run-in, it normally needs no further adjustment. This means greatly reduced maintenance. The resiliency and no-lint structure of CRP remain unchanged at any temperature. There is no lubricant or additive to be squeezed out, vaporized, or carbonized. Also, it has a long shelf and service life.

WARNING

CRP conducts electricity. Identification and warning stickers must be clearly visible on all containers to assure prevention of its use for electrical insulation.

Use CRP with anti-extrusion rings made of graphite filament yarn (GFY) packing. Install the rings at the bottom (first ring) and at the top (last ring) of every stuffing box. Set the GFY to prevent the CRP from being forced out of the stuffing box (extruded) through stem-stuffing, stem-gland, and gland-stuffing box clearances.

If GFY is not available, you can install a ring of conventional packing as an anti-extrusion ring. However, the use must be temporary. At the earliest opportunity, disassemble, inspect, and repack the valve using GFY anti-extrusion rings with CRP.

GFY packing *(Figure 16-33)* is a severe service packing ideal for use in difficult fluid-handling applications. It is unaffected by the most destructive corrosive fluid substances. It will withstand the extreme temperatures of over 1,000 °F encountered in valve stuffing boxes. GFY packing is self-lubricating. It also has exceptional heat dissipation characteristics. These characteristics allow tight packing adjustment to make leakage almost nonexistent and provide maximum protection against stem scoring. This packing greatly reduces system fluid loss, maintenance, and downtime to provide longer, trouble-free valve life. GFY is available in sizes from 1/8 inch to 1 inch square on spools.

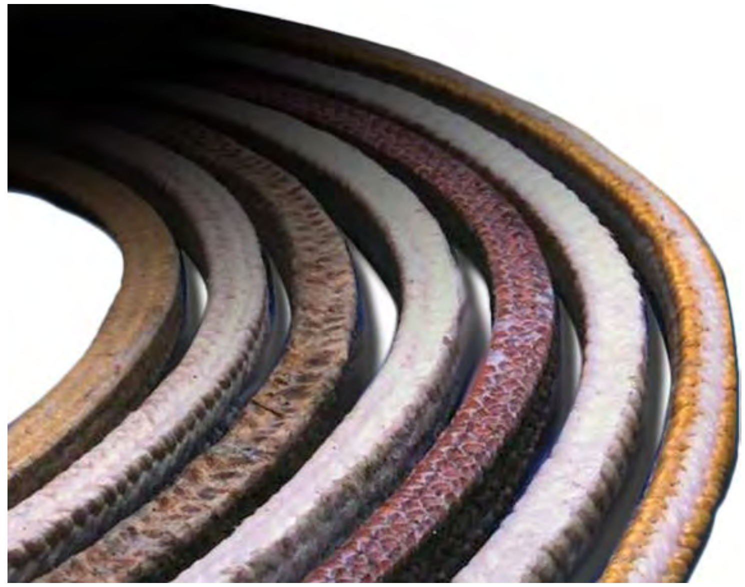

Figure 16-33 — Graphite filament yarn.

NOTE

Regardless of how good the packing material is, if the surface of the shaft passing through the stuffing box is scored or damaged in any way, the packing will not last long. When replacing packing, carefully inspect the shaft in the area where it passes through the stuffing box. Inspect the interior of the stuffing box itself. Take whatever steps you can to ensure that the packing will make contact with the straightest, smoothest possible surface. (You may have to have the shaft repaired and refinished, or replaced).

Gaskets

At one time, fixed steam joints could be satisfactorily sealed with gaskets of compressed asbestos sheet packing (*Figure 16-34, view A*). However, the 15 percent rubber content of the gasket makes it unsatisfactory for modern high-temperature steam equipment. Gaskets of corrugated copper or of asbestos and copper are sometimes used on low and medium pressure lines. The serrated-face metal gasket (*Figure 16-34, view B*) and the spiral-wound metallic-asbestos gasket (*Figure 16-34, view C)* are used in present day high-temperature, high pressure installations.

Plain Full-Faced Gaskets

When cutting a plain full-faced gasket from compressed asbestos sheet, lay an appropriate size piece of the asbestos sheet on the flange. Scribe in the bolt holes and flange circle lines with light blows of a ball peen hammer. Then use a gasket punches about 1/16 inches larger in diameter than the bolts cut the bolt holes into the gasket material. Use a piece of hardwood as the supporting and backing surface for the material while punching it to prevent damage to the lips of the punch. After punching the holes, use shears or a sharp knife to cut the center and outside circles to form the ring.

Serrated-Face Metal Gasket

Serrated-face metal gaskets (*Figure 16-34, view B*) are made of steel, Monel, or soft iron. They have raised serrations to make a better seal at the piping flange joints. These gaskets have resiliency; line pressure tends to force the serrated faces tighter against the adjoining flange. Two variations of serrated-face metal gaskets are shown: the single-plate type and the expanding (double-plate) type.

Spiral Wound Metallic Asbestos Gaskets

Spiral-wound metallic-asbestos gaskets (*Figure 16-3 4*, *view C*) are made of two parts. The first is interlocked piles of preformed corrugated metal and asbestos strips, spirally wound, called filler. The second is a solid metal outer or centering ring, sometimes called a retaining ring. The filler piece is replaceable. When renewing a gasket, remove the filler piece from the retaining metal ring and replace it with a new refill. Do not discard the solid metal retaining outer ring unless it is damaged. Then place the gasket into a retainer or centering ring. The solid steel centering ring also acts as reinforcement to prevent blowouts. The gaskets can be compressed to the thickness of the centering ring.

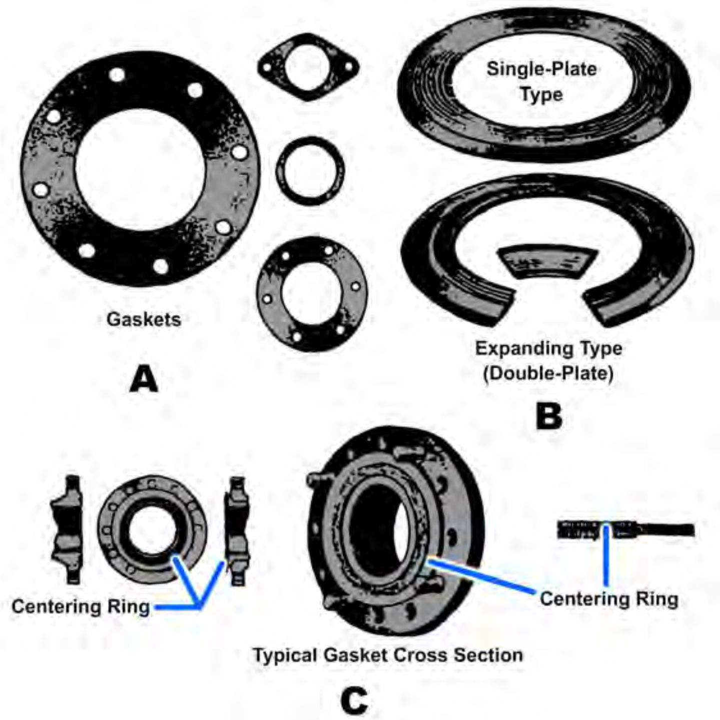

Figure 16-34 — Fixed joint gasket. A. Sheet asbestos gasket. B. Serrated-face metal gasket. C. Spiral-wound metallic asbestos gasket.

Precautions

When renewing a gasket in a flanged joint, use special precautions. When breaking the joint, particularly in steam and hot water lines, or in saltwater lines that have a possibility of direct connection with the sea, be sure of the following conditions:

1. There is no pressure on the line.
2. The line pressure valves, including the bypass valves, are firmly secured, wired closed, and tagged.
3. The line is completely drained.
4. At least two flange-securing bolts and nuts diametrically opposite remain in place until the others are removed. These bolts are then slackened to allow breaking of the joint. They are removed after the line is clear.
5. Precautions are taken to prevent explosions or fire when breaking joints of flammable liquid lines.
6. Proper ventilation is ensured before joints are broken in closed compartments.

These precautions may prevent serious explosions, severe scalding of personnel, or flooding of compartments. Thoroughly clean all sealing and bearing surfaces for the gasket replacement. Then check the gasket seats with a surface plate. Scrape as necessary to ensure uniform contact. Replace all damaged bolt studs and nuts. In flanged joints that have raised faces, the edges of gaskets may extend beyond the edge of the raised face.

WARNING

Asbestos materials are health hazards and require special storage, handling, and disposal according to NSTM Chapter 635 and NAVOSH Program Manual for Forces Afloat, OPNAVINST 5100.19(series).

Packing Precautions

Observe the following general precautions with regard to the use of packing:

1. Do NOT use metallic or semi-metallic packing on bronze or brass shafts, rods, plungers, or sleeves. These materials may cause scoring. Use a braided packing that is lubricated throughout, or a nonmetallic plastic packing in the center of the box with an end ring of the braided packing at each end of the box.
2. Do NOT use a packing frictioned with rubber or synthetic rubber of any kind on rotary or centrifugal shafts. Such packing will overheat.
3. Do NOT use braid-over-braid packing on rotary or centrifugal shafts. The outer layer will wear through quickly and eventually the packing will become rags.
4. Do NOT use packing with a rubber binder on rotary-type compressors. It will swell and bind, thereby developing excessive frictional heat. The use of flexible metallic packing is recommended. Or you may use a lead-base plastic packing alternated with the flexible metallic packing.
5. On hydraulic lifts, rams, and accumulators, use a V-type packing or O-ring. For water, this packing should be frictioned with crude, reclaimed, or synthetic rubber. For oils, the packing should be frictioned with oil-resistant synthetic rubber.
6. Do NOT use a plastic packing, such as symbol 1433 or 1439, alone on worn equipment or out-of-line rods; it will not hold. Use a combination of 1433 with end rings of plain braided asbestos (1103) or flexible metallic packing (1430). These will be satisfactory for temporary service until defective parts can be repaired or replaced.
7. Do NOT use a soft packing against thick or sticky liquids or against liquids having solid particles. This packing is too soft to hold back liquids, such as cold boiler fuel oil, and it usually gets torn. Solid particles that may be suspended in these liquids will embed themselves in the soft packing. These particles then act as an abrasive on the rod or shaft. Flexible metallic packing is best for these conditions.

Insulation

The purpose of insulation is to retard the transfer of heat from piping that is hotter than the surrounding atmosphere or to piping that is cooler than the surrounding atmosphere. Insulation helps to maintain the desired temperatures in all systems. In addition, it prevents sweating of piping that carries cool or cold fluids. Insulation also protects personnel from being burned by hot surfaces. Piping insulation is the composite piping covering that consists of the insulating material, lagging, and fastening. The insulating material offers resistance to the flow of heat. The lagging, usually of painted canvas, is the protective and confining covering placed over the insulating material. The fastening attaches the insulating material to the piping and to the lagging.

Insulation covers a wide range of temperatures, from the extremely low temperatures of the refrigerating plants to the very high temperatures of the ship’s boilers. No one material could possibly be used to meet all these conditions with the same efficiency.

The following quality requirements for the various insulating materials are taken into consideration by the Navy in the standardization of these materials:

1. Low heat conductivity
2. Non-combustibility
3. Lightweight material
4. Easy molding and installation capability
5. Moisture repellence
6. Noncorrosive, insoluble, and chemically inactive constituents
7. Composition, structure, and insulating properties unchanged by the temperatures at which it is to be used
8. Longevity—once installed, does not cluster, become lumpy, disintegrate, or build up in masses from vibration
9. Vermin-proof material

Flange Safety Shields

A fire in the engine room can be caused by a leak at a fuel or lube oil pipe-flange connection. Even the smallest leak can spray fine droplets of lube oil or fuel on nearby hot surfaces, such as the exhaust manifold of a diesel engine. To reduce this possibility, spray shields (flange safety shields) are installed on piping flanges of flammable liquid systems, especially in areas where the fire hazard is apparent *(Figure 16-35, frames 1 through 3).* The spray shields are usually made of aluminized glass cloth and are simply wrapped and wired around the flange.

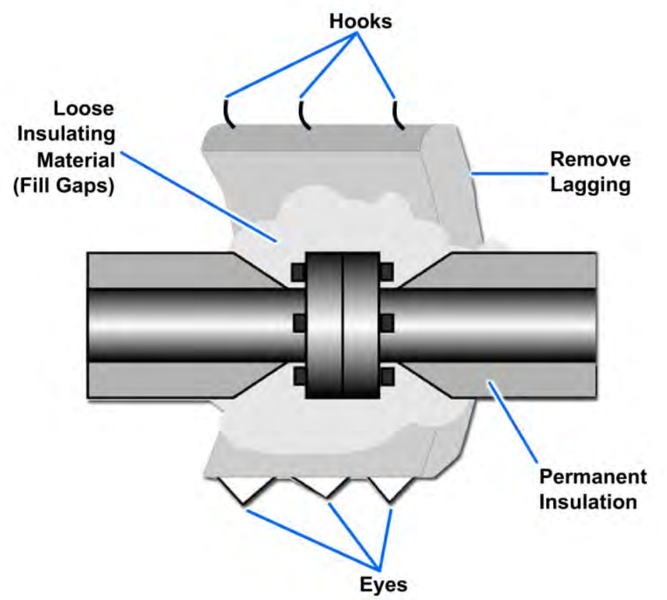

Figure 16-35 — Flange safety shields.

SUMMARY

This chapter has provided you with an overview of the pumps and valves you will be required to operate and maintain. Now that you have read the information in this chapter, you should understand the relationship of a pump or a valve to the system it serves. You should also readily understand the necessity for keeping these components operating at top efficiency through proper maintenance.

End of Chapter 16

Pumps and Valves

Review Questions

16-1. What are the most numerous units of auxiliary machinery aboard ships?

- A. Water foundation
- B. Pumps
- C. Unit coolers
- D. Steam kettles

16-2. How is fluid trapped and forced through the screw pump?

- A. Rotation of the screws
- B. Gravity
- C. Positive displacement
- D. Centrifugal force

16-3. Why are centrifugal pumps provided with replaceable wearing rings?

- A. Easier to replace than the shaft
- B. Cheaper to replace than the whole pump
- C. Easier to renew than the impeller
- D. Always have spares on hand

16-4. What is considered an automatic-operated valve?

- A. Deck washing connection
- B. Fuel tank fill
- C. Pressure regulating valve
- D. Potable water tank fill

16-5. When is a gate valve used in a system?

- A. When maximum flow restriction is needed
- B. When throttling is needed
- C. To bypass the relief valve in the system
- D. When minimum flow restriction is needed

16-6. How many directions does the check valve allow the medium to flow through the system?

- A. One
- B. Two
- C. Three
- D. Four

16-7. How many valves should a reducing station have at minimum?

A. One
B. Two
C. Three
D. Four

16-8. What is NOT a basic design of a pressure-reducing valve?

A. Pneumatic
B. Fuel
C. Air-pilot
D. Spring

16-9. What do remote-operated valves have to show what their actual position is?

A. Alarms
B. Flags
C. Position indicators
D. Nothing

16-10. Where would you find information on how to select the right packing and gasket material?

A. *Naval Sea Systems Command* (NAVSEA), Mechanical Standard Drawing B0153
B. *Naval Sea Systems Command* (NAVSEA), Mechanical Standard Drawing F2355
C. *Naval Sea Systems Command* (NAVSEA), Mechanical Standard Drawing R7544
D. *Naval Sea Systems Command* (NAVSEA), Mechanical Standard Drawing Z6957

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CHAPTER 17

COMPRESSED AIR SYSTEMS

As an engineman, you should have a thorough knowledge of the compressed air system, the systems it serves, and purposes it provides throughout the ship. These purposes include the operation of pneumatic tools and equipment, diesel engine starting and speed control systems, and propulsion control systems. The compressor is the heart of any compressed air system. It takes in atmospheric air, compresses it to the pressure desired, and pumps the air into supply lines or into storage for later use.

After studying the information in this chapter, you should be able to identify the common types of air compressors used in Navy ships in terms of their design and classification, purpose, function, principles of operation, and associated equipment. You should also be able to identify the components of a compressed air system. You should be able to recognize how compressed air is prepared and delivered for use aboard ship. You should also be able to identify some of the operational and safety procedures you must use when you are working with compressed air systems.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the compressed air system.
2. Describe the compressor classifications.
3. Identify the components of the low pressure air compressor (LPAC).
4. Explain the operating procedures for the LPAC.
5. Identify the components for the RIX high pressure air compressor (HPAC).
6. Identify the components for the Worthington HPAC.
7. Explain the general operating procedures for Navy HPAC.

COMPONENTS AND SYSTEMS

Reciprocating air compressors consist of a system of connecting rods, a crankshaft, and a flywheel. These parts transmit power developed by the driving unit to the pistons as well as to the lubrication systems, cooling systems, control systems, and unloading systems.

Compressing Element

The compressing element of a reciprocating air compressor consists of the cylinders, pistons, and air valves.

Cylinders

The design of the cylinders depends mostly upon the number of stages of compression required to produce the maximum discharge pressure. There are different types of cylinder arrangements for air compressors depending on which are required for the specific mission. Notice that a three-stage arrangement and a four-stage arrangement are both shown. The basic stage arrangement is similar for the five- and six-stage compressors.

Pistons

The pistons may be either of two types: trunk or differential *(Figure 17-1, view A and B).* Trunk pistons are driven directly by the connecting rods *(Figure 17-1, view A).* The upper end of a connecting rod is fitted directly to the piston by a wrist pin. This design produces a tendency for the piston to develop a side pressure against the cylinder walls. For the side pressure to be distributed over a wide area of the cylinder walls or liners, pistons with long skirts are used. The design of the trunk piston helps minimize cylinder wall wear. Differential pistons (*Figure 17-1, view B*) are modified trunk pistons with two or more different diameters. These pistons are fitted into special cylinders and arranged so that more than one stage of compression is achieved by a single upward stroke of the piston. The compression for one stage takes place over the piston crown; compression for the other stage(s) takes place in the annular space between the large and small diameters of the piston.

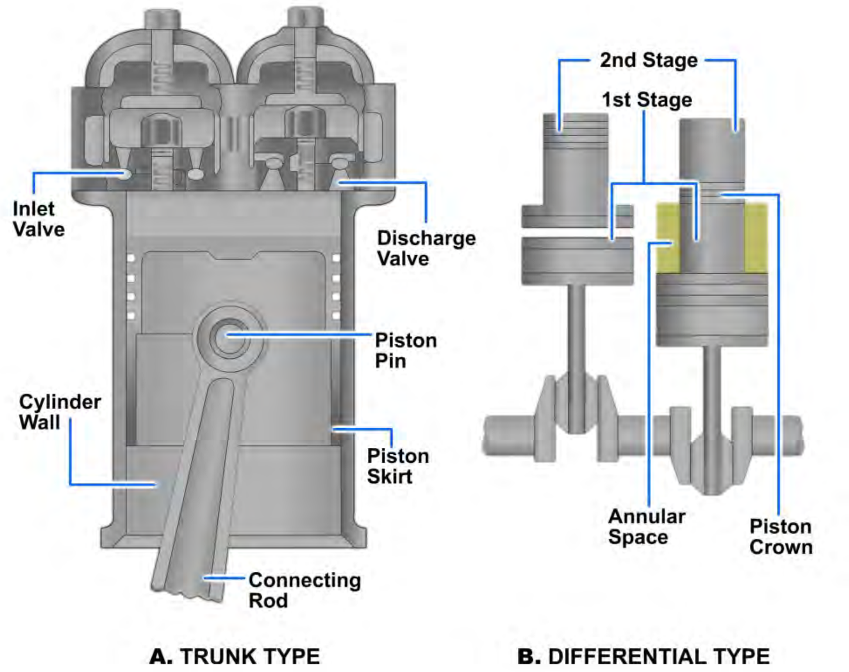


Figure 17-1 — Air compressor pistons.

Valves

The valves are made of special steel and come in a number of different types. The opening and closing of the valves is caused by the difference between the pressure of the air in the cylinder and the pressure of the external air on the intake valve or the pressure of the discharged air on the discharge valve.

Two types of valves commonly used in HPAC are shown in *Figure 17-2, view A and B*. The strip or feather-type valve *(Figure 17-2, view A)* is used for the suction and discharge valves of the lower-pressure stages (1 and 2). The valve is a suction valve; the discharge valve assembly (not shown) is identical except that the positions of the valve seat and the guard are reversed. At rest, the thin strips lie flat against the seat. They cover the slots and form a seal when pressure is applied to the guard side of the valve. The following action works in either a suction or a discharge operation (depending on the valve service). As

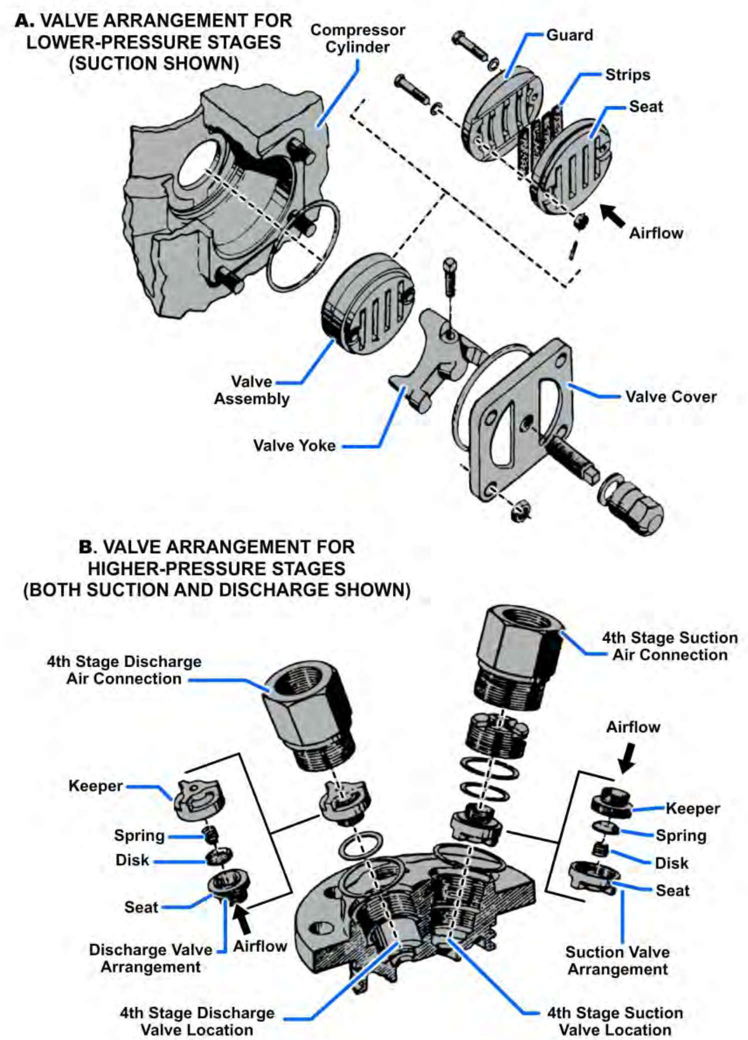


Figure 17-2 — HPAC valves.

soon as pressure on the seat side of the valve exceeds the pressure on the guard side, the strips flex against the shape recesses in the guard. As soon as the pressure equalizes or reverses, the strips unflex and return to their original position, flat against the seat.

The disk-type valve in *Figure 17-2, view B,* is used for the suction and discharge valves of the higher-pressure stages (3 and 4). The valves shown are the spring-loaded, dished-disk type. At rest, the disk is held against the seat by the spring. It forms a seal when pressure is applied to the keeper side of the valve. The following action works in either a suction or a discharge operation (depending on the valve service). When the pressure on the seat side of the valve exceeds the pressure on the keeper side, the disk lifts against the stop in the keeper. This action compresses the spring and permits air to pass through the seat, around the disk, and through the openings in the sides of the keeper. As soon as the pressure equalizes or reverses, the spring forces the disk back onto the seat.

Lubrication Systems

There are generally three types of lubrication systems in reciprocating compressors. They are for high pressure, low pressure, and oil-free air compressors.

HPAC cylinders (except for non-lubricated compressors) are generally lubricated by an adjustable mechanical force-feed lubricator. This unit is driven from a reciprocating or rotary part of the compressor. Oil is fed from the cylinder lubricator by separate lines to each cylinder. A check valve at the end of each feed line keeps the compressed air from forcing the oil back into the lubricator. Each feed line has a sight-glass oil flow indicator. Lubrication begins automatically as the compressor starts up. *Figure 17-3* shows the lubrication connections for the cylinders. The type and grade of oil used in compressors is specified in the applicable *Naval Sea System Command (*NAVSEA) technical manual. The correct type is vital to the operation and reliability of the compressor.

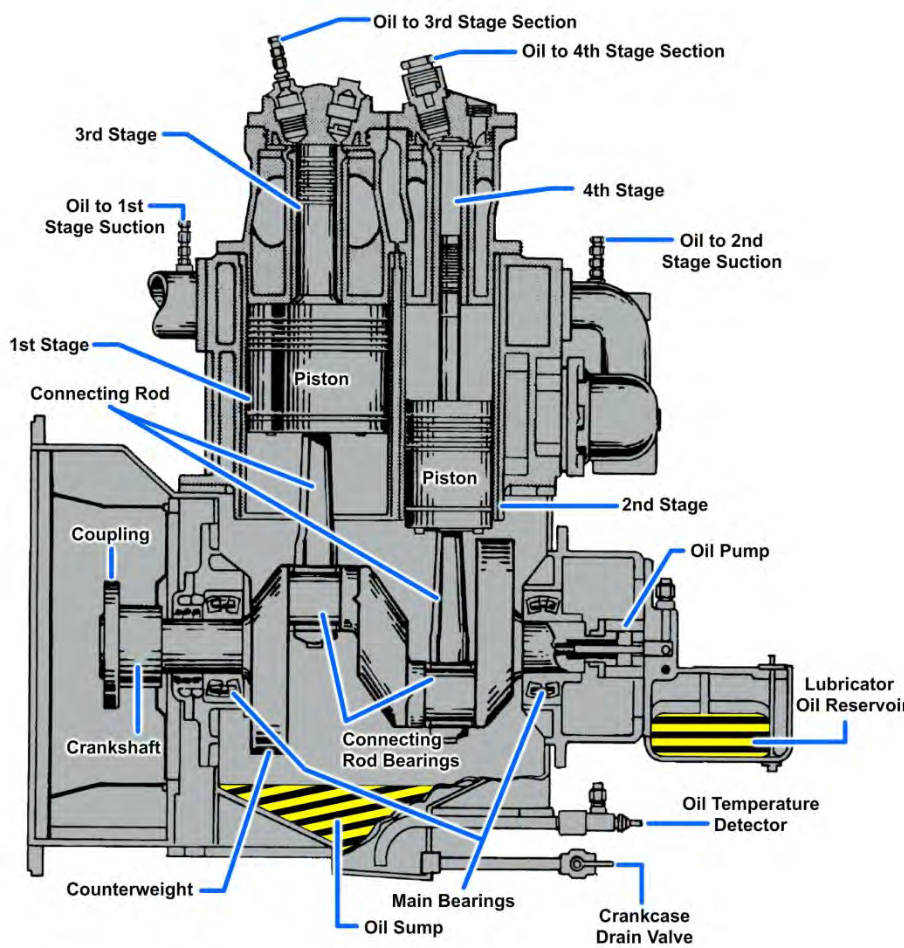


Figure 17-3 — HPAC showing the lubricating oil system.

The running gear is lubricated by an oil pump that is attached to the compressor and driven from the compressor shaft. This pump is usually a gear type. It moves oil from the reservoir (oil sump) in the compressor base and delivers it through a filter to oil cooler (if installed). From the cooler, the oil is distributed to the top of each main bearing, to the spray nozzles for the reduction gears, and to the outboard bearings. The crankshaft is drilled so that oil fed to the main bearings is picked up at the main bearing journals and carried to the crank journals. The connecting rods contain passages that conduct lubricating oil from the crank bearings up to the piston pin bushings. As oil is forced out from the various bearings, it drips back into the oil sump (in the base of the compressor) and is recirculated. Oil from the outboard bearings is carried back to the sump by drain lines. An LPAC lubrication system (*Figure 17-4*) is similar to that of the running gear lubrication system for the HPAC. Non-lubricated reciprocating compressors have lubricated running gears (shaft and bearings) but no lubrication for the pistons and valves. This design produces oil-free air.

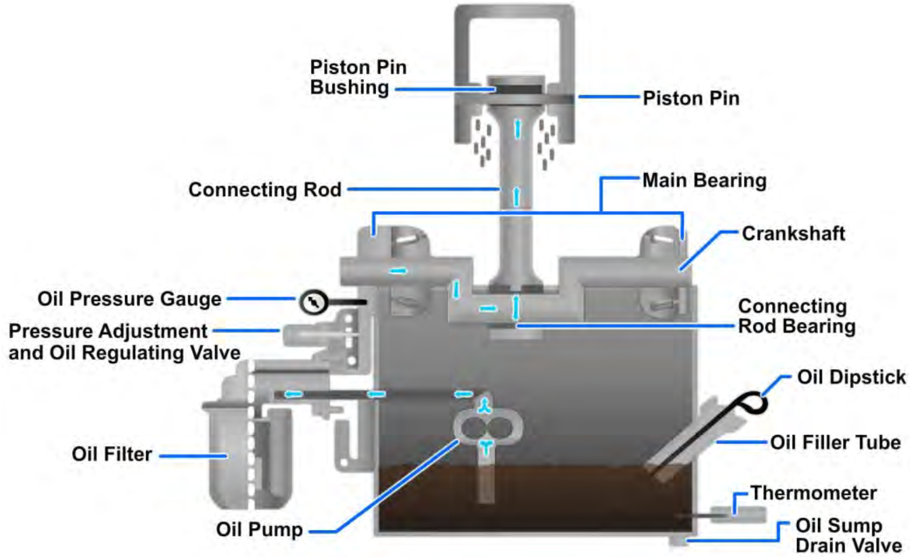


Figure 17-4 — Lubricating oil system of a LPAC.

Cooling Systems

The power input to the compressor is converted to heat in the compression process. This heat is removed by a cooling system for two primary reasons: to prevent the compressed air and various compressor parts from reaching excessively high temperatures and to improve the efficiency of multistage compressors by increasing the density of air between stages of compressions.

In reciprocating compressors, the compression cylinders are cooled by freshwater or seawater, which is circulated through cooling water passages in the cylinder block. When removable cylinder liners or cylinder sleeves are used, the cylinder block may incorporate wells or bores for the liners so that the cooling water does not come into direct contact with the cylinder liners (dry liners). In another design, the liner may be held in shoulders with O-ring seals within the cylinder block so that the cylinder liners are "wetted" by the cooling water (wet liners). Cylinder jackets are fitted with handholes and covers so that the water spaces may be inspected and cleaned. On many compressors, water passes directly through the joint between the cylinder and the head. On such designs, extreme care must be taken so that the joint is properly seated to the gasketed to prevent leakage. If allowed to continue, water leakage would cause corrosion problems or more severe damage.

In addition to cylinder cooling, each stage of a reciprocating compressor has an air cooler in which the discharge air is cooled before it enters the next stage. The coolers are usually of the shell and tube design. Compressed air is directed through the tubes of the cooler, with the cooling water flowing through the shell and over the tubes. On some compressors, this design may be reversed on the low pressure stages (first and second) so that the cooling water flows through the tubes and the air through the shell. The coolers between stages are called intercoolers. The last cooler is the aftercooler (Intercoolers and aftercoolers will be discussed in greater detail later in this chapter). You may encounter several different types of cooling systems, depending, of course, on the ship to which you are assigned. On older air compressors, cooling is provided by a seawater system that serves the compression cylinders as well as the intercoolers and aftercooler *(Figure 17-5).* In these systems, the seawater flows essentially in a series arrangement—first through the intercoolers and aftercooler, and then through the compression cylinders. This process ensures that the air entering the cylinders is always cooler than the valve chambers and cylinders. Therefore, moisture from condensation is minimized. However, with seawater temperatures substantially lower than 85 degrees Fahrenheit, condensation may occur within the cylinders and discharge valve chambers (or cylinder heads) on the compression stroke. Also, because of the compact design of some air compressors, low seawater temperatures can cause the compressor frame and oil sump to reach temperatures that are sufficiently low to cause condensation within the oil sump. This condition can cause rapid water buildup and subsequent bearing failure. For protection against the overcooling of compressors that are cooled entirely by seawater, it is recommended that cooling water be throttled. This action will reduce the cooling effect in the compression cylinders. However, excessive reduction in cooling water flow can result in hot spots in the cylinder areas where flow under normal conditions becomes marginal. In this regard, you must follow the recommendations in the NAVSEA technical manual for any specific compressor.

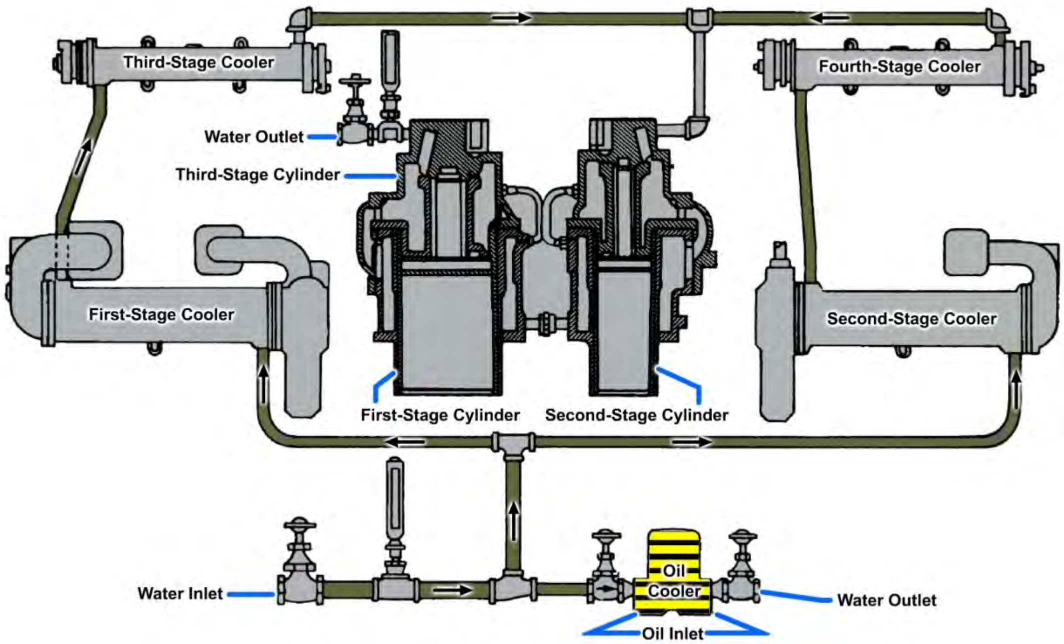


Figure 17-5 — Seawater cooling (open) system of a multistage air compressor.

The majority of compressors, including oil-free compressors on surface ships, employ seawater cooling systems for the intercoolers and aftercoolers and a secondary freshwater system for cylinder cooling *(Figure 17-6).* The closed freshwater cooling system consists of a pump, a surge tank, a thermostatic valve, and a heat exchanger. The pressurized coolant is moved from the surge tank by the water pump and is directed to each cylinder assembly. A high-water-temperature shutdown switch downstream from the cylinder assemblies monitors the coolant temperature. Coolant at the thermostatic valve flows either directly to the cylinders or through the heat exchanger if the cylinder water requires cooling. The design provides a constant rate of flow and thermostatic temperature control in the cylinder cooling system. This type of control ensures uniform operating conditions for the compression stages and helps the system avoid the harmful excessive cooling of cylinders. As we mentioned earlier, excessive cooling cause's condensation on cylinder walls—a condition that results in early catastrophic seal failure.

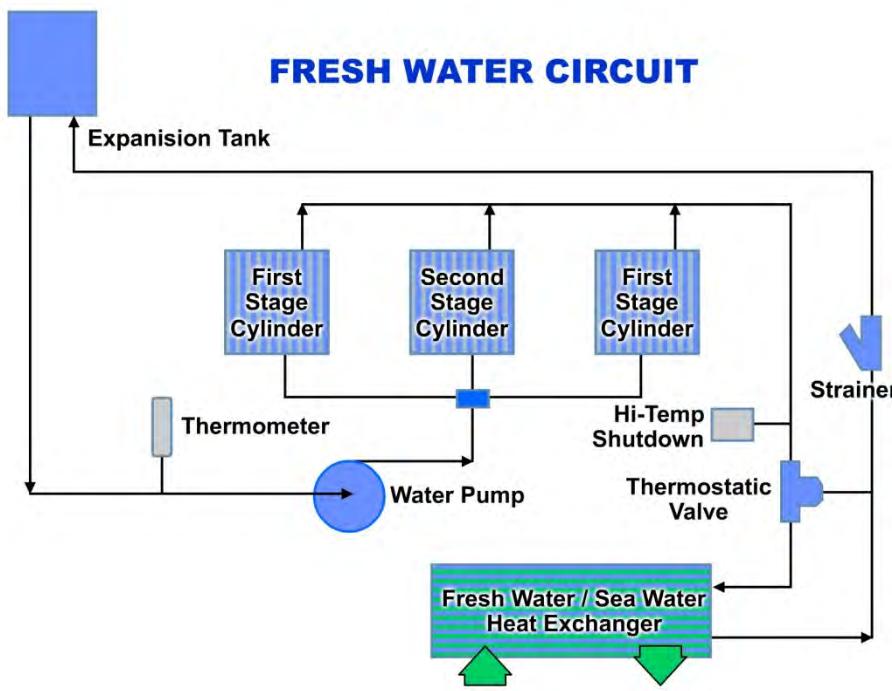


Figure 17-6 — Cooling water diagram showing a freshwater system.

The intercoolers and aftercoolers act to remove heat that is generated whenever air is compressed. They also cause any water vapor that may be present in the airstream to condense into a liquid. *Figure 17-7* is a diagram of a basic cooler and separator unit. Intercoolers and aftercoolers are normally fitted with moisture separators. Moisture separators, which come in a variety of designs, serve to remove the condensed moisture and oil vapor from the airstream. The liquid is removed by centrifugal force, impact, or sudden changes in velocity of the airstream. Notice that the condensate collects in the lower section of the outlet header. Drains on each separator serve to remove the water and oil. The condensate must be drained at regular intervals to prevent carryover into the next stage of compression. When the condensate accumulates at low points, it may cause water hammer or freezing and bursting of pipes in exposed locations. It may also cause faulty operation of pneumatic tools and diesel engine air start systems and possible damage to electrical apparatus when air is used for cleaning. The removal of heat is also necessary for efficient compression. During compression, the temperature of the air increases. As explained earlier, heated air expands to a larger volume. The larger volume of air requires a corresponding increase of work to compress it. Multi-staging with inter-stage cooling of the air reduces the power requirement for a given capacity.

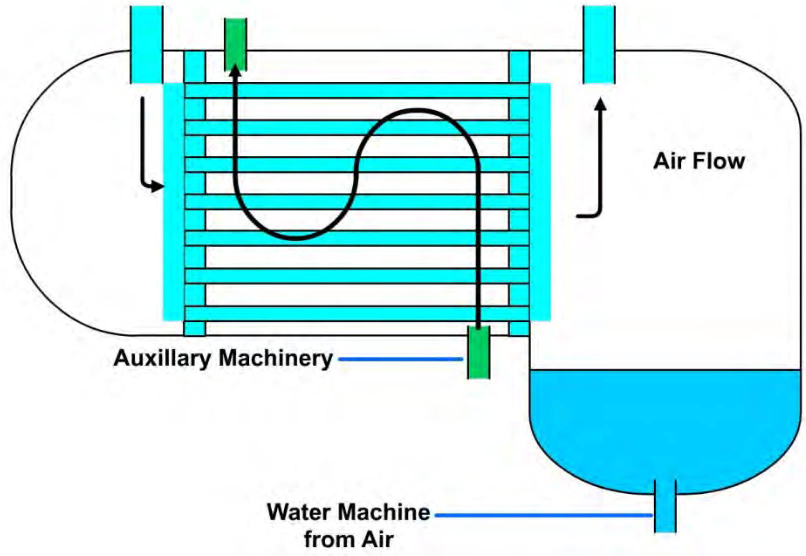


Figure 17-7 — Basic cooler and separator.

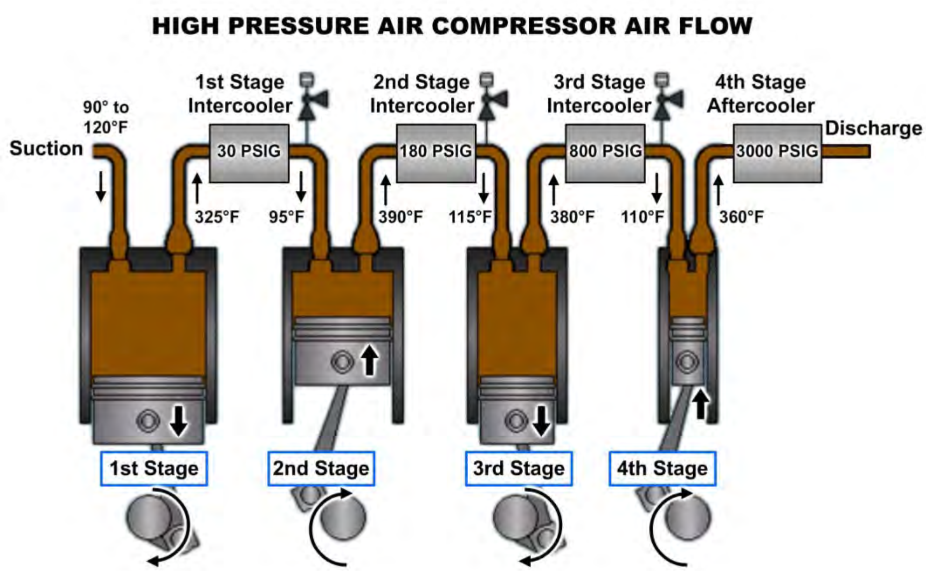


Figure 17-8 — Pressure and temperature resulting from multi-staging and inter-staging cooling.

Inter-stage cooling reduces the maximum temperature in each cylinder. This temperature reduction, of course, reduces the amount of heat that must be removed by the water jacket at the cylinder. *Figure 17-8* illustrates the pressures and temperatures through a four-stage compressor. The intercoolers and the aftercoolers (on the output of the final stage) are of the same general construction. The exception is that the aftercoolers are designed to withstand a higher working pressure than that of the intercoolers. Both intercoolers and aftercoolers are generally fitted with relief valves on both the air and the water sides. The relief valves must be set according to planned maintenance system (PMS).

In all compressors fitted with thermostatically controlled freshwater cooling systems, the possibility of overcooling the cylinders occurs only when the thermostat is malfunctioning. The air cannot be cooled too much in the intercoolers and aftercoolers. There are no detrimental effects for low air discharge temperatures from the coolers. The more the air is cooled in the intercoolers, the lower the brake horsepower will be. When more water is condensed within the cooler, fewer chances exist for the water to condense during the subsequent compression stroke.

Oil coolers may be of the coil type, shell and tube type, or a variety of commercial designs. Although external oil coolers are generally used, some compressors are fitted with base-type oil cooler. In this design, cooling water circulates through a coil placed in the oil sump. On most compressors, the circulating water system is arranged so that the amount of cooling water passing through the oil cooler can be regulated without disturbing the quantity of water passing through the cylinder jackets, intercoolers, or aftercoolers. Thermometers are fitted to the circulating water inlet and outlet connections, the intake and discharge of each stage of compression, the final air discharge, and the oil sump.

Control Systems

The control system of a reciprocating air compressor may include one or more control devices. These control mechanisms may include start-stop control, constant-speed control, cooling water failure switches, and automatic high temperature shutdown devices.

Control or regulating systems for air compressors in use by the Navy are largely of the start stop type. In the start-stop design, the compressor starts and stops automatically as the receiver pressure falls or rises within predetermined set points. On electrically driven compressors, the system is very simple. As air pressure in the receiver increases, it actuates a pressure switch that opens the electrical control circuit when the pressure acting upon the switch reaches a given value, commonly called a set point. The switch closes the control circuit when the pressure drops a predetermined amount. Because of their high horsepower rating, centrifugal compressors do not have automatic start-stop controls. Instead, an automatic load and unload control system is used.

Some electrically driven units, such as the medium pressure system, are required to start at either of two pressures. In these units, there are two pressure switches. One of these switches has a three-way valve that admits pressure from the air accumulator to the selected pressure switch. In other electrically driven units, the air is directed from the receiver through a three-way valve to either of two control valves adjusted for the required range of pressure settings. A line connects each control valve to a single pressure switch. This switch may be set to any convenient pressure. The setting of the control valve selected will determine the operation of the switch.

The constant-speed control regulates the pressure in the air receiver by controlling the output of the compressor. This control works without stopping or changing the speed of the unit. The constant-speed control prevents frequent starting and stopping of compressors when there is a fairly constant but low demand for air. Control is provided when air is directed to unloading devices through a control valve that is set to operate at a predetermined pressure.

Automatic high-temperature shutdown devices are fitted on almost all HPACs. If the cooling water temperature rises above a safe limit, the compressor will stop and will not restart automatically. Some compressors are equipped with a device that will shut down the compressor if the temperature of the air leaving any stage exceeds a preset value.

Oil-Free LPACs

The most common method of providing oil-free air aboard Navy ships is to use low or high pressure reciprocating oil-free air compressors. For the purpose of our discussion of the oil-free design, we will use the reciprocating low pressure, oil-free air compressor as our example.

Reciprocating Oil-Free LPACs

For many years, the reciprocating types of air compressors had to use lubricating oil to reduce the friction and wear of piston rings sliding on the walls of the cylinders. Some of the oil, in the form of vapor, would be picked up by the airstream and carried to the outlet of the compressor. Like water vapor, oil vapor tends to collect in low places. When oil vapor mixes with water vapor, the resulting emulsion may deposit itself on machined surfaces, which generally become collecting points for dirt and particles of rust. This sludge formation can foul pneumatic valves, which must have very close clearances and operating tolerances. However, fouling of machine parts is minor compared to the potentially hazardous condition that results when oil vapor is entrained in the airstream of an HPAC.

From earlier discussion, you should remember that air is mostly nitrogen (about 78 percent) and oxygen (about 21 percent). Nitrogen is an inert gas. When mixed with oil vapor, nitrogen is not hazardous. On the other hand, when oil vapor is mixed with oxygen in the air, two of the three elements needed for an explosion or fire have been combined. All that is needed to trigger this combination is heat. Where could the heat possibly come from? Think about it. When air is compressed, a lot of heat is produced. Now, let's consider what could happen when a careless operator quickly opens a valve in a high pressure air system. The air and oil vapor mixture will flow rapidly into the next part of the system until it reaches the next obstruction, which will cause the air to be compressed. At this point, all three elements needed for an explosion are present—oxygen, fuel, and heat.

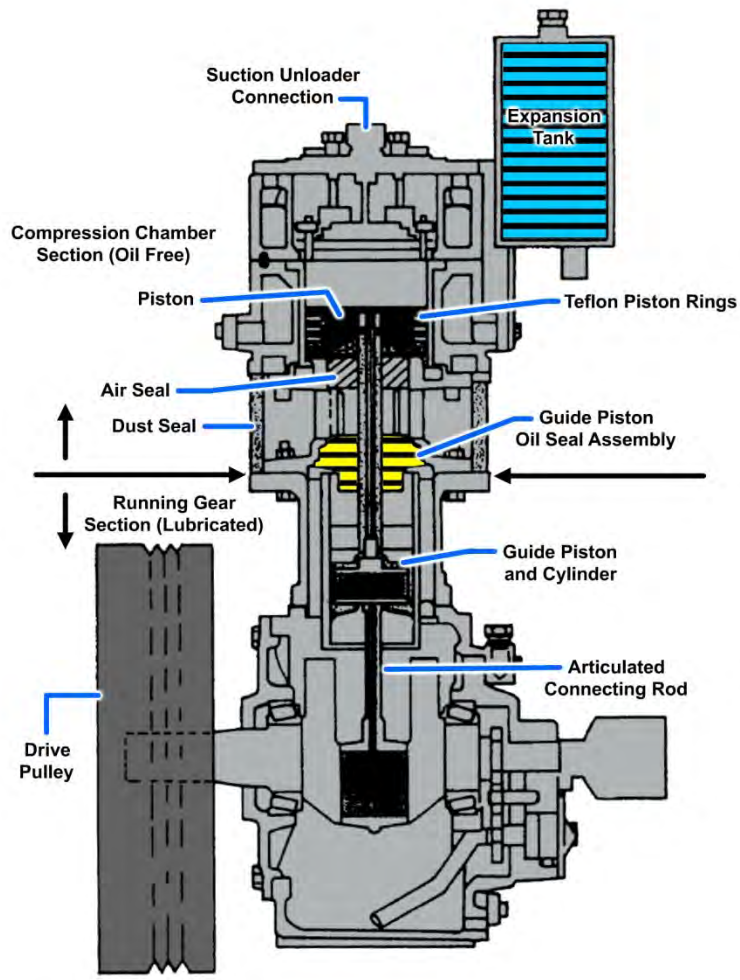


Figure 17-9 — Cutaway view of an oil-free, LPAC.

The danger associated with the use of lubricated air compressors has caused the Navy to replace LPACs and HPACs with the oil-free type. Oil-free air compressors are designed to prevent any oil vapor from getting into the airstream in the compressor. (Navy standard oil-free compressors have not been developed for the medium pressure range). The design of oil-free air compressors was made possible by the development of new materials for piston rings. These materials do not require lubrication, only cooling by water. The design of the oil-free air compressor makes it possible for the compression stages to be separated from the running gear, which still uses oil for lubrication.

Components

Oil-free reciprocating air compressors use a crosshead arrangement consisting of a guide piston and cylinder and guide piston seal assembly. The design separates the compressor section from the running gear section and still transfer's mechanical power from the lubricated crankshaft to the piston and connecting rod assemblies of the non-lubricated compressor stages (refer to *Figures 17-9 and Figure 17-10).*

NOTE

The connecting rods are connected to the guide piston in the oil-free air compressor.

The compression piston is hollow and is connected to the guide piston by the guide piston seal assembly *(Figure 17-9).* The piston rings are made from a Teflon-bronze material that will become damaged upon contact with lube oil.

The guide piston seal assembly contains oil control rings and seal rings, retainer rings, a cup, and a cover (*Figure 17-10*). The seal assembly prevents oil from entering the compression chamber by scraping the oil from the piston connecting rod as it moves up and down in the seal assembly. The running gear chamber consists of a system of connecting rods, a crankshaft, and a flywheel. The valve assemblies are of the strip/feather type previously discussed in this chapter.

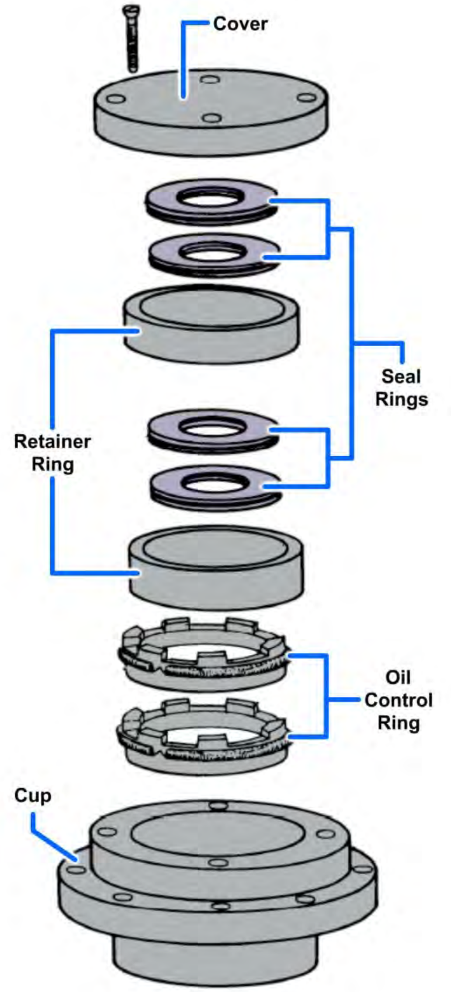


Figure 17-10 — Guide piston seal assembly.

Helical Screw Compressor

A relatively new design of oil-free air compressor is being installed aboard some of our newer ships, such as the FFG-7 class and CG-47 class ships. This LPAC is a single-stage, positive-displacement, axial-flow, helical-screw type of compressor. It is often referred to as a screw-type compressor *(Figures 17-11, and Figure 17-12*). Compression is caused by the meshing of two helical rotors (male and female) located on parallel shafts and enclosed in a casing. Air inlet and outlet ports are located on opposite sides of the casing. Atmospheric air is drawn into the compressor through the filter-silencer. The air passes through the air cylinder-operated unloader (butterfly) valve and into the inlet part of the compressor when the valve is in the open (load) position. Freshwater is injected into the airstream as it passes through the inlet port of the compressor casing.

The injected freshwater serves two purposes: it reduces the air discharge temperature caused by compression, and it seals the running clearances to minimize air leakage. Most of the injected water is entrained into the airstream as it moves through the compressor.

The compression cycle starts as the rotors unmesh at the inlet port. As rotation continues, air is drawn into the cavity between the male rotor lobes and into the grooves of the female rotor. The air is trapped in these grooves, or pockets, and follows the rotated direction of each rotor. As soon as the inlet port is closed, the compression cycle begins as the air is directed to the opposite (discharge) end of the compressor. The rotors mesh, and the normal free volume is reduced. The reduction in volume (compression) continues with a resulting increase in pressure until the closing pocket reaches the discharge port.

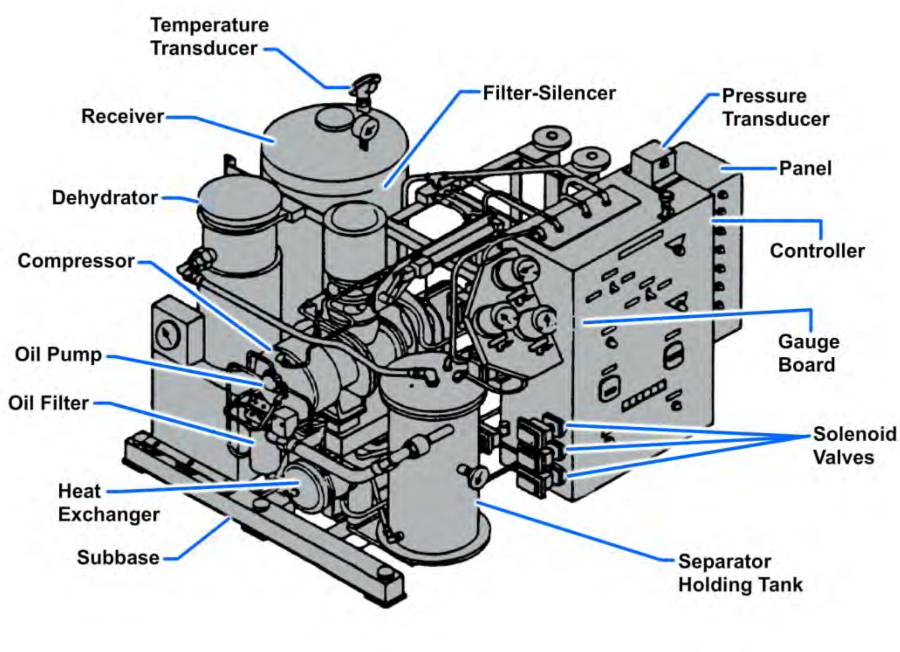


Figure 17-11 — Low pressure, oil-free rotary helical screw compressor.

The entrained water is removed from the discharged air by a combined separator and water holding tank. The water in the tank passes through a seawater-cooled heat exchanger. The cooled water then recirculates to the compressor for reinjection.

During rotation and throughout the meshing cycle, the timing gears maintain the correct clearances between the rotors. Since there is no contact between the rotor lobes and grooves, between the rotor lobes and casing, or between the rotor faces and end walls, no internal oil lubrication is required. This design allows the compressor to discharge oil-free air.

For gear and bearing lubrication, lubricating oil from a force-feed system is supplied to each end of the compressor. Mechanical seals serve to keep the oil isolated from the compression chamber.

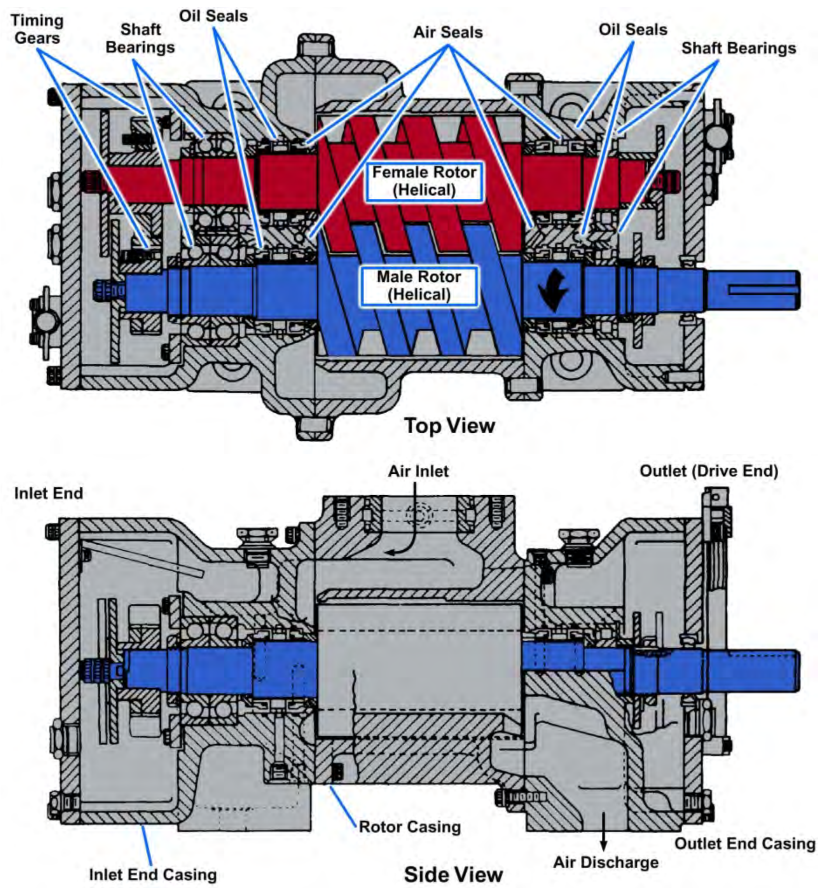


Figure 17-12 — Helical screw compressor.

Compressed Air Receivers

An air receiver is installed in each space that houses air compressors (except centrifugal and rotary lobe types of air compressors). A compressed air receiver is an air storage tank. If demand is greater than the compressor capacity, some of the stored air is supplied to the system. If demand is less than the compressor capacity, the excess is stored in the receiver or accumulator until the pressure is raised to its maximum setting. At that time, the compressor unloads or stops. Thus, in a compressed air system, the receiver minimizes pressure variations in the system and supplies air during peak demand. This capability serves to minimize the start-stop cycling of air compressors.

Air receivers may be mounted horizontally or vertically. Vertically mounted receivers have convex bottoms that permit proper draining of accumulated moisture, oil, and foreign matter. All receivers have fittings, such as inlet and outlet connections and drain connections and valves. They have connections for an operating line to compressor regulators, pressure gauges, and relief valves (set at approximately 12 percent above the normal working pressure of the receiver). They also have manhole plates (depending on the size of the receiver). The discharge line between the compressor and the receiver is as short and straight as possible. This design eliminates vibrations caused by pulsations of air and reduces pressure losses caused by friction.

In high pressure air systems, air receivers are called air flasks. Air flasks are usually cylindrical in shape with belled ends and female-threaded necks. The flasks are constructed in shapes that will conform to the hull curvature for installation between hull frames. One or more air flasks connected together constitute an air bank.

Compressed Air Supply Systems

The remainder of the compressed air system is the piping and valves that distribute the compressed air to the points of use.

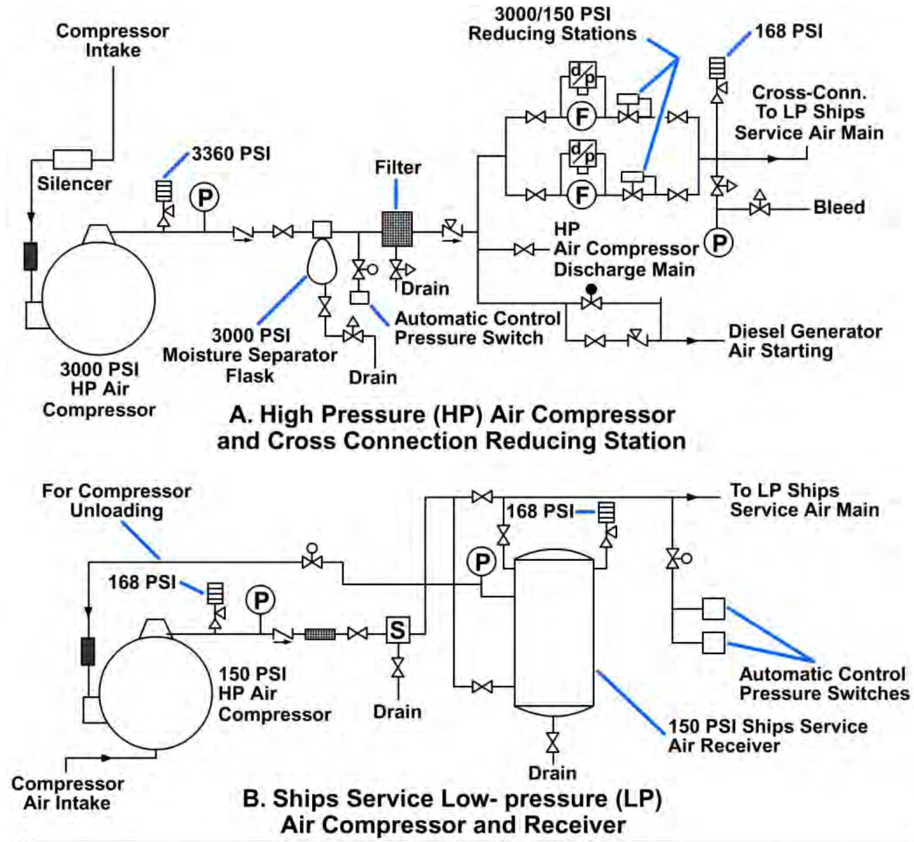
High Pressure (HP) Air

A high pressure air aboard a surface ship (*Figure 17-13, view A*), the 3,000/150-pounds per square inch (psi) reducing station, is used for emergencies or abnormal situations to provide air to the low pressure air system.

Low Pressure (LP) Air

Low pressure (LP) air is the most widely used air system aboard the ship, sometimes referred to as ship's service air, (*Figure 17-13, view B)*, the first part of a low pressure air system. Many of the low pressure air systems are divided into subsystems, referred to as vital and non-vital air.

Vital air is used primarily for engineering purposes, such as automatic boiler controls, water level controls, and air pilot-operated control valves. Vital air is also supplied to electronics systems. Vital air systems are split between all main machinery groups with cross-connect capability.



Legend		
Pressure Reducing Valve	Globe Valve	Differential Pressure Indicator
Pressure Switch	Needle Valve	LP Air Purifier
Globe Valve Locked Shut	Swing Check Valve	Filter
Globe Valve Locked Open	Lift Check Valve	Angle Relief Valve
Pressure Gauge	Flexible Connector	

Figure 17-13 — High pressure and low pressure air systems.

Non-vital air has many different purposes, such as laundry equipment, tank-level indicating systems, and air hose connections. Air for a non-vital air system is supplied through a priority valve. This valve will shut automatically to secure air to non-vital components when the pressure in the air system drops to a specified set point. It will reopen to restore non-vital air when pressure in the system returns to normal. This system gives the vital air first priority on all the air in the low pressure system.

COMPRESSOR CLASSIFICATION

An air compressor is generally classified according to capacity (high or low), the type of compressing element, and the type of driving unit, how it is connected to the driving unit, the pressure developed, and whether the discharged air is oil free. Because of our increasing need for oil-free air aboard ship, the oil-free air compressor is replacing most of the standard LPAC. For this reason, we will discuss it in some detail further along in this chapter.

Shipboard air compressors may be swashplate, reciprocating, rotary lobe, or rotary. The swashplate or reciprocating type is generally selected for capacities of 22 cubic feet per hour and for pressures of 1,000 to 3,000 psi. The rotary lobe type is selected for capacities up to 8,800 cubic feet per minute (cfm) and for pressures of no more than 20 psi. The rotary type is selected for 200 cfm and for pressures up to 125 psi. Most general-service-use air compressors aboard ship are rotary (*Figure 17-14*).

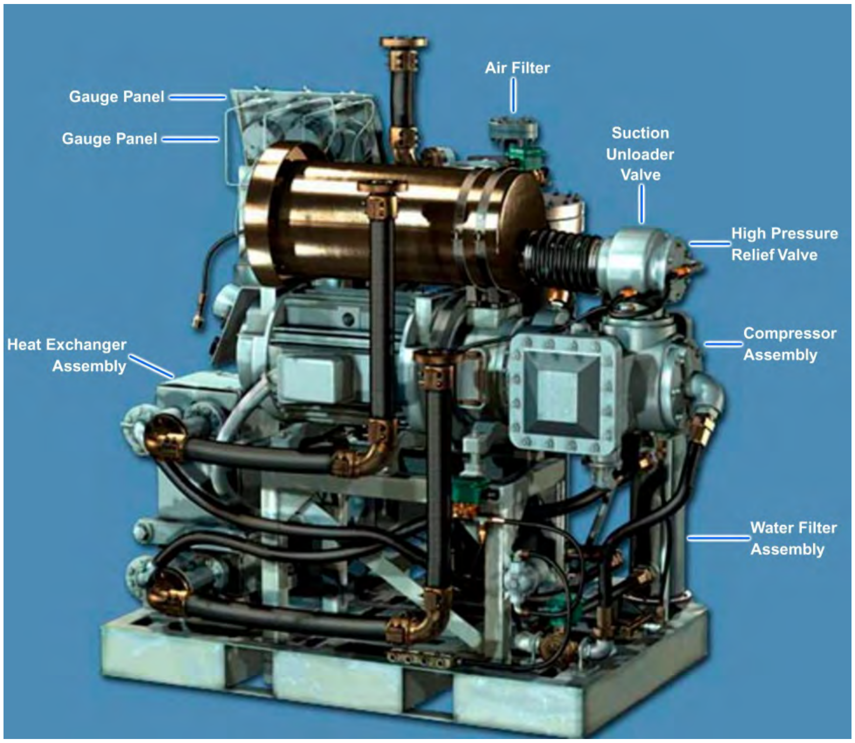


Figure 17-14 — Rotary LPAC.

LPAC

This topic addresses only main components, characteristics, and functions of the rotary oil-free air compressor.

The LPAC is a rotary single-screw, water-flooded, non-lubricated, positive displacement unit. It is rated at 200 cfm at 125 pounds per square inch gauge (psig) discharge pressure.

Components

Drive Motor

The drive motor (*Figure 17-15*) drives the compressor assembly's main rotor shaft. It is a 60-horsepower (hp), 440-volt alternating current (ac), three-phase, 60-hertz (Hz) motor that runs at a constant speed.

A coupling directly couples the drive motor shaft to the compressor assembly's main rotor shaft. The drive motor is horizontally mounted behind the separator on a raised frame welded to the LPAC base.

Figure 17-15 — Drive motor.

Air End of the Compressor Components

Air Inlet Filter

Ambient air is drawn into the compressor assembly through the air inlet filter (*Figure 17-16*). This filter contains a replaceable element that removes particles of 10 microns or larger from the inlet air.

It also contains a differential pressure indicator that pops up to indicate a clogged filter element. Some filters may have a vacuum pressure transducer in place of the pop-up indicator.

Compressor Assembly

The compressor assembly (*Figure 17-16)* compresses air and water and discharges the mixture from the bottom of the compressor housing to the ship's LP air system.

Suction Unloader Valve

The suction unloader valve (*Figure 17-16)* is a spring-loaded diaphragm-type valve that is pneumatically opened by the suction of the compressor. This design permits compression loads to be removed automatically during startup and applied automatically when the unit is back up to operating speed.

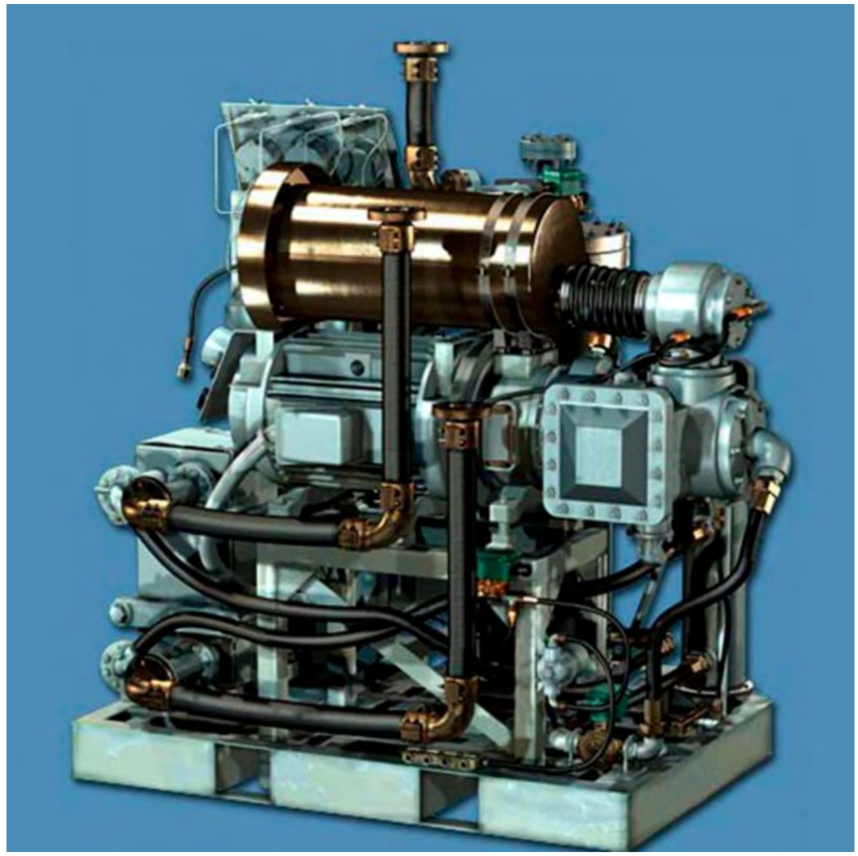


Figure 17-16 — Rotary LPAC.

Heat Exchanger Assembly

The plate and frame heat exchanger assembly (*Figure 17-16)* has 31 titanium plates that separate potable injection water and seawater. Potable injection water is routed over one side of the plates, and seawater is routed over the other side. Excess injection water heat is transferred through the plate to the seawater, which carries it out of the heat exchanger assembly.

Water Filter Assembly

The water filter assembly (*Figure 17-16*) uses a replaceable filter element to remove dirt and other solid particles of 20 microns or greater from the injection water.

This assembly includes an injection water pressure gauge and a discharge air pressure gauge that should be monitored for an indication of a dirty water filter element. Normally, the injection water pressure is 10 to 12 psig below the discharge air pressure. An injection water pressure reading of 20 to 25 psig below the discharge air pressure indicates a dirty water filter element, causing restricted water flow.

High Pressure Relief Valve

High pressure relief valves (*Figure 17-16*) prevent excess pressure buildup in the separator assembly and the compressor assembly. High pressure relief valves are been set by the manufacturer at 150 psig.

Air End Controls, Indicators, and Safety Devices

High pressure relief valves prevent excess pressure from building up in the separator assembly and the compressor assembly. A discharge air pressure gauge and a shipboard air pressure gauge mounted on the gauge panel (*Figure 17-16)* provide the operator with a continuous reading of those pressures.

Each of the gauges is equipped with a gauge valve so that the associated gauge can be isolated from the system for calibration or repair. The discharge air pressure transducer, shipboard air pressure transducer, and discharge air temperature air resistive temperature device (RTD) provide inputs used by the compressor management system (CMS) to control the compressor operation.

Separator Assembly

The separator assembly (*Figure 17-17)* serves as a reservoir to store the injection loop water. A sight glass on the side of the assembly allows monitoring of the water level within the separator.

The separator assembly has a water level switch that contains six magnetic reed switches that are activated by float assemblies to indicate water level.

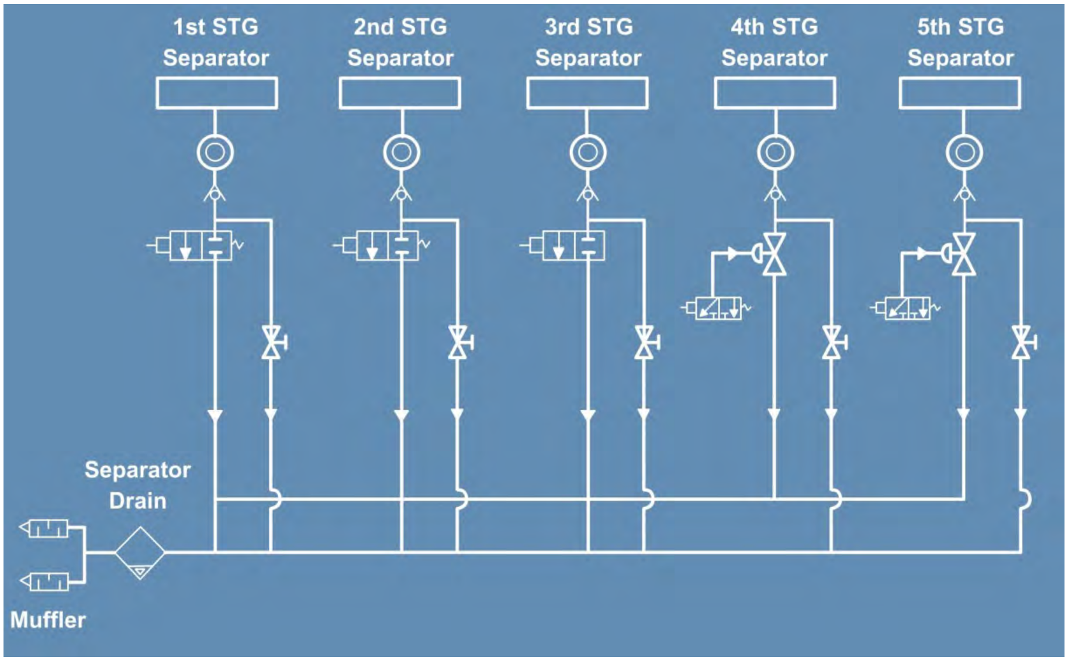


Figure 17-17 — Separator assembly.

The separator assembly also contains manual ball valves, check valves, make-up and drain solenoid valves, shut-off injection solenoid valves, and a blowdown solenoid valve for operation.

Air End Check Valve

An air end check valve (*Figure 17-18)* prevents the separator assembly pressure from backing into the compressor assembly. Similar to other check valves, air end check valves are constructed with a seat, plug, and valve body.

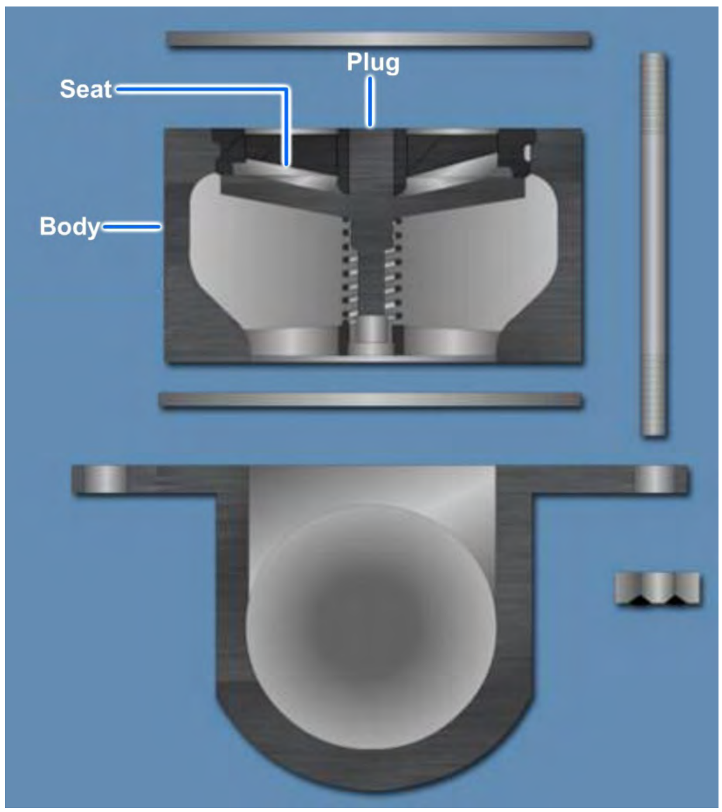


Figure 17-18 — Air and check valve.

Operating Procedures

The air compressor operating procedures must be followed to ensure the safety of personnel, equipment, and systems operations.

Prestart procedures are conducted in addition to shipboard procedures such as engineering operational sequencing system (EOSS). Conduct prestart procedures before every start of the compressor to ensure safe and proper operation of the compressor. Follow all safety procedures. Prestart procedures include checking valve alignment, visually inspecting air compressor piping, and checking air compressor wiring.

LPAC is controlled by the operator and started by setting the CMS MAN/AUTO switch to MAN *(Figure 17-19)*. In the manual mode, the compressor is started by pushing the start pushbutton.

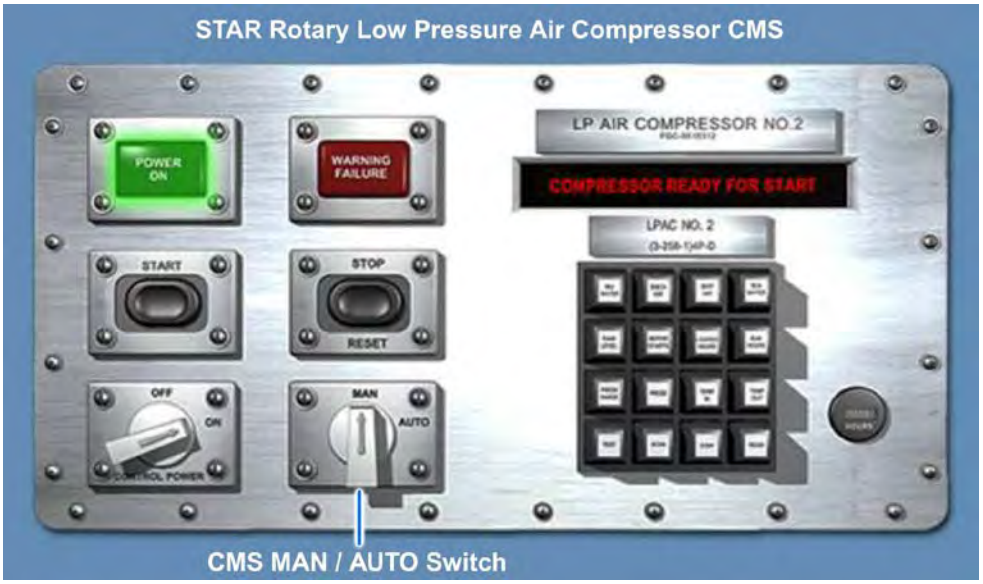


Figure 17-19 — CMS MAN/AUTO switch.

RIX HPAC

The RIX HPAC (*Figure 17-20*) is a five-stage, oil-and-water-cooled, swashplate-type vertical air compressor. It has a discharge of 3,000 psig with a capacity of 22 cubic feet per hour in a continuous, automatic operational mode. It is driven by a 60 hp direct drive electric motor.

Figure 17-20 — RIX HPAC.

Components

Drive Motor

The drive motor (*Figure 17-21*) drives the compressor assembly's main rotor shaft.

The main drive motor is a 60 hp, 440-volt ac electric motor that drives the compressor. The motor is fully enclosed and oil cooled. The vertical motor shaft extends into the crankcase.

Base

The base contains oil drain passages that allow oil from the crankcase to drain through oil drain passages in the main motor frame to the oil sump.

Crankcase

The crankcase (*Figure 17-22)* houses the crankshaft, swashplate drive system, and connecting rods. The crankcase also supports the first through fifth stage cylinder assemblies.

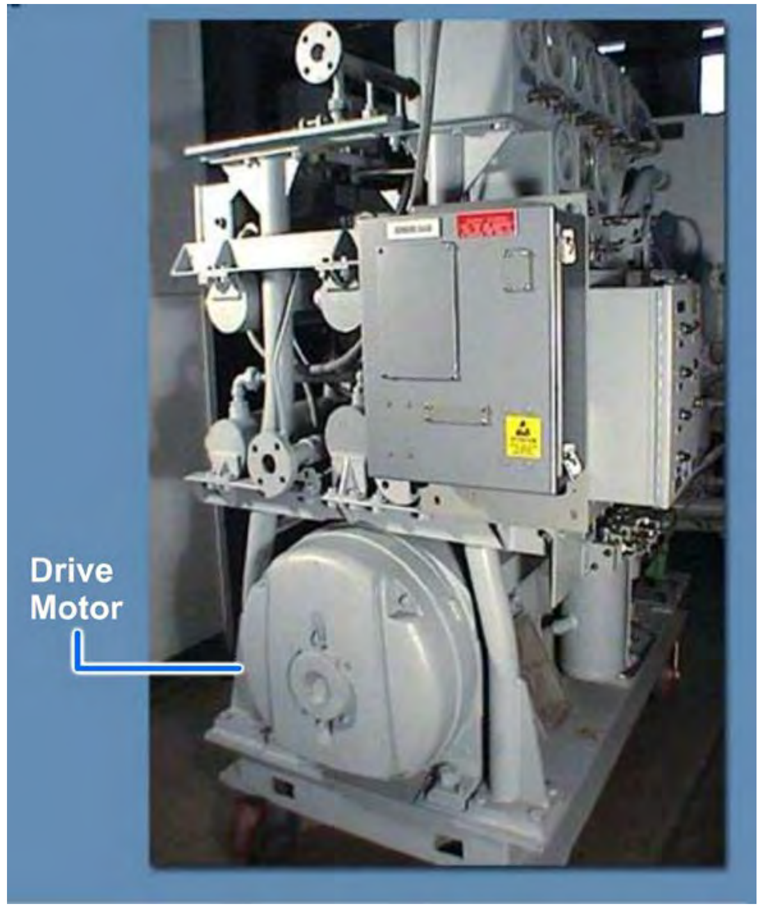


Figure 17-21 — Drive motor.

Crankcase/Taper Roller Bearing

The crankshaft is keyed to the rotating main motor shaft. The crankshaft top half is inclined about 15 degrees from vertical. The inclined crankshaft causes the swashplate to be permanently inclined by the same 15 degrees. This angle keeps the anti-rotation gear mounted on the underside of the swashplate to be in constant contact. Two spherical roller bearings and the taper roller bearing (*Figure 17-23*) permit the crankshaft to rotate.

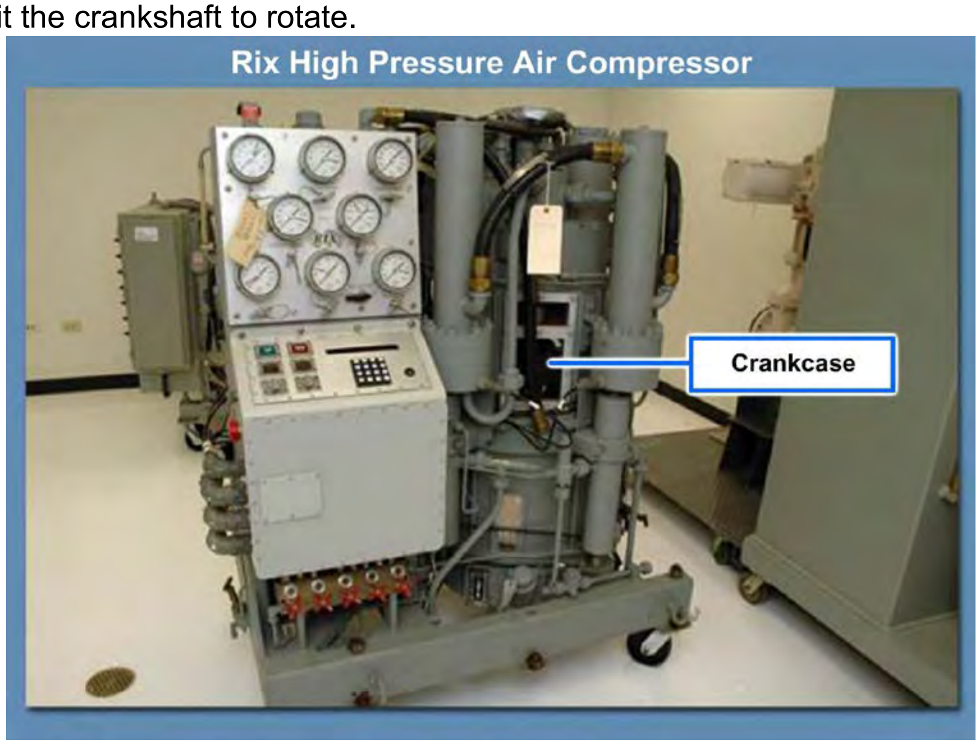


Figure 17-22 — Crankcase.

Swashplate Assembly

The swashplate (*Figure 17-23*) is mounted on top of the crankshaft, which is bolted to the rotating main motor shaft. Anti-rotation gears keep the swashplate from rotating with the crankshaft. The swashplate tilts back and forth, through spherical bearings and connecting rods. The swashplate drives the pistons vertically up and down. A counterweight is used to provide a smooth running balance. The connecting rods for the five stages that link the swashplate to their respective pistons have spherical thrust bearings at each end to allow the necessary freedom of motion.

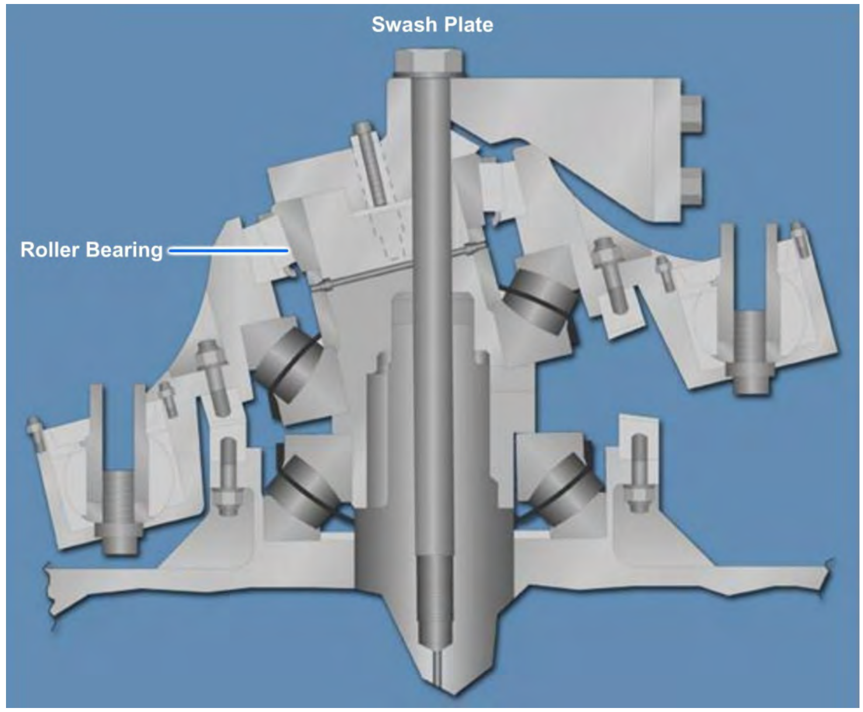


Figure 17-23 — Swashplate assembly.

Connecting Rods

The connecting rods (*Figure 17-24*) are connected between the swashplate and the piston. The connecting rods allow the pistons to be driven up and down due to the action of the swashplate, caused by the angled crankshaft.

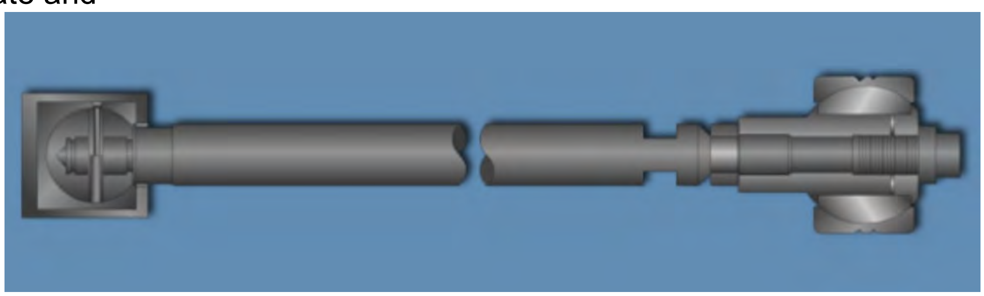


Figure 17-24 — Connecting rod.

WORTHINGTON HPAC

This topic addresses only main components, characteristics, and functions of the Worthington reciprocating oil-free air compressor (*Figure 17-25).*

Though the Navy also uses the Ingersoll Rand high pressure reciprocating air compressor with similar components, characteristics, and functions as the Worthington, only the Worthington is discussed in this topic.

The Worthington is a five-stage vertical reciprocating compressor. It is motor driven and has a discharge of 3,000 psig in continuous, automatic operational use.

Components

Compressor Running Gear Assembly

The running gear assembly (*Figure 17-25*), consists of the base, frame, crankshaft, connecting rods, crossheads, frame oil heads, and oil deflectors. The drive motor is connected to the crankshaft by direct coupling, allowing the rotation motion of the drive motor to be converted to the reciprocating motion of the piston.

Crankshaft

The crankshaft (*Figure 17-25),* provides the mounting surface for the crossheads, piston rods, and connecting rods. It is a one-piece forging, accurately machined and balanced with removable counterweights to counteract shaking forces. The crankshaft rides under slung from the frame in precision bearing half shells.

Frame Oil Heads

Frame oil heads (*Figure 17-25)* is spring-loaded, cast-iron rings and is housed in a nodular iron frame oil head. The frame oil heads are positioned around the piston rods in the upper part of the frame atop the crossheads. They prevent oil from traveling up the piston rod.

Oil Deflectors

The oil deflector (*Figure 17-25*) consists of a rubber V-ring that tightly grips the rod so that oil may not travel upwards into the cylinders. The oil deflector is positioned on each piston rod between the piston rod packing and the frame oil head.

Main Bearing/Crankpin Bearing

The main bearings (*Figure 17-26*) are precision made of steel-bracket tri-metal that supports the crankshaft. Crankpin bearings (*Figure 17-26)* support the connecting rods. Both bearings have a layer of bronze and a Babbitt with a flashing of tin bonded to the steel backing, which serves to "seat-in" the bearing during initial operation.

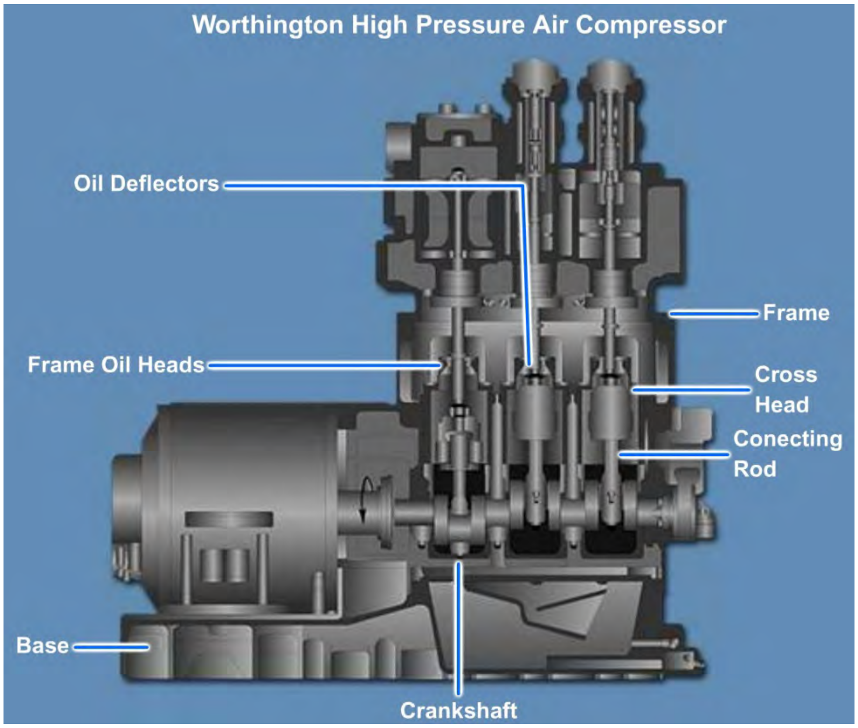


Figure 17-25 — Worthington HPAC.

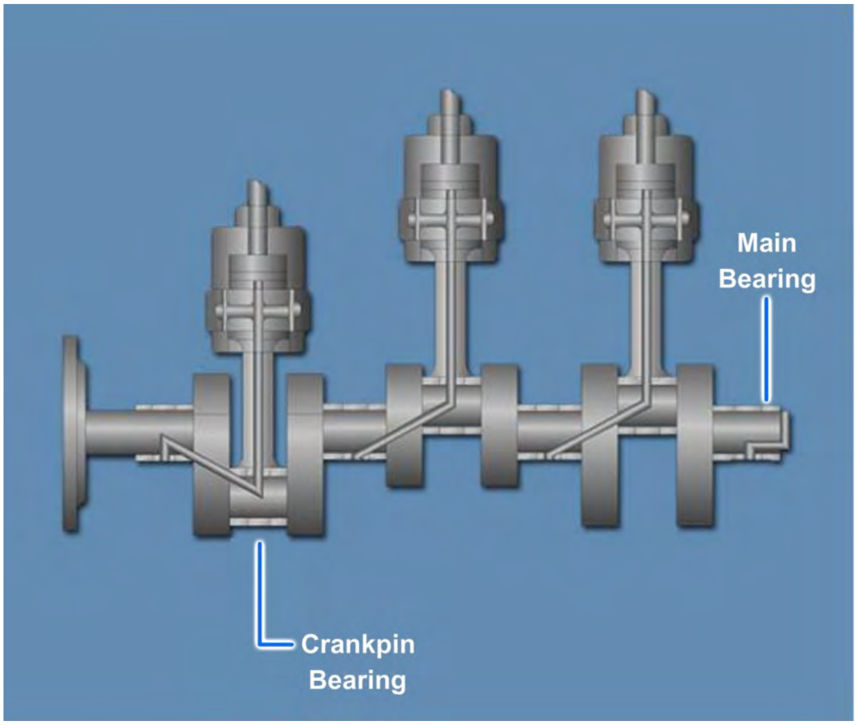


Figure 17-26 — Main and crankpin bearings.

Crossheads

The crossheads (*Figure 17-27)* form the link between connecting rod and piston rod. They are constructed of Babbitt-faced nodular iron.

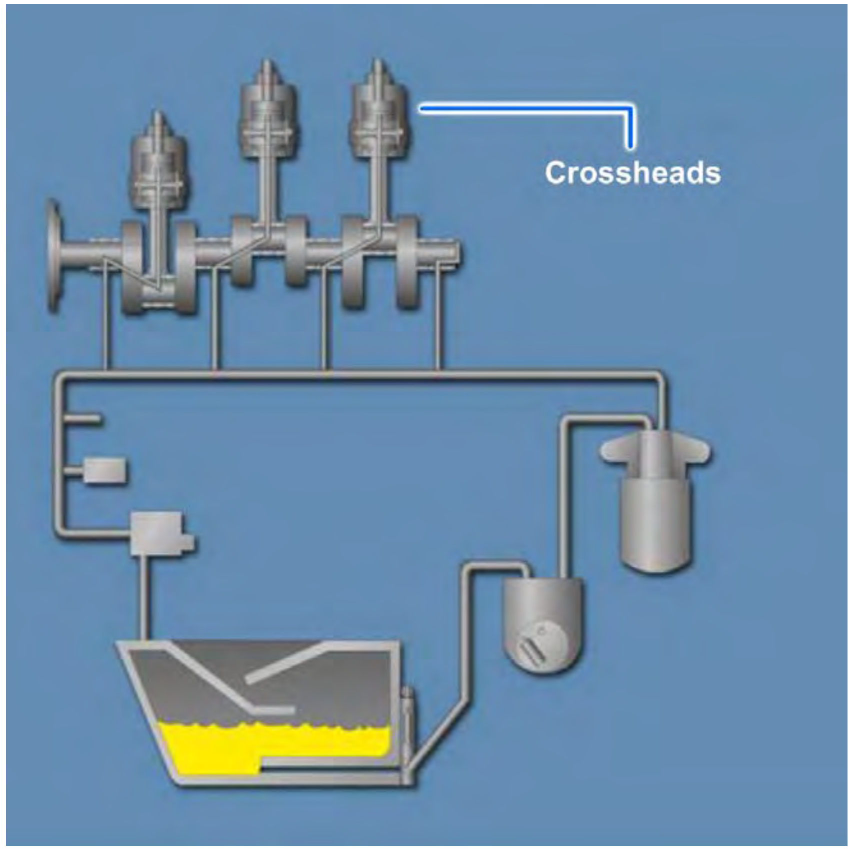


Figure 17-27 — Cross heads.

Unloader Valve

The unloader valve consists of a bronze body that is machined internally to house the piston. The purpose of the unloader valve (*Figure 17-28)* is to automatically and quickly release residual pressure from the condensate accumulator, cylinders, and coolers whenever the compressor stops.

Suction Filter

The suction filter (*Figure 17-29*) removes dirt from the inlet air before it is directed into the first stage cylinder. It is located at the motor-end of the compressor attached to the first stage suction port. The filter body is a welded steel assembly and has a steel mesh and rayon filter element that can be removed for cleaning.

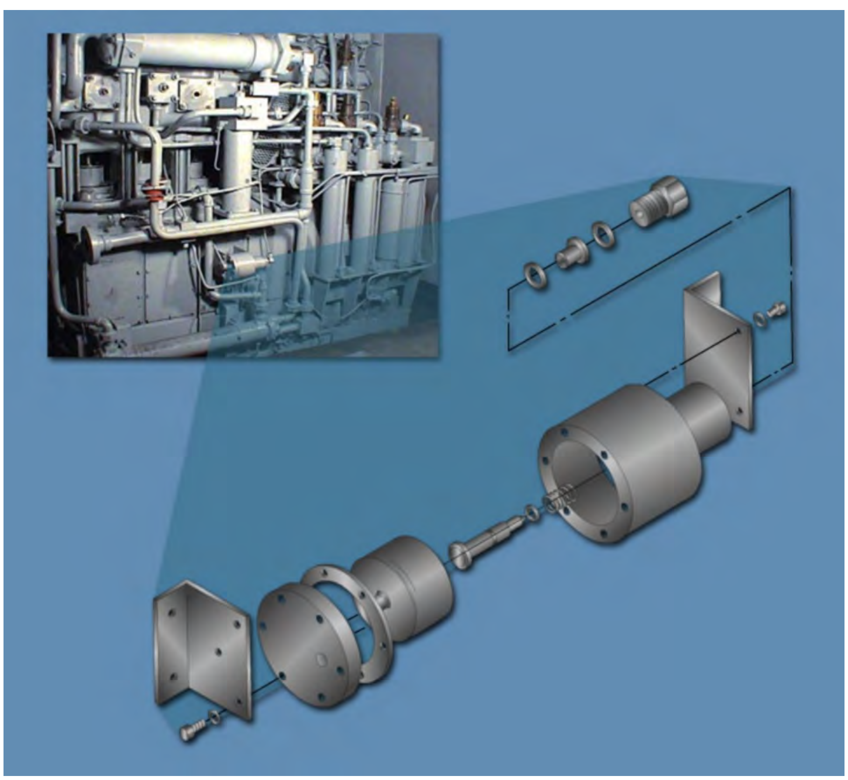


Figure 17-28 — Unloader valve.

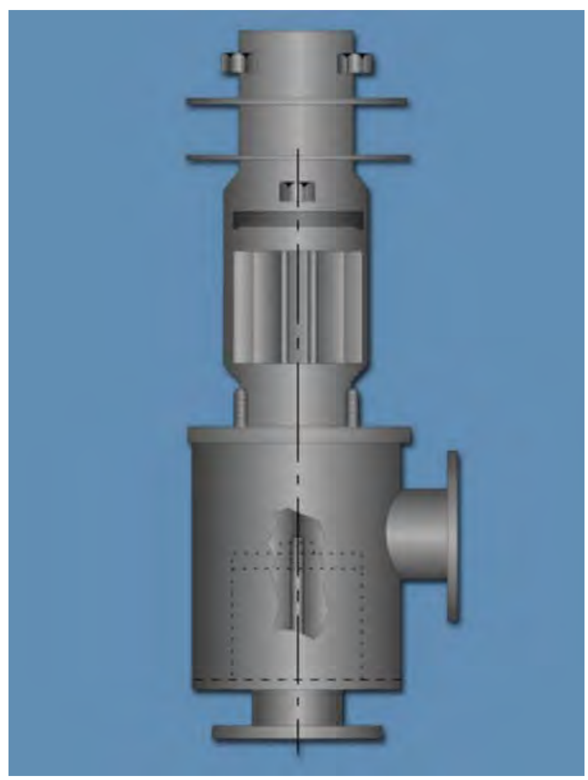


Figure 17-29 — Suction filter.

General Operations of Navy HPAC

Navy standard HPAC are multistage, reciprocating compressors having four, five, or six stages of compression. Each stage consists of identical components, with the output of one stage feeding the input of the next, and the last stage feeding the air system (*Figure 17-30)*.

Navy standard HPACs provide compressed air to run ships' services that require a system pressure in excess of 1,000 pounds. These services include, but are not limited to; torpedo systems, engine starting air, and diesel starting air.

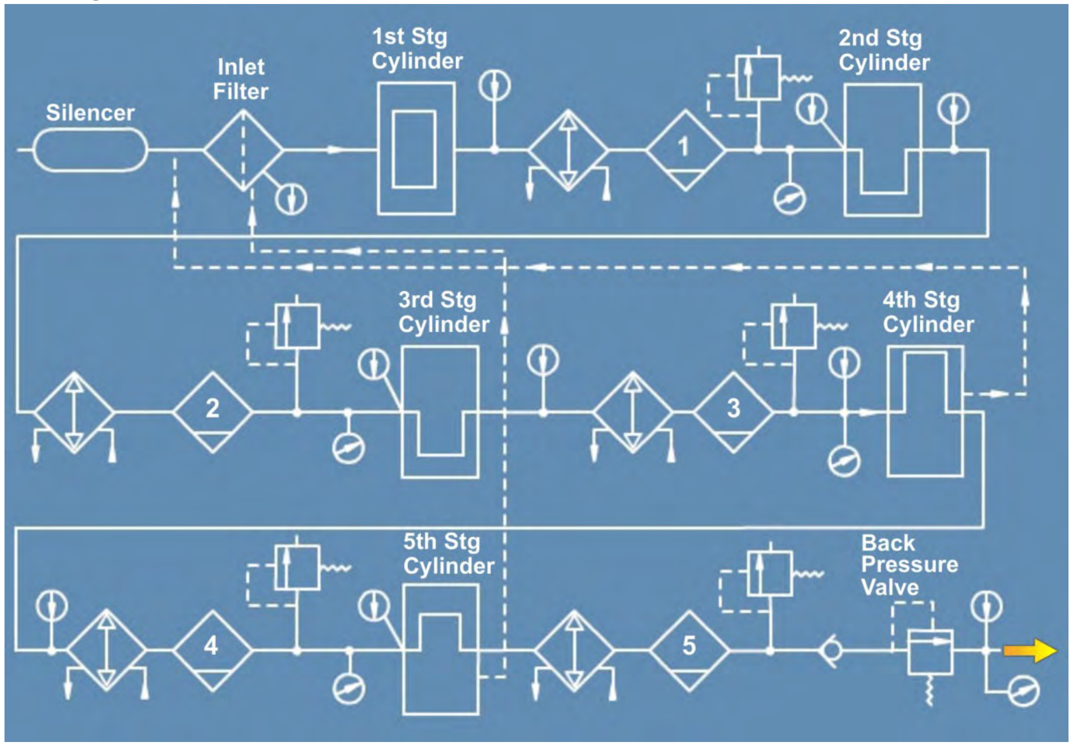


Figure 17-30 — HPAC air flow.

The HPAC is a multistage, reciprocating compressor that uses four, five, or six stages of compression. A multistage compressor is really a composite of several compressors (each stage being considered as one compressor) that are driven by a single common crankshaft. The air is compressed and cooled in each successive stage and discharged from the last stage to the ship's compressed air system. Each stage consists of similar components, such as an inlet valve, a piston and cylinder, a discharge valve, an air cooler, and a water separator. Each stage is also identically instrumented with discharge pressure gauges, an overpressure relief valve, and inlet and discharge temperature sensors for temperature indication and high-temperature shutdown.

SUMMARY

In this chapter we have discussed the many uses of compressed air aboard ship. We discussed how the air is compressed and some of the safety precautions to be used when you are operating or working on a compressed air plant or system.

End of Chapter 17

Compressed Air Systems

Review Questions

17-1. What connects the upper end of the connecting rod to fit directly to the trunk piston on an air compressor?

A. Stationary pin
B. Wrist pin
C. Free-floating pin
D. Semi-floating pin

17-2. What kind of pump moves oil from the reservoir in the compressor base and delivers it through a filter to a cooler to the cylinders?

A. Centrifugal
B. Lobe
C. Gear
D. Rotary

17-3. How would colder air from the intercooler affect the brake horsepower of the air compressor?

A. Lower it
B. Rise it
C. No change
D. Air compressors do not have brake horsepower

17-4. What component do vertical-mounted receivers have that permit proper draining of accumulated moisture, oil, and foreign matter?

A. Manual drain valve
B. Automatic drain valve
C. Relief valve
D. Convex bottoms

17-5. Air compressors are classified by what characteristics?

A. Amount of air supplied to the compressed
B. Capacity
C. Dimensions
D. Size of final stage cylinder

17-6. What is the discharge pressure rate of a low pressure air compressor (LPAC) in (a) cubic feet per minute and (b) pounds per square inch gauge?

A. (a) 100, (b) 105
B. (a) 200, (b) 125
C. (a) 200, (b) 145
D. (a) 400, (b) 165

17-7. The air inlet filter is capable of removing particles what size, in microns?

A. 10
B. 25
C. 50
D. 75

17-8. What component permits compression loads to be removed automatically during startup and applied automatically when the unit is back up to operating speed?

A. Air inlet filter
B. Water filter assembly
C. Heat exchanger
D. Suction unloader valve

17-9. What component uses a replaceable filter element to remove dirt and other solid particles of 20 microns or greater from the injection water?

A. Air inlet filter
B. Heat exchanger
C. Suction unloader valve
D. Water filter assembly

17-10. At what pounds per square inch gauge (psig) is the high pressure relief valve set from the manufacturer?

A. 150
B. 175
C. 200
D. 225

17-11. What component serves as a reservoir to store the injection loop water?

A. Air end check valve
B. High pressure
C. Separator assembly
D. Water filter assembly

17-12. The drive elector motor on the RIX high pressure air compressor (HPAC) is how much horsepower (hp)?

A. 40
B. 60
C. 80
D. 100

17-13. What assembly houses the crankshaft, swashplate drive system, and connecting rods?

A. Base
B. Crankcase
C. Drive motor
D. Swashplate

17-14. What component is located at the motor-end of the compressor attached to the first stage suction port?

A. Suction relief valve
B. Suction gauge
C. Suction filter
D. Suction bypass valve

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CHAPTER 18

DISTILLING PLANTS

Freshwater is needed aboard ship for boiler/steam generator feed, drinking, cooking, bathing, washing, and cleaning. Therefore, a naval ship must be self-sufficient in producing freshwater. Space limitations permit only enough storage tanks for a couple of days' supply. The ship depends on distilling plants to produce freshwater of high purity from seawater.

As an Engineman (EN), you will operate, troubleshoot, and repair the submerged tube, flash-type, and reverse osmosis (RO) distilling plants used by the Navy.

The type and size of distilling plants used on each class of ship are determined by many factors. Some of these factors are type of propulsion plant, number of personnel assigned, safety, and reliability. For more information, see the manufacturer's technical manual for the type of plant on your ship.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the principles of distillation.
2. List some of the type of distilling plants.
3. Explain the procedures of distilling plant carryover and salinity.
4. Describe what RO desalination units.

PRINCIPLES OF DISTILLATION

The principle by which distilling plants produce freshwater from seawater is quite simple. There are several different types of distilling plants. Each plant may appear very complicated at first, but they all work on the same basic principles. When water is boiled, it gives off steam vapor, which is relatively free of salt and minerals. The distillation process heats seawater to the boiling point and condenses the vapor (steam) into freshwater. This process leaves behind the impurities of the seawater. *Figure 18-1* contains a simple illustration of the process for a shipboard plant. Notice that the seawater after boiling is identified as brine.

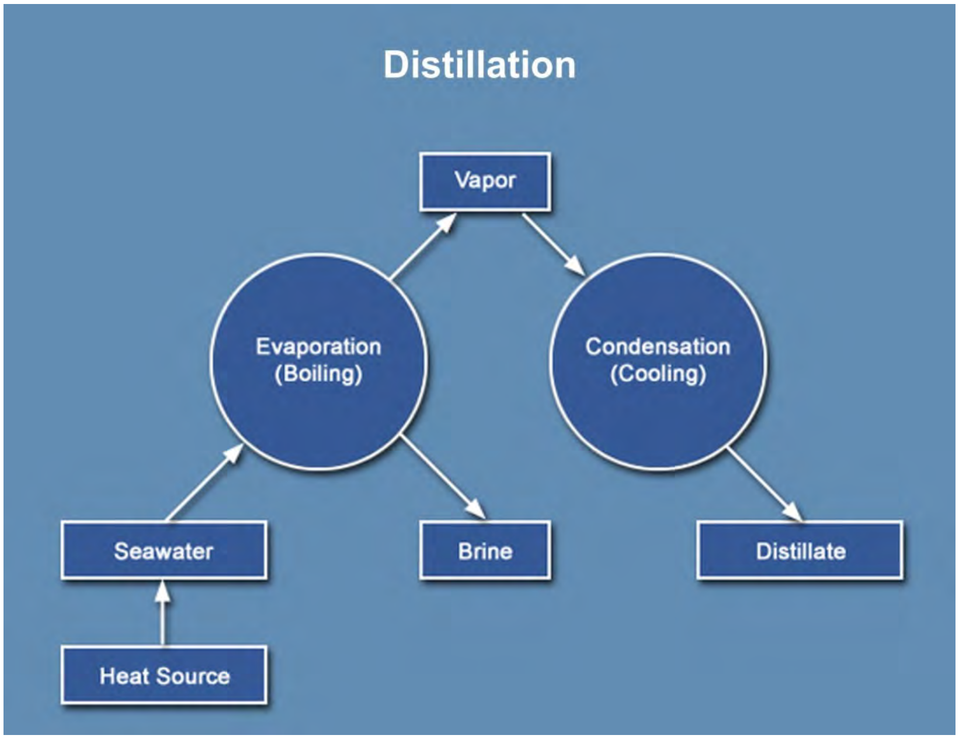

Figure 18-1 — Distillation.

Seawater is a solution of water and various minerals and salts. Seawater also contains suspended matter, such as vegetable and animal growths, bacteria, and other microorganisms. When properly operated, naval distilling plants produce freshwater that contains only slight traces of chemical salts and no biological contaminants.

Distilling plants are not effective, however, in removing volatile gases or liquids, which have a lower boiling point than water. These dissolved gases and liquids will simply boil into the vapor and be combined with the freshwater (distillate).

There are two reasons why naval distilling plants are designed to operate at low pressures and low boiling temperatures. One is that low temperatures help to prevent the formation of harmful scale. Scale is formed when certain sea salts crystallize out of solution at high temperatures. The other reason is that a low pressure plant is more efficient. Less heat is required to raise the temperature of the feedwater (seawater) to make it boil; therefore, less heat is wasted by the plant.

Common Terms

Before getting into the discussion on the process of distillation, you should learn the meanings of the terms in the following paragraphs. These terms apply to all types of distilling plants now used in naval service. You should not try to read the rest of this chapter until you understand them.

Distillation

Distillation is the process of boiling seawater and then cooling and condensing the resulting vapor to produce freshwater.

Evaporation

Evaporation is the process of boiling seawater to separate it into freshwater vapor and brine. Evaporation is the first half of the process of distillation.

Condensation

Condensation is the process of cooling the freshwater vapor produced by evaporation to produce usable freshwater. Condensation is the second half of the process of distillation.

Feed

Feed is the seawater, which is the raw material of the distilling unit; also called seawater feed or evaporator feed. Be careful how you use these terms. Do not confuse the “feed” (water) for the distilling units with the “feed” (water) for the boilers. Feed for the distilling units is nothing but raw seawater. Feed for the boilers is distilled water of very high purity.

Vapor

Vapor is the product of the evaporation of seawater feed.

Distillate

Distillate is the product resulting from the condensation of the steam (vapor) produced by the evaporation of seawater.

Brine

As seawater feed is evaporated in the distilling plant; the concentration of chemical salts in the remaining seawater feed becomes greater. Any water in which the concentration of chemical salts is higher than it is in seawater is called brine.

Salinity

Salinity is the concentration of chemical salts in water and is measured by electrical devices, called salinity cells (discussed later in this chapter), of either equivalents per million (epm) or parts per million (ppm).

Effect

In a distilling plant, an effect is that part of a unit where a distillation process occurs. For example, the first place where boiling (or evaporation) of feed into vapor occurs is in the first-effect. Most distilling plants have two, three, four, or five effects. This number means that the feed is boiled more than once within the plant. An effect may also be called a stage.

Saturated Steam

The properties of saturated steam are defined in *Table 18-1* according to pressure and temperature.

Superheated Steam

Superheated steam is a vapor which is not adjacent or next to its liquid source and has been heated to a temperature above its saturation temperature.

Degree of Superheat

Degree of superheat is the temperature difference of a superheated vapor between its saturation temperature and its existing temperature. For example: *The steam pressure past an orifice is 16 inches mercury (Hg), and auxiliary exhaust steam temperature is 240 °F (116 °C). Table 18-1 gives the properties of saturated steam. Look in the column "Vacuum Inches of Hg Gauge" and find 16.69 and 15.67. By interpolation (estimation), we find the saturation temperature (at the right) to be 176 °F (80 °C). However, the auxiliary exhaust steam is approximately 240 °F (116 °C). In this case, then, there is about 64 °F (36 °C) of superheat in the incoming steam (240 °F – 176 °F = 64 °F).*

Table 18-1 — Properties of saturated steam

ABSOLUTE PRESSURE			TEMPERATURE	
LB. PER SQ. IN.	INCHES OF HG	VACUUM INCHES OF HG GAUGE	°C	°F
0.20	0.41	29.51	11.74	53.14
0.25	0.51	29.41	15.17	59.30
0.30	0.61	29.31	18.04	64.47
0.35	0.71	29.21	20.52	68.93
0.40	0.81	29.11	22.70	72.86
0.45	0.92	29.00	24.66	76.38
0.50	1.02	28.90	26.43	79.58
0.60	1.22	28.70	29.56	85.21
0.70	1.43	28.49	32.27	90.08
0.80	1.63	28.29	34.66	94.38
0.90	1.83	28.09	36.80	98.24
1.0	2.04	27.88	38.74	101.74
1.2	2.44	27.48	42.18	107.92
1.4	2.85	27.06	45.14	113.26
1.6	3.26	26.66	47.77	117.99
1.8	3.66	26.26	50.13	122.23
2.0	4.07	25.85	52.27	126.08
2.2	4.48	25.44	54.23	129.62
2.4	4.89	25.03	56.05	132.89
2.6	5.29	24.63	57.74	135.94
2.8	5.70	24.22	59.33	138.79
3.0	6.11	23.81	60.82	141.48
3.5	7.13	22.79	64.21	147.57
4.0	8.14	21.78	67.91	152.97
4.5	9.16	20.76	69.91	157.83
5.0	10.18	19.74	72.36	162.24
5.5	11.20	18.72	74.61	166.30
6.0	12.22	17.70	76.70	170.06
6.5	13.23	16.69	78.64	173.56
7.0	14.25	15.67	80.47	176.85
7.5	15.27	14.65	80.52	176.94
8.0	16.29	13.63	83.81	182.86
8.5	17.31	12.61	85.36	185.64
9.0	18.32	11.60	86.82	188.28
9.5	19.34	10.58	88.22	190.80
10.0	20.36	9.56	89.57	193.21
11.0	22.40	7.52	92.08	197.75
12.0	24.43	5.49	94.42	201.96
13.0	26.47	3.45	96.60	205.88
14.0	28.50	1.42	98.64	209.56

TYPES OF DISTILLING PLANTS

Naval ships use three general types of distilling plants: the vapor compression-type, heat recovery distilling plant, and the low pressure steam distilling unit. The major differences between the three are the kinds of energy used to operate the units and the pressure under which distillation takes place. Vapor compression units use electrical energy (for heaters and a compressor). Steam distilling units use low pressure steam from either the auxiliary exhaust systems or the auxiliary steam system. In addition, vapor compression units boil the feedwater at a pressure slightly above atmospheric, while the low pressure steam units depend on a relatively high vacuum for operation.

> **NOTE**
>
> Another process for producing potable water from seawater is reverse osmosis.

Low pressure steam distilling units are "low pressure" from two points of view. First, they use low pressure steam as the source of energy; and second, their operating shell pressure is less than atmospheric pressure.

There are three major types of low pressure steam distilling units:

- Submerged tube
- Flash-type
- Vertical basket

Heat Recovery Distilling Units

These units use low pressure hot water from the diesel jacket water system as a heat source. Heat recovery units are also of the low pressure design in that they also operate with a relatively high vacuum like the low pressure steam distilling plants.

There are two reasons why naval distilling plants are designed to operate at low pressures and low boiling temperatures. One is that low temperature operation helps to prevent the formation of harmful scale on heat transfer surfaces. The other reason is that heated seawater will flash into steam when the pressure is lower than the saturation pressure corresponding to the temperature.

Submerged Tube Distilling Plants

There are three classifications, or arrangements, of submerged tube distilling plants:

- Two-shell double-effect
- Double-effect
- Triple-effect

The principal difference between the double-effect type and the triple-effect type is the number of stages of evaporation.

In a submerged tube distilling plant, feed floods into the bottom of the unit and surrounds the tubes that contain circulating low pressure steam. The steam in the tubes causes the surrounding feed to boil and produce steam (vapor). The vapor passes up into the moisture separators where any entrained (drawn-in) seawater droplets are removed. The clean vapor then passes on and is condensed into distillate. Submerged tube distilling plants are found on older ships. We will use the double-effect plant as an example of distillation in a submerged tube plant.

As the name implies, the double-effect plant, (*Figure 18-2*), is a double-effect distilling unit contained in a single shell. A division wall separates the two effects. Each effect has a set, or nest, of steam tubes in the bottom of its shell and a vapor separator unit in the upper part of its shell.

Follow along in *Figure 18-3, frames 1 and 2*, as we trace the feed through several circuits on its way to becoming distillate.

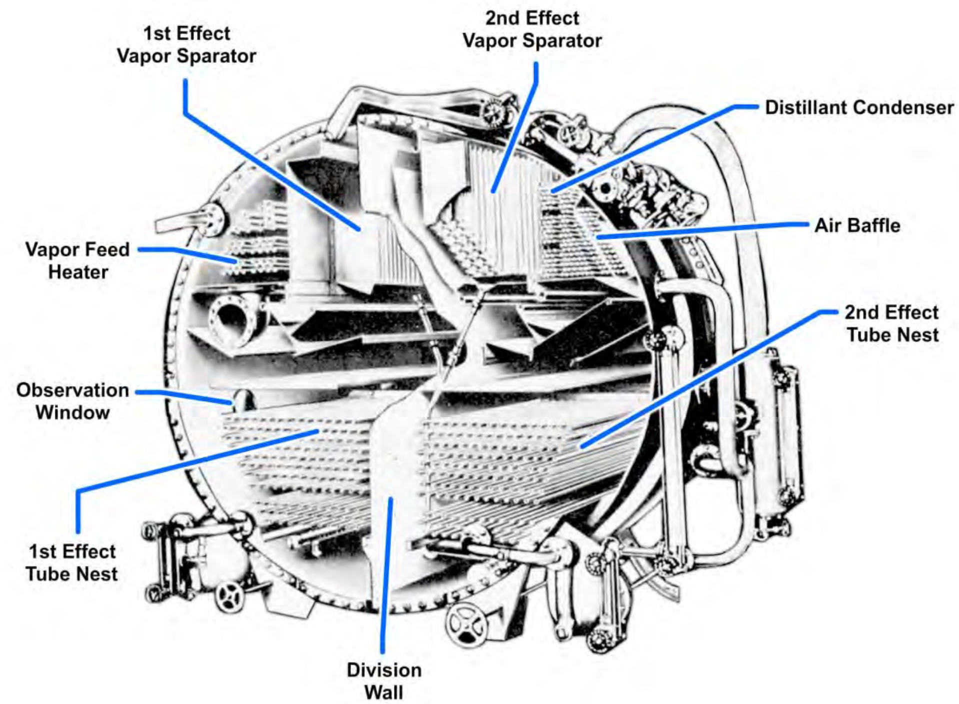

Figure 18-2 — Internal construction of a double-effect distilling plant.

Locate the exhaust steam in *Figure 18-3, frames 1 and 2,* and trace it to the tubes of the first-effect via a reducing valve. This steam may be from either the auxiliary exhaust system or the auxiliary steam system. The reducing valve controls the steam pressure going to the orifice located below the reducing valve in the supply to the first-effect tube nest. The orifice controls the quantity of steam to the first-effect tube nest. The output capacity of the plant can be altered by changing the size of the orifice plate. By passing through the orifice, the steam pressure is decreased to a vacuum. This decrease is caused by the throttling (expanding) action of the orifice. Because the temperature of the steam is still at saturation temperature for existing auxiliary exhaust pressure, the steam is now superheated. Therefore, the steam is desuperheated in the inlet line by a spray of water from the tube nest drain pump. The desuperheated steam then passes on through the first-effect tubes. The steam in the tubes is indicated on the figure by the black dashed line. The first-effect tubes can be seen in detail in *Figure 18-2*. The area surrounding the steam tubes is flooded with feed (seawater), indicated by the white area in *Figure 18-3, frames 1 and 2*. The steam gives up its heat to the feed and then condenses in the tubes. The condensate that forms in the tubes is continuously being removed by the tube nest drain pump. A portion of this condensate is used to desuperheat incoming steam, as described earlier; the rest is sent to the freshwater drain collecting tank or the main or auxiliary condenser. A drain regulator controls the discharge of the pump to maintain a water seal in the first-effect tubes. This seal prevents steam from entering the pump and prevents the steam from “blowing through” the tubes without condensing. As the surrounding feedwater absorbs latent heat from the steam, the steam condenses and the water boils.

Evaporator Assembly

This assembly is contained within a single shell mounted on the distiller base. Feedwater that is pumped into the bottom of the evaporator will eventually be converted into steam. Jacket water from the diesel engine is pumped through the heating tube bundle and serves as a source of heat for the tube bundle.

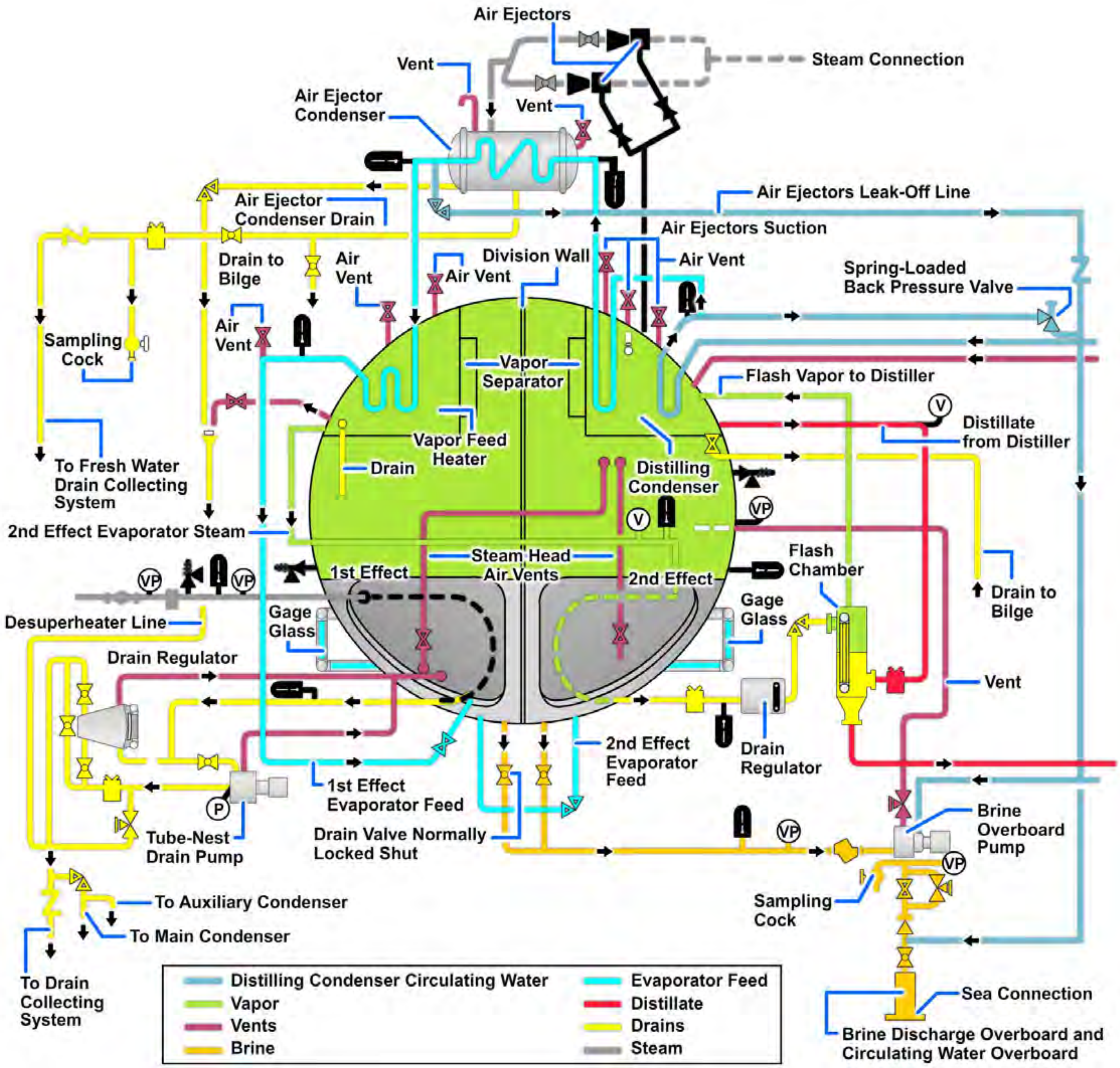

Figure 18-3 — Schematic diagram of a double-effect distilling plant.

Submerged in the feedwater, the heating tube bundle transfers the heat by conduction from the hot jacket water to the feedwater which boils off causing steam. As the steam rises, it first passes through to the suppression baffles. While the baffles allow the steam to pass through to the demister, they also block the larger moisture-laden droplets of steam from entering the demister. The steam then passes through the demister, working by separating the moisture from the vapor, thereby producing a dry saturated steam. The separated moisture which may contain salt particles, drips back to the feedwater as brine.

A pressure relief valve located on the back of the evaporator shell prevents the shell from being damaged by high internal pressure that may result from improper operation of the unit. A brine out connection, installed in the lower section of the shell, maintains the proper level of feedwater while drawing off the brine. The connection is located at a height that allows it to maintain the feedwater level slightly above the heating tube bundle. This design assures adequate and continued submersion of the heating tube bundles. A screen in the brine out connection blocks any debris that might foul the brine eductor.

Observation windows are installed in the evaporator shell. These windows will allow for monitoring of the system by viewing water level conditions in the vapor and distillate collection areas.

Vapor Circuit

Some of the feed surrounding the tubes in the first effect will boil into vapor. The vapor, indicated by the light green area in the first-effect shell, passes up into the first-effect vapor separator via baffles. Located near the surface of the feedwater, these baffles trap some of the entrained moisture from the vapor near the feedwater surface. The vapor separator removes the rest. The vapor separator contains a series of baffles or vanes that cause the vapor to change its direction of flow often and rapidly. Centrifugal force (caused by the steam changing directions) forces moisture droplets out of the vapor and onto the sides of the separator where the moisture collects and drains back down into the feed section of the first effect.

The clean moisture-free vapor passes into the vapor feed heater. The vapor feed heater and vapor separator can also be seen in *Figure 18-2*. In this section, incoming feedwater (flowing through tubes) is preheated by the first-effect vapor (surrounding the tubes). Some of the vapor will condense in this process.

The vapor and condensate leave the vapor feed heater through the line labeled second-effect evaporator steam and pass into the tube nest of the second-effect. As you can see, vapor from the first-effect is used as a heating medium for the second-effect. The shell pressure of the second-effect is a vacuum of approximately 26 in Hg. This lower pressure allows the use of the first-effect vapor to heat and boil the feedwater in the second-effect. According to *Table 18-1*, at a pressure of 26 in Hg, the boiling point of water is approximately 125 °F (52 °C). As it passes through the second-effect tube nest, the vapor from the first-effect is condensed.

Vapor produced in the shell of the second-effect passes through baffles into the second-effect vapor separator. Then it passes into the distilling condenser. In the distilling condenser, the second-effect vapor condenses into distillate by circulating seawater and evaporator feed. (This vapor also preheats the feed). Distillate from the distilling condenser leaves via the red line labeled distillate from distiller and is piped into the flash chamber. Distillate in the second-effect tubes (which was first-effect vapor) is also piped, via a drain regulator, into the flash chamber. The drain regulator maintains a water seal between the second-effect tube nest and the shell. The flash chamber has a line (green) labeled flash vapor to distiller. This line passes any flash vapors that may form from the hot distillate back to the distilling condenser. The vapors are vented to the condenser and recooled into distillate.

Distillate Circuit

Distillate that collects in the flash chamber is pumped by the distillate pump through a distillate cooler line (red) and to the test tank. From the test tank, the distillate is directed by a valve manifold (not shown) to either the potable water system or reserve feedwater tanks by the freshwater pump. If the water in the test tanks is contaminated with chloride, it can be sent to the bilge.

Seawater and Feed Circuits

Locate the sea chest (blue) at the lower right of *Figure 18-3, frames 1 and 2*. Seawater is brought in the distilling condenser circulating water pump from the sea chest and strainer. The water is pumped through the distillate cooler into the distilling condenser (blue line) and overboard through a spring-loaded back-pressure regulating valve. A back-pressure regulating valve provides a back pressure of 5 pounds per square inch (psi) on the circulating water. This valve sets the pressure head required for the evaporator feed (blue-striped line), which is tapped off the circulating water line as it leaves the distilling condenser. The evaporator feed passes through the feed heater section of the distilling condenser, through the tubes of the air-ejector condenser, through the vapor feed heater, and into the bottom of the shell of the first-effect. Leaving the first-effect, feed passes through a loop seal and manual regulating valve, into the bottom of the second-effect shell. The direction of flow from the first-effect to the second-effect is due to the pressure difference between the two effects (1st effect—16 in.Hg; 2nd effect—26 in.Hg).

Water Meter

It is located in the evaporator distillate line, immediately downsteam of the three-way solenoid trip valve. This direct-reading meter measures the production in gallons of acceptable distillate that is produced by the evaporator.

Brine Circuit

Brine is removed (orange line) from the evaporator by the brine pump. The pump takes suction from the bottom of the second-effect shell and discharges the brine overboard. Gland sealing water for the brine pump is provided by the circulating water system.

Air-Ejector Circuit

A two-stage air-ejector unit (black-striped line) is located at the top of the plant. The air ejectors remove air and non-condensable gases, such as carbon dioxide (CO_2) from the evaporator, which helps maintain a high vacuum in the shell of the second-effect. Steam discharged from the air ejector is condensed by the evaporator feed. The resulting condensate is returned (yellow line) to the ship's feed system through the freshwater drain collecting system.

The distillation process is similar for all submerged tube plants, whether they are two-shell, double-effect, or triple-effect. As a rule, submerged tube distilling plants are very large compared to other plant types of the same capacity. They have problems with scale formation on the steam tubes. For these reasons, primarily, the submerged tube plants are being phased out for naval use. You may, however, be assigned to a ship with these plants aboard.

Operational Procedures

As a engineman, you will be required to operate submerged-tube distilling plants; here are some basic operational practices:

1. Check the flow rate of the feedwater through the ratosight meter and the flow rate of the distillate through the water meter. Adjust the feed inlet control valve to maintain a feedwater to distillate flow ratio of 3 to 1. This procedure will help you prevent excessive scale buildup in the unit.
2. When you are operating the unit in seawater temperature below 85 °F, adjust the cooling water control overboard valve (using the indication on the ratosight meter), to maintain the evaporator shell temperature at 130 °F.
3. Maintain the distillate level below the top of the observation window on the evaporator by adjusting the water meter shutoff valve.
4. Make frequent inspections through the distillate observation windows. Watch for a rise in the feedwater level. (The rise may be caused by an insufficient brine discharge rate). Check for a malfunctioning brine eductor supply pump or brine eductor. Air leaks in the suction piping will impair (or prevent entirely), the operation of the unit pumps and will be indicated by a consequent rise in brine or distillate levels.

For additional information, consult the Naval Sea Systems Command (NAVSEA) technical manual for your unit.

Troubleshooting a Submerged Tube Plant

Naval distilling plants are designed to produce distillate of very high quality. The chloride content of distillate discharged to the ship's tanks must not exceed 0.065 epm. Any distilling unit that cannot produce distillate of this quality is not operating properly.

Steady operating conditions are essential to the satisfactory operation of a distilling unit. Fluctuations in the pressure and temperature of the first-effect generating steam will cause fluctuations in the pressure and temperature throughout the entire unit. These fluctuations may cause priming, with increased salinity of the distillate. They may also cause chaotic operation of the feed and brine pump. Rapid fluctuations of pressure in the last effect also tend to cause priming.

Except under emergency conditions, no plant should be forced beyond its rated capacity. Such forcing requires higher steam pressures, which produce higher temperatures that cause more rapid scaling of the evaporator tubes. The same is true if the unit is operated at less than designed vacuum—the heat level rises throughout the unit, causing an increased tendency toward scale formation.

In operation, the elements of any plant are interdependent because of the heat and fluid balances throughout the plant. Adjustment of any one control can produce widespread effects on these balances. For example, an increase in the feeds to the first-effect raises the liquid level in the first-effect. More heat is required to raise the feed to the boiling point. Less heat is then available for evaporation in the first-effect shell, and a smaller amount of heat flows to the second-effect tube nest. These changes will work out to a new balanced condition, but other adjustments will be required to make the new balance satisfactory. It is best to make adjustments singly and in small increments, allowing enough time between each adjustment for the conditions to become steady.

A failure to get full-rated capacity is one of the most frequent troubles in the operation of a distilling plant. The trouble may be very difficult to remedy because it may be caused by a combination of things. The following factors promote low output of the distilling plant:

1. Low steam pressure above the orifice
2. Low vacuum in the first-effect tube nest
    a. Air leaks
    b. Improper water levels in the evaporator shell
    c. Scale formation on the evaporator tube nest
        i. Improper feed treatment or lack of feed treatment
        ii. Brine density maintained above 1.5/32
3. Improper water levels
4. Improper venting of the evaporator tube nest
5. Low vacuum in the last-effect shell

Steam Pressure

A distilling plant cannot maintain its full output unless it is supplied with dry steam at the designed pressure. The orifices must pass the proper amount of steam to ensure plant output with a pressure of about 5 pounds per square inch gauge (psig) above the orifice. Inspect the orifice annually. During the inspection, the orifice should be measured and the reading compared with the figure stamped on the plate. The orifice should be replaced if necessary.

If the steam pressure above the orifice varies, the source of trouble must be located and corrected.

The diaphragm control valve should be checked to determine whether or not it is operating properly. If it is functioning properly and the pressure cannot be maintained above the orifice, the plant is not getting enough steam.

The auxiliary exhaust steam supply for the distilling plants; after passing through the regulating valve is usually slightly superheated. Superheating is caused by the pressure drop through the reducing valve and orifice plate. A small amount of superheat has little or no effect on operation or scale formation. However, if it is necessary to use live steam, the installed desuperheater spray connection should be used to control the superheat. The water for desuperheating must be taken from the boiler feed system, preferably from the first-effect tube nest drain pump. Water for desuperheating must never be taken directly from the freshwater distilled by the distilling plant.

Fluctuations in the first-effect generating steam pressure and temperature cause fluctuations of pressure and temperature throughout the entire plant. The fluctuations may cause priming, with increased salinity of the distillate, as well as erratic water levels in the shells. Proper operation of automatic pressure regulators in the steam supply line will eliminate fluctuation of the pressure in the first-effect heat exchanger.

First-Effect Tube Nest Vacuum

The pressure in the first-effect tube must range from 14 in.Hg, with clean tubes, to 3 in.Hg as scale forms. The output of a submerged-tube type of distilling plant is not greatly reduced until the deposits on the tubes have caused the vacuum to drop to about atmospheric pressure. When the first-effect tube nest vacuum is lost entirely, there is a great reduction in output. If the reduction in vacuum is caused by scale and not by improper operating conditions, the tubes must be cleaned.

The vacuum in the first-effect tube nest should be kept as high as possible. A high vacuum helps keep scale formation to a minimum, enabling the plant to operate at full capacity.

To reduce deposits and greatly prolong the time between cleanings a vacuum reduction that is caused by any factor other than deposits on tube surfaces should always be corrected. The primary factors affecting the first-effect tube nest vacuum are air leakage, low water level in the evaporator shells, improper venting of the evaporator shells, scale or other deposits on the tubes, and improper draining of the evaporator tube nests.

Loss of vacuum resulting from deposits on evaporator tubes should be gradual. Under normal conditions, there will be no large change of vacuum for any one day’s operation. A sudden drop in vacuum can be traced to causes other than scale deposits.

The generating steam circuit operates under vacuum and is subject to air leaks. Leaks from the steam side of the first-effect tube nest to the first-effect shell space will cause losses of capacity and economy. Air leaks from the atmosphere into the generating steam line (downstream from the orifice plate), the first-effect tube nest front header, and the first-effect tube nest drain piping will cause a loss of vacuum and capacity. Air leaks in this part of the distilling plant may be less noticeable than air or water leaks elsewhere because the effect on the plant is similar to the scaling of the tube surfaces.

Proper Water Levels

A reduced first-effect tube nest vacuum can result from too low a water level in any evaporator shell. On older plants, the water levels are controlled by manually regulating the feed valves. On newer ships, the water levels are automatically controlled by weir types of feed regulators. Inability to feed the first-effect is usually caused by scale deposits in the feed lines between the effects. It is important that the gauge glass and the gauge glass fittings be kept free of scale, which causes false water level indications. Air leaks around the gauge glass will also cause false level indications in the gauge glass.

Once the distilling plant is in operation, the feeding must be maintained at a steady rate. Sudden rising of the water levels or too high a water level will cause priming or a carry-over of small particles of brine with the vapor. The level of water in the shell must be carried at the highest level that can be held and still prevent priming because scale will form rapidly on exposed tube surfaces.

The pressure differential between the first- and second-effects permits the second-effect feed to discharge into the second-effect shell. A partial or total loss of pressure differential indicates air leaks between the first- and second-effect shells in the two-effect distilling plants. Large air leaks between the first-effect and second-effect can be readily detected; the vacuum gauge for the first-effect will read approximately the same as the vacuum gauge for the second-effect. Large air leaks of this type will disrupt the operation of the plant. They must be located and repaired before the plant will operate properly.

Proper Venting of Various Units

Careful attention should be paid to the problem of air collection in various parts of the distillery unit. Air is mixed with water and steam and enters the unit at various parts of the system. Because air is heavier than water and lighter than steam, it tends to settle between the two, usually in the following points:

- The evaporator heat exchange and drain regulator
- The high points of the feed line
- The water side of the distillery condenser
- The vapor and evaporator heat exchanger drain feed heater

Air vents should be cracked open to ensure adequate venting. If an evaporator does not reach its rated capacity, it is usually caused by a failure to vent the accumulated air. An accumulation of air in any part of the system causes a loss in capacity and erratic operation. Excessive venting of an evaporator heat exchanger can mean reduced economy. The proper setting of vent valves during operation is largely a matter of experience.

Last-Effect Shell Vacuum

Most manufacturers' technical manuals call for a vacuum of approximately 24 in.Hg in the last-effect shell, when the temperature of the seawater is 85 °F; the vacuum should be higher when the seawater is colder. Lower vacuum can generally be traced to one of the following problems: air leaks, improper operation of air ejectors, insufficient flow of seawater, and ineffective use of the heat transfer surface in the distilling condenser.

Maintenance

The plant will operate at full output for relatively long periods of time only if every part is maintained in proper operating condition. Full output can be ensured by periodic inspections and tests and by cleaning or replacing parts as necessary. Some parts require more attention than others. Some of the more common plant maintenance tasks are discussed below.

Testing for Air Leaks

The importance of eliminating air leaks cannot be overemphasized. Many distilling plant problems are caused directly by air leaks in the shells of distilling plants. These leaks cause a loss of vacuum and capacity. Joints should be carefully made to be kept tight and periodically checked under pressure for leaks.

There are several ways to test for air leaks in the tube nests, heat exchangers, shells, and the piping systems. When the plant is in operation, a candle flame can be used to test all joints and parts under vacuum. When the plant is secured, you can use an air-pressure or soapsuds test on the various component parts. The manufacturer's technical manual describes how the various parts of the plant can be isolated and placed under air pressure.

You can also detect air leaks by hydrostatic tests of the various parts of the plant. While performing air tests or hydrostatic tests, do NOT exceed the maximum limit of the test pressures specified by the manufacturer.

Testing for Saltwater Leaks

If you find a leak in a heat exchanger, locate the defective tube(s) by means of an air test or a hydrostatic test, in accordance with the recommended procedure in the manufacturer's instructions. Use blueprints to study the construction details of the individual heat exchanger.

As soon as a leaky tube has been located, plug it at both ends. Use special composition plugs that are provided in the allowance repair parts (APL).

Plugging the tubes reduces the amount of heating surface; therefore, the heat exchanger will not give satisfactory performance after a number of tubes have been plugged. It will then become necessary to retube the heat exchanger. Under normal conditions, this work should be accomplished by a naval shipyard or tender. However, repair parts and a number of special tools are included in the Ship's Allowance List so that emergency repairs can be made.

To find which of the tubes within a removable tube bundle is leaking, you need to test the individual bundles hydrostatically. If the leak is in a removable bundle (vapor feed heaters when within an evaporator shell, evaporator tube nests, or distilling condensers on Solo-shell end-pull plants), withdraw the bundle and apply a hydrostatic test at full pressure. Apply 50 psi on the tube side.

If a leak occurs in a non-removable tube bundle (distillate coolers, air-ejector condenser, or external vapor feed heaters), remove the tube nest covers and apply a full test pressure of 50 psi on the shell side of the unit. If a non-removable distillate condenser bundle is within an evaporator shell, remove the tube nest covers and apply a full test pressure of 30 psi to the evaporator shell.

Air-Ejector Operation

In operation, air ejectors require little attention. However, the points that follow should be noted.

The steam pressure at the nozzle inlet must not be less than that for which the ejector is designed (and which is stamped on the nameplate). There may be a substantial pressure drop in the steam line, and it may be necessary to carry a higher pressure on the gauge. However, pressures at the air-ejector nozzle (*Figure 18-4, frame 1*) may be 10 to 15 psig higher than the minimum specified by the manufacturer.

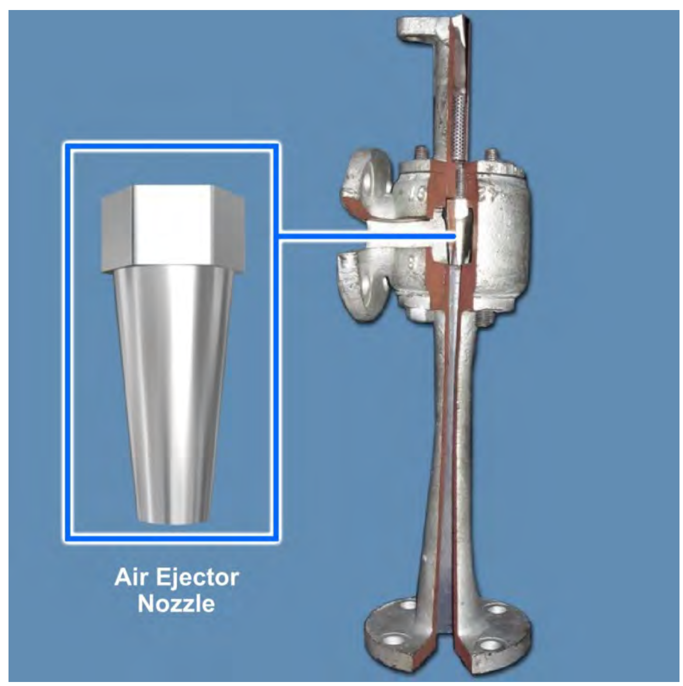

Figure 18-4 — Air ejector.

The primary causes of air ejector problems are low steam pressure, wet steam, an obstructed nozzle, or a clogged steam strainer (*Figure 18-4, frame 2*). Such problems are indicated by a lower than normal vacuum. The problem may be caused by low steam pressure or wet steam. If so, increase the steam pressure or provide suitable drainage, either by installing a trap or by manual means. If the nozzle or steam strainer is clogged, remove it and clean it. Most plants have two sets of air ejectors to permit the use of the plant on one unit while the second is cleaned or repaired. However, some of the latest plants have only one set of air ejectors.

When it is necessary to clean air ejector nozzles, use the special nozzle reamers furnished to each ship for this purpose. Never use sharp-edged tools to clean nozzles. You will damage the nozzle surfaces and impair the efficiency of the air ejectors.

You will find a procedure for testing air ejectors in the manufacturer's technical manual. In general, follow the same maintenance procedures for distilling plant air ejectors as for main condenser air ejectors.

The air ejector strainer is usually an integral part of the air-ejector inlet. It should be inspected and cleaned in accordance with the planned maintenance system (PMS). When a new plant is initially put into operation, the strainer may require cleaning every day or even more frequently. A dirty strainer will cause a reduced or fluctuating vacuum. If a strainer or a nozzle becomes damaged, it should be replaced with a new one.

Insufficient Circulating Water

An insufficient flow of circulating water is indicated if the temperature of the water rises more than 20 °F in passing through the condensing section of the distiller condenser. The last-effect shell pressure is directly dependent upon the distiller condenser vacuum. The vacuum is dependent upon the temperature and quantity of the circulating water and the proper operation of the air ejectors. If the overboard discharge temperature of the distiller condenser circulating water is too low, it will cause a loss of efficiency in the distilling plant. The overboard discharge temperature should be kept as high as possible without exceeding the desired 20 °F temperature rise through the distiller condenser. In addition, limiting the quantity of circulating water tends to prolong the service life of the tubes and tube sheets. When problems occur that are not caused by improper operating procedures, the condenser circulating water system should be inspected to determine the cause of faulty operation.

Carry out preventive maintenance procedures to ensure that the circulating water pump is maintained in good material condition. The maintenance and repair of this pump are similar to that for the other pumps of the plant.

Carry out routine procedures to ensure the proper setting and maintenance of the back-pressure regulating valve. If this valve is not functioning properly, disassemble it and repair or replace parts as needed before it interferes with the operation of the distilling plant.

To ensure that the condenser circulating water system is clean and free from scale and foreign matter, inspect the piping at regular intervals. Inspect and clean the strainers in accordance with the PMS to prevent accumulations of foreign matter from interfering with the proper operation of the distilling plant.

Improper Drainage

The distilling plant may not produce designed output even when the pressure above the orifice is 5 psig and the first-effect tube nest vacuum is several inches of mercury. If so, this always indicates improper drainage of the distiller condenser or of one of the evaporator tube nests subsequent to the first-effect. Complete flooding of the flash chamber gauge glass also indicates improper draining of the condenser.

Each regulator is installed to prevent steam or vapor from being blown through the heat exchanger before it has condensed and given up its latent heat. Improper operation may result in either stopped-up drains or the blowing of steam or vapor through the heat exchanger. The stoppage of drains in the first-effect causes condensate to back up and reduce the heating surface. The result is the same in the second-effect. In addition, because the drains make up a part of the distilled water output, the capacity is reduced. Because these regulators all operate under vacuum, it is important that all joints are free from air leaks.

Constant Brine Density

The concentration of brine in the evaporators, to a certain extent, has a direct bearing on the quality of the distillate. Because varying quantities of brine discharged overboard may affect the operating conditions, the quantity of brine discharged and the brine density must be kept as constant as possible.

If the brine concentration is too low, there will be a loss in capacity and economy. If the brine concentration is too high, there will be an increase in the rate of scaling of the evaporator heating surfaces, and the quality of the distillate will be impaired.

The brine density, which should never exceed 1.5/32, is dependent mainly on the quantity of brine pumped overboard and the amount of freshwater being produced. Check the density frequently during each watch and adjust it to the required density. On older distilling plants, the brine density is adjusted by means of a hand-controlled valve located in the discharge line of the brine overboard pump.

Frequent changes of brine density tend to disrupt steady performance of the plant. Therefore, only very small changes should be made. The proper setting for a specific plant should be learned from experience and maintained as practical.

A salinometer is used to measure the degree of salinity or the concentration of brine. To check the accuracy of the salinometer, it should occasionally be placed in distilled water. If it is accurate, it should sink to the zero mark on the scale corresponding to the temperature of the water.

Flash-Type Distilling Plants

The flash-type distilling plant is widely used throughout the Navy. Flash-type plants have some distinct advantages over the submerged tube plant. One is that the flash-type "flashes" the feed into vapor (steam) rather than boiling it inside the evaporator shell. The flashing process involves heating the feed before it enters the evaporator shell. The shell is under a relatively high vacuum. The feed is heated to a temperature at which it will flash into vapor when it enters the vacuum. This design has no submerged heat transfer surfaces within the evaporator shell, such as the steam tubes in the submerged tube unit. The elimination of these surfaces greatly reduces the scale formation problem of evaporators and allows prolonged operation at maximum efficiency. Any scale that may form is composed mainly of soft calcium carbonate compounds that are relatively easy to remove.

Principal Components

The components discussed in this section are for a five-stage plant in which feedwater is flashed to vapor in five evaporator stages at successively lower pressures. The two-stage flash-type plant will also be discussed later in this chapter.

The connections, or passages, between evaporator stages are the feedwater and distillate loop seals. These seals permit the flow of feedwater and distillate from stage to stage while preserving the varying degrees of vacuum in each stage.

The condensers are mounted on top of each stage between the front and rear water boxes. Feedwater flows through the tubes in six passes. It enters at the lowest tubes at the front of the condenser, reverses direction at the water boxes three times, and leaves at the top of the tubes in the condenser. Each condenser has a pet cock for venting entrained air or non-condensable gases.

The evaporator stages become larger in the direction of reduced pressure. The feedwater loop seals that extend from the bottom of evaporator stage one through stage four are visible as cylinders. An evaporator drain is located in the center of the dished bottom of each loop seal. The flanged brine outlet from the evaporator is at the bottom of the fifth stage.

The distillate loop seal between the distillate collection trough of one stage and the condensers of the following stages also protrude below the bottom of the evaporator. If the salinity of the distillate reaches 0.065 epm per gallon, a warning device indicates the high salinity.

The salinity cell shutoff valves permit withdrawal and descaling of the salinity cells without securing the unit.

Although the condenser at each stage produces an equal amount of distillate, the amount flowing from each stage is larger than the preceding, as in the distillate cooler. Therefore, the loop seal piping grows progressively larger.

The total distillate production of the five stages is withdrawn from the bottom of stage five, pumped into the shell of the distillate cooler, and passed on to the storage tanks.

The distillate cooler is a heat exchanger of the shell and tube type. The heat of the hot distillate flowing around the tubes is transferred by conduction to the cooler feedwater flowing through the tubes.

Distillate flows into the shell space surrounding the tubes through an inlet near the feedwater outlet. The distillate is retained in the cooler long enough to transfer its heat through the tubes by vertically placed baffles as it flows from the top to the bottom of the cooler.

Thermometers are mounted on the inlet and outlet piping of the cooler. Another thermometer is mounted on the feedwater inlet piping.

As the distillate leaves the cooler, and if the salinity does not exceed 0.065 epm per gallon, it is pumped to storage tanks. If the salinity exceeds 0.065 epm per gallon, a solenoid trip valve, operated by a salinity indicating cell, dumps the distillate to the bilges or waste tank. This process continues until the salinity is at or below 0.065 epm per gallon. At that time, the operator should manually engage the dump valve so the distillate will go to the storage tank.

Pet cocks are located on each end of the cooler to bleed off any accumulation of air or non-condensable gases.

The feedwater preheater is a gas or liquid heat exchanger of the shell and tube type, similar in design to the distillate cooler. The preheater is located in the feedwater line between the condenser of the first evaporator stage and the saltwater heater.

High pressure (HP) ship's steam, first used by the air ejectors to evacuate the stage evaporators, is piped into the preheater shell. A series of five baffles, spaced closely together in the top steam outlet, reduces the velocity of the steam that condenses on the outside of the heat transfer tubes.

Feedwater that has already been partially heated in the tubes of the distillate cooler and the five-stage condensers flows through the tubes of the preheater via the front water box in a single pass. There, it acquires the heat of condensation of the air-ejector steam before leaving the preheater at the rear water-box outlet.

A salinity cell, set to energize at 0.10 epm, operates a shutoff valve in the piping below the condensate outlet. The valve dumps high-salinity water to the bilge or a drain tank. A 6-inch loop seal in the condensate line ensures that the salinity cell is submerged at all times.

A thermometer is located on the front of the preheater. A pet cock for venting is also located on the water box.

The saltwater heater is a gas or liquid heat exchanger that raises the feedwater temperature before it enters the flash chamber of the first evaporator stage. The saltwater heater is mounted on the operating end of the evaporator and extends the full width of the unit. Feedwater enters and leaves the heater from the front water box after making four passes through the heater.

Four thermometers are installed on the heater. Two measure the feedwater inlet and outlet temperature. A third, mounted on the heater shell, measures the steam temperature surrounding the tubes. A fourth, mounted on top of the heater shell, measures the temperature of the desuperheating temperature in the steam side.

Low pressure steam in the heater passes through an orifice that provides, within limits, a uniform flow of steam. It then flows past the desuperheater nozzle, which reduces steam temperature in the shell of the heater. Steam pressure is indicated by a pressure gauge on the operating panel.

The entering steam is directed along the length of the tubes by impingement baffles, which prevent erosion of the tubes. Steam condenses on the tubes and falls to a condensate well at the bottom of the heater shell. A float-type drain regulator controls the level of the condensate in the well. A salinity cell, set to energize at 0.10 epm, controls a shutoff valve located in the ship's piping between the drain pump and regulating valve. The desuperheater atomizes the heater condensate in the low pressure steam side of the heater.

The saltwater heater provides feedwater to the inlet of the first evaporator stage flash chamber, and the amount of heat from the steam is constant; therefore, the feedwater flow through the heater must be adjusted according to the inlet temperature. The feedwater flow is controlled by a valve on the outlet side of the heater.

The air-ejector pre-cooler is a gas or liquid heat exchanger. It cools non-condensables and condenses steam drawn from the first three evaporator stages and the saltwater heater by a two-stage vacuum-producing air ejector.

The pre-cooler uses feedwater pumped into the distilling unit as a coolant. The water makes six passes through heat transfer tubes, entering and leaving at the front end of the cooler. Steam and non-condensables are drawn into the cooler at the top near the rear of the cooler.

The flow of hot gases is directed around the transfer tubes for efficient heat transfer by impingement baffles at the inlet and seven vertical baffles through which the tubes run.

Condensate collects on the tubes and drops to the bottom of the shell. A salinity cell operates a shutoff valve in the pre-cooler condensate line. The valve dumps the condensate to the bilge or drain tank when the salinity is greater than 0.065 epm.

The outlet for non-condensables is mounted on the top of the shell. It is flanged to the suction chamber of the first ejector of the two-stage air ejector system. The two air ejectors produce a vacuum in the pre-cooler that results in the flow of steam and non-condensables from the evaporator. A thermometer is mounted on the feedwater inlet of the cooler.

Cooling water from the air-ejector pre-cooler flows into the after-condenser, the fifth of the heat exchangers mounted on the evaporator. The after-condenser completes the condensation of any air-ejector steam not condensed in the pre-cooler and cools non-condensable gases before venting them to the atmosphere. It enables the unit to operate without emission of steam from the evaporator.

Cooling water enters and leaves the after-condenser through an inlet in the front and an outlet pipe in the rear of the condenser.

Air-ejector steam and non-condensable gases enter the shell side through an inlet in the front of the unit. Non-condensable gases are vented through a valve on the rear of the unit. A series of vertical baffles directs the steam around the tubes on which it condenses. Condensate is removed through bottom outlets on both ends of the condenser.

A salinity cell set to operate at 0.10 epm controls a shutoff valve below the condenser.

Three HP, steam-operated, vacuum-producing air ejectors are mounted on the pre-cooler side of the evaporator unit. The ejector system consists of a single-stage (booster) and a two-stage air-ejector arrangement in which the steam outlet from one air ejector is flanged to the suction side of the other.

The single-stage ejector uses ship's steam to draw vapor and non-condensables from evaporator stages four and five. Gases are drawn from the evaporator through a vapor duct in each distillate collection trough so that a minimum of steam is withdrawn. Pipes from stages four and five lead to a bronze tee flanged to the ejector.

The single-stage ejector steam and entrained gases leave the ejector outlet tubing, flow through a check valve, and reenter the evaporator shell through the top of stage three. From there, they are piped into the bottom of the stage-three condenser sections.

This arrangement allows the single-stage ejector to produce the high degree of vacuum required in stages four and five. An ejector discharging into a vacuum is able to achieve a higher degree of vacuum than one discharging to atmosphere. A vacuum 28 in.Hg is required in stage five.

The two-stage ejector draws non-condensables from the saltwater heater and the first three evaporator stages. The non-condensables from stages four and five are directed back into stage three. Therefore, the two-stage ejector actually handles all non-condensables within the unit.

The suction chamber of the second ejector is flanged to the non-condensables outlet of the pre-cooler. The gases pass through the pre-cooler before they are entrained in the air-ejector steam. The two stage ejectors use ship's steam and produce a vacuum in the pre-cooler slightly greater than in the first evaporator stage.

Orifice plates of varying sizes are flanged into the piping from the evaporator stages and saltwater heater leading to the air ejectors. These plates prevent the air ejectors from withdrawing an undue amount of steam from the evaporator along with the non-condensables.

The discharge of the second ejector is flanged to the suction chamber of the third ejector. The discharge of the third ejector is flanged to piping that contains a check valve and runs diagonally across the top of the evaporator shell to the air-ejector steam inlet of the preheater shell near the front water box.

The pressure of ship's steam piped to the ejectors is indicated on the independently mounted pressure gauge panel. Line pressure to the air ejectors must be maintained at or above 135 psig; a lower pressure will cause unstable operation of the ejector and will affect the vacuum in the evaporator.

A duplex strainer, located in the ship's feedwater inlet piping, removes solid matter from seawater by filtering through one of the two perforated and screened bronze baskets. Basket wells are located in the body or housing of the strainer on either side of the centrally located flanged inlet and outlet.

A lever handle between the wells directs the feedwater into the left- or right-hand well. When one basket becomes clogged, flow is switched to the other. The clogged basket should be removed and cleaned.

An inlet and outlet angle type of relief valve is flanged into the feedwater inlet between the feedwater pump and the air-ejector pre-cooler. The valve is set to open at 75 psig, which prevents pressure buildup from an obstruction in the feedwater lines or accidental operation of the feedwater pump with the feedwater control valve closed.

Two-Stage Flash

Figure 18-5 is an illustration of the major components of the two-stage flash distilling plant. *Figure 18-6, frames 1 and 2,* shows the major flow paths through the two-stage, 12,000 gallons per day (gpd) flash distilling plant. Follow along on the diagram during the explanation of the plant that follows.

Seawater Feed Circuit

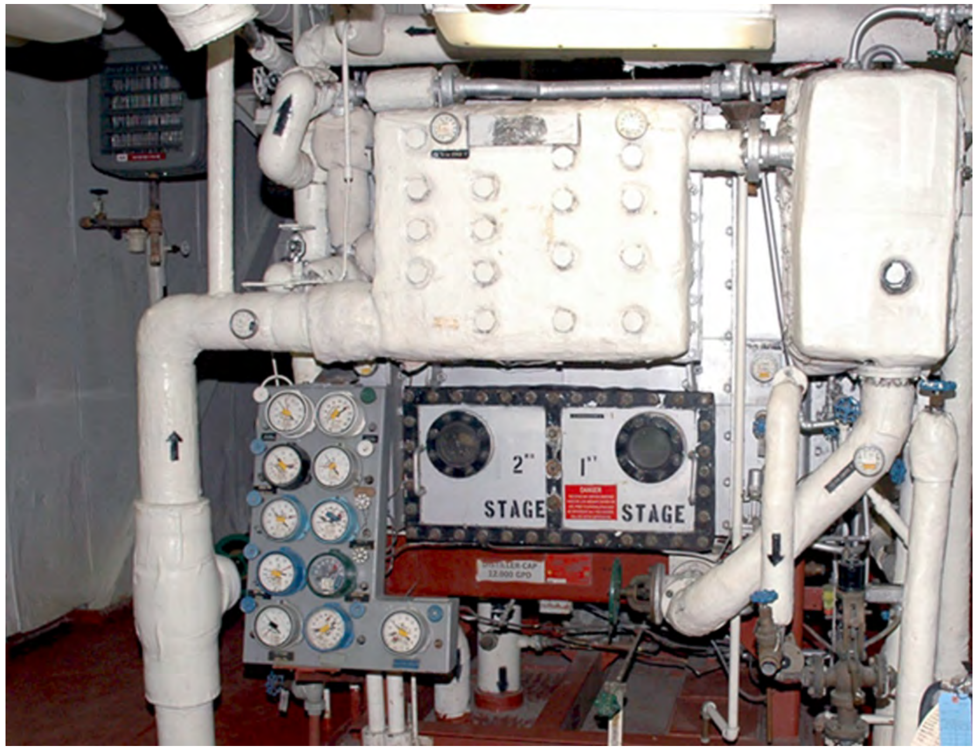

Figure 18-5 — Two-stage flash distilling plant.

The seawater feed pump (*Figure 18-6, frames 1 and 2*) takes suction through a sea chest and strainer. It discharges the seawater into the tubes of the condensing section of the second stage of the evaporator. The seawater feed then flows into the tubes of the first-stage condensing section. The condensing section of the evaporator is a shell and tube heat exchanger. It extends the full length of the evaporator shell; that is, through both the first stage and the second stage.

In the condensing sections, the seawater feed condenses the surrounding vapor. As a result of the heat exchanger process, the feed increases in temperature. When the incoming seawater feed has a temperature of 85 °F (29 °C), the feed leaving the first-stage condensing section of the evaporator should be approximately 138 °F (59 °C). Upon leaving the first-stage condensing section, the feed enters the air-ejector condenser/seawater heater assembly. In this double-flow shell and tube heat exchanger, the feed picks up heat by condensing steam from the air ejectors and from steam admitted to the seawater heater from the auxiliary exhaust steam system.

The feedwater leaves the air-ejector condenser/seawater heater assembly at a temperature of approximately 170 °F (77 °C). It is then fed to the first-stage of the evaporator shell. The feed enters the bottom of the shell through two spray pipes. These pipes partially atomize the water, which aids in flashing the feed into vapor. Feed that does not flash in the first stage goes to the second-stage through an internal loop seal located at the bottom of the shell. Water flows to the second-stage because it has a higher vacuum than the first-stage. The first-stage shell pressure is approximately 27 in.Hg, while the second-stage shell pressure is approximately 27 in.Hg. Also assisting is the head due to the higher water level in the first-stage, which overflows into the second-stage. This loop seal method prevents the pressure from equalizing between the stages. The water to the first-stage is controlled by a manually-operated valve. Feedwater that does not flash in the second-stage becomes brine, which is pumped overboard.

Vapor Circuit

Vapor is formed in the first-stage shell by the hot feedwater (170 °F [77 °C]) as it enters the shell, which is under a vacuum (23 in.Hg). Saturation temperature for 23 in.Hg is approximately 148 °F (64 °C). The feed enters the first-stage shell through two spray pipes. These pipes are fitted with deflector plates, which cause the feed to spray downward and form a thin, circular curtain of water. This partially atomized curtain of spray results in more complete transformation of the water into vapor steam. The vapor then rises through copper nickel (Monel) mesh-type demisters (moisture separators), which remove entrained moisture from the vapor. (The moisture removed from the vapor drains back into the bottom [feed] section of the evaporator shell.) The vapor then passes into the condensing section of the evaporator shell where it is condensed into distillate by the cooling action of the incoming feedwater. Vapor produced in the second-stage goes through the same process. The shell pressure is lower (27 in.Hg) in the second-stage, however, with a subsequent lowered saturation temperature of approximately 115 °F (46 °C).

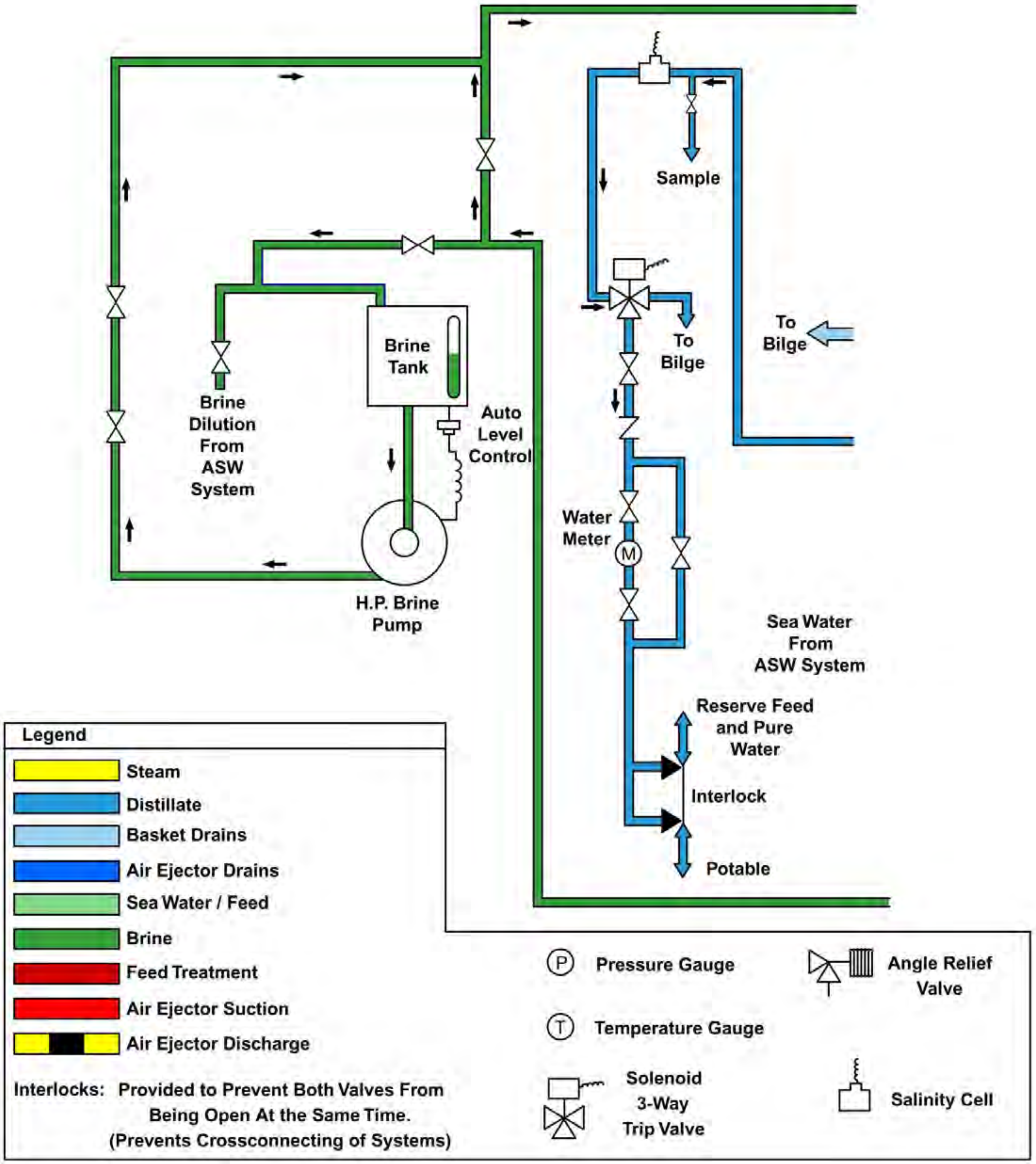

Figure 18-6 — Two-stage flash distilling plant 12,000 gpd capacity.

Distillate Circuit

Distillate is formed in the condensing section of both stages of the evaporator. The distillate from the first-stage collects in the bottom of the first-stage condensing section in a hotwell-like area (trough). This area is formed by the joint between the evaporator shell division plate and the first-stage collection tray. The distillate passes through a loop seal into a lower trough (or tray) in the second-stage. The piping between the two stages contains an orifice plate with a 5/8-inch diameter hole. This orifice controls the flow rate and assists in preventing equalization of pressure between the stages. It also prevents premature flashing of the distillate as it enters the lower pressure area of the second-stage.

The distillate is then pumped out of the second-stage distillate trough by the distillate pump. The distillate pump discharges the water through a three-way solenoid-operated trip valve (*Figure 18-7*). This valve, when tripped, will automatically divert the flow of distillate to the bilge if the salinity content reaches a predetermined set point (usually 0.065 epm). When the valve is in the reset (normal) position, distillate passing through it goes on through a flowmeter and into an interlock two-valve manifold. This manifold directs the distillate to either the potable water system or the reserve feed system. The manifold is interlocked to prevent opening of both valves at the same time. The potable water system can be contaminated by chloride from a shore water source, which may be suitable for drinking but not for boiler feed. The potable water system and the reserve feed system, therefore, should NEVER be cross-connected in any way.

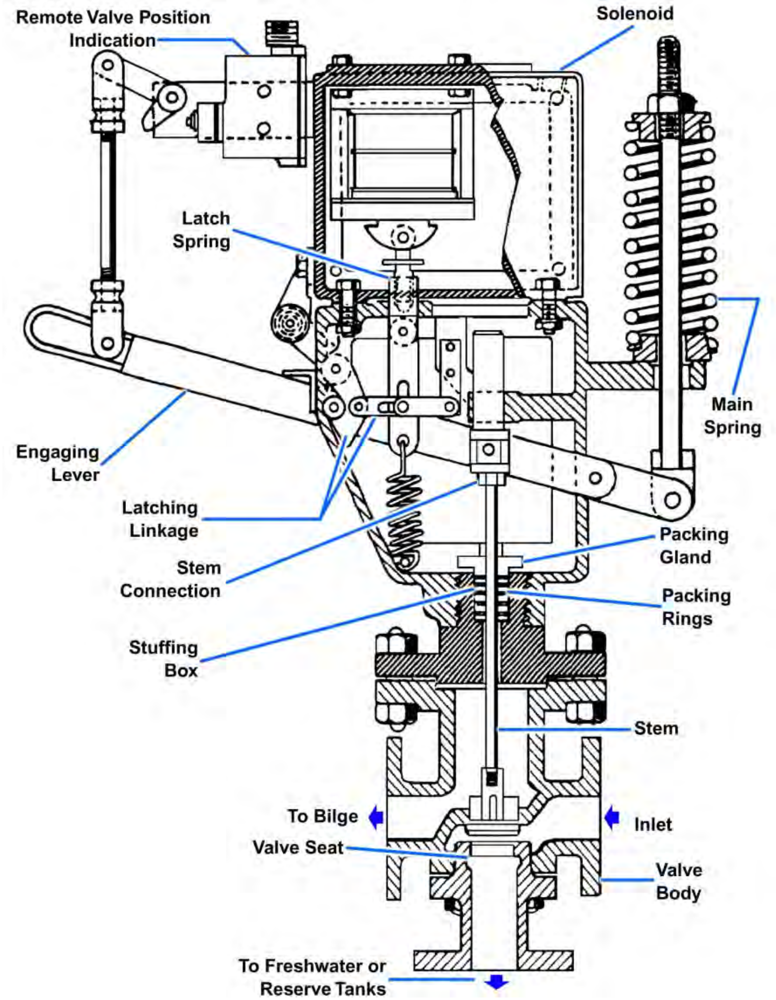

Figure 18-7 — Three-way solenoid trip valve.

Air-Ejector Circuit

A two-stage air-ejector unit, using auxiliary steam, is located at the top of the distilling plant. It draws vacuum and maintains the vacuum in the evaporator shell. The air-ejector second-stage discharges into the air-ejector condenser seawater heater assembly. The air-ejector condenser condenses the steam and vents air and non-condensables (such as CO_2) to the atmosphere. The condensate is formed from the steam. It then drains to either the bilge or the steam drain collecting system through a three-way solenoid-operated trip valve.

Brine Circuit

Brine (dark green) is pumped out from the bottom of the second-stage shell. A centrifugal pump is used for this purpose.

Heating Steam Circuit

Auxiliary exhaust steam is used in the seawater heater to provide the heat required to raise the temperature of the seawater feed to approximately 170 °F (77 °C). The auxiliary exhaust steam entering the seawater heater passes through an orifice, which controls the quantity of the steam admitted to the heater. The steam pressure upstream of the orifice is approximately 3 psig.

The seawater heater is vented to the first-stage evaporator through a line with a 1/4-inch orifice. This venting brings the seawater heater pressure to approximately 9 in.Hg (10 psi). The pressure differential between the auxiliary exhaust steam pressure above the orifice and the seawater heater pressure is critical in providing proper steam flow to the heater. Improper steam flow will cause the distilling plant output to vary.

Before it enters the seawater heater, the auxiliary exhaust steam is desuperheated by water sprayed into the steam inlet piping. The amount of water is adjusted by an automatic control valve. This valve maintains the steam temperature 5 to 10 °F higher than seawater heater shell temperature, which keeps the temperature of the seawater feed relatively constant as it leaves the air-ejector condenser/seawater heater assembly.

The water supply for the desuperheating water is a portion of the discharge from the seawater heater drain pump. During plant startup, water from the seawater heater drain pump may not be available. At that time, the ship’s condensate system furnishes the water supply. There is a two-valve interlock between the supply from the seawater heater drain pump and the supply from the condensate system. This interlock prevents cross-connecting of these two systems. The interlock is similar to that described for the distillate circuit.

Seawater Heater Drain Circuit

Condensed auxiliary exhaust steam is pumped from the shell of the seawater heater by the seawater drain pump. A drain regulator serves as a hotwell and assures a constant suction head for the pump. The drain regulator is a ball float-operated valve attached below the condensate drain connection of the seawater heater. The ball float in the drain regulator operates the valve to maintain a relatively constant water level in the housing, which is indicated by a gauge glass. A decrease in water level will tend to close the valve in the drain regulator. Therefore, the amount of condensate discharge by the drain pump will be throttled until the water level in the float housing rises again. The water level in the regulator maintains a suction head for the seawater heater drain pumps. This suction prevents loss of vacuum in the seawater heater by maintaining a water seal between the heater and the pump.

The drain pump discharges condensate from the seawater heater to the condensate system (startup only), to the steam drain collecting system (normal lineup), or to the bilge.

Other Applications of the Flash-Type Distilling Unit

Flash-type distilling plants may have any number of stages and output capacities. For example, the Navy uses a three-stage, 30,000 gpd plant as well as a five-stage, 50,000 gpd unit. All flash-type plants operate on the same basic principles as those described for the two-stage plant.

Operating Notes for Flash-Type Units

The rate of feed to the first-stage inlet box should be kept constant at all times if the plant is producing its normal capacity or less. Distilling plants operate at a definite number of gallons of feed per minute. The feed rate is indicated by rotameters in the feed line between the distilling condenser circulating water pump and the distillate cooler. All other valves in the feed line should be opened wide to prevent interference with the proper flow of feed through the plant.

With proper feed flow and a clean plant, the temperature of the feed entering the first-stage feed inlet box will be 175 °F (79 °C) or less, depending on the temperature of the seawater. Plants operate with a feed temperature of 175 °F (79 °C) maximum when the temperature of the seawater is 85 °F (29 °C). When the seawater temperature is lower, the feed temperature will be correspondingly lower.

Operators should not attempt to control the feedwater temperature after it leaves the feedwater heater and enters the first-stage flash box. The temperature should adjust itself to the varying plant conditions. Full capacity will be realized with proper feed flow, proper vacuums throughout the plant, and proper steam pressure above the orifice. The feed temperature should never be allowed to exceed 175 °F (79 °C). Higher operating temperature will greatly increase the amount of scale formation.

The capacity of the flash-type distilling plant depends on:

- The quantity of evaporator feedwater entering the first-stage feed box.
- The difference in temperature between the feedwater entering the first-stage and the vapor in succeeding stages.

However, the capacity can be changed only by increasing or decreasing the amount of heat added to the seawater by the feedwater heater.

DISTILLING PLANT CARRYOVER AND SANILITY

At this point, we need to mention the problem of distilling plant “carryover.” Practically all cases of high salinity (salt content) in the distillate (freshwater) output of a distilling unit will be caused by internal seawater leakage (from a tube, basket, and so forth) or by carryover. Carryover actually consists of molecules of seawater. These molecules are not filtered out of the vapor produced in a distilling plant before the vapor is condensed into distillate. All types of distilling plants have some type of device to prevent carryover. They are usually called moisture separators or vapor separators. If the plant is operated improperly, these separators will not function properly. Some seawater will pass through them and show up as high salinity in the distillate. High salinity may occur when an attempt is made to increase the output of the plant beyond rated capacity.

Salinity, which is caused by chemical salts in seawater, is undesirable. Chemical salts in boiler feedwater will cause corrosion of the tubes. In addition, the normal operating temperature of a naval distilling plant may not be high enough to completely sterilize the distillate. Therefore, any carryover (or leakage) of seawater is a potential health hazard. Many types of microorganisms (primarily coliform bacteria) may be present. For these reasons, restrictions are placed on the operation of distilling plants aboard ships operating in either contaminated water or freshwater.

Freshwater carryover may not have enough salinity to be detected by either the operator or the salinity indicating system. Restrictions for operation under these conditions are found in *Naval Ships' Technical Manual (*NSTM), Chapter 531.

Flash-Type Operation and Maintenance

Distillate must meet specific standards of chloride content. To ensure that these standards are met, the distillate must be monitored continuously by the salinity indicator and chemically tested periodically.

The results of distillate tests for chloride are expressed in terms of either epm or parts per million (ppm).

Parts per million is a weight-per-weight unit denoting the number of parts of a specified substance in a million parts of water. For example, 58.5 pounds of salt in one *million* pounds of water represents a concentration of 58.5 ppm. Note also that 58.5 ounces of salt dissolved in one *million* ounces of water or 58.5 tons of salt dissolved in one *million* tons of water represents the same concentration—58.5 ppm.

Equivalents per million can be defined as the number of equivalent parts of a substance per million parts of water. (The word “equivalent” refers to the chemical equivalent weight of a substance). The chemical equivalent weight is different for each element or compound. The chemical equivalent weight of sodium chloride (common table salt) is 58.5. A solution containing 58.5 ppm of this salt is said to contain 1 epm. If a substance has a chemical equivalent weight of 35.5, a solution of that substance containing 35.5 ppm is described as having a concentration of 1 epm.

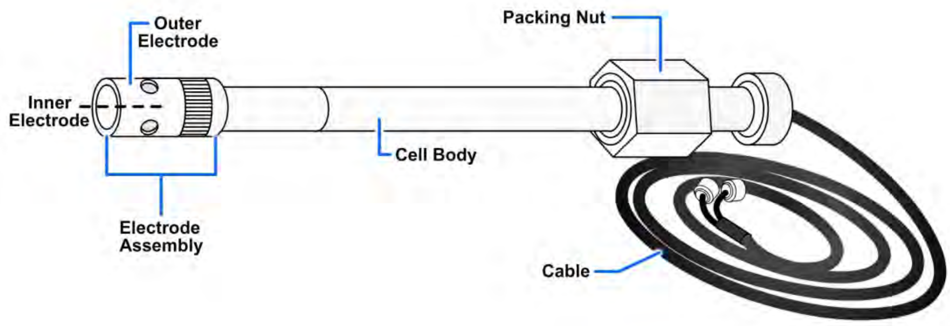

Figure 18-8 — Salinity indicator cell.

Salinity Monitoring

The salinity of distillate is monitored continuously by an electrical salinity monitoring system. A salinity cell (*Figure 18-8*) is placed in the distillate line in constant contact with the distillate flowing out of the evaporator. The details of salinity cell installation into the line are shown in *Figure 18-9*.

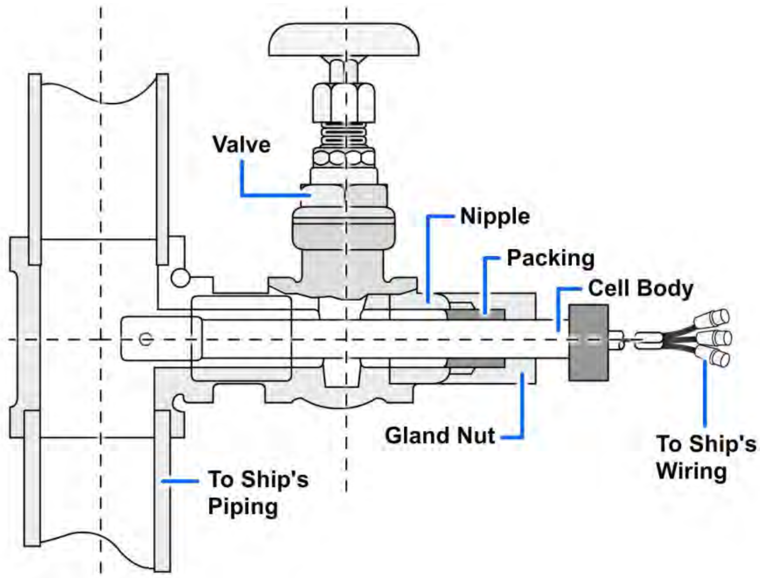

Figure 18-9 — Salinity cell installation.

A salinity cell actually measures the ability of water to conduct electrical current (conductivity). The higher the concentration of chemical impurities in the water will cause the conductivity of the water. This measurement is read out on a salinity monitoring panel, which may be of the type shown in *Figure 18-10*. The electrical reading from the cell is converted to either epm or ppm chloride on the meter face. The chloride reading is based on the assumption that all of the impurities in the distillate are from seawater; however, a salinity cell cannot differentiate between seawater and any other impurity. For this reason, the salinity cell readings are checked frequently by a chemical test for chloride. A high salinity cell reading must be taken seriously (such as an alarm or tripped valve situation) until it is proven absolutely false. Some older salinity indicator panels have scales calibrated in grains per gallon (gpg) of sea salt. To convert a reading of gpg to epm, multiply the gpg reading by 0.261.

Figure 18-10 — Salinity indicator panel.

In practically all cases, the measurement made by the distillate salinity cell will also operate the trip function of a three-way, solenoid-operated trip valve. If the salinity of the distillate reaches a preset value (0.5 ppm for some ships, 0.065 epm for others), the solenoid in the valve will de-energize. This will allow spring pressure to disengage the latching linkage from the engaging lever, and the valve stem assembly will drop due to main spring pressure. When the stem assembly drops, the valve seat shuts off the water path of distillate to the freshwater tanks or reserve feed system and opens a path to the bilge or suitable dirty drain system. This type of three-way valve is also used on the air-ejector condenser drains of many distilling plants. These valves have locking pins that can be used to lock the main valve engaging lever in the reset position.

Salinity cells are normally installed in other places in the evaporator system to monitor the salinity levels. Two examples are:

- The seawater heater drain pump discharge.
- The loop seal between the first-and second-stages of the two-stage, flash-type distilling plant.

Cells installed in these places have meter readout and an alarm but do not actuate trip valves.

The temperature of the water affects the reading of the salinity cell; higher water temperature greater conductivity. Salinity cells are designed to automatically compensate for changes in water temperature.

WARNING

The locking pins should NEVER be used without the specific permission of the engineering officer. Contaminated water can be put into clean tanks and systems at an excessive rate if these pins are used to prevent the trip valves from tripping.

Chemical Test for Chlorides

In our discussion of salinity and the salinity monitoring system, we described one method of preventing contamination by the evaporators. In that situation, salinity cells were used to continuously monitor the salinity content of water in piping systems connected to the evaporator and to set alarms and tripping valves if the salinity concentration rose above a set point. Another method is to chemically test water for chloride concentration. The chemical tests may be performed at some interval dictated by specific operating procedures. One chemical analysis is used to determine the actual chloride concentration in a sample of water by titration. When performed properly, the titration method is extremely accurate. This test can be used on distillate, air-ejector drains, main condensate, or any other water that is not greatly discolored. (Even discolored water can be used if it is filtered).

Additional specific information on water and water testing can be found in NSTM, Chapter 220.

Brine Density

Not all of the seawater feed that is fed into an evaporator is changed into distillate. That portion of the feed that does not become distillate is called brine. The concentration of sea salts in this water is called brine density. It has a direct bearing on the quality of the distillate produced by the evaporator. A low brine density indicates that not enough of the feedwater is being converted to distillate and means poor efficiency in the plant, which results in a reduced output capacity.

A high brine density indicates that too much of the feedwater is being converted into distillate. Operation with a high brine density causes excessive scale on heat transfer surfaces, which causes poor quality distillate due to excessive vapor formation. There is possible carryover and reduced efficiency due to the loss of heat energy carried over with the brine.

The ideal value of brine density is just under 1.5/32. The density should never exceed this level. Because the average seawater contains approximately 1 part of dissolved sea salt to 32 parts of water (l/32 by weight), the brine density should be just under 1 l/2 times the density of average seawater, or 1.5/32.

Brine density is measured with a salinometer, which works on the same principle as a hydrometer. The float, or hydrometer, is a hollow metal shell attached to a square stem, weighted with shot at one end. Each side of the stem is graduated in thirty-seconds, from 0/32 to 5/32, and calibrated for four different temperatures: 110, 115, 120, and 125 °F.

Figure 18-11 shows a salinometer and a brine sampling pot. A brine sample is drained into the pot from a test valve, and the temperature is measured. The temperature must be adjusted to correspond with one of the temperature scales on the salinometer to accurately measure the density. The salinometer is then placed in the pot, weighted end down, and allowed to float in the brine. The brine density is read where the brine water level crosses the scale on the side of the graduated stem that corresponds to the brine temperature.

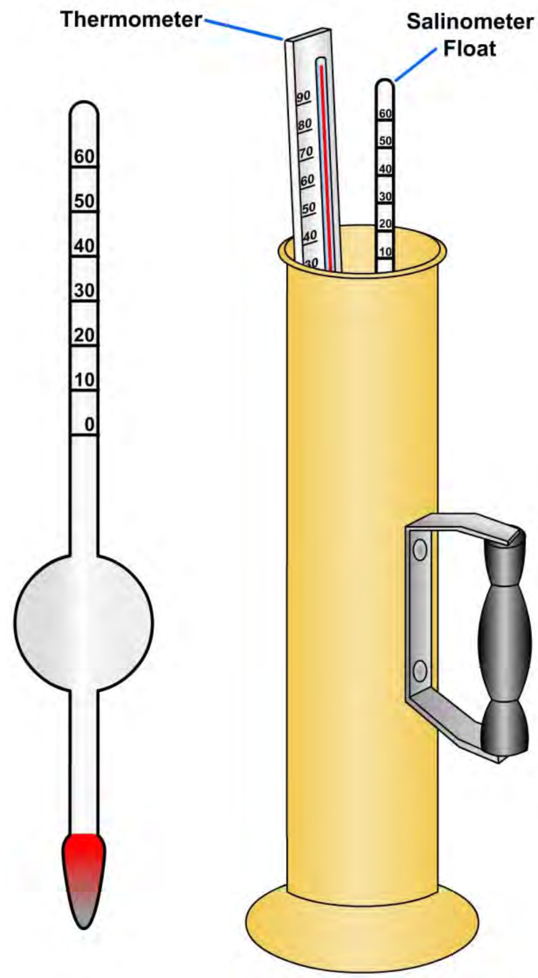

Figure 18-11 — Salinometer and sampling pot.

Salinometers should be checked monthly by measuring the density of distilled water. A sample at the proper temperature can be obtained by bypassing the distillate cooler, or a sample of the distillate may be heated. The reading of the pure water should always be zero.

Different evaporator types will have different methods for adjusting the brine density. Follow the instructions and procedures in the engineering operational sequencing system (EOSS) for your plant and ship.

Heat Exchanger Surfaces

Scale deposits on heat transfer surfaces will not appreciably reduce the output of a low pressure submerged tube distilling plant until the deposits have caused the vacuum in the first-effect tube nest to be reduced to 1 or 2 in. Hg. When the first-effect tube nest vacuum is lost entirely, the reduction in plant output becomes very great. The reduction in vacuum is due to scale and is not the result of improper operating conditions. If so, the evaporator tubes must be cleaned when the tube nest vacuum approaches zero.

When the plant is properly operated and the evaporation feed is treated, the interval between cleanings should be 6 months or more.

Saltwater flows inside the tubes of the distilling condenser, air-ejector condenser, and vapor feed heaters. Under some operating conditions, scale deposits may accumulate inside these tubes. This accumulation may happen particularly in the air-ejector condenser and the first-effect feed heater. Every 6 months or whenever the plant is secured to descale the evaporator tubes, the inside surfaces of the heat exchanger tubes should be inspected and cleaned if necessary. Neglect can lead to thick scale deposits, which will be difficult to remove.

Scale Formation

Very little hard scale should form in a distilling plant that uses seawater as feed if:

- Feedwater distribution is proper.
- Steam pressure above the orifice is not more than 5 psi.
- A high vacuum is maintained.
- The brine density is not over 1.5/32.

During normal operating conditions, scale deposits will form at a certain rate on the distilling plant evaporator tubes. The rate of scaling depends on the concentration of suspended matter and carbonates present in the water used to feed the distilling plant. However, excessive scaling of the evaporator can be used by improper operation of the plant.

Scale deposits increase as the density of the brine in last-effect shell increases. The brine concentration is dependent mainly on the quantity of brine pumped overboard and on the amount of distillate produced. If the brine concentration is too high, the rate of scaling of the evaporator tubes will increase. The quality of the distillate may be impaired.

To retard the formation of scale on evaporator tubes and to minimize priming, solutions are continuously injected into the evaporator.

A chemical compound, Ameroyal ®, is used in all Navy evaporators that are feed treated. Ameroyal® increases the production of distilled water by decreasing downtime of plants for scale removal.

A proportioning pump and tank assembly are used to mix Ameroyal and inject it into the evaporator feed at a controlled rate. The tank has a gauge glass or an internal, fixed measuring plate that is marked off in gallons. The tank usually holds 24 gallons of mixture with room left for expansion.

The proportioning pump is a small, motor-operated reciprocating pump unit and may be either simplex (one pump) or duplex (two pumps) in design. The maximum capacity of the proportioning pump is 2.5 gallons per hour (gph) per pump.

The simplex pump consists of one pump and one motor. The duplex pump consists of two pumps, driven by one motor, served by the same mixing tank. Duplex pumps may serve two distilling plants ONLY when the two plants have the same design distillate capacity and are located in the same compartment. In all other cases, simplex pumps must be installed.

The length of the stroke determines the pump capacity of either the simplex or duplex pump. The stroke can be adjusted but is never set at less than 20 percent to assure accuracy of the injection rate and lubrication of the pump plunger. If possible, the pump stroke (or strokes on a duplex pump) should be set to empty the mixing tank, from the top to the bottom of the gauge glass, in exactly 24 hours. If this rate of injection requires a stroke of less than 20 percent, the stroke should be set to empty the tank in less than 24 hours.

If the pump stroke must be changed, the setting can be made from the indicator scale mounted on the connecting rod. The stroke can be verified by checking the amount of time required to empty the mixing tank. The indicator scale is calibrated from 0 to 10. If the pump has a maximum capacity of 17 gph, set the indicator pointer at 5 to deliver 3 1/2 gph. To change the stroke, stop the pump and loosen the connecting rod locknut. Watch the pointer on the indicator scale and turn the adjusting screw the required amount. Tighten the connecting rod locknut and restart the pump. Check the time required to empty the tank and reset the pump stroke if necessary.

A vacuum drag injection line, used when the proportioner pump fails, runs from the mixing tank to a point downstream (vacuum side) of the feed control valve. A needle valve is installed in the line. It allows the operator to make relatively fine adjustments in the amount of solution that flows into the evaporator.

Ameroyal® comes in concentrated liquid form. Therefore, it is not necessary to premix it before putting it in the tank. Pour the correct amount into the injection tank and stir thoroughly. The injection rate for Ameroyal® is 1 pint per 4,000 gpd output.

In accordance with the PMS, the mixing tank should be drained to the bilges and flushed out with freshwater weekly, or more often if necessary. This process prevents accumulation of sludge in the tank.

> ⚠ **CAUTION** ⚠
>
> Ameroyal® is an alkaline chemical. (A more familiar form of an alkaline chemical is lye.) Use extreme care when handling and mixing Ameroyal® to prevent splashing the liquid into the eyes or on the skin. Rubber gloves and chemical splash goggles MUST be worn during the handling of this chemical. DO NOT dump excess Ameroyal® in the bilges.

Scale Removal

As previously stated, the evaporator tubes of a submerged tube unit MUST be cleaned when the first-effect tube nest vacuum approaches zero. The vertical basket unit should be cleaned when it becomes necessary to use a basket steam pressure of 8 psig to produce rated capacity. The flash-type unit will require cleaning when it becomes necessary to use a steam pressure of 4 psig in the evaporator feedwater heater. Assuming these reductions in capacity are due to scale and not the result of improper operation, an approved cleaning method should be used to remove the scale.

Chill Shocking

The temperature in the first-effect nest is near that of the steam supply. This tube nest tends to scale up more quickly than other parts of the plant. Chill shocking (cold shocking) the tubes are generally used to combat this scale. Drain the brine from all shells, and then reflood them by means of a hose line connected to a flushing pipe or flooding connection on the shell. This reflooding chills the tube nest bundles. Next, quickly admit steam into the tubes, causing differential expansion and contraction to take place. This process breaks the scale loose from the tubes.

If a feed treatment is not used, the distilling plant should be chill-shocked daily. If the Navy standard feed treatment is used, daily chill shocking may be desirable, but longer intervals are satisfactory.

Mechanical Cleaning

Mechanical cleaning (*Figure 18-12*) should be used only as a last resort. Clean with chemicals if possible. The chemical cleaning process is covered later in this chapter. The evaporator tube nest must be withdrawn from the shell for mechanical cleaning. Lifting gear suitable to the type of installation is usually provided to help remove the tube nest.

Figure 18-12 — Nylon bristle brush.

Chemical Cleaning

Chemical cleaning is faster, more economical, more effective, and less damaging to evaporator parts than mechanical cleaning. In chemical cleaning, a heated, diluted acid solution circulates through the saltwater circuits of the system. The three acids used are hydrochloric, sulfamic, and citric.

> ⚠ **CAUTION** ⚠
>
> These acids may be harmful to personnel. Observe the safety precautions and follow the procedures listed in NSTM, Chapter 670.

Hydrochloric acid comes in liquid form and presents hazards in both handling and storing. Hydrochloric acid is authorized ONLY when properly supervised by qualified naval shipyard personnel, NEVER by ship's force alone.

Sulfamic acid comes in powdered form and is safe for storage aboard ship when stored in the original containers. Sulfamic acid is authorized under the supervision of qualified tender or naval shipyard personnel. At the discretion of type commanders, individual ships may be authorized to carry sulfamic acid and cleaning may be performed by qualified personnel in the ship's crew.

Citric acid comes in powder form. It allows you to acid clean the plant while it is in operation. However, it cannot be used in port because the pH of the effluent exceeds the limits for discharge in port.

Citric acid is injected into the plant through the installed injection system or by vacuum drag. The injection rate is adjusted to obtain a distilling plant feed or brine pH, which is monitored by a pH meter or pH paper. Normally, successful cleaning can be accomplished within 8 hours. If the plant is not clean after 20 hours, the distilling plant should be opened and inspected at the first opportunity.

Citrus acid may be used on nuclear power plants of surface ships. However, when using it on nuclear power plants, the distillate must be sent to the potable water system or to the bilge. Also, the distilling plant steam drains must be sent to the bilge during cleaning.

When using citric acid, you should refer to the NSTM, Chapter 670.

> ⚠ **CAUTION** ⚠
>
> Unnecessary use of citric acid may result in tube metal waste.

Testing for Saltwater Leaks

If a leak is detected in a heat exchanger, the defective tube(s) should be located by an air test or a hydrostatic test. Testing should be done following the recommended procedure in the manufacturer's instructions. Blueprints should also be used to study the construction details of the individual heat exchanger.

As soon as a leaky tube has been located, it should be plugged at both ends. Plugging the tubes reduces the amount of heating surface. Therefore, the heat exchanger will fail to give satisfactory performance after a number of tubes have been plugged. It will then become necessary to retube the heat exchanger. Under normal conditions, this work should be accomplished by a naval shipyard or tender. However, repair parts and a number of special tools are included in the ship's allowance so that emergency repairs can be made to the heat exchangers and to other parts of the distilling plant.

To find which of the tubes within a removable tube bundle is leaking, test the individual bundles hydrostatically. The leak may be in a removable bundle. These bundles may be in vapor feed heaters within an evaporator shell, evaporator tube nests, or distillate condensers on end-pull plants. If so, the bundle must be withdrawn, and a hydrostatic test at full pressure (50 psi) must be applied on the tube side.

The leak may occur in a nonremovable tube bundle. These bundles may be in the distillate cooler, air-ejector condenser, or external vapor feed heaters. If so, the tube nest covers must be removed, and the full test pressure (50 psi) applied on the shell side of the unit.

If a nonremovable distillate condenser bundle is within an evaporator shell, the tube nest covers must be removed, and a full test pressure of 30 psi should be applied to the evaporator shell.

The proper instructions should be followed at all times during the operation and maintenance of distilling plants. A properly operated and maintained distilling plant will give many years of satisfactory service.

REVERSE OSMOSIS (RO) DESALINATION PLANT

General Description

Reverse osmosis (RO) (*Figure 18-13*) desalination plants have several advantages over other types of distilling plants in terms of their function, characteristics, and operation.

Function

The RO plant is used to produce pure water for drinking, cooking, and other freshwater uses. The reverse osmosis distillation unit (RODU) uses a process that removes salt by forcing HP saltwater through a membrane with holes small enough to filter salt and produce freshwater.

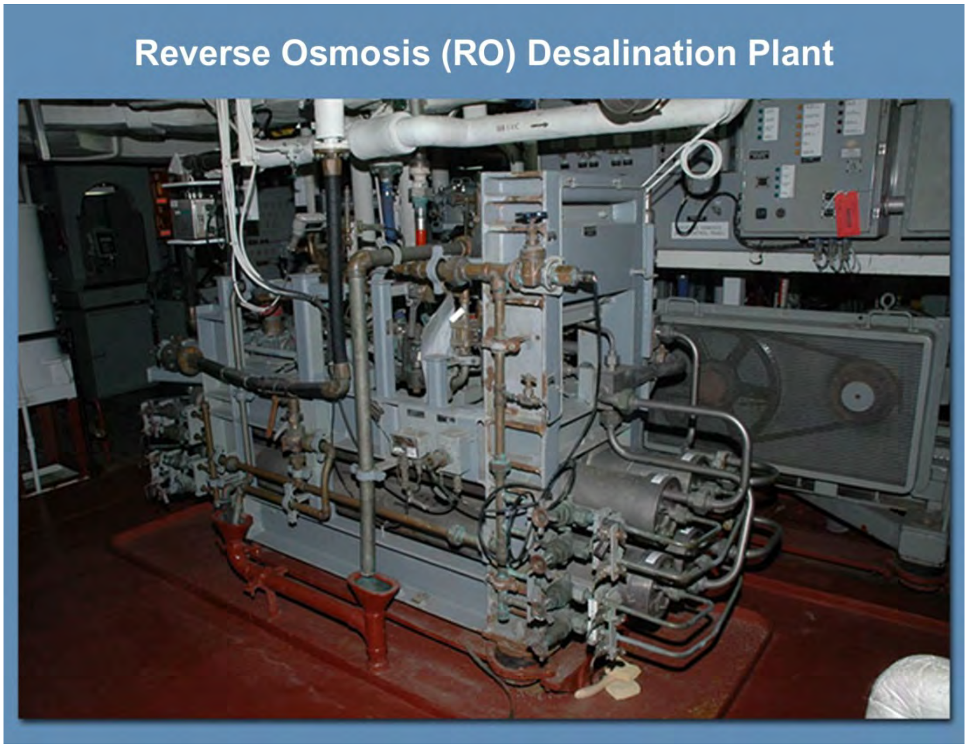

Figure 18-13 — Reverse osmosis (RO) desalination plant.

Basic Characteristics

One major advantage of RO plants is that pure water is made within 5 minutes of system startup, which is much faster than other systems. An RO plant requires no steam heat and involves no phase change of the seawater. Plants are significantly lighter in weight, less complex, and more energy efficient than other processes in Navy ships.

The RO plant operates semi-automatically when valves have been aligned according to the EOSS manual; however, an operator monitoring via a touch screen control panel aids its operation. Monitoring safety pressure switches and the permeate salinity for abnormal conditions enables the operator to stop the HP pumps and unlatch dump valves to prevent high-salinity water from entering the potable water system. Manual operation of the appropriate valves and control panel switches is required to completely secure the RO.

The reverse omission distilling plant (RODP) is designed for operation in uncontaminated seawater. Operation must be suspended if operating near an oil spill, high silt areas, and/or high algae areas.

Theory of Operation

Normal Osmosis

Normal osmosis of saltwater (*Figure 18-14*) occurs when two liquid solutions, freshwater and saltwater, are separated by a semipermeable (filtering) membrane. Freshwater permeates through the membrane, mixes with the saltwater, and dilutes the concentration of saltwater. The flow of water through the membrane is called osmosis.

During osmosis, when the water height (volume) of the saltwater increases, the freshwater's height decreases. This difference in water height, which creates a pressure difference at the membrane surface, is called the osmotic pressure. The osmotic pressure for saltwater is 350 psi.

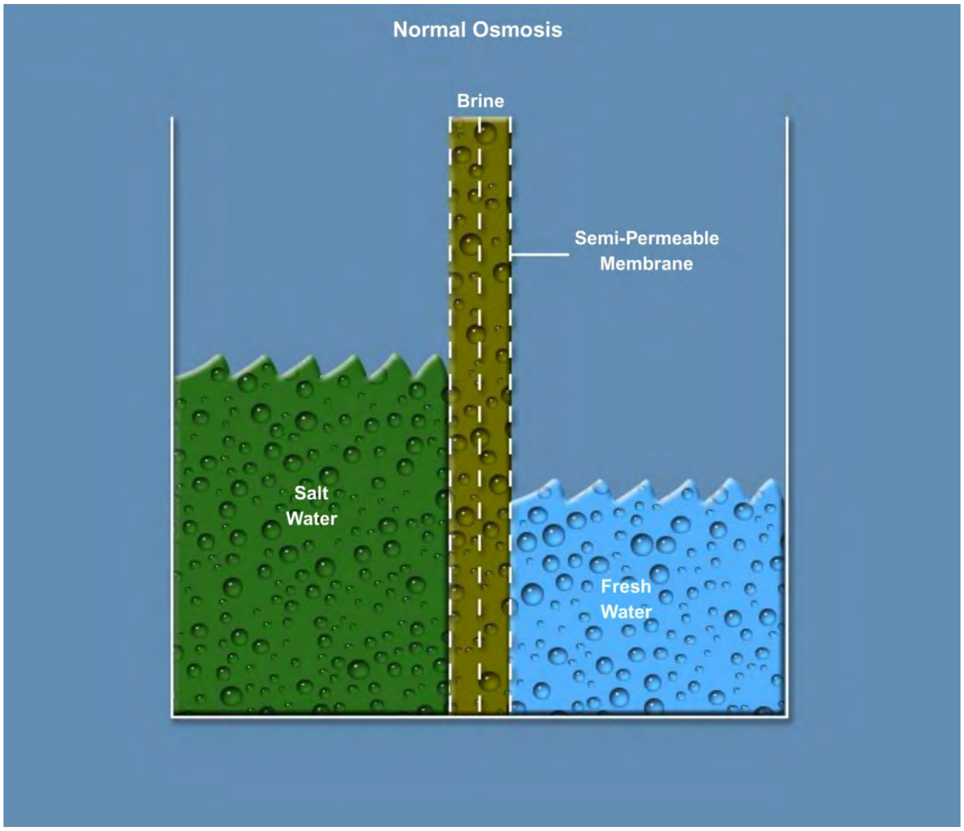

Figure 18-14 — Normal osmosis.

Reverse Osmosis (RO)

Osmosis can be reversed (*Figure 18-15*) by overcoming the osmotic pressure. When the dilute solution is freshwater and the concentrated solution is saltwater, osmosis is reversed by applying a higher pressure to the saltwater side in excess of the osmotic pressure (higher than 350 psi). The result is desalination of seawater to produce freshwater.

During RO, small amounts (18 to 22 percent of the flow) of saltwater pass through semipermeable membranes over to the dilute (freshwater) side. The constant volume of seawater applies pressure against the membranes and maintains a constant osmotic pressure. The greater the difference between the applied

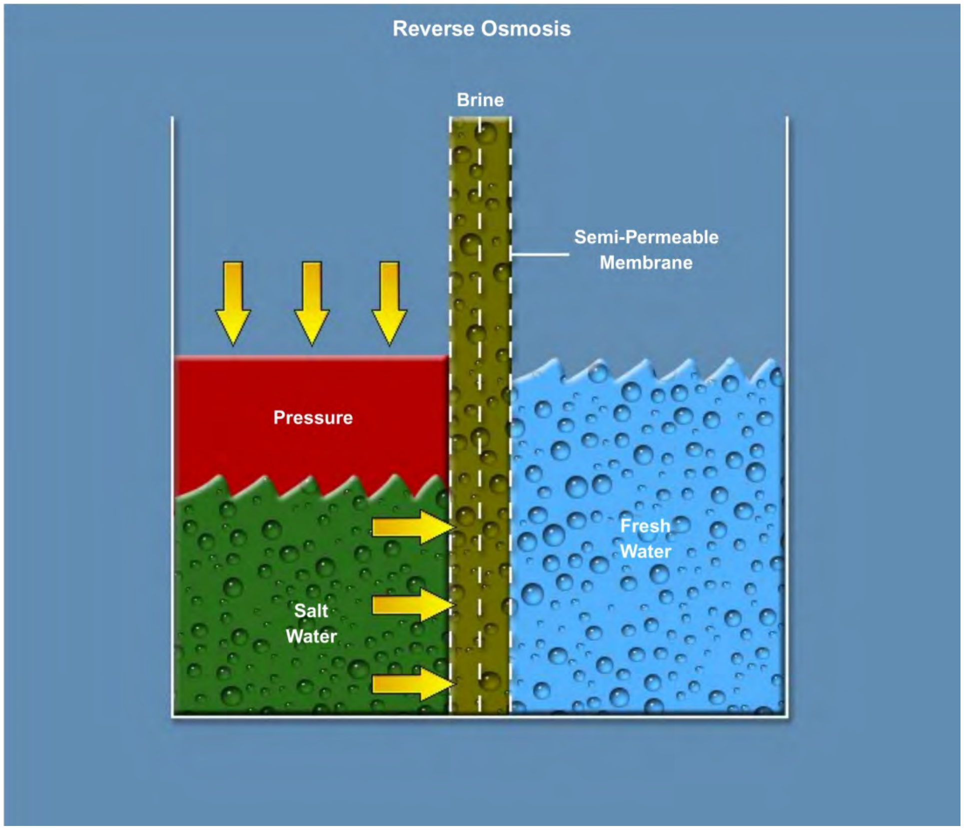

Figure 18-15 — Reverse osmosis (RO).

pressure and the osmotic pressure, the faster the water will permeate the membranes, and the purer the permeated freshwater will be. In practice, a pressure of 700 to 1,000 psi is required to obtain an acceptable flow of saltwater through the membrane.

Components

There are two complete RO plants per ship; each plant having its own control panel mounted on the bulkhead and components mounted on three separate skids. The RODP consists of the following major components.

Filter Skid

Maintaining the filters is vital to the performance of the RO plant. Large quantities of solid particles and sea creatures entering the RO modules, when the filters are not maintained, will shorten the life of the RO membranes and lower the permeate production rate.

The skid consists of an electric heater, centrifugal separator, 20-micron filter, 3-micron filter, and activated carbon (AC) filter.

The filter skid (*Figure 18-16*) heats incoming seawater so that the permeate does not freeze and damage the RO membranes. The filter skid also removes bromine and chlorine before it is used for freshwater flush.

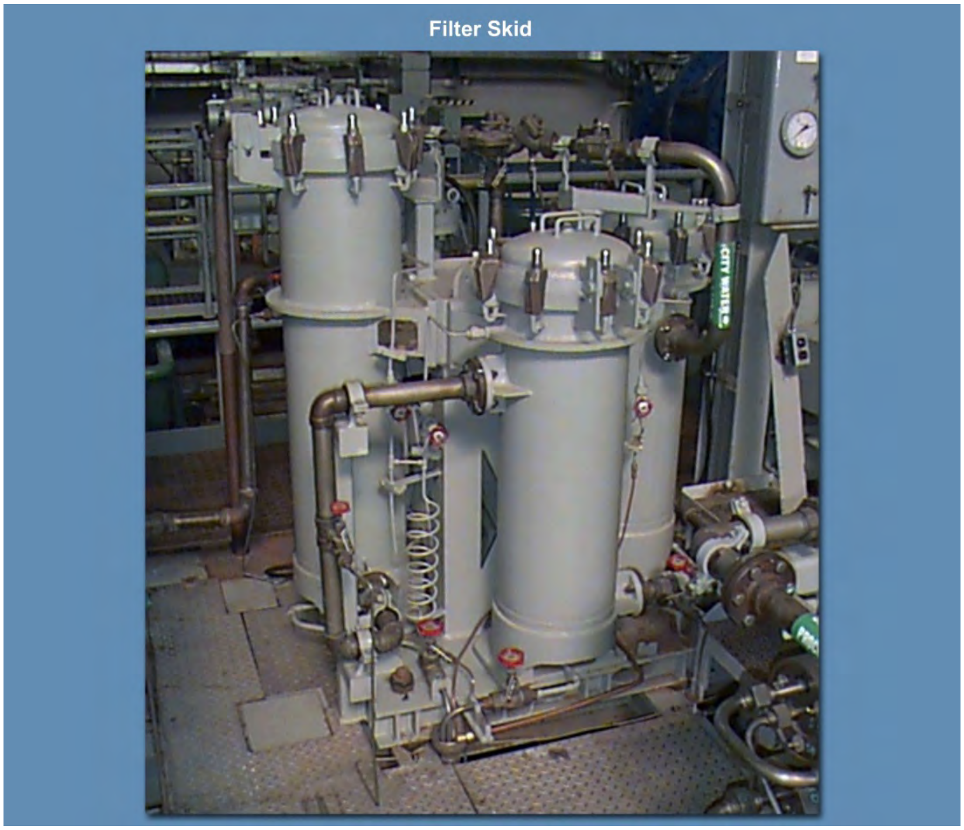

Figure 18-16 — Filter skid.

High pressure (HP) Pump Skid

The purpose of the HP pump skid (*Figure 18-17*) is to increase the pressure above osmotic pressure to allow efficient RO to take place across the RO membranes. The HP pump skid contains an HP pump, motor, V-belt driver, and accumulator.

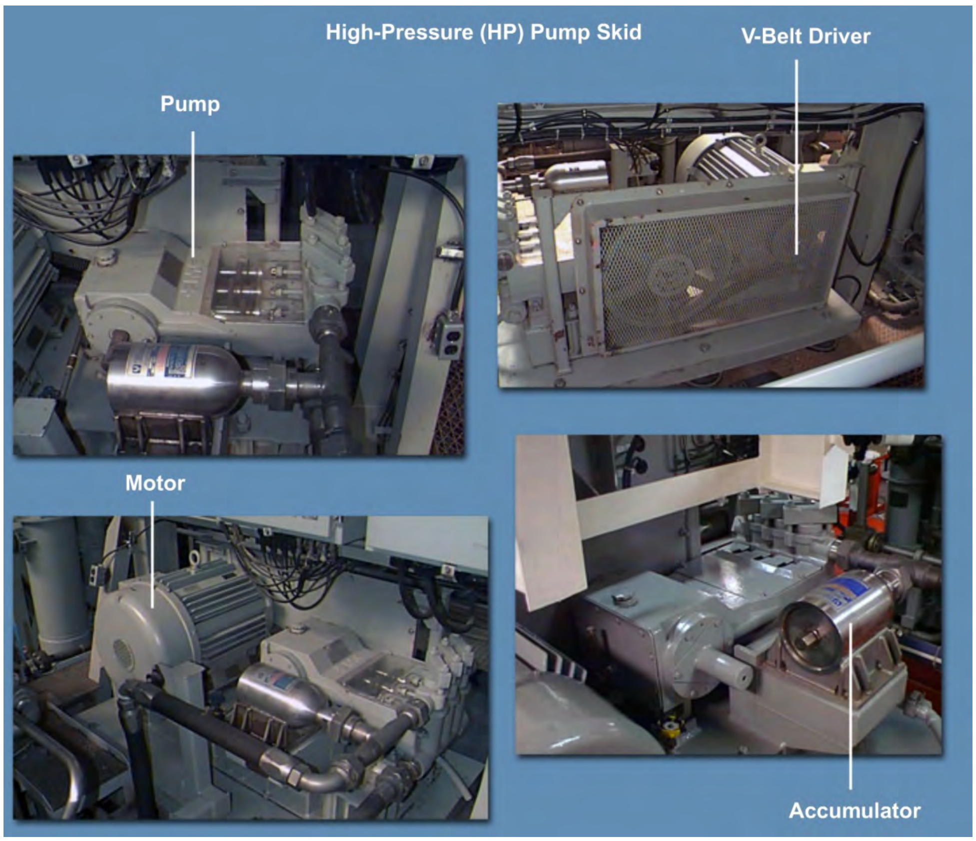

Figure 18-17 — High pressure (HP) pump skid.

An accumulator is installed in the discharge piping to absorb the vibration in fluctuation in pressure. Without the accumulator, these unhampered stressed or fluctuations in pressure would eventually cause failures in surrounding auxiliary components and membranes. The accumulator consists of a nitrogen-charged rubber bladder inside a vessel.

Reverse Osmosis (RO) Module Skid

The actual desalination process occurs in the RO (*Figure 18-18*) module skid, which contains the pressure vessels, RO membranes, brine restrictor valve, pressure-reducing coil, dump valve, flow meters, salinity cell, RO isolation valves, and sample and relief valves.

The eight spiral-wound membranes are the core of the RODU. The unit has two parallel, which permit permeate to pass through but prevent most of the solids from passing through. The water that does not pass through the first membrane becomes more concentrated as it flows from one membrane to the next membrane in line. What does not go through the fourth membrane gets discharge as brine overboard.

Each permeate discharge tube is connected at a common header. Each tube has a cutout valve and sample valve on them. This allows you to isolate a failed membrane from the permeate header and leaves the unit online. There is a permeate temperature switch on the header to prevent the pressure vessel from freezing up, and rupturing the membrane. The switch will shut down the system if proper temperature is not maintained.

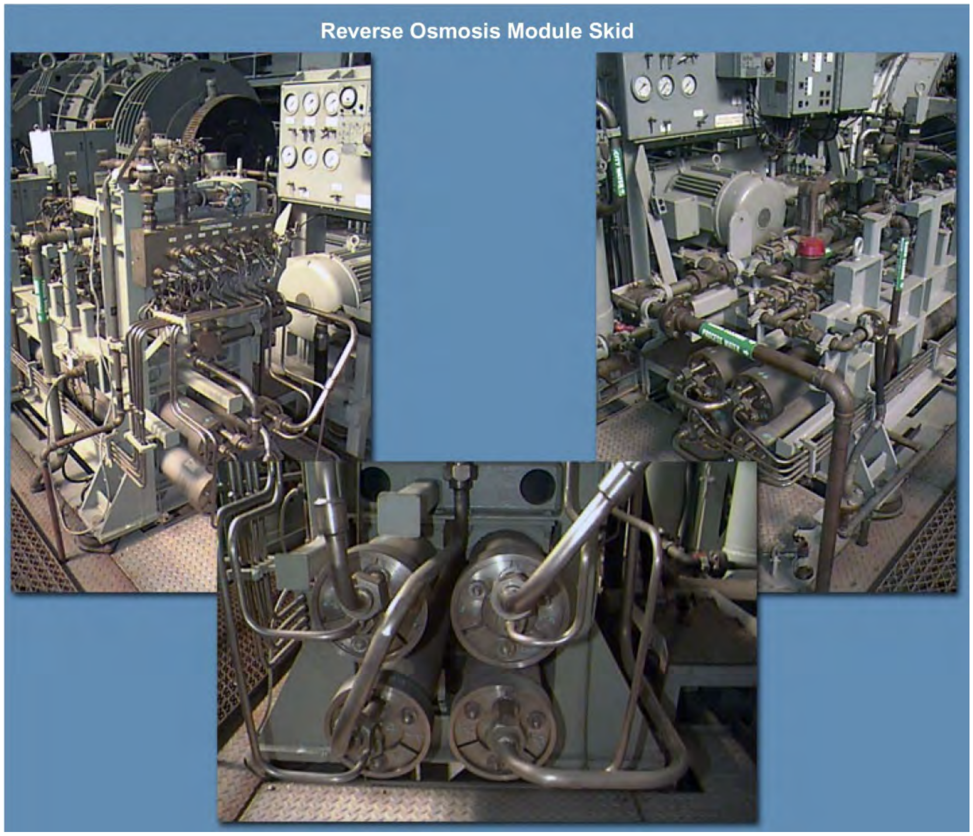

Figure 18-18 — Reverse osmosis (RO) module skid.

Figure 18-19 — Main control panel.

Main Control Panel

The main control panel (*Figure 18-19*) is the central control system for the RO plant. RO plant controls and instruments are organized by three panels and are usually mounted in the ship's structure or in an RO module skid. These panels are usually mounted on the front of the RO unit to simplify operation and maintenance. The manual control panel consists of a control panel, salinity indicating panel, and the gauge panel.

Dump Valve

It is a three-way solenoid valve that diverts permeates water from the RODU to either the wastewater drain system, or to the freshwater storage tanks. The conductivity of the water decides where the water goes.

Flow Meters

There are two meters in the system. One is on the brine line and the other is on the permeate line. Both flow meters tell gallons per minute (GPM). By adding the two flow meters together you can tell whether the HP pump is performing properly.

Reverse Osmosis (RO) Troubleshooting

Troubleshooting is important in maintaining and operating RO desalination plants. Troubleshooting requires an understanding of equipment operation and an ability to recognize the symptoms of faulty operation. Troubleshooting is the systematic analysis of a malfunction used to identify the cause of that malfunction. Troubleshooting procedures can be found in NSTM*,* Chapter 531, Volume 3 Desalination – Reverse Osmosis Desalination Plants.

Directions provided in troubleshooting guides are based on the assumption that all operating and maintenance procedures have been followed correctly. Troubleshooting guides are divided into three columns (*Figure 18-20*):

- Symptom(s)
- Probable cause(s)
- Remedy

Following the troubleshooting guides enables engineering personnel to isolate common malfunctions and acquire direction as to the proper corrective action.

From left to right, the left-hand column (Symptoms) lists common malfunctions. After locating the malfunction that best describes the problem, the user proceeds to Probable Cause(s) for the problems that are listed in the center column.

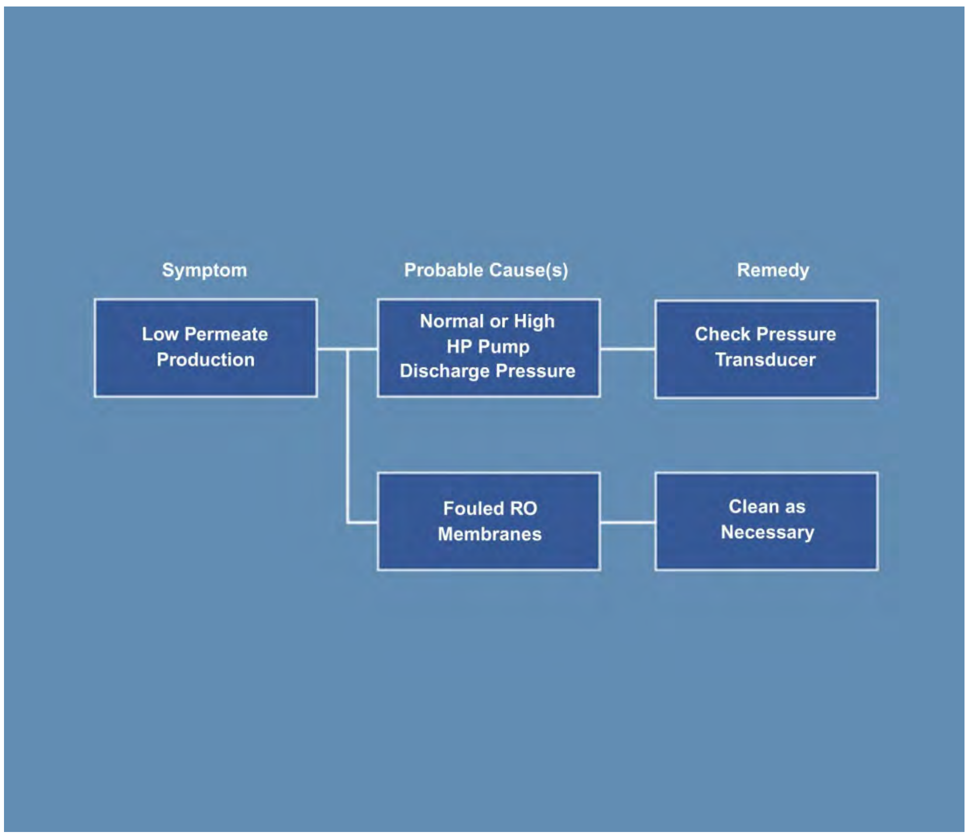

Figure 18-20 — Reverse osmosis (RO) troubleshooting.

Each probable cause is investigated to confirm the actual cause of the malfunction. Probable causes are listed in the recommended order that they should be checked, but it is not mandatory that this order be followed.

The last column (Remedy) provides recommended corrective actions/remedies that, when followed, resolve the abnormality so that the engineer can return the component, and thus the plant, back to normal operation.

Low Permeate Production

While taking logs on the RO plant, the engineer notices that the permeate flow rate is below the minimum allowed according to the logs.

The troubleshooting guide indicates that some of the possible causes for the low permeate production are the following factors (*Figure 18-20*):

- Normal or high HP pump discharge pressure.
- Fouled RO membranes.

Common Malfunctions Requiring Troubleshooting

High pressure (HP) Pump Alarm

While taking logs on the RO plant, an engineer hears an alarm. Checking the alarm panel, the engineer notices that the HP pump alarm light is illuminated. Upon consulting the troubleshooting guide, the engineer determines the possible causes for the alarm could be the following conditions (*Figure 18-21*):

- Brine resistor valve throttle closed too fast or completely closed
- Operating in cold water
- Operating with severely fouled membranes

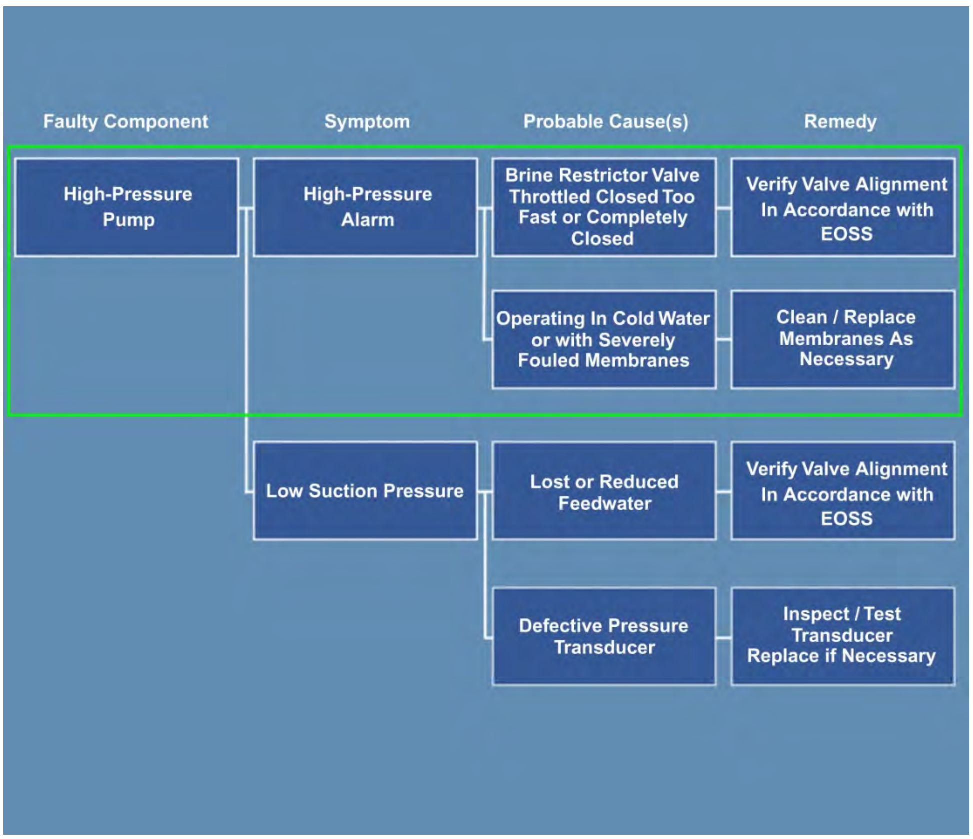

Figure 18-21 — High pressure pump alarm.

Oil Leaking from the High pressure (HP) Pump

While performing a visual inspection of the HP pump, the engineer notices oil leaking from the oil fill cap of the HP pump. The troubleshooting guide indicates that the possible causes for the oil leaking could be the following factors (*Figure 18-22*):

- Oil reservoir level low
- HP pump diaphragm leaking water into the pump housing

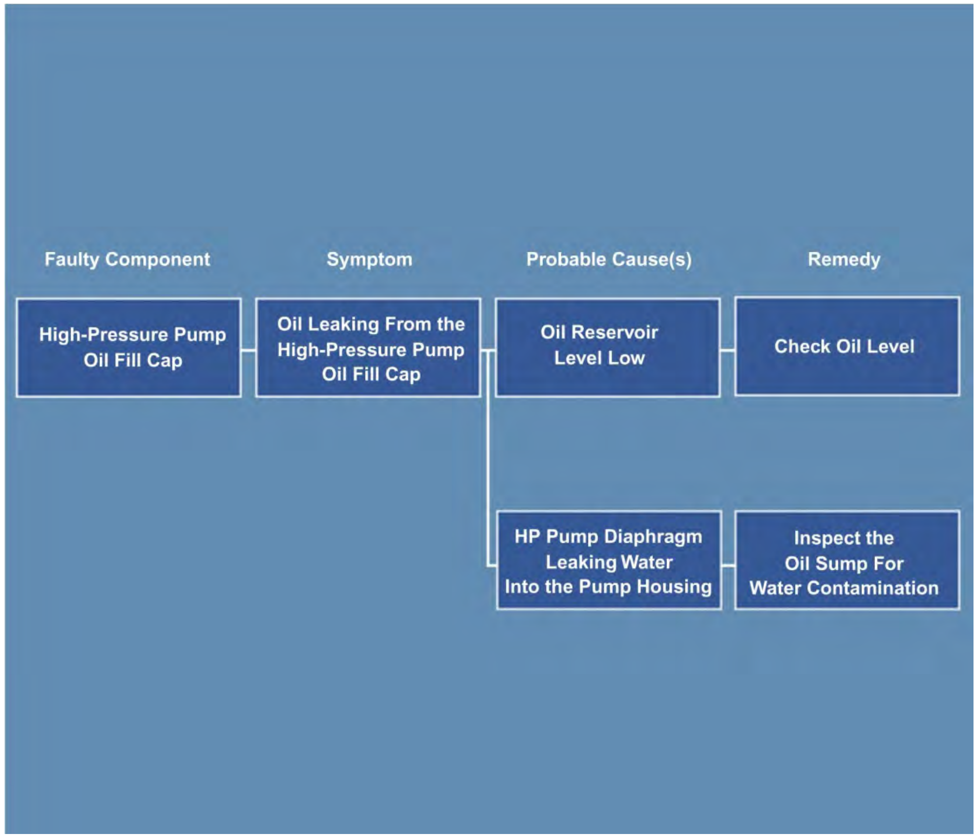

Figure 18-22 — Oil leaking from the high pressure pump.

Low Suction Pressure on High pressure (HP) Pump

While performing a watch tour, the engineer hears an alarm. The pump suction low pressure alarm is illuminated on the alarm panel. Upon consulting the troubleshooting guide, some of the possible causes for the alarm could be the following factors (*Figure 18-23*):

- Lost or reduced feedwater
- Defective pressure transducer

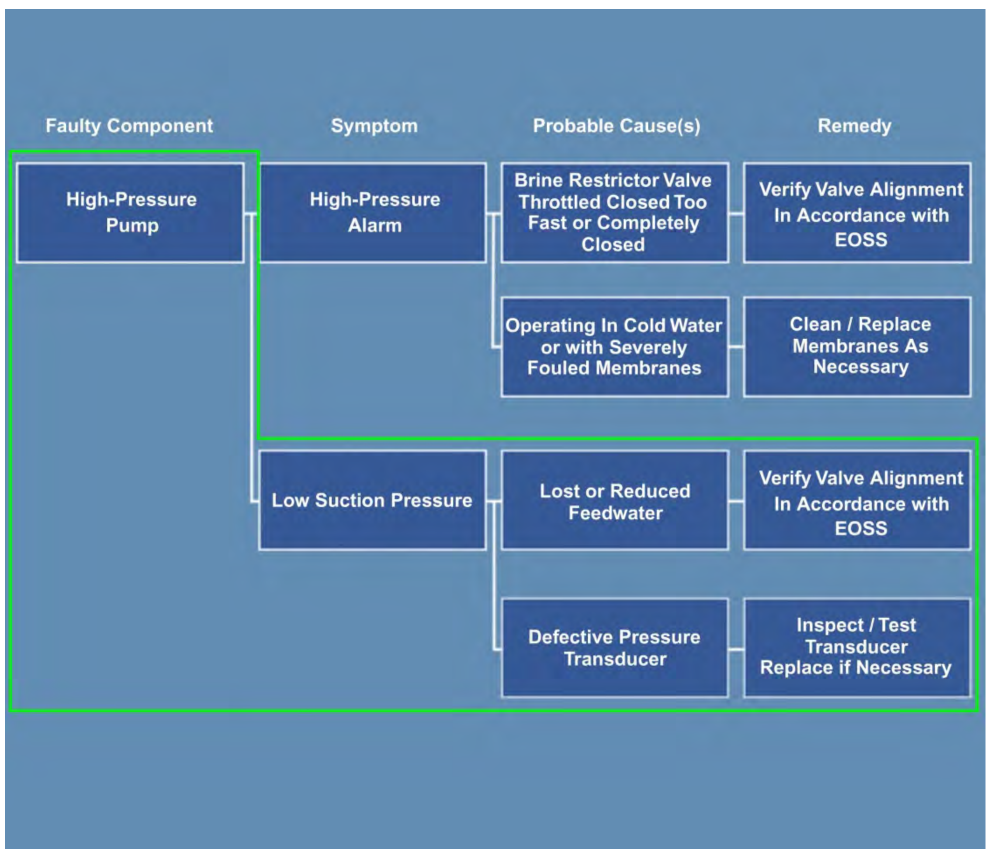

Figure 18-23 — Low suction pressure on high pressure pump.

Low Discharge Pressure on High pressure (HP) Discharge

While taking logs on the RO plant, the engineer hears an alarm. Upon checking the alarm panel, the engineer notices that the high-pump discharge light is illuminated. By consulting the troubleshooting guide, the engineer finds that some of the possible causes for the alarm could be the following factors (*Figure 18-24*):

- Bound or clogged transducer airline
- Eroded brine restrictor valve
- Incorrect valve alignment

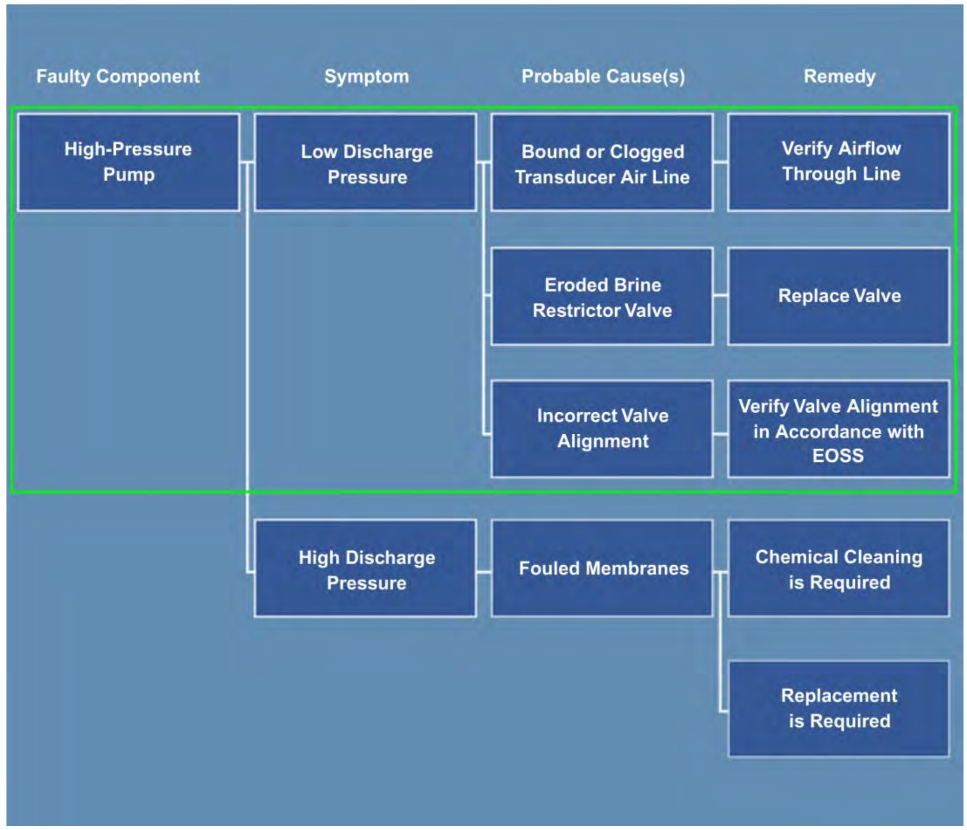

Figure 18-24 — Low discharge pressure on high pressure discharge.

High Discharge Pressure on High pressure (HP) Discharge

The engineer is performing a watchstation tour. During the tour, an alarm is heard. Checking the control panel, it is noticed that an HP pump discharge alarm is illuminated. Upon consulting the troubleshooting guide, the engineer determines possible cause for the alarm is fouled membranes. The remedy for this problem is either chemical cleaning or replacement (*Figure 18-25*).

- Fouled membranes and chemical cleaning is required.
- Fouled membranes and replacement is required.

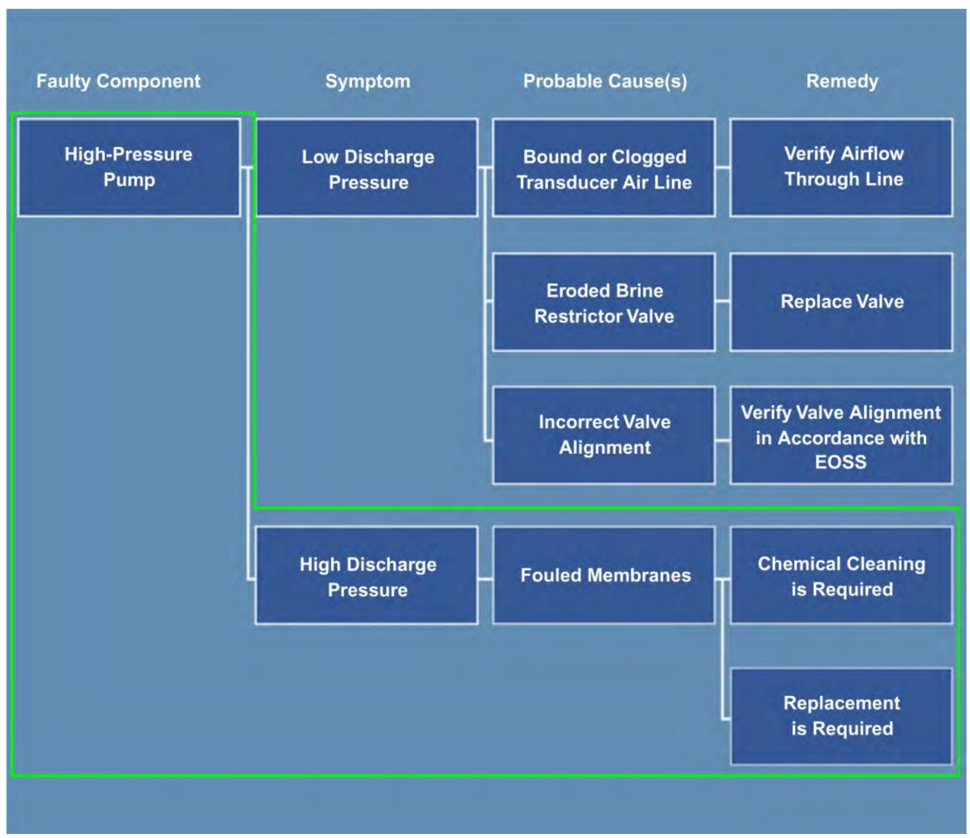

Figure 18-25 — High discharge pressure on high pressure discharge.

Reverse Osmosis (RO) Corrective Maintenance

In spite of the best preventive maintenance and troubleshooting, equipment will unexpectedly malfunction or cease to function. When this occurs, corrective maintenance is necessary.

Corrective maintenance procedures provide personnel with detailed guidance for the performance of a specified maintenance requirement. Corrective maintenance procedures consist of actions to restore failed equipment to an operational condition within predetermined parameters. They are presented in a format similar to maintenance requirements cards (MRCs) of the PMS or in a technical work document. Corrective maintenance procedures are intended for alignment, adjustment, repair, or replacement of faulty equipment after the fault has been isolated.

The following examples of references contain valid corrective maintenance procedures (*Figure 18-26*):

- MRCs
- Ship systems manuals
- Component technical manuals
- Shipyard process instructions
- Ship alteration instructions
- Steam and electric plant manuals

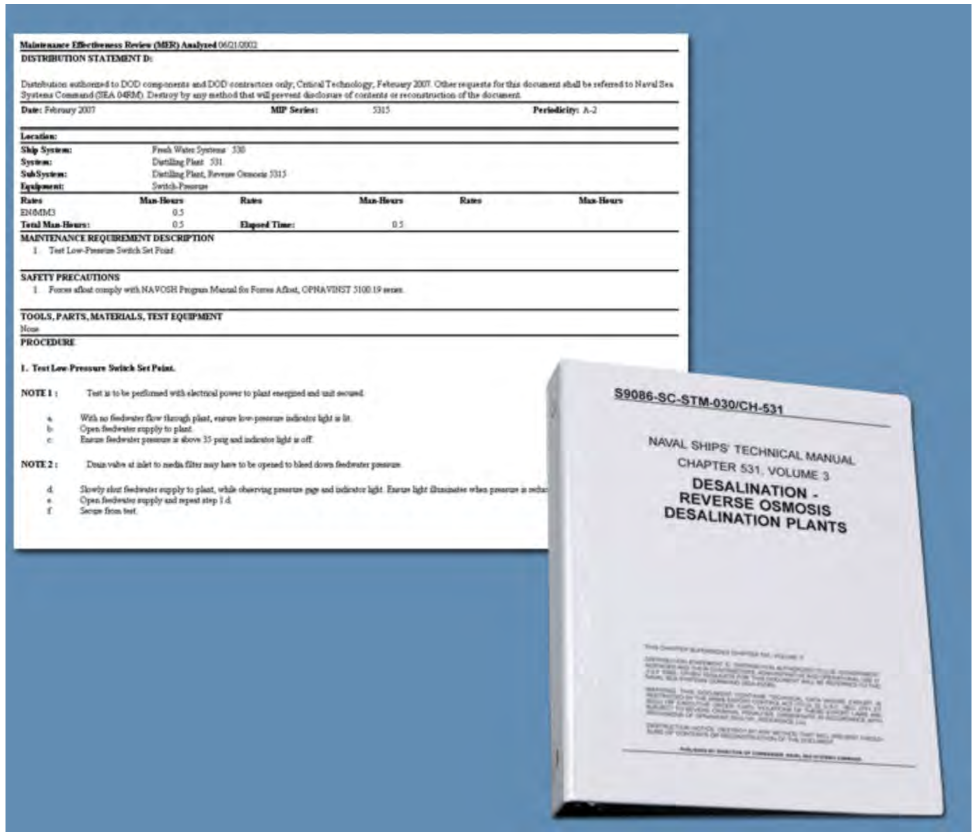

Figure 18-26 — Reverse osmosis (RO) corrective maintenance.

SUMMARY

This chapter gave you information on the operation, troubleshooting, and repairs of distilling plants. As an Engineman, you are also responsible for the upkeep and maintenance of distilling plants. Remember to consult the manufacturer's technical manual for the type of plants on your ship.

End of Chapter 18

Distilling Plants

Review Questions

18-1. What term best describes the process of boiling seawater, then cooling and condensing the resulting vapor to produce freshwater?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-2. What term best describes the process of cooling the freshwater vapor produced by evaporation to produce usable freshwater?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-3. What term best describes the process of boiling seawater to separate it into freshwater vapor and brine?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-4. What term best describes a vapor that is NOT adjacent or next to its liquid source and has been heated to a temperature above its saturation temperature?

A. Brine
B. Effect
C. Superheated steam
D. Vapor

18-5. How many major types of low pressure steam distilling units are there?

A. One
B. Two
C. Three
D. Four

18-6. What method is recommended to test for air leaks when the plant is secured?

A. Using an air-pressure or soapsuds test on the various component parts
B. Using a candle flame to test all joints and parts
C. Using the pressure from the main pump to test all parts
D. Visually inspecting the parts

18-7. Which of the following methods should you use to find a leak in a heat exchanger?

A. Candle test
B. Hydrostatic test
C. Non-destructive test
D. Visual test

18-8. Which of the following conditions is a primary cause of air ejector problems?

A. Clear nozzle
B. Obstructed nozzle
C. Scale formation
D. Low vacuum pressure

18-9. What condition does a complete flooding of the flash chamber gauge glass indicate?

A. Improper drainage
B. Inconsistent brine density
C. Insufficient circulating water
D. Vacuum loss in the two-stage flash

18-10. Which of the following pieces of equipment is used to produce pure water for drinking, cooking, and other freshwater uses?

A. Centrifugal purifier
B. Normal osmosis plant
C. Reverse osmosis (RO) plant
D. Zinc oxide purifier

18-11. In what chapter of the *Naval Ships' Technical Manual* (NSTM) is troubleshooting procedures for reverse osmosis (RO)?

A. 351
B. 431
C. 458
D. 531

18-12. Which of the following conditions can cause the high-pump discharge light to be illuminated?

A. Bound or clogged transducer airline
B. Defective pressure transducer
C. Oil reservoir level low
D. Operating with severely fouled membranes

RATE TRAINING MANUAL – User Update

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CHAPTER 19

ENVIRONMENTAL POLLUTION PROGRAM AND POLICIES

The Federal Government continues to emphasize how important it is that Federal agencies do everything possible to prevent environmental pollution. Presidential executive orders and congressional legislation support this emphasis. All facilities owned by, or leased to, the Federal Government must be designed, operated, maintained, and monitored to conform to air, water, and noise standards established by Federal, State, and local authorities.

The Navy will work to protect and improve the quality of the environment. We will follow all regulatory standards that apply to us, and we will initiate actions to conserve natural resources, protect historical and cultural properties, and prevent or control pollution. This chapter covers the policies and instructions under which we work to protect and improve the environment, and it provides an overview of the procedures we use to do so.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain pollution control laws and regulations.
2. Identify the precautions in handling fuel oil (FO).
3. Describe the fueling responsibilities and procedures.
4. Describe the measures for preventing and handling oil spills.
5. Explain shipboard sewage and waste disposal.
6. Describe the ballasting system.

POLLUTION CONTROL LAWS AND REGULATIONS

The following paragraphs offer a brief overview of the more important laws and regulations we use to protect the environment.

In 1899, Congress passed a law prohibiting the discharge of refuse in navigable waters of the United States. The Oil Pollution Act of 1924 prohibits the discharge of oil of any kind (fuel oil [FO], sludge, oily waste, and so forth) into navigable waters. The Oil Pollution Act of 1961 prohibits the discharge of oil or oily mixtures, such as ballast, within the prohibited zones established by any nation, and those zones range from 50 to 150 miles seaward from the nearest land. The 1961 act ratified a 1954 international agreement known as the Convention for the Prevention of Pollution of the Sea by Oil. Proposed amendments would abolish prohibited zones and extend oil dumping prohibitions to all ocean areas.

The Oil Pollution Act of 1924 was repealed by the Water Quality Improvement Act of 1979. This act prohibits the non-casual discharge of any type of oil from any vessel, onshore facility, or offshore facility into or upon navigable waters of the United States, adjoining shorelines, or waters of the contiguous 12-mile zone. Other features of the act provide for the control of hazardous substances other than oil and for the control of sewage discharges from vessels.

The Clean Air Amendments of 1970 set goals for the reduction of pollutant emissions from stationary sources and vehicles. New stationary sources that burn fossil fuels must conform to emission standards determined by the Environmental Protection Agency (EPA).

In 1970, Congress also passed two acts that declared a national policy to improve the environment. They were the National Environmental Policy Act of 1969 and the Environmental Quality Improvement Act of 1970. These acts require Federal, State, and local governments to create and maintain conditions where man and nature can exist together.

The Navy's environmental quality program is the *Environmental and Natural Resources Program Manual,* OPNAVINST 5090.1(series). This manual contains guidelines to prevent, control, and abate air and water pollution. In general, we must ensure that all facilities, including ships, aircraft, shore activities, and vehicles, are designed, operated, and maintained to conform with standards set forth in the 1970 and 1979 acts. The following paragraphs cover the most important requirements of the instruction.

Shore activities will use municipal and regional waste collection and disposal systems whenever possible. We will handle all materials such as solid fuels, petroleum products, and chemicals in ways that prevent or minimize pollution of the air and water. We will reprocess, reclaim, and reuse waste material whenever feasible. Ships will use port disposal facilities for all waste before they get underway and when they return to port. We will not discharge oil products within any prohibited zone, and we will not discharge trash and garbage within 12 miles of shore. We will normally burn waste material in open fires. We will not use sinking agents and dispersants to fight oil spills except when there is a substantial fire hazard or danger to human life.

To meet the requirements of the Clean Air and Water Quality Improvement Acts, the Navy has instituted several ongoing programs. Some of these programs are in operation, and others are being tested and evaluated. For example, we now operate completely enclosed firefighting training facilities from which no smoke escapes. Aboard ship, we have shifted from Navy standard FO to distillate, which reduces air pollution because it has low sulfur content and burns more cleanly than standard FO. We are now evaluating several models of self-contained shipboard sanitary treatment systems that eliminate the discharge of polluted sewage.

You can see that the Navy is using time, money, and effort to reduce environmental pollution. To support that policy, you should closely supervise all operations that involve fuel handling, waste disposal, and the use and disposal of toxic materials. Indoctrinate personnel on the causes of pollution and the necessity to reduce it. Be sure personnel under your supervision comply with regulations and operating procedures for pollution control devices.

In the rest of this chapter, we will cover the procedures and facilities we use to help improve the environment.

PRECAUTIONS IN HANDLING FUEL OIL (FO)

All petroleum products, including FO, are potentially dangerous. Heated FO may generate vapors that are flammable, explosive, and dangerous if you inhale them. The Oil King must have thorough knowledge of these hazards. The Oil King also must make certain that all personnel in FO details take the necessary precautions. The following list covers the most important precautions:

- Do NOT allow anyone to smoke or to carry matches or lighters while handling FO.
- Use only approved types of protected lights when working near FO.
- Do NOT allow oil to accumulate in bilges, voids, and so forth. The vapor from even a small pool of heated FO can cause an explosion.
- NEVER raise the temperature of FO above 120 °F in FO tanks. If the tanks are next to a magazine, NEVER allow the oil to become hot enough to raise the magazine's temperature above 100 °F, nor to maintain the magazine's temperature at more than 90 °F.
- NEVER exceed the designed pressure in any part of a FO system.

- Do NOT allow smoking, open flame, or any spark-producing object near FO tank vent pipes.
- Be sure the wire screen protectors in the vent pipes are intact. Do NOT allow the wire screen protectors to be painted.
- REMEMBER THAT FO FUMES ARE DANGEROUS IF INHALED. If your eyes sting or burn, you probably also are inhaling the fumes. The symptoms range from headache and dizziness to unconsciousness and suffocation. Give first aid to any person suffering from inhalation of FO fumes; refer to *Navy Safety and Occupational Health (SOH) Program,* OPNAVINST 5100.19(series). Remember, also, that a person who is suffering only mild effects from inhaling FO fumes may be confused or drowsy enough to cause a serious accident.
- NEVER enter and do NOT allow anyone else to enter any FO compartment until the gas free engineer declares it SAFE FOR PERSONNEL. Always get permission from the gas free engineer before any person enters an FO tank.
- Observe all safety precautions for closed or poorly ventilated compartments. These precautions are listed in the *Naval Ships' Technical Manual (NSTM)*, Chapter 074.
- When the ship is in drydock, be sure oil does NOT drain from the ship onto the dock.
- Do NOT heat distillate fuel by using the ship's FO heaters. In general, you will not need to heat tanks, but severe cold weather may create a need to do so. If the transfer pump is having difficulty moving the fuel, and the fuel in the tank is below 50 °F, you may heat FO to approximately 75 °F to dissolve the waxy constituents.
- Use only the sprayer plates recommended for use with the distillate fuel.
- When burning a distillate fuel, do NOT allow a smoky, hazy stack. Improper combustion causes excessive fuel consumption and a dangerous stack condition, and it adds to air pollution.
- When ships are refueled where the ambient temperature is below 40 °F, do not fill storage tanks above 95 percent of capacity. If a tank exceeds that amount, pump the oil down to 95 percent of capacity as soon as possible.
- Be sure all personnel under your supervision know the provisions of the Oil Pollution Act and the Federal Water Pollution Control Act.

FUELING RESPONSIBILITIES AND PROCEDURES

Many preparations need to be made before the ship actually takes on fuel. The deck force or other personnel are responsible for some of these precautions, but the Oil King is responsible for others. For simplicity, this section will be addressed to you, the Oil King, though some others will supervise or perform some of the procedures.

Deballast and strip oil tanks as soon as possible after you get word that the ship will take on fuel. If sea conditions make it impossible to deballast before the ship enters port, get permission from port authorities to deballast into a barge after the ship enters port. Be sure the ballasted tanks are pumped out according to the recommended sequence tables so the ship will retain as much stability and maneuverability as possible. We will include more information on ballasting later in this chapter.

Before receiving fuel, order soundings or readings on all FO storage tanks and all FO service tanks. Then, submit a statement to the officer in charge of fueling showing the amount and location of all FO aboard. Always know how much fuel is aboard, where it is located, how much more can be taken on, and the order in which the tanks should be filled.

In some ships, such as destroyers, FO is delivered directly into an FO service tank. When you refuel this type of ship, take FO service suction from the receiving service tank until just before the approach alongside the delivering ship, and then shift suction to a fuel standby service tank.

> ⚠ **CAUTION** ⚠
>
> Never take FO service suction from the service tank that is receiving FO.

Post a fueling watch list well in advance of fueling time, and be sure all personnel involved in the operation know their stations and duties. A fueling detail includes messengers, pneumercator personnel and tank sounders, personnel at the forward and after hose connections, personnel at the manifolds, and telephone talkers. Be sure all fueling detail personnel are experienced and capable.

As a rule, man fueling stations one-half hour before fueling time. Assign only the number of personnel required to handle the fueling. Additional personnel may get in each other’s way.

After the fueling stations are manned, but before fueling is started, test the phone circuits; connect the air hoses to the fueling connections; and screw thermometers and pressure gauges into the fueling connections if they are required.

Before starting fueling, check equipment at all stations. Equipment required for fuel tank sounding stations includes graduated sounding rods or tapes (if used), rags, and tee wrenches. Equipment required for topside fueling stations (depending on the type of refueling rig used) includes sledge hammers, axes, ball peen hammers, bolt cutters, hose coupling spanner wrenches, rags, and end fittings.

When FO is received from a naval source of supply, such as a naval ship, a naval storage tank, or a naval fuel barge, the activity supplying the oil must furnish the Commanding Officer (CO) of the receiving ship with an analysis of the oil. If possible, you and an officer of the receiving ship should witness soundings and the drawing of samples from the tanks of the supplying activity. The samples must be taken from the suction level of the tank from which the oil is to be drawn. One sample should be taken before the unloading is started, and another after the loading is completed. Both samples must be centrifuged to determine the percentage of sediment and water.

When fueling is done at sea, it may be impossible for the delivery ship to furnish a complete analysis of the oil and for the receiving ship to send representatives to witness the soundings and samplings. In this case, the supplying vessel furnishes a statement of the American Petroleum Institute (API) gravity and water and sediment content of the oil. The receiving ship must then take samples during delivery and make tests to determine the percentage of water and sediment. Take the samples with a dipper from the tank that is being filled, or draw them through connections in the delivery pipeline. Take enough small samples to make a total sample of at least 5 gallons. Then, take smaller samples from the total sample for the test. Before you take the samples, clean all the containers you will use for that purpose.

When fuel is coming aboard, keep a constant check on all tanks that are receiving fuel. In large ships in particular, you must follow a systematic procedure to get all tanks properly filled without unnecessary loss of time. You also must be sure the stability of the ship is not impaired.

When several tanks are in each overflow group, initially open one or two tanks in each group. When the tanks have been filled to approximately 85 percent capacity, start filling the others in the group. Close down on the valves to the tanks that are almost full, and top them off slowly. Fill the overflow tank in each group last.

Each tank has a sounding rod or a tank-capacity indicator of the pneumercator type. Other systems may be in uses that are not covered in this chapter. You can get information about these systems from the manufacturers' technical manuals. As oil is being received, assign someone to each tank that is receiving fuel. If you are using a sounding rod, sound the tank every 3 or 4 minutes until it is nearly three-fourths full. From this point on, take continuous soundings. Fill tanks to the 95 percent level. You can fill to slightly above this mark to allow the oil to foam, but be sure the FINAL level of oil in any tank is at the 95 percent mark.

As each succeeding tank is filled, be sure personnel at the remaining tank sounding stations are even more alert than before. As the last tank is being filled, notify the delivery ship to drop the pump pressure or to slow down the pump, as appropriate.

After you have determined the amount of FO being received per minute, you can give the delivery ship a "stop pumping" time. If your calculations are correct, all tanks will be full when the pump is stopped.

You must keep the Fueling Officer informed of the amount of oil received as a percentage of the total to be received and the probable time required to complete the fueling. The Fueling Officer keeps the CO posted on the progress of the fueling.

When all tanks are full, empty the fuel hose by one of two methods: (1) blow back the oil in the hose to the delivery ship by opening the compressed air valve to the fueling connection, or (2) have the supplying ship take a back suction, which also requires that the air valve be opened. As soon as the fuel hose has been cleared, IMMEDIATELY uncouple the hose and return it to the delivery ship.

You also must be familiar with the procedures used to discharge fuel. The following list shows some of the steps typically used to discharge FO:

1. Be sure the tanks from which fuel is to be discharged are filled and topped off to the 95-percent level.
2. If necessary, heat the oil to the temperature required to produce a viscosity of 450 Saybolt Seconds, Universal (SSU). This procedure is not usually required with distillate fuel.
3. Sound all tanks that will be used.
4. Couple the fuel hose and rig it according to prescribed procedures.
5. Line up the FO system to discharge fuel, and test the operation of the FO pumps.
6. Place red flags over the side of the ship at the fueling stations.
7. Be sure the Officer of the Deck (OOD) has draft readings taken forward and aft before and after fueling.
8. Set the fueling detail, set up the fueling board, and fill in available data on the fueling sheet for the Fueling Officer.
9. Man fueling stations about one-half hour before the expected time of approach of the ship to be fueled. Be sure personnel at the fueling stations test sound-powered phone circuits, connect air hoses to the fueling connections, screw in thermometers and pressure gauges, warm up the fuel pumps, and open valves to the fuel tanks. When the fueling detail is ready and has made all required checks and preparations, report to the Fueling Officer. The Fueling Officer will inform the bridge and request that the smoking lamp be out.
10. When you get word to start discharging fuel, start the pumps and operate them slowly at first, then bring them up to full-rated capacity. Build up a pressure of approximately 40 pounds per square inch (psi) at the fueling connections.
11. Continue pumping at the rated pump capacity until a tank is down to approximately 35 percent of its capacity; then shift pump suction to another tank. Slow the pumps and stop them upon a request from the receiving ship.

12. Remove FO from the fuel hose by blowing air through it, or the delivery ship may take a back suction. Disconnect the hoses and rig and handle them according to prescribed procedures.
13. Sound the tanks and compute the amount of fuel discharged.

PREVENTING OIL SPILLS

The preferred method to reduce and control environmental pollution is to prevent the pollution. We must integrate prevention measures into any planned industrial programs, operation, or product as part of the cost of daily operations. The following paragraphs discuss ways to prevent pollution caused by oil spills.

Before you start any fueling, defueling, or internal transfer operation, check all machinery and piping systems for tightness and for signs of leaking glands, seals, and gaskets. When you change oil or add oil to machinery, take care not to spill the oil into the bilge. Keep a drip pan and rags ready for use if needed. Keep a close watch on centrifugal purifiers when they are in operation to make sure they do not lose the water seal and dump the oil into the bilge or contaminated oil tank.

When you deballast, keep a careful watch on the overboard discharge to make sure that no oil is pumped overboard with the water from the ballast tanks.

Pump all oily waste from tank cleaning operations into a sludge barge.

Control of shipboard oil pollution is complicated by the many and varied sources of oily waste. The Navy is incorporating oil pollution control systems and components into its ships that will reduce oil pollution by the following means:

- Reduce the generation of oily waste.
- Store waste oil and oily waste.
- Monitor oil and oily waste.
- Transfer or offload waste oil and oily waste to shore facilities.
- Process oily waste.

Environmental Pollution Control

Environmental pollution is the condition that results when chemical, physical, or biological agents in the air, water, or soil alter the natural environment in a way that an adverse effect is created on human health or comfort, aquatic resources, plant life, or structures and equipment. The adverse effects of environmental pollution are economic loss, impaired recreational opportunity, and marred natural beauty.

Because oil pollution has a serious effect on our environment, there are strict regulations and water quality standards that apply to the navigable waters. Oil spill cleanup operations are both difficult and costly. Each year thousands of dollars are spent because of oil spills. The costs of oil spillage are not only counted in money. Each year, oil spillage affects our natural environment, damages the hulls of yachts or boats, pollutes our beaches, and destroys fish and wildlife. Much of this destruction can be avoided and many organizations, including the United States Navy, are doing as much as possible to prevent such pollution. Current oil and water pollution control regulations are defined in the *Environmental Readiness Program Manual,* OPNAVINST 5090.1(series). Navy ships must operate according to existing federal, state, and local regulations governing the oil content of shipboard water discharge overboard (effluent). Specific regulations applicable to Navy ships are as follows:

1. When the ship is operating within waters 50 nautical miles from the U.S. coast line, the discharge of oil is prohibited in such quantities as to cause a film or sheen upon or discoloration of the surface of the water of adjoining shorelines (discharges greater than 15 to

20 parts per million of effluent may create a sheen), or to cause a sludge or emulsion to be deposited beneath the surface of the water or upon the adjoining shorelines.

2. Navy vessels operating in internal waters and territorial seas (up to 12 nautical miles from land) of foreign countries must abide by oily waste discharge regulations that are specified in the applicable Status of Forces Agreement (SOFA). If no SOFA exists, vessels must operate consistent with the substantive oil waste discharge standards observed by the military forces of the host country. When the discharge standards for a foreign county are undefined, no oily waste shall be discharged within 50 nautical miles from land unless it is processed through an oil water separator (OWS). Ships not equipped with an OWS shall retain all oily waste for proper disposal to a shore facility.

The discharge of oil or any oil mixture is not deemed unlawful when such action is required for the safety of the ship or its cargo and for the saving of lives at sea. In addition, the escape of oil or any oily mixture is not considered to be unlawful if it results from damage to the ship or from unavoidable leakage. All reasonable precautions must be taken, after occurrence of the damage or discovery of the leakage, to keep the oil leakage to a minimum.

While in port, a U.S. Navy ship may dispose of oily bilge water by using one or more of the following methods:

- OWS system—ships equipped with bilge OWS systems should use the OWS unless prohibited by state standards or local port authorities.
- Oil disposal rafts (donuts) and oil ship waste offload barges (O-SWOBS)—ships not equipped with bilge OWS systems should use this method to transfer contaminated oil and oily waste.
- Permanent shore receiving facilities—where adequate oil waste collection lines are provided, contaminated oil and oily waste can be pumped directly ashore.

In the event of an oil spill, the Naval Sea Systems Command has developed a shipboard oil spill containment and cleanup kit for quick response “first aid” capability. Quick reaction by a trained crew (oil spill party) can result in containment, and often, collection of the entire spill. Additional information can be obtained in the *Environmental Readiness Program Manual,* OPNAVINST 5090.1(series), and the NSTM, Chapter 593.

The Training Officer must ensure that formal training is provided to key personnel who maintain and operate pollution control equipment. The Training Officer is responsible for training that achieves an acceptable level of expertise.

As a supervisor, you should be sure that all engineering personnel are familiar with the sources of oil spills and oil waste that may cause pollution. The following lists show common sources of oil and oily waste that find their way into the water.

1. Lubricating oil
    a. Leakage and drainage from equipment and systems
    b. Contaminated oil from centrifugal purifiers
    c. Used oil removed from equipment during an oil change
2. Fuel oil (FO)
    a. Spillage during fueling, defueling, and internal transfer operations
    b. Leakage through hull structures into bilges
    c. Stripping from the contaminated oil settling tank
    d. Ballast water from fuel tanks of non-compensated fuel systems or bulk carriers

e. Ballast water from compensated fuel tank systems during refueling, defueling, and internal transfer operations

f. Tank cleaning operations

3. Hydraulic fluids

a. Leakage from glands and seals into hydraulic pump room bilges

b. Spillage during system filling replenishment

c. Spillage caused by hydraulic system casualties

A schematic diagram of a typical shipboard oil pollution control system is shown in *Figure 19-1.*

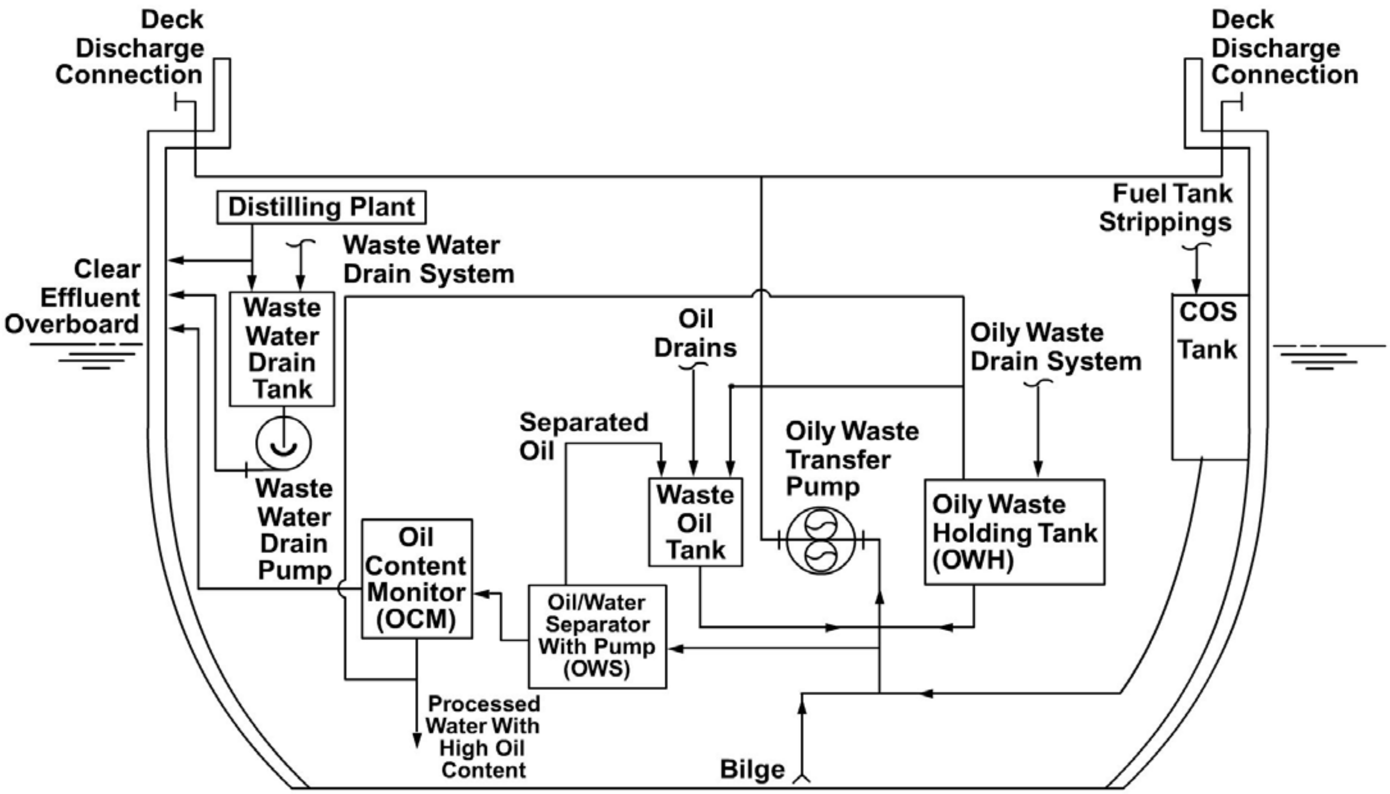

Figure 19-1 — Typical shipboard oil pollution control system.

HANDLING OIL SPILLS

All oil spills and slicks or sheens within the 50-mile prohibited zone of the United States shall be reported immediately according to the *Environmental Readiness Program Manual,* OPNAVINST 5090.1(series). Navy ships can now provide immediate remedial action on oil spills until they are relieved by shore-based response units. Because U.S. shore-based units are seldom available in non-Navy or foreign ports, a ship may have to clean up the entire spill.

A cleanup kit has been developed for use by the ship's crew. The *U.S. Navy Oil Spill Containment and Cleanup Kit,* NAVSEA 0994-LP-013-6010, contains a description of the kit and instructions for its use. The manual describes safety precautions for use of the kit as well as the recommended shipboard allowance. A trained crew that acts quickly can contain a spill and can often collect the entire spill without help from shore-based personnel.

SHIPBOARD SEWAGE AND WASTE DISPOSAL

The environmental harm caused by sewage discharges into rivers, harbors, and coastal waters by naval ships is of great concern. Secretary of Defense regulations require the Navy to control sewage discharges. Navy policies and responsibilities are defined in the *Environmental Readiness Program Manual,* OPNAVINST 5090.1(series).

The Navy intends that all naval ships will be equipped with marine sanitation devices (MSDs) that will allow them to comply with the sewage discharge standards without compromising mission capability. However, sewage discharge regulations do not forbid overboard discharge during an emergency when there is danger to the health and safety of personnel. In the past, shipboard sewage has been discharged overboard routinely. We changed that practice when evidence showed that concentrations of sewage in inland waters, ports, harbors, and coastal waters of the United States were bad for the environment.

In 1972, the Chief of Naval Operations (CNO) decided that the Navy would install the sewage collection, holding, and transfer (CHT) system (a type of MSD) aboard naval ships that could use that method of sewage pollution control without serious reduction in military capabilities. The CHT system represented the least cost and risk solution to the problem. Most operational fleet ships of sufficient size have CHT systems.

Navy ships have two types of CHT systems. The type used on a particular ship depends on the holding tank capacity. Systems with tanks with a capacity of more than 2,000 gallons use a comminutor and aeration system. Smaller systems with capacities of less than 2,000 gallons use strainers. The comminutor-type and the strainer-type CHT systems are shown in *Figures 19-2 19-3*.

The goal for the CHT system is to provide the capacity to hold shipboard sewage generated over a 12-hour period. Large ships can usually reach the goal, but smaller ships often reach their capacity in about 3 hours—probably not enough time to get outside the 3-mile restricted zone. Ships can get a waiver if they cannot reach the 12-hour holding time because of serious impact on military or operational characteristics. NSTM, Chapter 997, discusses sewage discharge procedures for ships in drydock.

The CHT system accepts soil drains from water closets and urinals, and waste drains from showers, laundries, and galleys. The three functional elements of sewage collection, holding, and transfer make up the CHT system.

The collection element consists of soil and waste drains with diverter valves. Depending on the position of the diverter valves, the soil or waste can be diverted overboard or into the CHT tank.

The holding element consists of a holding tank. The transfer element includes sewage pumps, overboard and deck discharge piping, and deck discharge fittings.

The CHT system can be used in any of three distinct modes of operation, depending on the situation.

- When the ship passes through restricted zones, the CHT system is set up to collect and hold discharges from the soil drains only.
- During in-port periods, the CHT system will collect, hold, and transfer to a shore sewage facility all discharges from the soil and waste drains.
- When the ship operates at sea outside restricted areas, the CHT system will be set up to divert discharges from soil and waste drains overboard.

NSTM, Chapter 593, has more information on the operation and maintenance of CHT systems.

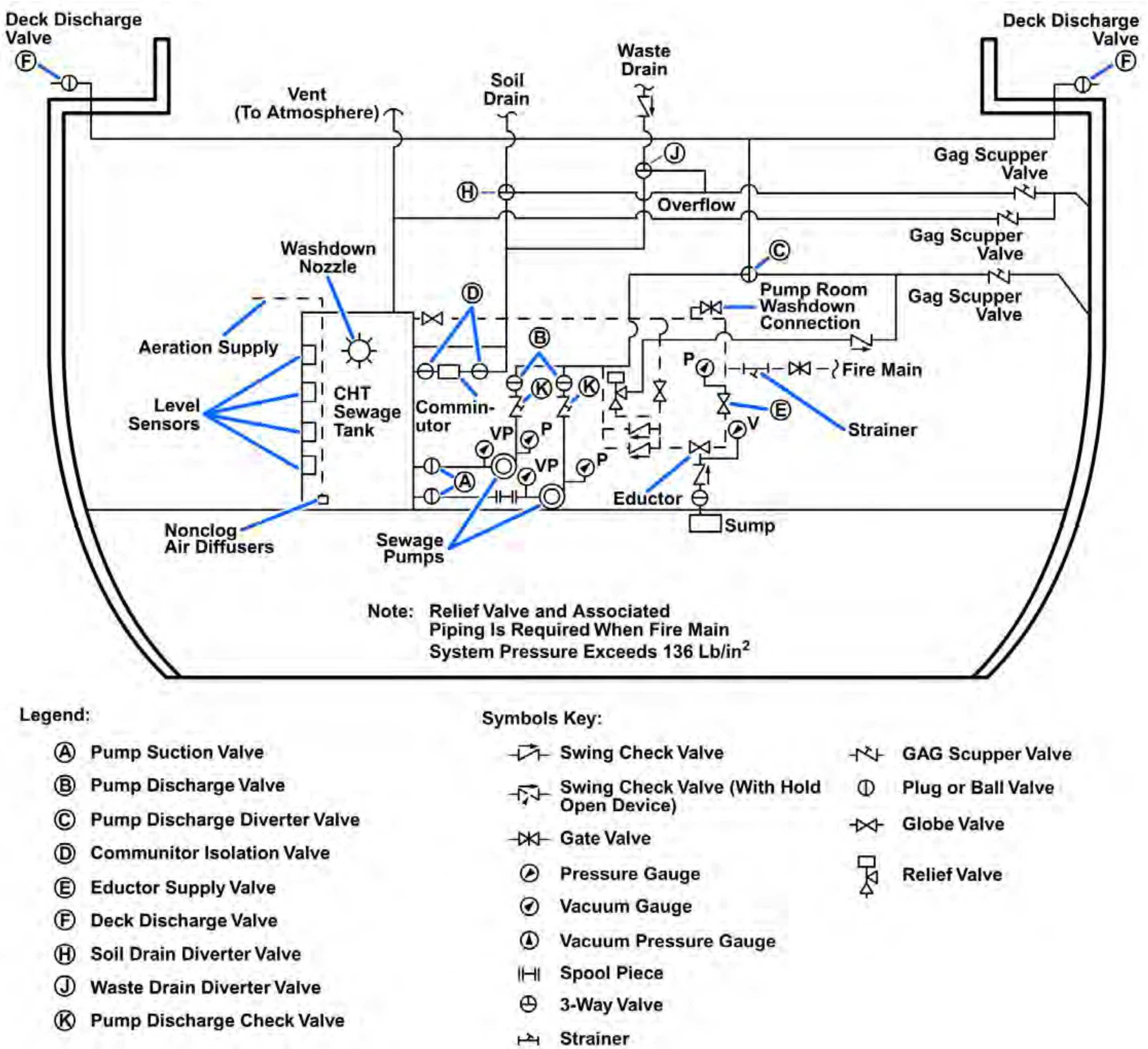

Figure 19-2 — Comminutor-type CHT system.

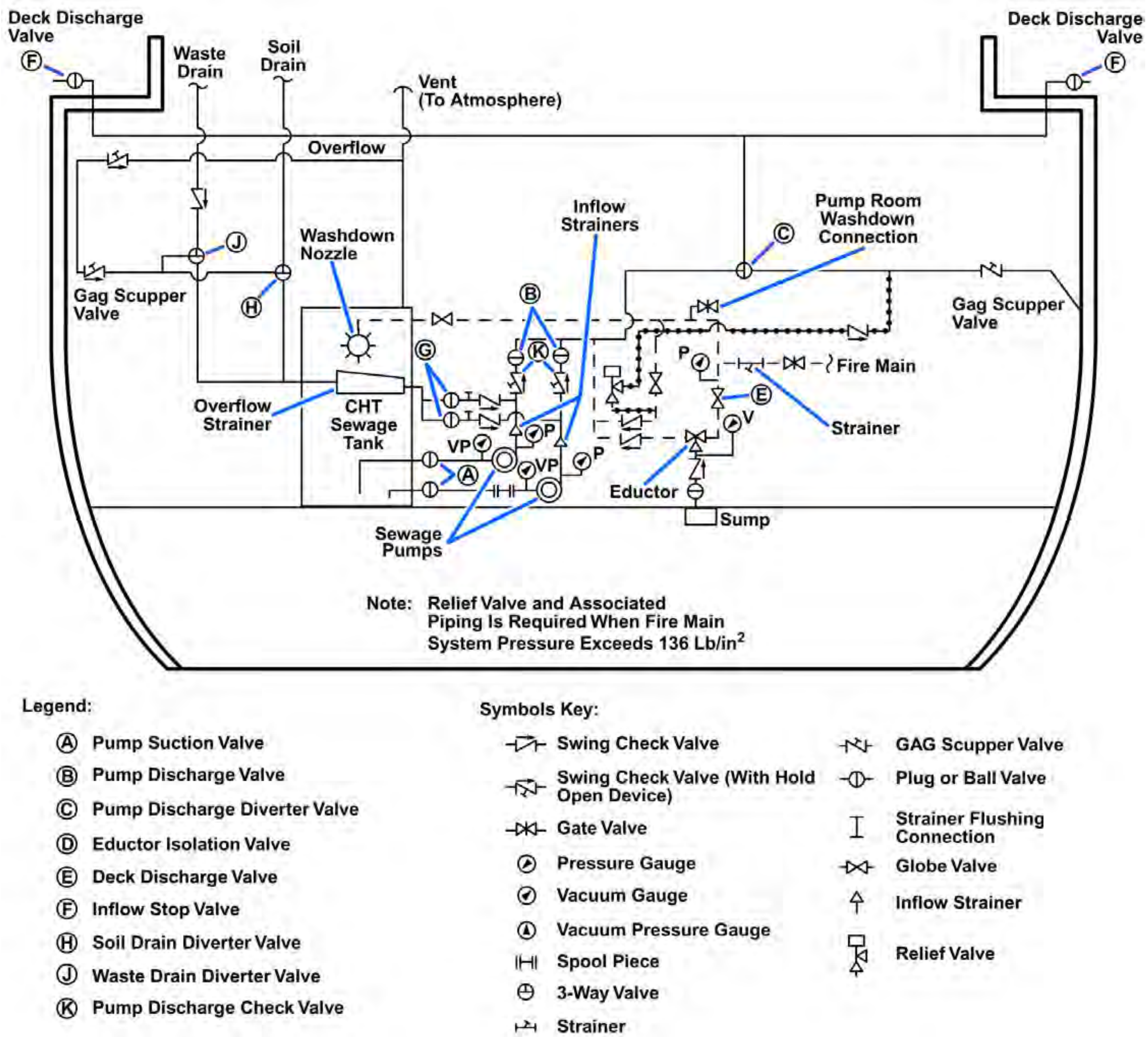

Figure 19-3 — Strainer-type CHT system.

BALLASTING SYSTEM

Whenever a liquid is shifted from one place to another aboard ship, there is an effect on the ship's list, trim, or stability. One of your routine jobs is to reduce any instability. To do that, you should keep as many FO tanks as possible filled with FO to the 95-percent level. There may be other times when you may have to use the ballasting system to move seawater to or from empty tanks. Normally, you will need to do move seawater only in case of damage or when the ship has an unusually small store of FO that brings on instability.

To keep the FO tanks at 95 percent capacity, you should accumulate leftover FO from partly used tanks so only those tanks actually in use are less than 95 percent full. This method prevents the free surface effect that occurs when a liquid only partly fills a tank and moves freely back and forth as the ship moves. There is some free surface effect when a tank is filled to the 95-percent level, but the effect is limited because the overhead interferes with the free movement of the liquid beyond a certain point. There is more danger of serious loss of stability from tanks that are half full than from tanks that are 95 percent full.

The ballasting system allows controlled flooding of certain designated tanks to control the ship's stability. You can use the ballasting system to flood all tanks that are designated as FO and ballast tanks and to flood certain voids. The ballasting and deballasting systems are arranged so all designated compartments and tanks can be ballasted either separately or together and drained either separately or together. Seawater is used as ballast, and it may be taken from the firemain or directly from sea chests. Use drainage pumps or eductors to remove the ballast water. Handle all ballasting and deballasting according to the sequence tables furnished for each ship or class of ship.

Ballasting empty FO tanks helps control stability by maintaining a low center of gravity in the ship and by keeping off-center tanks full to prevent off-center flooding. Ballasting also contributes to torpedo protection—it provides a layer of nonflammable liquid at the shell of the ship to absorb fragments and otherwise minimize torpedo damage.

Admit ballast water only to those tanks that are designated for ballasting. Be sure the tanks are empty of FO before you add ballast. After you have used water ballast in any tank, remove as much water as possible before you fill it with FO. Use the lower level suction lines for that purpose.

If your ship suffers collision or battle damage, the damage control aspects of the job may suddenly become vital. To make stability calculations, damage control central must have accurate information on the distribution of all liquids carried on board. To maintain or improve stability, they may order the immediate transfer of FO, feedwater, or other liquids. If you are the Oil King during such an emergency, you will not have time to learn your job or to catch up on details you may have forgotten or overlooked. You must ALWAYS know how much liquid is in all tanks and exactly how the FO or feedwater transfer systems must be lined up to shift liquids from tank to tank.

SUMMARY

In this chapter we covered the policies and instructions under which we work to protect and improve the environment, and covered an overview of the procedures we use to do so.

End of Chapter 19

Environmental Pollution Program and Policies

Review Questions

19-1. In what year did Congress pass a law prohibiting the discharge of refuse in navigable waters of the United States?

A. 1812
B. 1899
C. 1928
D. 1942

19-2. What act prohibits the discharge of oil or oily mixtures, such as ballast, within the prohibited zones established by any nation, and those zones ranging from 50 to 150 miles seaward from the nearest land?

A. The Oil Pollution Act of 1961
B. The Oil Pollution Act of 1978
C. The Water Quality Act of 1961
D. The Water Quality Act of 1978

19-3. What instruction contains guidelines to prevent, control, and abate air and water pollution?

A. *Clean Water and Air Program Manual*, OPNAVINST 5090.1(series)
B. *Clean Water and Air Program Manual*, SECNAVINST 5190.2
C. *Environmental and Natural Resources Protection Manual*, SECNAVINST 5190.2
D. *Environmental and Natural Resources Protection Manual*, OPNAVINST 5090.1

19-4. Over how many miles from shore must you be in order to discharge trash and garbage?

A. 12
B. 15
C. 20
D. 22

19-5. The Navy replaced fuel oil (FO) with what fluid, which reduces air pollution because it has low sulfur content and burns more cleanly?

A. Distillate
B. Ethanol
C. Lube oil
D. Water

19-6. What publication lists safety precautions for closed or poorly ventilated compartments?

A. OPNAVINST 5090.1
B. OPNAVINST 5290.2
C. *Naval Ships' Technical Manual (NSTM)*, Chapter 074
D. *Naval Ships' Technical Manual* (*NSTM*), Chapter 230

19-7. As a safety precaution, when ships are refueled where the ambient temperature is below 40 °F, you should NOT fill storage tanks above what percent of capacity?

A. 65
B. 75
C. 85
D. 95

19-8. Regarding the immediate reporting of oil slicks and spills or sheens, the prohibited zone of the United States is how many miles?

A. 12
B. 25
C. 50
D. 75

19-9. What publication defines the policies and procedures for dealing with sewage discharge?

A. *Clean Water and Air Program Manual*, OPNAVINST 5090.1(series)
B. *Clean Water and Air Program Manual*, SECNAVINST 5190.2
C. *Environmental and Natural Resources Protection Manual*, SECNAVINST 5190.2
D. *Environmental and Natural Resources Protection Manual*, OPNAVINST 5090.1

19-10. What system is installed on Navy ships to comply with the sewage discharge standards without compromising mission capability?

A. Marine abatement controller (MAC)
B. Marine sanitation devices (MSDs)
C. Sanitation and waste purifier
D. Sewage storage and filtration

19-11. In what year did the Chief of Naval Operations (CNO) decide that the Navy would install the sewage collection, holding, and transfer (CHT) system?

A. 1948
B. 1965
C. 1972
D. 1978

RATE TRAINING MANUAL – User Update

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Rate____ Course Name____

Revision Date__________ Chapter Number____ Page Number(s)____________

Description

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(Optional) Correction

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CHAPTER 20

ADVANCED ADMINISTRATION, SUPERVISION, AND TRAINING

The higher you go in the Navy, the more responsibility you will have for administration, supervision, and training. This chapter deals briefly with some of your administrative and supervisory responsibilities and then takes up certain aspects of your responsibility for training others.

Although it is possible to consider administration, supervision, and training as three separate areas of responsibility, it is important to remember that the three cannot be totally separated. Much of your work requires you to administer, supervise, and train, all at the same time. As a supervisor you will oversee the work and make sure it is done correctly. As a trainer, you will provide information and instruction on repair parts, repair procedures and policies, safety precautions, and other matters. The only way to keep things running smoothly is to take your administrative, supervisory, and training responsibilities seriously.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain engineering management programs.
2. Discuss engineering records and logs.
3. Discuss inspection and trials for the engineering department.
4. Explain Engineering Operational Sequencing System (EOSS) manual.
5. Discuss the maintenance and repair responsibilities in the engineering department.
6. Explain the utilization of Quality Assurance (QA) repair forms.
7. Discuss health and safety program use in the engineering department.

ENGINEERING MANAGEMENT PROGRAMS

As an engineman (EN), you will have administrative and supervisory responsibilities in connection with engineroom and auxiliary operations and with equipment maintenance and repair. The engineering department administrative organization is set up to provide a means for the proper assignment of duties and for the proper supervision of personnel.

However, no organization can run itself. Personnel—including you—are needed to see that all pertinent instructions are carried out; that all machinery, equipment, and piping systems are operated in accordance with good engineering practice; that operating instructions and safety precautions are posted near the machinery and obeyed by all engineroom personnel; that all watch standers are properly supervised; that records and reports are filled in correctly and submitted as required; and that the entire engineering plant is operated with maximum reliability, efficiency, and safety.

In order for you to monitor and record your plant's status and performance, you need to know which engineering records and reports for the administration, maintenance, and repair of naval ships are prescribed by directives from such authorities as the type commander (TYCOM), Naval Ship Systems Command (NAVSHIPS), and Chief of Naval Operations (CNO). These records must be accurate and up to date in accordance with current instructions.

As an engineman third class (EN3) and engineman second class (EN2), you have been primarily concerned with operating logs and similar records. As an engineman first class (EN1) or engineman chief (ENC), you will have new supervisory duties, which will require that you have a greater knowledge of engineering paperwork and the associated administrative procedures. Supervisory duties and responsibilities require knowledge of not only engineering records but also inspections, administrative procedures, training, preventive maintenance, and repair procedures.

Information on the most common engineering records and reports is given in this chapter. These standard forms are prepared by the various systems commands and CNO. The forms are for issue to forces afloat and can be obtained as indicated in the *Navy Stock List of Forms and Publications,* NAVSUP 2002. Since these forms are revised as conditions warrant, personnel ordering forms must be sure that the most current forms are obtained. When complementary forms are necessary for local use, make certain that an existing standard form will not serve the purpose before having complementary forms prepared and printed.

LEGAL ENGINEERING RECORDS

The Engineering Log and the Engineer's Bell Book are the only legal records compiled by the engineering department. The Engineering Log is a midnight-to-midnight record of the ship's engineering department. The Engineer's Bell Book is a legal record of any order regarding change in the movement of the propellers.

Engineering Log

The Engineering Log, Naval Sea System Command (NAVSEA) 3120/2 *(Figure 20-1),* and the Log Continuation Sheet, NAVSEA 3120/2A, are used to record important daily events and data pertaining to the engineering department and the operation of the engineering plant. A table is provided in the log for recording the hourly average revolutions per minute (rpm) (to the nearest tenth) of all shafts and the resultant speed, in knots. Additional tables and spaces are provided for recording the ship's draft and displacement (upon getting underway and anchoring or mooring); the total engine miles steamed for the day and the distance traveled through water; the number of days out of dock; the amount of fuel, water, and lubricating oil on hand, received, and expended; the name of the ship, the date, and the location or route of the ship; and remarks chronicling important events.

Entries in the Engineering Log must be made in accordance with instructions given (1) on the log sheet (NAVSEA 3120/2); (2) in *U.S. Navy Regulations,* Chapter 10; (3) in *Naval Ships' Technical Manual (NSTM),* Chapter 079, Vol. 3; and (4) in directives of the TYCOM.

Remarks written in the Engineering Log must include the following:

1. Boilers in use
2. Engine combination in use
3. Major speed changes
4. All injuries to personnel
5. Casualties occurring to equipment
6. Start/Stop of equipment

Each entry must be a complete statement and employ standard phraseology. The TYCOM's directives contain other specific requirements pertaining to the "remarks" section of Engineering Logs for ships of the type; the Engineer Officer must ensure compliance with these directives.

ENGINEERING LOG (9-77 EDITION
NAVSEA 3120/2B (REV. 10-81) S/N 0116-LF-031-2115 IS OBSOLETE) CLASSIFICATION

U. S. S.					HULL NUMBER
DAY	MONTH	YEAR	TIME	TIME ZONE CHANGE TO	TIME ZONE CHANGE FROM
AT/PASSAGE FROM				PASSAGE TO	TOTAL MILES TRAVELED TODAY

EQUIPMENT STATUS *(Need not be completed for continueing pages)*

MAIN ENGINES	PLANT STATUS	BOILERS

GENERATORS	STEERING ENGINES COMBINATION

DAYS OUT OF DRY DOCK	CATAPULT STATUS *(CV'S Only)*	DAYS SINCE LAST HULL CLEANING

DRAFT FWD	DRAFT AFT	DRAFT MEAN	TONS

LIQUID LOAD	PERCENT OF FULL LOAD (%)

MAJOR EQUIPMENT OUT OF COMMISSION

EXAMINED DAILY AND CERTIFIED TO BE CORRECT

SIGNATURE OF ENGINEER OFFICER/RANK	DATE OF SIGNATURE

TIME	RECORD OF ALL EVENTS OF THE DAY	DAY	MONTH	YEAR

CLASSIFICATION PAGE NO.

(Leave back side blank)

Figure 20-1 — An example of an Engineering Log.

The original Engineering Log, prepared neatly and legibly in ink, is the legal record. The remarks should be prepared—and must be signed—by the engineering officer of the watch (EOOW) (underway) or the engineering department duty officer (in port). No erasures are permitted in the log. When a correction is deemed necessary, a single line is drawn through the original entry so that the entry remains legible and the correct entry is inserted in such a manner as to ensure clarity and legibility. Corrections, additions, or changes are made only by the person required to sign the log for the watch and are initialed by the person on the margin of the page.

The Engineering Officer verifies the accuracy and completeness of all entries and signs the log daily. The Commanding Officer (CO) approves the log and signs the log on the last calendar day of each month and on the date he relinquishes command. The Engineering Officer should require that the log sheets be submitted to him in sufficient time to allow him to check and sign them prior to noon of the first day following the date of the log sheet(s).

When the CO (or Engineering Officer) directs a change or addition to the Engineering Log, the person concerned must comply unless he believes the proposed change or addition to be incorrect; in this event the CO (or Engineering Officer) enters such remarks over his signature as he deems appropriate. After the log has been signed by the CO, no change is permitted without his permission or direction.

Completed Engineering Log sheets are filed in a post-type binder. Pages of the log are numbered consecutively with a new series of page numbers commencing with the first day of each calendar year.

Engineer’s Bell Book

The Engineer’s Bell Book, NAVSEA 3120/1 *(Figure 20-2),* is a record of all bells, signals, and other orders received by the Throttleman regarding movement of the ship’s propellers. Entries are made in the Bell Book by the Throttleman (or an assistant) as soon as an order is received. Entries may be made by an assistant when the ship is entering or leaving port, or engaging in any maneuver, which is likely to involve numerous or rapid speed changes. This procedure allows the Throttleman to devote his undivided attention to answering the signals.

The Bell Book is maintained in the following manner:

1. A separate bell sheet is used for each shaft each day, except where more than one shaft is controlled by the same throttle station, in which case the same bell sheet is used to record the orders for all shafts controlled by the station. All sheets for the same date are filed together as a single record.
2. The time of receipt of the order is recorded in column 1 *(Figure 20-2).*
3. The order received is recorded in column 2. Minor speed changes (generally received via revolution telegraph) are recorded by entering the number of rpm ordered. Major speed changes (normally received via engine order telegraph) are recorded using the following symbols:

    1/3 — ahead 1/3 speed

    2/3 — ahead 2/3 speed

    I — ahead standard speed

    II — ahead full speed

    III — ahead flank speed

    Z — stop

    B1/3 — back 1/3 speed

ENGINEER'S BELL BOOK - ALL VESSELS
NAVSEA 3021/1 (12-75)
(Formerly NAVSHIPS 3120/1)

ENGINEER'S BELL BOOK

D	A	SHIP TYPE	HULL NUMBER	SHEET SERIAL	YEAR	MONTH	ZONE	DAY
1	2	3 - 4	3 - 4	10-11	12	13-14	15	16-17

Ship Name ______ J

SHAFT NUMBER(S)				CLASS	HANDL
1	2	3	4	78	09

Record of all "BELLS," SIGNALS, and ORDERS received regarding movement of propellers this date

En Route from ______ to ______ Clock set back or ahead ______ hrs. ______ min, at ______

(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET	(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET	(1) TIME	(2) SIGNAL	(3) R.P.M.	(4) COUNTER OR PITCH SET

S/N 0116-LF-030-2000

Figure 20-2 — An example of the Engineer's Bell Book, NAVSEA 3120/1.

B2/3 — back 2/3 speed

BF — back full speed

BEM — back emergency speed

4. The number of revolutions corresponding to the major speed change ordered is entered in column 3.

> **NOTE**
>
> When the order received is recorded as rpm in column 2 (minor speed changes), no entry is made in column 3.

5. The shaft revolution counter reading (total rpm) at the time of the speed change is recorded in column 4. The shaft revolution counter reading—as taken hourly on the hour, while underway—also is entered in column 4.

Ships and craft equipped with controllable reversible pitch propellers record in column 4 the propeller pitch in feet and fractions of feet set in response to a signaled speed change, rather than the shaft revolution counter readings. The entries for astern pitch are preceded by the letter B. Each hour on the hour, entries are made of counter readings, thus facilitating the calculation of engine miles steamed during those hours when the propeller pitch remains constant at the last value set in response to a signaled order.

Before going off watch, the EOOW signs the Bell Book on the line following the last entry for his watch and the next EOOW continues the record immediately thereafter. In machinery spaces where an EOOW is not stationed, the bell sheet is signed by the watch supervisor.

The Bell Book is maintained by bridge personnel in ships and craft equipped with controllable reversible pitch propellers, and those in which the engines are directly controlled from the bridge. When control is shifted to the engineroom, however, the Bell Book is maintained by the engineroom personnel. The last entry made in the Bell Book on the bridge indicates the time that control is shifted; and the first entry made in the Bell Book in the engineroom indicates the time that control is taken by the engineroom. Similarly, the last entry made by engineroom personnel indicates when control is shifted to the bridge. When the Bell Book is maintained by the bridge personnel, it is signed by the Officer of the Deck (OOD) in the same manner as prescribed for the EOOW.

Alterations or erasures are not permitted in the Bell Book. An incorrect entry is corrected by drawing a single line through the entry and recording the correct entry on the following line. Deleted entries are initialed by the EOOW, the OOD, or the watch supervisor, as appropriate.

Operating Orders

The Engineering Officer issues two important operating orders: the steaming orders and the night orders.

Steaming Orders

Steaming orders are written orders issued by the Engineering Officer. They list the major machinery units and readiness requirements of the engineering department based upon the time set for getting the ship underway. The orders normally specify the following information:

1. The engine combinations to be used
2. Times for lighting fires and cutting-in boilers
3. Times for warming up and testing main engines

4. Times for starting and paralleling ship's service generators
5. Standard speed
6. EOOW and principal watch supervisors

Steaming orders should be posted early to get a ship with a large engineering plant underway with minimum confusion.

Engineering Officer's Night Order Book

The Engineering Officer keeps a Night Order Book, which is preserved as a part of the engineering records. The Engineering Officer's orders are entered with respect to (1) operation of the engineering plant, (2) any special orders or precautions concerning the speed and operation of the main engines, and (3) all other orders for the night for the EOOW. The Night Order Book is prepared and maintained according to instructions issued by the TYCOM. Some instructions specify that the Night Order Book use a specific format that is standard for ships of the type. Other commands allow use of a locally prepared (mimeographed) form but specify certain contents of the book.

The Engineering Officer's Night Order Book must contain orders covering routine situations of a recurring nature (engineering department standing orders) as well as orders for the night for the EOOW. Standing orders are issued by the Engineering Officer as a letter-type directive (instruction), according to the ship's directives system. A copy of the instruction is posted in the front of the Night Order Book. Orders for the night for the EOOW generally specify the boilers and other major items of machinery to be used during the night watches.

The Night Order Book is maintained in port and at sea. In the temporary absence of the Engineering Officer in port, the book may be maintained by the engineering department duty officer. Underway, the Night Order Book is delivered to the EOOW before 2000 and is returned to the log room before 0800 of the following day. In addition to the EOOW, principal engineering watch supervisors and the Oil King should read and initial the night orders for the watch. In port, the night orders should be read and initialed by each leading duty petty officer of each engineering division. Each watch supervisor will also read and initial the Night Order Book.

Operating Records and Reports

Engineering operating records are meant to ensure regular inspection of operating machinery and to provide data for performance analysis. Operating records are not intended to replace frequent inspections of operating machinery by supervisory personnel and are not to be trusted implicitly to provide warning of impending casualties. Personnel who maintain operating records must be properly indoctrinated. They must be trained to correctly obtain, interpret, and record data, and to report any abnormal conditions noted.

The TYCOM's directives specify which engineering operating records will be maintained and prescribe the forms to be used when no standard record forms are provided. The Engineering Officer may require additional operating records when (all factors considered—including the burden of added paperwork) he deems them necessary.

The operating records discussed in this chapter are generally retained on board for a period of 2 years, after which time they may be destroyed in accordance with current disposal regulations. Completed records must be stowed where they will be properly preserved, and in such a manner as to ensure that any one of the records can be easily located.

Diesel Engine Operating Record

For all ships, the Diesel Engine Operating Record, NAVSEA 9231/2 *(Figure 20-3, frames 1 and 2),* is a daily record maintained for each operating diesel engine. In ships with more than one main engine in the same engineroom, a separate record sheet is maintained for each operating engine.

DIESEL ENGINE OPERATING RECORD-ALL SHIPS

NAVSEA 9231/2 (9-78) (FORMALLY NAVSEC 94 10/2) S/N 0116-LF-092-3110 RETAIN 2 YEARS - THEN DISPOSE ACCORDING TO CURRENT DISPOSAL INSTRUCTIONS

CHECK ONE ☐ PROPULSION ☐ AUXILIARY ENGINE NO. ______ *Preferred to 30" Barometer **DISREGARD WHEN NOT REQUIRED**

TIME	TACHOMETER	GENERATOR ELECTRIC LOAD AMPS.	GENERATOR ELECTRIC LOAD VOLTS	GENERATOR TEMPERATURE AIR TO CLR.	GENERATOR TEMPERATURE FWD. BRG.	GENERATOR TEMPERATURE FWD. BRG.	TEMPERATURES SALT WATER INJECTION	TEMPERATURES SALT WATER OVER-BD	TEMPERATURES FRESH WATER TO ENG.	TEMPERATURES FRESH WATER FROM ENG.	TEMPERATURES FRESH WATER TO OIL CLR.	TEMPERATURES LUBE OIL TO ENG.	TEMPERATURES LUBE OIL FROM ENG.	TEMPERATURES HOTTEST CYLINDER NO.	TEMPERATURES HOTTEST CYLINDER TEMP.	TEMPERATURES SCAV-ENG-ING AIR	PRESSURES SEA-WATER AT PUMP	PRESSURES FRESH WATER TO ENG.	PRESSURES LUBE OIL AT PUMP	PRESSURES LUBE OIL AT ENG.	PRESSURES FUEL OIL TO FILT.	PRESSURES FUEL OIL FROM FILT.	PRESSURES SCAV-ENG-ING AIR	PRESSURES BACK PRES-SURE (IN.)	PRESSURES VAC-*UUM (IN.)	PRESSURES CRANK CASE MA-MOM-ETER (IN.)	LUBE OIL SUMP (GAL.)	CLUTCH AND REDUCTION GEAR L.O. IN CLUTCH (°F)	L.O. OUT CLUTCH (°F)	L.O. IN R. GEAR (°F)	L.O. OUT R. GEAR (°F)	L.O. OR AIR IN CLUTCH (°F)	L.O. IN R. GEAR (PSI)
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ENGINE HOURS	THIS COMMISSION TOTAL TODAY	BROUGHT FWD.	TOTAL	SINCE OVERHAUL TOTAL TODAY	BROUGHT FWD.	TOTAL	SNORKEL TOTAL TODAY	BROUGHT FWD.	TOTAL

0000-0400	1800-2000	2000-2400

CHECKED ENG. APPROVED ENGINEERING OFFICER, U. S. N.

Figure 20-3 — Diesel Engine Operating Record (All ships).

The watch supervisor enters the remarks and signs the record for his watch. The petty officer in charge of the engineroom or the senior EN checks the accuracy of the record and signs the record in the space provided on the back of the record. Any unusual conditions noted in the record are immediately reported to the Engineering Officer, and the record is sent to the Engineering Officer for approval.

Fuel and Water Accounts

The maintenance of daily diesel fuel, lubricating oil, and water accounts is vital to the efficient operation of the engineering department. Forms and procedures necessary to account for and preserve a limited supply of freshwater and fuel are generally prescribed by the TYCOMs.

Principally, the accounts inform the Engineering Officer of the status of the ship's liquid load and form the basis of reports submitted to higher authority by the Engineering Officer.

It is fundamental to all naval operations that the ship and unit commanders know the exact amount of burnable fuel on hand. When computing the amount of burnable fuel on board, consider only the fuel in the service and storage tanks. All the fuel below the fuel suction line is to be considered not burnable.

Fuel and Water Reports

The Fuel and Water Report, NAVSEA 9255/9 *(Figure 20-4, frames 1 and 2),* is a report submitted daily to the CO. This report indicates the amount of fuel oil and water on hand as of midnight, the previous day. The Fuel and Water Report also includes the previous day's feed and potable water performance and results of water tests. The original and one copy are submitted to the OOD in sufficient time for submission to the CO or command duty officer with the 1200 reports. The copy is retained by the OOD.

Disposal of Engineering Records and Reports

Before any of the engineering department records are destroyed, *the Navy and Marine Corps Disposition Manua*l, *USN and USNS Vessels*, SECNAVINST P5212.5(series), should be studied. This publication explains the procedures for disposing records on Navy ships for each department aboard ship, these instructions list the permanent records that must be kept, and the temporary records that may be disposed of in accordance with an established schedule.

Both the Engineering Log and Engineer's Bell Book must be preserved as permanent records on board ship for a 3-year period unless they are requested by a Naval Court or Board, or by the Navy Department. In such case, copies (preferably Photostatic) of such sheets or parts of these records that are sent away from the ship are certified by the Engineering Officer as being true copies for the ship's files.

At regular intervals, such as each quarter, the parts of those records that are over 3 years old are destroyed. When a ship that is less than 3 years old is decommissioned, the current books are retained. If a ship is scrapped, the current books are forwarded to the nearest Naval Records Management Center.

All reports forwarded to, and received from, NAVSEA or other superior command may be destroyed when 2 years old, if they are no longer required.

Only those reports that are required or serve a specified purpose should be maintained on board ship. However, any report or record that may assist personnel in scheduling or making repairs and that will supply personnel with information not contained in publications or manuals should also be kept on board.

Trend and Spectrographic Analysis

Two types of inspections and tests that can be used to "spot" impending trouble in an internal combustion engine before it can seriously affect its operation are called trend and spectrographic analyses. We will now discuss and explain their importance and use in detecting problems in internal combustion engines.

Engine Trend Analysis

Preventive maintenance receives a great deal of attention from everyone in the field of diesel engine operation, since the idea of letting an engine run as long as it will run and fixing it only after a breakdown occurs is not only foolish, but extremely costly. You should know that vital parts of engine last longer and operate better if they are not tampered with unnecessarily.

One way is to determine the condition of an engine is by monitoring its operation. This is done by regularly obtaining certain engine operating data to study, analyze, and compare with previous data. This information is then reduced to a form that all engineering personnel can interpret and, based on the findings, decide whether the engine needs to be overhauled in order to ward off serious and costly damage or just temporarily shut down for some simple maintenance.

FUEL AND WATER REPORT

DATE ______________

TO: COMMANDING OFFICER, USS

	FUEL (gallons)		LUBE OIL STORAGE TANKS (gallons)		WATER (gallons)	
	BOILER/GT FUEL	DIESEL FUEL/ JP-5	2190	9250/23699	POTABLE	RESERVE FEED
ON HAND LAST REPORT						
RECEIVED (+)						
DISTILLED (+)						
EXPENDED (−)						
GAIN (+) LOSS (−) BY INVENTORY						
ON HAND THIS REPORT						
ON HAND %						

POTABLE WATER RECORD		
PERSONNEL ON BOARD	GALLONS USED PER PERSON	STANDARD

FEEDWATER CONSUMPTION	
NOT UNDERWAY (gallons per hour)	UNDERWAY (gallons per hour)

REMARKS:

NAVSEA 9255/9 (6−94)(FRONT) NSN 0116−LF−018−2600

Figure 20-4 — Fuel and Water Report.

The key to utilizing engine performance data as a tool is to make graphs from the data that show at a glance the signs of impending distress. Analysis of this graphical display is commonly called trend analysis.

To get a good indication of the engine condition, the following specific items are recorded:

1. Cylinder compression pressures.
2. Cylinder firing pressures.
3. Fuel pump rack or governor power piston position.
4. Cylinder exhaust temperature.
5. Crankcase vacuum.
6. Lubricating oil pressure at engine inlet or upper header.
7. Manifold air or scavenging air pressure.

To produce meaningful graphs, all data must be plotted under the same conditions and be obtained at some readily duplicated condition. It is not important that the engine be under full load at full speed when taking data, but it is important that all data be obtained under similar conditions. For example:

1. Always obtain data from generator sets at 80% load and 100% speed.
2. Always obtain data from propulsion engines (for example, standard or full).

Data need not be plotted daily. In most cases, a set of readings should be plotted every 200 hours of operation. In some cases it may be prudent to repeat a set of readings when a large change in operating characteristics has apparently occurred.

The first step in preparing the graphs for trend analysis is to collect the data. Data collection is done by observing and recording the above items with the engine operated at a selected type of condition for a sufficient time, prior to taking data, to allow pressures and temperatures to stabilize. (It can be assumed that conditions have stabilized when lube oil and freshwater temperatures are within ± 5° F of the normal operating temperatures.)

These data are then plotted on 10 × 10 lines per inch graph paper as shown on the examples *(Figure 20-5, frames 1 through 8).* For convenience, the first points are located at zero time for an engine that has just been overhauled or at the number of hours on the engine since the last overhaul (0, 400, 1000, 1600 hours, etc.). The first point for lube oil consumption occurs at 200 engine hours. This is done because it is easier to start with a full engine sump and monitor the amount of oil added each 200 hours to obtain the consumption rate. Once the initial points have been plotted, all that is required is to record and plot the same information each 200 hours and observe the trends that develop.

NOTE

Remember to always take data under the same controlled conditions!

A close look at the sample graphs will reveal how they can be used to determine engine condition. For purposes of illustration, the ideal trend of each graphed value is shown for a hypothetical engine. Unfortunately, the Navy does not have too many ideal engines so some samples of problem indications that may be expected are also included.

In *Figure 20-5, frames 1 and 2*, a high, average, and low value is plotted for both firing and compression pressures. Under normal conditions these curves will remain flat until the engine is approaching the time of overhaul ; then the curves will start to fall off. The high and low firing pressures will remain at about ± 50 psi (100 psi spread) from the average firing pressure for a well-balanced engine. If you look at *Figure 20-5, frame 1*, you can see that a decided drop in firing pressure has occurred at 1600 hours. This failure in the compressing pressures indicates that the rings are either sticking, broken, or beginning to wear; that the valves are not functioning properly; that the liner is beginning to score; or possibly that a piston has cracked. Remember that any change in a curve (beyond normal limits) indicates that immediate attention is required. At this point, it should be pointed out that more than one indicator will usually reveal the same distress signal. Therefore, before any corrective action is taken, it is best to make a study of other curves to deny or confirm the problem. In this case check the lube oil consumption, crankcase vacuum, and exhaust temperature curves. In *Figure 20-5, frames 2, 3, and 8*, the typical indications for this problem are marked as point A. All indications point to a definite internal problem in one cylinder. No rise in lube oil consumption is indicated *Figure 20-5, frame 8*, because a slightly worn set of rings or liner probably would not cause a measurable increase in lube oil consumption. The logs should now be consulted to find the problem cylinder and initiate appropriate repairs.

If only firing pressures and exhaust temperature are low, the fuel system should be checked on the problem cylinder.

The crankcase vacuum graph *(Figure 20-5, frame 3)* indicates ring, piston, or liner condition. As long as everything is normal, this curve will also be flat. A cracked piston or worn rings or liner will increase blow-by, causing decreased crankcase vacuum. If crankcase vacuum decreases with no change in other indicators, the crankcase scavenging system should be checked for proper operation. An increase in crankcase vacuum may be caused by a clogged intake screen.

The exhaust temperature graph *(Figure 20-5, frame 4)* indicates general cylinder conditions and engine balance, although this item is not necessarily a definite indication of trouble itself. Any abnormal temperature with no accompanying change in the various other indicators can usually be attributed to a faulty pyrometer. The pyrometer in question should then be carefully inspected and tested before any other inspections or adjustments are accomplished.

The lube oil pressure graph *(Figure 20-5, frame 5)* indicates the engine bearing condition, lube oil pump condition, piping conditions, by-pass relief valve conditions, etc. Lube oil pressure obtained at the upper header of Fairbanks Morse opposed piston engines is particularly useful in monitoring the condition of the internal portion of the lube oil system.

The manifold pressure graph *(Figure 20-5, frame 6)* indicates the condition of the scavenging system. Increased air box pressures indicate port clogging, while reduced air box pressures indicate some abnormality in the air intake systems, blower, or turbocharger. Both of these cases require immediate attention.

The fuel rack or governor power piston position graph *(Figure 20-5, frame 7)* indicates the general condition of the fuel system. Increased rack settings for a given power output indicate fuel pump deterioration or a decrease in engine combustion efficiency.

The lubrication oil consumption graph *(Figure 20-5, frame 8)* is for the lubricating oil consumption in gallons per 200 hours operation. It should be noted that the values on this curve are initially very high. They decrease and then remain nearly constant until the engine is approaching its overhaul time. The initial high consumption is due to unseated piston rings. As rings become seated, the consumption will decrease to a normal value and remain nearly constant until the rings or liners begin to wear. Any significant increase in lube oil consumption must be carefully evaluated to determine if the oil is really being consumed in the engine or is being lost because of external leaks. Too many times an engine is assumed to be at fault when lube oil is really being lost due to leakage.

A review of *Figure 20-5, frames 1 through 8,* will also indicate other problems that are not discussed in this text. Each sample problem is marked on the various graphs at the appropriate engine hours so a study of the samples can be made.

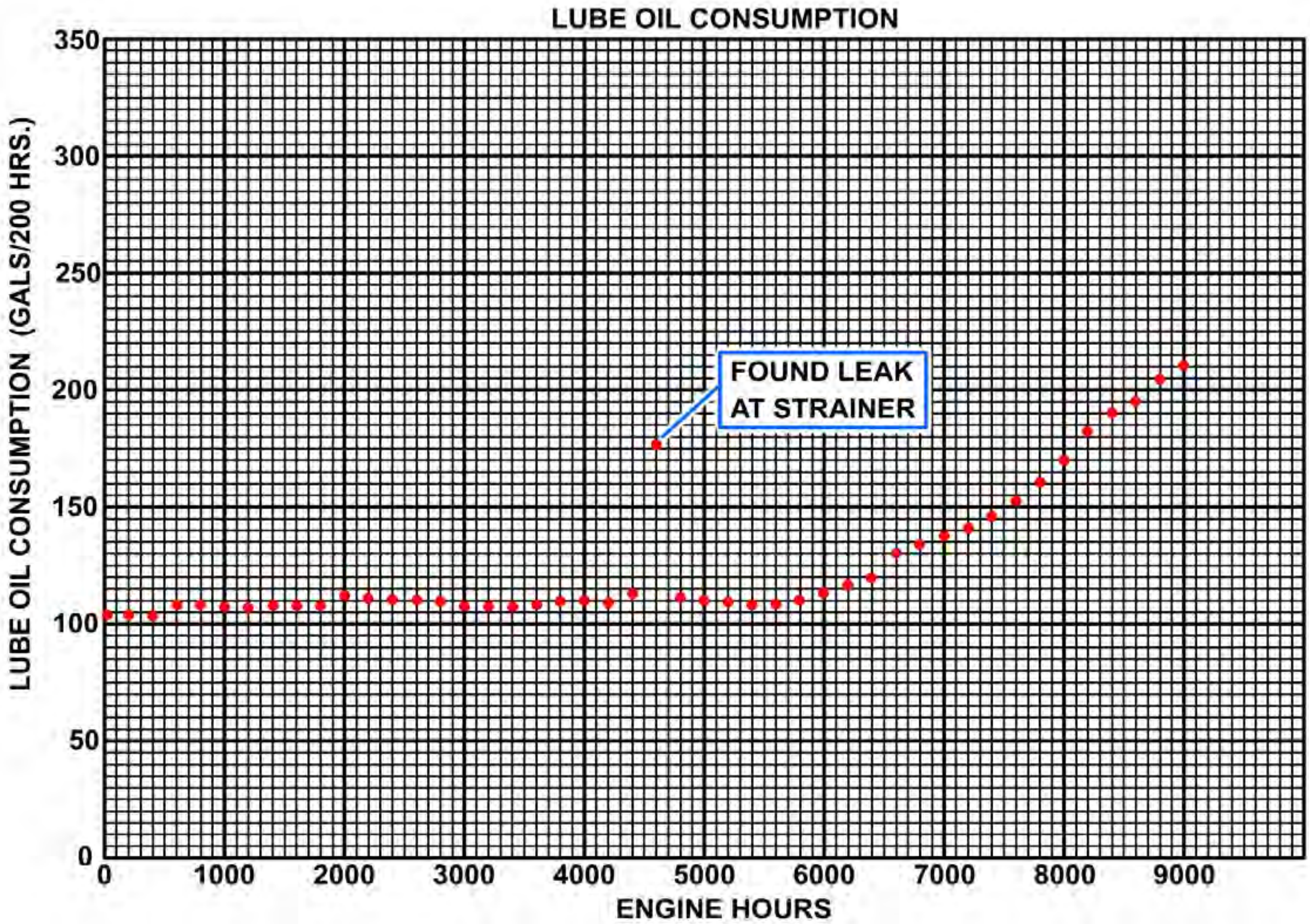

Figure 20-5 — Firing pressure graphs.

Operational graphs show the condition of the engine. They show what is happening, what needs to be done, and what has to be planned for in advance. The life expectancy of vital parts can be determined from these curves, and the parts can be renewed before they reach the point of failure.

The trend analysis program must be followed closely, especially during the initial period of the program when care must be taken to ensure that the data gathered are meaningful. However, if the condition of any particular engine indicates that an overhaul is required to maintain its operation, this should be accomplished at the earliest possible time.

Engine Lube Oil Analysis

Spectrometric oil analysis is another valuable tool that can be used to determine the extent of accelerated wear in internal combustion engines and other machinery that use closed lube oil or hydraulic oil systems. By the use of spectrometric oil analysis, the accelerated wear in machinery can be detected without disassembling the equipment long before there is any other indication of immediate trouble. As a result of this type of analysis, skilled maintenance personnel have been able to pinpoint wear areas early, and to take corrective and preventive maintenance action during an emergency or on a pre-planned basis as determined by the type of accelerated wear detected. By replacing worn out minor parts, a major failure can be prevented, and the requirement for costly parts replacements or complete overhaul of the equipment can be eliminated.

Ships shall maintain accurate records of operating hours since major overhauls, oil changes, and samplings in order to provide the testing facility with the information requested in the sampling kit.

Commander, Naval Surface Force Atlantic (COMNAVSURFLANT) uses the services of the Charleston Naval Shipyard and Commander; Naval Surface Force Pacific (COMNAVSURFPAC) uses Intermediate Maintenance Activities (IMA) for analyzing oil samples from machinery employing closed lube oil/hydraulic systems. In addition, a record of conditions found and repairs affected as a result of inspections conducted following recommendations of the laboratory must also be maintained.

When the shipyard or IMA laboratory receives the oil sample, a physical test and a spectrometric analysis are performed. The physical test consists of the following:

1. All samples are tested for fuel dilution, and a report is provided to all concerned by percent volume as per requirements of ASTM D92057.
2. All samples are tested for solids by centrifuge to show the amount of suspended particles separately from precipitated solids. The test must differentiate between those fine particles suspended by the active compounds in the oil and those that can settle out of the oil spontaneously to give a ratio of colloidal/precipitated solids.
3. Allowable “use limits” are tested and recorded.

Testing will be done for all the above elements.

The sensitivity and reliability of the equipment used for the test will be such that the standard deviation obtained in the analysis for each specified element must not exceed the appropriate value shown in *Table 20-1.*

Table 20-1 — Element and symbols

Iron (Fe)	Nickel (Ni)	*Sodium (Na)
Lead (Pb)	Silver (Ag)	Phosphorus (P)
Copper (Cu)	Tin (Sn)	Zinc (Zn)
Chromium (Cr)	Silicon (Si)	Calcium (Ca)
Aluminum (Al)	Boron (B)	Barium (Ba)
*Only when evidence of water is present.		

When the physical test is completed, the shipyard/IMAs should make a spectrometric analysis of each used oil sample, then record and report to all concerned the concentrations of the following elements in parts per million (ppm) *(Table 20-2)*.

Table 20-2 — Element Concentrations

ELEMENT CONCENTRATION IN STANDARD REFERENCE SPECIMEN (RANGE IN PPM)	STANDARD DEVIATION (MAXIMUM IN PPM)
3-9	1.5
10 - 19	2
20 - 49	3
50 - 99	5
100 - 199	8
200 - 500	15

Testing will be done for all the above elements.

The sensitivity and reliability of the equipment used for the test will be such that the standard deviation obtained in the analysis for each specified element must not exceed the appropriate value shown in *Table 20-2*.

Additional information on trend analysis and oil spectrometric analysis is contained in COMNAVSURFLANTINST 9000.1 or COMNAVSURFPACINST 4700.1(series).

Inspections and Trials

A naval ship must be inspected periodically to ensure that its operation, administration, and equipment reflect a high standard of readiness for war. The frequencies with which the various types of inspections are held are determined by the CNO, the fleet commander, and the TYCOM. For ships of a type, the TYCOM usually designates the type of inspection and when it will be held.

A ship is frequently notified some time in advance when an inspection will take place, but preparation for an inspection should not be postponed until the notice of inspection is received. It is a mistake to think that a poorly administered division or department can, by a sudden burst of energy, be prepared to meet the inspector's keen observation By using proper procedures, and keeping up to date on such items as repair work, maintenance work, operating procedures, training of personnel, engineering casualty control drills, maintenance records, and reports, you will always be ready for an inspection.

Since your ship may be required to furnish an inspecting party to make an inspection on another ship, you as a chief petty officer (CPO) or petty officer first class (PO1) may be assigned the duty as an assistant inspector. You should know something about the different types of inspections and how they are conducted.

Administrative Inspection

Administrative inspections cover administrative methods and procedures normally employed by the ship. Each inspection is divided into two general categories—the general administration of the ship as a whole, and the administration of each department. In this discussion we will consider the engineering department only.

The purpose of the administrative inspection is to determine whether (1) the department is being administered in an intelligent, sound, and efficient manner and (2) the organizational and administrative methods and procedures are directed toward the objective of every naval ship—namely, being prepared to carry out its intended mission.

Inspecting Party

It is a routine procedure for one ship to conduct an inspection of a similar division on another ship. General instructions for conducting the inspection are usually given by the division commander; however, the selecting and organizing of the inspecting party is done aboard the ship that must conduct the inspection.

The chief inspector, usually the CO of the ship, will organize the assisting board. The organization of the assisting board, in general conformance with the departmental organization of the ship, is divided into appropriate groups, each headed by an inspector with as many assistant inspectors as necessary. CPOs and PO1s may be assigned as assistant inspectors.

The engineering department inspecting group (or party) is organized and supervised by the Engineering Officer. The manner in which an individual inspection is carried out depends to a great extent upon the knowledge and ability of the members of the group (or party).

General Inspection of the Ship as a Whole

One of the two categories of administrative inspection is the general administration of the ship as a whole. Items of this inspection that will have a direct bearing on the engineering department, and for which the report of inspection indicates a grade, are as follows:

1. Appearance, bearing, and smartness of personnel.
2. Cleanliness, sanitation, smartness, and appearance of the ship as a whole.
3. Adequacy and condition of clothing and equipment of personnel.
4. General knowledge of personnel regarding the ship's organization, ship's orders, and administrative procedures.
5. Dissemination of all necessary information among the personnel.
6. Indoctrination of newly reported personnel.
7. General education facilities for individuals.
8. Comfort and conveniences of living spaces, including adequacy of light, heat, ventilation, and freshwater.
9. Economy of resources.

Engineering Department Inspection

The engineering department administrative inspection is primarily the inspection of the engineering department paper work, which includes publications, bills, files, books, records, and logs. Additionally, this inspection includes other items with which the CPO and PO1 must be concerned. Some of these items are the cleanliness and preservation of machinery and engineering spaces, the training of personnel, the assignment of personnel to watches and duties, the proper posting of operating instructions and safety precautions, the adequacy of warning signs and guards, the marking and labeling of lines and valves, and the proper maintenance of operating logs.

Administrative Inspection Checkoff Lists

Administrative inspection checkoff lists are usually furnished to the ships by the TYCOM. These lists help inspecting officers and chiefs ensure that no important item is overlooked. However, inspecting personnel should not accept these lists as all-inclusive, since usually during an inspection, additional items develop that must be considered or observed.

As a petty officer, you should be familiar with the various checkoff lists used for inspections. These checkoff lists will give you a good understanding of how to prepare for an inspection as well as how to carry out your daily supervisory duties. You will find it helpful to obtain copies of the various inspection checkoff lists from the log room and to carefully look them over. They will give detailed information about what type of inspection you may expect for your type of ship.

Following is an abbreviated sample of an engineering department checkoff list. You should get a better understanding of the scope and purpose of administrative inspections by reviewing this list.

1. BILLS FOR BOTH PEACE AND WAR:
   a. Inspect the following, among others, for completeness, correctness, and adequacy:
      (1) Department Organization.
      (2) Watch, Quarter, and Station Bills.
      (3) Engineering Casualty Bill.
      (4) Fueling Bill.

2. ADMINISTRATION AND EFFECTIVENESS OF TRAINING:

   a. Administration and effectiveness of training of personnel for current and prospective duties.

      (1) Are sufficient nonrated personnel in training to replace anticipated losses?

      (2) NAVEDTRA training courses:

         (a) Number of personnel enrolled.

         (b) Percentage of personnel in department enrolled.

         (c) Number of personnel whose courses are completed.

      (3) Are personnel concerned familiar with operating instructions and safety precautions?

      (4) Are personnel concerned properly instructed and trained to handle casualties to machinery?

      (5) Are personnel properly instructed and trained in damage control?

      (6) Are training films available and used to the maximum extent?

      (7) Are training records of personnel adequate and properly maintained?

3. DISSEMINATION OF INFORMATION WITHIN DEPARTMENT:

   a. Is necessary information disseminated within the department and divisions?

   b. Are the means of familiarizing new personnel with department routine orders and regulations considered satisfactory?

4. ASSIGNMENT OF PERSONNEL TO STATIONS AND WATCHES:

   a. Are personnel properly assigned to battle stations and watches?

   b. Are sufficient personnel aboard at all times to get the ship under way?

   c. Are personnel examined and qualified for important watches?

   d. Does it appear that personnel on watch have been properly instructed? (Question personnel at random.)

5. OPERATING INSTRUCTIONS, SAFETY PRECAUTIONS, PLANNED MAINTENACE SYSTEM (PMS), AND CHECKOFF LISTS:

   a. Inspect completeness of the following:

      (1) Operating instructions posted near machinery.

      (2) Posting of necessary safety precautions.

   b. Are PMS schedules properly posted and maintained in the working spaces?

   c. Is the Master PMS Schedule posted and up to date?

   d. Are responsible personnel familiar with current instructions regarding routine testing and inspections?

   e. Are lighting-off and securing sheets properly used?

6. PROCEDURES FOR PROCUREMENT, ACCOUNTING, INVENTORY, AND ECONOMY IN USE OF CONSUMABLE SUPPLIES, REPAIR PARTS, AND EQUIPAGE:

   a. Is an adequate procedure in use for replacement of repair parts?

   b. Are adequate measures used to prevent excessive waste of consumable supplies?

c. Is there proper supervision in the proper supply of, care of, and accountability for hand tools?

d. Are inventories taken of repair parts that are in the custody of the engineering department?

e. How well are repair parts preserved and stowed?

f. What type of system is used to locate a repair part carried on board? (Have a CPO or PO1 explain to you how a repair part for a certain piece of machinery is obtained.)

g. Are custody cards properly maintained for the tools and equipment accountable?

7. MAINTENANCE OF RECORDS AND LOGS:

a. Inspect the following for compliance with pertinent directives, completeness, and proper form:

(1) Engineering Log.

(2) Bell Book.

(3) Operating Records.

(4) Maintenance Records.

(5) Alteration and Improvement Program.

(6) Daily Oil and Water Records.

(7) Engineering Reports.

(8) Training Logs and Records.

(9) Work Books for Engineering Spaces.

8. AVAILABILITY AND CORRECTNESS OF PUBLICATIONS, DIRECTIVES, AND TECHNICAL REFERENCE MATERIAL:

a. Engineering blueprints recommended:

(1) Ship's Plan Index (SPI).

(2) Proper indexing of blueprints.

(3) Completeness and condition.

b. Manufacturers' instruction books:

(1) Proper indexing.

(2) Completeness and condition.

c. TYCOM Material Letters.

d. NSTM.

e. General Information Book.

f. Booklet Plans of Machinery.

9. CLEANLINESS AND PRESERVATION:

a. Preservation and cleanliness of space (including bilges).

b. Preservation and cleanliness of machinery and equipment.

c. Neatness of stowage.

d. Condition of ventilation.

e. Condition of lighting.

f. Compliance with standard painting instructions.

Operational Readiness Inspection

The operational readiness inspection is conducted to ensure that the ship is ready and able to perform the operations that might be required of it in time of war.

This inspection consists of the conduct of a battle problem and of other operational exercises. A great deal of emphasis is placed on damage control, engineering casualty control, and other appropriate exercises. Various drills are held and observed, and the ship is operated at full power for a brief period of time.

The overall criteria of performance include:

1. Can the ship as a whole carry out its operational functions?
2. Is the ship's company well trained, well instructed, competent, and skillful in all phases of the evolutions?
3. Is the ship's company stationed in accordance with the ship's Battle Bill, and does the Battle Bill meet wartime requirements?

Observing Party

The personnel and organization of the operational readiness observing party are similar to those of the administrative inspection party. However, more personnel are usually required for the operational readiness observing party. These additional personnel are very often CPOs and PO1s. The observing party members are briefed in advance of the scheduled exercises and about the drills that are to be conducted. They must have sufficient training and experience so that they can properly evaluate the exercises and drills that are to be held. Each observer is usually assigned to a specific station and should be well qualified in the procedure of conducting drills and exercises for that station. That each observer be familiar with the type of ship to be inspected is also highly desirable.

Battle Problems

In this discussion we will consider the battle problem from the viewpoint of the observer and present some general information on the requirements and duties of a member of the engineering department observing party. The knowledge of the viewpoint and duties of an observer should help you prepare yourself and your personnel for a battle problem and other appropriate exercises.

Preparation of a Battle Problem

The degree of perfection achieved in any battle problem is reflected in the skills and applications of those who prepare it. A great deal depends upon the experience of officers and CPOs.

The primary purpose of a shipboard battle problem is to provide a medium for testing and evaluating the ability of all divisions of the engineering department to function together as a team in simulated combat operations.

Battle problems are the most profitable and significant of all peacetime training experiences, since they demonstrate a department's readiness for combat. The degree of realism of this test determines its value: the more nearly it approximates actual battle conditions, the more valuable it is.

Another element in the conduct of a battle problem that significantly increases the value of these tests to the ship's company is the element of surprise.

Conduct of a Battle Problem

Before a battle problem is to be conducted, the ship is furnished specific information such as that listed below:

1. Authority for conducting the inspection.
2. Time of boarding of the inspecting party.
3. Time the ship is to get underway.
4. Time for setting the first material readiness condition.
5. Time for conducting the inspection to zero problem time conditions.
6. Zero problem time.
7. End of problem time.
8. Time of critique.

Observers must be proficient in the proper methods of introducing information. In general, when practical, the information delivered to ship's personnel should be verbal and should contain only that information which would help the ship's personnel develop adequate procedures for the search and investigation of the imposed casualty. In the event the ship's personnel fail to locate the casualty, the observer may resort to coaching, but a notation should be made on the observer's form as to the time allowed before coaching and information were furnished. Special precautions should be taken to give the symptoms of casualty the same degree of realism that they would have if the casualty were actual rather than simulated.

In order to impose casualties, valves may have to be closed, switches opened, or machinery stopped. In each case the observer should inform responsible ship's personnel of the action desired, and the ship's personnel should operate the designated equipment. A casualty should be simulated, or omitted entirely, if there is danger that personnel injury or material damage might result because of lack of preparation or the experience of personnel. The supply of lubricating oil to the main engines or the supply of feedwater to the boilers MUST NOT be stopped to simulate casualties.

NOTE

An emergency procedure should be set up, by the observing party and ship's company, to ensure proper action in case actual casualties—as distinguished from simulated or problem casualties—should occur.

Although the general announcing system (the 1MC circuit) may be used by the ship, observers normally have priority of its use. The problem time announcer uses the general announcing system to announce the start of the battle problem, the problem time at regular intervals, the conclusion of the problem, and the restoration of casualties. The general announcing system is kept available at all times for use in case of actual emergency. All other announcing system circuits and other means of interior communications are reserved for the use of the ship.

Engineering telephone circuits should be monitored by one or more observers. A check should be made for proper procedure and circuit discipline, and for the proper handling of information or casualties.

An inspection should be made to see that the engineering plant is properly split in accordance with current directives. Fire hazards such as paint, rags, or oil, and missile hazards such as loose gear, loose floor plates, tool boxes, and repair parts boxes should be noted. The condition of firefighting, damage control, and remote control gear should be carefully inspected.

Analysis of the Battle Problem

The maximum benefit obtained from conducting a battle problem lies in pinpointing existing weaknesses and deficiencies, and in the resulting recommendations for improvement in organization and training. Every effort should be made by the observers to emphasize strong points as well as deficiencies. Knowledge of existing strong points is helpful to boost the morale of the ship's personnel.

Analysis of the battle problem affords the observers an opportunity to present to the ship their opinion of its performance, and for the ship to comment on the observers' remarks as well as to consider suggested improvements.

Analysis is conducted in two steps: the critique and the observers' reports. The critique of the battle problem is the various points of interest of the battle problem and discussed, and the chief observer comments on the overall conduct of the problem after the senior observer complete their analysis as reported in their observer's report. The observers' report provides the inspected ship with detailed observations of the battle problem which, because of time limitations, may not have been brought out during the critique.

Material Inspection

The purpose of material inspection is to determine the actual material condition of the ship. Based on what the inspection discloses, it may be necessary to recommend repairs, alterations, changes, or developments that will ensure the material readiness of the ship to carry out the mission for which it was designed. In addition, the material inspection determines whether proper procedures are being carried out in the care and operation of machinery and equipment. Administrative procedures and material records that are inspected include maintenance records, routine tests, and inspections.

The requirements prescribed for material readiness are as follows:

1. Established routines for the conduct of inspections and tests, a schedule for preventive maintenance, and a system that will ensure timely and effective repairs.
2. Adequate material maintenance records, kept in accordance with current directives that give the history and detailed description of the condition of the machinery and the equipment.
3. Planned and effective utilization of the ship's facilities for preservation, maintenance, and repair.
4. Correct allocation of necessary work to the following categories: (a) the ship's force, (b) the tenders and repair ships, and (c) the naval shipyards or other shore repair activity.

The scope of the material inspection is similar to that of the inspection made by the Board of Inspection and Survey (INSURV). (These inspections are discussed later in this chapter.) Material inspection should be thorough and searching, and cover, in detail, maintenance and repair rather than general appearance. The distinction between administrative inspections and material inspections should be readily recognized, and there should be as little duplication as possible. Examination of the material maintenance records and reports should be made to determine the material condition of machinery and equipment. General administrative methods, general appearance, cleanliness of compartments, and cleanliness of machinery are not part of this inspection, except in cases where they have a direct bearing on material condition.

The composition of the inspecting party for the material inspection is similar to that of the administrative inspection party.

Preparation for the Material Inspection

At an appropriate time prior to the date of the inspection, the chief inspector will furnish the ship with advance instructions. These instructions will include:

1. List of machinery and major equipment to be opened for inspection. The limit that a unit of machinery or equipment should be opened is that which is necessary to reveal known or probable defects. The units selected to be opened should be representative and, in case of a multiple-shaft ship, should not disable more than one-half of the propulsion units. Proper consideration must be given to the ship's operational schedule and safety.
2. List of equipment to be operated. Auxiliary machinery such as the anchor windlass, winches, and steering gear are normally placed on this list.
3. Copies of the condition sheets. These are check off lists that are used for the material inspection.
4. Any additional instructions considered necessary by the TYCOM or other higher authority.

Each department must prepare work lists showing the items of work to be accomplished and the recommended means for accomplishment (shipyard, tender or repair ship, or ship's force during an overhaul or upkeep period). The items are arranged in the recommended order of importance and numbered. A list of the outstanding alterations is also made for the inspection. Work lists usually consist of 5-inch by 8-inch cards, with one repair or alteration item on each card. The work list should include all maintenance and repair items, because if material deficiencies are found during the inspection, they will be checked against the work list. If the item does not appear on the work list, a discrepancy in maintaining the required records will be noted by the inspector.

Condition Sheets

Condition sheets are made in accordance with the needs of the different material groups. The engineering department is primarily concerned with the machinery. Condition sheets contain checkoff sheets and material data sheets and consist of a large number of pages. Items for data and checkoff purposes are listed for all parts of the ship and for all machinery and equipment on board ship.

In advance of inspection, the ship to be inspected must fill in a preliminary copy of the condition sheets. To complete this preliminary copy, detailed data is obtained from the maintenance records and reports.

An entry for any known fault or abnormal condition of the machinery or equipment is made in the proper place on the condition sheets. Details and information are given, as necessary, to indicate the material condition to the inspecting party. If corrective work is required in connection with a unit or space, a reference is made to the work list item. Data and information requested in the condition sheets should be furnished whenever possible. The preliminary copy, if properly filled out, represents the best estimate of the existing material condition of the ship.

When the condition sheets have been completed, they are turned over to the respective members of the inspecting party upon their arrival on board ship. During the inspection, the inspectors fill in the various checkoff sections of the condition sheets. These sheets are then used to prepare the final inspection report on the condition of the ship.

For more detailed information concerning a ship, you should obtain a copy of the applicable condition sheets from the engineering log room.

Opening Machinery for Inspection

The ship will open machinery as previously directed by the chief inspector to obtain the inspector's opinion concerning known or probable defects. The information given in NSTM, Chapter 090, is used as a guide in opening particular machinery units.

A list of machinery, tanks, and major equipment opened, and the extent of opening, should be supplied to the inspecting party on its arrival. Test reports on samples of lubricating oil should be furnished to the machinery inspector.

Ship's company should have portable extension lights rigged and ready for the units of machinery opened for inspection. The lighting of the space should be good. The inspectors should be furnished flashlights, chipping hammers, file scrapers, and similar items. Precision measuring instruments should be readily available.

Assembly of Records and Reports

The material inspection also includes an inspection of various material records and reports. These documents are assembled so as to be readily available for inspection. Records must be kept up to date at all times; it is a good idea to check over all records to make sure that they ARE up to date and that nothing has been overlooked. The individual records should be filled out and maintained in accordance with current directives. Where applicable, the petty officer in charge of an engineering space should check all records or reports that concern the material or the maintenance procedures of that space.

Conduct of the Inspection

The inspecting group for the engineering department should conduct a critical and thorough inspection of the machinery and equipment under the cognizance of the department. The condition sheets supplied by the TYCOM serve as a guide and a checkoff list in making the inspection. Appropriate remarks, comments, and recommendations are entered on the condition sheets for any particular unit of machinery or equipment.

The inspectors should conduct the inspection together with the ship's personnel. No attempt must be made to follow a predetermined inspection schedule, but different units should be inspected as they are made available by the ship's company. If the ship is prepared for the inspection, there should be no delay between the inspections of the different units of machinery. It is not necessary that all machinery of one type be inspected simultaneously nor is it necessary to complete the inspection of one space before going to another.

Important items to be covered by the inspection are indicated below:

1. All opened machinery and equipment is carefully inspected, especially where the need of repair work is indicated on the work list.
2. Investigations are made to locate any defects, in addition to those already known, that may exist in material condition or design.
3. Operational tests of machinery and equipment are conducted in accordance with the furnished list.
4. Electrical equipment is not endangered by saltwater from hatches, doors, or ventilation outlets. Possible leaks in piping flanges are checked.
5. Currently required firefighting and damage control equipment in the engineering space is installed and properly maintained in accordance with current directives.
6. Supports and running gear of heavy suspended material are inspected.
7. Hold-down bolts, plates, and other members of machinery foundations are inspected. Hammer may be used for sounding, and file scrapers may be used for removing paint to disclose any condition of metal corrosion.
8. Condition sheets are checked to see that all the required information has been filled in by the ship being inspected and that all items have been checked off and filled in by the inspector.

9. Routine tests of mechanical and electrical safety devices are observed to ensure that they are being conducted according to current directives.
10. Maintenance records and reports are carefully inspected to see that they are maintained in accordance with prescribed procedures. A check is made to ensure that all known repair requirements are listed.

Analysis and Reports

A critique is held on board the inspected ship, at a convenient time after the completion of the material inspection, so the ship may derive the greatest benefit from the inspection. It is attended by the ship's commanding and executive officers, the heads of departments, the chief inspector, the inspectors of each inspection group, and such other personnel as may be designated from the inspected ship.

The inspectors, after receiving data from the assistant inspectors, submit reports of their inspections to the chief inspector. These reports provide the inspected ship with those observations that may not be fully discussed during the critique but are of interest to the ship's officers concerned. The inspectors' reports include evaluations and any recommendations for the items inspected or observed. These reports are used by the ship as checkoff lists for corrective action and material improvement.

The chief inspector, after receiving the reports from the inspectors, makes a report on evaluating and grading the inspection. The chief inspector discusses, with appropriate comment, the following items:

1. Those conditions requiring remedial action that should be brought to the attention of the CO of the ship inspected and to higher authority.
2. Those conditions of such excellence that their dissemination will be of value to other ships.
3. Those suggestions or recommendations that merit consideration by higher authority.

The final smooth report is written in a detailed procedure in accordance with the TYCOM's directives.

Board of Inspection and Survey (INSURV) Inspection

The INSURV is under the administration of CNO. This board consists of a flag officer, as president, and other senior officers that may be required to assist the president in carrying out the duties of the board. Regional boards and sub-boards are established, as necessary, to assist the INSURV in the performance of its duties. In this discussion we will consider shipboard inspections that are made by the sub-boards. These sub-boards consist of the chief inspector and about 10 or more members, depending upon the type of ship that is to be inspected.

Material Inspections Made by the Board

The inspection made by the INSURV is in several respects similar to the material inspection that has just been discussed. In fact, the INSURV's inspection procedures, condition sheets, and reports are used as guidelines in establishing directives for the material inspection. The primary difference, in regard to material inspections, is that the material inspection is conducted by forces afloat, usually a sister ship, and the INSURV inspection is conducted by a specially appointed board. This distinction, however, refers only to routine shipboard material inspection. It must be remembered that the INSURV conducts other types of inspections.

Inspections of ships are conducted by the INSURV, when directed by CNO, to determine their material condition. Their inspection usually takes place 4 to 6 months prior to regular overhaul. Whenever practicable, such inspections are held sufficiently in advance of a regular overhaul of the ship so as to include in the overhaul all the work recommended by the Board following the inspection. Upon the completion of its inspection, the Board reports the general condition of the ship and its suitability for further naval service, together with a list of the repairs, alterations, and design changes, which, in its opinion, should be made.

Acceptance Trials and Inspections

Trials and inspections are conducted by the INSURV on all ships prior to final acceptance for naval service to determine whether the contract and authorized changes there to have been satisfactorily fulfilled. The builder's trials and acceptance trials are usually conducted before a new ship is placed in commission. After commissioning, a final contract trial is held. Similar inspections are made on ships that have been converted to other types. All material, performance, and design defects and deficiencies found, either during the trials or as a result of examination at the completion of trials, are reported by the Board, together with its recommendations as to the responsibility for correction of defects and deficiencies. The Board also recommends any design changes that it believes should be made on the ship itself or other ships of its type. These recommendations are made to the Secretary of the Navy.

Unless war circumstances prevent it, an acceptance trial takes place at sea over an established trial course. The tests include full power runs ahead and astern, quick reverse, boiler overload, steering, and anchor engine tests. During the trial, usually the builder's personnel operate the ship and its machinery. Ship's personnel who are on board to observe the trial carefully inspect the operation and material condition of machinery and equipment. They note all defects or deficiencies and bring them to the attention of the division or Engineering Officer, so that each item can be discussed with the appropriate members of the INSURV.

Survey of Ships

Survey of a ship is conducted by the INSURV whenever a ship is deemed by CNO to be unfit for further service because of material condition or obsolescence. The Board, after a thorough inspection, renders an opinion to the Secretary of the Navy as to whether the ship is fit for further naval service or can be made so without excessive cost.

When the Board believes that the ship is unfit for further naval service, the Board makes appropriate recommendations as to the ship's disposition.

Ship Trials

There are a number of different types of trials that are carried out under specified conditions. The following list contains most of them:

1. Builder's trial.
2. Acceptance trials.
3. Final contract trials.
4. Post repair trials.
5. Laying up or pre-overhaul trial.
6. Recommissioning trials.
7. Standardization trials.
8. Tactical trials.
9. Full power trials.
10. Economy trials.

The trials that are considered to be routine ship's trials are numbers 3, 9, and 10 of the above list. Post repair, full power, and economy trials are the only ones discussed in this chapter, but information on the other types of trials can be found in NSTM*,* Chapter 094.

Post Repair Trial

The post repair trial should be made whenever the machinery of a vessel has undergone extensive overhaul, repair, or alteration that may affect the power or capabilities of the ship or the machinery. A post repair trial is usually made when the ship has completed a routine naval shipyard overhaul period; the trial is optional whenever machinery has undergone only partial overhaul or repair. The object of this trial is to ascertain if the work has been satisfactorily completed and efficiently performed, and if all parts of the machinery is ready for service.

The post repair trial should be held as soon as practicable after the repair work has been completed, the preliminary dock trial has been made, and the persons responsible for the work are satisfied that the machinery is in all respects ready for a full power trial. The conditions of the trial are largely determined by the character of the work that has been performed. The trial should be conducted in such manner as the CO and commander of the shipyard may deem necessary. In cases where repairs have been slight and the CO is satisfied that they are satisfactorily performed and can be tested without a full power trial, such trial may be dispensed with.

Any unsatisfactory conditions found to be beyond the capacity of the ship's force should be corrected by the naval shipyard. When necessary, machinery should be opened and carefully inspected to determine the extent of any injury, defect, or maladjustment that may have appeared during the post-trial.

A certain number of naval shipyard personnel—technicians, inspectors, and repairmen—accompany the ship on a post repair trial. They check the operation of machinery that has been overhauled by the yard. If a unit of machinery does not operate properly, the yard technicians carefully inspect it to determine the cause of unsatisfactory operation.

Full Power and Economy Trials

Trials are necessary to test engineering readiness for war. Except while authorized to disable or partially disable, ships are expected to be able to conduct prescribed trials at any time. Ships normally should be allowed approximately a 2-week period after tender overhaul, and a 1-month period after shipyard overhaul, to permit final checks, tests, and adjustments of machinery before being called upon to conduct competitive trials.

Trials are also held periodically to determine machinery efficiency under service conditions, the extent (if any) of repairs necessary, the sufficiency of repairs, and the most economical rate of performance under various conditions of service.

Inspections and Tests Prior to Trials

The full power and the economy trials, as discussed in this chapter, are considered competitive trials.. It is assumed that the ship has been in full operational status for sufficient time to be in a good material condition and to have a well-trained crew.

Prior to the full power trial, inspections and tests of machinery and equipment should be made to ensure that no material item will interfere with the successful operation of the ship at full power. The extent of the inspections and the tests will largely depend upon the recent performance of the ship at high speeds, the material condition of the ship, and the time limits imposed by operational commitments.

Not later than 1 day before a trial, the Engineering Officer must report to the CO the condition of the machinery, stating whether it is in proper condition and fit to proceed with the trial.

General Rules for Trials

During all full power trials, and during other machinery trials, the following general rules should be observed:

1. Prior to commencing a power trial, the machinery should be thoroughly warmed up; this can be accomplished by operating at a high fractional power.
2. The speed of the engines should be gradually increased to the speed specified for the trial.
3. The machinery should be operated economically, and designed pressures, temperatures, and number of revolutions must not be exceeded.
4. The full power trial should not be conducted in shallow water, which is conducive to excessive vibration, loss of speed, and overloading of the propulsion plant.
5. A full power trial should continue beyond the length originally specified, and all observations should be continued until the trial is finished.
6. The trial should be continuous and without interruption. If a trial at constant rpm must be discontinued for any reason, that trial should be considered unsatisfactory and a new start made.
7. No major changes of the plant setup or arrangement should be made during economy trials.

Underway Report Data

Reports of trials include all the attending circumstances, especially draft forward, draft aft, mean draft, and corresponding displacement of the ship at the middle of the trial; the condition of the ship's bottom; the last time drydocked; the consumption of fuel per hour; the average speed of the ship through the water; and the average revolutions of the propelling engines. The methods by which the speed was determined should also be described.

Reports should also include tabulations of gage and thermometer readings of the machinery in use and the revolutions or strokes of pertinent auxiliaries. The auxiliaries in use during the trial should be stated. Each report should state whether the machinery is in a satisfactory condition. If the machinery's condition is found to be unsatisfactory, all defects and deficiencies should be fully described and recommendations made for correcting them.

Trial Requirements

Trial requirements for each ship cover the rpm for full power at various displacements and injection temperatures. They are furnished to commanders and units concerned by the CNO (Operations Readiness Division).

Full power trials are documented on reports as having 4 hours duration. The usual procedure is to operate the ship at full power for a sufficient length of time until all readings are constant, and then start the official 4-hour trial period. Economy trials are of 6 hours duration, a different speed being run at each time a trial is made.

Once scheduled, trials should be run unless prevented by such circumstances as:

1. Weather conditions that might cause damage to the ship.
2. Material troubles that force the ship to discontinue the trial.
3. Any situation in which running or completing the trial would endanger human life.

If a trial performance is unsatisfactory, the ship concerned will normally be required to hold a retrial of such character as the TYCOM considers appropriate. The fact that a ship failed to make the required rpm for any hour during the trial, and the amount by which it failed, should be noted in the trial report.

Observation of Trials

When full power trials are scheduled, observing parties are appointed from another ship whenever practicable. When a ship is scheduled to conduct a trial while proceeding independently between ports or under the other conditions where it is considered impractical to provide observers from another ship, the ship under trial may be directed to appoint the observers.

The number of personnel assigned to an observing party may vary according to size and type of ship. The duties of the observing party are usually as follows:

1. The chief observers organize, instruct, and station the observing party. They check the ship's draft, either at the beginning of the trial or before leaving port; supervise the performance of the engineroom observers; check the taking of counter readings; render all decisions in accordance with current directives; and check and sign the trial reports.
2. The assistant chief observers assist the chief observers as directed, supervise the performance of the observers, check the taking of fuel oil soundings and meter readings, and make out the trial reports.
3. Assistant observers take fuel soundings, meter readings, counter readings, and the ship's draft and collect all other data that may be required for the trial reports.

The following items should be accomplished or considered before starting the trial:

1. When requested by the observing party, the ship under trial should provide or designate a suitable signaling system so that fuel soundings and the readings of counters and meters may be taken simultaneously.
2. The ship under trial should furnish the chief observer with a written statement of the date of last undocking, and the authorized and actual settings of all main machinery safety devices and dates when last tested.
3. The ship should have its draft, trim, and loading conform to trial requirements. In case a least draft is not specified, the liquid loading should equal at least 75 percent of the full load capacity.
4. The chief observer should determine draft and trim before and after the trial, verify the amount of fuel on board. The draft observer should also determine the rpm required for the full power trial at the displacement and injection temperature existing at the start of the trial.
5. The observing party should detect and promptly correct any errors in recording data, since it is important that the required data be correct within the limits of accuracy of the shipboard instruments.
6. The chief observer should instruct members of the observing party to detect any violation of trial instructions, of instructions in the NSTM, or of good engineering practice, and then verify any such report and provide the CO with a detailed account of each violation.

Manner of Conducting Trials

Some of the requirements for conducting full power and economy trials are as follows:

1. Unless otherwise ordered, a full power trial may be started at any time on the date set.
2. The trial should be divided into hourly intervals, but readings should be taken and recorded every half hour. Data are submitted as hourly readings in the trial report.
3. Fuel expenditures for each hourly interval of the trial should be determined by the most accurate means practicable, normally by meter readings corrected for meter error and verified by soundings.

4. The appropriate material condition of the ship should be set during the different trials.
5. During all trials the usual “housekeeping” and auxiliary loads should be maintained and the minimum services provided should include normal operation of the distilling plant, air compressor, laundry, galley, ventilation systems, elevators (if installed), and generators for light and power under load conditions similar to those required for normal operations at similar speeds under the prescribed material condition.
6. All ships fitted with indicators, torsion-meters, and other devices for measuring shaft or indicated horsepower should make at least two observations during the full power trial to determine the power being developed.
7. The chief observer’s report of the trial should state whether all rules for the trial have been complied with.

Some Hints Regarding Full Power Trials

There are special forms used for full power and economy trial reports. Illustrations of these forms are not given in this training manual, but you can obtain copies from your log room and in this way get an idea of the data and readings that are required for full power and economy trials.

Trial forms, and such items as tachometers, stop watches, and flashlights, should be available to the observing party and to the personnel who take readings. Any gages or thermometers that are considered doubtful or defective should be replaced before trials are held. A quartermaster must check and adjust all clocks in the engineering spaces and on the bridge before any trials are held.

It is important to make careful inspections and tests of equipment and items of machinery that may cause difficulties during full power operation. These inspections and tests are needed because it is possible that unknown defects or conditions may go undetected during operation at fractional powers—the normal operating condition of the ship most of the time.

Before a trial run is made, the main engines should be inspected to make sure that the power output of the individual cylinders is equal; this inspection ensures a balanced, smooth-operating engine, at maximum speed and power. Equal load distribution between the individual cylinders depends on the following factors being as nearly equal as possible for all cylinders:

1. Compression pressures.
2. Fuel injection timing.
3. Quantity and quality of fuel injected.
4. Firing pressures.
5. Inlet valve timing and lift.
6. Exhaust valve timing and lift.
7. Exhaust gas temperatures.

A common practice among many COs, when making full power trials, is first to bring the ship up to a speed of 1 or more knots below the trial run speed of the ship and then turn the control of the speed (except in cases of emergency nature) over to the Engineering Officer. The control engineroom, under the supervision of the Engineering Officer, brings the speed up slowly, depending upon the conditions of the plant, until the specified speed has been reached.

Engineering Operational Sequencing System (EOSS)

To help make the job of supervision and training easier and more effective, and to enhance the operational capability of shipboard engineering personnel, the Navy has developed a system known as the EOSS. Essentially, the EOSS is to the operator what the PMS is to the maintainer.

Operational Problems

The main propulsion plants in the ships of the modern day Navy are becoming more technically complex as each class of ship is built and joins the fleet. Increased complexity requires increased engineering skills for proper operation. Ships that lack the required experienced personnel have had material casualties that jeopardized their operational readiness. In addition, the rapid turnover of the engineering personnel who man and operate the ships further compounds the problem of developing and maintaining a high level of operator and operating efficiency.

The Navy has been increasingly aware of these problems and has undertaken studies to evaluate the methods and procedures presently used in operating complex engineering plants. The results of these studies have shown that in many instances sound operating techniques were not followed. Some of the circumstances found to be prevailing in engineering plants are described below:

- The information needed by the watchstander was usually scattered throughout publications that were generally not readily available.
- The bulk of the publications were not systems oriented. Reporting engineering personnel had to learn specific operating procedures from "old hands" presently assigned. Such practices could ultimately lead to misinformation or degradation of the transferred information. They were costly and resulted in non-standard operating procedures not only between adjoining spaces but also between watch sections within the same space.
- The posted operating instructions often did not apply to the installed equipment. They were conflicting or incorrect. No procedures were provided for aligning the various systems with other systems.
- The light-off and securing schedules were prepared by each ship and were not standardized between ships. The schedules were written for general, rather than specific, equipment or system values and did not include shifts between all the existing modes of operation.

Following these studies, NAVSEA developed the EOSS, designed to help eliminate operational problems. EOSS involves the participation of all personnel from the department head to the watchstander on watch. The EOSS consists of a set of systematic and detailed written procedures that utilize charts, instructions, and diagrams developed specifically for the operational and casualty control function of a specific ship's engineering plant and configuration.

EOSS is designed to improve the operational readiness of the ship's engineering plant by increasing its operational efficiency, providing better engineering-plant control, reducing operational casualties, and extending the equipment life. These objectives are accomplished by first defining the levels of control and operating within the engineering plant and then providing each supervisor and operator with the information needed—in words they can understand—at their watch station.

The EOSS is comprised of three basic parts:

1. The User's Guide
2. The Engineering Operational Procedures (EOP)
3. The Engineering Operational Casualty Control (EOCC)

Engineering Operational Sequencing System (EOSS) User's Guide

The User's Guide is a booklet that explains the EOSS package and how it is used to the ship's best advantage. It contains document samples and explains how they are used. It provides recommendations for introducing the EOSS system and the methods for training the ship's personnel in utilizing the procedures set forth in this system.

EOSS documentation is developed using work-study techniques. All existing methods and procedures for plant operation and casualty control procedures are documented, including the actual ship procedures as well as those procedures contained in available reference sources.

Each action taken is subjected to a critical examination to evaluate the adequacy of the present procedures. At the completion of this analysis phase, new procedural steps are developed into an operational sequencing system, and step-by-step time-sequenced procedures and configuration diagrams are prepared to show the plant layout in relation to operational components. The final step in the development phase of an EOSS is a validation on board ship check conducted to ensure technical accuracy and adequacy of the prepared sequencing system. All required corrections are made and then incorporated into the package before installation aboard ship.

The resulting sequencing system provides the best tailored operating and engineering operational casualty control procedures available pertaining to a particular ship's propulsion plant. Each level is provided with the information required to enable the engineering plant to respond to any demands placed upon it.

Engineering Operational Procedures (EOP)

The operational portion of the EOSS contains all the information necessary for the proper operation of a ship's engineering plant. It also contains guides for scheduling, controlling, and directing plant evolutions through operational modes from receiving shore services, to various modes of inport auxiliary plant steaming, to underway steaming.

The EOP documentation is prepared for specifically defined operational stages. These are defined as Stages I, II, and III.

Stage I is considered as the total engineering plant level under the direct cognizance of the plant supervisor (EOOW). The officer coordinates the placing in operation and securing of all systems and components normally controlled by the various space supervisors. The EOOW also supervises those functions that affect conditions external to the engineering plant such as jacking, testing, and spinning main engines. The EOP documentation assists you, the plant supervisor, in ensuring optimum plant operating efficiency, properly sequencing events in each operational evolution, and training newly assigned personnel. During a plant evolution, you will control and designate the operation of the following systems and components:

- Systems that interconnect one or more engineering plant machinery spaces and the electrical system.
- Major components such as boilers, main engines, and electrical generators.
- Systems and components required to support the engineering plant or other ship functions such as distilling plants, air compressors, and steam system to catapults, and thrust blocks that are placed in operation or secured in response to demand upon their services.

To assist you, the plant supervisor, with these operations, the EOP section provides you with the following documents:

- Index pages listing each document in the Stage I station book by identification number and title.
- Plant procedure charts *(Figure 20-6)* providing step-by-step procedures for each engineering plant evolution.

NOTE

At the time this publication was prepared for printing, EOSS diagrams illustrating specific equipment for which the Engineman is responsible were not available; the example used in this section, however, illustrates the types of EOSS diagrams used regardless of equipment.

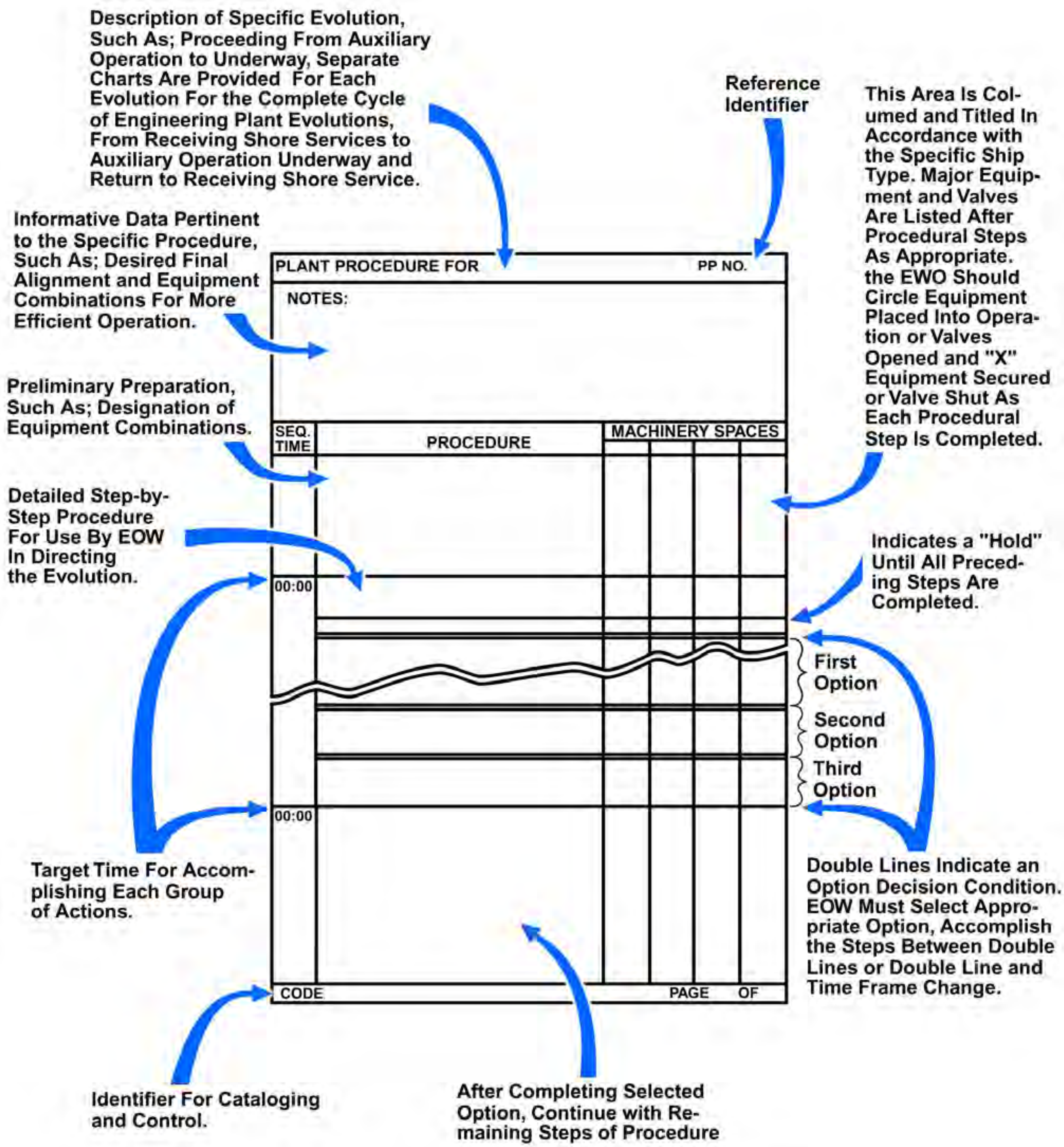

Figure 20-6 — Sample plant procedure chart.

- Plant status diagram (*Figure 20-7*) providing a systematic display of the major systems and cross-connect valves as well as a graphic presentation of the major equipment in each machinery space. These boards are used to maintain a current plot of systems alignment and equipment operating status.
- A diagram for plant steaming conditions versus optimum generator combinations delineating the preferred electric power generator combinations for the various plant operating conditions. This diagram is also provided in the Stage II electrical documentation.

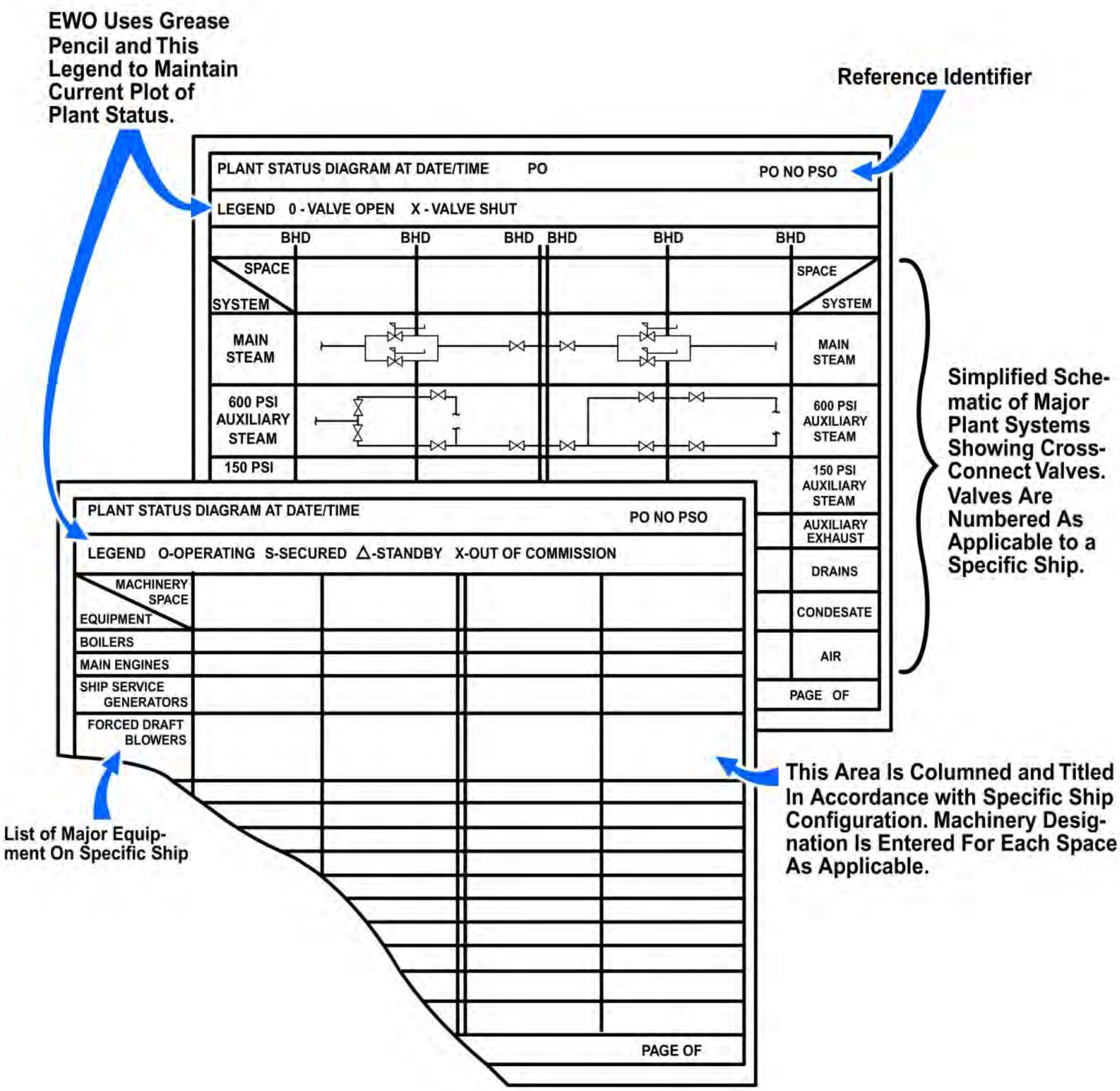

Figure 20-7 — Sample plant status diagram.

- System alignment diagrams *(Figure 20-8)* delineating the preferred initial and final alignment for each engineering plant.
- A diagram for equipment versus speed requirement delineating the equipment normally required for various ship speeds.
- A diagram for shore services connection locations delineating the location of shore service connections for steam, electrical power, feedwater, potable water, saltwater, and fuel oil.

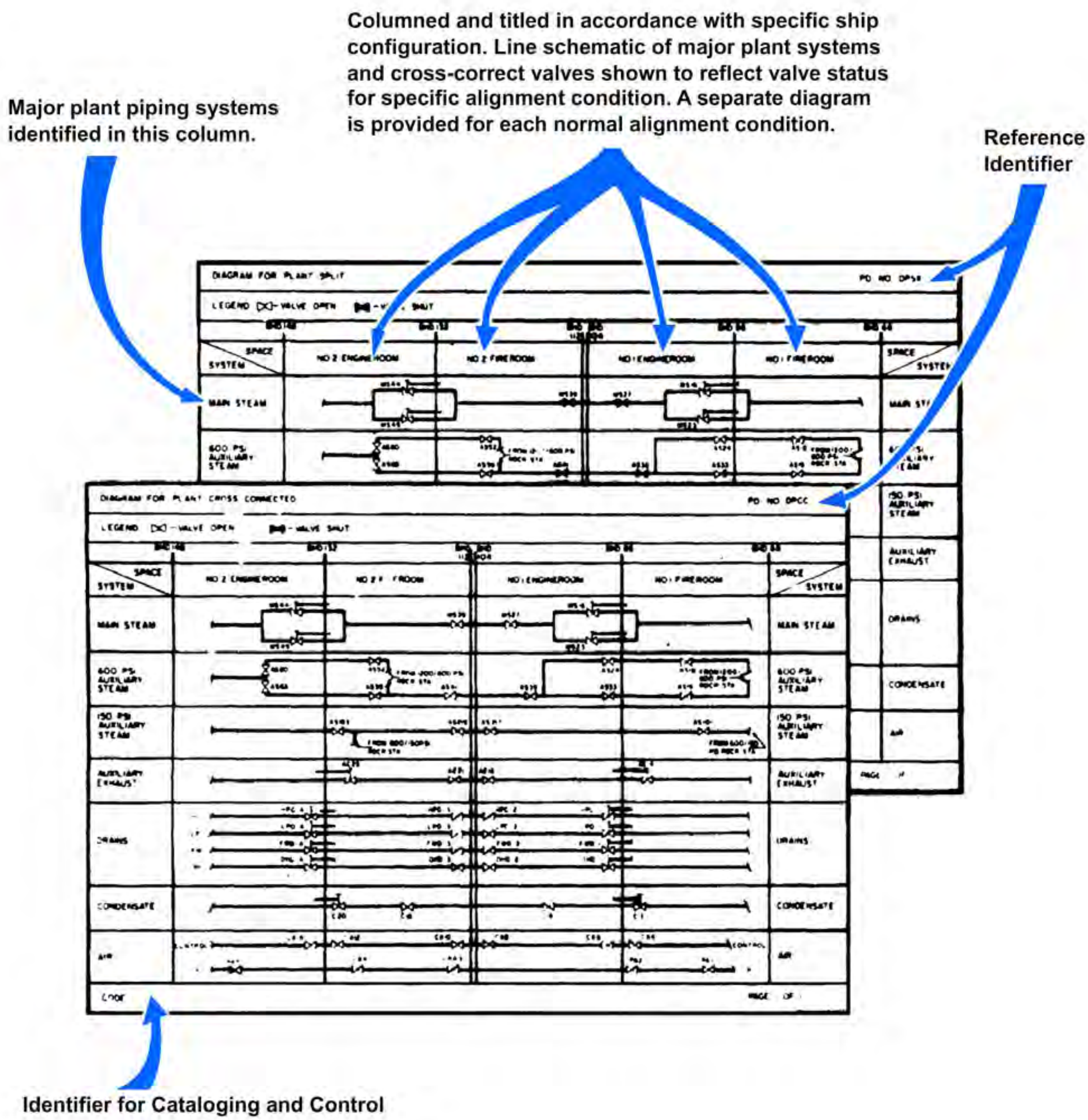

Figure 20-8 — Sample preferred alignment diagrams.

- Training diagrams (*Figure 20-9*) delineating each major piping system to aid in plant familiarization and training of newly assigned personnel. These diagrams indicate the relative locations of lines, valves, and equipment.

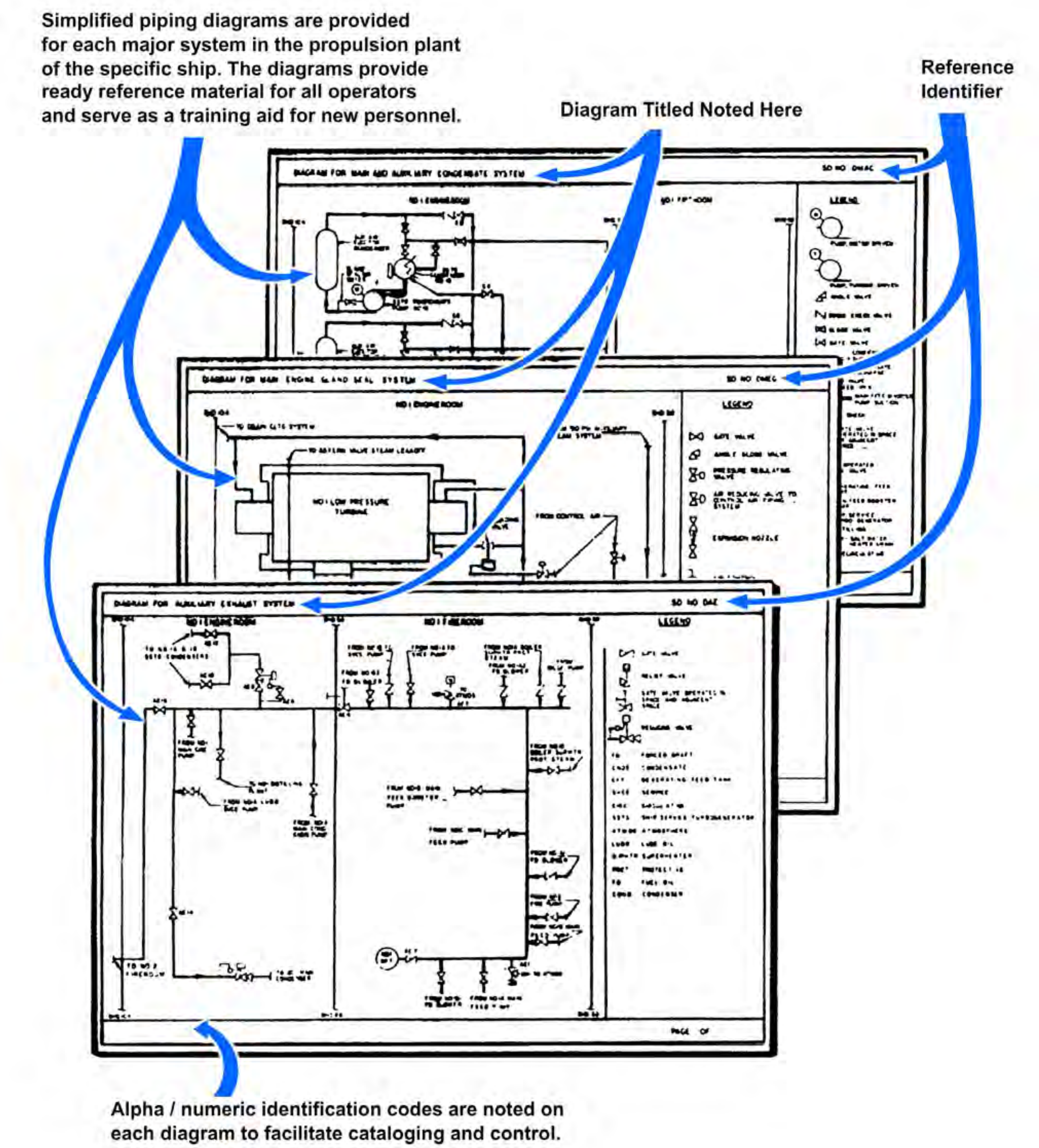

Figure 20-9 — Sample training diagram.

Stage II is considered as the system component level supervised by the space supervisor in each engine room and the electrical plant supervisor (electrical load dispatcher). In Stage II, the space supervisor accomplishes the tasks delegated by the plant supervisor. The EOP documentation assists the space supervisor in properly sequencing the events, controlling the operation of equipment within the machinery space or electric-power complex, maintaining an up-to-date status of the operational condition of the assumed equipment assigned, and training newly assigned personnel. To assist the space supervisor in this effort, the EOP section provides the following Stage II documents:

- Index pages listing each document by identification number and title for each specified operating group such as engine room, and electrical.
- Space procedure charts (similar to the plant procedure chart) providing the step-by-step procedure to be accomplished within a space to satisfy and support the requirements of the plant procedure charts.
- Space status board providing a schematic of major systems and a tabular listing of the major equipment within the individual machinery spaces for maintaining a plot of systems alignment and equipment operating status.
- Diagram for Electrical Plant Status (DLS) delineating generators, switchboards, and shorepower connections within the electrical distribution systems. The DLS is provided in both the electrical operating group and in the Stage I (EOOW) documentation for maintaining a plot of the system alignment.
- Diagram for plant steaming conditions versus optimum generator combinations provided in the electrical operating group documentation delineating the preferred electric power generator combination. This diagram is the same as that provided in the Stage I documentation.
- Training diagrams of each major piping system developed for Stage I, plus diagrams of such systems as fuel-oil service and main engine lube oil that are normally located within the machinery spaces.

Stage III is considered as the system component level attended by the component operators. The component operators place equipment in and out of operation, align systems, and monitor and control their operation by manipulating the required valves, switches, and controllers. Stage III documents include:

- Index pages listing each document by identification number and title for each specified system such as fuel-oil service system and lube oil service system.
- Component procedure cards providing step-by-step procedures for systems alignment or component operation.
- Component procedure cards as required to support each operation or alignment.
- Alignment diagrams (*Figure 20-10*) amplifying the written procedure to assist the component operator in proper systems alignment. Alignment diagrams are provided whenever two or more alignment conditions exist for a given system or component.

The operational use of EOP documentation is of primary importance at all levels in controlling, supervising, and operating the evolutional functions of the engineering plant.

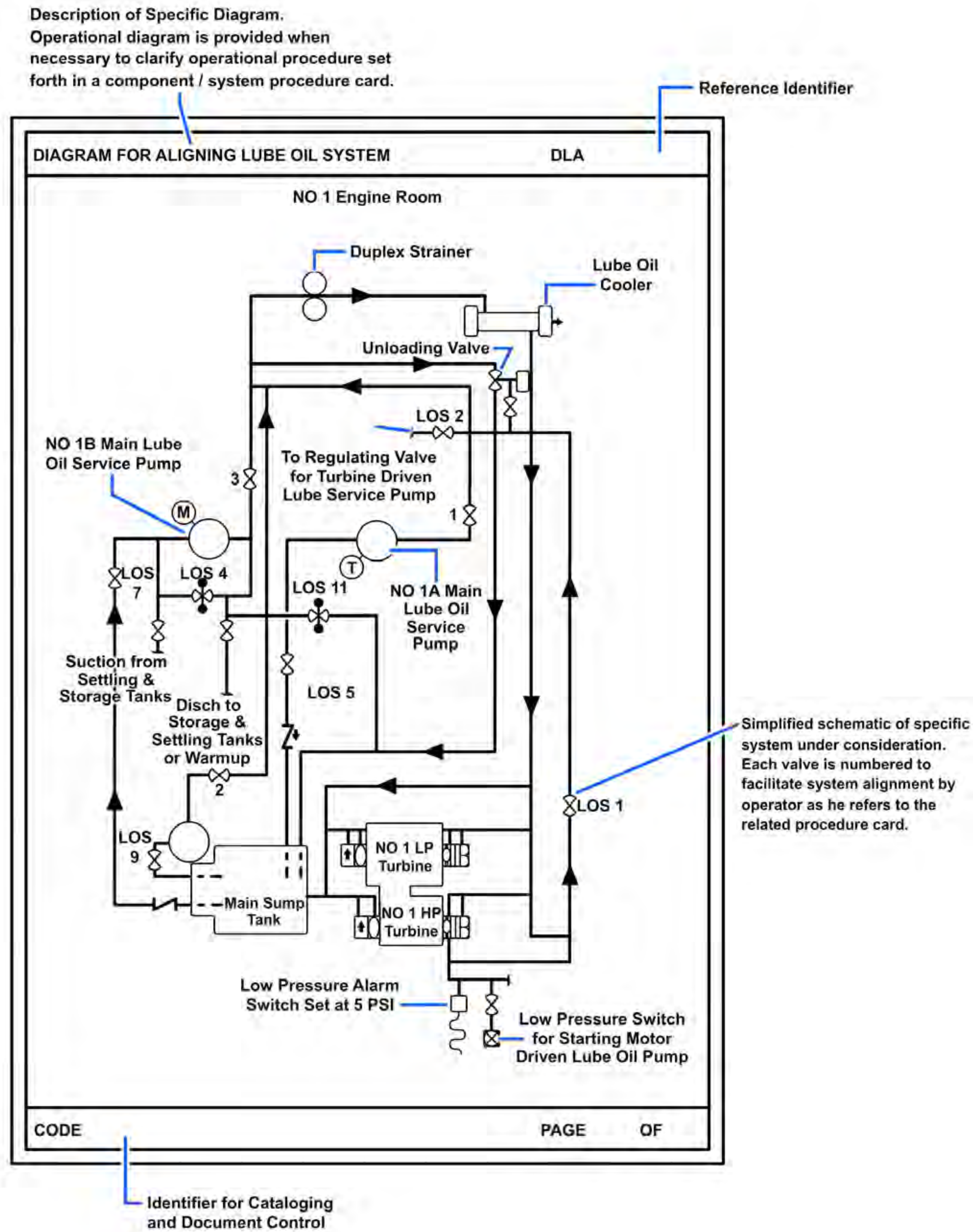

Figure 20-10 — Sample component/system alignment diagram.

Engineering Operational Casualty Control (EOCC)

The casualty control portion of EOSS contains information relative to the recognition of casualty symptoms and their probable causes and effects. In addition, it contains information on preventive action to be taken to preclude a casualty and on procedures for controlling single and multiple source casualties.

Casualty prevention must be the concern of everyone on board. Proper training of all personnel must provide for adequate knowledge and experience in effective casualty prevention. The EOCC manual contains efficient, technically correct casualty control and prevention procedures that relate to all phases of an engineering plant. The EOCC documents elaborate on possible casualties caused by error, material failure, and battle. The EOCC manual describes tried and proven methods for the control of a casualty and prevention of further damage to the component, the system, or the engineering plant concerned.

The EOCC manuals are available to the personnel in their own machinery space so that they can be used as a means of self-indoctrination for newly assigned personnel and as an instrument with which to improve casualty control procedure techniques for all watch standers. The manual contains the documentation required to effectively assist engineering personnel in developing and maintaining maximum proficiency in controlling casualties to the ship's propulsion plant.

Proficiency in EOCC procedures is maintained through a well-administered training program. Primary training concentrates on controlling single-source casualties—those that may be attributed to the failure or malfunction of a single component or the failure of piping at a specific point in a system. Advanced training concentrates on controlling multiple casualties or on conducting a battle problem. An effective and well-administered EOCC training program must contain, as a minimum, the following elements:

- Recognition of the symptoms.
- Probable causes.
- Probable effects.
- Preventive actions that may be taken to reduce, eliminate, or control casualties.

An EOSS package is not intended to be forgotten once it is developed and installed aboard a ship. It offers many advantages to the ship's operational readiness capabilities, providing detailed step-by-step sequencing of events for all phases of the engineering-plant operation. Its procedures are tailored to each specific ship and are prepared for each level of management and operation. Because it is work studied and system oriented, the EOSS provides the basic information for the optimum utilization of equipment and systems by specifying correct procedures tailored for a specific plant configuration.

The EOSS is not intended to eliminate the need for skilled plant operators. No program or system can achieve such a goal. The EOSS is a tool for better utilization of manpower and skills available. Although the EOSS is an excellent tool for shipboard training of personnel, it is primarily a working system for scheduling, controlling, and directing plant operations and casualty-control procedures.

MAINTENANCE AND REPAIR RESPONSIBILITIES

In order to fulfill your maintenance and repair responsibilities along with your administrative and supervisory responsibilities, you must plan your work ahead of time.

You must determine all the work that must be done and prepare a schedule to ensure that it is done. You must also keep your schedule flexible enough to allow unexpected maintenance and repair work to be done whenever the need for such work arises.

Review the *Maintenance and Material Management (3-M) Manual*, OPNAVINST 4790.4(series). It will make your planning and scheduling considerably easier.

Materials and Repair Parts

You are just as responsible as the supply department for maintaining adequate stocks of engine room repair parts and repair material. The duties of the supply officer are to procure, and account for the repair parts and materials for the support of the ship. However, the supply officer is not the prime user of repair parts and repair materials; the initiative for maintaining adequate stocks of repair materials, parts, and equipment must come from the personnel who are going to use such items. Namely you!

Basic information on supply matters is given in *Military Requirements for Petty Officers Third and Second Class,* NAVEDTRA 14504, *Military Requirements for Petty Officer First Class,* NAVEDTRA 14145, *Military Requirement for Chief Petty Officers,* NAVEDTRA14144, and OPNAVINST 4790.4, volume II.

Identification of Repair Parts and Materials

Identification of repair parts and materials is not usually a great problem when you are dealing with familiar equipment on your own ship, but it may present problems when you are doing repair work for other ships, as you would if assigned to the machine shop on a repair ship or tender.

The materials and repair parts to be used are specified for many repair jobs but not for all. When materials or parts are not identified in the instructions accompanying a job, you will either have to use your own judgment or do research to find out just what material or part should be used. When you must make the decision yourself, select materials based on the service conditions they must withstand. Operating pressure and operating temperature are primary considerations in selecting materials and parts for most engineroom repair work.

The fact that materials and repair parts are not specified in the instructions accompanying a job does not mean that you are free to use your own judgment in selecting parts and materials to accomplish a job. Instead, it usually means that you must know where to look for information on the type of material or repair parts needed, then locate and requisition them in order to complete the assigned job.

There are several shipboard sources of information that will be useful to you in identifying the equipment and/or the repair parts needed. They include the Coordinated Shipboard Allowance List (COSAL); nameplates on the equipment; manufacturers' technical manuals; and ships' plans, blueprints, and other drawings.

Coordinated Shipboard Allowance List (COSAL)

The COSAL is both a technical and a supply document prepared for an individual ship. It lists the equipment or components required for the ship's operation, the repair parts and special tools required the overhaul and repair equipment, and the miscellaneous portable items necessary for the care and upkeep of the ship.

For your purpose, the COSAL is the basic source of information on repair parts and materials needed for a job. A COSAL gives you information on such items as the noun name of a system (engine, pump, ejector, etc.), the manufacturer's name and the I.D. number (General Motors Corporation #3255), the technical manual number for the system, the manufacturer's drawing numbers, and the Allowance Parts List (APL) numbers for related systems (governors, starters, transmissions, etc.). In addition, COSAL provides specific information about National Stock Numbers (NSNs), units of issue, costs, and the number of items needed. It may also include lists of part numbers and Federal Stock Numbers (FSNs) for crossover checks.

To request materials and repair parts from the supply department aboard ship, you must fill out and submit a Navy Supply (NAVSUP) Form 1250, a single item consumption/management document. If the item is not stocked aboard ship, the supply department will requisition the material from a supply activity, using the identifying information that you have given on the NAVSUP Form 1250. However, if all the information you have available is a manufacturer's part number, then you must also fill out and submit, along with the NAVSUP Form 1250, a DD-1348-6 Form, non-nsn requisition. For information on how to fill out these supply forms, review *Military Requirements for Petty Officers Third and Second Class* or volume II of OPNAVINST 4790.4, or ask your ship's supply personnel for assistance.

Whenever you find it necessary to request materials or repair parts, remember two things:

1. If at all possible, find the correct NSN for each item requested. All materials now in the supply system have been assigned an NSN, and you should be able to locate them by using the COSAL and the other sources of information available to you such as the following:
   a. NAMEPLATES on equipment supply information regarding the characteristics of the equipment. Nameplate data seldom, if ever, include the exact materials required for repairs; however, the information given on the characteristics of the equipment and on pressure and temperature limitations may provide useful clues for the selection of materials.
   b. MANUFACTURERS' TECHNICAL MANUALS are furnished with all machinery and equipment aboard ship. Materials and repair parts are sometimes described in the text of these technical manuals; more commonly, however, details of materials and parts are given on the drawings. Manufacturers' catalogs of repair parts are also furnished with some shipboard equipment; when available, these catalogs are a valuable source of information on repair parts and materials.
   c. SHIPS' PLANS, BLUEPRINTS, and OTHER DRAWINGS available on board ship are excellent sources of information on materials and parts to be used in making various kinds of repairs. Many of these plans and blueprints are furnished in the regular large sizes, but lately, microfilm is being used increasingly for these drawings. Information obtained from plans, blueprints, and other drawings should always be checked against the information given on the ship's COSAL to be sure that any changes made since the original installation have been noted on the drawings.
2. Work informally with the supply department personnel who are actually responsible for identifying and requesting material. You have the technical knowledge, and you know what you need. If you cannot find the correct stock number, however, your job is to give enough standard identification information, such as manufacturer part numbers, and Allowance Parts List/Component Identification Description (APL/CID) numbers, so that supply personnel on board ship or ashore can identify the item you want. Experienced supply personnel are familiar with identification publications and can help you to locate the correct stock numbers and other important identifying information.

Ship Equipment Configuration Accounting System (SECAS)

When the structure or composition of either the ship or a particular system or equipment on board a ship is modified, this modification must be documented. This action will ensure proper accounting of configuration changes and will help improve supply and maintenance support technical manuals, PMS coverage, updated COSAL, etc., to your ship. Ship Equipment Configuration Accounting System SECAS is the designated system responsible for maintaining the configuration status reported by your ship.

Although the responsibility for identifying and reporting these changes rests at all levels of the command, the work center supervisor is responsible for ensuring that the proper documentation is completed and processed as described in volume II of OPNAVINST 4790.4.

OPNAV Form 4790/CK, Ship’s Configuration Change Form, is used to report configuration changes at the individual equipment level.

Ship-to-Shop Work

Many repair jobs are designated by the ship or approved by the repair activity as “ship-to-shop” jobs. In this type of job, the ship’s force does a large part of the repair work. For example, the repair or renewal of a damaged pump shaft might well be written up as a ship-to-shop job. The ship’s force will disassemble the pump and remove the shaft. Then the shaft and any necessary blueprints or technical manuals are delivered to the designated shop of the repair activity. After the shaft has been repaired, or a new one has been made, it is picked up and brought back to the ship by the ship’s force. The pump is reassembled, inspected, and tested by the ship’s force to make sure that it is operating satisfactorily.

An important thing to remember is that you and the repair facility have different responsibilities. The repair facility personnel are responsible for repairing or manufacturing this shaft to the manufacturer’s specifications, performing all tests required by Quality Assurance (QA), and properly filling out all the required forms. It is your responsibility to witness any test required by QA, monitor the status of the job at all times, and reassemble and test operate the equipment properly, so that the end results will produce a reliable operating piece of.

Equipment Tests

As an EN1 or ENC, you have the responsibility for scheduling and performing various tests on your equipment. The purpose of those tests is to determine how your equipment is performing and if there are any equipment malfunctions. These tests are performed at various times, such as (1) before going to the shipyard for overhaul, (2) after post deployment, (3) during a tender availability, or (4) as required by PMS. The tests are performed by the ship’s force, IMA personnel, shipyard personnel, or an inspection team (such as the INSURV Board). Detailed types of inspections are described in COMNAVSURFLANT Inst. 9000.1 or COMNAVSURFPAC Inst. 4700.1(series).

Scheduling Work

Careful planning is required to keep up with all auxiliary maintenance and repair work in the enginerooms. You should already have in your work center the necessary items that can help you schedule your work. These items are (1) the Quarterly PMS Schedule, which is the visual display of your work center’s PMS requirements for a specific 3-month period; (2) the weekly schedule (taken from the quarterly schedule), which displays all your work center’s PMS schedule for completion in a given week; and (3) the Maintenance Data Collection Subsystem (MDCS) forms, such as the OPNAV 4790-2K, OPNAV 4790-2L, and OPNAV 4790-2Q. Of these, OPNAV Form 4790.2K is used to show completion of specific PMS requirements, to request repair of equipment or services from IMAs or shipyards, or to describe equipment malfunctions. OPNAV Form 4790/2L is a supplemental form used to provide amplifying information relating to a maintenance action described on a corresponding 4790/2K. The OPNAV 4790/2L may also be used to list multiple item serial numbers and locations for which identical maintenance requirements exist from an outside activity, and drawings and sketches.

OPNAV Form 4790/2Q is an automated work request produced by an IMA with computer capabilities. The “2Q” is produced from the original 4790/2K, which is in your Current Ship’s Maintenance Project (CSMP) suspense file. For more detailed information about these forms and schedules, and how to fill them out, review OPNAVINST 4790.4, volumes I and II.

Some of the proven uses you should follow when scheduling maintenance and repair work are listed below:

1. Size up each job before you let anyone start working on it. Check the applicable Maintenance Requirement Cards (MRCs) so that you will know exactly what needs to be done. Also, check all applicable drawings and manufacturer's technical manuals.
2. Check on materials before you start. Be sure that all required materials are available before your personnel start working on any job. Do not overlook small items—nuts, bolts, washers, packing and gasket materials, tools, measuring devices, and so forth. A good deal of labor can be saved by the simple process of checking on the availability of materials before a job is actually started. An inoperable piece of machinery may be useless, but it can become a nuisance and a safety hazard if it is spread around the engineroom in bits and pieces while you wait for the arrival of repair parts or materials.
3. Check the priority of the job and that of all other work that needs to be done.
4. When assigning work, carefully consider the capabilities and experience of your personnel. As a rule, the more complicated jobs should be given to the more skilled and more experienced people. When possible, however, less experienced people should be given difficult work to do under supervision so that they may acquire skill in such jobs.
    a. Be sure that the person who is going to do a job is given as much information as necessary. An experienced person may need only a drawing and a general statement concerning the nature of the job. A less experienced person is likely to require additional instructions and, as a rule, closer supervision.
5. Keep track of the work as it is being done. In particular, check to be sure that proper materials and parts are being used, that the job is properly laid out or set up, that all tools and equipment are being used correctly, and that all safety precautions are being observed.
6. After a job has been completed, make a careful inspection to be sure that everything has been done correctly and that all final details have been taken care of. Check to be sure that all necessary records and reports have been prepared. These job inspections serve at least two very important purposes. First, they are needed to make sure that the work has been properly performed; and second, they provide for an evaluation of the skills and knowledge of the person who has done the work. Do not overlook the training aspects of a job inspection. When your inspection of a completed job reveals any defects or flaws, be sure to explain what is wrong, why it is wrong, and how to avoid similar mistakes in the future.

Estimating Work

You will often be required to estimate the amount of time, the number of personnel, and the amount of material that will be required for specific repair jobs. Actually, you are making some kind of estimate every time you plan and start a repair job, as you consider such questions as: How long will it take? Who can best do the job? How many people will be needed? Are all necessary materials available?

However, there is one important difference between the estimates you make for your own use and those that you make when your division officer asks for estimates. When you give an estimate to someone in authority over you, you cannot tell how far up the line this information will go. It is possible that an estimate you give to your division officer could ultimately affect the operational schedule of the ship; it is essential, therefore, that such estimates be as accurate as you can possibly make them.

Many of the factors that apply to the scheduling of all maintenance and repair work apply also to estimating the time that will be required for a particular repair job. You cannot make a reasonable estimate until you have sized up the job, checked on the availability of materials, checked on the availability of skilled personnel, and checked on the priority of the various jobs for which you are responsible. In order to make an accurate estimate of the time required to complete a specific repair job, you must also consider (1) what part of the work must be done by other shops and (2) what kinds of interruptions and delays may occur. Although these factors are also important in the routine scheduling of maintenance and repair work, they are particularly important when estimates of time that may affect the operational schedule of the ship are made.

If part of the job must be done by other shops, you must consider not only the time actually required by these shops but also time that may be lost if one of them holds up your work and the time spent to transport the material between shops. Each shop should make a separate estimate, and the estimates should be combined to obtain the final estimate. Do NOT attempt to estimate the time that will be required by other personnel. Attempting to estimate what someone else can do is risky because you cannot possibly have enough information to make an accurate estimate.

Consider all the interruptions that might cause delay, over and above the time required for the work itself. Such things as drills, inspections, field days, and working parties can have quite an effect on the number of people who will be available to work on the job at any given time.

Estimating the number of personnel who will be required for a certain repair job is, obviously, closely related to estimating time. You will have to consider not only the nature of the job and the number of people available but also the maximum number of people who can work EFFECTIVELY on a job or on part of the job at the same time. Doubling the number of personnel will not cut the time in half; instead, it will result in confusion and aimless milling around.

The best way to estimate the time and the number of personnel needed to do a job is to divide the total job into the various phases or steps that will have to be done, and then estimate the time and the personnel required for each step.

Estimating the materials required for a repair job is often more difficult than estimating the time and labor required for the job. Although your own past experience will be your best guide for this kind of estimating, a few general considerations should be noted:

1. Keep accurate records of all materials and tools used in any major repair job. These records serve two purposes: First, they provide a means of accounting for materials used; and second, they provide a guide for estimating materials that will be required for similar jobs in the future.
2. Before starting any repair job, plan the job carefully and in detail. Make full use of manufacturers' technical manuals, blueprints, drawings, and any other available information, and find out in advance all the tools and materials that will be required for the accomplishment of each step of the job.
3. Make a reasonable allowance for waste when calculating the amount of material you will need.

Current Ship's Maintenance Project (CSMP)

The standard CSMP is a computer-produced report. It lists deferred maintenance and alterations that have been identified by the MDCS reporting. Copies of the CSMP should be reviewed monthly. The Engineering Officer gets a copy for each engineering department center, and each work center gets a copy with its own deferred maintenance only.

The purpose of the CSMP is to provide shipboard maintenance managers with a consolidated listing of deferred corrective maintenance so they can manage and control its accomplishment. The work center supervisor is responsible for ensuring the CSMP accurately describes the material condition of his or her work center. Each month when the new CSMP is received, verified, and updated, the old CSMP may be destroyed. OPNAVINST 4790.4, volumes I, II, and III, contains complete instructions and procedures for completing and routing all 3-M forms.

QUALITY ASSURANCE (QA) PROGRAM

The QA program was established to provide personnel with information and guidance necessary to administer a uniform policy of maintenance and repair of ships and submarines. The QA program is intended to instill discipline into the repair of equipment, safety of personnel, and configuration control, thereby enhancing ship's readiness.

Purpose of QA Manuals

The various QA manuals set forth minimum QA requirements for both the surface fleet and the submarine force. If more stringent requirements are imposed by higher authority, such requirements take precedence. If conflicts exist between the QA manual and previously issued letters and transmittals by the appropriate force commanders, the QA manual takes precedence. Such conflicts should be reported to the appropriate officials.

The instructions contained in the QA manual apply to every ship and activity of the force. Although the requirements are primarily applicable to the repair and maintenance done by the force IMAs, they also apply to maintenance done aboard ship by ship's force. In all cases where specifications cannot be met, a departure-from-specifications request must be completed and reported.

Because of the wide range of ship types and equipment and the varied resources available for maintenance and repair, the instructions set forth in the QA manual are necessarily general in nature. Each activity must implement a QA program to meet the intent of the QA manual. The goal should be to have all repairs conform to QA specifications.

Program Components

The basic thrust of the QA program is to ensure that you comply with technical specifications during all work on ships of both the surface fleet and submarine force. The key elements of the program are as follows:

- Administrative. This includes training and qualifying personnel, monitoring and auditing programs, and completing the QA forms and records.
- Job execution. This includes preparing work procedures, meeting controlled material requirements, requisitioning material, conducting in-process control of fabrication and repairs, testing and recertifying, and documenting any departure from specifications.
- A properly functioning QA program points out problem areas to maintenance managers so they can take appropriate action to accomplish the following:
- Improve the quality, uniformity, and reliability of the total maintenance effort.
- Improve work environment, tools, and equipment used in the performance of maintenance.
- Eliminate unnecessary man-hour and dollar expenses.
- Improve the training, work habits, and procedures of maintenance personnel.
- Increase the excellence and value of reports and correspondence originated by the maintenance activity.
- Distribute required technical information more effectively.
- Establish realistic material and equipment requirements in support of the maintenance effort.

The Quality Assurance Organization

The QA program for naval forces is organized into different levels of responsibility. For example, the COMNAVSURFPAC QA program is organized into the following levels of responsibility: TYCOM, readiness support group/area maintenance coordinator, and the IMAs. The QA program for the COMNAVSURFLANT is organized into five levels of responsibility: force commander, audits, squadron commanders, IMAs, and force ships.

The QA program organization (Navy) begins with the **commander in chief of the fleets,** who provides the basic QA program organization responsibilities and guidelines.

The **TYCOMs** provide instruction, policy, and overall direction for implementation and operation of the force QA program. TYCOMs have a force quality assurance officer (QAO) assigned to administer the force QA program.

The **COs** are responsible to the force commander for QA in the maintenance and repair of the ships. The CO is responsible for organizing and implementing a QA program within the ship to carry out the provisions of the TYCOM's QA manual.

The CO ensures that all repair actions performed by ship's force conform to provisions of the QA manual as well as other pertinent technical requirements.

The **QAO** is responsible to the CO for the organization, administration, and execution of the ship's QA program according to the QA manual.

The QAO is responsible for coordinating the ship's QA training program, maintaining ship's QA records, and submitting test and inspection reports. The QAO conducts QA audits as required and follows up on corrective actions to ensure compliance with the QA program.

The **ship quality control inspectors (SQCIs),** usually the work center supervisor and two others from the work center, must have a thorough understanding of the QA program. Some of the other responsibilities of SQCIs are as follows:

1. Inspect all work for compliance with specifications.
2. Maintain ship records to support the QA program.
3. Ensure that only calibrated equipment is used in acceptance testing and inspection of work.
4. Witness and document all tests.
5. Ensure that all materials or test results that fail to meet specifications are recorded and reported.

Levels of Essentiality

A number of early failures in certain submarine and surface ship systems were traced to use of the wrong materials. This led to a system for prevention involving levels of essentiality. A level of essentiality is simply a range of controls in two broad categories representing a certain high degree of confidence that procurement specifications have been met. These categories are as follows:

1. Verification of material
2. Confirmation of satisfactory completion of tests and inspections required by the ordering data

Levels of essentiality are codes, assigned by the ship according to the QA manual, that indicate the degree to which the ship's system, subsystem, or components are necessary in the performance of the ship's mission. They also indicate the impact that catastrophic failure of the associated part or equipment would have on the ship's mission capability and personnel safety.

Levels of Assurance

QA is divided into three levels: A, B, and C. Each level reflects certain quality verification requirements of individual fabrication in process or repair items. Here, verification refers to the total of quality controls, tests, and/or inspections, tests, and/or inspections. **Level A** assurance provides for the most stringent of restrictive verification techniques. This level normally will require both quality controls and test or inspection methods. **Level B** assurance provides for adequate verification techniques. This level normally will require limited quality controls and may or may not require tests or inspections. **Level C** assurance provides for minimum or "as necessary" verification techniques. This level normally will require very little should this be quality controls, tests, or inspections..

The QA concept involves preventing the occurrence of defects. QA covers all events from the start of a maintenance action to its completion and is the responsibility of all maintenance personnel.

By carefully following the methods and procedures outlined in your QA program manuals and by paying careful attention to the quality of work in your area, you will contribute greatly to the operational effectiveness of your ship as well as tended units. For further in-depth knowledge concerning the QA procedures and practices, consult your area COMNAVSURFLANT/ PACINST QA manual.

NAVY OCCUPATIONAL SAFETY AND HEALTH PROGRAM

In your day-to-day operations in the engineroom, you will be directly involved with three health programs: electrical, heat stress, and hearing conservation.

Electrical Safety Program

Until now, we have discussed only the programs most related to the EN rating. However, electrical safety is an ALL HANDS effort. When you reported aboard your ship, you should have been given electrical safety program indoctrination. You should be given electrical safety training at least annually thereafter.

Most people have a healthy respect for the 440 volts the generators put out. However, few people really respect the 110 volts that most equipment uses. This lack of respect for 110 volts is what gets most people hurt, or even killed. Shipboard electricity is not the same as the electricity in your home. Sure, it is the same voltage and still uses wiring to carry it. The similarity ends there. Leave electrical repairs to the Electrician's Mates (EMs).

Most ENs come in contact with portable electric power tools. You should be sure that portable electric power tools are clean, properly maintained, and in good operating condition. When you receive a power tool from electric tool issue, look it over. Is the power cord frayed or are bare wires showing? Is the plug in good condition, and does it have three prongs? Is the electrical safety tag up to date? Are there any obvious breaks in the housing? If any of these defects are present, return it to tool issue immediately.

There are certain rules for use of portable electric power tools. Most are common sense, but take a minute to review them. Never use power tools in or around water. When you use an extension cord, hook it to the tool before plugging it into the power source/outlet. Arrange the power cords so no one will trip over them. Never use jury-rigged extension cords; the extension cord should not exceed 25 feet in length. Do not unplug cords by yanking on the cord. Unplug the extension cord from the receptacle before unplugging the power tool. Rubber gloves and eye protection are required when using a power tool. Hearing protection is required if the tool produces hazardous noise. Better safe than sorry is more than a slogan, it is a life saver!

Heat Stress

Heat stress has been encountered in the engineering spaces aboard U.S. Navy ships. Reports by the president of the INSURV have continued to identify conditions of unwarranted, excessively high heat stress and humidity in ships' engineering spaces. The primary causes of heat stress in the spaces are the following. Heat stress is a combination of air temperature, thermal radiation, humidity, air flow, and workload that strains the body as it attempts to regulate body temperature. Unwarranted, excessively high heat and humidity in the engineroom are usually caused by the following correctable deficiencies:

- Excessive steam and water leaks.
- Missing, damaged, improperly installed, or deteriorated thermal insulation on steam piping, valves, and machinery.
- Ventilation system deficiencies such as missing or damaged duct work, misdirected terminals, improper or clogged screens, closed or partially closed "Circle William" dampers, dirty ventilation ducting, and inoperative fan motors and controllers.

As an engineroom watch stander, you can help reduce excessively high temperatures and humidity by the following means:

- Perform corrective or preventive maintenance on piping, valves, pumps, and other components in accordance with proper procedures.
- When you work on a protected system, ensure that you restore thermal insulation to its proper condition to allow only for designed leakage.
- Look for, report, and correct when possible those system deficiencies that cause heat stress.

You can also take the following additional measures to protect yourself against heat stress:

- Ensure that a hanging dry bulb thermometer is permanently mounted to show the correct temperature at the watch station.
- Read and record the temperature at least once each watch period. (Take these readings hourly during space casualties, full power runs, casualty control exercises, and unusually hot and/or humid weather, and when doing hard work.)
- Report to the EOOW a dry bulb temperature of 100 degrees Fahrenheit (°F) or greater.
- Start wet bulb globe temperature (WBGT) meter monitoring whenever the dry bulb temperature is at least 100 °F.
- Know your physiological heat exposure limit (PHEL), determined from WGBT meter monitoring at your watch station.
- Notify your supervisor if you expect to exceed the PHEL for your watch station.

If you are exposed to heat stress, take the following precautions:

- Eat three adequate, well-balanced meals daily.
- Drink plenty of water (a scuttlebutt must be readily available to you and working properly—if not, notify your supervisor).
- Do not take salt tablets.
- Do not drink commercially prepared electrolyte supplements in place of water.
- Get at least 6 hours continuous sleep every 24 hours.
- Do not wear starched clothing.
- Wear clean clothing composed of at least 35% cotton (more natural fiber content means more evaporation). Work clothing issued and sold by the Navy meets these criteria.

Be aware of the symptoms of heat injury and take corrective action if you detect these symptoms within yourself or your shipmates. Obtain treatment for heat rash or heat cramps from sick bay. Heat exhaustion (indicated by profuse sweating, headache, tingling sensation in extremities, paleness, nausea, or vomiting) should be reported to supervisors and the individual should receive medical treatment. Heat stroke is a medical emergency; the individual should be cooled by any possible means and medical help should be immediately requested.

Heat stress conditions within the engineering spaces can be improved by preventing heat stress-related deficiencies and identifying and systematically correcting deficiencies within the spaces. Prevention is accomplished by training personnel to properly perform corrective and preventive maintenance actions. The identification of deficiencies should be accomplished by a thorough examination of equipment and spaces by formal inspections and by walks through the spaces while on watch or during the work day. Assigned personnel should be trained to report deficiencies identified during operations or while on watch. Identified deficiencies should be systematically corrected. Correction of deficiencies should be planned and executed on a priority basis.

Heat stress control and personnel protection is predicated upon an effective monitoring program.

All personnel who work or stand watch in the engine room shall be trained regarding heat stress upon reporting aboard and annually thereafter. Heat stress training shall include the following:

- Heat stress health hazards
- Heat stress symptoms
- Heat stress first aid procedures

> **NOTE**
>
> The Engineer Officer is responsible for notifying the CO of any heat stress condition within the engineering spaces.

- Heat stress monitoring
- Causes of heat stress

Heat stress training shall also include viewing the videotapes *Heat Stress Monster* or *If* You *Can't Stand the Heat.*

Further information and guidance on the Navy Heat Stress Control and Prevention Program may be found in Shipboard Heat Stress Control and Personnel Protection, OPNAVINST 5100.20; Navy Occupational Safety and Health Program Manual for Forces Afloat, OPNAVINST 5100.19; and Manual of Naval Preventive Medicine, NAVMED P-5010-3, Chapter 3, "Ventilation and Thermal Stress Ashore and Afloat."

Hearing Conservation

The loud, high-pitched noise produced by an operating propulsion plant can cause hearing loss. A hearing loss can seldom be restored. For this reason, ear protection must be worn in all areas where sound level is 84 decibels (dB) or greater. In these places, warning signs must be posted cautioning about noise hazards that may cause loss of hearing.

Labeling of Hazardous Noise Areas and Equipment

Hazardous noise areas and equipment, which produce sound levels greater than 84 dB (A) or 140 dB peak sound pressure level, must be so designated and appropriately labeled. Hazardous Noise Warning Decal Noise Warning Decal NAVMED 6260/2, 8" × 10-1/2", and Hazardous Noise Labels NAVMED 6260/2A, (displayed on hand tools), 1" × 1-1/2", are the approved decals and labels for marking hazardous noise areas or equipment.

Personal Hearing Protective Devices

Hearing protective devices should be worn when entering or working in an area where noise levels are greater than 84 (dB) (A) sound levels or when sound pressure level is 140 dB peak or greater.

A combination of insert-type and circumaural-type hearing protective services (double protection) should be worn in all areas where noise levels exceed 104 dB (A) sound level.

For further information on occupational safety and health programs, refer to OPNAVINST 5100.19(series), *NAVOSH Program Manual for Forces Afloat*, or NAVOSH Program Manual (Shore Activities) OPNAVINST 5100.23,

SUMMARY

The higher you go in the Navy, the more responsibility you will have for administration, supervision, and training. This chapter briefly presented some of the administrative and supervisory responsibilities as well as your responsibility for training others.

As a supervisor you oversee all work to make sure it is done correctly. As a trainer, you provide information and instruction on repair parts, repair procedures and policies, safety precautions, and other matters. You must understand that these administrative, supervisory, and training tasks have a direct relationship to the job at hand.

End of Chapter 20

Advanced Administration, Supervision, and Training

Review Questions

20-1. What in the engineering department provides a means for the proper assignment of duties and proper supervision of personnel?

A. Watch bills
B. Training
C. Evaluation program
D. Administration organization

20-2. Which of the following engineering department records must be preserved as permanent legal records?

A. Engineering Log and Fuel and Water Report
B. Engineering Bell Book and Monthly Summary
C. Engineering Log and Engineer's Bell Book
D. Machinery History and Engineroom Operating Records

20-3. What is the standard engine order telegraph symbol for back emergency speed?

A. Z
B. 1
C. BEM
D. BF

20-4. What does the Engineering Officer use to list major machinery units and readiness of the engineering department based upon the time set for getting the ship underway?

A. Steaming orders
B. Night orders
C. Daily orders
D. Electronic orders

20-5. When computing the amount of burnable fuel on board, which of the following is NOT considered burnable fuel?

A. Fuel in the service tanks
B. Fuel in the storage tanks
C. Fuel below the suction line
D. Fuel in the purifiers

20-6. What is the major advantage of engine lube oil analysis?

A. You send it to be tested
B. You can add a quick mark in the box
C. You can detect issues without disassembling
D. There is no time line

20-7. Who usually designates the type of inspection and when it will be held?

A. Commanding Officer (CO)
B. Chief of Naval Operations (CNO)
C. Fleet forces
D. Type Commander (TYCOM)

20-8. What kind of inspection determines whether proper procedures are being carried out in the care and operation of machinery and equipment?

A. Routine
B. Administration
C. Material
D. Daily

20-9. Which of the following ship's trials is considered a routine trial?

A. Economy
B. Final contacts
C. Laying up
D. Standardization

20-10. What stage of Engineering Operational Procedures (EOP) is considered as the total engineering plant level under the direct cognizance of the engineering officer of the watch (EOOW)?

A. 1
B. 2
C. 3
D. 4

20-11. What level of assurance provides for minimum or "as necessary" verification techniques and normally requires very little quality controls, tests, or inspections?

A. A
B. B
C. C
D. D

20-12. In which of the following circumstances should you immediately return an electrical tool to tool issue?

A. Wires are good (no frayed wires)
B. Plug is broken
C. Safety tag is up to date
D. Housing is in tact

20-13. Which of the following Training films has been included in the Navy's heat stress training for the engineering department?

A. *Heat Stress Monster*
B. *I Can Stand the Heat*
C. *It Not Hot I Have This*
D. *No Breaks for Me*

20-14. At what decibel (dB) level must ear protection be worn and warning signs posted cautioning about noise hazard that may cause loss of hearing?

A. Greater than 50
B. Greater than 67
C. Greater than 74
D. Greater than 84

RATE TRAINING MANUAL – User Update

SWOS makes every effort to keep their manuals up-to-date and free of technical errors. We appreciate your help in this process. If you have an idea for improving this manual, or if you find an error, a typographical mistake, or an inaccuracy in SWOS manuals, please write or e-mail us, using this form or a photocopy. Be sure to include the exact chapter number, topic, detailed description, and correction, if applicable. Your input will be brought to the attention of the Technical Review Committee. Thank you for your assistance.

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Revision Date__________ Chapter Number____ Page Number(s)____________

Description

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(Optional) Correction

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(Optional) Your Name and Address

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CHAPTER 21

ENGINE MAINTENANCE

Keeping an internal combustion engine (diesel or gasoline) in good operating condition demands a well-planned procedure of periodic inspection, adjustments, maintenance, and repair. If inspections are made regularly, many malfunctions can be detected and corrected before a serious casualty results. A planned maintenance program will help prevent major casualties and the occurrence of many operating troubles.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain the importance of diesel engine inspections.
2. Explain the adjustments and maintenance required on diesel engines.
3. Explains the diesel engine lubricating system.
4. Discuss the diesel engine fuel injection equipment and control system.
5. Discuss the procedures for processing fluid samples.
6. Describe some of the repairs of internal combustion engines.

DIESEL ENGINE INSPECTIONS

Inspections and maintenance are vital in order to maintain engines (diesel and gasoline) in proper operating condition and to minimize the occurrence of casualties caused by material failure.

A comparatively minor engine malfunction, if not recognized and remedied in its early stages, might well develop into a major casualty. You and your work center personnel must be able to recognize the symptoms of any developing malfunction by using your senses of sight, hearing, smell, or even touch or feel (heat/vibration).

Your personnel must be trained to pay particular and continuous attention to the following indicators of oncoming malfunctions:

- Unusual noises
- Vibrations
- Abnormal temperatures
- Abnormal pressures
- Abnormal operating speeds

All operating personnel should thoroughly familiarize themselves with the specific temperatures, pressures, and operating speeds of equipment that are required for normal operation, so that any departure from the normal will become more readily apparent.

If a gauge, or other instrument for recording operating conditions of machinery, gives an abnormal reading, the cause of the malfunction must be fully investigated. Normally the installation of a spare instrument, or a calibration test, will quickly indicate whether the abnormal reading is due to instrument error. Any other cause must be traced to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external evidence is apparent. Changes in the operating speeds (from those normal for the existing load) of pressure-governor-controlled equipment should be viewed with suspicion. Most variations from normal pressures, lubricating oil temperatures, and system pressures indicate either inefficient operation or poor condition of machinery.

When a material failure occurs in any unit, a prompt inspection should be made of all similar units to determine whether there is any danger that a similar failure might occur in other units. The cause of the failure must also be determined and corrected in order to avoid repeated failure of the same or similar components. Prompt inspection may eliminate a wave of repeated casualties.

Strict attention must be paid to the proper lubrication of all equipment, including frequent inspection and sampling to ensure that the correct quantity of the proper lubricant is in the unit. It is good practice to make a daily check of samples of lubricating oil in all auxiliaries. Such samples should be allowed to stand long enough for any water to settle. When auxiliaries have been idle for several hours, particularly overnight, a sufficient sample to remove all settled water should be drained from the lowest part of the oil sump. Replenishment with fresh oil to the normal level should be included in this routine.

The presence of saltwater in the oil can be detected by drawing off the settled water by means of a pipette and by running a standard chloride test. A sample of sufficient size for the test can be obtained by adding distilled water to the oil sample, shaking it vigorously, and then allowing the water to settle before draining off the test sample. Because of its corrosive effects, saltwater in the lubricating oil is far more dangerous to a unit than is an equal amount of freshwater. Saltwater is particularly harmful to units containing oil lubricated ball bearings.

The information given so far relates to the inspections that Enginemen make on operating engines (either diesel or gasoline). Since the Navy uses more diesel than gasoline engines, the remainder of this chapter will deal with diesel engines and with the inspection and maintenance procedures that are required by the planned maintenance system (PMS) and the manufacturers' technical manuals.

Compression and Firing Pressures

Readings of the compression and firing pressures must be taken every 200 hours for the trend analysis graphs. They may also be taken at other times when engine operating conditions require additional monitoring, such as when an engine misfires, fires erratically, or when any one cylinder misfires regularly. There can be many reasons for an engine to misfire; some of these are a clogged air cleaner/filter, an engaged fuel cutout mechanism, or a loss of compression. If, after checking the air cleaner, the filter, and the fuel cutout mechanism, you determine that the problem is due to loss of compression, then you must perform a compression check with a cylinder pressure indicator.

There are several different types of indicators that may be used. Most indicators used with diesel-cylinder engines are either of the spring balanced type or the trapped pressure type. Some of these indicators measure only compression pressure; others measure both compression and firing pressures.

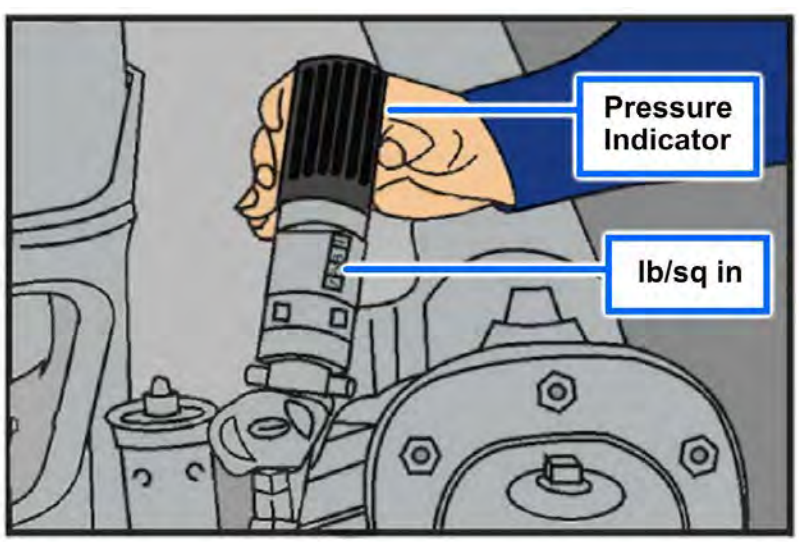

Figure 21-1 — Spring balanced pressure indicator.

Spring-Balanced Indicator

A spring-balanced indicator *(Figure 21-1*) employs a spherical ball piston, which is held on its seat by the force of a helical spring actuated by the cylinder pressure, which acts against the bottom of the ball piston to oppose the spring tension. Before the indicator is attached to the engine, the vulcanized handle must be rotated clockwise until the reading on the counter is greater than the maximum cylinder pressure expected. The amount of this pressure is listed in the engine manufacturer's technical manual. When the indicator is installed, the operator must make sure that it is placed as near the cylinder as possible and position it so that it can be read easily. After the indicator is installed the engine is operated at the specified revolutions per minute (rpm), then the fuel to the cylinder being tested is cut out, the cylinder test cock is opened, and the spring tension on the indicator is adjusted. The tension of the spring is reduced by rotating the vulcanized handle counterclockwise until the maximum cylinder pressure barely offsets the spring pressure. At this point, the latch mechanism of the indicator trips and locks the handle firmly in position, giving a direct and exact reading of the pressure in pounds per square inch (psi). To reset the lock mechanism for a new reading, the handle must be rotated counterclockwise one-fourth turn. When this indicator is stowed for future use, the indicator spring must be unloaded by rotating the handle counterclockwise until a zero pressure reading is obtained.

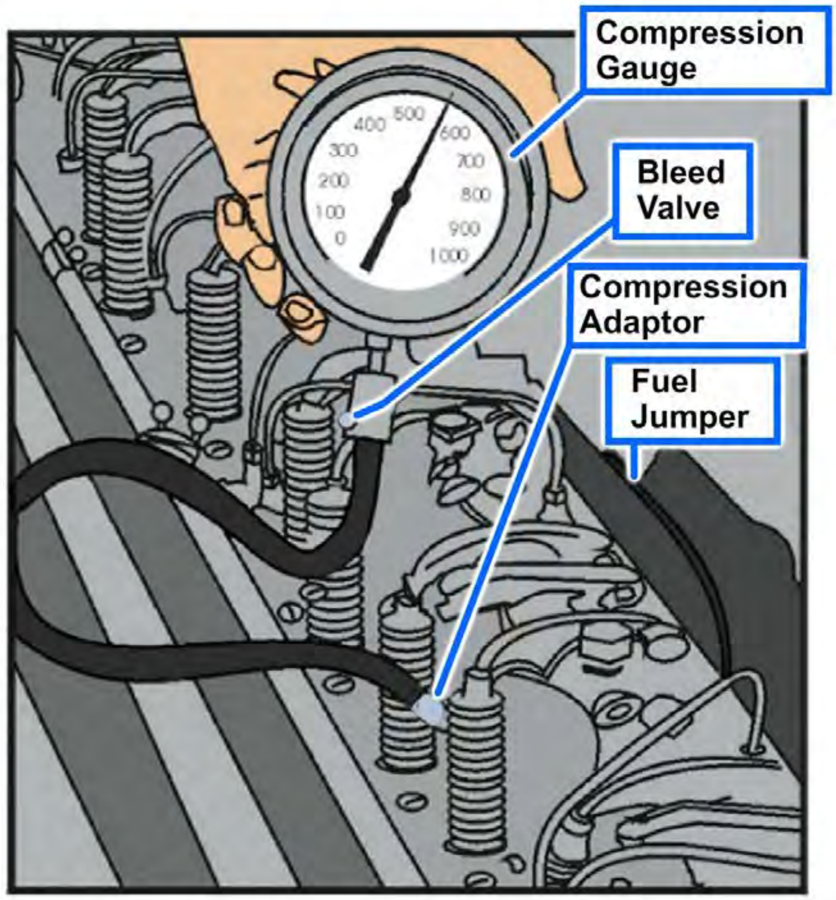

Figure 21-2 — Trapped pressure indicator (small boat).

Trapped Pressure Indicators

In this type of indicator, the cylinder gases enter past a valve into a chamber which leads to a gauge. When the pressure above the valve equals that of the cylinder, the valve seats and traps the gas above the valve at its highest pressure, and this pressure is read on the gauge. This type of indicator is used to take compression reading on engines installed on small boats *(Figure 21-2),* because these engines do not have indicator cocks installed.

When taking compression readings you will perform the following steps:

1. Check the manufacturer's technical manual for the minimum compression pressure required for the engine.
2. Start the engine and run it at approximately one-half the rated load until normal operating temperatures are reached.
3. Stop the engine and remove the fuel pipes from the injector and the fuel connectors on the cylinder to be tested.
4. Remove the injector and install the indicator adapter with pressure gauge attached, using the crab nut to hold the adapter in place.

5. Use a space fuel pipe to fabricate a jumper connection between the fuel inlet and the return manifold connectors to by-pass fuel to and from the injector.
6. Start the engine again and run it at approximately 600 rpm.
7. Observe and record the compression pressure as indicated on the gauge.

Another type of trapped pressure indicator is the Kiene indicator *(Figure 21-3).* This indicator is basically a Bourdon gauge connected to a cylindrical pressure chamber. The pressure chamber contains a check valve which allows the gas to flow from the engine into the chamber until the pressures are equalized. This gauge is attached to the chamber and the pressure is read directly. The check valve is an inverted piston seating on a seat piece. The valve moves up and down in a guide. A stop nut is used to adjust the travel of the check valve.

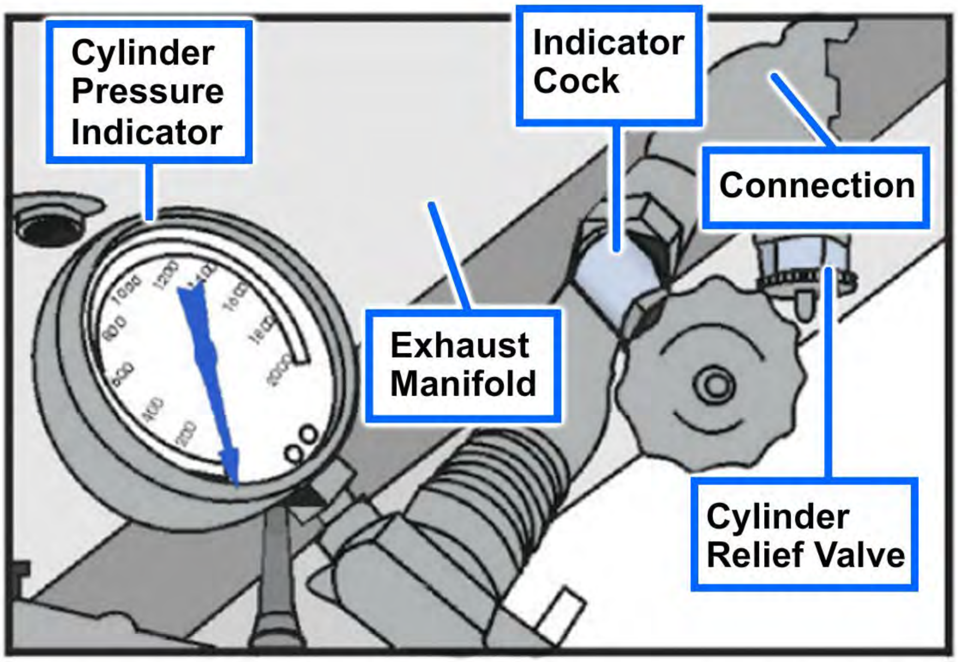

Figure 21-3 — Trapped pressure indicator.

Most of you should become familiar with this indicator since it is widely used to check both the compression and firing pressures on main diesel engines and emergency generator diesel engines, (review *Figure 21-4, frames 1 and 2*). It is a PMS situation requirement to be performed when the engine operating conditions indicate problems.

SHIP SYSTEM	SUBSYSTEM	MRC CODE	
		A-2 R-5	
SYSTEM	EQUIPMENT	RATES	MIN
	Emergency Generator Diesel Engine	EN1 EN3	1.0 1.0
		TOTAL MIN 2.0	ELAPSED TIME 1.0

MAINTENANCE REQUIREMENT DESCRIPTION

1. Measure compression and firing pressures.

SAFETY PRECAUTIONS

1. Forces afloat comply with Navy Safety Precautions for Forces Afloat, OPNAVINST 5100 series.
2. Wear gloves when handling indicator.

TOOLS, PARTS, MATERIALS, TEST EQUIPMENT

1. Kiene indicator
2. Asbestos gloves
3. Pencil and paper
4. Injector lockout wrench, mtr. part NO. 3385742

PROCEDURE

NOTE: Accomplish when directed as result of engine operating condition.

Preliminary

a. Ensure engine is at normal temperature and operating at full speed and no load.

1. Measure Compression and Firing Pressures.
   a. Measure compression pressures.
      (1) Remove cover from cylinder being tested.
      (2) Open cylinder test cock to blow out passage; shut test cock.

WARNING: Wear gloves when handling indicator.

(3) Attached indicator to test cock.
(4) Install lockout wrench and lock out the injector.
(5) Open indicator vent and cylinder test cock.
(6) Shut indicator vent and adjust indicator for minimum vibration.
(7) Record compression pressure and shut cylinder test cock; normal compression pressure is 550 psi to 650 psi.
(8) Remove injector lockout wrench.
(9) Repeat steps 1.a.(2) through 1.a.(0) for each remaining cylinder under cover removed in step 1.a.(1), if applicable.
(10) Reinstall cylinder cover.
(11) Repeat steps 1.a.(1) through 1.a.(10) for remaining cylinders.

b. Operate engine at full speed and full load.
c. Measure firing pressure.

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LOCATION	DATE
	May 2013

MAINTENANCE REQUIREMENT CARD (MRC)
OPNAV 4790/82 (REV 2-82)

Figure 21-4 — Maintenance requirement card (MRC) for measuring compressing and firing pressures.

Exhaust and Cylinder Temperatures

One of the most useful tools that the engine operator has for monitoring an engine's performance is the thermocouple pyrometer. The principal use of this device is in the exhaust system (but it can also be used for other purposes) where it is used to measure the exhaust gas temperatures at each cylinder or the common temperature in the exhaust manifold. By comparing the exhaust gas temperatures of each cylinder, the operator can determine if the load is balanced throughout the engine.

The two types of pyrometers in use are the fixed installation and the portable hand-held instrument *(Figure 21-5).* Both types use a thermocouple unit installed in the exhaust manifold.

In its simplest form, a thermocouple consists of two dissimilar metal wires, usually iron and constantan (55% copper and 45% nickel) that are joined at both ends to form a continuous circuit. When the temperatures at the junctions are different, an electrical current is produced and flows in the circuit. The greater the temperature difference, the greater the voltage produced.

One junction, known as the hot junction, is contained in a closed-end tube installed in the exhaust manifold of each cylinder. The other junction called the cold junction, is exposed to room temperature, and is located at the pyrometer wire terminals *(Figure 21-6).* A pyrometer (millivolt meter) measures the voltage produced and shows the results on a scale that has been calibrated to read in degrees of temperature. In fixed installation pyrometers, if the connecting wires are of the same type as those of the thermocouples, the thermocouple element becomes, in effect, extended to the pyrometer terminals and the temperature at the meter (now the cold junction) becomes the reference temperature. Then the selector switch can be rotated to any cylinder and contact can be made between the pyrometer and the hot junction. A reading can then be obtained for that particular point.

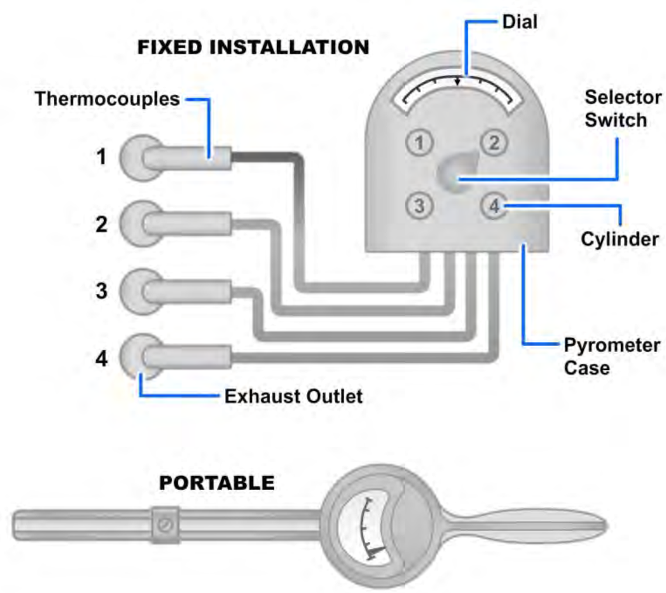

Figure 21-5 — Pyrometers used in diesel exhaust systems.

The hand-held pyrometer consists of an indicator and a pair of pointed prods attached to a sub-base and supported by a handle. To obtain a reading, the prod points are pressed against the exposed thermocouple terminals. The reading is taken from the scale; a point to remember is that the zero adjuster must be set to indicate room temperature rather than 0° temperature.

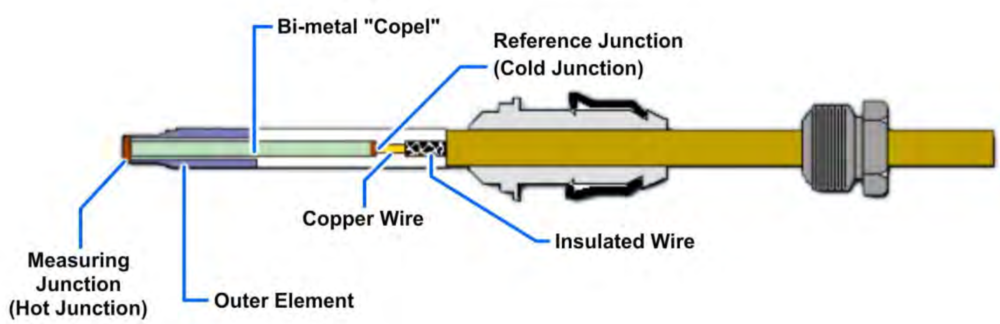

Figure 21-6 — Sectional view of a thermocouple.

Graphic Records

Graphic records play an important part in keeping an engine in proper operating condition. When used properly they can tell you how your engine is performing and what is happening inside the engine. Graphic records indicate the overall condition of an engine and warn you when certain parts are beginning to wear out so that you may take prompt corrective actions and prevent major casualties.

ADJUSTMENT AND MAINTENANCE

An internal combustion engine is a complicated machine, built with a high degree of precision throughout and capable of long dependable service if it is kept in good operating condition. To keep an engine in good operating condition you must perform all the adjustments and maintenance prescribed in your installed PMS and the manufacturers' technical manuals. In this section you will read about the adjustment and maintenance of various components of an internal combustion engine.

Automatic Regulating Valve

In many engines, freshwater temperature is regulated by an automatic regulating valve which maintains the freshwater temperature at any desired value by bypassing a portion of the water around the freshwater cooler. An automatic temperature regulator of the type commonly used in the cooling systems of marine engine is shown in *Figure 21-7*. Even though these regulators are automatic (self-operated), provisions are included in most installations for manual operation in the event that the automatic feature fails.

The temperature regulator consists of a valve and a thermostatic control unit mounted on the valve. The thermostatic control unit consists of a temperature-control element and a control assembly.

The temperature-control element is essentially two sealed chambers consisting of a bellows connected by a flexible armored capillary tube to a bulb mounted in the engine cooling-water discharge line. One chamber is formed by the bellows and cap, which are sealed together at the bottom; the other chamber is in the bulb. The entire system (except for a small space at the top of the bulb) is filled with a mixture of ether and alcohol, which vaporizes at a low temperature. When the bulb is heated, the liquid vaporizes and the pressure within the bulb increases. This forces the liquid out of the bulb and through the capillary tube to the bellows. As the bellows is moved down, it operates the valve.

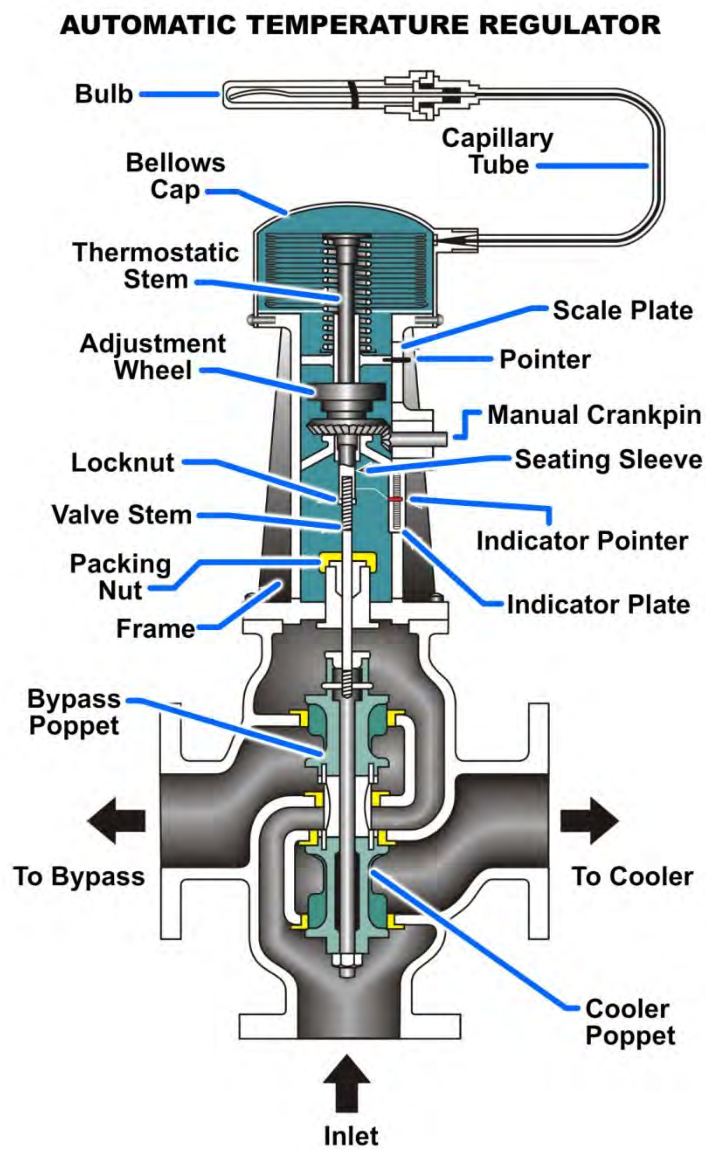

Figure 21-7 — Automatic temperature regulator.

The control assembly consists of a springloaded mechanical linkage which connects the temperature-control element to the valve stem. The coil spring in the control assembly provides the force necessary to balance the force of the vapor pressure in the temperature-control element.

Thus, the downward force of the temperature control element is balanced, at any point, by the upward force of the spring. This permits the valve to be set to hold the temperature of the engine cooling water within the allowed limits.

The regulator operates only within the temperature range marked on the nameplate; it may be adjusted for any temperature within this range. The setting is controlled by the range adjusting wheel, located under the spring seat. A pointer attached to the spring seat indicates the temperature setting on a scale which is attached to the regulator frame. The scale is graduated from 0 to 9, representing the total operating range of the regulator.

A temperature regulator may be located in either the seawater or freshwater circuit. In most engines, the regulator is located in the freshwater circuit.

When located in the seawater circuit, the regulator controls the amount of seawater flowing through the coolers. As the temperature of the freshwater becomes greater than the temperature for which the regulator is set, the regulator actuates a valve to increase the flow of seawater through the coolers. On the other hand, when the freshwater temperature is below the temperature for which the regulator is set, the regulator actuates the valve and decreases the flow of seawater through the coolers.

In installations where the regulator is in the freshwater circuit, water is directed to the cooler when the temperature of the water is above the maximum setting of the regulator. After passing through the cooler where the temperature of the water is lowered, the water returns to the suction side of the freshwater pump to be recirculated. When the temperature of the water is below the maximum setting of the regulator, the water bypasses the cooler and flows directly to the suction side of the pump. Bypassing the cooler permits the water to be recirculated through the engine; in this way, the temperature of the water is raised to the proper operating level.

Regardless of whether the regulator is in the fresh or seawater circuit, the bulb which causes the regulator to operate is located in the freshwater discharge line of the engine.

Temperature regulators not only control directly the temperature of the freshwater but also control indirectly the temperature of the oil discharged from the lubricating oil cooler. Control of the lubricating oil temperature is possible because the water (freshwater or saltwater) that is passed through the regulator and the freshwater cooler is also the cooling agent for the lubricating oil cooler. When the lubricating oil is cooled by seawater, two temperature regulators are installed in the seawater circuit. The temperature regulator bulb of the regulator that controls the temperature of the freshwater is installed in the freshwater circuit; the bulb of the regulator that controls the temperature of the lubricating oil is installed in the lubricating oil system.

Maintenance

To allow proper operation of a temperature regulator, the valve stem must not bind in the stuffing box, but must move freely. The valve stem must be lubricated frequently where it enters the stuffing box and also around the threaded sleeve used for the manual control. A small amount of grease should also be used on the bevel gears. The valve packing nut should be kept only finger tight and should be lubricated occasionally with a drop of oil. Should it become necessary to renew the packing, you will need to remove the nut, take out the packing gland, clean the stuffing box, and repack it with asbestos wicking saturated with oil.

If the temperature of the freshwater leaving the engine is too high when the regulator is set on the lowest adjustment setting, you should do the following:

1. Ensure that the manual pointer is set at the thermostatic position.
2. Ensure that the packing gland is not binding the valve stem and that the valve stem is not stuck in the cooler closed (minimum cooling) position.
3. Check the water lines for other causes of the difficulty. If this check does not reveal the cause of the trouble, it is probable that the temperature control element is inoperative, and that it should be checked.

If undercooling occurs when the temperature regulator is set on the highest adjustment setting, check for a sticking valve in the by-pass closed (maximum cooling) position. Sticking may be caused by a tight stuffing box or by dirt under the lower valve seat. If the temperature at the bulb is lower than the set temperature and the valve position indicator shows cooler closed, excessive leakage is indicated. In such case you will have to regrind the valve using the following procedure:

1. Disconnect the valve from the piping.
2. Remove the packing nut and the packing.
3. Disconnect the valve stem and remove the locknut from the thermostatic stem.
4. Remove the thermostatic control unit from the valve.
5. Clean the valve stem until it is smooth. If necessary, polish it with fine emery cloth.
6. Grind the valve seats until a perfect seal is obtained; then remove all grinding compound from the valve and the seats.
7. Reassemble the valve and the control unit.
8. Repack the stuffing box and lubricate it with engine oil.
9. Secure the packing gland nut finger tight.
10. Insert the bulb into the ship's piping in either a horizontal or vertical position, *(Figure 21-8, views A through C)*. When the bulb is installed in the vertical position, the nut must be at the top; when it is installed in the horizontal position, the arrow on the indicator disk must point upward. NEVER INSTALL THE BULB WITH THE NUT AT THE BOTTOM *(Figure 21-8, view C)*, because in this position the liquid would be below the end of the internal capillary tube and would have little or no effect on the bellows of the temperature regulator valve.
11. Adjust the regulator.

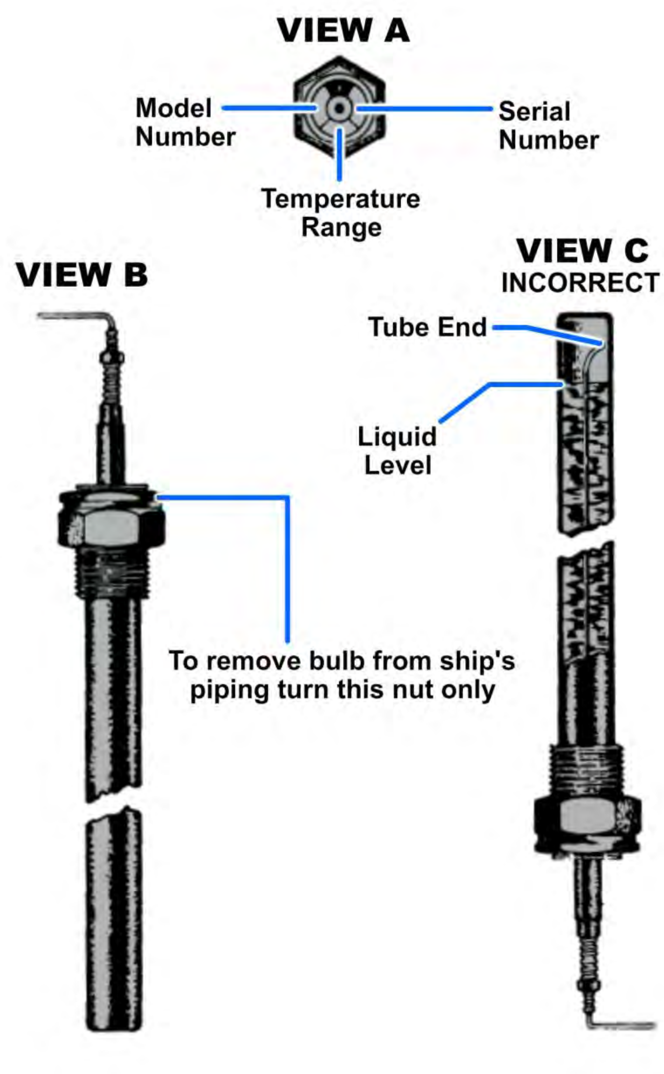

Figure 21-8 — Bulb installation.

NOTE
The preceding steps should be performed with the thermostatic bulb removed from the ship's piping and when the bulb temperature is below 100 °F.

Adjustment

A close-up of the adjusting and indicating features of the temperature regulator is shown in *Figure 21-9.* The procedure for adjusting a temperature regulator is as follows:

1. Rotate the manual crank pin until the indicator pointer is in the thermostatic position.
2. Turn the adjusting wheel until the pointer is opposite 2 on the scale plate.
3. Loosen the locknut and unscrew the valve stem until it is free of the thermostatic stem.
4. Then turn the adjusting wheel until the pointer is opposite 8 on the scale plate.
5. Again rotate the manual crankpin until the lower end of the seating sleeve is flush with the lower end of the thermostatic stem.
6. With the seating sleeve and the indicator pointer in this position, loosen the screws in the indicator plate and slide the plate up or down as needed to align the thermostatic mark in the center of the plate with the indicator pointer.
7. Then retighten the screws. (The marks cooler closed and cooler by-pass on the indicator plate are only approximate).
8. Screw the valve stem into the thermostatic stem and turn it until the cooler poppet valve seats firmly.
9. Turn the adjusting wheel until the pointer is opposite 2 on the scale plate.
10. Turn the valve stem one full turn into the thermostatic stem and retighten the locknut.
11. With the manual control on the thermostatic position, turn the adjusting wheel in a direction to bring the pointer to number 9 on the scale plate.

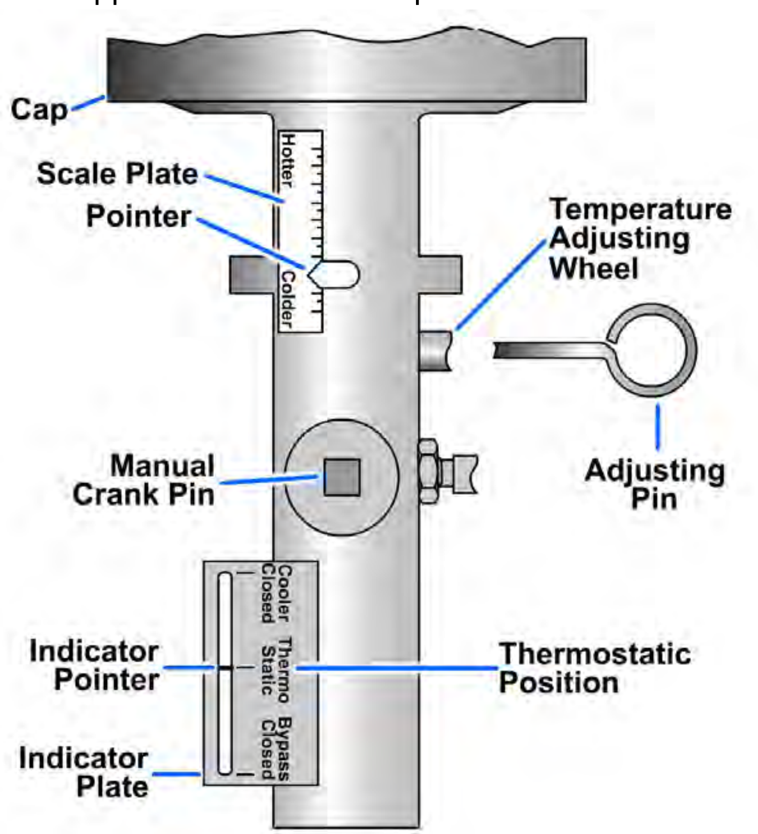

Figure 21-9 — Scale and indicator plates of temperature regulator.

12. Run the engine at warmup speed until the temperature of the fluid, as indicated by the thermometer in the line with the thermostatic bulb, rises to the desired temperature. (The desired temperature must be determined in advance from applicable instructions).
13. With the engine running at warmup speed and the temperature at the thermostatic bulb at the desired value, turn the adjusting wheel until the cooler poppet just begins to leave its seat.
14. This action is shown by the movement of the mark on the valve stem downward from the cooler closed mark on the valve position indicator.

15. Valves adjusted in accordance with this procedure will normally maintain the temperature of the fluid at the thermostatic bulb between the desired value and a temperature approximately 20 °F higher, under any conditions of engine load or injection temperature.
16. This 20° difference is the temperature rise required to cause the poppet valve to move through the necessary travel.

Heating Exchanger Definitions

Problems with the cooling system of an engine may prevent the cooling system from keeping the engine parts and working fluids at safe operating temperatures. Failure of the system may lead to several of the troubles and casualties that have been discussed earlier.

In marine installations, lubricating oil and most of the engine parts are cooled by the circulation of seawater, freshwater, or both. When the cooling of an engine part is mostly by oil spray or oil circulation, the oil is cooled by circulation through oil cooler. A cooling system in which both freshwater and seawater serve as coolant is illustrated in *Figure 21-10*.

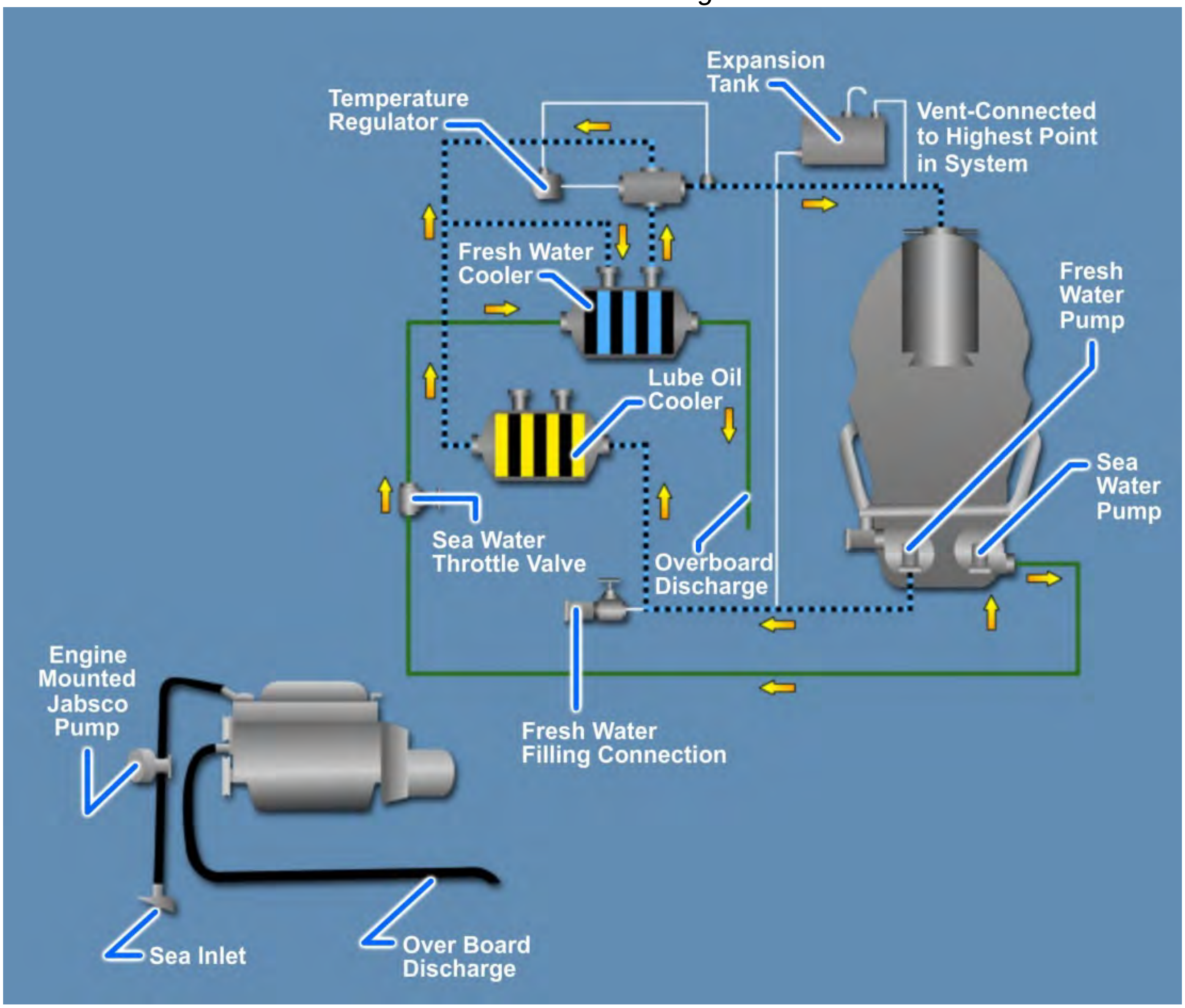

Figure 21-10 — A cooling water system.

When maintaining engine cooling water temperatures within specified limits, the principal difficulties you may encounter are in maintaining circulating pumps in operating condition; preventing corrosion; reducing the cause of scale formation in water jackets and heat exchangers; cleaning jackets and heat exchangers according to proper procedures; and preventing leaks in the various parts of the system.

The coolers (or heat exchangers) which remove the heat from the cooling water of an engine may vary considerably in design. Those used in cooling systems may be classified basically as the radiator type and the tubular type. The radiator is sometimes referred to as the strut, while the tubular is identified as shell-and-tube type. Heat exchangers of both types are shown in *Figure 21-11*. The heat exchanger on the top of the picture is a radiator-type heat exchanger; the one on the bottom is a tubular-type heat exchanger. In heat exchangers of the radiator type, the freshwater passes through the tubes and the seawater passes around them. In the tubular type, the freshwater surrounds the tubes and the seawater passes through them.

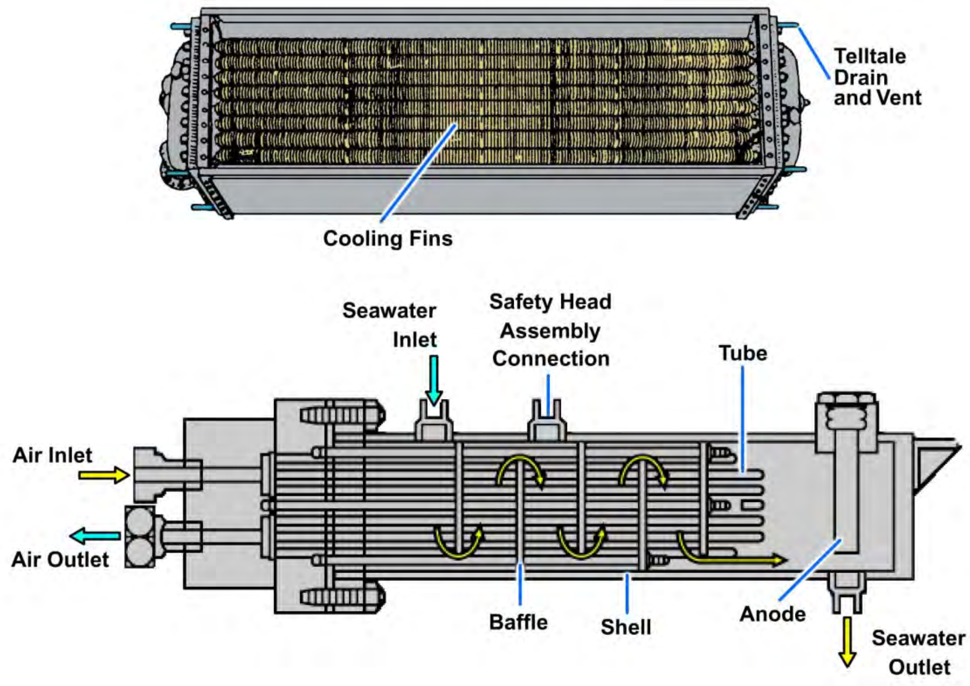

Figure 21-11 — Types of heat exchangers.

Casualties

Although heat exchangers vary in design, they are all subject to similar casualties. The principal difficulties which may prevent heat exchangers from functioning properly are excessive scale deposits on the cooler element, clogged cooler elements, or cooler leakage.

A gradual increase in the freshwater temperature is usually an indication of excessive scale on a cooler element. As scale formation increases, there is a gradual increase in the pressure difference between the inlet and outlet of the heat exchanger. Scale deposits generally form faster on the saltwater side than on the freshwater side, because of the greater amount of dissolved salt present in the water.

Complete prevention of scale formation is not possible, but steps can be taken to reduce scale by using proper cleaning methods and procedures. Seawater discharge temperature should be maintained below a specified limit (130 °F), because the rate of scale formation is increased as the temperature increases. The water used in closed cooling systems must be as pure as possible. Distilled water is recommended for a freshwater cooling system, but since distilled water is not absolutely pure, additional steps must be taken to control acidity and alkalinity. The treatment used to control these factors will not remove scale already formed, but it will prevent further precipitation of scale-forming slats. You will find details for water treatment in closed water systems in *Naval Ship's Technical Manua*l (NSTM), Chapter 233, and in most engine instruction manuals.

Cooler elements may be clogged or restricted not only by the hard deposits chemically precipitated from the circulating water, but also such items as marine life, grease, and debris of various types. The principal causes of cooler clogging by loose foreign matter are faulty seawater strainers, dirty freshwater, excessive lubrication of the pumps, and leaking oil coolers.

To prevent the entry of sea debris, a punctured screen in a seawater strainer must be replaced as soon as possible. Obviously, the use of dirty freshwater will hasten the clogging of a cooler element. Grease and oil may enter the cooling system and the film deposited on the cooler element will reduce the capacity of the cooler. Grease may come from grease cups that are used on some water pumps to lubricate bearings. If the cups are turned down too much or too often, grease is forced into the circulating water. A hole in the element of the oil cooler will allow oil to flow into the cooling system. Any source of oil or grease should be located and repairs made as soon as possible.

Corrosion or erosion of the element in a heat exchanger, as well as operation at excessive pressure, may cause leaks. These leaks can develop either in the element or in the casing. Leakage from the cooler casing can usually be detected by inspection. Element leaks, however, are more difficult to detect. Any noticeable decline or rise in the freshwater tank level, with the temperature remaining normal, usually indicates leakage.

A hole made by corrosion in a cooler element indicates that corrosion probably exists throughout the element, and a thorough inspection should be made. Corrosion can be prevented to a large extent by using the prescribed freshwater treatment, inspecting as necessary and venting the cooler to remove entrapped air.

Holes due to erosion are usually caused by particles of grit (sand, dirt, etc., resulting usually from operation in shallow water) striking an element at high velocity. Grit is, for the most part, so fine that it passes easily through the strainer. If the strainer is defective, even the larger particles of grit may enter the cooler.

Erosion by water at high velocity may also result in holes in a cooler element. This occurs when water flow has to be increased above the rated capacity in order to maintain a desired freshwater temperature. Whenever it is found necessary to greatly increase the water flow, the cooler should be cleaned.

If the designed maximum operating pressure (indicated on the exchanger name plate) is exceeded, leaks are apt to result. Excessive pressure is likely to occur in conjunction with clogging, because additional pressure is necessary to force a given quantity of water through a clogged element.

Maintenance and Repair

Because of the difference in their construction, methods of cleaning both types of heat exchangers (radiator and tubular) differ in some respects. Radiator-type heat exchangers are cleaned by chemical means because mechanical cleaning is not satisfactory for this type heat exchanger. In both types of heat exchangers, loose foreign matter such as seaweed, sand, and dirt may be removed by blowing steam through the element in a direction opposite to the normal flow of water. When an element is badly clogged, care must be exercised not to admit steam at a pressure exceeding the maximum specified for the element. If a film of oil or grease is evident, the element should be cleaned like an oil cooler element.

Leakage from the casing of a radiator-type heat exchanger may be caused by a damaged gasket. If so, the heat exchanger should be removed from the piping in order that flange faces may be tightened evenly after a new gasket is installed. If there is any reason to suspect that there are leaks in a heat exchanger element, the best method for locating them is by an air test. This test may be accomplished as follows:

1. Remove the element from the casing.
2. Block off the discharge side of the element.
3. Attach a pressure gauge to the inlet line of the element.
4. Supply low-pressure air to the inlet side of the element. Remember: Air pressure must NEVER exceed design pressure for the element.

5. Immerse the element in a tank of water.
6. Check for bubbles.

An element of a heat exchanger may also be tested hydrostatically by filling the element with water under pressure and checking for leaks.

Emergency repair of leaks in the element of a radiator-type heat exchanger can be made (*Figure 21-12)*. When emergency repairs to the radiator-type heat exchanger are necessary, they may be made with the use of soft solder and a small torch or soldering iron. Extreme care must be taken to prevent the surrounding area from being overheated, thus causing the existing solder to melt. Small radiator-type heat exchangers should be replaced as soon as a leak develops, if a replacement is available. The presence of one leak, unless caused by dropping or accidental puncture, indicates that other areas in the heat exchanger may be eroded.

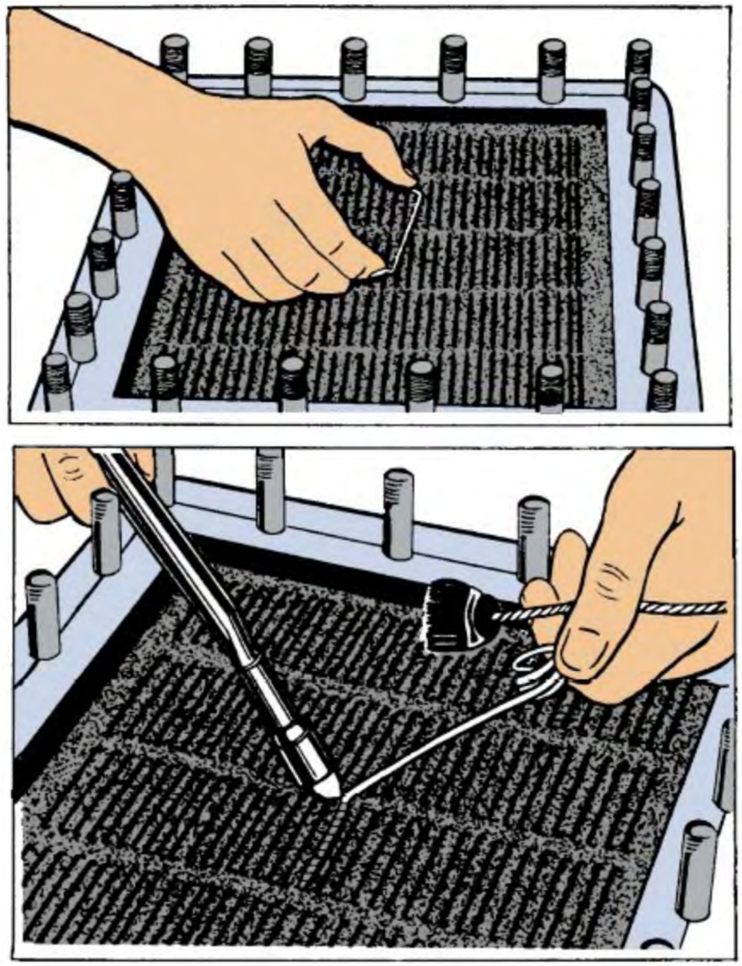

Figure 21-12 — Emergency repair of a tube leak in a radiator-type heat exchanger.

In shell-and-tube heat exchangers, a leaking tube must be replaced as soon as possible. In an emergency, a faulty tube may be blocked off by inserting a special plug at each end, until the tube can be replaced. An air lance or water lance should be used to clean the tubes of a shell-and-tube heat exchanger. If the scale has hardened in the tubes, a round bristle brush or soft rubber plugs may be used to clean the tubes. When cleaning the tubes by mechanical means, avoid damaging the protective coating inside the tubes. These tubes should never be polished, as the tarnish on the tubes acts as insulation to prevent further corrosion. Removing the tarnish will also reduce the tube wall thickness and, over a period of time and a number of cleanings, could sufficiently reduce tube strength, resulting in tube failure. For the proper procedures for cleaning shell-and-tube-type heat exchangers and the safety precautions, use the PMS maintenance requirements cards, the manufacturer’s technical manual, and NSTM*,* Chapter 254.

LUBRICATING SYSTEM

To ensure that all the parts of an engine receive adequate lubrication, it is essential that all parts of the lubricating oil system be properly maintained at all times. Some parts which may be a source of trouble are considered in this section.

Lube Oil Pumps

Pumps used in engine lubricating systems are of the positive displacement type. In some pumps pressure control is maintained by pressure regulating or pressure relief valves built directly into the pump; in other pumps, valves exterior to the pump are used for this purpose. Most regulating devices recirculate excess lube oil back to the suction side of the pump, but some pumps discharge excess oil directly into the engine sump.

Pump casualties, as well as many other lube systems failures, are indicated by the loss of lube oil pressure. The loss of oil pressure can be recognized by checking the pressure gauges at prescribed intervals, or by means of an electrical alarm system. Most lube oil pump failures are generally due to wear, and develop gradually. Failures may also occur abruptly if a drive shaft breaks, or some parts suffer physical deformation. Such failures are usually indicated by abnormal noise in the pump and by sounding of the low-pressure lube oil alarm.

The warning system should be tested at specified intervals, usually when an engine is being started or secured. Warning systems do not excuse personnel from their responsibility for keeping a vigilant and accurate watch on engine instruments. The instruments give the most reliable indication as to what an engine is doing and what adjustments should be made.

Oil Lines and Passages

Troubles occurring in the oil passages and oil lines are usually in the form of plugged or cracked lines. The former is generally the result of carelessness, while the latter is usually a result of improper support of the line.

Even though clogged passages may be indicated by increased pressure gauge readings, it is dangerous to rely wholly on such indications, since stoppage occurring beyond the pressure regulating valve and pressure gauge may cause very little, if any, pressure increase on the gauge. You can best determine if a bearing is receiving oil by inspecting it occasionally, just after engine shut-down. There should be plenty of oil in the vicinity of the parts being lubricated. Another method for checking bearing lubrication is to note the temperature of the bearings by feeling them with the hand after engine shut-down. You should be able to keep your hand on them for at least a few seconds.

You can help prevent most oil line stoppage by observing the following rules:

1. Never use cotton waste or paper towels for cleaning an engine. They may leave lint or small bits of material which later may collect in the lines.
2. Service the oil filters at specified intervals. Clean the case properly and, when the lines are removed, blow them out with compressed air.

FUEL INJECTION EQUIPMENT AND CONTROLS

The fuel system is one of the most complicated of all engine systems, special care must be exercised when making adjustments and repairs. Even though manufacturers have designed many different fuel systems, the basic principle involved is the same in all of them. If you understand the basic principle for one system, you will have no difficulty in becoming familiar with other systems. The procedures for the maintenance and repair of the various systems are also similar.

Let’s review briefly not only the function of a fuel system but also the various types of fuel systems. As you know, the function of a fuel injection system is to deliver fuel to the engine cylinders under specific conditions: at a high pressure, at the proper time, in the proper quantities, and properly atomized. This function may be carried out by either one of two types of systems: the air injection type or the solid injection type. Since there are few air injections systems now in use, we will consider only the solid (mechanical) injection type systems.

Solid injection systems may be classified as jerk pump systems and common rail systems. Variations are to be found in each of these systems. The following examples show some of the basic differences between the various solid injection systems.

Systems of the jerk pump type may be identified as either individual pump systems or unit injection systems. Some jerk pump systems use a separate pump and fuel injector for each cylinder, while the unit injection systems combine the pump and injector into a single unit.

In an individual pump system, the pump is a cam-actuated constant-stroke lapped plunger and barrel pump. The pump times, meters, distributes, and provides the necessary pressure to inject the fuel into the cylinder through a separate nozzle.

A unit injection system consists of a cam-actuated constant-stroke lapped plunger and bushing, a high pressure pump, and an injection nozzle, all in one unit.

A cam-actuated injector and nozzle assembly is mounted in each cylinder. This system employs a common metering device that distributes a measured quantity of fuel to each of the injectors. The injection system embodies characteristics of the unit injector and is sometimes classified as such, although it is also called a distributor system.

The injection system known as the common rail system includes two types: the basic common rail system and the modified common rail system. In the modified system; one untimed, high pressure pump supplies fuel at injection pressure to a main header (common rail). The fuel flows from the header to the injector valves and nozzles at each cylinder. The injector valves are cam operated and timed. Metering of the fuel is controlled by the length of time the nozzle remains open and by the pressure maintained by the high pressure pump in the common rail.

The modified common rail system (constant pressure) uses a high pressure pump to maintain fuel at the injection pressure in an accumulator bottle. The fuel is metered by individual valves mounted on the side of the engine; it then flows to the pressure-operated nozzles in the cylinder head, to be atomized and distributed in the cylinder.

Fuel Injection Pumps and Injectors

In any discussion of a fuel system, the importance of each of its parts cannot be overlooked. The first requirement for trouble-free operation of a fuel system is clean fuel. Accordingly, the filters, the strainers, the tanks, the transfer pumps, and the lines must be maintained according to prescribed instructions. Even when these parts function properly, the principal elements of the injection system—pressure pump, injection valves, and injection nozzles—are subject to troubles. The following discussion covers some of these troubles as well as their symptoms and causes, and provides general information concerning maintenance and repair of this equipment. As you study this information, keep in mind the differences which may exist between the various systems.

Damaged Plunger

In the plunger and barrel assembly of a high pressure pump and in the plunger and bushing assembly of a unit injector, the symptoms and causes of damage are similar.

Damage may become apparent through erratic engine operation. Symptoms vary widely and may include failure of the engine to develop full power, low exhaust temperature, low firing pressure for the affected cylinder, difficulty in balancing (calibrating) the pumps or injectors, and failure of one or more cylinders of the engine to fire. Damage to a plunger and the part in which it slides may also be recognized by testing the unit on a test stand. However, the best way to determine the extent of damage is to disassemble the unit, clean it thoroughly, and then carefully inspect each part.

Cleaning of the units can be best accomplished by use of an approved solvent. Clean diesel fuel may be used when more effective cleaners are not available. A brush must be used with diesel fuel and even then, removal of gummy deposits is difficult. Keep each plunger and barrel (bushing) together during the inspection to avoid improper assembly, as they are manufactured in matched sets.

The use of a magnifying glass during the examination of a plunger will facilitate the detection of damage. Inspect for fine scratches, dull surface appearance, cracks, pit marks (usually accompanied by dark discoloration), and erosion and roughness at the edge of the helix or at the end of the plunger *(Figure 21-13, view A and B*). An example of a badly scored plunger is illustrated in *Figure 21-13, view A*. A plunger with the lapped surface and helix edge in good condition is shown in *Figure 21-13, view B*. Surface irregularities in the region illustrated are serious because they affect metering and, consequently, engine operation.

When examining a barrel or bushing, search for erosion of the ports or scoring of the lapped surfaces. Pay particular attention to the lapped plane surface at the end of a pump barrel. Rust or pit marks on this surface must be removed by lapping before reassembly.

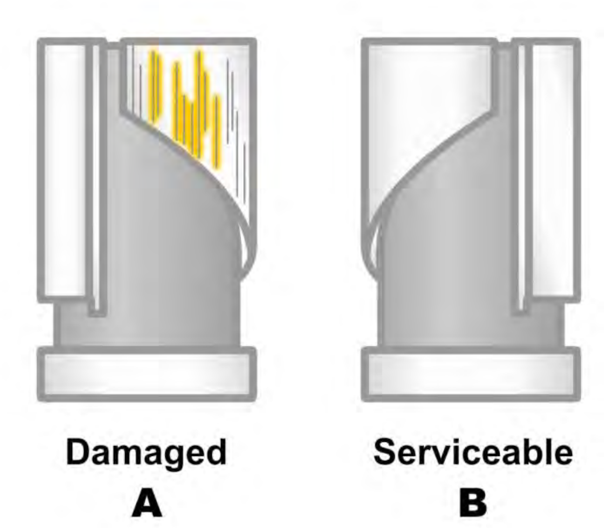

Figure 21-13 — A damaged and a serviceable plunger.

Damage to the plunger of a fuel injection pump or injector may be caused by such different factors as entry of dirt into the equipment, careless handling while the equipment is disassembled, corrosion, and improper assembly and disassembly procedures.

Dirt and water are responsible for practically all trouble encountered with fuel injection equipment. If the units are not properly protected, they can be damaged beyond repair within a very short period of operation. Remember that the clearances between the lapped surfaces are so small that occasionally extremely fine particles, such as dust from the atmosphere, are capable of scoring these surfaces. Then small amounts of water that may collect from condensation will corrode these surfaces.

An engine should never be operated unless the fuel has been properly filtered before reaching the injection equipment. Although regular filters and strainers are present in all fuel systems, in some systems special safety filters or screens are incorporated to further reduce the possibility of foreign matter mixing with the fuel as it reaches the pump and the injector. The location of these additional safety devices depends upon the system. In one system a screen is placed between the fuel transfer pump and the fuel distributor, while in another a filter is mounted directly on the pump.

During the overhaul of fuel injection equipment, a spotlessly clean working space is essential for the protection of all parts. Ideally, the area should also be air conditioned. All air should be thoroughly filtered before it enters the space. Benches should have smooth tops. Metal-topped benches should be covered with linoleum or lint free rags. Ample quantities of approved cleaning solvent, clean fuel oil, and compressed air to blow parts dry should be used to help ensure cleanliness during overhaul. Never use rags or waste to clean injectors, as lint particles from them may damage the injector parts.

From the time a unit is removed from the engine until it is replaced on the engine, extreme care must be exerted to keep dust and dirt away from all its parts. Before any connections are loosened, all dirt should be removed from the unit, tubing, and fittings by washing. After removal of the unit from the engine, all opening (pump, nozzle, tubing, or injectors) should be covered with approved caps or coverings.

Because many surfaces of the parts of pumps and injectors are lapped to extremely accurate finishes, it is essential that they be handled with great care. Parts that are dropped may be bent, nicked, dented, or otherwise ruined. All work should be done well over the center of the bench. The use of a linoleum covering will reduce casualties caused by dropping parts on the bench. Never leave parts uncovered on the bench, but keep them immersed in diesel fuel until handled. Never handle lapped surfaces when they are dry, as the perspiration on your hands may cause corrosion. Before a lapped surface is handled, it should be immersed in clean diesel fuel, and the hands rinsed in clean fuel. Since the mating parts of pumps and injectors are fitted to one another, such parts as plunger and barrel should be kept together to avoid interchanging.

Since water in the fuel, or improper storage of parts, can also cause corrosion of the parts of a pump or an injector, all fuel should be centrifuged, and filter and strainer cases drained periodically to prevent excessive collection of water. Information on proper stowage procedures should be obtained from the appropriate technical manual.

Special care must be exercised in disassembling and assembling the parts of a fuel injection system, since any damage to these finely finished surfaces will necessitate replacement of the parts. When work is being done on any part of a fuel injection system, the procedure outlined in the engine technical manual, or the manufacturer's fuel system technical manual, must be followed.

NOTE

Remember that the damage to a plunger and barrel assembly of a fuel pressure pump or to the plunger and bushing assembly of a unit injector generally requires replacement of the parts. A damaged part may not be replaced individually. A plunger and its mating part (barrel, bushing, or bore) must be installed as a complete assembly.

External Leakage

Trouble caused by external leakage from an injection pump or an injector may become sufficiently serious to cause an engine to misfire. It is of extreme importance that signs of external leakage be detected as soon as possible. Leakage outside of the combustion space may be sufficiently large not only to affect engine operation but also to create a fire hazard. External leakage of a unit injector can cause fuel dilution of the engine lube oil, reduce lubrication, and increase the possibility of a crankcase explosion.

In general, external leakage from pumps and injectors is caused by improper assembly, loose connections, faulty gaskets, damaged threads and sealing surfaces, broken springs, or cracked housings or bodies. While leakage from pumps is generally visible during engine operation, leakage from an injector may not become apparent until appropriate tests are performed.

You can stop the external leakage from a pump or injector either by tightening loose connections or by replacing the damaged parts. Before the equipment is inspected for leakage, thoroughly clean all parts. On some equipment, you may eliminate mild roughness or discoloration of the sealing surfaces by lapping.

Stuck Plunger

When the cylinder of an engine fails to fire, it is an indication that the injection pump plunger is stuck. Misfiring may occur intermittently if the plunger sticks and releases at intervals. Upon disassembly, it may be difficult to remove the plunger. Sometimes the plunger may stick when the pump or the injector is assembled, but will work smoothly when the unit is disassembled. At times, the plunger will not stick until sometime after the unit has been removed from the engine. This is particularly true when the plunger and mating part have been stored under conditions that cause corrosion, or when the parts have been mishandled after removal.

A unit injector may be checked, after removal from the engine, by performing the binding plunger test. This test is performed by depressing the plunger, either by hand or by using the “popping” fixture of a test stand, and noting the return action of the plunger. The plunger should return with a definite snap. This test should be performed at three successive rack settings. A sluggish return action indicates a sticky plunger.

A sticking plunger may be caused by dirt, gummy deposits in the unit, or distortion of the plunger and its adjacent part.

The movement of a plunger may be restricted or entirely prevented by small particles of dirt which may lodge between the plunger and its mating surface. Lacquer-like deposits from fuel will also interfere with the movement of the plunger.

The greatest care must be taken when handling the parts of a pump or injector. Because of the extremely close clearances between plunger and mating surfaces, a slight distortion of either will cause binding. Distortion may result from dropping, from striking the plunger and a mating part, or from improper assembly.

Stuck plungers in fuel pumps or injectors should be freed or replaced. Sometimes a little cleaning may eliminate the need for a replacement. The plunger and barrel or bushing assembly should be soaked in an approved cleaning fluid. The assembly should be soaked overnight, or longer if necessary. Cleaning fluids approved for this purpose will immediately soften and remove any paint or enamel with which they come in contact. These fluids should be used with care, since they will damage rubber gaskets.

The specific procedure for cleaning fuel injection equipment, although similar, varies to some degree, depending upon the unit involved and the manufacturer. The following brief description of the procedure for equipment made by the manufacturer emphasizes the need for following only the procedures indicated in the appropriate manufacturer’s technical manual.

Stains on plungers may be removed by the use of a limited quantity of jewelers’ rouge on a piece of soft tissue paper. It is important to remember that the plunger should not be lapped to the bushing with an abrasive such as jewelers’ rouge. After a plunger has been cleaned with jewelers’ rouge, it must be cleaned thoroughly with diesel fuel before being placed in the bushing. If after repeated cleanings the plunger still does not slide freely, you may assume that either the plunger or the bushing is distorted.

Broken Plunger Spring

A pump of an injector will fail when the plunger spring breaks and fails to return the plunger after injection has occurred. Factors which contribute to broken plunger springs are failure to inspect the springs thoroughly and careless handling.

Broken plunger springs must be replaced. Also they should be replaced when there is evidence of cracking, chipping, nicking, weakening of the spring, excessive wear, or when the condition of the spring is doubtful.

Jammed Fuel Control Rack

If an engine is to operate satisfactorily, the fuel control rack must be completely free to move. Since the rack controls the quantity of fuel injected per stroke, any resistance to motion will result in governing difficulties. When this occurs, the engine speed may fluctuate (decreasing as the engine is loaded; racing as the load is removed), or the engine may hunt continuously or only when the load is changed. If the fuel control rack becomes jammed, it may become impossible to control the engine speed with the throttle. The engine may even resist securing efforts under such conditions. Since a sticking fuel control rack can cause serious difficulty, especially in an emergency, every effort should be made to prevent its occurrence. The best way to check for a sticking fuel control rack is to disconnect the linkage to the governor and attempt to move the rack by hand. There should be no resistance to movement of the rack when all springs and linkages are disconnected.

A fuel control rack may stick or jam as a result of a stuck plunger, dirt or paint in the rack mechanism, a damaged rack or gear, or improper assembly. When this jamming or sticking occurs, it is necessary to determine the cause of binding. If it is due to damage, the damaged parts must be replaced; if the stickiness is due to the presence of dirt, a thorough cleaning of all parts will probably correct the trouble. Avoid errors in reassembly and adjustment by carefully studying the instructions.

Backlash in the Control Rack

Backlash, looseness, or play in the fuel control rack, like sticking or binding of the rack, will influence governing of the engine. Proper governing is based on the theory that for every change in speed of the engine, there will be a corresponding change in the quantity of fuel injected. This is impossible if backlash, looseness, or play exists in the control system. Continuous or intermittent movement of the rack may indicate excessive looseness. Engine speed variations are also indicative of this problem. Note that even though these symptoms are characteristic of a loose rack, a governor which is dirty or out of adjustment will present similar symptoms.

Backlash in a fuel control system is generally due to a worn-out gear, rack, or control sleeve. When you disassemble a pump or injector for overhaul, be sure to inspect all parts of the control system for signs of excessive wear. If the rack may be moved more than a prescribed amount without moving the plunger, find the parts that are worn, and replace them.

Improper Calibration

When improper calibration (balance) of fuel injector pumps or injectors occurs, there is a difference in the amount of fuel injected into each of the cylinders. If some pumps or injectors deliver more fuel per stroke than others, the engine will be unbalanced; that is, some cylinders will carry a greater load than others. This condition may be detected by differences in cylinder exhaust temperatures and firing pressures, and by smoky exhaust from the overloaded cylinders. Roughness in operation and engine vibration are also indicators of an unbalanced condition.

It is important to remember that many other types of engine difficulties may cause engine symptoms identical with those due to unbalance. So when unbalance is suspected, consider first a few of the other faults that may be present such as poor condition of piston rings, inaccurate exhaust pyrometers and thermocouples, mistimed or faulty engine exhaust or inlet valves.

Improper Timing

Improper timing of a fuel system will result in uneven operation or vibration of the engine. Early timing may cause the engine to detonate and lose power. Cylinders which are timed early may show low exhaust temperatures. Late timing usually causes overheating, high exhaust temperatures, loss of power, and smoky exhaust. Although, usually, improper fuel injection timing is caused by failure to follow the manufacturer’s instructions for timing, there may be other causes for the difficulty, depending upon design of the particular systems.

Governors

To control an engine means to keep it running at a desired speed, either in accordance with, or regardless of, the changes in the load carried by the engine. The degree of control required depends on two factors: the engine’s performance characteristics and the type of load which it drives. In diesel engines the speed and power output of the engine is determined by varying the amount of fuel that is injected into the cylinders to control combustion. There are two principal types of governors: hydraulic and mechanical.

Hydraulic Governors

It is beyond the scope of this training manual to list all of the possible troubles which may be encountered with a hydraulic governor. This section deals only with the most common ones. Poor regulation of speed may be due to the faulty adjustment of the governor or to faulty action of an engine, a generator, a synchronizing motor, a voltage regulator, or any piece of equipment which has a direct bearing on the operation of the engine.

Manufacturers state that 50% of all governor troubles are caused by dirty oil. For this reason, every precaution should be taken to prevent the oil from becoming contaminated. Most hydraulic governors use the same type of oil that is used in the engine crankcase, provided it is absolutely clean and does not foam. You should change the oil in the governor at regular intervals, depending upon the type of operation, and at least every six months regardless of the operation. You must ensure that the containers used to fill the governors with oil are clean, and that only clean, new, or filtered oil is being used. You should also check the oil level frequently to ensure the proper level is maintained and that the oil does not foam. Foaming of the oil is usually an indication that water is present in the oil. Water in the oil will cause serious damage to the governor. After installing a new governor or one that has been overhauled, adjust the governor compensating needle valve even though it has previously been done at the factory or repair facility. This adjustment must be made with the governor installed and controlling an engine with a load. If this is not done, high overspeeds and low underspeeds after load changes will result and the return to normal speeds will be slowed. Maintenance and repair of each unit must be in accordance with the manufacturer's maintenance manual and the PMS.

NOTE

When governor troubles are suspected, before performing any maintenance, always disconnect the governor fuel rod end from the fuel control rack and ensure that there is no sticking or binding of the rack. This procedure is necessary to determine if the trouble is actually in the governor.

The chart in *Table 21-1* lists some of the probable causes and troubles which are common to most hydraulic governors. This chart should be used for training purposes only; it must NOT be used to troubleshoot a governor. Always use the applicable manufacturer's instruction manual for troubleshooting. Following are the definitions of the terms used in the chart.

Table 21-1 — Troubleshooting Chart (Governor)

PROBLEM	CAUSE	CORRECTIVE ACTION
Engine hunts or surges	Compensating needle valve adjustment incorrect	Make needle valve adjustment; ensure that the opposite needle valve is closed
	Dirty oil in governor	Drain oil; flush governor; refill
	Low oil level	Fill to correct level with clean oil.
	Foamy oil in governor	Drain oil; refill
	Lost motion in engine governor linkage or fuel pumps	Repair linkage and realign pumps
	Governor worn or incorrectly adjusted	Remove governor and make internal checks for clearances according to applicable instructions
	Engine misfiring	Test and replace injectors
	External fuel linkage sticking or binding	Disconnect fuel rack from governor; manually move linkage and progressively disconnect fuel pump links until binding area is found (dirt, paint, and misalignment are the usual causes of binding)
Governor rod end jiggles	Rough engine drive	Check alignment of gears; inspect for rough gear teeth; check backlash of gear
	Governor base not bolted down evenly	Loosen bolts; realign and secure

Hunt

A rhythmic variation of speed which can be eliminated by blocking the fuel linkage manually, but which will reappear when returned to governor control.

Surge

A rhythmic variation of speed always of large magnitude which can be eliminated by blocking the fuel linkage and which will not reappear when returned to governor control unless the speed adjustment of the load changes.

Jiggle

This is a high frequency vibration of the governor’s fuel rod end, or engine linkage. Do not confuse jiggle with normal regulating action of the governor.

Mechanical Governors

Mechanical governors used in the Navy are generally of the spring-loaded flyball type. All mechanical governors have a speed droop. This means that as the load is increased at a constant throttle setting, the speed of the engine will drop or droop slightly, rather than remain constant. Consequently, mechanical governors are never used where absolute constant speeds are necessary.

There are several types of mechanical governors. One type, known as the constant-speed governor, is used on generator sets and is designed to hold the speed of the engine at a predetermined operating speed. The other type is similar in construction and is used primarily for propulsion engines. It has a throttle plate so designed that speeds intermediate between idling and full speeds may be obtained by manual adjustment. The following description applies to both types of governors. Do note, however, that on the constant-speed governor, there is no buffer spring adjustment.

In the idling speed range, control is effected by centrifugal force of two sets of flyweights *(Figure 21-14),* large and small, acting against a light (low speed) spring. Maximum speed control is affected by the action of the high speed (small) flyweights acting against a heavy (high speed) spring *(Figure 21-15).*

Mechanical governor faults usually manifest themselves in speed variations; however, not all speed variations indicate governor faults. When improper speed variations appear, do the following:

1. Check the load to be sure that speed changes are not the result of load fluctuations.
2. If the load is found to be steady, check the engine to be sure all cylinders are firing properly.
3. Make sure there is no binding in the governor mechanism or operating linkage between governor and engine, and that no binding exists in the injector control rack shaft or its mounting brackets. If you find no binding anywhere and the governor still fails to control the engine properly, you may assume the governor is worn or unfit for further service until the unit has been completely disassembled, inspected, and rebuilt or replaced.

Adjustment procedures for the replacement of any governor are listed in the manufacturer's instruction manual and should be followed, with particular attention given to the precautions listed.

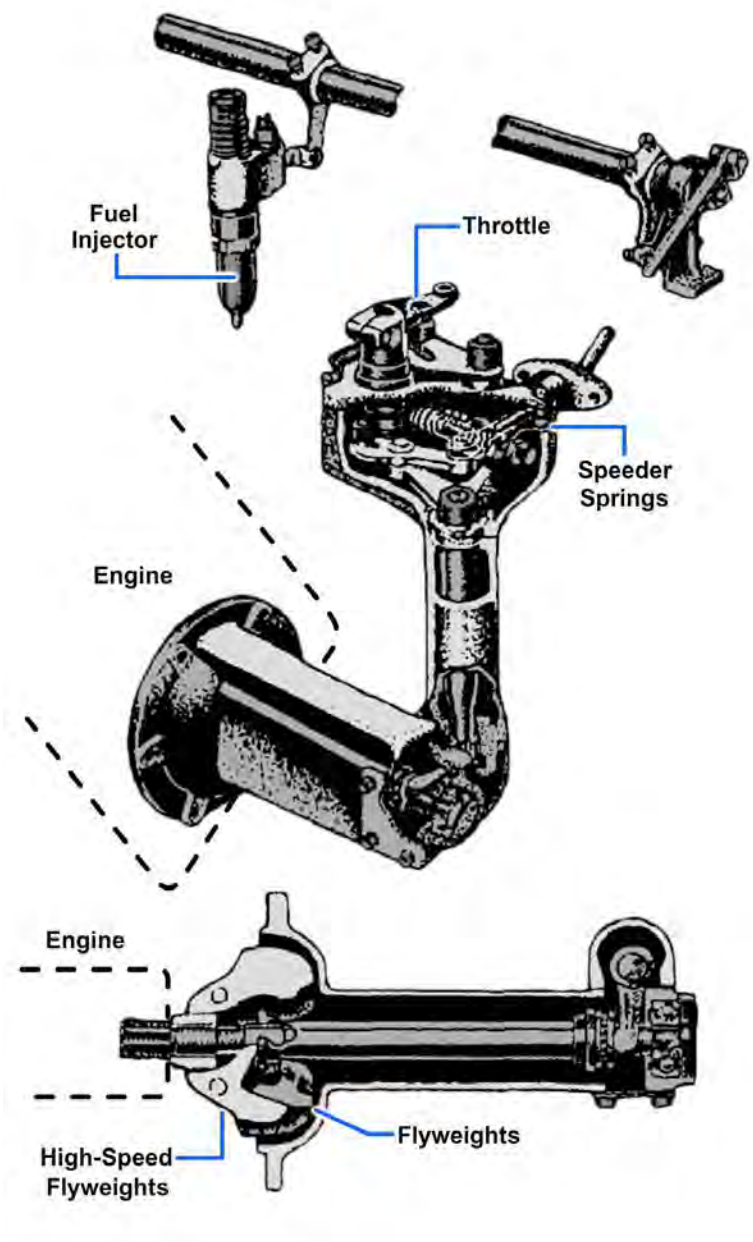

Figure 21-14 — Mechanical governor.

Overspeed Safety Devices

Mechanical overspeed trips depend on the centrifugal forces developed by the engine and should be maintained in good working condition. A faulty overspeed device can endanger not only the engine but also personnel if the engine explodes or flies apart because of uncontrolled speed.

The engine instruction manual contains information as to the speed at which the overspeed is supposed to function. Most overspeed trips are adjustable. Prior to making any change in the adjustment of the overspeed trip, determine if the engine did not trip out for some reason other than the action of the element of the overspeed trip. It is highly advisable that you first check the accuracy of the tachometer and then test the overspeed trip. All spring tension adjustments and linkage adjustments to an overspeed trip are critical. Instructions given for making these adjustments are found in the manufacturer's instructions manual and must be followed.

Hydraulic overspeed trips are extremely sensitive to dirt. Dirt or lacquer-like deposits may cause a trip to bind internally. The speed sensitive element must be kept clean and so should all parts of the linkage and mechanisms incorporated in this speed sensitive element. When painting around the engine, the painter should be cautioned against allowing paint to fall on joints, springs, pins, and other critical points in the linkage.

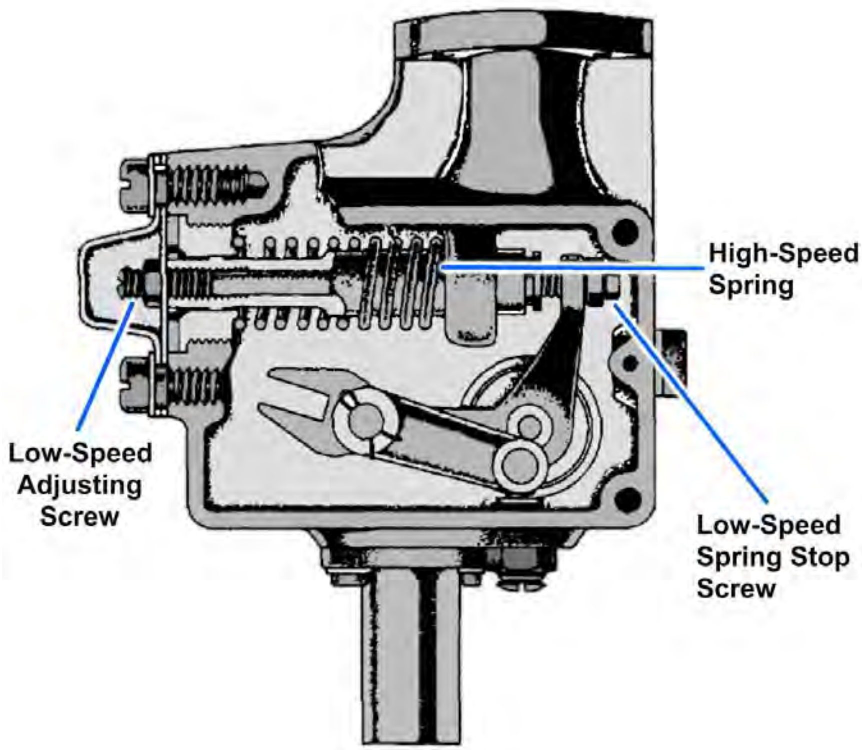

Figure 21-15 — Mechanical governor control mechanism.

All linkage binding should be eliminated. If parts are bent, badly worn, improperly installed, dirty, or if their motion is restricted by some other part of the engine, the trip will not function properly. On occasion the drive shaft of the overspeed trip may be broken and prevent rotation of the flyweight and the overspeed trip. Insufficient oil in the hydraulic trip may be another source of this problem. Oil should be maintained at the level specified in the instruction manual.

The cause of any malfunction should be determined and eliminated. This will involve cleaning the trip and its linkage, removing the source of binding, replacing faulty parts, adding oil to hydraulic type trips, or adjusting the speed sensitive element, always in accordance with the instruction manual. If the trip has been damaged, it is advisable to install a spare overspeed trip and completely rebuild or overhaul the damaged one.

LUBE OIL MANAGEMENT

Lube oil management procedures were developed because of the importance of good quality lubricating oil. If these procedures are properly followed, they will significantly reduce the downtime of machinery caused by oil-related failures. You should become very familiar with the lube oil management procedures outlined in NSTM*,* Chapter 262.

Sampling

Proper oil sampling is very important. An improper sample produces unreliable test results. Thus, the responsibility of taking and preparing samples should be carefully delegated.

Samples should be representative of the oil to be tested. The most representative samples are obtained from an operating system. Standard sample bottles should be thoroughly cleaned, inspected, and flushed with the oil to be sampled before use. All containers should be capped or closed promptly after the sample is taken to prevent contamination. Label the sample bottle to identify the following:

- Equipment
- Oil type

- Date
- Time

CAUTION

Always check for proper oil levels before and after sampling.

Visual Observation

A visual observation of an oil sample is used to determine the presence of free water and solid particulate matter. The criteria for this observation are a clear and bright appearance of the oil. The term clear refers to the absence of solid particulate matter in an oil sample. The term bright refers to the absence of visible free water in an oil sample.

Transparency Test

The transparency test is conducted only on auxiliary machinery oil samples that have failed the clear and bright criteria. The transparency test is conducted by placing a clean PMS card behind the sample bottle in a well-lighted area. The PMS card must be held against the sample bottle. You should then attempt to read the printed words on the PMS card through the bottle. If you can read the printed words on the PMS card, the oil sample has passed the transparency test.

Bottom Sediment and Water Test

A bottom sediment and water (BS&W) test will be conducted on all oil samples that fail the transparency test. When an oil sample fails the BS&W test (BS&W greater than 0.01 milliliter [mL] or 0.1 percent), you must secure the machinery and transfer the contaminated oil to the settling tank for renovation. You must then determine the problem and clean the sump if necessary. After you have corrected the problem, replenish the sump with new or renovated oil and resample the system after 30 minutes of operation.

CAUTION

Lube oil contaminated with salt water cannot be renovated.

All test results, cause of contamination, and corrective actions must be annotated in the Remarks section of the Lube Oil Log.

For additional information on lube oil management, refer to NSTM*,* Chapter 262.

Fuel Oil (FO) Management

Personnel involved in fuel oil (FO) management must have a thorough understanding of FO characteristics and receiving, sampling, testing, and record maintenance procedures. *Figure 21-16* shows an example of a locally prepared Fuel Oil Management Log.

Fuel Oil (FO) Characteristics

Certain characteristics must be known with respect to each consignment of FO. The most important of these are viscosity, flash point, gravity, and water and sediment content. These characteristics are determined by various tests. Some of the tests are so complicated that they can be performed only in a fully equipped laboratory; others are relatively simple and can be made aboard ship. You should know the purpose of each FO test and the procedures for performing those tests that are made on your own ship.

FUEL SAMPLE ANALYSES

DATE	FUEL TYPE	SAMPLE LOCATION	VISUAL	BS&W %	API GRAVITY	MK I (P/M)	MK III (MG/l)	FLASHPOINT (ºF)	SHORE LABORATORY

OPERATIONAL PROCEDURE CHECK-OFF LIST SUMMARY

		REPLACEMENT ACTION			TANK INSPECTIONS	
DATE	CENTRIFUGAL PURIFIER CLEANING	PREFILTER	COALESCER ELEMENT	SEPARATOR ELEMENT	TYPE	FINDING

DATE	TANK STRIPPING	SERVICE TANK RECIRCULATION	FUEL ROTATION	TANK BALLASTING	FUEL RECEIPT (QUANTITY)

Figure 21-16 — Fuel Oil Management Log (example).

Viscosity

Viscosity is the measure of resistance to flow. There are numerous methods by which viscosity is measured. Observations in each case are recorded on an individual scale adapted to suit the instrument. With the majority of instruments, viscosity is stated as the time in seconds required for a given quantity of the sample fuel at a stated temperature to flow through a small orifice. Or, viscosity may be stated as a ratio of the flow time of the fuel sample to the flow time of water or oil (used as a standard at a stated temperature). When recording viscosity as determined by an orifice, the name of the viscometer used must be given, as well as the temperature at which the viscosity was determined. The most accurate method of measuring viscosity is to observe the slow flow of the liquid through capillary tubes.

Fuel viscosity is a primary concern because it affects the fuel's behavior both when the fuel is pumped from storage tanks and when the fuel reaches the atomizing mechanism of the burners.

Flash Point

Flash point is the lowest temperature at which a liquid gives off sufficient vapor to form a flammable mixture with air above the liquid surface. A fuel will not form a flammable vapor-air mixture by evaporation at temperatures below its flash point temperature but will do so at the flash point temperature and above.

Flash points are determined by the use of a closed-cup flash point tester on most combatant ships. A minimum flash point of 60 degrees Celsius (°C) (140 °F) is required for F-76 and jet propulsion (JP)-5 FO.

Gravity

The gravity of petroleum oil is an index of the weight of a given volume of the material at a temperature of 60 °F (15.6 °C). There are two scales used with petroleum products: specific gravity and American Petroleum Institute (API) gravity.

Bottom Sediment and Water

Water and insoluble impurities are often present in heavy fuels. These materials are objectionable because of the danger of possible nozzle blockage and the likelihood of poor fuel combustion.

Although water is slightly soluble in fuels, only water in mechanical suspension in the fuel is of practical interest to the engineer. This suspended water is referred to as free water. Water and sediment are generally expressed as a single percentage by combined volume. However, it is more accurate to record them separately.

Sampling and Testing Fuel Oil (FO)

The water and sediment that collect in fuel tanks are major factors contributing to the gradual deterioration of shipboard fuel service pumps, diesel engines, gas turbines, and steam boilers. It is essential that ship fuel tanks be regularly tested for contamination and that they are stripped whenever contamination is detected.

Fuel quality maintenance is an ongoing process because fuel tanks can be contaminated by rust particles induced by ballasting or moisture drawn in through air vents, leakage of valves and tank seams, condensation on tank surfaces, and the setting of solids and residues picked up during fuel transfer. It cannot be assumed that the BS&W content will remain the same as that determined by the testing during initial dockside or at-sea refueling operations. Fuel quality maintenance procedures must be strictly followed to ensure the continued quality of fuel stowed in shipboard tanks.

Recording Fuel Oil (FO) Samples and Test Results

The Fuel Oil Management Log (*Figure 21-17*) is prepared locally. It should have space for entering the results of all shipboard fuel tests. When test results exceed maximum parameters, a notation should be made indicating what action was taken to correct the problem.

The Fuel Oil Management Log should include the following information:

1. A sequential listing of sample analysis
    a. Visual inspection
    b. Shipboard analysis
    c. Laboratory analysis
2. An operational procedure check-off list
3. Date and time centrifugal purifier was cleaned
4. Prefilter and filter/separator replacement actions
5. Tank inspections and findings

Fuel in ship stowage and service tanks must be tested according to the requirement set forth in NSTM, Chapter 541.

NOTE

More frequent fuel tank testing is often required during wartime operations (that is, after the ship has been subjected to shock, near misses, depth charge, explosions, direct battle damage, or collision).

SHIPBOARD SAMPLING AND TESTING REQUIREMENTS

Fuel Source/ Location	Sampling/Testing Frequency	Type of Sample/ Location	Ship Applicability			Test/Procedures See Note 1	Requirements
			Steam Propelled	Gas Turbine	Diesel Propelled		
Shore storage	Each receipt from a commercial supplier Or, every time emergency substitute fuel received	Thief/All levels	X	X	X	Flashpoint/ Pensky-Martens	60°C (140°F) Minimum
			X	X	X	API Gravity/ 60°F (15.6°C)	Record
			X	X	X	BS&W/Centrifuge	0.1% (Maximum)
Deck Connection(s)	Each refueling (a) At start midpoint, and end	Line/Deck connection	X	X	X	BS&W/Centrifuge	0.1% (Maximum)
	(b) Every 15 minutes	Line/Deck connection	X	X	X	Visual/Glass sample bottle	No free water Clear and Bright
Ship storage tanks (not applicable to water compensated tanks. See Note 2).	(a) 24 hours after receiving fuel	Sounding/ Bottom	X	X	X	Water level/Water indicating paste	See Note 7
	(b) Before transfer to service tank	Thief/Bottom	X		X*	BS&W/Centrifuge	0.1% (Maximum)
		Sounding/ Bottom		X	X See Note 4	Water level/Water indicating paste	See Note 7
	(c) Weekly	Sounding/ Bottom		X		Water level/Water indicating paste	See Note 7
	(d) Monthly	Sounding/ Bottom	X		X	Water level/Water indicating paste	See Note 7
Ship Service tanks	Prior to use	Thief/Bottom	X			BS&W/Centrifuge	0.1% (Maximum)
	Prior to use	Thief/Bottom		X	X See Note 5		
Fuel Purifier	Every 30 minutes	Line Purifier discharge		X	X	Visual/Glass sample bottle	Clear and bright
Filter-separator	Every 4 hours	Line-Filter-separator discharge	X See Note 3		X See Note 6	Visual/Glass sample bottle	Clear and bright
				X		Free water/AEL MK1	40 ppm (Maximum)**
				X		Contaminated fuel/AEK-MK III	2.64 mg/L (Maximum)**

*Diesel propelled ships without fuel purifier.

**AEL modified procedure calibration chart readings for F-76 of 5 ppm or less equates to approximately 40 ppm free water; 5 mg/L or less equates to 2.64mg/L sediment.

NOTE 1: JP-5 (F-44) that has been downgraded to F-76 for use in ship propulsion systems shall meet sampling and testing requirements for F-76.

NOTE 2: Ascertain sufficient fuel is available in tank group prior to transfer in order to eliminate the possibility of transfer of compensating water (ballast) to fuel service tanks.

NOTE 3: Applicable only to ship classes FF-1040, FF-1089, and FFG-1. Sample every 15 minutes during transfer operations.

NOTE 4: For MSO-422 Class ships, test with water indicating paste prior to initial transfer. Additional testing (water indication paste) is required only when the storage tank has not been on suction for 24 hours.

NOTE 5: For MSO-442 Class ships, and other ships with small service tanks that shall be filled every 24 hours or less, test by visual inspection.

NOTE 6: For MSO-422 Class ships, test once each time fuel is transferred from the storage tank to the service tank.

NOTE 7: If the water indicating paste test indicates a water level higher then the lowest recorded tank suction level, the tank must be stripped. Stripping must be continued until the BS&W content has fallen below 0.1% by volume.

Figure 21-17 — Shipboard sampling and testing requirement.

REPAIR OF INTERNAL COMBUSTION ENGINES

The Navy uses so many models of diesel engines that it is not possible to describe in any detail all the overhaul procedures used by the Navy. Detailed repair procedures are listed in the manufacturers' technical manuals. Always consult the manuals and the MRCs before starting any type of repair work. Pay particular attention to installation tolerances, wear limits, adjustments, and safety procedures. Also be sure to follow the general rules, listed below, which apply to all engines.

1. Observe the highest degree of cleanliness in handling engine parts. Engines have been completely wrecked by the presence of abrasives and various objects which have been carelessly left in the engines after overhaul. Make sure that any engine assembled for post-repair running is scrupulously free of foreign matter prior to running. Too much emphasis cannot be given to the necessity for maintaining engines clean both internally and externally. Since dirt entering the engine during overhaul causes increased wear and poor operation, it is essential that all repair work be done under clean conditions. When overhaul or repair of precision parts and surfaces is required, the parts and the surface should be thoroughly cleaned and wrapped in a clean cloth or suitable paper. The parts should then be stored in a dry place until reinstalled. During installation, parts should be wiped with a cloth free of lint and coated, where applicable, with clean lubricating oil. When removing or installing parts such as pistons, connecting rods, camshafts, and cylinder liners, make sure that these parts are not nicked or distorted. Take precautions to keep dirt and other foreign material in the surrounding atmosphere from entering the engine while it is being overhauled. Before starting repair work, make sure that all required tools and spare parts are available. Plan ahead for repair periods so everything needed is available to ensure successful and expeditious completion of the work.

WARNING

Never attempt to jack the engine over by hand without first disabling the starter circuit.

2. Keep detailed records of repairs, including measurements of worn parts (with hours in use), and the new parts installed. Later, an analysis of these records will indicate the number of hours of operation that may be expected from the various parts and will facilitate prediction as to when they should be renewed before a failure occurs. Measurement of new parts are needed to determine whether or not they come within the tolerances listed in the manufacturers' instruction books or the wear limit charts. In addition, before installation, all replacement parts should be compared with removed parts to ensure that they are suitable.

3. Do not test an overhauled diesel engine at 125% of full load or any other overload before the engine is returned to service. It has been reported that some overhauled diesel engines used for driving generators are being tested at 125% of full load before being returned to service. The original purpose for this test was to demonstrate a 25% overload capability for a 2-hour period to absorb occasional electrical peak loads. The nameplate rating of many of the older generator sets indicates a 25% temporary overload capacity. (More recent generator sets have a single rating with no stated overload requirement.) The earlier practice was a reasonable approach since the engine was frequently capable of substantially greater power than could be absorbed by the generator and the 125% test was not likely to be detrimental to the engine.

4. Another important point to remember is that if you cannot overhaul an engine due to lack of space, manpower, or expertise, you may request outside help by using an OPNAV Form 4790.2K. This form, when used as a work request, will be sent to a Norfolk Ship Support Activity (NSSA). The NSSA will then accept or reject the work request. If the work request is

accepted, the NSSA will order all repair parts, overhaul the engine, and perform an operational test in accordance with manufacturers' technical manuals and NSTM, Chapter 233.

Piston Assemblies and Rods

Piston assemblies may have trunk-type or the crosshead-type pistons. The majority of engines in use by the Navy have trunk-type pistons. Since the troubles encountered with crosshead pistons are very similar to those encountered with the trunk type, only the latter is discussed here.

Pistons

Trunk-type pistons are subject to such forces as gas pressure, side thrust, inertia, and friction. These forces, together with overheating and the presence of foreign matter may cause such troubles as piston wear, cracks, piston seizure, and piston pin bushing wear *(Table 21-2).*

Piston wear is characterized by an excessive clearance between the piston and the cylinder. Symptoms of excessive clearance between a piston and cylinder are piston slap and excessive oil consumption. Piston slap occurs just after top dead center and bottom dead center, as the piston shifts its thrust from one side to the other. As the cylinder taper increases with wear, oil consumption increases. Since taper causes the rings to flex on each stroke of the piston, excessive ring wear occurs, allowing lubricating oil to pass and be burned in the cylinder. This results in the accumulation of excessive carbon deposits on the piston, the combustion chamber, and the engine exhaust valves or ports. This accumulation of carbon deposits will cause erratic operation and greatly reduce engine efficiency.

Table 21-2 — Piston Troubles and Their Causes

Trouble	Causes
Dirty bearing	Improper handling or storage Use of dirty or improper lubricant Failure to clean housing Poor condition of seal
Spoiled or pitted roller or races	Dirt in bearing Water in bearing Improper adjustment of tapered roller bearing Bearing misaligned or off square
Dented (brinelled) races	Improper installation or removal Vibration while bearing is inoperative
Failed separator	Initial damage during installation or removal Dirt in bearing
Races abraded on external surfaces	Locked bearing Improper fit of races
Cracked race	Improper installation of removal (cocking)
Excessive looseness	Abrasives in lubricants

Occasionally pistons and liners become sufficiently worn to permit the piston to cock over in the cylinder. This allows the crown and ring lands to drag on the cylinder wall. The results of dragging can be determined by visually inspecting the parts of the piston in question. However, most of the pistons now in use in the Navy are free from this trouble, since the crown and ring lands are of smaller diameter than the skirt and do not contact the cylinder wall.

Some piston wear is normal in any engine; the amount and rate depends on several controllable factors. The causes of excessive piston wear are also the causes of other piston troubles.

One of the factors controlling wear is lubrication. An adequate supply of oil is essential to provide the film necessary to cushion the piston and other parts within the cylinder and prevent metal-to-metal contact. Inadequate lubrication will not only cause piston wear but the extra friction may also cause piston seizure, land breakage, and piston pin bushing wear.

Lack of lubrication is caused either by a lack of lube oil pressure or by restricted oil passages. The pressure-recording instruments usually give warning of low oil pressure before any great harm occurs. However, clogged passages offer no such warnings. Only by inspecting and cleaning the piston and connecting rod assembly may you ensure adequate lubrication.

Another controllable factor that may be directly or indirectly responsible for many piston troubles is improper cooling water temperatures. If an engine is operated at higher than the specified temperature limits, lubrication troubles will develop. High cylinder surface temperatures will reduce the viscosity of the oil. As the cylinder lubricant thins, it will run off the surfaces. The resulting lack of lubrication leads to excessive piston and liner wear. On the other hand, if the engine is operated at temperatures that are below those specified, viscosity will be increased, and the oil will not readily reach the parts requiring lubrication.

Oil plays an important part in the cooling of the piston crown. If the oil flow to the underside of the crown is restricted, deposits caused by oxidation of the oil will accumulate and lower the rate of heat transfer. For this reason, the underside of each piston crown should be thoroughly cleaned whenever pistons are removed.

While insufficient lubrication and uneven cooling may cause ring land failure, excessive oil temperatures may cause piston seizure. An increase in the rate of oxidation of the oil may result in clogged oil passages or damage to piston pin bushings.

Seizure and excessive wear of pistons may be caused by improper fit. New pistons or liners must be installed with the piston-to-cylinder clearances specified in the manufacturer's technical manual. If clearance is insufficient, a piston will NOT wear in and will probably bind. The resulting excess surface temperatures may lead to seizure or breakage. Binding increases wear and shortens piston life by scuffing the liner or galling the piston skirt. Scuffing roughens the liner so that an abrasive action takes place on the piston skirt, thus generating additional heat which may distort or crack the piston or liner. Galling, especially on aluminum pistons, causes the metal to be wiped in such a manner that the rings bind in the grooves. A loose fitting piston may be just as destructive as one which is too tight. A loose piston may cause dragging and cocking of the piston, which in turn may cause broken or cracked ring groove lands.

Excessive wear on the piston and piston pin bushing may be caused by either an overload or by an unbalanced load. Overloading an engine increases the forces on the pistons and subjects them to higher temperatures, thus increasing their rate of wear. There should be a load balance on all pistons at all times. Balance of an engine is determined by checking the exhaust gas temperature at each cylinder, the rack settings, and the firing and compression pressures.

Cracking of the lands of a piston is caused by insufficient ring groove clearance. For correct piston ring operation, proper clearance must be maintained between the ring and the land, and also between the ends of the ring. This is necessary in order that the ring may be free to flex at all temperatures of operation. The clearance depends upon the ring and the materials involved. After installing a ring, check the clearance between the ring and the land. This check is made with a thickness gauge, and must be made completely around the piston.

Replace most damaged or excessively worn pistons. Since replacement of damaged pistons is usually necessary, shipboard repair parts should always be maintained at full allowance.

PISTON RINGS

The troubles to which piston rings are subject, their symptoms, and the causes are illustrated in *Figure 21-18*.

Excessive Wear	Sticking	Breakage
A. Symptoms: 1. Low compression 2. Hard starting 3. Loss of power 4. Smoky exhaust 5. Waste of fuel 6. Excess oil consumption 7. Poor engine operation (Other factors which may cause low compression pressure: a. Leaking cylinder valves b. Faulty injector gasket c. Faulty head gasket d. Leaking after-chamber valves e. Clogged intake ports f. Intake air header leakage g. Faulty blower h. Clogged air filter) Other factors which may cause excessive oil consumption: a. Loose bearings b. High lube oil temperatures c. Oil line leakage d. Improper oil)	C. Symptoms: 1. Low compression 2. Loss of power 3. Smoky exhaust 4. Excessive oil consumption 5. Blow-by forcing fumes from crankcase	E. Symptoms: 1. Hard starting 2. Loss of power 3. Excess oil consumption 4. Possible emission of smoke from crankcase breather
B. Causes: 1. Inadequate lubrication 2. Excessive piston heat 3. Rings damaged during installation 4. Ring- to-land clearance insufficient 5. Dust or dirt in intake air 6. Dirt in lube oil or fuel 7. Rings stuck in grooves 8. Worn cylinder liners	D. Causes 1. Improper ring-to-land clearance 2. Insufficient ring pressure 3. Excessive operating temperature 4. Improper oil 5. Improper installation	F. Causes: 1. Cylinder liner ridge 2. Cylinder port damage 3. Insufficient gap clearance 4. Insufficient clearance behind ring

Figure 21-18 — Piston ring troubles, their symptoms and causes.

All symptoms and causes shown for ring wear are either directly or indirectly related to other ring and piston troubles. In addition to symptoms and causes of piston ring troubles, there are other factors that may also be responsible either for low compression or for excessive oil consumption.

When a cylinder with a low compression pressure is located, the possibility of the cause being some factor other than excessive wear should be eliminated before the pistons rings are disassembled or replaced. Look at *Figure 21-18*. Of the causes listed under "Other factors which may cause low compression pressure," a, b, c, and d; are causes that would affect the pressure in only one cylinder assembly of a multicylinder engine. Causes f, g, and h may affect a group of cylinders, or possibly all cylinders. Therefore, when symptoms indicate compression ring wear consider first other possibilities. Excessive oil consumption is generally associated with worn oil rings, but there are other factors which may cause abnormal oil usage, and these should be checked before replacement of oil rings is undertaken.

Oxidation of the lube oil leaves carbon deposits on the rings and in the grooves. It is caused by excessive operating temperatures. The carbon buildup limits movement and expansion of the rings, sticking, excessive wear, or breakage.

Proper clearance must exist between the ring and land as well as behind the ring, since insufficient ring groove clearance can cause the rings to stick. It is not the function of the rings to support or position the piston in the cylinder bore, but if the proper clearance does not exist, the rings are likely to become loaded by inertia forces and by side thrust on the piston—forces which should be borne solely by the skirt of trunk-type pistons.

Two factors that cause improper ring clearance are:

1. Abnormal amount of carbon deposits on rings and in grooves.
2. Improper dimensions. New rings must have the proper thickness, width, diameter, and gap.

One cause of undue loads on a ring could be insufficient gap clearance. This condition would cause the ring to be forced out and into a port of a ported cylinder, and possibly result in breakage.

A bright spot found on each end of a broken ring indicates insufficient gap clearance. Sufficient gap clearance must exist at both the top and the bottom of the cylinder bore when rings are installed.

Sticking and binding of the ring may result from insufficient ring pressure. The tendency of the ring to return to its original shape pushes it against the cylinder wall, and makes the initial seal. The pressure of the combustion gases behind the rings reinforces this seal. Pressures (compression and combination) within the cylinder force the combustion rings down and create a seal between the bottom side of the rings and the upper side of the lands; properly wearing rings will appear shiny on the outer face and bottom side. Any discoloration (usually appearing as black lines) indicates the leakage of gases past the rings. Extended use and overheating may weaken rings to the point where they do not seat properly, and the rings are then likely to bind in the grooves. A check of the free gap for a piston ring will indicate the ring's condition with respect to sealing qualities. If the instruction manual does not give a prescribed dimension for free gap, compare the gap with that of a new ring.

Conditions which cause piston rings to stick in the grooves, wear excessively, or break are often the result of using improper lube oil. Some lube oils cause a resinous gumlike deposit to form on engine parts. Trouble of this nature can be avoided by using Navy-approved oils, or oil recommended by the manufacturer.

Probably the greatest factor affecting the wearing of piston rings is a worn cylinder liner. When new rings are installed, surface condition, amount of taper, and out-of-roundness of the liner must all be considered. The ring is in the best position to make allowance for cylinder wear if the ring gaps are in line with the piston bosses. Gaps of adjacent rings should be staggered 180° to reduce gas leakage.

With the wearing away of material near the top of a cylinder liner, a ridge will gradually be formed. When a piston is removed, this ridge must also be removed, even though it has caused no damage to the old set of rings. The new rings will travel higher in the bore by an amount equal to the wear of the old rings, and the replacement of the connecting rod bearing inserts will also increase piston travel. As the top piston ring will strike the ridge because of this increase in travel, breakage of the ring and perhaps of the land is almost certain if the ridge is not removed.

Piston Pins and Pin Bearings

Piston pins are made of hardened steel alloy, and their surfaces are precision finished. Piston sleeve bearings or bushings are made of bronze or a similar material. These pins and pin bearings require very little service and total failure seldom occurs.

Wear, pitting, and scoring are the usual troubles encountered with piston pins and piston pin bearings.

Wear of a pin or bearing is normal, but the rate of wear can be unnecessarily increased by such factors as inadequate and improper lubrication, overloading, misalignment of parts, or failure of adjacent parts.

Every time a piston assembly is removed from an engine, the complete assembly should be checked for wear. Piston pins and bushings should be measured with a micrometer to determine if wear is excessive. Do NOT measure areas that do not make contact, such as those between the connecting rod and piston bosses, and the areas under the oil holes and grooves. The correct and limiting values for measurements may be found in the manufacturer's technical manual for the particular engine.

Excessive wear of pins, bushings, or bearings is often the result of insufficient or improper lubrication. (These parts are usually pressure lubricated). The failure of a pressure lubricating system is usually detected before piston pins, bushings, or bearings are seriously damaged. Insufficient lubrication of these parts is usually caused by obstructions blocking the oil passages of the connecting rods. If the bushings have been installed so that the oil holes do not line up, lubrication may be restricted. Such misalignment of oil holes may also be caused by a bushing coming loose and revolving slightly out of position. Also, interchanging the upper and lower connecting rod bearings ON SOME ENGINES may obstruct the flow of oil to the upper end of the rod. Always check the manufacturer's technical manual for information on interchangeability of parts.

If there is misalignment of the connecting rods, uneven loading on piston pins and bearings will result. The fact that a rod is misaligned is usually indicated by uneven wear of the piston pin and bushing and by piston skirt wear. Misalignment may be caused by improper reaming of the bushing for proper clearance.

Connecting Rods

Connecting rod troubles usually involve either the connecting rod bearing or the piston pin bearing. Some of these troubles, such as misalignment, defective bolts, cracks, or plugged oil passages, can be avoided by performing proper maintenance and by following instructions in the manufacturer's technical manual.

Misalignment causes binding of the piston, piston pin, and the connecting rod journal bearing. This binding is likely to result in breakage and in increased wear of the parts, leading to total failure and possible damage to the entire engine structure. Connecting rods must be checked for proper alignment before being installed in an engine, and after any derangement involving the piston, cylinder, or crankshaft.

Defective bolts are often the result of overtightening. Connecting rod bolts should be tightened by using a torque wrench or an elongated gauge to ensure that a predetermined turning force is applied to the nut. Defective threads can cause considerable trouble by allowing the connecting rod to be loosened and cause serious damage to the engine. Whenever rod bolts are removed they should be carefully inspected for stripped or damaged threads and elongation.

Cracked rods are usually the result of overstressing caused by overloading or overspeeding or because defective material was used at the time of manufacture. It is of prime importance to discover the cracks before they have developed to the point where the failure of the rod will take place. No attempts should be made to repair cracked rods. They should be replaced; serious damage may result if breakage occurs during operation.

Restricted oil passages are often the result of improper assembly of the bushing and the connecting rod bearing inserts. They may also be due to foreign matter lodging in the oil passages.

Shafts and Bearings

The principal shafts (crankshafts and camshafts) and associated bearings (journal bearings and antifriction bearings) of an internal combustion engine are all subject to several types of trouble. Some of the troubles may be common to all of these parts; others may be related to only one part. Causes of troubles common to all parts are metal fatigue, inadequate lubrication, and operation of the engine at critical speeds.

Metal fatigue in crankshafts, camshafts, and bearings may lead to shaft breakage or bearing failure; however, you must keep in mind that metal fatigue is only one of several possible causes which may lead to such troubles.

Fatigue failure of journal bearings in internal combustion engines is usually caused by cyclic peak loads. Such failures are accelerated by improper or loose fit of the bearing shell in its housing, and by the lack of adequate priming of the lubricating oil system before the engine is started.

Severe overloading or overspeeding of an engine increases fatigue failure. Some indication of the cause of the failure may be obtained by noting which half of a bearing failed. Overloading of the engine will cause failure of the lower halves of main journal bearings, while overspeeding may cause either the upper or the lower halves to fail.

Crankshaft or camshaft failure does not occur too often. When it does occur, it may be due to metal fatigue. Shaft fatigue failure may be caused by improper manufacturing procedures, such as improper quenching or balancing, or by the presence of torsional vibration. Shaft fatigue failures generally develop over a long period of time.

The importance of lubrication cannot be overstressed. Much that has been stated previously about proper lubricants and adequate supply and pressure of lube oils is also applicable to crankshafts, camshafts, and their associated bearings. Some of the troubles which may be caused by improper lubrication are damaged cams and camshaft bearing failure, scored or out-of-round crankshaft journals, and journal bearing failure. Lubrication difficulties you should watch for are low lube oil pressure, high temperatures, and lube oil contamination by water, fuel, and foreign particles.

Operation of an engine at critical torsional speeds and in excess of the rated speed will lead to engine shaft and bearing difficulties. Each multicylinder engine has one or several critical speeds which must be avoided in order to prevent possible breakage of the crankshaft, camshaft, and gear train.

A critical speed of the first order exists when impulses due to combustion occur at the same rate as the natural rate of torsional vibration of the shaft. If the crankshaft receives an impulse from firing at every other natural vibration of the shaft, a critical speed of the second order occurs. Operation at these speeds for any length of time may cause the shaft to break. If critical speeds are not avoided, torsional vibrations may not only cause shaft breakage but may also cause severe damage to the entire gear train assembly.

In some engines, critical speeds fall within the normal operating range; the instruction manual for the specific engine will warn against engine operation for any length of time within the critical speed range. If the critical speed range falls within the normal operating range, it must be conspicuously marked upon the engine tachometer, and every effort should be made to keep the engine from operating in the range. If this is not possible, the critical speed should be passed over as fast as possible.

Overspeeding of an engine must be avoided. If the rated speed is exceeded for any extended period of time, the increase in inertia forces may cause excessive wear of the journal bearings and other engine parts, and in uneven wear of the journals.

CRANKSHAFTS

Scored crankshaft journals are caused not only by lubrication difficulties but also by journal bearing failure or improper and careless handling during overhaul.

Journal bearing failures may cause not only scoring but also broken or bent crankshafts and out-of-round journals. Journal bearing failures may be caused by several different factors and may lead to more than one trouble. The causes and the prevention of such failures are discussed in more detail later in this chapter.

Broken or bent crankshafts may be caused by the improper functioning of a torsional vibration damper. Vibration dampers are mounted on the crankshafts of some engines to reduce the torsional vibrations set up within the crankshaft and to ensure a smoother running engine. If a damper functions improperly, torsional vibrations may rupture the internal structure of the shaft.

The principle of operation is similar in most dampers, yet their construction and their component parts vary somewhat. If the engine is equipped with a vibration damper, the engine instruction manual must be consulted for information on type, construction, and maintenance of the damper.

In most engines, one end of the crankshaft is flanged to receive the damper, the damper being bolted or doweled onto the flange. A damper must be fastened securely to the crankshaft at all times during engine operation; otherwise, the damper will not control the crankshaft vibrations.

Small dampers are usually grease-packed, while larger ones frequently receive lubrication from the main oil system. Dampers that are grease lubricated must have the grease changed periodically, as specified in the manufacturer’s instructions. If the assembly is of the elastic type, it must be protected from fuel, lube oil, grease, and excessive heat, all of which are detrimental to the rubber.

Excessive rumbling at certain engine speeds may indicate that the damper is not functioning properly. You must learn to distinguish between this and the normal noise usually heard in some engines during the first and last few revolutions when the engine is starting or stopping. This noise is normal; it is due to the large designed clearances in the damper and is not a sign of impending trouble.

Crankshaft breakage or bending may be the result of excessive bearing clearances. Excessive clearance in one main bearing may place practically the entire load on another main bearing. Flexing of the crankshaft under load may result in fatigue and eventual fracture of the crank web *(Figure 21-19).*

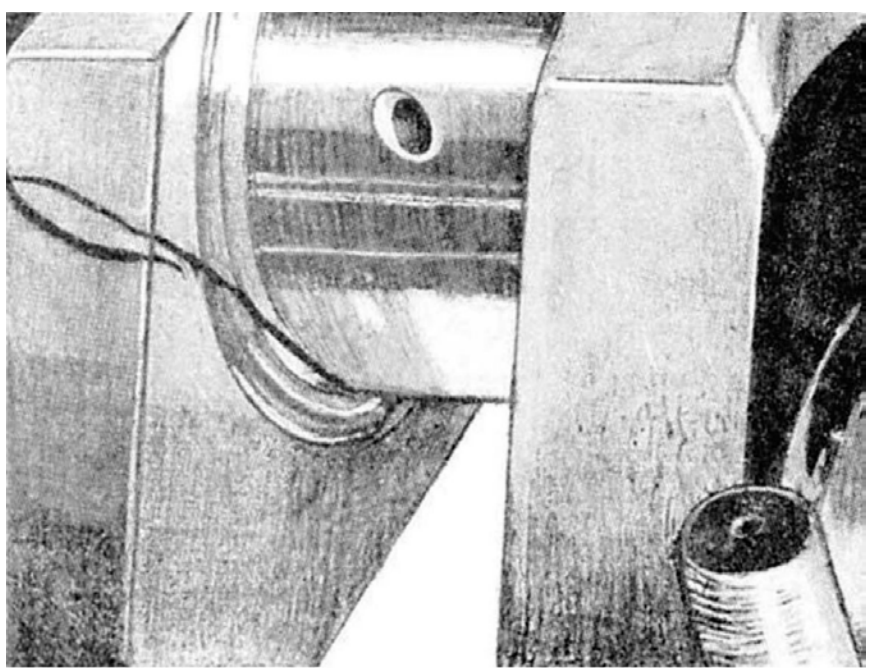

Figure 21-19 — Cracked crank web.

Excessive bearing clearance may be caused by the same factors that cause journal bearing failure. Furthermore, off-center and out-of-round journals tend to scrape off bearing material. This leads to excessive wear and to the increase of the clearance between the shaft and bearing. You can minimize the possibility of journal out-of-roundness by taking measures to prevent improper lubrication, journal bearing failure, overspeeding or overloading of the engine, excessive crankshaft deflection, and misalignment of parts.

Crankshaft bending breakage (out-of-roundness) may also result from excessive crankshaft deflection. Excessive shaft deflection, caused by improper alignment between the driven unit and the engine, may result in a broken or bent shaft along with considerable other damage to bearings, connecting rods, and other parts. Excessive crankshaft deflection may also be caused by overspeeding an engine. The amount of deflection of a crankshaft may be determined by the use of a straight gauge.

The straight gauge is merely a dial-reading inside micrometer used to measure the variation in the distance between adjacent crank webs where the engine shaft is barred over. When installing the gauge or indicator between the webs of a crank throw, place the gauge as far as possible from the axis of the crankpin. The ends of the indicator should rest in the prick-punch marks in the crank webs. If these marks are not present, you must make them so that the indicator may be placed in its correct position. Consult the manufacturer’s technical manual for the proper location of new marks.

Readings are generally taken at the four crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others, the connecting rod may interfere, making it necessary to take the reading as near as possible to bottom dead center without having the gauge come in contact with the connecting rod. The manufacturer’s technical manual for the specific engine provides information concerning the proper position of the crank when readings are to be taken. When the gauge is in its lowest position, the dial will be upside down, necessitating the use of a mirror and flashlight to obtain a reading.

NOTE

Once the indicator has been placed in position for the first deflection reading, do NOT touch the gauge until all four readings have been taken and recorded.

Variations in the readings obtained at the four crank positions will indicate distortion of the crank. Distortion may be caused by several factors, such as a bent crankshaft, worn bearings, or improper engine alignment. The maximum allowable deflection can be obtained from the manufacturer’s technical manual. If the deflection exceeds the specified limit, take steps to determine the cause of the distortion and to correct the trouble.

Deflection readings are also employed to determine correct alignment between the engine and the generator, or between the engine and the coupling. When alignment is being determined, a set of deflection readings is usually taken at the crank nearest to the generator or the coupling. In aligning an engine and generator, it may be necessary to install new chocks between the generator and its base to bring the deflection within the allowable value. It may also be necessary to shift the generator horizontally to obtain proper alignment. When an engine and a coupling are to be aligned, the coupling must first be correctly aligned with the drive shaft; then, the engine must be properly aligned to the coupling, rather than the coupling aligned to the engine.

Camshafts

In addition to the camshaft and bearing troubles already mentioned, the cams of a camshaft may be damaged as a result of improper valve tappet adjustment, worn or stuck cam followers, or failure of the camshaft gear.

Cams are likely to be damaged when a loose valve tappet adjustment or a broken tappet screw causes the valve to jam against the cylinder head, and the push rods to jam against their cams. This will result in scoring or breaking of the cams and followers, as well as severe damage to the piston and the cylinder.

Valves must be timed correctly at all times, not only for the proper operation of the engine but also to prevent possible damage to the engine parts. You should inspect frequently the valve actuating linkage during operation to determine if it is operating properly. Such inspections should include taking tappet clearances and adjusting, if necessary; checking for broken, chipped, or improperly seated valve springs; inspecting push rod end fittings for proper seating; and inspecting cam follower surfaces for grooves or scoring.

Journal Bearings

Engine journal bearing failures and their causes may vary to some degree, depending upon the type of bearing. The following discussion of the causes of bearing failure applies to most bearings—main bearings as well as crank pin bearings. The most common journal bearing failures may be due to one or to a combination of the following causes:

1. Corrosion of bearing materials caused by chemical action of oxidized lubricating oils. Oxidation of oil may be minimized by changing oil at the designated intervals, and by keeping engine temperatures within recommended limits. Bearing failures due to corrosion may be identified by very small pits covering the surfaces. In most instances, corrosion occurs over small areas in which high localized pressures and temperatures exist. Since the small pits caused by corrosion are so closely spaced that they form channels, the oil film is not continuous and the load-carrying area of the bearing is reduced below the point of safe operation.
2. Surface pitting of bearings due to high localized temperatures that cause the lead to melt. This is generally the result of very close oil clearances and the use of oil having a viscosity higher than recommended. Early stages of the loss of lead, due to melting, will be evidenced by very small streaks of lead on the bearing surface.
3. Inadequate bond between the bearing metal and the bearing shell. A poor bond may be caused by fatigue resulting from cyclic loads, or it may be the result of defective manufacturing. A failure due to inadequate bond is shown in *Figure 21-20*. In such failures, the bearing shell shows through the bearing surface clearly.
4. Out-of-round journals due to excessive bearing wear. As the bearings wear, excessive clearance is created; this leads to engine pounding, oil leakage from the bearing, reduced flow of oil to other bearings, and overheating, with the consequent melting of bearing material. To prevent bearing wear, the journals should be checked for out-of-roundness. Manufacturers require crank pins to be reground when the out-of-roundness exceeds a specified amount. Always check the engine manual for this type of data.
5. Rough spots. Burrs or ridges may cause grooves in the bearings and lead to bearing failure. Removal of rough spots is done with a fine oil stone and a piece of crocus cloth. Be sure to place a clean cloth beneath

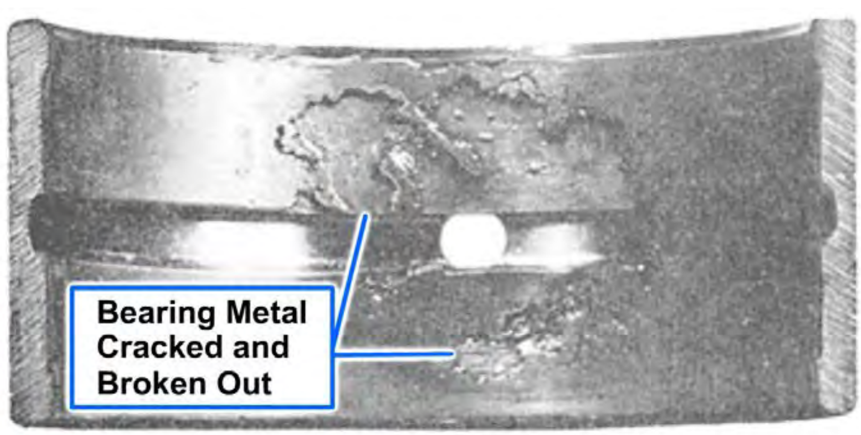

Figure 21-20 — Bearing failure due to inadequate bond.

the journal to catch all particles. Apply a coat of clean lubricating oil to the journal and to the bearing before a bearing is installed.

6. Misalignment of parts. Misalignment of the main bearings can be caused by a warped or bent crankshaft. Such misalignment imposes heavy loads on the main bearings because of the force that is necessary to retain correct alignment between the bearing and the journal.
7. A bent or misaligned connecting rod can be the cause of a ruined crank-pin bearing. Misalignment between the connecting rod bore and the piston pin bushing bore is indicated by the cracking of the bearing material at the opposite ends of the upper and lower-bearing shell. An indication of a bent connecting rod is heavy wear or scoring on the piston surface.
8. Faulty installation due to negligence or lack of experience. The paramount factor is inattention to cleanliness. Hard particles lodge between the bearing shell and the connecting rod bore, and create an air space. This space retards the normal flow of heat and causes localized high temperatures. Such condition may be further aggravated if the bearing surface is forced out into the oil clearance spaces and creates a high spot in the bearing surface. The result of a bearing failure is illustrated in *Figure 21-21*. Foreign particles, excessive clearance, or rough surface may cause poor contact between a bearing shell and a connecting rod; poor contact is indicated by the formation of a gumlike deposit (sometimes referred to as lacquer or varnish) on the back of the shell. Bearing failures may result from improper fit of the shell to the connecting rod. If the locking lip of a bearing does not fit properly into the recess of the bearing housing, distortion of the shell and failure of the bearing results. Another source of trouble during installation is due to the interchanging of the upper and lower shells. The installation of a plain upper shell in place of a lower shell, which contains an oil groove, completely stops the oil flow and leads to early bearing failure. The resulting damage may not only ruin the bearing but also extend to other parts, such as the crankshaft connecting rod, piston, and wrist pin.

Figure 21-21 — Bearing failure resulting from wiping and excessive temperatures.

9. Failure to follow recommended procedures in the care of lubricating oil. Lack of proper amount of lubricating oil will cause the overheating of a bearing, causing its failure *(Figure 21-22)*. In large engines, the volume of the lubricating oil passages is so great that the time required filling them when starting an engine could be sufficient to permit damage to the bearings. To prevent this, separately driven lubricating oil priming pumps are installed, and by their action, the oil is circulated to the bearings before an engine is started. Priming pumps should be secured prior to starting the

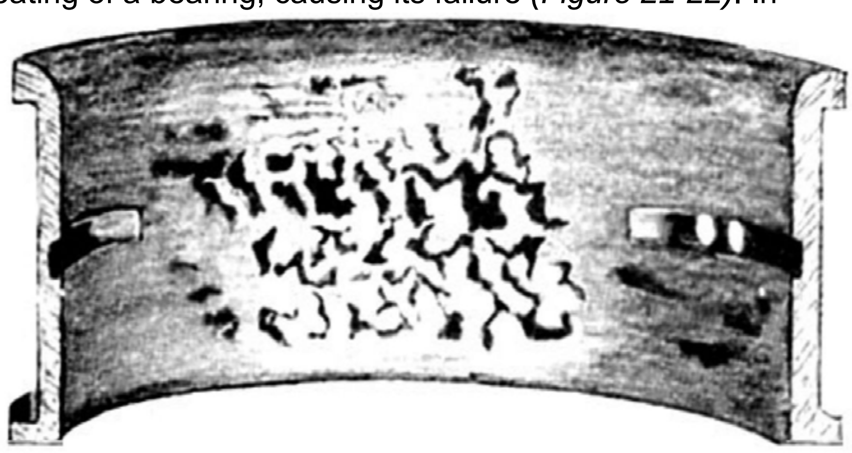

Figure 21-22 — Overheating bearing.

engine when the prescribed pressure has been obtained.

Maintenance of recommended oil pressures is essential to ensure an adequate supply of oil at all bearing surfaces. Refer to the oil pressure gauge as it is the best source of operational information to indicate satisfactory performance.

Use Navy-approved, low-corrosive lubricating oils at recommended oil temperatures. Recommended temperatures have been determined by extensive tests in laboratory and in service. They are sufficiently high to assure satisfactory circulation, and sufficiently low to prevent excessive oxidation of the lubricating oil. Normally, the manufacturer’s technical manual should be followed as to the correct lubricating oil temperature to maintain. However, if no manual is available, the temperature of the oil leaving the engine should be maintained between 160 and 200 °F. When possible, oil must be analyzed at recommended intervals to determine its suitability for further use. In addition, regular service of oil filters and strainers must be maintained, and oil samples must periodically be drawn from the lowest point in the sump to determine the presence of abrasive materials or water. The lube oil purifier should be used in accordance with required procedures. Strict adherence to recommended practices will reduce the failure of bearings and other parts because of the contaminated oil or insufficient supply of clean oil.

Frictionless Bearings

A list of the troubles that may be encountered with all types of antifriction frictionless bearings is illustrated on *Table 21-3.*

Table 21-3 — Antifriction Frictionless Bearing Troubles and Their Causes

Trouble	Possible Causes
Undue piston wear; crown and land dragging	Insufficient lubrication Improper cooling water temperature Overload Unbalance Improper fit Dirty intake air cleaner Dirty oil Improper starting procedures
Cracks; crown	Faulty cooling Loose piston Obstruction in cylinder Faulty nozzle spray
Lands	Insufficient lubrication Cocked piston Insufficient ring grooves clearance Excessive wear od piston ring grooves Broken ring Improper installation or removal
Piston seizure	Inadequate lubrication Excessive temperature Improper cleaning
Piston pin bushing wear	Insufficient lubrication Excessive temperatures Overload Unbalanced load

Since dirty bearings will have a very short service life, every possible precaution must be taken to prevent the entry of foreign matter into bearings. Dirt in a bearing which has been improperly or insufficiently cleaned may be detected by noise when the bearing is rotated, by difficulty in rotating, or by visual inspection. Do not discard an antifriction bearing until you have definitely established that something in addition to dirt has caused the trouble. You may determine this by properly cleaning the bearing.

Spalled or pitted rollers or races may be first recognized by the noisy operation of the bearing. Upon removal and after a very thorough cleaning, the bearing will still be noisy when rotated by hand. Roughness may indicate spalling at one point on the raceway.

WARNING

Never spin a frictionless bearing with compressed air.

Pay particular attention to the inner surface of the inner race, since it is here that most surface disintegration first occurs. Since pits may be covered with rust, any sign of rust on the rollers or contact surfaces of the races is a probable indication that the bearing is ruined.

Brinelled or dented races are most easily recognized by inspection after a thorough cleaning. Brinelling receives its name from its similarity to the Brinnell hardness test, in which a hardened ball is pressed into the material. The diameter of the indentation is used to indicate the hardness of the material. Bearing races may be brinelled by excessive and undue pressures during installation or removal or by vibration from other machinery while the bearing is inoperative. If heavy shafts supported by frictionless bearings are allowed to stand motionless for a long time, and if the equipment is subject to considerable vibration, brinelling may occur. This is due to the peening action of the rollers or balls on the races.

Brinelled bearings MUST NOT be placed back in service. Steps can be taken to prevent brinelling. Proper maintenance will help a great deal, and the best insurance against brinelling caused by vibration is to rotate the shafts supported by the frictionless bearings at regular intervals (at least once a day) during periods of idleness. These actions will prevent the rollers from resting too long upon the same portion of the races.

Separator failure may become apparent by noisy operation. Inspection of the bearings may reveal loose rivets, failure of a spot weld, or cracking and distortion of the separator. Failure of separators can usually be avoided if proper installation and removal procedure are followed, and steps are taken to exclude the entry of dirt.

Abrasion (scoring, wiping, burnishing) on the external surface of a race indicates that relative motion has occurred between the race and the bearing housing or shaft surface. The race adjacent to the stationary member is usually made a push fit so that some creep will occur. Creep is a very gradual rotation of the race. This extremely slow rotation is desirable as it prevents repeated stressing of the same portion of the stationary race. Wear resulting from the proper creep is negligible and no damaging abrasion occurs. However, abrasion caused by locked bearings or the improper fit of the races must be prevented.

Cracked races will usually be recognized by a definite thump or clicking noise in the bearing during operation. Cleaning and inspection is the best means of determining if cracks exist. Cracks usually form parallel to the axis of the race. The cracking of bearing races seldom occurs if proper installation and removal procedures are followed.

Excessive looseness may occur on rare occasions even though no surface disintegration is apparent. Since many frictionless bearings appear to be loose, even when new, looseness is not always a sign of wear. The best check for excessive looseness is to compare the suspected bearing with a new one.

Wear of bearings, which cause looseness without apparent surface disintegration, is generally caused by the presence of fine abrasives in the lubricant. Taking steps to exclude abrasives and keeping lubricating oil filters and strainers in good condition is the best way to prevent this type of trouble.

Most of the troubles listed in *Table 21-23* require the replacement of an antifriction bearing. The cause of damage must be determined and eliminated so that similar damage to the replacement bearing may be prevented.

Dirty bearings may be made serviceable with a proper cleaning, providing other damage does not exist. In some cases, races abraded on the external surfaces can be made serviceable, but it is generally advisable to replace abraded bearings. Dirty frictionless bearings must be thoroughly cleaned before being rotated or inspected.

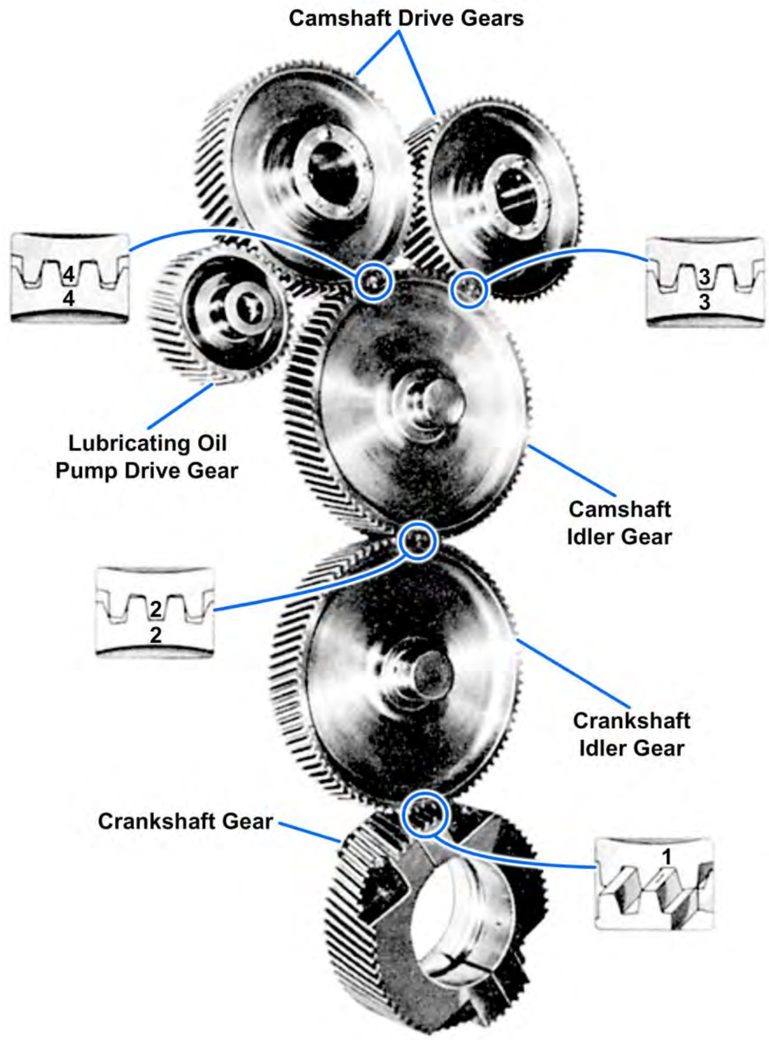

Figure 21-23 — Relative arrangement of the gears in an auxiliary drive mechanism.

Auxiliary Drive Mechanisms

Auxiliary drive mechanisms are used in internal combustion engines to maintain a fixed and definite relationship between the rotation of the crankshaft and the camshaft. This is so that the sequence of events necessary for the correct operation of the engine may be carried out in perfect unison. Timing and the rotation of various auxiliaries (blowers, governor, fuel and lubricating oil pumps, circulating water pumps, overspeed trips, etc.) are accomplished by a gear or chain drive mechanism from the crankshaft. (Some small engine auxiliaries may be belt-driven).

Gear Mechanisms

The principal type of power transmission for timing and accessory drives in most diesel engines is a system of gears *(Figure 21-23).* In some of the larger engines, there may be two separate gear trains, one for driving the camshaft and the other for driving certain accessories.

The type of gear employed for a particular drive depends upon the function it is to perform. Most gear trains use single helical spur gears, while governor drives are usually of the bevel type; reverse and reduction gear units employ double helical gears to balance fore and aft components of tooth pressure.

Small gears are usually made from a single forging, while larger ones are quite often built up in split sections; see the crankshaft in *Figure 21-23*. Most gears are made of steel, although cast iron, bronze, or fibers are sometimes used.

The camshaft rotates at the same speed as the crankshaft in the timing gear of the two-stroke cycle diesel engine (*Figure 21-23)*. Note that two idler gears are necessary to transfer crankshaft rotation to the camshaft gears. The idler gears are used because the camshafts and crankshaft are displaced a considerable distance. If idler gears were not used, the crankshaft and camshaft gears would have to be considerably larger.

A similar timing gear train may be found in some four-stroke cycle engines, except that the camshaft gear or gears will have twice as many teeth as the crankshaft gear to permit the camshaft to rotate at one-half the crankshaft speed.

A different type of drive gear mechanism is used for a four-stroke cycle, V-type gasoline engine. The camshaft gears are driven through a train of bevel gears from the crankshaft. This arrangement serves to drive not only the camshaft but also other accessories, such as a magneto or distributor, a fuel pump, and a tachometer. An additional gear, called the oil and freshwater pump drive gear, meshes with the crankshaft gear.

The causes of gear failure (improper lubrication, corrosion, misalignment of parts, torsional vibration, excessive backlash, wiped gear bearings and bushings, metal obstructions, and improper manufacturing procedures) are basically the same as the causes of similar troubles in other engine parts. The best method of prevention is to adhere to the prescribed maintenance procedures and follow the instructions given in the manufacturer's technical manual.

Maintenance and repair of gear trains involve a thorough check (for scoring, wearing, pitting, etc.) of the gear shafts, bushings and bearings, and gear teeth during each periodic inspection. Be sure that the oil passages are clear, and that the woodruff keys, dowel pins, and other locking devices are secured to a tight fit in order to prevent longitudinal gear movement. It is essential that all broken or chipped parts be removed from the lubrication system before new gears are installed.

An engine must not be barred over while the camshaft actuating gears are removed from the train. Should the engine be barred over, there is danger that the piston will strike valves that may be open and extending into the cylinder. Make certain that any gears removed are replaced in the original position. Special punch marks, or numbers, are usually found on gear teeth that should mate (shown in *Figure 21-23)*. If they are not present, make identifying marks to facilitate the correct mating of the gears later.

Bearing, bushing, and gear clearances must be properly maintained. If bushing clearances exceed the allowable value, the bushings must be renewed. The allowable values for backlash and bushing clearances should be obtained from the instruction manual for the engine involved.

Usually, a broken or chipped gear must be replaced. Care should be exercised in determining whether a pitted gear should be replaced.

Blower Rotor Gears

One of the most important parts of a root-type blower is the set of gears that drive and synchronize the two rotors. Satisfactory operation depends on the condition of these gears.

Worn gears are found by measuring the backlash of the gear set. Gears with a greater backlash than specified in the applicable technical manual are considered to be excessively worn and, if not replaced, will eventually cause extensive damage to the entire blower assembly.

A certain amount of gear wear is to be expected, but scored and otherwise damaged rotor lobes resulting from excessively worn gears are inexcusable. It is the duty of the engineering force to inspect the gears and lobes, and to measure the clearance at frequent intervals. During the inspection, it will be possible to measure accurately the values of backlash. These values should be recorded. By observing the rate of increase of wear, it will be possible to estimate the life of the gears and to determine when it will be necessary to replace them.

Lobe clearance can be found by determining the difference of the maximum and minimum rotor lobe clearance at the same distance from the center. To find the maximum clearance, hold the rotors so that there is maximum clearance between the two rotor lobes. Then, with feeler gauges determine the value of the rotor lobe clearance *(Figure 21-24).*

The minimum clearance is found in a similar manner except that rotor lobes are held in such a position as to take up all slack and backlash. The difference of the two clearance readings is the value of the backlash of the rotor lobes. Since a chang e in lobe clearance is normally caused by wear of the gears, the gear clearance must be checked. The most direct method for checking gear clearance is by the use of feeler gauges (*Figure 21-25).*

Any gear set which has excessive lash or shows any sign of fracture must be replaced with a new set. Since blower drive gears come in matched sets, gears from different sets must not be interchanged.

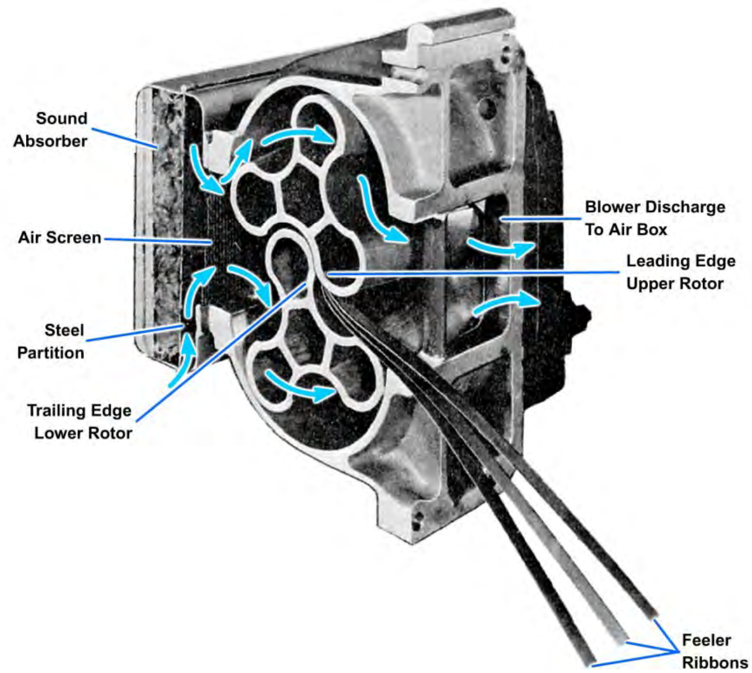

Figure 21-24 — Checking clearance of positive displacement blower lobes.

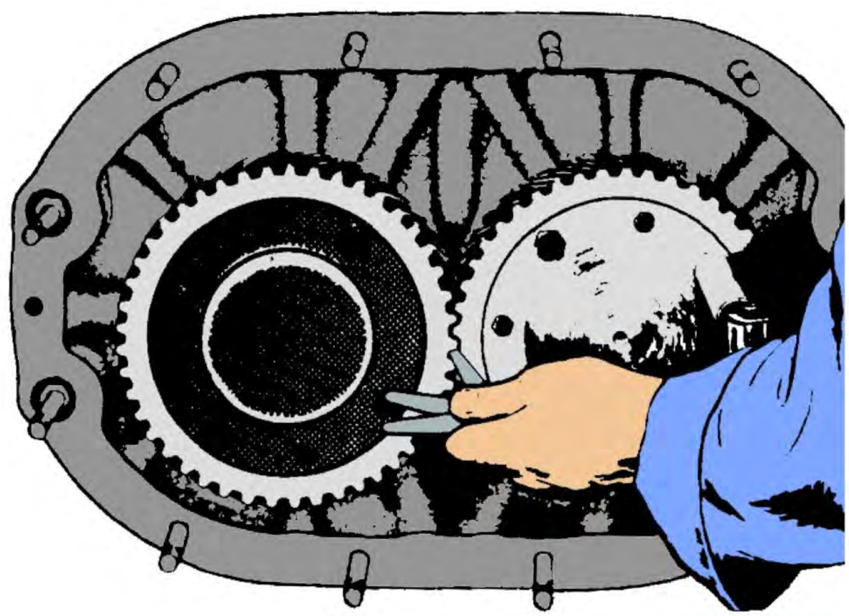

Figure 21-25 — Checking the blacklash of the blower rotor gears.

Chain Mechanisms

In some engines, chains are not only used to drive camshafts and auxiliaries but also to drive such parts as rotating supercharger valves *(Figure 21-26*). Note that the connecting pins in one are secured by cotter pins, while the joint pins shown in the other are riveted. The principal causes of drive chain failure are improper chain tension, lack of lubrication, sheared cotter pins or improperly riveted joint pins, and misalignment of parts, especially idler gears.

Chain drives should be checked for any symptoms of such difficulties, in accordance with the instructions in the appropriate engine manual. The tension should be adjusted as required during these inspections. An idler sprocket and chain tightened are used on most engines to adjust chain tension. During operation, chains increase slightly in length because of stretch and wear. Adjustments should be made for these increases whenever necessary.

When you are installing a new chain, peen the connecting link pins into place, but avoid excessive peening. After peening, make sure the links move freely without binding in position. Cotter pins must be secured or the joint pin ends riveted, whichever is applicable. Repair links should be carried at all times. Always check engine timing after installing a new timing and accessory drive mechanism.

The turbochargers used in the Navy today may operate with temperatures as high as 1200 °F and speeds up to 75,000 revolutions per minute (rpm). Therefore, it is of utmost importance that turbochargers be maintained in proper working order at all times. If a turbocharger is allowed to operate without lubrication, cooling, or the proper clearances, it not only could be completely destroyed in a matter of minutes but also could possibly cause extensive damage to other machinery and personnel.

All oil lines and air duct connections should be inspected and free of leakage. The air filter should be clean and in place and there should be no build-up of dust or dirt on the impeller. Turn the impeller by hand and check for binding or rubbing and listen for any unusual noises.

When the turbocharger is operating, listen for any unusual noise or vibrations. If you hear a shrill high-pitch whine, shut down the engine at once. The whine may be caused by a failing bearing, and serious damage may result. Do not confuse the whine heard as the turbine runs down with that of a bad bearing.

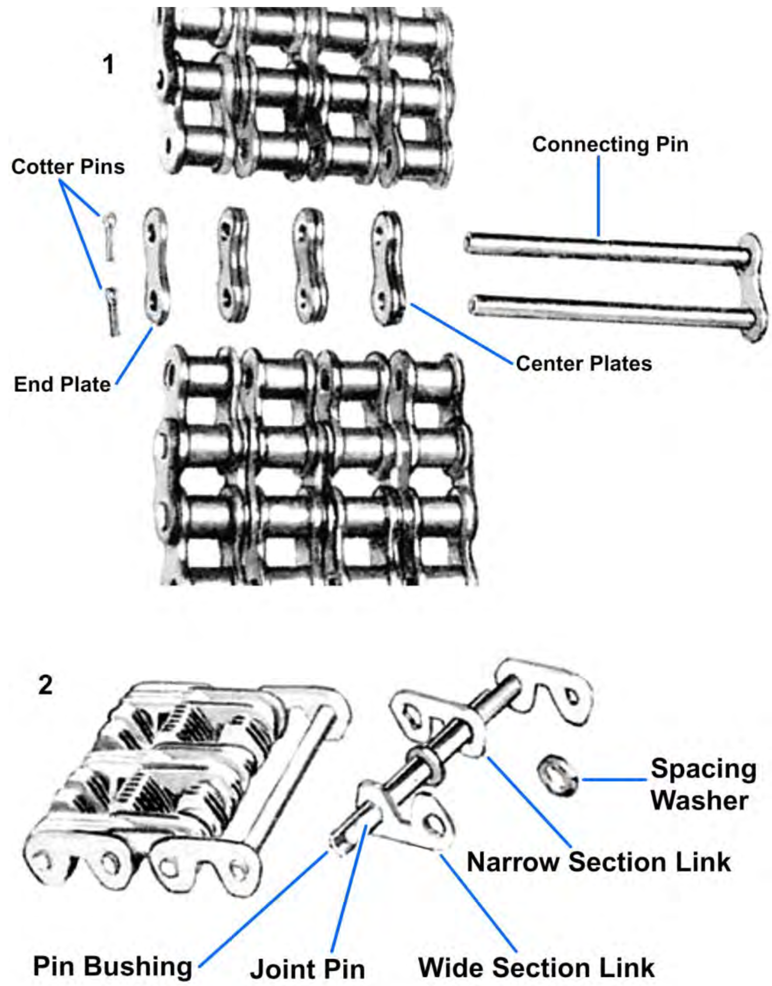

Figure 21-26 — Accessory drive chain link assemblies.

Noise from the turbocharger may also be caused by improper clearances between the turbine wheel and the turbine housing. The clearances should be checked at predetermined intervals in accordance with the PMS. Check bearing axial end play and shaft radial movement. Crankcase vents should not be directed towards the turbocharger air intakes, as the corrosive gases may cause pitting of the blades and bearings, thereby reducing the life of the turbocharger.

SUMMARY

You should be familiar with the importance of diesel engine inspection, and some of the adjustment and maintenance required on diesel engines. You should have an understanding of the diesel engine lubricating oil, fuel oil, and controlling systems. In our discussion of fluid processing, you have learned how important the quality of the fluids is for diesel engines. You have also learned some of the repairs for the internal combustion engines.

End of Chapter 21

Engine Maintenance

Review Questions

21-1. How often, in hours, should compression and firing pressure readings be taken on diesel engine for trend analysis graphs?

A. 200
B. 250
C. 300
D. 350

21-2. A thermocouple pyrometer, is used in which principal engine system?

A. Intake
B. Exhaust
C. Saltwater
D. Freshwater

21-3. In what system is the temperature regulating valve located in on most diesel engines?

A. Fuel
B. Lubricating oil
C. Saltwater
D. Freshwater

21-4. What is used for making emergency repairs to the radiator-type heat exchanger?

A. Hard solder
B. Cooper nickel
C. Soft solder
D. Steel

21-5. What kind of pumps is used in diesel engine lubricating oil systems?

A. Gear
B. Jerk
C. Positive displacement
D. Centrifugal

21-6. How are pump casualties, and many other lube system failures indicated?

A. Increase of lubricating oil temperature
B. Decrease of lubricating oil temperature
C. Increase of lubricating oil pressure
D. Decrease of lubricating oil pressure

21-7. What kind of fuel delivery system embodies a cam-actuated constant-stroke lapped plunger and bushing, a high pressure pump, and an injection nozzle, all in one unit?

A. Individual pump system
B. Unit injection system
C. Common rail
D. Individual pump

21-8. What kind of fuel delivery system employs a common metering device that distributes a measured quality of fuel to each of the ejectors?

A. Cam-actuated injector and nozzle assembly
B. Individual pump system
C. Common rail
D. Individual pump

21-9. What causes the diesel engine to have uneven operation or vibrations?

A. Improper timing of the fuel system
B. Improper purification of the fuel system
C. Improper purification of the lubricating oil system
D. Improper cooling of the lubricating oil system

21-10. What information is found on the label of the lubricating oil sample bottle?

A. Sump level
B. Person taking sample
C. Equipment
D. Sample code

21-11. What is it called when the piston shifts its thrust from one side to the other side after it reach top dead center (TDC) and bottom dead center (BDC)?

A. Smack
B. Strike
C. Slap
D. Swipe

21-12. What condition causes oxidation, leaving carbon deposits on the rings and in the grooves of a diesel engine?

A. Low operating temperatures
B. Excessive operating temperatures
C. Low cooling temperatures
D. Excessive cooling temperatures

21-13. What is the first indication of a spalled or pitted roller or race in a frictionless bearing?

A. Smoke
B. Red color
C. Bubbling of oil
D. Noisy bearing

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CHAPTER 22

REDUCTION GEARS AND RELATED EQUIPMENT

This chapter deals primarily with reduction gears used in geared diesel engine driven propulsion systems and related equipment such as bearings and shafting. We will discuss the construction, operation, and precautionary care of main reduction gears and reduction gears.

High-speed propellers are less efficient than low-speed propellers. They waste much of their horsepower just churning up water instead of using it to move the ship. Therefore, diesel engines use reduction gears to gear down to the appropriate speed for the size propeller the ship can carry.

This chapter contains information on the operation, care, and maintenance of the main reduction gear used on Navy ships. As an Engineman, you must be familiar with the design and construction details of naval reduction gears. To acquire this information, we recommend that you study this chapter and the *Naval Ships' Technical Manual (NSTM)*, Chapter 241. Details of any particular reduction gear installation will be found in the manufacturer's technical manual.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose of the reduction gear.
2. List some of the factors affecting the operating of the reduction gear.
3. Describe the inspection, safety, and security of the main reduction gear.
4. Identify the purpose of the lubrication process for the gears and bearing of the reduction gears.
5. Describe the purpose of the controllable pitch propeller.
6. Explain the procedures for preparing to get underway.

REDUCTION GEARS

Reduction gears are coupled to the diesel engine shaft through various arrangements of gearing. These gears reduce the speed of the diesel engine to the low speed required by the propulsion shaft and propeller. Reduction gears may be driven by one or more diesel engines. A combination of gears is known as a train, and that term will be used in this chapter.

Reduction gears are classified according to the number of steps used to reduce speed and the arrangement of the gearing. When two gears are meshed and the driving gear (called a pinion) is larger than the mating gear, the driving gear is called a speed increaser. A driving gear that is smaller than the mating gear is called a speed decreaser. The ratio of the speeds is proportional to the diameters of the pinion and gear. When there are just two gears, the train is known as a single-reduction gear (single-speed increaser or decreaser). Double-reduction gears have more than two gears working together. They keep the size of the bull gear (large gear attached to the propeller shaft) from becoming too large.

Main Reduction Gear

The main reduction gear is one of the largest and most expensive units of machinery found in the engineering department. It is made up of a number of smaller gears. A main reduction gear that is installed properly and operated properly will give years of satisfactory service. However, a serious casualty to a main reduction gear will either put the ship out of commission or force it to operate at reduced speed. Extensive repairs to the main reduction gear can be very expensive because they usually have to be made at a shipyard.

Propulsion Reduction Gears

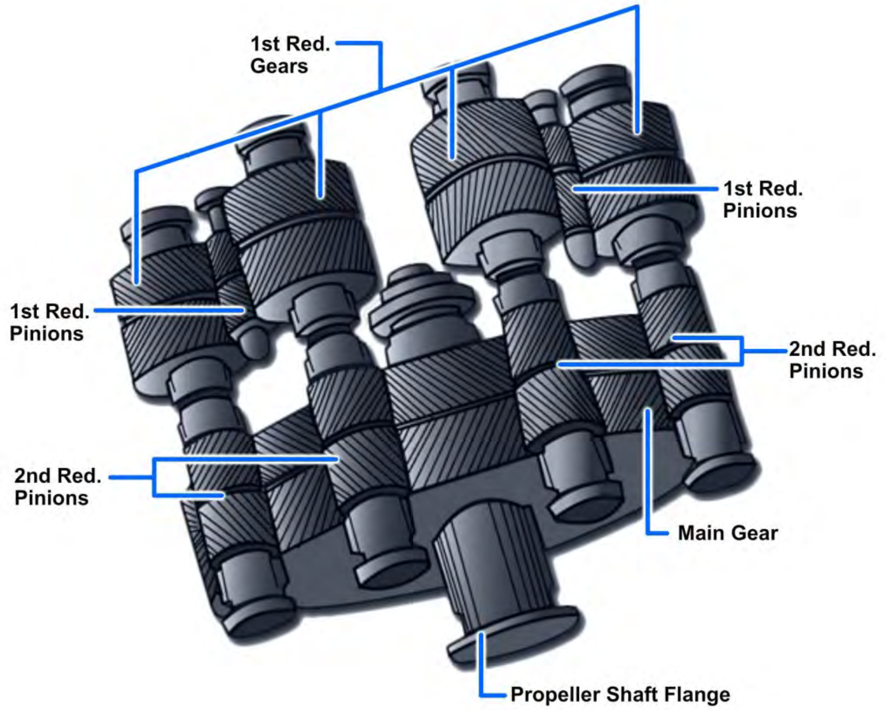

Figure 22-1 — Articulated locked train, doubled-reduction gear.

Diesel engine drives normally use double-reduction gears. The articulated locked train, double-reduction gear *(Figure 22-1)* is the most common. All propulsion reduction gears in combatant ships use the articulated, double-helical, and double-reduction type. These gears produce smoother action of the reduction gearing and avoid tooth shock. A double-helical gear has two sets of teeth at complementary angles to each other; therefore, axial thrust is eliminated. Each member of a double-helical gear set should be capable of axial float to prevent excessive tooth loads caused by a mismatch of the meshing elements. (Axial float means "capable of free motion, neither supporting nor supported by other gears axially"). There is a groove around the center of the gear where the teeth sets come together. This groove provides a path for oil flow, so that hydraulic pressure is not created between the gears where they mesh.

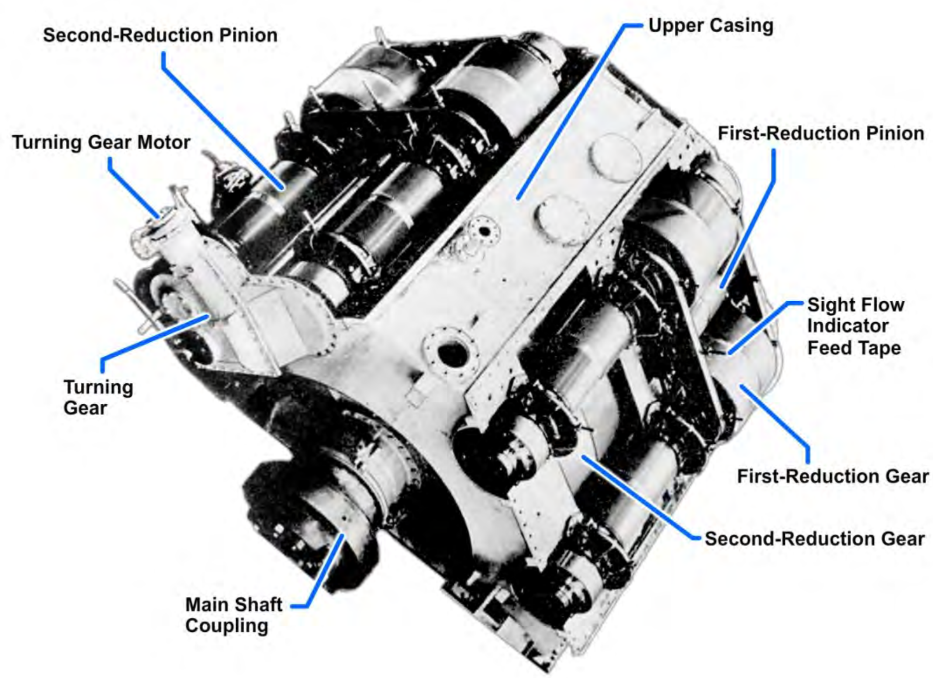

Figure 22-2 — Typical destroyer-type propulsion gear.

When the first-reduction gear and the second-reduction pinion each have two bearings and are connected by a quill shaft and flexible coupling(s), the design is called articulated. A quill shaft is essentially a gear coupling. It has two shaft rings with internal teeth and a shaft with external teeth around each end. The shaft rings are bolted on the far ends of each of the two gears to be connected. The floating member, now called a quill shaft, passes through the hollow centers of both gears. It is supported only at the ends where its teeth mesh with the shaft ends. An articulated locked train gear has two high-speed pinions. Each pinion drives two first-reduction gears connected by quill shafts to two separate second-reduction pinions. Each gear and pinion is mounted in its own two bearings. *Figure 22-2* shows the major parts of a main reduction gear unit. The term locked train means that the two first-reduction pinions are locked between the two first-reduction gears and transmit the power from the diesel engines equally to the two gears. This method reduces the load on each gear tooth by 50%.

Construction of Main Reduction Gears

The main rotating elements in a propulsion gear unit (main gears and pinions) operate at high rotational **speeds.** They transmit tremendous power loads. Very slight unevenness of tooth contour and tooth spacing will cause the gears to operate noisily or even to fail. Therefore, these gears are manufactured to very close tolerances. They are cut in rooms in which the temperatures and humidity are closely controlled. Expansion and contraction of the gear-blank during machining are negligible. Oxidation due to moisture in the air is nearly eliminated. In addition, all gears are carefully checked for errors.

Casings

Except for some small units, gear casings are of welded construction. Most gears have an upper and a lower casing and gear case covers. These casings are of box-girder construction with integral-bearing blocks. The low-speed bull-gear bearing housing is an integral part of the lower casing. Gear case covers are bolted and securely locked to the upper casing. They are arranged so that they can be removed for access to gearing and bearing caps. Inspection plates are usually provided in covers and gear cases so that the rotating parts may be inspected. Casings are arranged for access to oil spray fittings so that the fittings may be cleaned. Turning gears, tachometer drives, lube oil pump drives, sight-flow and thermometer fittings, thermocouples or resistance temperature element (RTE) junction boxes, and electrostatic precipitator vent connections are attached to gear casings.

Gears

Gears are forged-steel, one-piece constructions (*Figure 22-3*). The gear wheel construction and materials depend on the size of the gear. For small gears, the entire gear wheel may be made from a single steel forging. *Figure 22-3* shows an example of a single forged-steel pinion. Large gears are generally built up by welding. These gear sections usually include the shaft, the webs, the hub or center (which may be omitted when the webs are welded to the shaft), and the rim into which teeth are cut. The shaft is always of forged steel. When propeller-thrust bearings are located within the propulsion gear casing, a collar may be located at the forward end of the low-speed gear shaft. Or, an integral flange for attachment of thrust bearing facing collars may be located on the other end of the shaft, forward of the line shaft flange. Other types of construction consist of a close-grained cast-steel body. The body is welded to a shaft, with teeth cut directly in the casting, or a cast-steel body is pressed on a shaft and secured by fore and aft shrink rings and a locknut. A typical first-reduction gear journal bearing is shown in *Figure 22-4.* A bull gear with a flange for an after-thrust bearing is seen in *Figure 22-5*.

Figure 22-3 — Single forged-steel pinion.

In a double-reduction, articulated, divided power path gear set, the high-speed and second-reduction pinions are usually machined from forgings. The first- and second-reduction gears are usually fabricated. The gear shaft and rim are made of steel forgings and are assembled with steel webs welded to the shaft and rim. In wide-faced gears, the position of the steel webs with respect to the gear teeth is important in that it may affect gear tooth wear patterns. This assembly is stress relieved and heat treated for desired hardness.

Some gears are rough cut before heat treatment and the final finish operation brings them to the proper size. The journals are then cut slightly oversize to permit a final finishing operation. The teeth are cut in a temperature-controlled room to prevent changes in the ambient temperature from affecting the roundness of the gear. Additionally, the cutting operation is continuous to prevent heat that is generated in cutting from affecting the roundness of the finished gear.

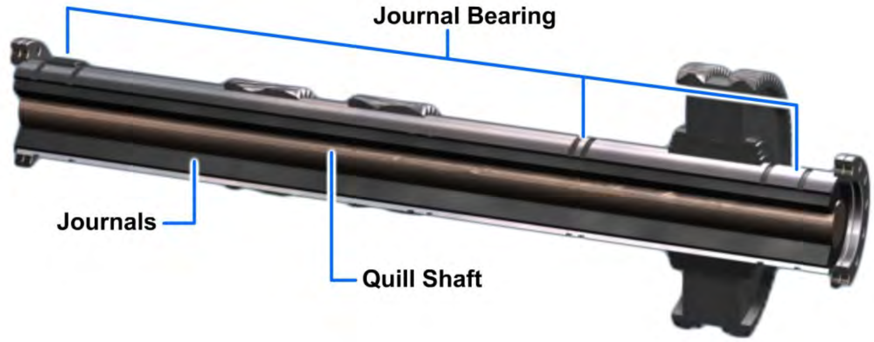

Figure 22-4 — Cutaway view of first-reduction gear journal bearing.

When the tooth cutting and the finishing operations are completed, the journals are finished so that they are concentric with the shaft axis. The assembly is then balanced. The bull gear is made in a similar fashion. Some first-reduction gears and bull gears in naval use are keyed and locked to the shaft with a locking device. This is done before the teeth are cut and before balancing. When the gears are all completed, the contact between pinion and gear is usually checked in a gear rolling machine before they are assembled in the gear case.

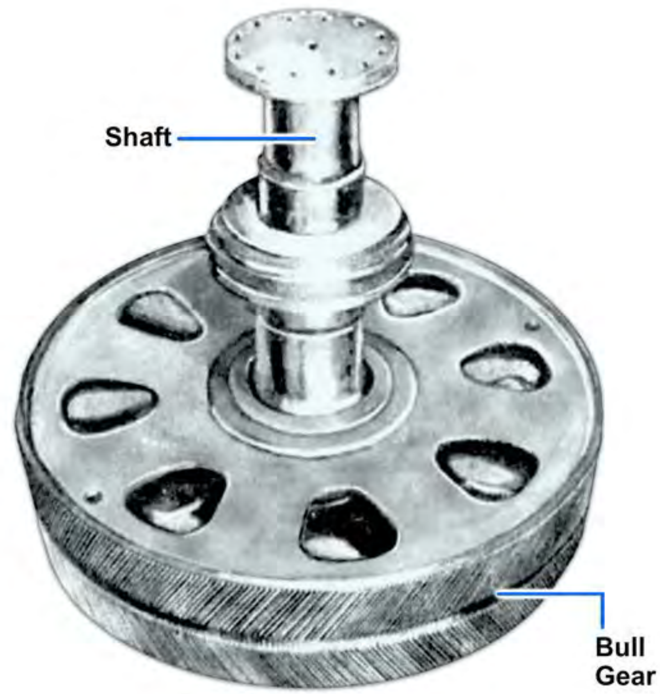

Figure 22-5 — Bull gear assembly with shaft.

Gear Teeth

The importance of proper gear tooth contact cannot be overemphasized. Any abnormal condition that may be revealed by operational sounds or by inspections should be corrected as soon as possible. Any abnormal condition that is not corrected will cause excessive wear, which may result in general disintegration of the tooth surfaces.

If proper tooth contact is obtained when the gears are installed, little wear of teeth will occur. Excessive wear cannot take place without metallic contact. Proper clearances and adequate lubrication will prevent most gear tooth trouble.

Wear-In of Gear Teeth

Gears that have been realigned and new gears should be given a wearing-in period at low power before they are subjected to the maximum tooth pressure at full power.

Tooth Contact

For proper operation of the gears, the total tooth pressure must be uniformly distributed over the total area of the tooth faces. This uniform pressure is accomplished by accurate alignment and adherence to the designed clearance. Maintain the designed center-to-center distance of the axes of the rotating elements as accurately as practical, keeping in mind that the axes of pinions and gear shafts must always be parallel. If the shafts are not parallel, the load is concentrated on one end of a helix. The result may be flaking, galling, pitting, featheredges on teeth, deformation of tooth contour, or breakage of tooth ends.

Checking Tooth Contact

The length of tooth contact across the face of the pinion is a means of determining if reduction gear alignment is satisfactory. One method used to static check the length of tooth contact is to apply a thin coat of Prussian blue to a band of teeth on one element and to coat a similar band on the mating element with red lead. The coatings must be thin and even. Rotate the two bands into contact by jacking back and forth three or four times. Use either copper sulfate or blue or red Dykem to determine tooth contact for operating conditions. Use Dykem for dock trials because it will show markings for light load conditions. Copper sulfate markings will remain visible longer after high-power operations than will Dykem markings. Remove lubricating oil from the gear teeth with a cleaning agent before you apply the compound. After the tooth contact is determined, remove the compound from the gear teeth to prevent possible contamination of the lubricating oil.

Then, oil the gear teeth. Remember that some gear teeth are cut with a very slight taper to offset the effects of torsional twist and bending. In such gearing, full contact across the teeth will not be obtained.

Tooth Contour

The designed tooth contour must be maintained. A lack of this tooth contour can cause load concentrations with consequent scoring.

Tooth Surface Wear

If proper contact is obtained when the gears are installed, the initial wearing, which takes place under conditions of normal load and adequate lubrication, will smooth out rough and uneven places on the gear teeth. This initial wearing is referred to as normal wear or running in. As long as operating conditions remain normal, no further wear will occur.

Small shallow pits *(Figure 22-6)* starting near the pitch line will frequently form during the initial stage of operation; this process is called initial pitting. Often the pits (about the size of a pinhead or even smaller) can be seen only under a magnifying glass. These pits are not detrimental and usually disappear in the course of normal wear.

Pitting that is progressive and continues at an increasing rate is known as destructive pitting. The pits are fairly large and are relatively deep. Destructive pitting is not likely to occur under proper operating conditions. It can be caused by excessive loading, too soft material, or improper lubrication. This type of pitting is usually caused by misalignment or improper lubrication.

The condition in which groups of scratches appear on the teeth (from the bottom to the top of the

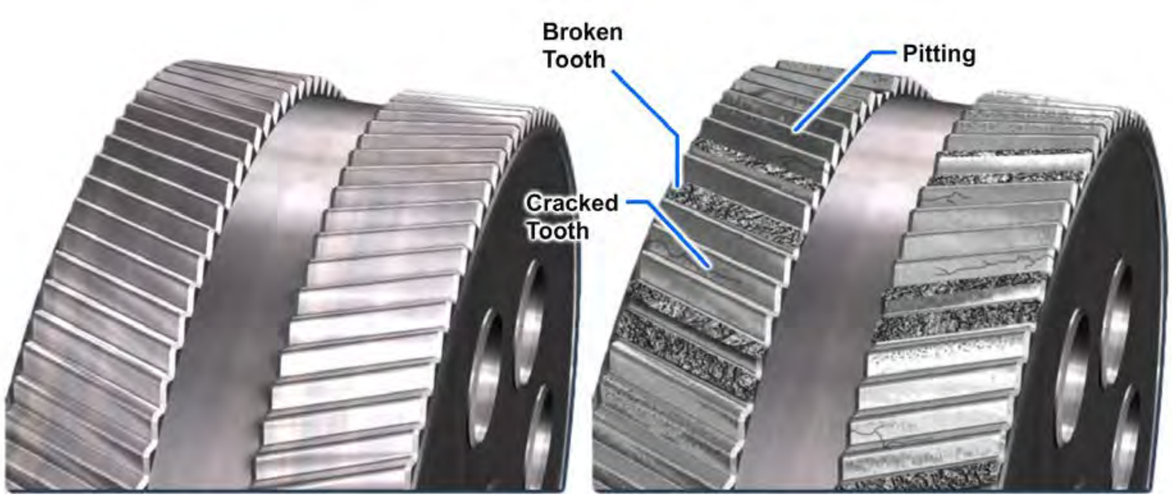

Figure 22-6 — Tooth surface.

tooth) is termed “abrasion”, or “scratching.” It may be caused by inadequate lubrication or by foreign matter in the lubricating oil. When abrasion, or scratching, is noted, you should immediately examine the lubricating system and the gear spray fixtures. If you find that dirty oil is responsible, the system must be thoroughly cleaned and the whole charge of oil centrifuged.

The term “scoring” denotes a general roughening of the whole tooth surface. Scoring marks are deeper and more pronounced than scratching; they cover an area of the tooth instead of occurring haphazardly, as in scratching. Small areas of scoring may occur in the same position on all teeth. Scoring with proper alignment and operation usually results from inadequate lubrication and is intensified by the use of dirty oil. If these conditions are not corrected, continued operation will result in a general disintegration of the tooth surfaces.

Spotting Gear Teeth

If you find any abnormal conditions that may be revealed by operational sounds or by inspections, correct them with the least possible delay. Stone rough gear teeth until they are smooth if you are certain that the roughening was caused by the passage of some foreign matter. Investigate any tooth deterioration that cannot be traced to a casualty. Give special attention to the condition of the bearing, to lubrication, and to the possibility of a change in the supporting structure, which has disturbed the parallelism of the rotors.

To spot-in surfaces of reduction gear teeth, coat the pinion teeth lightly with Prussian blue. Then, turn the gear in its ahead direction by using the jacking gear. As the gear teeth come in contact with the marked pinion teeth, an impression is left on the high part of the gear tooth. After the gear is turned one-fourth turn or is in a convenient position for stoning, use a small hand stone to remove all high spots indicated by the marks. You will need to replace the bluing on the pinion teeth repeatedly, but if the bluing is applied too thickly, false impressions will be left on the teeth. You may scrape gear teeth to remove a local hump or deformation; however, you may not scrape gear teeth to obtain contact without the approval of Naval Sea Systems Command (NAVSEA).

Backlash

Backlash is the play between the unloaded surfaces of the teeth in mesh on the pitch circle. Backlash increases with wear and can increase considerably without causing trouble.

Root Clearance

The designed root clearance with gear and pinion operating on their designed centers can be obtained from the manufacturer’s blueprints. The actual clearance can be found by taking leads or by inserting a long feeler gauge or wedge. The actual clearance should check with the designed clearance. If the root clearance is considerably different at the two ends, the pinion and gear shaft will not be parallel. There should be sufficient backlash, and the teeth should not mesh so closely that lubrication is poor or that clearance is reduced below specified limits. If these conditions are present, the tolerance will be satisfactory.

Flexible Couplings

Flexible couplings provide longitudinal and angular flexibility between the diesel engine shafts and the pinion shafts. This permits each shaft to be adjusted axially to its proper position to obtain total axial float. Most installations have gear-type flexible couplings. Power is transmitted through a floating intermediate member with external teeth. These teeth mesh with the internal teeth of the shaft rings (sleeves) mounted on the driving and driven shafts.

A design of the gear-type flexible couplings that connect the main diesel engines to the high-speed pinions of the main reduction gear *(Figure 22-7).* The couplings also allow for expansion of the diesel engine shafts; this takes care of any slight misalignment between the main diesel engines and the reduction gears, such as thermal expansion and hull movements. Another type of flexible coupling is shown in *Figure 22-8*. In this coupling the floating member consists of two sleeves that are bolted together.

The internal teeth of the sleeve mesh with the external teeth of the hubs mounted on the shaft. This type of coupling is used most often in diesel engine gears and where self-contained lubrication is advantageous.

Figure 22-7 — Gear-type flexible coupling.

The design of a flexible coupling that connects the first-reduction gears and the second-reduction pinions is shown in *Figure 22-9*. In this case, a quill shaft of high torsional flexibility is used as the floating member. This shaft provides equal distribution of the load among the several elements of the gear train. The quill shaft runs inside the hollow bore of the high-speed gear and the slow-speed pinion. The flexibility is obtained between the first-reduction gear and the second-reduction pinion.

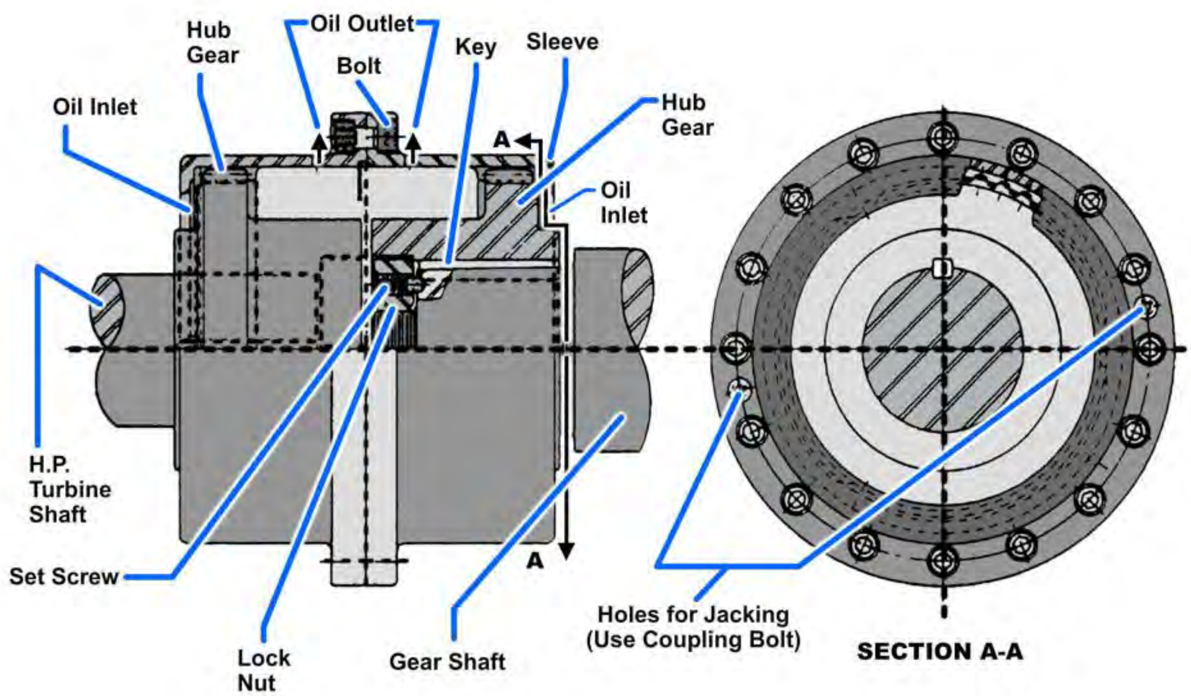

Figure 22-8 — Another gear-type flexible coupling.

A steady flow of oil from the supply passages of adjacent bearings is directed into the flexible couplings when the reduction gears are turning. The oil is caught by projecting edges of the diesel engine and pinion flanges or sleeves *(Figure 22-7).* Centrifugal action forces oil through the horizontal holes in the flanges to the coupling teeth. Oil is discharged from the teeth into coupling guards and then flows into the oil drain system.

Turning Gears

All geared-diesel engine installations are equipped with an electric motor-driven jacking or turning gear *(Figure 22-10)*. The unit is used to turn the main engine during warming up and securing periods so that the diesel engine rotor can heat or cool evenly. (The rotor of a hot diesel engine, or of one that is in the process of being warmed up with gland-sealing steam cut in, will become bowed or distorted if left stationary even for a few minutes). The turning gear is used for other routine purposes. One example is turning the reduction gear to bring the reduction gear teeth into view during routine inspection. Another is the required periodic rotation of the main engines when they are secured.

The turning gear is mounted on top and at the after end of the reduction gear casing. A shaft extends from the end of the high pressure, first-reduction pinion to the after end of the reduction gear casing. It connects to the turning gear by a manually operated jaw clutch.

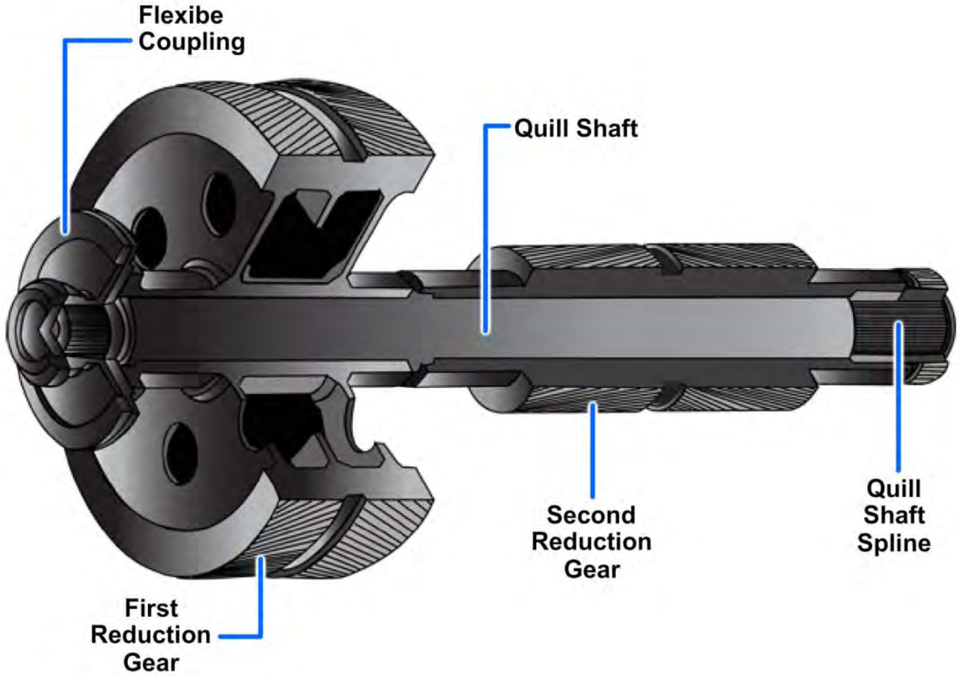

Figure 22-9 — Quill shaft assembly.

Engaging this clutch connects the pinion to an electric motor through a train of gears. These gears usually consist of one or more sets of worm gears and one or more sets of spur or helical gears.

Engaging the clutch and operating the motor will turn one first-reduction pinion. This turns the reduction gears, the main diesel engines, and the main propeller shaft.

On some installations, the reduction ratio between the main shaft and the electric motor may be as high as 17,000 to 1. With the motor turning and the turning gear engaged, the main shaft will make 1 1/4 turns in approximately 15 minutes.

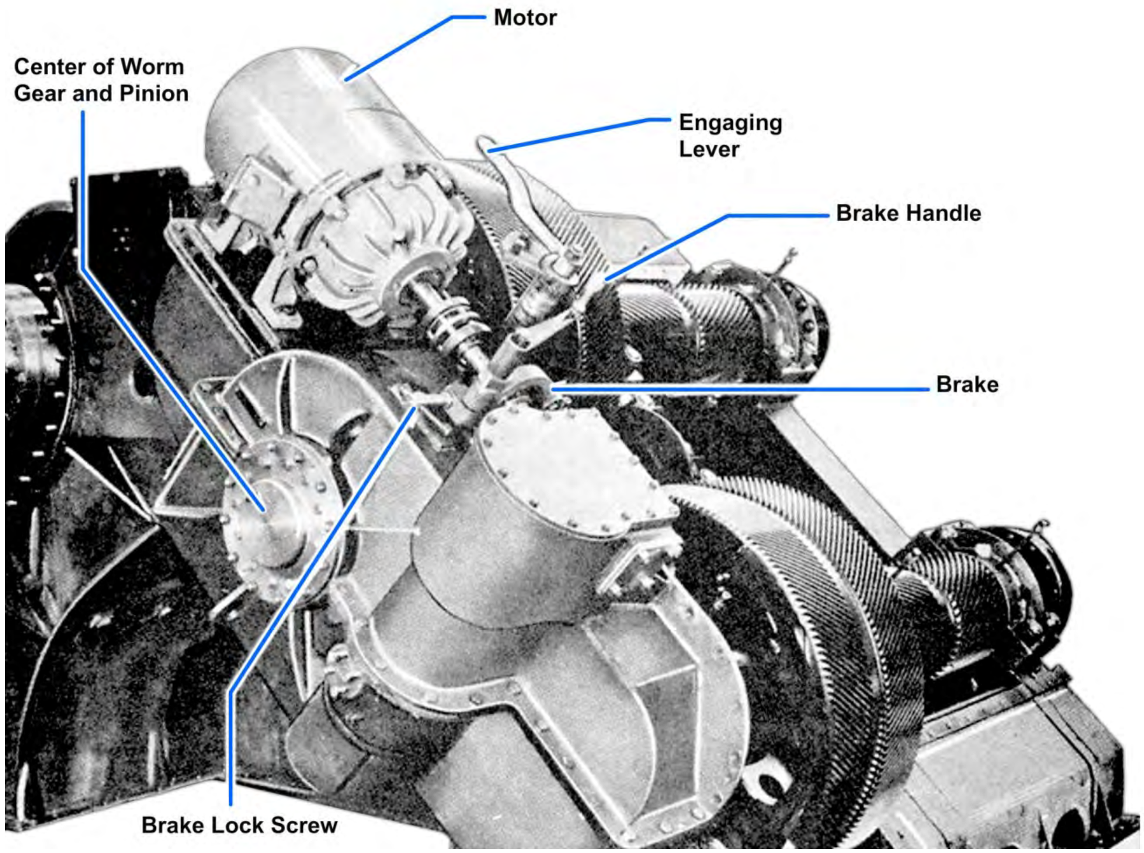

Figure 22-10 — Propulsion gear.

Because of the gearing arrangement, the diesel engines should never be turned with steam while the turning gear is engaged. It will cause serious damage to the turning mechanism.

WARNING

To engage the jacking gear clutch, first stop the shaft. This can be done either by stopping the ship or by using the astern diesel engine to stop and then hold the shaft stationary. **NEVER, UNDER ANY CIRCUMSTANCES, ATTEMPT TO ENGAGE THE JACKING GEAR WITH THE SHAFT TURNING**. Regardless of how slow the propeller shaft movement may be damage to the motor or gears, or both, will occur.

The turning gear is equipped with a shaft locking device *(Figure 22-10*). This device is used to lock the shaft against rotation while the ship is underway. (On multi-screw ships, if one shaft is stopped with one or more others operating, the stopped shaft must be locked or it will rotate due to propeller drag through the water). For this purpose, a friction brake is usually installed on the first-reduction worm shaft. Either a brake drum is mounted on the worm shaft or the shaft coupling serves as a drum. When the turning gear is engaged and the brake is set, a ship can go ahead on its other engines and the idle shaft will be held stationary.

Some turning gears have positive locking devices, which use internal and external gear teeth in engagement. Turning gears operated by air motors or by hand are generally used where continuous turning is not required.

Main Thrust Bearings

The main thrust bearing is usually located in the reduction gear casing. It absorbs the axial thrust transmitted through the shaft from the propeller.

Segmental pivoted-shoe thrust bearings (*Figure 22-11, frames 1 and 2*) are commonly used for main thrust bearings. This bearing consists of pivoted segments or shoes (usually six or eight) against which the thrust collar revolves. The action of the thrust shoes against the thrust collar restrains the ahead or astern axial motion of the shaft to which the thrust collar is secured. These bearings operate on the principle that a wedge-shaped film of oil is more readily formed and maintained than a flat film, and that it can, therefore, carry a heavier load for any given size.

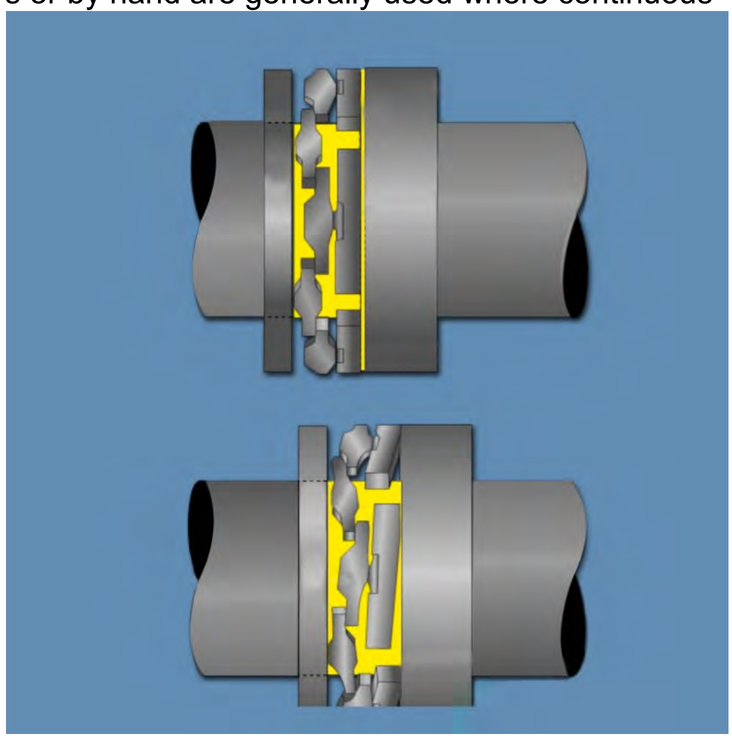

Figure 22-11 — Pivoted-shoe thrust bearing.

Journal Bearings

Each babbitted bearing shell of the reduction gear may be considered as having a pressure bearing half and a non-pressure bearing half. The non-pressure bearing half has a radial scribe line at one end of the geometric center. The pressure bearing half has three radial scribe lines at one end. The central scribe is at the geometric center, and the additional scribes on either side of the central scribe are at an angle of 45°. These scribes are placed by the manufacturer. The crown thickness of each shell at these scribe points is measured with a micrometer, usually 1 1/4 inches from the end of the shell. Such measurements are taken during the initial alignment by the manufacturer. They are stenciled adjacent to each scribe line to be used as constants for future alignment checks. In this way, the amount of wear can always be determined, whether the wear is against the upper or lower half of the shell.

Some older ships are not equipped to check alignment by the crown-thickness and proof-staff methods. On these ships, the gears are first checked for alignment by measuring the percentage of tooth contact in accordance with NSTM, Chapter 241.

After alignment is established, remove and mark the bearings. Measure the crown thickness of the bearing and stencil the measurement adjacent to each scribe line. Measure subsequent bearing wear by using the crown-thickness method based on the constants as stenciled.

The amount of bearing clearance allowed should not be great enough to allow incorrect gear tooth contact. The designed bearing clearances are given in the manufacturer’s technical manual. These clearances are also given in the blueprints for the main reduction gear. The maximum allowable clearance can be found in NSTM, Chapter 241.

Replacing bearings in the main reduction gear is a major undertaking. When a casualty (such as the loss of lube oil) occurs, the high-speed pinion shaft bearings are more likely to be wiped than the other main gear bearings. These high-speed pinion shafts are coupled to the high pressure and low pressure diesel engines. They will have a higher rotary speed than other shafts in the reduction gear. If the bearings are inspected, the high-speed pinion bearings should be checked first. If these bearings are not wiped, it is safe to assume that the bearings that rotate at lower speeds are not wiped. If you make repairs, first study the manufacturer’s technical manual and the blueprints for the main reduction gear. As an Engineman, you should be able to decide whether the repair work should be attempted. You should also have a clear understanding of the construction details and repair procedures before starting a repair job. The factors to be considered are location of the ship, available repair facilities, available repair parts, and the operating schedule of the ship.

In making repairs, the first step is to engage the turning gear and set the brake to ensure that the shaft will not turn while repairs are being made. Pump all oil out of the main sump tank. Store the oil in a clean settling or storage tank until it is ready for use again. Next, lift a section of the reduction gear cover by using chain falls and wire slings. When the gear cover is moved out of the way, remove the bearing cover. Next, turn the bearing so that the bearing split is on the horizontal plane and the top half of the bearing can be lifted off. The gear shaft must be supported when the bottom half of the bearing is removed. Roll a dummy bearing in while the lower half is rolled out. The dummy bearing supports the weight of the shaft and keeps the shaft in position. Take special precautions to prevent the shaft from being turned or lifted, which may allow the gear teeth to become unmeshed. If the gear teeth become unmeshed and are not match-marked, a complicated and detailed procedure must be followed to reassemble and time the gears. The setting up of the locked-train gear system is done at the factory and at shipyards.

If the bearing has excessive clearance, is badly wiped, or is heavily scored, examine other representative bearings to determine the extent of the damage. Replace all bearings on that particular shaft to maintain correct gear alignment.

To replace a bearing, proceed as follows:

1. Review the maintenance history of the reduction gears to determine if special bearings are necessary.
2. Measure the diameter of the journal (with a micrometer) and compare the present readings with the original readings, as recorded.
3. Check the crown thicknesses of installed and replacement bearings and compare readings. If scraping is required for the replacement bearing, use a full-sized mandrel and Prussian blue to check the work. Shaft parallelism must be maintained.

4. To maintain shaft parallelism, ensure that bearings on the ends of gear or pinion shafts do not differ more than 0.002 inch.
5. When a spare bearing is installed or a damaged bearing is scraped to maintain correct tooth contact, stamp the crown thickness on the bearing shell.
6. Use dowels between the bearing halves to locate the bearings in the upper casing. Upper and lower bearing halves must be mated parts. Interchanging of upper and lower bearing halves is prohibited.
7. Examine the condition of the journal whenever bearings are removed. If the surface of the journal is slightly scored, it must be stoned very lightly and polished. Only experienced personnel should stone a journal. Always oil a journal before rolling in a new bearing.

NOTE

If journals are badly scored, they may be ground undersize or restored to design diameter by chrome plating. If a journal is ground undersize, it might be necessary to provide undersize bearings. This should be done only by a shipyard and in accordance with NAVSEA instructions. The new journal diameters and bearing clearances must be recorded.

When installing a spare bearing, make sure it is well oiled; then, roll the lower half into position, removing the dummy bearing. Place the upper half in position, and then shift the complete bearing to its proper position. Ensure that the dowels are in place and that the bearing assembly is in its required position, in accordance with the manufacturer's instructions. Lower the bearing cap into position and securely bolt it down.

Before the gear cover is lowered into position, make a careful inspection to see that the inside of the gear installation is free of all dirt, tools, rags, and other foreign matter that would be harmful to the gears. After the gear cover is lowered into position and bolted down, pump the lube oil to the sump. Before the oil is circulated through the system, place muslin bags in oil strainers. The muslin bags will trap any dirt or foreign matter that is too fine to be stopped by the strainer. Start a lube oil service pump to circulate oil through the system. Change the muslin bags at 30-minute intervals until they no longer pick up dirt. Then, you can engage and start the turning gear.

Thrust Bearings

A thrust bearing is a particular type of rotary bearing. Like other bearings, they permit rotation between parts, but they are designed to support a high axial load while performing this function.

Always check the end play for any six- or eight-shoe thrust bearing with the top half of the bearing bolted down solidly; otherwise, the base rings will tilt because of the freedom of movement given the leveling plates, and you will get a false reading.

Keep and refer to a record of the main thrust readings when you check the main thrust bearing. Over a period of years, the normal wear of a pivoted-shoe thrust bearing is negligible. However, when the bearing is new, the leveling plate may settle slightly. If any increase occurs in the end play of a main thrust bearing, inspect the surfaces of the thrust shoes and make necessary repairs.

Some main thrust bearings have a port (in the main thrust bearing cap over the thrust shoes) for inspection purposes. This port has a removable cover of sufficient size to permit the withdrawal of thrust shoes that are in line with it.

The upper leveling plates, upon which the shoes rest, and the lower leveling plates equalize the thrust load among the shoes (*Figure 22-12, frames 1 and 2).* The base ring, which supports the lower leveling plates, holds the plates in place. This ring transmits the thrust on the plates to the ship's structure via housing members, which are bolted to the foundation. Shoe supports (hardened steel buttons or pivots), located in the shoes, separate the shoes and the upper leveling plates. This separation enables the shoe segments to assume the angle required to pivot the shoes against the upper leveling plates. Pins and dowels hold the upper and lower leveling plates in position. This allows ample play between the base ring and the plates to ensure freedom of movement (oscillation only) of the leveling plates. The base ring is kept from turning by its keyed construction, which secures the ring to its housing.

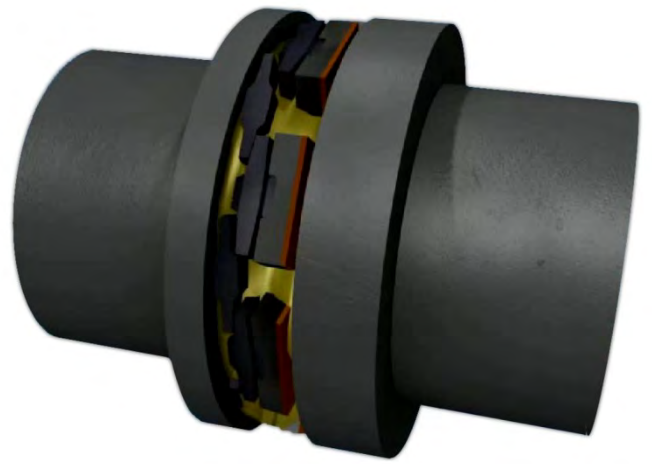

Figure 22-12 — Diagrammatic arrangement of a pivoted-shoe thrust bearing showing oil film.

FACTORS AFFECTING THE OPERATING OF THE REDUCTION GEAR

Lubrication

Proper lubrication of reduction gears is extremely important. Oil at the designated working pressure and temperature must be supplied to the gears at all times while they are being turned over, with or without load. Navy symbol 2190 TEP lubricating oil is used for the propulsion gears as well as for the diesel engines.

Clean, pure oil is essential for long life and successful operation of the gear. Oil must be free from all impurities—especially water, dirt, grit, and metallic particles. Metal flakes, dirt, lint, and fine chips must be removed when new gears are being worn into a working fit or after work on the gearing or lubrication system. Lint or dirt will clog the spray nozzles and damage the gear teeth. Fine metallic particles may not be picked up by the magnets in the lube oil strainers. Dirt may get through the strainers. These may become embedded in the babbitted bearings and eventually score the journals. In addition, the mixture of dirt and metallic particles may erode metal from the gear tooth surfaces.

The solution is clean, purified oil. For this reason, a lube oil purifier is installed in the engine room. It is used to remove water and other impurities from the oil that lubricates the bearings of the main engine diesel engines and the bearing and teeth of the main reduction gears.

Sump Oil Level

Some reduction gears are located directly above the lubricating oil sump tank or in a casing that also serves as the sump. You must be sure that the bull gear wheel will not rotate in the oil. If it does, the churning action will aerate the oil and cause the oil temperature to rise. Oil churning can also prevent full-speed operation of the shaft. This condition can be identified by high bearing temperatures and too much air (bubbles) in the sight-flow glasses. If this occurs, the engines must be slowed or stopped until the excess oil can be removed and normal conditions restored. Many bull gears have an oil exclusion pan. It is fitted at the time of manufacture to ensure against rotation of the gears in the oil. Other reduction gear constructions separate the reduction gears from the main sump completely and have oil return lines from the reduction gear casing to the sump. Ensure the proper oil level in the sump by checking the liquid level indicator. (Some installations may use a dipstick).

Unusual Sounds

A properly operating reduction gear has a certain definite sound. You should be familiar with that sound and investigate any unusual noises. When you hear one, operate the gears with caution until the cause is discovered and remedied.

The following procedures are essential for the proper operation of reduction gears:

- Supply the required amount of oil to the gears and bearings, and keep the lube oil clean and at proper temperatures. If these requirements are met and if the gears are properly aligned, reduction gears should give reliable service for the lifetime of the ship.
- Lock and unlock the shaft in accordance with the engineering operational sequencing system (EOSS).
- Use the motor-driven turning gears to keep the gears and diesel engine rotors rotating slowly during cooling-down periods.
- Investigate noises and vibrations and take corrective action.
- Inspect gears in accordance with the planned maintenance system (PMS).

Maintenance of a Main Reduction Gear

Under normal conditions, a shipyard should handle major repairs and major items of maintenance on a main reduction gear. When a ship is deployed overseas and at other times when shipyard facilities are not available, emergency repairs should be done, if possible, by a repair ship or an advanced base. Inspections, checks, and minor repairs should be done by the ship's force.

REDUCTION GEAR SECURITY, SAFETY, AND INSPECTION

All inspection covers, whether hinged, pinned, or bolted, should be secured by locks of a high-security type. The custody of keys for these locks is the responsibility of the Engineering Officer. Plates and panels secured with more than 12 bolts or nuts need not be locked. Piping and fixtures need not be locked but should be secured to prevent unauthorized access to gear internals. You should carry out an ongoing program of security training of engineering personnel. Encourage all hands to recognize and report instances that may lead to unauthorized entry into the main reduction gear. For detailed information on ways to improve reduction gear security, refer to NSTM, Chapter 241.

Reduction Gear Casing Opening and Access

Access into reduction gear casings is strictly controlled. In most cases, the Engineering Officer must be present before any inspection or work on or around the reduction gears is done where access is possible. Access is not limited to an opening of the inspection covers. Work on oil bubble repair or flexible couplings or gear vents on some ships allow access to the gears. The NSTM, Chapter 241 lists the requirements, suggested procedures, and precautions for accessing control to main reduction gearing. The maintenance requirements cards (MRCs) are another reference for maintenance on reduction gearing where access is required.

The following procedures are examples of the rules that may be in force when reduction gear access is required. Actual approved procedures will differ somewhat, but the basic rules and concepts will apply.

- Usually, a controlled area will be set up around the work area. This area may also require the use of some type of tent to surround and cover the access being opened. This tent will protect against material dropped from above or thrown into the area.

- Flashlights, wrenches, inspection mirrors, and other tools should be securely tied with a lanyard to either a person or a fixed object. Items with potentially loose parts, such as a flashlight, should be taped so that the parts will not fall free if the item comes apart.
- Personnel entering the controlled area should not have items such as watches, rings, necklaces, arm bracelets, or unsecured eyeglasses on their persons. Pockets should be empty and taped.
- This area is required to have a logbook to record all personnel and equipment entering the controlled area. It is used for to keep track of who had access to the area as a legal record, and to record what equipment entered to ensure there is nothing left behind after the reduction gear is secured.
- T-shirts or plain, pocketless undershirts should be worn in the area, or all buttons and pockets on the shirts should be securely taped.

A watch should be posted at the entrance to the controlled area at all times that reduction gear access is in progress. This is to ensure that procedures are followed and to limit access to the area to those persons designated by the Engineering Officer. These procedures (and those similar) are necessary. Reduction gear casualties can be caused when even a small piece of foreign material gets into the wrong place. You learned some of these reasons in the discussion of reduction gear construction.

Safety Precautions

Anyone who works around a main reduction gear should understand and use the following safety precautions:

- If churning or emulsification of oil and water occurs in the gear case, slow down or stop the gear until the defect is remedied.
- If the supply of oil to the gear fails, stop the gear until the cause can be located and remedied.
- When bearings have been overheated, do not operate the gear, except in extreme emergencies, until bearings have been examined and defects remedied.
- If excessive flaking of metal from the gear teeth occurs, do not adjust the gears, except in an emergency, until the cause has been corrected.
- Investigate unusual noises at once, and operate the gear cautiously until the cause for the noise has been discovered and corrected.
- Do not remove any inspection plate, connection, fitting, or cover that permits access to the gear casing without specific authorization by the Engineering Officer.
- Keep the immediate vicinity of an inspection plate free from paint and dirt.
- When gear cases are open, take precautions to prevent the entry of foreign matter. Never leave the openings unattended unless satisfactory temporary closures have been installed.
- Inspect lifting devices carefully before using them, and do not overload them.
- When ships are anchored in localities where there are strong currents or tides, lock the main shaft.
- When the rotation of the propellers may cause injury to a diver over the side or damage to the equipment, lock the propeller shafts.
- When a ship is being towed, lock the propellers unless it is permissible and advantageous to allow the shafts to trail with the movement of the ship.

- When a shaft is allowed to turn or trail, the lubrication system must be in operation. In addition, keep a careful watch on the temperature within the low pressure diesel engine casing to see that windage temperatures cannot build up to a dangerous degree. This can be controlled either by the speed of the ship or by maintaining vacuum in the main condenser.

> ⚠ **CAUTION** ⚠
>
> Any disassembly and assembly of a large reduction gear should be done in a shipyard under the guidance of trained personnel or manufacturers' representatives. When the ship is not in a shipyard, permission to open any portion of the gear casing or the access openings, plugs, piping, or attached fixtures must come from the ship's officers.

- Bring the main propeller shaft to a complete stop before engaging the clutch of the turning gear. (If the shaft is turning, it will cause considerable damage to the turning gear.) When the turning gear is engaged, set the brake quickly and securely to prevent the shaft from turning and damaging the turning gear.
- When a main shaft is to be unlocked, take precautions to disengage the turning gear clutch before releasing the brake. If the brake is released first, the main shaft may begin to rotate and cause injury to the turning gear and to personnel.
- In an emergency, when the ship is steaming at a high speed, you can stop the main shaft and hold it stationary by the astern diesel engine until the ship has slowed down to a speed at which you can safely lock the main shaft.
- When there is a limiting maximum safe speed at which a ship can steam with a locked propeller shaft, know this speed and do not exceed it.
- Before the turning gear is engaged and started, check to see that the turning gear is properly lubricated. Some ships have a valve in the oil supply line leading to the turning gear. See that a lube oil service pump is in operation and that the proper oil pressure is being supplied to the turning gear before the motor is started.
- Definitely determine that the turning gear has been disengaged before the main engines are turned over.
- While working on or inspecting an open main reduction gear, the person or persons performing the work should not have any article about their person that may accidentally fall into the gear case.
- Tools, lights, and mirrors used to work on or inspect gears, bearings, and so forth, should be lashed and secured to prevent them from being accidentally dropped into the gear case.

Safety Precautions for Bearings

Most bearings are similar in operation. Therefore, these safety precautions apply to all bearings. The following safety precautions help prevent most bearings casualties:

- NEVER use a piece of machinery if the bearings are known to be in poor condition.
- Where possible, be sure that bearings have the proper quality and quantity of lube oil before starting the machinery.

- Be sure the operating temperature of each bearing is not above the specified normal for the particular load and speed conditions. Investigate and report abnormal temperature immediately.
- Remember that rapid heating of the bearing is a danger sign. A bearing that feels hot to the hand after an hour's operation may be all right, but the same heat reached in 10 or 15 minutes indicates trouble.
- Newly installed bearings should be given a run-in period with no load applied.
- Use clean rags (lint free) to clean bearings, shafting, and sumps.
- When you assemble and install bearings with symmetrical halves, take care NOT to place the halves end-to-end or to reverse the assembled bearing in its pedestal. This may cover the lube oil inlet passage.
- Clean out wells of self-lubricated sliding surface bearings at frequent intervals. See that the rings run freely and do not drag.
- Refit or renew a wiped bearing.
- When taking leads, be sure that the bearing halves are set up metal to metal.
- Do not file or machine bearing joints.
- After spotting-in a bearing, be sure that all shavings and dirt are cleaned from the parts.

Inspections

The minimum tests and inspections should be conducted in accordance with the shipboard preventive maintenance program. An example of the requirements is shown on the maintenance index page *(Figure 22-13).* When defects are suspected or operating conditions indicate the necessity, you should make inspections at more frequent intervals.

SYSTEM, SUBSYSTEM, or COMPONENT REDUCTION GEARS						REFERENCE PUBLICATION			
BUREAU CARD CONTROL NO.					MAINTENANCE REQUIREMENT	M.R NO.	RATE REQ'D	MAN HOURS	RELATED MAINT.
MB	ZZZFGE5	35	5025	Q	Inspect the reduction gear including spray nozzles	Q-1	EO MM1 MM3	 1.0 1.0	 None
MB	ZZ2FSC1	65	5290	Q	Measure main shaft thrust clearance	Q-2	EO MM1 MM2	 0.3 0.3	 None
MB	ZZZFGE1	84	5064	S	Inspect and clean oil sump and reduction gear casing	S-1	EO MM1 MM3 2FN	 5.0 6.0 12.0	None
MB	ZZ1FCW4	65	A188	A	Inspect flexible couplings. Measure clearances	A-1	MMC MM1 2FN	2.0 8.0 16.0	None
MB	ZZZFGE5	78	6679	A	Sound and tighten foundation bolts	A-2	FN	1.0	None

Figure 22-13 — Maintenance index page.

Before replacing any cover, connection, or inspection plate that permits access to the gear casing, an officer of the engineering department should make a careful inspection to ensure that no foreign matter has entered, or remains in, the casing. If the work is being done by a repair activity, an officer from that activity must also inspect the gear casing. The inspections and the name of the officer or officers must be entered in the Engineering Log.

Shipyard Overhaul

During shipyard overhauls, the following inspections should be made:

- Inspect condition and clearance of thrust shoes to ensure proper position of gears. Blow out thrusts with dry air after the inspection. Record the readings. Inspect the thrust collar, nut, and locking device.
- If diesel engine coupling inspection has indicated undue wear, check alignment between pinions and diesel engines.
- Pump the oil out of the gear sump and clean the sump internally. Scrape off and remove rust deposits from the sump.
- Inspect turning gear assemblies for proper operation and condition.

Ten-Year Inspection

When conditions warrant or if trouble is suspected, submit a work request to a naval shipyard to perform a 10-year inspection of the main reduction gear. Shipyard personnel should perform the following inspections and related actions:

- Inspect to determine the condition of all bearings, journals, and gear teeth. Record the bearing crown thickness or lead readings of all main pinion and gear bearings.
- Check the intermediate coupling bolts for tightness.
- Take and record alignment readings of the prime mover to the gear. Do this with the ship waterborne and the propulsion plant in the ready-to-operate condition.

NAVSEA authorization is not necessary to lift reduction gear covers. These covers should be lifted when you suspect trouble. However, an open gear case is a serious hazard to the main plant. Through this opening, rags can get in oil lines, and tools can get in gear teeth. These kinds of mistakes have caused serious and expensive casualties that were attributable directly to a lifted gear cover. Before you lift a gear cover, carefully consider the dangers of uncovering the gear against the reasons for suspecting internal trouble. The 10-year inspection may be extended by the type commander when operating conditions indicate that a longer interval between inspections is desirable.

Before Trials

Before a trial, you should make the following inspections, in addition to those which may be directed by proper authority: Open the inspection plates; examine the tooth contact, the condition of teeth, and the operation of the spray nozzles. You should not open gear cases, bearings, and thrusts immediately before trials.

After Trials

After a trial, you should make the following inspections, in addition to those which may be directed by proper authority: Open the inspection plates and examine the tooth contact and the condition of the teeth to note changes that may have occurred during the trials. Running the engines for a few hours at high power will show any possible condition of improper contact or abnormal wear that would not have shown up in months of operation at lower power. Check the clearance of the main thrust bearing.

LUBRICATION OF GEARS AND BEARINGS

Proper lubrication of reduction gears and bearings is of the utmost importance. The correct quantity and quality of lubricating oil must, at all times, be available in the main sump. The oil must be clean, and it must be supplied to the gears and bearings at the pressure and temperature specified by the manufacturer.

Several conditions must be met for proper lubrication of gears and bearings. The lube oil service pump must deliver the proper discharge pressure. All relief valves in the lube oil system must be set to function at their designed pressure. The quantity of oil to each bearing is controlled by an orifice in the supply line; the orifice opening must be in accordance with the manufacturer's instructions, or the supply of oil will be affected. Too small a quantity of oil will cause the bearing to run hot. If too much oil is delivered to the bearing, the excessive pressure may cause the oil to leak at the oil seal rings. Too much oil may also cause a bearing to overheat.

Lube oil must reach the bearings at the proper temperature. If the oil is too cold, one of the effects is insufficient oil flow for cooling purposes. If the oil supply is too hot, some lubricating capacity is lost.

For most main reduction gears, the normal temperature of oil leaving the lube oil cooler should be between 120 and 130 °F. For full power operation, the temperature of the oil leaving the bearings should be between 140 and 160 °F. The maximum temperature rise of oil passing through any gear or bearing, under any operating conditions, should not exceed 50 °F; and the final temperature of the oil leaving the gear or bearing should not exceed 180 °F. This temperature rise and limitation may be determined by installed thermometers or RTEs. Cleanliness of lubricating oil cannot be overstressed. Keep it free from impurities, such as water, grit, metal, and dirt. Take particular care to clean out metal flakes and dirt when new gears are wearing in or when gears have been opened for inspection. Lint or dirt, if left in the system, may clog the oil spray nozzles; keep the spray nozzles open at all times. Spray nozzles must never be altered without the authorization of NAVSEA.

The lube oil strainers cannot trap particles of metal and dirt that are fine enough to pass through the mesh. These fine particles can become embedded in the bearing metal and cause wear on the bearings and journals. These fine abrasive particles passing through the gear teeth act like a lapping compound and remove metal from the teeth.

Main Sump Oil Level

Lubricating oil is supplied to the gears from the main engine lubricating system. The system has a connection to each bearing. Nozzles are located so that a constant spray of oil is directed over the gears. This constant spray of oil over the gears lubricates and cools the gears. In reduction gears, the maximum oil level in the sump may reach the bottom of the bull gear. An oil excluding pan is fitted around the bottom of the bull gear to ensure that the bull gear does not dip into the oil.

If the gear dips into the oil, the churning action of the gear will produce foam. Under normal conditions, only a small quantity of oil comes in contact with the bull gear; therefore, no dangerous vibration and no churning effect will occur. Oil from the gears is swept out of the pan by the bull gear and drained into the sump. A drain hole on the bottom of the pan is located to drain any accumulated water when the ship is on an even keel. When there is too much oil in the sump, the gear will churn and aerate the oil. Because the aerated oil is a poor lubricant, there will be an increase in engine and oil temperature. If this occurs, the engines must be slowed or stopped until the excess oil can be removed and normal conditions restored. Make routine checks to see that the lubricating oil is maintained at the proper level. Any sudden loss or gain in the amount of oil in the main sump should be investigated immediately.

Bearing Maintenance

Under normal conditions, the main reduction gear bearings and gears will operate for an indefinite period. Enough spares are carried aboard to replace 50% of the number of bearings in the main reduction gear. Usually, each bearing is interchangeable for the starboard or port installation. Check the manufacturer's technical manual to determine interchangeability of gear bearings. Special tools and equipment needed to lift main reduction gear covers, to handle the quill shaft when removing bearings from it, and to take required readings and measurements are normally carried aboard. These items are carried in case emergency repairs have to be made by repair ships or bases not required to carry these items. The manufacturer's technical manual is the best source of information concerning repairs and maintenance of any specific reduction gear installation.

Effects of Acid and Water in Oil

Water and acid in oil are extremely dangerous. Test oil frequently for water and at regular periods for acid. Even a small amount of water in oil can cause pitting and rusting. Freshwater can accumulate because of leaking diesel engine packing glands or from condensation. Where main sump tanks are located at the skin of the ship, saltwater may leak into the lube oil. Saltwater may also enter through leaks in the lube oil cooler. When saltwater is found in a lube oil system, take corrective steps to find and seal off the source of the saltwater. Remove the contaminated oil from the system by flushing with clean oil.

When oil is contaminated with freshwater, adequate purification will prevent an accumulation of water in the oil. However, you must find and eliminate the source of water. Under normal operating conditions, operate the lube oil purifier 12 hours a day while underway. However, if the presence of freshwater is noted, operate the purifier until there is no visual indication of water in the oil and no water is discharged from the purifier. If, with additional purifier operating time, the oil does not clear up, check the purifier for improper operation.

WARNING

Never ignore the presence of saltwater or freshwater in lube oil. Check the system immediately and eliminate the source of contamination.

When the main engines are secured, keep a lube oil pump running and keep the jacking gear engaged and turning until the engines have cooled to approximately room temperature (ambient). While oil is circulating, leave the lube oil cooler in use and operate the purifier. Circulating oil will carry away the heat from the engines, which might otherwise reach the bearings. Turning the engines will prevent the rotors from becoming bowed.

Operating the purifier will eliminate water caused by condensation on the interior of the reduction gear casing.

Ships should take every opportunity to have laboratory tests made of the lube oil. Good engineering practice dictates that this be done every 3 months, or more frequently in unusual conditions. Samples should be tested for water, acid, and sediment content. When the neutralization number exceeds 0.50, replace the lube oil.

Oil Emulsion

With continuous use, the lube oil will increase in acidity. The free fatty acids will form mineral soaps that can form a stable oil and water emulsion. Once the emulsion has formed, the removal of water becomes more difficult. More importantly, the oil loses its lubricating quality, the formation of an oil film becomes impossible, and the oil must be renovated. Emulsified oil will cause wiped bearings and worn gear teeth.

CONTROLLABLE PITCH PROPELLER ARRANGEMENT

Each Controllable Pitch Propeller (CPP) arrangement, starboard and port, consists of an independent CPP with associated mechanical, hydraulic, and electronic pitch control systems *(Figure 22-14).* The CPP controls the position of the propeller blades. Blade pitch control permits a full range of ahead or astern thrust, including no thrust in the zero pitch position, while the main propulsion machinery operates at a constant speed, thus improving overall plant efficiency.

The major components of each CPP are (1) the electrohydraulic servo control assembly, (2) the oil distribution (OD) box, (3) the hydraulic oil power module (HOPM) assembly, (4) the valve rod assembly, (5) the hub assembly, and (6) the prairie air system assembly, which is used to mask propeller sounds. Each of these will be described in the following sections:

1. The electrohydraulic servo control assembly, located in each engine room, is in an enclosure that electronically controls, monitors, and actuates the display of propeller pitch settings and changes.
2. The OD box and its major components direct high pressure (HP) oil to and from the hub assembly through the propeller shaft, operate the valve rod assembly, and provide passage for the prairie air tubing.
3. The HOPM provides low pressure (LP) control oil to the OD box to operate the valve rod actuating mechanism and provides HP oil to the OD box to operate the hub piston mechanism. The HOPM is a self-contained, resiliently mounted unit consisting of various hydraulic components installed in a welded structure. The HOPM is connected by hydraulic piping to the sump tank, standby screw pump (gear driven), and manifold block assembly. The main components of the HOPM are the alternating current (ac) motor, steel flex coupling, screw pump (main pump), pressure control assembly, suction strainer, oil filters, sensors, and indicators.
4. The valve rod assembly provides passage for the HP hydraulic oil from the OD box to the hub assembly, and it also translates hydraulic pitch control commands in the OD box into pitch changes by the blade turning mechanism in the hub assembly.
5. The hub assembly is attached to the aft end of each propulsion shaft. Five propeller blades are bolted symmetrically to each hub. A blade port cover and blade seal ring prevent seawater from entering the hub around each blade. Each hub

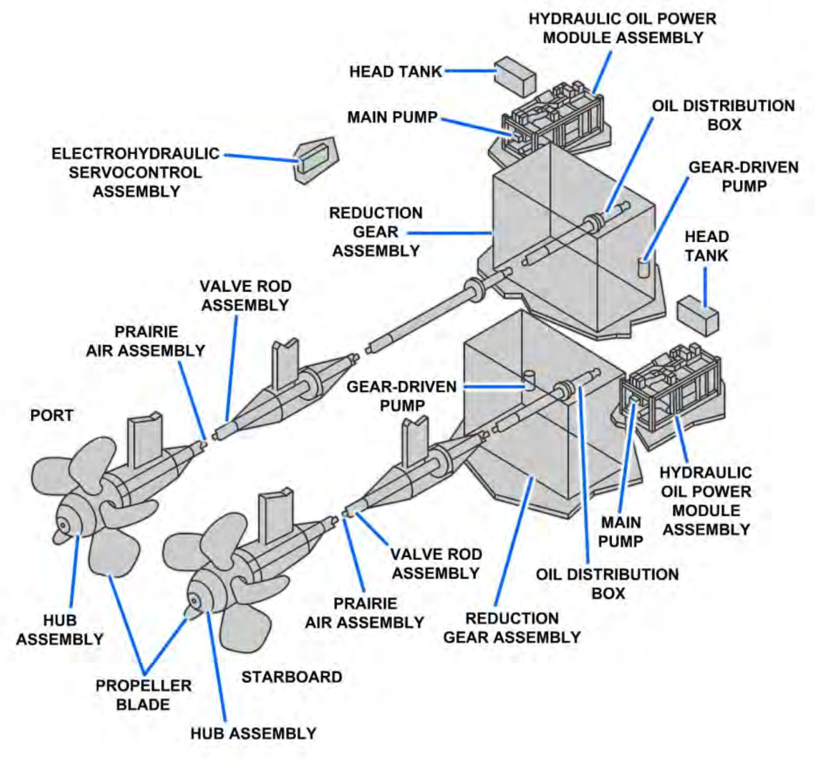

Figure 22-14 — Controllable pitch propeller (CPP).

contains a piston, piston rod assembly, piston nut, and propeller blade turning mechanism to change pitch and hold the pitch position of the blade. The piston and the aft end of the piston rod are located in the hub cone. The forward end of the piston rod is attached to the crosshead of the blade turning mechanism. These components move axially when HP oil is directed to either the forward or aft face of the hub piston. Five sliding blocks are fitted into the machined slots in the crosshead. An eccentric pin on the underside of each crankpin ring fits into the hole in the sliding block. Two dowel pins transmit torque from the crankpin ring to the blade, and eight blade bolts attach the blade to the crankpin ring.

6. The prairie air assembly tubing enters the CPP through the end cover at the forward end of the OD box. The tubing passes through the center of the OD box, and then through the bore of the valve rod to the propeller hub. The tubing consists of fabricated sections of seamless steel piping joined by threads and setscrews.

Shaft Alignment

Under normal conditions all alignment inspections and checks, plus the necessary repairs, are done by naval shipyards. Incorrect alignment will be indicated by abnormal vibration, unusual noise, and wear of the flexible couplings or main reduction gears. When misalignment is indicated, a detailed inspection should be made by shipyard personnel.

⚠ CAUTION ⚠

Any disassembly and assembly of a large reduction gear should be done in a shipyard under the guidance of trained personnel or manufacturers' representatives. When the ship is not in a shipyard, permission to open any portion of the gear casing or the access openings, plugs, piping, or attached fixtures must come from the ship's officers.

PREPARATION TO GET UNDERWAY

To prevent misunderstanding and confusion in preparing to get underway, use EOSS. It provides a convenient and simple procedure for checking the required steps in proper sequence. It ensures that no important step is overlooked or forgotten. Some of the most important steps are listed below:

1. Inspect the sump or supply to ensure there is enough oil for system operation.
2. Inspect for water in the lube oil at the bottom of the lube oil sump.
3. Determine if circulating water is available at the lube oil cooler.
4. The lube oil in the sump should be about 90 °F when you start the lube oil pumps. It may be necessary to heat the oil before starting the lube oil pump if it is below this temperature.
5. Make sure that oil is flowing freely at correct pressure to all gear shaft bearings, spray nozzles, and line shaft components. When the oil is flowing at operating temperature to all bearings and sprays, check the operating level in the sump or supply tank.

When the ship is underway, observe all oil pressures and temperatures to see that they remain normal. Record these pressures and temperatures hourly. Check the oil level in the sump frequently; if the level changes, check for leaks. Take and post oil samples frequently. For more information on oil sampling, purification, and cleaning procedures, refers to NSTM, Chapter 262.

Checking Thrust While Underway

The simplest means of checking end play is to use a dial indicator on any accessible flange on the main shaft while the engines are going slowly ahead and then astern. This can usually be done when the ship is maneuvering to approach a pier or an anchorage. The speeds should be slow enough to avoid adding deflections of bearings parts and housing to the actual end play. However, the speed should be sufficient enough to ensure that the full end play is actually taken up.

Some ships have the main thrust bearing located at the forward end of the main reduction gear and constructed as a component part of the gear. Use a spring-loaded pin gauge (located in the bearing end cover housing) and a micrometer depth gauge to measure the end play. Remove the pin gauge cover and place the anvil of the depth gauge on the machined surface of the pin gauge housing. Carefully turn the micrometer so that the spindle pushes the installed pin against the main shaft. Take up all slack, but do not use excessive force, as it will lift the micrometer anvil from the machined surface.

Take another reading with the main shaft operating in the opposite direction. The difference between the two readings is the end play. It is always good practice to take more than one set of readings to ensure that the total end play was taken up and that the readings are accurate.

Noises and Vibrations

Once the ship is underway, you will need to be alert for any unusual noises and vibrations. On steam diesel engine-driven ships, noises may occur at low speeds, when maneuvering, or when passing through shallow water. Generally, these noises do not result from any defect in the propulsion machinery and will not occur during normal operation. A rumbling sound that occurs at low-shaft revolutions per minute (rpm) is generally caused by the low pressure diesel engine gearing floating through its backlash. The rumbling and thumping noises that may occur during maneuvering or during operation in shallow water are caused by vibrations initiated by the propeller. These noises are characteristic only of some ships and should be regarded as normal sounds for these units. These sounds will disappear with a change of propeller rpm or when the other causes mentioned are no longer present. These noises can usually be noticed in destroyers when the ship is backing, especially in choppy seas or in ground swells.

Unusual Noises

A properly operating reduction gear has a definite sound. An experienced watch stander should be able to recognize these sounds at different speeds and under various operating conditions.

If any abnormal sounds occur, investigate immediately. Your investigation should depend on how you interpret the sound or noise.

The lube oil temperature and pressure may or may not help you determine the reasons for the abnormal sounds. A badly wiped bearing may be indicated by a rapid rise in oil temperature for the individual bearing. A certain sound or noise may indicate misalignment or improper meshing of the gears. If unusual sounds are caused by misalignment of gears or foreign matter passing through the gear teeth, stop the shaft and make a thorough investigation before the gears are operated again.

For a wiped bearing or any other bearing casualty that has caused a very high temperature, follow this procedure: If the temperature of the lube oil leaving any bearing has exceeded the permissible limits, slow or stop the unit, and inspect the bearing for wear. The bearing may be wiped only a small amount, and the shaft may be operated at a reduced speed until the tactical situation allows sufficient time to inspect the bearing.

Vibration

The most common causes of vibration in a main reduction gear are faulty alignment, bent shafting, damaged propellers, and improper balance.

A gradual increase in the vibration in a main reduction gear that has been operating satisfactorily for a long period of time can usually be traced to a cause outside of the reduction gears.

The diesel engine rotors, rather than the gears, are more likely to be out of balance.

When reduction gears are built, the gears are carefully balanced (both statically and dynamically). A small amount of unbalance in the gears will cause unusual noise, vibration, and abnormal wear of bearings.

When the ship has been damaged, vibration of the main reduction gear installation may be caused by misalignment of the diesel engine, the main shafting, the main shaft bearings, or the main reduction gear foundation. When vibration occurs within the main reduction gear, damage to the propeller should be one of the first possible causes to be considered. The vulnerable position of the propellers makes them more liable to damage than other parts of the plant. Bent or broken propeller blades will transmit vibration to the main reduction gear. Propellers can also become fouled with line or cable, which will cause the gears to vibrate. No reduction gear vibration is too trivial to overlook. Always make a complete investigation.

> ⚠ **CAUTION** ⚠
>
> During drills, the shaft should not be locked more than 5 minutes, if possible. The ahead throttle should NEVER be opened when the turning gear is engaged. The torque produced by the ahead engines is in the same direction as the torque of the locked shaft; to open the ahead throttle would result in damage to the turning gear.

Locking and Unlocking the Main Shaft

There may be times when you need to stop and lock the main propeller shaft for an emergency or casualty. It may be necessary to stop the shaft in these conditions to prevent damage to the machinery while you resolve the problem. The best way to lock a propeller shaft while the ship is underway is to wait for the shaft to stop, engage the turning gear, and then apply the brake.

Locking the Main Shaft

Engine-room personnel should be trained through drills to safely lock and unlock the main shaft. Each steaming watch should have enough trained personnel available for this purpose.

The maximum safe operating speed of a ship with a locked shaft can be found in the manufacturer’s technical manual. Additional information on the safe maximum speed that your ship can steam with a locked shaft can be found in NSTM, Chapter 241.

Unlocking the Main Shaft

If practical, the simplest way to unlock the shaft is to stop the ship, release the turning gear and brake, and warm the diesel engines. If the shaft has been locked for 5 minutes or more, the diesel engine rotors may have become bowed, and special precautions are recommended. Before the shaft is turned, station personnel at the diesel engines to check for unusual noises and vibration. If, when the propeller starts to turn, vibration indicates a bowed rotor, the ship’s speed should be reduced to the point that you notice little or no diesel engine vibration. Maintain this speed until the rotor is straightened. When the shaft is operated at that speed, the steam passing through the ahead throttle will warm the rotor and help straighten it. You can lower the main condenser vacuum to add additional heat to the diesel engines; this will increase the exhaust pressure and temperature. As the vibration decreases, increase the shaft speed slowly and continue to check for vibration. The diesel engine is not ready for normal operation until vibration has disappeared at all possible speeds.

Jacking on a Shaft Flange

Jacking on a shaft flange is not practical to measure the end play while the engine is running. The alternative is to jack the shaft (while it is still warm) fore and aft at some convenient main shaft flange. Mount a dial indicator on a rigid support, convenient to some main shaft flange, and jack the shaft forward and then astern. Make certain that the shaft movement is free, but do not use too great a force; excessive force might cause deflections of metal parts to be added to the actual end play. The main difficulty in using the jacking method is finding suitable supports where no structural damage will be done.

SUMMARY

This chapter has given you an overview of main reduction gears. It is not intended as a substitute for information in operation and maintenance manuals. We have referred to two NSTM’s and the maintenance card for reference where it was appropriate.

You were introduced to the types of reduction gears and their operations. You were given information on lubricating, getting underway, checking for unusual noises, and some of the procedures used to maintain the gears and their related parts. Last, you were given some pointers on reduction gear security and safety precautions.

If some of these areas are not as clear as they should be to you, review them now to address the gaps in your knowledge.

End of Chapter 22

Reduction Gears and Related Equipment

Review Questions

22-1. In reference to reduction gears, the term axial float has what meaning?

- A. The gears are not subject to excessive tooth loads due to mismatch of the journal bearing halves.
- B. The gears are double-helical, and axial thrust is eliminated.
- C. The gears are capable of free motion, neither supporting nor supported by other gears radially.
- D. The gears are capable of free motion, neither supporting nor supported by other gears axially.

22-2. What is the term for play between the unloaded surfaces of the teeth in mesh on the pitch circle?

- A. Spotting
- B. Wear
- C. Backlash
- D. Contour

22-3. What is the purpose of the reduction gear?

- A. To change rotary motion into linear action
- B. To reduce high speed to low speed
- C. To minimize thrust on the main diesel engines
- D. To transmit thrust from the main shaft to the ship's hull

22-4. What is essential for the long life span of the reduction gear?

- A. Low speed
- B. Clean lubricating oil
- C. Programming
- D. Proper shifting

22-5. How does the operator keep the reduction gear and the diesel engine rotating slowly during cool down period?

- A. Applying the clutch
- B. Applying the brakes
- C. Using the motor-driven turning gear
- D. Backing down the engine speed

22-6. Who has the custody of and responsibility for the reduction gear keys?

- A. Commanding Officer (CO)
- B. Type Commander (TYCOM)
- C. Main Propulsion Assistant (MPA)
- D. Engineering Officer

22-7. In what Naval Ship's Technical Manual (NSTM) Chapter can you find the list of requirements, suggested procedures, and precautions for accessing control to the main reduction gear?

A. 115
B. 187
C. 241
D. 302

22-8. What must you ensure has been done before engaging and starting the turning gear?

A. Plug it in
B. Lubricate properly
C. Align cooling
D. Secure heater

22-9. During the 10-year inspection, shipyard personnel perform which of the following inspections?

A. Lead reading on gear bearing
B. Lead reading on journals
C. Lead reading on gear teeth
D. Lead reading on gear thickness

22-10. What component in the main reduction gear provides a constant spray of lubricating oil that is directed over the gears?

A. Nozzle
B. Spray plate
C. Spray gun
D. Spray wheel

22-11. What component electronically controls, monitors, and actuates the display of the propellers pitch settings and changes?

A. Oil distribution (OD) box
B. Hydraulic oil power module (HOPM) assembly
C. Electrohydraulic servo control assembly
D. Hub assembly

22-12. What tool should you use to measure end play?

A. Dial indicator
B. Level
C. Micrometer
D. Torque wrench

22-13. What is the most common cause of vibration in a main reduction gear?

A. Damaged propeller
B. Damaged diesel engine
C. Faulty lubricating oil supply
D. Incorrect lubricating oil

RATE TRAINING MANUAL – User Update

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CHAPTER 23

ENGINE PERFORMANCE AND EFFICIENCY

Your prime concern as an engineman is to keep the machinery for which you are responsible operating in the most efficient manner possible. From your past experience and training, you know that engine efficiency and performance depend upon much more than just operating the throttle and changing oil at prescribed intervals.

To understand the various factors that influence engine performance and efficiency, a thorough knowledge of the internal combustion process is necessary. Once the combustion process is understood, it will be much easier for you to appreciate the part played by such factors as engine design, engine operating conditions, fuel characteristics, fuel injection, ignition, pressures and temperatures, and compression ratios. This chapter provides some of the information necessary for a better understanding of the many factors that affect engine performance and efficiency. As an Engineman, you will be able to gain complete understanding of such factors only through continued study and practical experience.

You should know how the power which an engine can develop is limited by such factors as the mean effective pressure, the length of piston stroke, the cylinder bore, and the engine speed. You must also know how these factors are used in determining the power developed by an engine.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. Explain why engine performance is important.
2. Explain why engine efficiency is important.

ENGINE PERFORMANCE

In addition to mechanical difficulties, any engine performance may be affected by other causes, such as engine design and operator's performance. A comparison of the principal conditions which influence the performance of internal combustion engines is given in *Table 23-1.*

> **NOTE**
> The performance conditions for the two types of internal combustion engines (diesel and gasoline) are somewhat similar, except for some differences due to factors dealing with fuel and ignition.

Table 23-1 — Factors That Influence Engine Performance

Factors	Diesel Engines	Gasoline Engines
1. Fuel characteristics	X	X
2. Compression ratio	X	X
3. Engine operating conditions		
Combustion chamber design	X	X
Valve arrangements	X	X
Size of valves	X	X
Manifold arrangements	X	X
Hot spots (presence/absence)	X	X
Location of spark plugs		X
Number of spark plugs		X
4. Pressure and temperature of air in the engine cylinder at start of compression	X	
5. Pressure/temperature of the charge in the engine cylinder at the start of compression		X

Power Limitations

The design of an engine limits the amount of power that an engine can develop. Other limiting factors are the mean effective pressure, the length of stroke, the cylinder bore, and the number of revolutions per minute (rpm) (piston speed) of the engine. The latter, piston speed, is limited by the frictional heat and by the inertia of the moving parts.

You must learn how heat losses, efficiency of combustion, volumetric efficiency, and the proper mixing of fuel and air limit the power which a given engine cylinder can develop. You must become familiar with the factors which cause overloading of an engine and unbalance between engine cylinders. You should know the symptoms, causes, and effects of cylinder load unbalance and the steps that are necessary to maintain an equal load on each cylinder.

You must know what is meant by engine efficiency and know how the various types of efficiencies and losses are used in analyzing the internal combustion process. You must also be familiar with those factors which may cause the efficiencies to increase or decrease, and with the ways these variations affect engine performance.

Mean Effective Pressure (MEP)

The mean effective pressure (MEP) is the average pressure exerted on the piston during each power stroke, and is determined from a formula or by means of a planimeter. There are two kinds of MEP: indicated mean effective pressure (IMEP), which is developed in the cylinder and can be measured; and brake mean effective pressure (BMEP), which is computed from the brake horsepower (bhp) delivered by the engine.

Length of Stroke

The distance a piston travels between top dead center (TDC) and bottom dead center (BDC) is known as the length of stroke. This distance is one of the factors that determine the piston speed. In some modern diesel engines, piston speeds may reach about 1600 feet per minute (fpm).

Cylinder bore is used to identify the diameter of the cylinder. The cylinder bore is the area of the piston crown that pressure acts on to create the driving force. This pressure is calculated and expressed for an area of one square inch as pounds per square inch (psi). The ratio of length of stroke to cylinder bore is fixed in engine design; in most slow speed engines, the stroke is greater than the bore.

$$A = \frac{1}{2}bh$$

Revolutions Per Minute (rpm)

Revolutions per minute (rpm) are the speed at which the crankshaft rotates. Since the piston is connected to the shaft, the rpm, along with the length of the stroke, determine piston speed. Since, during each revolution, the piston completes one up-stroke and one down-stroke, piston speed is obtained by multiplying the rpm by twice the length of the stroke. This speed is usually expressed in fpm. If the stroke is 10.5 inches (or 10.5/12 of a foot), and the speed of rotation is 720 rpm, the piston speed is computed as follows:

$$720x2x\frac{10.5}{12} = 1260\ fpm$$

Horsepower (hp) Computation

The power developed by an engine depends upon the type of engine as well as the speed of the engine. A cylinder of a single-acting, 4-stroke cycle engine will produce one power stroke for every two crankshaft revolutions, while a single acting, 2-stroke cycle engine produces one power stroke for each revolution.

Indicated Horsepower (ihp)

The power developed within a cylinder can be calculated by measuring the IMEP and the engine speed. (The rpm of the engine is converted to the number of power strokes per minute). With the bore and stroke known (available in engine manufacturers' technical manuals), the horsepower (hp) can be computed. This power is called indicated horsepower (ihp) because it is obtained from the pressure measured with an engine indicator. Power loss due to friction is not considered in computing ihp.

Using the factors which influence the engine's capacity to develop power, the general or standard formula for calculating ihp is as follows:

$$ihp = \frac{PxLxAxN}{33{,}000}\ \frac{10.5}{12}$$

Where

P = Mean indicated pressure, in psi

L = Length of stroke, in feet

A = Effective area of the piston, in square inches

N = Number of power strokes per minute

33,000 = Unit of power (one horsepower), or foot-pounds per minute.

To illustrate the use of this formula, assume that a 12-cylinder, 2-stroke cycle, single-acting engine has a bore of 8.5 inches and a stroke of 10 inches. Its rated speed is 744 rpm. With the engine running at full load and speed, the IMEP is measured and found to be 105 psi. What is the ihp developed by the engine?

In this case;

$$P = L = \frac{10}{2};$$

$$A = 3.1416\left(\frac{8.5}{2}\right)^2$$

Substituting these amounts in the formula, you have

$$105\,X\,\frac{10}{12}\,X\;3.1416\left(\frac{8.5}{2}\right)^2\,X$$

$$ihp = \frac{744}{33{,}000} = 111.9$$

This amount represents the hp developed in only one cylinder; since there are 12 cylinders in this engine, total horsepower for the engine will equal 12 times 111.9, or approximately 1343.

Brake Horsepower

Brake horsepower (bhp), sometimes called shaft horsepower, is the amount of power available for useful work. Bhp is less than ihp because of the various power losses which occur during engine operation.

To determine the brake or shaft horsepower that is delivered as useful work by an engine, the sum total of all mechanical losses must be deducted from the total ihp.

Cylinder Performance Limitations

The factors which limit the power that a given cylinder can develop are the piston speed and the MEP. The piston speed, as stated before, is limited by the inertia forces set up by the moving parts and by frictional heat. In the case of the MEP, the limiting factors are as follows:

- Heat losses and efficiency of combustion
- Volumetric efficiency (the amount of air charged into the cylinder and the degree of scavenging)
- Mixing of the fuel and air

The limiting MEPs, both BMEP and IMEP, are prescribed by the manufacturer or Naval Sea Systems Command (NAVSEA). They should never be exceeded. In a direct-drive ship, the MEPs developed are determined by the rpm of the power shaft. In electric-drive ships, the hp and BMEP are determined by a computation based on readings from electrical instruments and from generator efficiency.

Cylinder Load Balance

In order to ensure a balanced, smooth operating engine, the general mechanical condition of the engine must be properly maintained so that the power output of the individual cylinders is within the prescribed limits at all loads and speeds. In order to have a balanced load on the engine, each cylinder must produce its share of the total power developed. If the engine is developing its rated full power, or nearly so, and one or more cylinders are producing less than their share, the remainder of the cylinders will become overloaded.

Using the rated speed and bhp, it is possible to determine for each individual cylinder a rated BMEP, which may not be exceeded without overloading the cylinder. Then the cylinder BMEP generally drops to a lower value. The BMEP should never exceed the normal MEP at lower engine speed. Usually, it will be somewhat lower if the engine speed is decreased.

Some engine manufacturers design the fuel systems so that it is impossible to exceed the rated BMEP. This is done by installing a positive stop to limit the maximum throttle or fuel control. This positive stop regulates the maximum amount of fuel that can enter the cylinder and limits the maximum load of the cylinder.

In order to meet emergency situations, engines used by the Navy are generally rated lower than those designed for industrial use. The economical speed for most of the Navy's diesel engines is approximately 90% of the rated speed. For such speed, the best load conditions have been found to be from 70 to 80% of the rated load or output. When an engine is operated at an 80-90 combination (80% of rated load at 90% rated speed) the parts last longer and the engine remains cleaner and in better operating condition.

Diesel engines do not operate well at exceedingly low BMEP such as that occurring at idling speeds. You are well aware that idling an engine tends to gum up parts associated with the combustion spaces. Operating an engine at idling speeds for long periods will result in the necessity for cleaning and overhauling the engine much sooner than when operating at 50 to 100% of load.

Symptoms of Unbalance

Evidence of an unbalanced condition between the cylinders of an engine may be indicated by the following symptoms:

- Black exhaust smoke. When this occurs, it is not always possible to determine immediately whether the entire engine or just one of the cylinders is overloaded. To determine which cylinder is overloaded, you must open the indicator cock on each individual cylinder and check the color of the exhaust.
- High exhaust temperatures. If the temperatures of exhaust gases from individual cylinders become higher than normal, it is an indication of an overload within the cylinder. If the temperature of the gases in the exhaust header becomes higher than usual, it is an indication that all cylinders are probably overloaded. Frequent checks on the pyrometer will indicate whether each cylinder is firing properly and carrying its share of the load. Any sudden change in the exhaust temperature of any cylinder should be investigated immediately. The difference in exhaust temperatures between any two cylinders should not exceed the limits prescribed in the engine manufacturer's technical manual.
- High lubricating oil and cooling water temperatures. If the temperature gages for these systems show an abnormal rise in temperature, an overloaded condition may exist. The causes of the abnormal temperature in these systems should be determined and corrected immediately if engine efficiency is to be maintained.

- Excessive heat. In general, excessive heat in any part of the engine may indicate overloading. An overheated bearing may be the result of an overloaded cylinder; an abnormally hot crankcase may be the result of overloading the engine as a whole.
- Excessive vibration or unusual sound. If all cylinders are not developing an equal amount of power, the forces exerted by individual pistons will be unequal. When this occurs, the unequal forces cause an uneven turning movement to be exerted on the crankshaft, and vibrations are set up. Through experience, you will learn to tell by the vibrations and sound of an engine when a poor distribution of load exists. You should use every opportunity to observe and listen to engines running under all conditions of loading and performance.

Causes of Unbalance

An engine must be kept in excellent mechanical condition to prevent unbalance. A leaky valve or fuel injector, leaky compression rings, or other mechanical difficulties will make it impossible for you to balance the load unless you secure the engine and dismantle at least a part of it.

To obtain equal load distribution between individual cylinders, the clearances, tolerances, and the general condition of all parts that affect the cycle must be maintained so that very little, if any, variation exists between individual cylinders. Unbalance will occur unless the following conditions are as nearly alike as possible for all cylinders:

- Compression pressures
- Fuel injection timing
- Quantity and quality of fuel injected
- Firing pressures
- Valve timing and lift

When unbalance occurs, correction usually involves repair, replacement, or adjustment of the affected part or system. Before any adjustments are made to eliminate unbalance, it must be determined beyond any doubt that the engine is in proper mechanical condition. When an engine is in good mechanical condition, few adjustments will be required. However, after an overhaul in which piston rings or cylinder liners have been renewed, considerable adjustment may be necessary. Until the rings become properly seated, some lubricating oil will leak past the rings into the combustion space. This excess oil will burn in the cylinder, giving an incorrect indication of fuel oil combustion. If the fuel pump is set for normal compression and the rings have not seated properly, the engine will become overloaded. As the compression rises to normal pressures, there will be an increase in the power developed, as well as in the pressure and temperature under which the combustion takes place. Therefore, when an overhaul has been completed, the engine instruments must be carefully watched until the rings are seated and all necessary adjustments are made. Frequent compression tests will serve as a helpful aid in making the necessary adjustments. Unless an engine is so equipped that compression can be readily varied, the engine should be operated under light load until the rings are properly seated.

Effect of Unbalance

From the preceding discussion, it can be readily seen that, in general, the result of unbalance will be overheating of the engine. The clearances established by the engine designer allow for sufficient expansion of the moving parts when the engine is operating at the designed temperatures, but an engine operating at temperatures in excess of those for which it was designed is subject to many casualties. Excessive expansion soon leads to seizure and burning of the engine parts. Should the temperatures in the crankcase rise above the flash point of the lubricating oil vapors, an explosion may result. High temperature may destroy the oil film between adjacent parts, and the resulting increased friction will further increase the temperature.

Since power is directly proportional to the MEP developed in a cylinder, any increase in MEP will cause a corresponding increase in power. If the MEPs in the individual cylinders vary, power will not be evenly distributed among the cylinders. The quality of combustion obtained depends upon the heat content of the fuel. The amount of heat available for power depends upon temperature. Temperature varies directly with pressure. Cylinder load balance is essential if the desired efficiency and performance of an engine is to be obtained. To avoid the harmful effects of overloading and unbalancing of load, the load on an engine should be properly distributed among the working cylinders; neither the cylinder, nor the engine as a whole, should ever be overloaded.

In general, load balance in an engine can be maintained if the following procedures are observed:

1. Maintain the engine in proper mechanical condition.
2. Adjust the fuel system according to the manufacturer's instructions.
3. Operate the engine within the temperature limits specified in appropriate instructions.
4. Keep cylinder temperatures and pressures as evenly distributed as possible.
5. Train yourself to recognize the symptoms of serious engine conditions.

ENGINE EFFICIENCY

Engine efficiency is the amount of power developed as compared to the energy input which is measured by the heating value of the fuel consumed. The term "efficiency" is used to designate the relationship between the result obtained and the effort expended to produce the result.

The term "compression ratio" is frequently used in connection with engine performance. From your study of the principles of internal combustion, you will recall that compression ratio is the ratio of the volume of air above the piston, when the piston is at the BDC position, to the volume of air above the piston when the piston is at the TDC position.

Efficiencies

The principal efficiencies which must be considered in the internal combustion process are cycle, thermal, mechanical, and volumetric.

Cycle Efficiency

The efficiency of any cycle is equal to the output divided by the input. The efficiency of the diesel cycle is considerably higher than the Otto or constant volume cycle because of higher compression ratios and because combustion starts at a higher temperature. In other words, the heat input in a diesel engine is at a higher average temperature. Theoretically, a gasoline engine using the Otto cycle would be more efficient than the diesel engine if equivalent compression ratios could be used. However, engines operating on the Otto cycle cannot use a compression ratio comparable to that of diesel engines because fuel and air are drawn together into the cylinder and compressed. If comparable compression ratios were used, the fuel would fire or detonate before the piston reached the correct firing position.

Since temperature and the amount of heat content which is available for power are proportional to each other, the cycle efficiency is actually computed by measuring the temperature. The specific heat of the mixture in the cylinder is either known or assumed, and when combined with the temperature, the heat can be calculated at any instant.

Thermal Efficiency

Thermal efficiency is the measurement of the efficiency and completeness of combustion of the fuel, or, more specifically, the ratio of the output or work being done by the working substance in the cylinder in a given time to the input or heat energy of the fuel supplied during the same time. Two kinds of thermal efficiency are generally considered for an engine: indicated thermal efficiency and overall thermal efficiency.

Since the work is being done by the gases in the cylinder is called indicated work, the thermal efficiency determined by its use is often called indicated thermal efficiency (ite). If all the potential heat in the fuel could be delivered as work, the thermal efficiency would be 100%. Because of the various losses, however, this percent is not possible in actual installations.

If the amount of fuel injected is known, the total heat content of the injected fuel can be determined from the heating value, or British thermal units (Btu) per pound, of the fuel; and the thermal efficiencies for the engine can then be calculated. From the mechanical equivalent of heat (778 foot-pounds equal 1 Btu and 2545 Btu equal 1([horsepower- hour] hp-hr); the number of foot-pounds of work contained in the fuel can be computed. If the amount of fuel injected is measured over a period of time, the rate at which the heat is put into the engine can be converted into potential power. Then, if the ihp developed by the engine is calculated, as previously explained, the indicated thermal efficiency can be computed by the following expression:

$$ite = \frac{hp\ x\ 2545\ Btu\ per\ hr\ per\ hp}{Rate\ of\ heat\ input\ of\ fuet\ in\ Btu\ per\ hr}\ x\ 100$$

For example, assume that the same engine used as an example in computing ihp consumes 360 pounds (approximately 50 gallons) of fuel per hour, and that the fuel has a value of 19,200 Btu per pound. What is the ite of the engine?

The work done per hour when 1343 ihp are developed is 1343 × 2545 or 3,417,935 Btu. The heat input for the same time is 360 × 19,200 or 6,912,000 Btu. Then, by the above expression, the indicated thermal efficiency is as follows:

$$ite - \frac{1345\ x\ 2545}{360\ x\ 19{,}200}\ x\ 100$$

$$= \frac{3{,}417{,}935}{6{,}912{,}000}\ x\ 100 = 49.2\ \%$$

The other type of thermal efficiency— overall thermal efficiency—considered for an engine is a ratio similar to ite, except that the useful or shaft work (bhp) is used. Therefore, overall efficiency (often called brake thermal efficiency) is computed by the following expression:

Converting these factors into the same units (Btu), the expression is written as power output in Btu divided by fuel input in Btu.

$$Overall\ thermal\ efficiency =$$

$$\frac{bhp}{Heat\ input\ of\ fuel}\ x\ 100$$

For example, if the engine used in the preceding problem delivers 900 bhp (determined by the manufacturer), what is the overall thermal efficiency of the engine?

$$1hp - hr = 2545\ Btu$$

$$900\ bhp\ x\ 2545\ Btu\ per\ hp\ - hr =$$

$$2{,}290{,}000\ Btu\ output\ per\ hr$$

Substituting factors already known, overall thermal efficiency is computed as follows:

$$Overall\ thermal\ efficiency =$$

$$\frac{2{,}290{,}500}{6{,}912{,}000} = 0.331 \text{ or } 33.1\ \%$$

Compression ratio influences the thermal efficiency of an engine. Theoretically, the thermal efficiency increases as the compression ratio is increased. The minimum value of a diesel engine compression ratio is determined by the compression required for starting; this compression is, to a large extent, dependent on the type of fuel used. The maximum value of the compression ratio is not limited by the fuel used, but is limited by the strength of the engine parts and the allowable engine weight per bhp output.

Mechanical Efficiency

This is the rating that shows how much of the power developed by the expansion of the gases in the cylinder is actually delivered as useful power. The factor which has the greatest effect on mechanical efficiency is friction within the engine. The friction between moving parts in an engine remains practically constant throughout the engine's speed range. Therefore, the mechanical efficiency of an engine will be highest when the engine is running at the speed at which maximum bhp is developed. Since power output is bhp, and the maximum horsepower available is ihp, then;

$$Mechanical\ efficiency = bhp$$

$$ihp\ x\ 100$$

During the transmission of ihp through the piston and connecting rod to the crankshaft, the mechanical losses which occur may be due to friction, or they may be due to power absorbed. Friction losses occur because of friction in the various bearings, between piston and piston rings, and between piston rings and the cylinder walls. Power is absorbed by valve and injection mechanisms, and by various auxiliaries, such as the lubricating oil and water circulating pumps and scavenge and supercharge blowers. As a result, the power delivered to the crankshaft and available for doing useful work (bhp) is less than indicated power.

The mechanical losses which affect the efficiency of an engine may be called frictional horsepower (fhp) or the difference between ihp and bhp. The fhp of the engine used in the preceding examples, then, would be 1343 (ihp) – 900 (bhp) = 443 fhp, or 33% of the ihp developed in the cylinders. Then, using the expression for mechanical efficiency, the percentage of power available at the shaft is computed as follows:

$$Mechanical\ efficiency = \frac{900}{1343} = \ 0.67\ or\ 67\ \%$$

When an engine is operating under part load, it has a lower mechanical efficiency than when operating at full load. The explanation for this is that most mechanical losses are almost independent of the load, and therefore, when load decreases, ihp decreases relatively less than bhp. Mechanical efficiency becomes zero when an engine operates at *no* load because then bhp equals zero, but ihp is not zero. In fact, if bhp is zero and the expression for fhp is used, ihp is equal to fhp. To show how mechanical efficiency is lower at part load, assume the engine used in preceding examples is operating at three-fourths load. Brake horsepower at three-fourths load is 900 × 0.75 or 675. Assuming that fhp does not change with load, fhp = 443. The ihp is, by expression, the sum of bhp and fhp.

$$ihp = 675 + 443 = 1118$$

$$Mechanical\ efficiency = \frac{675}{1118} = 0.60, or\ 60\ \%;$$

(This is appreciably lower than the 67% indicated for the engine at full load.)

BMEP is a useful concept when dealing with mechanical efficiency. BMEP can be obtained if the standard expression for computing horsepower (ihp) is applied to bhp instead of ihp and the mean pressure (p) is designated as BMEP.

$$bhp = (bmep) x\ L\ xA\ x\ N$$

$$33{,}000$$

$$or$$

$$33{,}000\ x\ bhp$$

$$bmep = L\ x\ A\ x\ N$$

From the relations between BMEP, bhp, ihp, and mechanical efficiency, by designating indicated mean effective pressure by IMEP in the expression, one can also show:

$$bmep = imep\ x\ mechanical\ efficiency$$

To illustrate this, the BMEP for the engine in preceding examples at full load and three-fourths load is computed as follows:

$$bmep = \frac{33{,}000 \text{ x } \frac{bhp}{12}}{\text{L x A x N}}\ x\ \frac{33{,}000 \text{ x } \frac{900}{12}}{10 \text{ x } 56.14 \text{ x } 744}$$

$$= 70\ psi$$

or

$$bmep = imep\ x\ mechanical\ efficiency$$

$$= 105\ x\ 67, or\ 70\ psi$$

BMEP gives an indication of the load an engine carries, and what the output is for piston replacement. As the BMEP for an engine increases, the engine develops greater horsepower per pound of weight. For a given engine, BMEP changes in direct proportion with the load.

Volumetric Efficiency

The volumetric efficiency of a 4-stroke engine is the relationship between the quantity of intake air and the piston displacement. In other words, volumetric efficiency is the ratio between the charge that actually enters the cylinder and the amount that could enter under ideal conditions. Piston displacement is used since it is difficult to measure the amount of charge that would enter the cylinder under ideal conditions. An engine would have 100% volumetric efficiency if, at atmospheric pressure and normal temperature, an amount of air exactly equal to piston displacement could be drawn into the cylinder. This is not possible, except by supercharging, because the passages through which the air must flow offer a resistance, the force pushing the air into the cylinder is only atmospheric, and the air absorbs heat during the process. Therefore, volumetric efficiency is determined by measuring (with an orifice or venturi-type meter) the amount of air taken in by the engine, converting the amount to volume, and comparing this volume to the piston displacement.

The concept of volumetric efficiency does not apply to 2-stroke cycle engines. Instead, the term "scavenge efficiency" is used. Scavenge efficiency shows how thoroughly the burned gases are removed and the cylinder filled with fresh air. As in the case of a 4-stroke cycle engine, it is desirable that the air supply be sufficiently cool. Scavenge efficiency depends largely upon the arrangement of the exhaust; scavenge air ports, and valves.

Engine Losses

As the heat content of a fuel is transformed into useful work during the combustion process, many different losses take place. These losses can be divided into two general classifications: thermodynamic and mechanical. The net useful work delivered by an engine is the result obtained by deducting the total losses from the heat energy input.

Thermodynamic Losses

Losses of this nature are a result of the following: loss to the cooling and lubricating systems, loss to the surrounding air, loss to the exhaust, and loss due to imperfect combustion.

Heat energy losses from both the cooling water systems and the lubricating oil system are always present. Some heat is conducted through the engine parts and radiated to the atmosphere or picked up by the surrounding air by convection. The effect of these losses varies according to the part of the cycle in which they occur. The heat of the jacket cooling water cannot be taken as a true measure of heat losses, since all this heat is not absorbed by the water. Some heat is lost to the jackets during the compression, combustion, and expansion phases of the cycle; some is lost (to the atmosphere) during the exhaust stroke; and some is absorbed by the walls of the exhaust passages.

Heat losses to the atmosphere through the exhaust are unavoidable. This is because the engine cylinder must be cleared of the hot exhaust gases before the next air intake charge can be made. The heat lost to the exhaust is determined by the temperature within the cylinder when exhaust begins. The amount of fuel injected and the weight of air compressed within the cylinder are the controlling factors. Improper timing of the exhaust valves, whether too early or too late, will result in increased heat losses. If too early, the valve releases the pressure in the cylinder before all the available work is obtained; if too late, the necessary amount of air for complete combustion of the next charge cannot be realized, although a small amount of additional work may be obtained. Proper timing and seating of the valves is essential in order to maintain heat loss to the exhaust at a minimum.

Heat losses due to imperfect or incomplete combustion have a serious effect on the power that can be developed in the cylinder. Because of the short interval of time necessary for the cycle in modern engines, complete combustion is not possible, but heat losses can be kept to a minimum if the engine is kept in proper adjustment. It is often possible to detect incomplete combustion by watching for abnormal exhaust temperatures and changes in the exhaust color, and by being alert for unusual noises in the engine.

Mechanical Losses

There are several kinds of mechanical losses, but all are not present in every engine. The mechanical or friction losses of an engine include bearing friction; piston and piston ring friction; pumping losses caused by operation of water pumps, lubricating pumps, and scavenging air blowers; power required to operate valves; etc. Friction losses cannot be eliminated, but they can be kept to a minimum by maintaining the engine in its best mechanical condition. Bearings, pistons, and piston rings should be properly installed and fitted; shafts must be in alignment; and lubricating and cooling systems should be at their highest operating efficiency.

SUMMARY

This chapter helped you to understand the various factors that influence engine performance and efficiency. A thorough knowledge of the internal combustion process makes it easier for you to appreciate the part played by such factors as engine design, engine operating conditions, fuel characteristics, fuel injection, ignition, pressures and temperatures, and compression ratios.

This chapter provided some of the information necessary to understand the factors that affect engine performance and efficiency. You learned how the power which an engine can develop is limited by such factors as the mean effective pressure, the length of piston stroke, the cylinder bore, and the engine speed. These factors are used in determining the power developed by an engine.

It is important for you to learn how heat losses, efficiency of combustion, volumetric efficiency, and the proper mixing of fuel and air limit the power which a given engine cylinder can develop.

End of Chapter 23

Engine Performance and Efficiency

Review Questions

23-1. What is the area of the piston crown that pressure acts on to create the driving force of the cylinder?

A. Boss
B. Bore
C. Crown
D. Seat

23-2. What is the amount of power available to do useful work?

A. Brake horsepower (bhp)
B. Indicated horsepower (ihp)
C. Actual horsepower (ahp)
D. True horsepower (thp)

23-3. When does the thermal efficiency of a diesel engine increase?

A. As the speed of the diesel engine decreases
B. As the speed of the diesel engine increases
C. As the compression ratio is increased
D. As the compression ratio is decreased

23-4. What is the term for the amount of power developed as compared to the energy input that is measured by the heating value of the fuel consumed?

A. Proficiency
B. Competence
C. Productivity
D. Engine efficiency

23-5. How is the work being done in the cylinder by the gases measured?

A. Actual thermal efficiency (ate)
B. True thermal efficiency (tte)
C. Proficient thermal efficiency (pte)
D. Indicated thermal efficiency (ite)

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CHAPTER 24

ENGINEERING CASUALTY CONTROL

This chapter provides general information on engineering casualty control, a phase of damage control. If a review of damage control principles and related information is necessary, see *Basic Military Requirements,* NAVEDTRA 14325(series); *Military Requirements for Petty Officer 3 & 2,* NAVEDTRA 14504(series); *Fireman,* NAVEDTRA 14104(series); and *Naval Ships' Technical Manual* NSTM*,* Chapter 079. The mission of engineering casualty control is to maintain all engineering services in a state of maximum readiness and reliability. To carry out this mission, engineering personnel must know what actions are necessary to prevent, minimize, and correct any effects of operational and battle casualties on the machinery and the electrical and piping installations of their ship.

The primary objective of casualty control is to maintain a ship in such a condition that it will function effectively as a fighting unit. This requires effective maintenance of propulsion machinery, electrical systems, interior and exterior communications, fire control, electronic services, ship control, firemain supply, and such miscellaneous services as heating, air conditioning, and compressed air. Failure of any of these services will affect a ship's ability to fulfill its primary objective, either directly, by reducing its power, or indirectly, by creating conditions that would lower personnel morale and efficiency.

A secondary objective of casualty control is to minimize personnel casualties and secondary damage to vital machinery. You can find detailed information on casualty control in the *Engineering Casualty Control Manual, Damage Control Book,* and the *Ship's Organization Book,* and the *Ship's Repair Party Manual*. Although these publications vary from ship to ship, they explain the organization and the procedures that must be followed when engineering casualties, damage to the ship, or other emergency conditions occur.

LEARNING OBJECTIVES

When you have completed this chapter, you will be able to do the following:

1. List some of the factors influencing casualty control.
2. Describe how to correct and prevent casualties.
3. Discuss engineroom casualties.
4. Discuss battle casualties.

FACTORS INFLUENCING CASUALTY CONTROL

The basic factors influencing the effectiveness of engineering casualty control are much broader than the immediate actions taken at the time of the casualty. Engineering casualty control efficiency is obtained through a combination of sound design, effective communication careful inspection, thorough plant maintenance (including preventive maintenance), and effective personnel organization and training. Casualty prevention is the most effective form of casualty control.

Design

Design influences the effectiveness of casualty control in two ways: (1) the elimination of weaknesses that may lead to material failure and (2) the installation of alternate or standby equipment for supplying vital services in the event of a casualty to the primary equipment. Both of these factors are considered in the design of naval ships. Each individual plant aboard ship is equipped with duplicate vital auxiliaries, loop systems, and cross connections. All complete propulsion plants are designed to operate as isolated units (split-plant design).

Casualty Control Communications

Casualty control communications are extremely important to the operation and organization of the ship. Without adequate and proper means of communication between the different units, the whole organization of casualty control will fail in its primary objective.

To ensure that sufficient means of communication are available, several different systems are installed aboard ship. The normal means of communication are the battle telephone circuits (sound powered), interstation 2-way systems (intercoms), ship service telephones, ship's loud speaker (1-MC), and voice tubes. Messengers are also used in some situations when other methods of communication are not available or when written reports are required.

The transmission of correct information regarding a casualty and the speed with which the report is made are essential to any method of communication.

It is also essential that control of all communication circuits be established by the controlling station. The circuits must never be allowed to get out of control because of "cross-talk" caused by more than one station operating at the same time and each assuming that it has the priority message. Casualty control communication must be incorporated into casualty control training, since prompt action to notify the control station or engineering control of a casualty must be taken to prevent the development of other casualties, which could be more serious than the original casualty.

Inspection and Maintenance

Inspection and maintenance are vital to successful casualty control, since they minimize the occurrence of casualties due to material failures. Continual and detailed inspections are necessary not only to discover partly damaged parts that may fail at a critical time, but also to eliminate any underlying conditions that may lead to early failure (maladjustment, improper lubrication, corrosion, erosion, and other causes of machinery damage). Particular and continual attention must be paid to symptoms of malfunctioning, such as unusual noises, vibrations, abnormal temperatures, abnormal pressures, and abnormal operating speeds.

Operating personnel should thoroughly familiarize themselves with the specific temperatures, pressures, and operating speeds required for the normal operation of equipment, in order to detect all departures from normal operation.

When a gauge, or other instrument recording the operating conditions of machinery, gives an abnormal reading, the cause must be fully investigated. A spare instrument or a calibration test will quickly indicate whether the abnormal reading is due to instrument error. Any other cause must be traced to its source.

Because of the safety factor commonly incorporated in pumps and similar equipment, considerable loss of capacity can occur before any external evidence is readily apparent. Changes in the operating speeds (from those normal for the existing load) of pressure-governor-controlled equipment should be viewed with suspicion. Variations from lubricating oil temperatures and system pressures indicate either inefficient operation or poor condition of machinery.

When a material failure occurs in any unit, all similar units should be inspected promptly to determine if other similar failures may occur. Prompt inspection will prevent a series of repeated casualties. Strict attention must be paid to the proper lubrication of all equipment. Frequent inspections and samplings must be made to ensure that the correct quantity of the proper lubricant is in the unit. Lube oil samples must be taken daily on all operating auxiliaries. Lube oil samples should be allowed to stand long enough for any water to settle. When auxiliaries have been idle for several hours, particularly overnight, a sufficient sample should be drained from the lowest part of the oil sump to remove all settled water. Replenishment with fresh oil to the normal level should be included in this routine.

Training

Casualty control training must be a continuous step-by-step procedure and should provide for refresher drills. Any realistic simulation of casualties must be preceded by adequate preparation. You and your work center personnel must learn to understand fully the consequences of any error that may be made in handling real or simulated casualties.

The majority of engineering plant casualties can be attributed to watch station personnel lacking knowledge of correct procedures. Often a relatively simple problem, if allowed to compound itself, could ultimately lead to the disabling of the ship. The causes of ineffective casualty control and their prevention are listed as follows:

- Lack of positive control. The engineering officer of the watch (EOOW) must maintain positive control of every situation that arises and must possess thorough knowledge of the correct procedures and systems operation.
- Lack of effective communications. Communications throughout the engineering plant must be maintained at all times. The repeat back technique for watchstanders is the only means of ensuring that communications are received and understood.
- Lack of systems knowledge. Watch personnel are frequently lacking in experience and in knowledge of systems and approaches to casualty control. Watch sections must be familiar with the operation and theory of all vital engineering systems.
- Lack of casualty control assistance. Off watch personnel are not called to assist in casualty control follow-up actions with the result that watchstanders are unable to satisfactorily deal with recovering from a casualty. Off watch personnel must be called to provide requisite expertise and augment assigned watchstanders performing restoration actions.

In the past, the primary emphasis in casualty control training has been speed. However, with the development and implementation of the Engineering Operational Casualty Control (EOCC) portion of the Engineering Operational Sequence System (EOSS), a more methodical and organized approach to casualty control has resulted in increased control, less disabling of a plant, and increased overall safety to the plant and personnel.

To ensure maximum engineering department operational readiness, a ship must be self-sufficient in the conduct of propulsion plant casualty control drills. The management required for such drills involves the establishment of the Engineering Casualty Control Evaluation Team (ECCET) and the preliminary administrative support for the training program.

Engineering Casualty Control Evaluation Team (ECCET)

An ECCET should be developed for each underway watch section, and a sufficient number of personnel should be assigned to evaluate each watch station during the drills.

The Engineer Officer must ensure the development of an accurate, comprehensive drill package adequate to exercise the engineering department in all phases of casualty control procedures. The drill package should contain a complete file of drill scenarios and drill cards for each type of casualty that could reasonably occur to the propulsion plant. The scenarios should contain the drill title, scenario number (if assigned), a general description of the casualty, the method of imposing the drill, the cause (several possible causes should be listed) and estimated time of repair (ETR), cautions to prevent personnel hazards or machinery damage, and any simulations to be used in the drill. The drill cards must give the correct procedure to be followed by each watch team member in the proper sequence for the drill. The purpose of the drill cards is to give the ECCET members ready reference to the proper procedures to be followed. The Engineer Officer must ensure that adequate research is done to ensure the accuracy of each scenario and pertinent drill cards. EOCC, if installed, should be the prime information source. The Main Propulsion Assistant (MPA) should have custody of a master drill package, with appropriate copies of applicable drill scenarios and drill cards for each space.

The planning and scheduling of casualty control drills should receive equal priority with other training evolutions that are conducted during normal working hours. When a specified time for conducting casualty control drills is authorized by the commanding officer, the Engineer Officer must prepare a drill plan that provides for the training desired. Careful preplanning and sequencing of events are mandatory.

After the proposed drill plan is approved by the Commanding Officer, the designated ECCET personnel meet and make sure that each member of the team understands the procedures and the sequencing of events. In preparing the drill plan, consideration is given to the following:

- General condition of the engineering plant.
- Machinery and safety devices out of commission.
- Length of time set aside for drills.
- State of training of the watch section.
- Power to be provided to vital circuits.

Within the constraints of the items listed above, first priority on drill selection is given to diesel engine casualty drills and propulsion space fire drills because these drills represent the greatest danger and involve the largest number of propulsion plant watch team personnel. Second priority is given to lube oil system casualties because of the inherent danger to main and auxiliary equipment that these casualties represent. Third priority is given to other main engine casualties. In selecting drills, the Engineer Officer must give emphasis to the development of watch team proficiency in handling priority one type casualties.

Normally, ECCET members arrive on station shortly before the drills commence and ensure that communications are established throughout the plant. With the Officer of the Deck's (OOD's) permission, the drill initiator imposes a casualty in accordance with the drill plan. Within the boundaries of safety to personnel and equipment, drills are conducted as realistically as possible and simulations are kept to an absolute minimum. Any time a hazardous situation develops, ECCET members assist the watch section in restoring the plant to the proper operating parameters. Additionally, the ECCET members complete a drill critique form during the course of the drill.

As soon as possible following the drill, a critique is conducted. It is attended by personnel of the applicable watch section, the ECCET, and the Engineer Officer. The ECCET leader gives the finding for the drill and, in the case of unsatisfactory drills, provides the reasons for that finding. All other ECCET members then read their drill critique form. Drills are evaluated as satisfactory or unsatisfactory by the ECCET leader, based on a review of the critique sheets prior to the critique. The following deficiencies form a basis for a finding of unsatisfactory for a drill:

- Loss of plant control by the EOOW or space supervisor when they are unaware of the status of the plant or unable to restore the plant to a normal operating condition utilizing EOSS/EOCC or other promulgated casualty control procedures.
- Safety violations that cause a hazard to personnel or may result in serious machinery derangement.
- Significant procedural deficiencies that indicate a lack of knowledge of the proper procedures to be followed in correcting a casualty.

CORRECTION AND PREVENTION OF CASUALTIES

The speed with which corrective action is applied to an engineering casualty is of paramount importance. This is particularly true when dealing with casualties that affect propulsion power, steering, and electrical power generation and distribution. If casualties associated with these functions are allowed to spread, they may lead to serious damage to the engineering plant, which often cannot be repaired without loss of the ship's operating performance. Where possible risk of permanent damage exists, the Commanding Officer has the responsibility for deciding whether or not to continue the operation of the equipment under casualty conditions. The operation of equipment under casualty control can only be justified where the risk of even greater damage, or loss of the ship, may be incurred by immediately securing the affected unit.

Whenever there is no probability of greater risk, the proper procedure is to secure the malfunctioning unit as quickly as possible even though considerable disturbance to the ship's operations may occur. Although speed in controlling a casualty is essential, these actions should never be undertaken without accurate information; otherwise, the casualty may be mishandled, and irreparable damage and possible loss of the ship may result. War experience has shown that the cross-connecting of an intact system with a partly damaged one should be delayed until it is certain that such action will not jeopardize the intact system. Speed in the handling of casualties can be achieved only with a thorough knowledge of the equipment and associated systems, and by thorough and repeated training in the routine required to handle specific predictable casualties.

Phases of Casualty Control

The handling of any casualty can usually be divided into three phases:

1. Limitation of the effects of the damage.
2. Emergency restoration.
3. Complete repair.

The first phase is concerned with the immediate control of the casualty so as to prevent further damage to the unit affected and to prevent the casualty from spreading.

The second phase consists of restoring, as far as practicable, the services that were interrupted as a result of the casualty. For many casualties, the completion of this phase eliminates all other operational handicaps, except for the temporary loss of the standby units, which lessens the ship's ability to withstand additional failures. If no damage to machinery occurred, this phase usually completes the damage control restoration.

The third phase of casualty control consists of making repairs that completely restore an installation to its original condition.

Split-Plant Operation

In ships having two or more shafts, a fundamental principle of engineering casualty control is split-plant operation. The purpose of the split-plant design is to minimize damage that might result from any one hit.

Most naval ships built primarily as warships have at least two engineering plants. The larger combatant ships have four individual engineering plants.

Split-plant operation means separating the engines, pumps, and other machinery so that two or more engineering plants are available, each complete in itself. Each main engine installation is equipped with its own piping systems and other auxiliaries. Each engineering plant operates its own propeller shaft. If one engineering plant were to be put out of action by an explosion, shellfire, or flooding, the other plant could continue to drive the ship ahead, though at somewhat reduced speed.

Split-plant operation is not an absolute insurance against damage that might immobilize the entire engineering plant. However, it does reduce the chances of such a casualty, and it prevents damage to one plant from being transmitted to, or seriously affecting the operation of, the other plant or plants. Split-plant operation is the first step in the prevention of major engineering casualties.

The FO system is generally arranged so that FO transfer pumps can take suction from any FO tank on the ship and pump it to any other FO tank. FO service pumps are used to supply FO from the service tanks to the main engines. In split-plant operations, the forward FO service pumps of a ship are lined up with the forward service tanks, and the after service pumps are lined up with the after service tanks. The cross-connection valves in the FO transfer lines are always closed except when oil is being transferred.

Although geared diesel propulsion plants are designed for split-plant operation only, some of the auxiliary and main systems may be run cross-connected or split. Among these are the starting air systems, the cooling water systems, the firemain systems, and, in some plants, the fuel and lube oil systems.

In diesel-electric installations, the diesel elements are designed for split operation, but generator elements can be run either split or cross-connected.

Locking Main Shaft

An engineering casualty may affect the rotation of the main shaft and cause further damage. In such cases, the main shaft should be locked until necessary repairs can be made, since, except at very low speeds, movement of the ship through the water will cause the shaft to turn, whether the ship is proceeding by its own power or being towed.

There are no standard procedures for locking a main shaft that are applicable to all types of diesel-driven ships. On ships that have main reduction gears, shaft locking by means of the jacking gear is permissible, provided that the jacking gear has been designed for this purpose (as indicated by the manufacturer’s instructions) or such action is approved by Naval Sea Systems Command (NAVSEA). On diesel-electric drive ships, no attempt should be made to hold the shaft stationary by energizing the electrical propulsion circuits.

Emergency Procedures

Under certain circumstances, you may receive the order to light off additional engines. When time will not permit following normal routine procedures, emergency procedures may have to be used. Since procedures differ depending on the installation, you must be familiar with the procedures established for your ship.

These emergency procedures are listed in the *Engineering Casualty Control Manual* for your ship. They are issued by the type commander (TYCOM). Upon receipt, manuals are modified to fit the individual installation. It is the responsibility of your ship’s Engineer Officer to establish the step-by-step emergency procedures and the necessary checklists.

ENGINEROOM CASUALTIES

The TYCOM for each class ship formulates the engineering casualty procedures that are applicable to a specific type of engineering plant.

In the event of a casualty to a component of the propulsion plant, the principal objective is the prevention of additional or major casualties. Where practicable, the propulsion plant must be kept in operation by means of standby pumps, auxiliary machinery, and piping systems. The important action to be taken is to prevent minor casualties from becoming major casualties, even if it means suspending the operation of the propulsion plant. It is better to stop the main engines for a few minutes than to risk putting them completely out of commission.

When a casualty occurs, immediately notify the EOOW, who will in turn notify the OOD and the Engineer Officer. Main engine control must keep the bridge informed as to the nature of the casualty, the ship's ability to answer bells, the maximum speed available, and the probable duration of the casualty.

Diesel Engine Casualties

The Engineman's (EN's) duties concerning engineering casualties and their control depend upon the type of ship, which may be anything from a coastal patrol (PC) boat to a carrier. An EN operates engines of various sizes, made by various manufacturers, and intended for different types of services.

Detailed information of diesel engine casualty control procedures must be obtained from the manufacturers' instructions, the pertinent TYCOM instructions, and the ship's *Engineering Casualty Control Manual.*

Some examples of the types of engineering casualties that may occur and the general action (these are not all the specific actions; for all the specific actions required, use the specific EOCC) to be taken are given below. The observance of all necessary safety precautions is essential in all casualty control procedures.

BROKEN INJECTION TIP

1. Notify the EOOW and request permission to secure engine.
2. Stop and secure the engine IAW approved operating procedures.
3. Remove and replace the faulty injector IAW current technical manual.
4. Perform operational test as required.
5. Make the necessary reports.

BROKEN CYLINDER LINER

1. Secure the engine.
2. Report to the EOOW. Request permission to proceed with repairs.
3. When permission is granted, remove the head and piston; pull the broken liner and replace it with the spare liner. Follow the procedure as outlined in the engine maintenance manual.
4. Make the necessary reports.

WATER IN AN ENGINE CYLINDER, CRANKCASE, OR AIR PORTS

1. Control the engine manually, if possible.
2. Report to the EOOW and keep him informed.
3. Do not allow the engine to be started until the cause of the casualty has been determined and corrected.
4. Check the cylinders by jacking over with test cocks open.
5. Perform pressure test on freshwater system and conduct visual inspection of the units.
6. Replace part or parts, as necessary.
7. Start the lube oil purifier to remove water from the lubricating oil.
8. After repairs have been completed, test the engine and place it back in commission.

INOPERATIVE SPEED GOVERNOR

1. Notify the EOOW and keep him informed.
2. Control the engine manually, if possible.
3. Request permission from EOOW to secure the engine for repairs.
4. When permission has been obtained, check the governor control mechanism.
5. Check the linkage for binding or sticking.
6. Check the lubrication; flush and refill with proper oil.
7. Check setting of needle valve.
8. When it is operating properly, notify the EOOW.

FAILED MAIN ENGINE LUBE OIL PRESSURE

1. Secure the engine immediately.
2. Notify the EOOW.
3. Check the sump oil level, the piping, the filters, the strainers, and the lube oil pump capacity. Make repairs.
4. After repairs have been completed, notify the EOOW.

ABNORMALLY HIGH LUBE OIL TEMPERATURE

1. Check the LO pressure and oil level.
2. Check the saltwater discharge pressure and the temperature of the cooling water.
3. Check the freshwater level in the expansion tank and the temperature of the freshwater.
4. Check the saltwater suction and the overboard discharge valves.
5. Vent the freshwater and the saltwater pumps.
6. Check the operation of the thermostat control valve to the lube oil and freshwater heat exchanger.
7. Report any trouble found to the EOOW. Request permission to secure the engine for repairs.
8. When permission is received, make repairs.
9. After repairs are completed, check the engine, and after it is operating properly, report to the EOOW.

HIGH JACKETWATER TEMPERATURE

1. Notify the EOOW.
2. Reduce the load and the speed of the engine.
3. Check the freshwater level in the expansion tank.
4. Check the saltwater discharge pressure.
5. Check the sea suction and the discharge valves.
6. Vent the freshwater and the saltwater pumps.
7. Check the setting and operation of the temperature regulating valve.
8. If conditions warrant securing the engine at any time, secure and notify the EOOW.
9. Make repairs, test out the engine, and, if it is operating properly, notify the EOOW.

Fuel Oil (FO) Casualties

In addition to casualties that may involve parts of the FO system within the engine, other casualties may occur that involve the system outside of the engine. Examples of some of the possible casualties, along with the action to be taken follow.

WATER IN DIESEL FUEL OIL (FO) SERVICE (DAY) TANK

1. Shift FO suction.
2. Notify the EOOW of the casualty.
3. Drain the water from all filters, strainers, and lines.
4. Open all test cocks on the engine, and turn the engine over until assured that the system is free of water.
5. Close the test cock. Start the engine. Check its operation. If operation is normal, notify the EOOW that the engine is ready for normal operation.
6. Strip or drain the contaminated service tank and refill with clean fuel using the FO purifier.

INOPERATIVE DIESEL FUEL OIL (FO) TRANSFER PUMP

1. Line up the diesel purifier to supply the tank as quickly as possible.
2. Notify the EOOW of the casualty.
3. In an emergency, line up and use the hand-operated pump to continue operation.
4. At the earliest possible time, inspect and repair the FO transfer pump.
5. Report the results of the investigation and repairs to the EOOW.

Hydraulic Coupling Casualties

Coupling casualties vary with each installation. The following examples, and the action to be taken, are applicable to some Fairbanks-Morse marine installations.

OVERHEATING COUPLING

1. Check the system to determine the cause of overheating.
2. Regulate the valves manually to maintain proper operating temperatures.
3. Notify the EOOW if it is necessary to secure the engine to effect repairs, request permission.
4. When permission is granted, secure the engine and effect repairs.
5. Upon completion of repairs, notify the EOOW.

INOPERATIVE COUPLING LUBE OIL REGULATING VALVE

1. Maintain the correct operating pressure by manually operating the clutch dump valve.
2. Report to the EOOW. Request permission to secure the engine to effect repairs.
3. When permission is granted, replace or repair the valve.
4. Test for proper operation.
5. If the valve is operating properly, report to the EOOW.

COUPLING THROWING OIL

1. Check the system. Attempt to repair the leak.
2. Report to the EOOW. If the leak is not repaired, request permission to secure the engine for repairs.
3. When permission is granted, secure the engine, conduct an investigation, and make necessary repairs.
4. Upon completion of repairs, test the coupling.
5. Report to the EOOW.

INOPERATIVE PROPELLER SHAFT PNEUMATIC BRAKE

1. Report the casualty to EOOW.
2. Check the air pressure to the brake.
3. Check the air reducing valve to the brake.
4. Check the electrical and pressure control switches to the air control valve.
5. If the trouble is not determined and the use of the engine is required, do the following:
   a. Secure the air to the brake system until proper inspection of the brake shoes and expansion core can be made.
   b. Notify the EOOW that the engine is being operated without the brake and that the throttle alone is being used for control.
   c. Use extreme caution during the operation.
   d. At the earliest possible time, inspect and repair the brake.
   e. Report the repairs to the EOOW

Heat Exchanger Casualties

Following are the procedures to be followed under various conditions of operation when diesel engine heat exchanger casualties occur.

UNDER NORMAL STEAMING CONDITIONS

1. Notify the EOOW and request permission to secure the engine.
2. When permission is granted, secure the engine.
3. Secure both the saltwater inlet and outlet valves to the heat exchanger.
4. Remove the visual inspection plate on the exchanger. Plug the expansion tank vent, apply pressure to the freshwater side of the system by opening the valve from the ship's freshwater supply system, and check for leaks.
5. Upon detection of the leak, plug the tubes or install another core.
6. Upon completion of the repairs, notify the EOOW.

Other Propulsion Plant Casualties

Examples of other casualties that may affect propulsion plant operation are described below.

Overheating Main Shaft Bearings

Hot bearings may generally be traced to one of the following causes:

1. Insufficient lubrication.
2. Defective oil ring.
3. Grit or dirt in the oil.
4. Bearing out of line.
5. Bearing improperly fitted.
6. Poor condition of bearing or journal surface.

If the trouble is due to insufficient lubrication and is discovered before the bearing metal has wiped, an abundant supply of oil should gradually bring the bearing back to its normal operating temperature.

A defective oil ring should be repaired or replaced.

Should the trouble be caused by grit, dirt, or foreign matter in the bearing, the oil should be renewed. The new oil may flush out the impurities in the bearing surfaces sufficiently to permit continued operation.

If the main shaft bearing is out of line or improperly fitted, or if the bearing or journal is not in proper condition, only temporary relief can be obtained from use of the various means suggested above. The most effective treatment will probably be the operation of the main engines at low or moderate speeds until such time as the proper adjustments or repairs can be made.

Abnormal temperatures of a bearing can be lowered by slowing down the main shaft and thus decreasing the amount of friction in the bearing. If the trouble has reached an advanced stage, it may be necessary to stop the main shaft. In an emergency, cold water may be used on a bearing to reduce the temperature so that it will be within safe operating limits; it must be remembered, however, that cold water will cause contraction of the bearing. Also, care must be taken to see that water does not contaminate the bearing oil.

Once a bearing has wiped, it should be reconditioned. If it has wiped out slightly, it can probably be scraped to a good bearing surface and restored to service. If badly wiped or burned out, the bearing will require replacement. Inspect the journal and remove any high spots by lapping the journal.

Unusual Noise in Reduction Gear

This information applies to diesel-driven ships that have main reduction gears. The action taken will depend upon the two following conditions:

1. When noise and conditions indicate that tooth failure is not probable:
    a. Slow the engine immediately and stop it if the noise persists.
    b. Check the oil discharge pressure, the temperature of the bearing, and the operation of oil sprays and strainers. Look for the presence of babbitt or other foreign matter.
2. When there is a loud or roaring noise indicating gear tooth damage:
    a. Stop the engine and check the shaft immediately.
    b. Lock the main shaft in accordance with EOSS/EOCC procedures or the manufacturer’s instruction.
    c. Make a preliminary investigation of the gear teeth and other parts of the main reduction gear.

Propulsion Shaft Vibrates Excessively

When the propulsion shaft vibrates excessively, take the following actions:

1. Slow the shaft. If the vibration continues, stop and lock the shaft.
2. Investigate to determine the cause of the vibration. Take necessary action to correct the cause of the vibration.

Frequently, the circumstances under which a ship is operating should be considered when trying to determine the probable cause for excessive vibration. For example, if the ship is in shallow water or close to a beach, the vibration may be caused by the propeller striking ground.

Electrical Casualty Control

ENs and Electrician's Mates (EMs) are assigned duties in operating diesel-driven emergency generating plants on steam-driven ships and all electrical generating plants on diesel-driven ships. Therefore, they must have a general knowledge of the purpose of electric generating plants, their operation under various conditions, and the types of casualties that will interfere with, or disrupt, the normal operation of an engineering plant.

The Electrical Plant

The ship's power and lighting plant consists of generators, switchboards, power panels, cables, circuit breakers, and other equipment necessary for the generation, distribution, and control of power supplies to electrically driven auxiliaries, lighting, interior communication, electronics equipment, and other electrically powered devices. In designing the electric plant, every effort is made to obtain the greatest reliability and continuity of service possible under casualty conditions.

The distribution system forms the vital connection between the generators and the equipment that uses electric power. Electrical power is generally distributed through either the ship's service or the emergency switchboards. Electrical power distribution may also be done through a casualty power circuit rigged from either of these switchboards.

The general arrangement of the ship's service system is such that any faulty circuit will be cut out automatically, without interruption of power supply to other circuits. This is done through the operation of protective devices. If the ship's service generators fail, the emergency generator is automatically placed in operation for battle functions. The emergency switchboard can supply power to all parts of the ship; however, all unnecessary circuits must be stripped from the board when the emergency generator is to supply emergency power to vital equipment. If the board is not stripped, the generator will be overloaded and the breakers will trip out or the diesel engine will stall.

Protection against loss of power on a ship with ship's service, emergency, and casualty power distribution systems is described below:

- Failure of one ship's service generating plant: The load is transferred, by the EM, to the other ship's service generating plant. Care must be taken to prevent overloading the generating plant that takes over the load.
- Circuit or switchboard failure: Vital loads are transferred to an alternate feeder and source of ship's service power by means of a transfer switch on the control panel.
- Failure of both normal and alternate power supply: Certain vital equipment is shifted to an emergency feeder that receives power from the emergency switchboard.
- Failure of the ship's service and emergency circuits: Temporary circuits are rigged with the casualty power cables from any live switchboard to supply power to vital circuits.

BATTLE CASUALTIES

As an Engineman First Class (EN1) or Engineman Chief Petty Officer (ENC), you will be responsible for handling battle casualties, you will have to know the location of isolating and cross-connecting valves, and recognize which of the valves are remotely controlled. As a general rule, personnel safety will be your first consideration in handling casualties.

Effective control of battle casualties depends on a good knowledge of the principal engineering piping systems and related equipment. This information may be found in the ship's *Engineering Casualty Control Manual*, in the plans of the principal engineering systems, and in other applicable sources located aboard ship.

In the event of a battle casualty to an engineering piping system, the damaged section must be isolated and the system should be cross-connected, when possible. Emergency or alternate equipment should be used, when provided, to restore service to vital systems. Whenever feasible, emergency repairs should be made and the system restored to normal operation. Special precautions should be taken to prevent additional damage that may result from any original casualty.

Emergency Power System

The purpose of the emergency power system is to furnish an immediate, automatic source of electric power to a limited number of selected vital circuits. It includes one or more diesel-driven emergency generators, the emergency switchboards, and a distribution system, which is separate from the ship's service electric plant and distribution system. Emergency feeders run from the emergency switchboards to at least one and usually to two different ship's service switchboards. Emergency power feeders for certain vital auxiliaries are also run to control panels. The emergency power system, with the use of transformers, is also used for furnishing emergency lighting.

Whenever practical, emergency generators and switchboards are installed above the waterline to minimize danger from flooding. Also, the emergency plant is installed as far away as practical from the ship's service plant to avoid both plants being put out of action by battle damage.

On most ships, the emergency generators do not have the same capacity as the ship's service plants. Therefore, care must be taken to prevent overloading the emergency generator, which in turn will overload the diesel engine.

Casualty Power System

The casualty power system is used to supply emergency power for steering gear, fireroom and engineroom auxiliaries, fire pumps, drainage pumps, communications equipment, and other vital machinery needed to keep the ship afloat or to get it out of a danger area.

The casualty power system is a simple electrical distribution system used to maintain a source of electrical supply for the most vital machinery and equipment needed to keep the ship afloat and functioning. This casualty power system is intended to supply power during emergencies ONLY. The system is purposely kept simple so that it can be rigged quickly and with a minimum chance of error; however, the very simplicity of its design limits the extent of its use.

Sources of supply for casualty power use are provided at each ship's service switchboard and at each emergency switchboard. They consist of casualty power terminals that are connected to the bus bars through circuit breakers. Some ships have small diesel-driven generators that are designed for casualty power use only; these generators are very small and have a minimum of control equipment. Casualty power terminals are installed on power panels that feed equipment designated to receive casualty power; these terminals may also be used as a source of supply to the casualty power system if power from the permanent feeders to the panels is still available.

The casualty power system is either alternating current (ac) or direct current (dc), as appropriate for the particular installation. Only the ac system is described here. The dc system is similar to the ac system but uses different types of cables and fittings. The portable, thermoplastic-covered or neoprene-covered cables for the ac casualty power system are stowed in racks in convenient locations throughout the ship. Each cable contains three leads (conductors), colored black, white, and red. This same color code is used in all three-wire power circuits throughout the ship.

On smaller ships, the bulkhead terminals for the casualty power system are arranged so as to allow for one horizontal run of the portable cable along the main deck, and generally, if possible, inside the deck house. On larger ships, generally there are terminals for two horizontal runs of cable, one port and one starboard. These are located on the second deck. The terminals extend through the bulkhead, project from it on each side, and do not impair the watertight integrity of the compartments in which they are installed. The cable ends are inserted into the holes that are provided around the outer rim (curved surface) of the terminal. Both the rim and the face of each terminal have three groups of three holes each, into which fit the square-shanked. The riser terminals for the casualty power system are similar to the bulkhead terminals, except that they are connected to other riser terminals by vertical runs of permanently installed, armored cable. The risers and the riser terminals carry the casualty power from the level of the generators to the main deck and second deck levels.

Portable switches are sometimes provided on the bulkheads, near the cable racks. These are simple ON-OFF switches that have special holes for use with the portable cables.

The terminals and the cables in an ac casualty power system are marked so that they can be identified easily when the system is being connected. The faces of the terminals are marked A, B, and C, and the three leads on each cable are colored black, white, and red, respectively. When connecting the cables to the terminals, you connect the black lead to A, the white lead to B, and the red lead to C. Since the letters and the colors cannot be seen in darkness, the terminals are further identified by molded knobs in the A, B, and C areas—one knob for A, two for B, and three for C. The cable leads are identified by servings of twine—one for black, two for white, and three for red. Each serving of twine is about 1 inch wide. Thus, each lead and its corresponding position in the terminal can be identified merely by feeling the leads and matching the number of pieces of twine on each lead with the number of raised knobs on the terminal. (In older ships, the casualty power fittings may still have identifying V-shaped notches in the outer edge instead of raised knobs.)

WARNING

When connecting a run of casualty power cable, ALWAYS CONNECT FROM THE LOAD BACK TO THE POWER SUPPLY! By rigging the system in this manner, you will avoid working with an energized cable. Also be sure to shut off the normal supply to any power panel before you connect the casualty power cable to the terminals on the power panel.

Emergency Fire Pumps

Most ships have electric-driven fire pumps located outside the engineering spaces. These pumps furnish water under pressure to their own piping system or to the ship's firemain. Provisions are made for different sources of electrical power to these pumps: normal and alternate supply from the ship's service generators, emergency supply from the diesel-driven emergency generators, and the casualty power system itself.

Many ships, such as carriers, tankers, and tugs, have independent diesel-driven fire pumps. If a ship's pumps and firemain are damaged, these diesel-driven pumps can be used to furnish large amounts of water for firefighting purposes.

Lighting System

On ships using ac generators, the ship's service and emergency lighting systems are energized from the generator and distribution switchboards through a bank of transformers. These transformers supply power to the lighting system through the lighting distribution panels.

Lighting throughout the machinery spaces is supplied from the normal switchboard for the compartments involved, with some lights in each space supplied from the alternate switchboard. A few lights in each compartment are supplied through automatic bus transfer equipment from circuits originating at the emergency switchboards.

Automatic type hand lanterns are provided to supply an instantaneous source of illumination if the ship's service and emergency lighting systems completely these relay-operated hand lanterns are installed at vital stations. In addition to these, nonautomatic type hand lanterns are also installed at these stations.

An EN1 or ENC in charge of an engineering space has the supervisory responsibility to see that the hand lanterns, especially the automatic type, are not removed except for actual intended use and that hand lanterns are available for use at all times. It is the duty of the petty officer in charge (POIC) of the space to see that personnel do not remove the lanterns or use them for unauthorized purposes. The EN1 or ENC should also ensure that personnel have an adequate number of operational flashlights available for use should all the lights in an engineering space go out.

ELECTRICAL POWER PANELS AND TERMINALS

Power panels are supplied with two or three sources of power—normal, alternate, and emergency. These panels are equipped with circuit breakers or switches that permit the transfer from one source to another in the event of a casualty.

Regular electrical outlets are installed throughout the engineering spaces for use with small portable tools; multipurpose outlets are installed in selected locations for use with portable submersible pumps and portable welding sets. These outlets are located so that it is possible to use two portable submersible pumps in any watertight compartment. Portable triple outlet extension cables are provided to permit the concentration of all submersible pumps in one area. An adapter provided with these extension cables permits connection of the submersible pumps to the casualty power terminals. All this equipment is stowed in the damage control lockers.

Engineering department personnel should be trained in the emergency use and operation of submersible pumps as well as other damage control equipment. They should know the location of both normal and emergency power outlets in their spaces and should understand the different methods used to supply electrical power for operating submersible pumps in the engineroom.

Engineering department personnel should also be familiar with sources of electrical power provided to the different power panels in an engineroom. During engineering casualty control drills and during actual emergencies, the Engineering department personnel should be able to shift from one source of electrical supply to another.

SUMMARY

This chapter provided general information on engineering casualty control, a phase of damage control. If a review of damage control principles and related information is necessary, see *Basic Military Requirements*, NAVEDTRA 14325 (series); *Military Requirements for Petty Officer 3 & 2*, NAVEDTRA 14504(series); *Fireman*, NAVEDTRA 14104(series); and NSTM, Chapter 079.

End of Chapter 24

Engineering Casualty Control

Review Questions

24-1. Which of the following is a factor for obtaining engineering casualty control efficiency?

A. Careless inspections
B. On-time inspections
C. Ineffective training program
D. Sound design

24-2. Which of the following introduced a more methodical and organized approach to casualty control, resulting in increased control, less disabling of a plant, and increased overall safety to the plant and?

A. Engineering Operational Procedures (EOP)
B. Engineering Department Organizational Readiness Manual (EDORM)
C. Engineering Operational Casualty Control (EOCC)
D. Damage Control Procedures (DCP)

24-3. What is the second priority for Engineering Operational Casualty Control (EOCC) drills?

A. Main space fire
B. Diesel engine casualty
C. Main shaft casualty
D. Lube oil system casualty

24-4. On a ship, how is speed and knowledge of the systems and equipment achieved?

A. Constantly reading the instructions
B. Standing under instruction (U/I) watches
C. Training repeatedly
D. Learning the content in “A” school

24-5. When a casualty occurs, who is the first person the equipment operator must notify?

A. Officer of the Deck (OOD)
B. Engineering officer of the watch (EOOW)
C. Main Propulsion Assistant (MPA)
D. Engineer Officer

24-6. A loud roaring noise coming from the reduction gears is an indication of what problem?

A. Tooth damage
B. Water in the lubricating oil
C. Hot bearing surface
D. Loss of lubricating pressure

24-7. What happens in the ship’s electrical service system when a faulty circuit is detected?

A. Cut out repeatedly
B. Cut out automatically
C. Cut out manually
D. Cut out frequently

24-8. Why are emergency generators and switchboards installed above the waterline?

A. To reduce the congestion in the engineering spaces
B. To meet ships' specifications
C. To minimize danger from flooding
D. To position them close to the pilot house

24-9. The casualty power system is used for what equipment?

A. Internet
B. Site television
C. Emergency generator
D. Laundry

24-10. What is the purpose of using the triple outlet extension cable in the engineroom?

A. Extra source of electric power
B. Emergency lighting
C. Concentration of all submersible pumps in one area
D. More ventilation

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APPENDIX I

GLOSSARY

ABSOLUTE PRESSURE—Actual pressure (includes atmospheric pressure).

ACCESSORY DRIVE—A drive consisting of gears, chains, or belts of secondary importance, not essential in itself but essential for the operation of engine accessories (fuel pump, water pump, and so forth).

ACCUMULATOR—A device used for storing liquid under pressure; sometimes used to smooth out pressure surges in a hydraulic system.

ACTUATING MECHANISM—The combination of parts that receives power from the drive mechanism and transmits the power to the engine valves.

ACTUATOR—A device that uses fluid power to produce mechanical force and motion.

ADDITIVE—A material that is added to improve fuel or oil.

AFTERCOOLER—A device used on turbocharged engines to cool air that has undergone compression.

AIR COMPRESSOR—A device used to increase air pressure.

AIR EJECTOR—A device to remove air and non-condensable gases from a main steam condenser.

AIR HEADERS—In some 2-stroke cycle engines, the passages that serve as a reservoir for intake air from the blower.

AIRFLEX CLUTCH—Consists of two clutches, one for forward rotation and one for reverse rotation. Both rotate with the engine at all times at any engine speed.

AIR-PILOT-OPERATED DIAPHRAGM CONTROL VALVES—Used as unloading valves to reduce pressure or to provide continuous regulation of pressure and temperature. They may also be used for the control of liquid levels.

AIR-STARTING VALVE—A valve that admits compressed air to the air starter for starting purposes.

ALTERNATING CURRENT (ac)—Current that is constantly changing in value and direction at regularly recurring intervals.

AMERICAN PETROLEUM INSTITUTE (API) GRAVITY—Gravity expressed in units of standard API (hydrometer).

ANNUNCIATOR—A device, usually electromechanical, used to indicate or transmit information.

ANTIFRICTION BEARINGS—Bearings that are mostly limited to the exterior areas of an engine. Used in cooling pumps, fuel-injection pumps, governors, starters, flywheel pilot bearings, turbochargers, and blowers.

ATMOSPHERIC PRESSURE—The pressure exerted by the atmosphere in all directions, as indicated by a barometer. Standard atmospheric pressure is 14.7 pounds per square inch, which is equivalent to 29.92 inches of mercury.

ATOMIZATION—The spraying of a liquid through a nozzle so the liquid is broken into tiny droplets or particles.

AUTOIGNITION POINT—The temperature at which the flammable vapors given off from oil will burn.

AUTOMATIC BUS TRANSFER (ABT)—An automatic electric device that supplies power to vital equipment. This device will shift from the normal power supply to an alternate power supply any time the normal supply is interrupted.

AUTOMATIC CONTROL SYSTEM—A system of instruments or devices arranged to control a process or operation at a set point without assistance from operating personnel.

AUTOMATIC CONTROLLER—An instrument or device that operates automatically to regulate a controlled variable in response to a set point and/or input signal.

AUTOMATIC OPERATION—Operation of a control system and the process under control without assistance from the operator.

AUTOMATIC REGULATING VALVE—A three-way control valve that maintains the temperature of the freshwater at any desired value by bypassing a portion of the water around the freshwater cooler.

AUXILIARY MACHINERY—Any system or unit of machinery that supports the main propulsion units or helps support the ship and the crew. Examples of auxiliary machinery are pumps, evaporators, steering engines, air conditioning and refrigeration equipment, laundry and galley equipment, and deck winches.

AUXILIARY WATCHES—Maintained in port and underway to provide services that supply light, power steam, and other services.

AXIAL—In a direction parallel to the axis. Axial movement is movement parallel to the axis.

BABBITT—An antifriction metal lining for bearings that reduces the friction between moving components.

BACK PRESSURE—A pressure exerted contrary to the pressure producing the main flow.

BACKLASH—The distance (play) between two movable components.

BAFFLE—A device that slows down or diverts the flow of gases, liquids, sound, and so forth.

BALL BEARING—A bearing that uses steel balls as its rolling element between the inner and outer ring (race).

BALL CHECK VALVE—A valve consisting of a ball held against a ground seat by a spring. It serves to check the flow or to limit the pressure of a liquid or substance.

BALL VALVES—Stop valves that use a ball to stop or start the flow of fluid. Most ball valves are the quick-acting type.

BALLASTING—The process of filling empty tanks with saltwater to protect the ship from underwater damage and to increase its stability.

BEARING—A mechanical component that supports and guides the location of another rotating or sliding member.

BEARING CLEARANCE—The distance between the shaft and the bearing surface.

BENDIX DRIVE MECHANISMS—Devices mounted on a spiral-threaded sleeve so that when the shaft of the motor turns, the threaded sleeve rotates within the pinion, moving the pinion outward, causing it to mesh with the flywheel ring gear and crank the engine.

BLEEDER—A small cock, valve, or plug that drains off small quantities of air or fluids from a container or system.

BLOCK DIAGRAM—A diagram in which the major components of a piece of equipment or a system are represented by squares, rectangles, or other geometric figures, and the normal order of progression of a signal or current flow is represented by lines.

BLOWER—A low-pressure air pump, usually a rotary or centrifugal type, that supplies air above atmospheric pressure to the combustion chambers of an internal-combustion engine.

BLUEPRINTS—Copies of mechanical or other types of technical drawings.

BOSCH METERING SYSTEM—A metering system with a helical groove in the plunger which covers or uncovers ports in the pump barrel.

BOTTOM DEAD CENTER (BDC)—The position of a reciprocating piston at its lowest point of travel

BOTTOM SEDIMENT AND WATER (BS&W) TEST—Test conducted on all oil samples that fail the transparency test. When an oil sample fails the BS&W test (BS&W greater than 0.01 milliliter [mL] or 0.1 percent), you must secure the machinery and transfer the contaminated oil to the settling tank for renovation.

BOURDON TUBE—A C-shaped hollow metal tube that is used in a gauge for measuring pressures of 15 pound per square inch and above. One end of the "C" is welded or silver-brazed to a stationary base. Pressure on the hollow section forces the tube to try to straighten. The free end moves a needle on the gauge face.

BOYLE'S LAW—The volume of any dry gas varies inversely with the applied pressure, provided the temperature remains constant.

BRAKE HORSEPOWER (bhp)—The usable power delivered by an engine.

BRAKE MEAN EFFECTIVE PRESSURE (BMEP)—Mean effective pressure acting on the piston, which would result in a given brake horsepower output if there were no losses from friction, cooling, or exhaust. The bmep is equal to mean indicated pressure times mechanical efficiency.

BRAKE THERMAL EFFICIENCY—Ratio of power output (in the form of brake horsepower) to equivalent power input (in the form of heat from fuel).

BRITISH THERMAL UNIT (Btu)—A unit of heat used to measure the efficiency of combustion. It is equal to the quantity of heat required to raise 1 pound of water 1 °F.

BULL GEAR—The largest gear in a reduction gear train; the main gear in a geared turbine drive.

BUTTERFLY VALVE—A lightweight, relatively quick-acting, positive shutoff valve.

BYPASS—To divert the flow of gas or liquid. Also, the line that diverts the flow.

CALIBRATION—The procedure required to adjust an instrument or device to produce a standardized output with a given input. The amount of deviation from the standard must first be determined in order to ascertain the proper correction requirements.

CALIPER—Instrument used to measure the inside or outside diameter of an object (dial or vernier) within 0.0001 inch.

CAM—A rotating component of irregular shape. It is used to change direction of the motion of another part moving against it. (For example, rotary motion is changed into reciprocating or variable motion).

CAM FOLLOWER (VALVE LIFTER)—A part that is held in contact with the cam and to which the cam motion is imparted and transmitted to the push rod.

CAMSHAFT—Shaft is designed to control the operation of the valves and fuel injection pump usually through various intermediate parts.

CAMSHAFT DRIVE—A separate drive mechanism that serves to transmit power to operate engine valves.

CAMSHAFT GEAR—The gear that is fastened to the camshaft.

CARBURETOR—An apparatus for supplying atomized and vaporized fuel mixed with air to an internal-combustion engine.

CASUALTY—An event or series of events in progress during which equipment damage and/or personnel injury has already occurred. The nature and speed of these events are such that proper and correct procedural steps are taken to limit damage and/or personnel injury only.

CASUALTY COMMUNICATIONS—The battle telephone (sound-powered) circuit, interstation 2-way system (intercoms), ships' service telephones, ships' loudspeaker (1-MC), and voice tubes.

CASUALTY POWER SYSTEM—Portable cables that are rigged to transmit power to vital equipment in an emergency.

CASUALTY TRAINING—Must be a continuous step-by-step procedure with constant refresher drills; completion of realistic simulations of casualties requires adequate preparation.

CAUTION TAG—YELLOW tag used as a precautionary measure. It provides temporary special instructions or warns that unusual caution must be used to operate the equipment. These instructions must state exactly why the tag is installed.

CELSIUS—The temperature scale with a freezing point of 0° and a boiling point of 100°, with 100 equal divisions (degrees) between. This scale was formerly known as the centigrade scale.

CENTRIFUGAL FORCE—The outward force on a rotating body.

CENTRIFUGAL PUMPS—These pumps are used for fire and flushing systems. Internal-combustion engines use centrifugal pumps to circulate cooling water.

CENTRIFUGAL PURIFIERS—These purifiers are used for purification of both fuel and lubricating oil. A purifier may remove both water and sediment.

CETANE VALUE—A measure of the ease with which diesel fuel will ignite.

CHECK VALVE—A valve that permits fluid flow in one direction, but prevents flow in the reverse direction.

CHEMICAL ENERGY—Energy stored in chemicals (fuel) and released during combustion of the chemicals.

CHLORIDE—A compound of the chemical element chlorine with another element or radical.

CIRCUIT BREAKER—An electromagnetic or thermal device that opens a circuit when the current in the circuit exceeds a predetermined amount. Circuit breakers can be reset.

CIRCULATING WATER—Water circulating through a heat exchanger (condenser or cooler) to transfer heat away from an operating component.

CLARIFIER—A purifier removes dirt or sediment from the lubricating oil.

CLOSED COOLING SYSTEM—Consists of two entirely separate circuits; a freshwater circuit and a seawater circuit.

CLUTCH—A component that disconnects the drive mechanism from the propeller shaft and permits the engine to be operated without turning the propeller shaft.

COHESION—The property that holds the lubricant together and enables it to resist breakdown under extreme pressure.

COLD IRON CONDITION—An idle plant, when all services are received from an external source such as shore or tender.

COLD IRON WATCH—A watch maintained alongside a repair ship or tender, or into a naval shipyard. a security and fire watch is usually set by each division. Frequent inspections of the assigned area, and checks for fire hazards, flooding, or other unusual conditions throughout the area.

COMBUSTION—The burning of fuel in a chemical process accompanied by the evolution of light and heat.

COMBUSTION CHAMBER—The chamber in which combustion mainly occurs.

COMBUSTION CYCLE—A series of thermodynamic processes through which the working gas passes to produce one power stroke. The full cycle is intake, compression, power, and exhaust.

COMBUSTION KNOCK—In a diesel engine is directly related to the amount of ignition delay and will take place at the end of the second phase.

COMPENSATING DEVICE—This device could be either mechanical or hydraulic action that prevents overcorrection of change.

COMPRESSED AIR RECEIVER—An air storage tank.

COMPRESSED AIR SUPPLY SYSTEMS—The piping and valves that distribute the compressed air to the points of use.

COMPRESSION RINGS—These rings are used to seal the cylinder and combustion space so that the gases within the space cannot escape until they have performed their function.

COMPRESSION STROKE—That stroke of the operating cycle during which air is compressed into a smaller space creating heat by molecular action.

CONDENSATE—In a distilling plant, the product resulting from the condensation of steam (vapor) produced by the evaporation of seawater. Condensate may also be referred as freshwater, freshwater distillate, or distillate.

CONDENSATION—The process of cooling the freshwater vapor produced by evaporation to produce usable freshwater. Condensation is the second half of the process of distillation.

CONDENSER—A heat transfer device in which vapor is condensed to liquid.

CONDUCTIVITY—The ease with which a substance transmits electricity.

CONNECTING ROD—The connecting link between the piston and the crankshaft.

CONSOLE—A panel equipped with remote manual controls and visual indicators of system performance.

CONSTANT-SPEED CONTROL—Device used to regulates the pressure in the air receiver by controlling the output of the compressor.

CONSTANT-SPEED GOVERNORS—Governors that maintain one speed, regardless of load.

CONTROL AIR SUPPLY—Clean, dry air at proper pressure for operation of pneumatic control equipment.

CONTROL RACK—Control system for the precise metering and delivery of fuel into the combustion chamber of a diesel engine.

CONTROL SYSTEMS—Control mechanisms that may include start-stop control, constant-speed control, cooling water failure switches, and automatic high temperature shutdown devices.

CONTROLLABLE PITCH PROPELLERS—A component that give a ship excellent maneuverability and allow the propellers to develop maximum thrust at any given shaft revolutions per minute.

COOLER—Any device that removes heat. Some devices, such as oil coolers, remove heat to waste in overboard seawater discharge; other devices, such as ejector coolers, conserve heat by heating condensate for boiler feedwater.

COOLING SYSTEM—Heat removal process that uses mechanical means to remove heat to maintain the desired air temperature. The process may also result in dehumidification.

CORROSION—A gradual wearing away or alteration of metal by a chemical or electrochemical process. Essentially, it is an oxidizing process, such as the rusting of iron by the atmosphere.

CORROSION INHIBITOR—A water-soluble chemical compound that protects the metallic surfaces of the cooling system against corrosive attack.

COUNTERWEIGHT—Weights that are mounted on the crankshaft opposite each crank throw. These weights reduce the vibration caused by putting the crank in practical balance and also reduce bearing loads due to inertia of moving parts.

COUPLING—A device for securing together adjoining ends of piping, shafting, and so forth, in such a manner to permit disassembly whenever necessary.

CRANK THROW—One crankpin with its two webs (the amount of offset of the rod journal).

CRANK WEB—The portion of the crank throw between the crankpin and main journal. This makes up the offset.

CRANKCASE—The part of an engine frame that serves as housing for the crankshaft.

CRANKPIN—The portion of the crank throw attached to the connecting rod.

CRANKSHAFT—A shaft that changes the movement of the piston and the connecting rod into the rotating motion that is needed to drive such items as reduction gears, propeller shafts, generators, and pumps.

CRANKSHAFT GEAR—The gear that is mounted to the crankshaft

CREATING PRESSURE—To create the high pressure required to force fuel into the pressurized combustion chamber.

CRITICAL SPEED—The speed at which natural torsional vibrations of a crankshaft tend to reinforce themselves, causing vibration and potentially destructive stresses.

CROSS-CONNECT—To align systems to provide flow or to exchange energy between machinery groups.

CROSS-CONNECTED PLANT—A method of operating two or more plants as one unit from a common supply.

CYCLE—An interval of time during which a sequence of a recurring succession of events is completed.

CYCLE EFFICIENCY—Equal to the output divided by the input.

CYLINDER—(1) A solid figure with two circular bases. (2) A hollow tube that contains the actions of combustion gases and the piston in an internal combustion reciprocating engine.

CYLINDER BLOCK—The part of the engine frame that supports the engine's cylinder liners, head (or heads), and crankshaft.

CYLINDER BLOCK HEATER—An electrically operated immersion heater to heat the water jacket surrounding the cylinder block of an engine to warm the coolant in cold weather.

CYLINDER HEAD—The device sits above the cylinder on top of the cylinder block. It closes the cylinder creating the combustion chamber.

CYLINDER HEAD WARPAGE—Ranges from blow gasket to warps head surface to cracks in cylinder head material**.**

CYLINDER LINER—The barrel or bore in which an engine piston moves back and forth. It may be an integral part of the cylinder block or a separate sleeve or liner.

DAILY BOAT FUELING RECORD—A routine record of daily fueling, which is highly recommended for any ship that carries or maintains a number of boats. Use of this schedule will help prevent special fueling at unusual hours and will keep the boats ready for unexpected calls.

DAMPER—A device for reducing the motion or oscillations of moving parts.

DAMPING—(1) A characteristic of a system that results in dissipation of energy and causes decay in oscillations. (2) The negative feedback of an output rate of change.

DANGER TAG—RED tag that prohibits the operation of equipment that could jeopardize the safety of personnel or endanger equipment, systems, or components.

DAY TANK—A fuel tank with the capacity to operate an engine for 24 hours.

DEGREE OF SUPERHEAT—The temperature difference of a superheated vapor between its saturation temperature and its existing temperature.

DEMULSIBILITY—Its ability to separate cleanly from any water present, an important factor in forced-feed systems.

DENTAL COUPLING—A flexible coupling assembly, consisting of a set of external/internal gear teeth, that compensates for shaft misalignment between a driver and a driven machinery component.

DESIGN TEMPERATURE—The intended operating temperature of the fresh water and lube oil at the engine outlet, at the specified rate of operation (normal) load, the specified rate of operation is usually normal load.

DETONATION—This action is caused by the presence of fuel or lubricating oil in the air charge of the cylinders during the compression stroke. Excessive pressures accompany detonation. If detonation is occurring in one or more cylinders, stop the engine immediately to prevent possible damage.

DIAL INDICATOR—A precision micrometer-type instrument that indicates the reading by a needle moving across a dial face**.**

DIAPHRAGM—A dividing membrane or thin partition.

DIESEL ENGINE—An engine using the diesel or semi-diesel cycle of operation; air alone is compressed and diesel fuel is injected before the end of the compression stroke. Heat of compression produces ignition.

DIESEL ENGINE OPERATING RECORD—A daily record maintained for each operating diesel engine.

DIFFUSER—(1) A duct of varying cross sections designed to convert a high-speed gas flow into low-speed flow at an increased pressure. (2) A device that spreads a fluid out in all directions and increases fluid pressure while decreasing fluid velocity.

DIRECT CURRENT (dc)—An electric current that flows in one direction only.

DIRECT DRIVE—A device that is coupled directly to the driven member.

DIRECTIONAL CONTROL VALVE—A valve that selectively directs or prevents flow to or from desired channels. Also referred to as selector valve, control valve, or transfer valve.

DISPLACEMENT—The volume of air or fluid that can pass through a pump, motor, or cylinder in a single revolution or stroke.

DISTILLATE—The product (freshwater) resulting from the condensation of vapors produced by the evaporation of seawater.

DISTILLATION—The process of boiling seawater and then cooling and condensing the resulting vapor to produce freshwater.

DISTILLING PLANTS—Units commonly called evaporators used to convert seawater into fresh water.

DISTRIBUTOR FUEL INJECTION—A process in which the fuel charges are distributed in the correct firing order by a rotary distributor that is integral with the pump. Equality of delivery to each nozzle is an inherent feature of the pump.

DOUBLE REDUCTION—A reduction gear assembly that reduces the high input revolutions per minute (rpm) to a lower output in two stages.

DRAWING NUMBER—An identifying number assigned to a drawing or a series of drawings.

DRIVE MECHANISM—The combination of devices used to transmit engine power to a driven unit.

DUPLEX STRAINER—A strainer containing two separate elements independent of each other.

DYER DRIVE MECHANISM—Component mounted on the starting motor and connected to the battery and motor. Remote control starting is accomplished by a starter switch on the instrument panel.

DYNAMIC PRESSURE—(1) The pressure of a fluid resulting from its motion, equal to one-half the fluid density times the fluid velocity squared. (2) In incompressible flow, dynamic pressure is the difference between total pressure and static pressure.

ECONOMIZER—A device provided in a carburetor to give the fuel-air mixture the richness required for high power.

EDUCTOR—A jet-type pump (no moving parts) that uses a flow of water to entrain and thereby pump water.

EFFECT—In a distilling plant, the part of a unit where a distillation process occurs. For example, the first place where boiling (or evaporation) of feed into vapor occurs is in the first-effect.

EFFICIENCY—The ratio of output power to input power, generally expressed as a percentage.

ELASTICITY—The ability of a material to return to its original size and shape.

ELECTRIC DRIVES—The electricity produced by an engine-driven generator. This electricity is transmitted through cables to a motor, which is connected to the propeller shaft directly, or indirectly, through a reduction gear. When a speed reduction gear is included in a diesel-electric drive, the gear is located between the motor and the propeller.

ELECTRIC STARTING—Device that uses direct current (dc) because electrical energy in this form can be stored in batteries and can be drawn upon when needed.

ELECTRICAL ENERGY—Energy derived from the forced induction of electrons from one atom to another.

ELECTROHYDRAULIC STEERING—A system having a motor-driven hydraulic pump that creates the force needed to actuate the rams to position the ship's rudder.

ELECTROLYSIS—A chemical action that takes place between unlike metals in systems using seawater.

EMERGENCY—An event or series of events in progress that will cause damage to equipment unless immediate, timely, and correct procedural steps are taken.

EMERGENCY DIESEL GENERATORS—Equipment that furnish power directly to vital electrical auxiliaries, such as the steering gear and the ship's gyro. Emergency generators may serve as a source of power for the casualty power distribution system.

EMITTER RINGS—Contain small holes that release the masker air into the sea, coating the hull with air bubbles. The bubbles disguise the shape of the ship so that it cannot be seen accurately by enemy sonar.

EMULSIFIED OIL—A chemical condition of oil in which the molecules of the oil have been broken up and suspended in a foreign substance (usually water).

ENERGY CELL—A device that converts the chemical energy from the fuel into electricity through chemical reaction with oxygen or another oxidizing agent.

ENGINE—A machine that converts heat energy into mechanical energy.

ENGINE ORDER INDICATOR—A device on the ship's bridge that transmits orders to the engine room for specific shaft speeds in revolutions per minute (revolution per minute).

ENGINE ORDER TELEGRAPH—Electromechanical device that transmits orders concerning desired direction and general speed of the engines to the engine room.

ENGINEER'S BELL BOOK—A legal record, maintained by the throttle watch, of all ordered main engine speed changes.

ENGINEERING DUTY OFFICER (EDO)—The officer that takes the place of Engineering Officer in his or her absence.

ENGINEERING LOG—A legal record of important events and data concerning the machinery of a ship.

ENGINEERING OFFICER OF THE WATCH (EOOW)—Officer on duty in the engineering spaces.

ENGINEERING OPERATIONAL CASUALTY CONTROL (EOCC)—Watch teams can then control the casualty to prevent possible damage to machinery and restore plant operation to normal.

ENGINEERING OPERATIONAL PROCEDURES (EOP)—Procedures are prepared specifically for each level of operation; plant supervision (level l), space supervision (level 2), and component/system operator (level 3). The materials for each level or stage of operation contain only the information necessary at that level.

ENGINEERING OPERATIONAL SEQUENCING SYSTEM (EOSS)—Consists of a set of detailed written procedures, using charts, instructions, and diagrams. These aids are developed for safe operation and casualty control of a specific ship's engineering plant and configuration.

EQUIVALENT PER MILLION (EPM)—A term used to describe the chemical concentration of dissolved material; used in reporting sample test results. It expresses the chemical equivalent unit weight of material dissolved in a million unit weights of solution.

ESCOPE—An instrument used to inspect internal parts on an engine without having to disassemble the engine. This instrument helps a great deal in estimating the amount of repair work needed and the time required for the repair.

ETHER PRIMER—Device that inject a highly volatile fluid into the air intake system to assist ignition of the fuel.

EVAPORATION—The process of boiling seawater to separate it into freshwater vapor and brine. Evaporation is the first half of the process of distillation.

EVAPORATOR—A distilling device to produce freshwater from seawater.

EXPANSION JOINT—(1) A junction in a piping system that allows for expansion and contraction. (2) A term applied to a joint that permits linear movement to take up the expansion and contraction due to changing temperature or ship movement.

EXPANSION TANK—A tank that provides for expansion, overflow, and replenishment of cooling (freshwater) water in an engine.

EXTREME PRESSURE GREASE—This grease has antirust properties and is suitable for lubrication of any sliding or rolling metal surfaces where the load may be high and where the equipment may be exposed to salt spray or moisture.

FATIGUE—The tendency of a material to break under repeated strain.

FEED—The seawater that is the raw material of the distilling unit. Feed for the distilling units is nothing but raw seawater.

FEEDBACK—(1) A transfer of energy from the output circuit of a device back to its input. (2) Information about a process output, which is communicated to the process input.

FERROUS METAL—Metal with a high iron content.

FILTER—A device through which gas or liquid is passed; dirt, dust, and other impurities are removed by the separating action.

FILTER SKID—For reverse osmosis plants, the filter skid consists of an electric heater, centrifugal separator, 20-micron filter, 3-micron filter, and activated carbon (AC) filter.

FIREMAIN—The seawater line that provides firefighting and flushing water throughout the ship.

FIRE POINT—The temperature at which the oil will continue to burn when it is ignited.

FIRING ORDER—The order in which the cylinders deliver their power stroke.

FIRING PRESSURE—The highest pressure reached in the cylinder during combustion.

FLAMMABLE—Capable of being burned easily, intensely, or quickly.

FLANGE SAFETY SHIELDS—Devices installed on piping flanges of flammable liquid systems, especially in areas where the fire hazard is apparent. The spray shields are usually made of aluminized glass cloth and are simply wrapped and wired around the flange.

FLASHPOINT—The temperature at which a substance, such as an oil, will give off a vapor that will flash or burn momentarily when ignited.

FLASH-TYPE DISTILLING PLANTS—This distilling plant flashes the feed into vapor (steam) rather than boiling it inside the evaporator shell. The flashing process involves heating the feed before it enters the evaporator shell.

FLEXIBLE COUPLING—A coupling that transmits rotary motion from one shaft to another while compensating for minor misalignment between the two units.

FLOWMETER—An instrument used to measure quantity or the flow rate of a fluid motion.

FLUID—A substance capable of flowing or conforming to the shape of its container (a liquid or gas or mixture thereof).

FLYWEIGHTS—A governor; weights that move and assume positions in accordance with the speed of rotation.

FLYWHEEL—A heavy wheel attached to the crankshaft. It stores up energy during the power event and releases it during the remaining events of the operating cycle.

FORCE—The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds.

FORCED FEED LUBRICATION—A lubrication system that uses a pump to maintain a constant pressure.

FRESHWATER—Water of relatively low dissolved solids content as compared to seawater. There are two types of shipboard fresh water—(1) feedwater (the low-pressure drains of the steam generator condensate system), and (2) potable water (supplied from either a shore water source or a shipboard distilling plant).

FRESHWATER SYSTEM—A piping system that supplies fresh water throughout the ship.

FRICTION—The action of one body or substance rubbing against another, such as fluid flowing against the walls of a pipe; the resistance to motion caused by this rubbing.

FRICTION BEARINGS—These bearings serve to support the crankshaft, connecting rod, camshaft, and gear train. In some engine applications, friction bearings also support the rocker arm shaft as well as various pumps.

FRICTION CLUTCHES—These clutches are engaged when two friction surfaces are mechanically forced into contact with each other by toggle-action linkage through stiff springs or through the use of hydraulic or pneumatic pressure.

FROZEN CLUTCH—A clutch that has failed to disengage.

FUEL AND WATER REPORT—A report that indicate the amount of fuel oil and water on hand as of midnight the previous day.

FUEL INJECTION—A system for admitting fuel into an engine.

FUEL OIL SERVICE TANKS—Tanks from which the fuel oil service pumps take suction for supplying diesel fuel oil to the engine.

FUEL TRANSFER PUMP—A mechanical device used to transfer fuel from the tank to the injection pump.

FUEL VALVE—A valve admitting fuel to the combustion chamber.

FULL-FLOATING PISTON PIN—A piston pin free to turn in the piston boss of the connecting rod eye.

FULL-FLOW OIL FILTER—A type of oil filter through which all engine oil passes before entering the lubrication channels.

FUSE—A protective device inserted in series with a circuit. It contains a metal that will melt or break when current is increased beyond a specific value for a definite period of time.

GAS—The form of matter that has neither a definite shape nor a definite volume.

GAS FREE—A term used to describe a space that has been tested and its atmosphere found safe for human occupation and for hot work (welding and cutting).

GASKET(S)—(1) A class of material that provides a seal between two stationary parts. (2) Packing materials by which air, water, oil, or steam tightness is secured on doors, hatches, cylinders, and manhole covers, or in valves, between the flanges of pipes, and so forth. Such materials as rubber, canvas, asbestos, paper, sheet lead and copper, soft iron, and commercial products are extensively used.

GATE VALVES—These valves are used when a straight line flow of fluid and minimum flow restriction are needed, such as in the inlet piping for a centrifugal pump.

GAUGE GLASS—A device for indicating the liquid level in a tank.

GAUGE PRESSURE—Pressure above atmospheric pressure.

GEAR—(1) A toothed machine part that meshes with another toothed part to transmit motion or to change speed and direct. (2) A complete assembly that performs a specific function in a larger machine.

GENERATOR—A machine that converts mechanical energy into electrical energy.

GLAND SEALING—Water piped to a pump casing stuffing box to maintain a seal against air entering the pump casing.

GLOBE VALVES—These valves are used for regulating flow of liquids and gases.

GLOW PLUG—A heating device used to aid starting diesel engines.

GOVERNOR—A speed-sensitive device designed to control or limit the speed of the engine.

GRAPHITE GREASE—This grease may be applied with compression grease cups to bearings operating at temperatures that do not exceed 150 °F.

GREASE—A semisolid lubricant consisting of soap emulsified and oil, high in initial viscosity. Applied to mechanism that can only be lubricated infrequently and where lubricating oil would not stay in position.

GRID RESISTORS—This component is preheated by current from the starting battery, before the engine is cranked, and is operated during the cranking period until the engine has reached operating speed.

HAMMERING—A mechanical knock (not to be confused with a fuel knock). It may be caused by a loose, excessively worn, or broken engine part.

HANDHOLE—An opening large enough for the hand and arm to enter areas, such as the engine, for making slight repairs and for inspection purposes.

HARDENING—The treatment or heating and cooling (quenching) of metal to harden the surface.

HARDNESS—A quality exhibited by water containing various dissolved salts, principally calcium and magnesium. Can result in a heat transfer resistant scale on the steam generating surfaces.

HEAD—(1) A separate unit from the engine cylinder block designed to seal the cylinder at the combustion end. (2) The pressure or energy content of a hydraulic system, expressed in the height of a column of water in feet.

HEAT EXCHANGER—Any device that is designed to allow the transfer of heat from one fluid (liquid or gas) to another.

HEAT EXCHANGER COOLING SYSTEM—A system that combines two separate cooling systems; a jacket-water (freshwater) system and the raw-water (seawater) cooling system. The principal components that comprise the freshwater system are an engine coolant pump, one side of the heat exchanger, and the expansion tank and piping.

HEATING SYSTEM—A system for adding heat to maintain the desired air temperature, as distinguished from heat added incidentally or unavoidably.

HELICAL GEAR PUMP—One of multiple modifications of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump.

HELICAL SCREW COMPRESSOR—This lowpressure air compressor is a single-stage, positive-displacement, axial-flow, helical-screw type of compressor.

HELIX—The curve formed on any cylinder by a straight line in a plane that is wrapped around the cylinder with a forward progression.

HERRINGBONE GEAR PUMP—A modification of the simple gear pump. One discharge phase begins before the previous discharge phase is entirely complete. This overlapping tends to give a steadier discharge pressure than is found in the simple gear pump.

HERTZ—The measurement of frequencies in cycles per second, 1 hertz being equal to 1 cycle per second.

HIGH PRESSURE (HP) PUMP SKID—A set of components to increase the pressure above osmotic pressure to allow efficient reverse osmosis (RO) to take place across the RO membranes.

HIGH-PRESSURE AIR—3,000-150 pounds per square inch.

HORSEPOWER (hp)—A unit to indicate the time rate of doing work equal to 550 foot-pounds per second or 33,000 foot-pounds per minute.

HUMIDITY—The vapor content of the atmosphere. Humidity can vary depending on air temperature; the higher the temperature, the more vapor the air can hold.

HUNTING—An undesirable oscillation, such as in the speed of a machine or the position of an automatic valve.

HYDRAULIC CLUTCHES (COUPLINGS)—These clutches that transmit power through very efficiently (97 percent) without the transmission of torsional vibrations or load shocks from the engine to the reduction gear.

HYDRAULIC GOVERNORS—The flyweights of the hydraulic governor are linked directly to a small pilot valve that opens and closes ported passages, admitting oil under pressure to either side of a power piston that is linked to the fuel control mechanism.

HYDRAULICS—The study of liquid in motion.

HYDROCARBON—Chemical compound of hydrogen and carbon. All petroleum fuels are composed of hydrocarbons.

HYDROMETER—An instrument used to determine the specific gravities of liquids.

HYDROSTATIC PRESSURE—Static (nonmoving) pressure generated by pressurizing liquid.

HYDROSTATIC TEST—A test using pressurized water to detect leaks in a closed system.

IGNITION, COMPRESSION—When the heat generated by compression in an internal combustion engine ignites the fuel (as in a diesel engine).

IGNITION DELAY—The time between when the fuel is injected and when it reaches the self-ignition point.

IGNITION, SPARK—When the mixture of air and fuel in an internal-combustion engine is ignited by an electric spark (as in a gasoline engine).

IMPELLER—An encased, rotating element provided with vanes, which draw in fluid at the center and expel it at a high velocity at the outer edge.

IMPULSE LINES—Piping that connects a sensing element to the point at which it is desired to sense pressure, flow, temperature, etc.

INDICATED HORSEPOWER (ihp)—The power transmitted to the pistons by the gas in the cylinders.

INDICATED THERMAL EFFICIENCY—The ratio of indicated horsepower to equivalent power input in the form of heat from fuel.

INDICATOR—Panel-mounted pressure gauge.

INDIRECT DRIVE—A drive mechanism coupled to the driven member by gears or belts.

INERTIA—The tendency of a stationary object to remain stationary and of moving objects to remain in motion.

INFLATABLE SEALING RING—A ring used when it is necessary to repair or replace the prime sealing elements when the ship is waterborne.

INHIBITOR—Any substance that retards or prevents such chemical reactions as corrosion or oxidation.

INJECTING—Forcing and distributing the fuel into the combustion chamber.

INJECTION NOZZLE—A device that protrudes into the combustion chamber and delivers fuel to the cylinder.

INJECTION SYSTEM—A system designed to deliver fuel to the cylinder at the proper time and in the proper quantity under various engine loads and speeds.

IN-LINE ENGINE—An engine in which the cylinders are arranged in one straight line.

INNER DEAD CENTER (IDC)—The point during the combustion cycle on an opposing engine where the pistons are closest.

INTAKE SYSTEM—Combination of components designed to supply air required for combustion.

INTERCOOLER—A device that cools a gas between the compression stages of a multiple stage compressor.

INTERNAL COMBUSTION ENGINE—Engine that converts heat energy into work by burning fuel in a confined chamber within the engine.

ISOCHRONOUS GOVERNOR—A condition that is maintaining the speed of the engine truly constant, regardless of the load. This means governing with perfect speed regulation or zero speed droop.

JACKET WATER—Water used as a coolant in the cooling system of an engine (usually chemically treated distilled water).

JACKING—Mechanically rotating an engine or reduction gear at very low speed.

JACKING GEAR—This gear it allows for the precise positioning of the crankshaft when required for timing.

JERK PUMP FUEL INJECTION—Consists of high-pressure pumps and pressure-operated spray valves or nozzles that are separate components. In some engines, there is only one pump and one nozzle for each cylinder.

JIGGLES—High-frequency vibrations of the governor fuel rod end or engine fuel linkage. Do not confuse jiggle with the normal regulating action of the governor.

JOURNAL—Device serves as the point of support and center of rotation for the shaft. That part of a shaft that is prepared to accept a bearing (connecting rod, main bearing).

KEY—A small wedge or rectangular piece of metal inserted in a slot or groove between a shaft and a hub to prevent slippage.

KEYWAY—A slot cut in a shaft, pulley hub, wheel hub, and so forth. A square key is placed in the slot and engages a similar keyway in the mating piece. The key prevents slippage between the two parts.

KINETIC ENERGY—The energy that a substance has while it is in motion.

LABYRINTH PACKING—A soft metal ring or rings arranged inside a casing throat in such a manner that the inside diametrical edges will form a series of seals along the surface of the rotating shaft. The edges fit either close to the surface of the shaft or in grooves machined in the shaft.

LAGGING—A protective and confining cover placed over insulating material.

LEAD—(1) The distance a screw thread advances in one turn, measured parallel to the axis. On a single-thread screw, the lead and the pitch are identical; on a double-thread screw, the lead is twice the pitch; on a triple-thread screw, the lead is three times the pitch. (2) A wire or connection.

LENGTH OF STROKE—The distance a piston travels between top dead center (TDC) and bottom dead center (BDC).

LINE SHAFT BEARINGS—Bearings that are designed primarily to align themselves to support the weight of the shafting.

LIQUID—A form of matter that has a definite volume but takes the shape of its container.

LOAD—(1) External resistance overcome by a prime mover. (2) The power that is being delivered by a generator.

LOADING—The act of transferring energy into or out of a system.

LOAD-LIMITING GOVERNOR—A control device to limit the load that the engine will handle at various speeds.

LOBE PUMP—One of multiple variations of the simple gear pump, on a lobe pump (heliquad type), the lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor.

LOCAL MANUAL OPERATION—Direct manual positioning of a control valve or power operator by means of a handwheel or lever.

LOCKED TRAIN—A gear arrangement that has each high-speed (prime mover) pinion "locked" between two primary gears, which cancel the tooth loading on the pinion bearings.

LOG—(1) The act of a ship in making a certain speed, as "The ship logged 20 knots." (2) A book or ledger in which the watch officer records data or events that occurred during the watch.

LOG BOOK—Any chronological record of events, such as the engineering watch log.

LOOP SEAL—A vertical U-bend in drain piping in which a water level is maintained to create an airtight seal.

LOW PRESSURE (LP) AIR—The most widely used air system aboard the ship.

LOWER CRANK LEAD—The number of degrees that a crank on the lower shaft travels in advance of the corresponding crank of the upper shaft.

LUBE OIL ANALYSIS—A method to measure the accelerated wear in machinery can be detected without disassembling the equipment long before there is any other indication of immediate trouble.

LUBE OIL PURIFIER—A unit that removes water and sediment from lubricating oil by centrifugal force.

LUBRICANT—Any material, usually of a petroleum nature, such as grease and oil, that is placed between two moving parts in an effort to reduce friction.

MACHINE FINISH—Operation of turning or cutting an amount of stock from the surface of metal to produce a finished surface.

MAGNETO—A generator that produces alternating current (ac) and has a permanent magnet as its field.

MAIN DRAIN SYSTEM—System used for pumping bilges; consists of pumps and associated piping.

MAIN JOURNALS—These journals serve as the points of support and as the center of rotation for the shaft.

MAIN REDUCTION GEAR—A component that provides gear reduction.

MAIN REDUCTION GEAR BEARINGS—These bearing must support the weight of the gears and their shafts.

MAIN THRUST BEARINGS—These bearing are usually located in the reduction gear casing. It absorbs the axial thrust transmitted through the shaft from the propeller.

MAINTENANCE AND MATERIAL MANAGEMENT (3-M)—An overall management tool that provides a simple and efficient way in which basic maintenance on all equipment can be planned, scheduled, controlled, and performed.

MANIFOLD—(1) A fitting or header that receives exhaust gases from several cylinders. (2) A fitting that has several inlets or outlets to carry liquids or gases.

MANUALLY OPERATED THROTTLING VALVE—This valve is used in the seawater circuit; regulates the amount of water passing through the seawater side of the freshwater cooler.

MATERIAL INSPECTION—This inspection is to determine the actual material condition of the ship.

MAXIMUM OPERATING PRESSURE—The highest pressure that can exist in a system or subsystem under normal operating conditions. This pressure is determined by such influences as pump or compressor shutoff pressures, pressure regulating valve lockup (no-flow) pressure, and maximum chosen pressure at the system source.

MAXIMUM SYSTEM PRESSURE—The highest pressure that can exist in a system or subsystem during any condition. Normal, abnormal, and emergency operation and casualty conditions shall be considered in determining the maximum system pressure. In any system or subsystem with relief valve protection, the nominal setting of the relief valve shall be taken as the maximum system pressure (relief valve accumulation may be ignored).

MEAN EFFECTIVE PRESSURE (MEP)—The calculated combustion in pounds per square inch (pounds per square inch) (average) during the power stroke, minus the pounds per square inch (average) of the remaining three strokes.

MEAN INDICATED PRESSURE (MIP)—The net mean gas pressure acting on the piston to produce work.

MECHANICAL CLEANING—A method of cleaning the firesides of boilers by scraping and wire brushing.

MECHANICAL CYCLE—The number of piston strokes occurring during any one series of events.

MECHANICAL DRAWING—Scale drawing of mechanical objects. (See DRAWING).

MECHANICAL DRIVES—Devices that reduce the shaft speed of the driven unit, provide a means for reversing the direction of shaft rotation in the driven unit, and permit quick-disconnect of the driving unit from the driven unit.

MECHANICAL EFFICIENCY—(1) The ratio of brake horsepower to indicted horsepower, or ratio of brake mean effective pressure to mean indicated pressure. (2) An engine’s rating, which indicates how much of the potential horsepower is wasted through friction within the moving parts of the engine.

MECHANICAL GOVERNOR—This governor controls the speed of the engine by virtue of the spring-balanced position of the flyweights.

MECHANICAL OVERSPEED TRIPS—These trips depend upon the centrifugal forces developed by the engine.

MECHANICAL SEALS—These seals serve to ensure that position liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

METERING—Accurate measuring of the fuel for the same fuel setting where exactly the same quantity of fuel will be delivered to each cylinder for each power stroke of the engine.

MICROMETER—A precision measuring instrument used to measure distances between surfaces in thousandth of an inch (inside, outside, depth).

MIL-A-53009 INHIBITOR—An inhibitor that neutralizes the acidic byproducts that result from the combustion blow-by gases that leak into the coolant.

MIL-I-24453 SOLUBLE OIL—Soluble oil is considered safe to use where there is a possibility of contaminating drinking water, and is effective at protecting aluminum heat-rejecting surfaces.

MISFIRING—A problem in which one or more of the cylinders are not compressing and/or igniting the fuel mix as they should.

MOTOR—(1) A rotating machine that transforms electrical energy into mechanical energy. (2) An actuator that converts fluid power to rotary mechanical force and motion.

MOTOR CONTROLLER—A device (or group of devices) that governs, in some predetermined manner, the operation of the motor to which it is connected.

MOTOR GENERATOR SET—A machine consisting of a motor mechanically coupled to a generator and usually mounted on the same base.

MULTIPLE-HOLE NOZZLE—These nozzles provides good atomization but less penetration than the pintle-type nozzle.

NALFLEET 9-111—Chemical is authorized for use in Isotta Fraschini engines on MCM (Mine Countermeasures) and MHC (Coastal Mine Hunters) class ships.

NALCOOL 2000—Chemical is used as a high temperature coolant for internal combustion engines, and machinery. By forming a physical barrier (a chemical film), by preventing corrosion of the metal surface, thus strengthening its resistance to cavitation.

NAVAL DISTILLATE (ND) DIESEL FUEL—Fuel used in steam-powered ships of the Navy. ND is a fuel of the middle to higher distillation range. Military specification MIL-F-24397 (ships) and NATO Symbol F85 cover the requirements for Navy distillate fuel. The fuel normally used in diesel engines.

NEEDLE VALVE—Type of valve with a rod-shaped, needle-pointed valve body that works into a valve seat so shaped that the needle point fits into it and closes the passage. Suitable for precise control of flow.

NEUTRAL OPERATION—A process that oil flows along one path, and no pressure is applied against any of the hydraulic components. The forward clutch disk rotates without turning any of the parts inside the transmission. This allows the transmission output shaft to remain stationary.

NEUTRALIZATION NUMBER—The number of milligrams of potassium hydroxide (KOH) required to neutralize 1 gram of oil; indicates the oil's acid.

NIGHT ORDER BOOK—A notebook containing standing and special instructions from the engineering officer to the engineering officers of the night watches.

NIPPLE—A piece of pipe that has an outside thread at both ends for use in making pipe connections. Various names are applied to different lengths, such as close, short, and long.

NITROGEN—An inert gas that will not support life or combustion.

NOMINAL OPERATING PRESSURE—The approximate pressure at which an essentially constant-pressure system operates. This pressure is used for the system's basic pressure identification.

NONVITAL AIR—Air has many different purposes, such as laundry equipment, tank-level indicating systems, and air hose connections.

NOZZLE—A taper or constriction used to speed up or direct the flow of gas or liquid.

NOZZLE AREA—Smallest opening (area) of a nozzle that is at a right angle to the direction of flow

OCCUPATIONAL STANDARDS (OCCSTDs)—Requirements that describe the work of each Navy rating.

OIL KING—A petty officer who receives, transfers, discharges, and tests fuel oil and maintains fuel oil records.

OIL POLLUTION ACTS—The Oil Pollution Act of 1924 (as amended), the Oil Pollution Act of 1961, and the Water Quality Improvement Act of 1970 prohibit the overboard discharge of oil or water that contains oil, in port, in any sea area within 12 miles of land, and in special prohibited zones.

OIL RINGS—These rings are designed to do two things: (1) distribute enough oil to the cylinder wall to prevent metal-to-metal contact, and (2) control the amount of oil distributed.

OIL STRAINER—A strainer placed at the inlet end of the oil pump to prevent dirt and other particles from getting into moving parts.

OILTIGHT—Having the property of resisting the passage of oil.

ONE-LINE SCHEMATIC DIAGRAM—A drawing of a system using only one line to show the tie-in of various components; for example, the three conductors needed to transmit three-phase power are represented by a single line.

OPEN COOLING SYSTEM—That the liquid that is used to carry heat away from the engine is drawn directly from the water in which the boat or ship operates.

OPERATING CHARACTERISTICS—The combination of a parameter and its set points.

OPERATING PRESSURE—The constant pressure at which a component is designed to operate in service.

OPERATING TEMPERATURE—The actual temperature of a component during operation.

OPERATIONAL READINESS INSPECTION—Consists of the conduct of a battle problem and of other operational exercises.

OPPOSED-PISTON—Identifies those engines that have two pistons and one combustion space in each cylinder.

ORIFICE—A circular opening in a flow passage that acts as a flow restriction.

ORIFICE PLATE—A plate with an opening fitted between flanges in piping systems to reduce velocity and pressure in steam traps and steam supply to distilling plants

OTTO COMBUSTION CYCLE—Combustion induced by spark ignition occurring at constant volume. The basic combustion cycle of a gasoline engine.

OUTER DEAD CENTER (ODC)—The point during the combustion cycle on an opposing engine where the pistons are furthest.

OUT-OF-CALIBRATION LABEL—ORANGE label used to identify instruments that are out of calibration and do not give accurate readings.

OUT-OF-COMMISSION LABEL—RED label used to identify instruments that will not give accurate readings because they are either defective or isolated from the system.

OVERHAUL—To inspect, repair, and put in proper condition for operation.

OVERLOAD—A load greater than the rated load of an engine or electrical device.

OVERSPEED TRIPS—Devices that bring an overspeeding engine to a full stop by completely shutting off the fuel or air supply.

OXIDATION—The process of various elements and compounds combining with oxygen. The corrosion of metal is generally a form of oxidation; rust on iron, for example, is iron oxide or oxidation.

PACKING—A class of seal that provides a seal between two parts of a unit, which move in relation to each other.

PARALLEL OPERATION—Two or more units operating simultaneously and connected so their output forms a common supply, as opposed to series or independent operation.

PARAMETER—A variable such as temperature, pressure, flow rate, voltage, current, and frequency, which may be indicated, monitored, checked, or sensed in any way during operation or testing.

PARTICULATE—Minute particles or quantities of solid matter resulting from incomplete combustion. Carbon, sulfur, ash, and various other compounds are all referred to as particulate, either collectively or individually, when discharged into a flow or into the atmosphere.

PARTS PER MILLION (PPM)—Concentration of the number of parts of a substance dissolved in a million parts of another substance.

PERSONNEL QUALIFICATION STANDARDS (PQS)—A written list of knowledge and skills. These skills are required for you to qualify for a specific equipment or system.

pH—A chemistry term that denotes the degree of acidity or alkalinity of a solution. The pH of water solution may have any value between 0 and 14. A solution with a pH of 7 is neutral. Above 7, it is alkaline; below 7, it is acidic.

PHYSICAL CHANGE—A change that does not alter the composition of the molecules of a substance, such as from gas to liquid.

PILOT VALVE—A small valve disk and seat, usually located within a larger disk, which controls the operation of another valve or system.

PILOT VALVE (governor)—A hydraulic control valve that regulates hydraulic pressure to a piston and cylinder.

PILOT-ACTUATED PRESSURE-REDUCING VALVES—These valves are uses a pilot valve to control the main valve. The pilot valve controls the flow of upstream fluid, which is ported to the pilot valve, to the operating piston, which operates the main valve.

PINION—A gear that meshes with a larger gear.

PINTLE-TYPE NOZZLE—A closed-type nozzle having a projection on the end of the fuel valve, which extends into the orifice when the valve is closed.

PIPING—An assembly of pipe or tubing, valves, and fittings that forms the transferring part of a system.

PISTON—A cylindrical plug that slides up and down in the cylinder and that is connected to the connecting rod

PISTON BOSS—The reinforced area around the piston-pin bore.

PISTON DISPLACEMENT—The volume of air moved or displaced by a piston as the piston moves from Bottom Dead Center to Top Dead Center.

PISTON HEAD—The portion of the piston above the top ring.

PISTON LANDS—The spaces in pistons between the ring grooves.

PISTON PIN (wrist pin)—A cylindrical alloy pin that passes through the piston bore and connects the connecting rod to the piston.

PISTON RING—A split ring of the expansion type placed in a groove of the piston to seal the space between the piston and the wall.

PISTON SKIRT—The portion of the piston that is below the piston bore.

PISTON SPEED—The total distance traveled by each piston in 1 minute.

PISTON WEAR—Deterioration of the pistons, which is normal in all engines. The amount and rate of piston wear depends on several controllable factors such as lubrication and improper cooling water temperature.

PITCH—(1) The distance a propeller will advance during one revolution. (2) The distance between the centers of the teeth of a gear wheel.

PITTING—The localized corrosion of iron and steel in spots, usually caused by irregularities in surface finish and resulting in small indentations or pits.

PLASTIGAUGE—A measuring tool used for measuring plain bearing clearances, for measuring plain bearing and drive shaft bearing clearances

PLATE-TUBE COOLERS—These coolers are used for cooling both oil and water, usually with seawater as a coolant.

PNEUMATICS—The branch of physics pertaining to the pressure and flow of gases.

PORT SCAVENGING—Introducing scavenging air through ports in the cylinder wall when they are uncovered by the piston near the end of the power stroke.

POTABLE WATER—Water that is suitable for drinking. The potable water system supplies scuttlebutts, sinks, showers, sculleries, and galleys, as well as provides makeup water for various freshwater cooling systems.

POTENTIAL ENERGY—(1) Energy at rest; stored energy. (2) The energy a substance has because of its position, its condition, or its chemical composition.

POUNDING—A mechanical knock (not to be confused with a fuel knock). It may be caused by a loose, excessively worn, or broken engine part.

POUR POINT—The lowest temperature at which the oil will barely flow from a container. At a temperature below the pour point, oil congeals or solidifies.

POWER—The rate of doing work or the rate of expending energy. The unit of electrical power is the watt; the unit of mechanical power is horsepower.

PRAIRIE-MASKER AIR SYSTEMS—This two-part system supplies a high volume of low-pressure air to a system of emitter rings or belts surrounding the hull and to the propeller blades through the hollow propulsion shafts.

PRECIPITATION NUMBER—A measure of the amount of solids classified as asphalts or carbon residue contained in the oil.

PRECOMBUSTION CHAMBER—A portion of the combustion chamber connected to the cylinder through a narrow throat.

PRESSURE—The amount of force distributed over each unit of area. Pressure is expressed in pounds per square inch (pounds per square inch), atmospheric units, kilograms per square centimeter, inches of mercury, and other ways

PRESSURE REDUCING VALVE—A valve designed to open when pressure in the system exceeds a certain limit.

PRESSURE SWITCH—An electrical switch operated by the increase and decrease of pressure.

PRESSURE-TIME FUEL SYSTEM—A system in which fuel is injected into the cylinders at a specific pressure in separately timed events.

PRIMARY SENSING ELEMENT—The control component that transforms energy from the controlled medium to produce a signal that is which is a function of the value of the controlled variable.

PRIME MOVER—(1) the source of motion—as a diesel engine. (2) The source of mechanical power used to drive a pump or compressor.

PRIMING—Filling, loading, or putting in working order (filling a fuel system with fuel or a pump with water).

PRIORITY VALVE—This valve will shut automatically to secure air to nonvital components when the pressure in the air system drops to a specified set point. It will reopen to restore nonvital air when pressure in the system returns to normal.

PROMPTNESS—The governor's speed of action. It identifies the time interval required for the governor to move the fuel control mechanism from a no-load position to a full-load position.

PROPELLER—A propulsive device consisting of a boss or hub carrying two or more radial blades.

PROPULSION CONTROL SYSTEM—In modern propulsion systems, an integrated system of pneumatic, hydraulic, and electric circuits that provides control of the speed and direction of the propeller shaft.

PROPULSION PLANT—The entire propulsion plant or system, including prime movers and those auxiliaries essential to their operation.

PSYCHROMETER—A form of hygrometer consisting of a wet and a dry bulb thermometer.

PULSATION—A rhythmical throbbing or vibrating.

PUMP—(1) A device that converts mechanical energy into fluid energy. (2) A device that raises, transfers, or compresses fluids or gases

PUMP CAPACITY—The amount of fluid a pump can move in a given period of time, usually stated in gallons per minute (gpm).

PUMP RISER—The section of piping from the pump discharge valve to the piping main.

PURGE—To make free of an unwanted substance (as to bleed air out of a fuel system).

PUSHROD—A device that transmits the motion from the roller type of lifter for intake and exhaust valve operation and it is activated by the respective intake and exhaust lobes of the camshaft.

PYROMETER—A device for measuring high temperatures such as the exhaust temperature of an internal-combustion engine.

QUALITY ASSURANCE (QA)—A program intended to introduce discipline into the repair of equipment, safety of personnel, and configuration control, thereby enhancing readiness.

QUALITY ASSURANCE OFFICER (QAO)—Responsible for coordinating the ship's QA training program, for maintaining ship's QA records, and for test and inspection reports.

RACE (bearing)—The inner or outer ring that provides a contact surface for the balls or rollers in a bearing.

RADIAL BEARINGS—Bearings designed to carry loads applied in a plant perpendicular to the axis of the shaft and used to prevent movement in a radial direction.

RADIAL THRUST BEARINGS—Bearings designed to carry a combination of radial and thrust loads. The loads are applied both radially and axially with a resultant angular component.

RADIATOR—A component that circulated engine coolant. In the radiator, the coolant gives up its heat to the stream of air forced through the fins of the radiator by a fan. The fan is belt driven from the crankshaft. The water pump draws the cooling liquid through the oil cooler and discharges it into the lower part of the cylinder block.

RATTLING NOISES—These noises are generally due to vibration of loose engine parts.

RAW WATER—Untreated water used for cooling.

REACH ROD—A length of pipe or bar stock used as extension on valve stems.

RECEIVER—A container in which compressed gas is stored to supply pneumatic power.

RECEIVER INDICATOR—Pressure-sensitive instrument indicating the loading pressure signals in percentage.

RECIPROCATING—Moving back and forth, as a piston reciprocating in a cylinder.

REDUCER—(1) Any coupling or fitting that connects a large opening to a smaller pipe or hose. (2) A device that reduces pressure in a fluid (gas or liquid) system.

REDUCING STATION—An assembly consisting of a reducing valve, isolation valves, and bypass valves for the reducer.

REDUCING VALVES—Automatic valves that provide a steady pressure lower than the supply pressure.

REDUCTION GEAR—An arrangement of shafts and gears such that the number of revolutions of the output shaft is less than that of the input shaft; generally used between a prime mover and the propeller shaft.

REGULATOR (gas)—An instrument that controls the flow of gases from compressed gas cylinders.

RELIEF VALVE—A pressure control valve used to limit system pressure.

REMOTE-OPERATED VALVES—These valves provides a means of operating certain valves from distant stations.

REPAIR ACTIVITY—Any activity other than the ship's force that is involved in the construction, testing, repair, overhaul, refueling, or maintenance of the ship (intermediate or depot level maintenance activities).

RESERVOIR—A container that serves primarily as a supply source of the liquid for a hydraulic system.

RESISTANCE—The opposition to the flow of current caused by the nature and physical dimensions of a conductor.

RESPONSE TIME—The time lag between a signal input and the resulting change of output.

RETURN LINE—A line used for returning fluid to the reservoir or atmosphere.

REVERSE GEARS—These devises are used to reverse the direction of the propeller in mechanical drive systems.

REVERSE OSMOSIS (RO) DESALINATION PLANT—The plant uses a process that removes salt by forcing High Pressure saltwater through a membrane with holes small enough to filter salt and produce freshwater.

REVERSE OSMOSIS (RO) MODULE SKID—The skid contains the pressure vessels, RO membranes, brine restrictor valve, pressure-reducing coil, dump valve, flow meters, salinity cell, RO isolation valves, and sample and relief valves.

REVOLUTIONS PER MINUTE (rpm)—The speed at which the crankshaft rotates.

RISER—A vertical pipe leading off a large one; for example, a firemain line.

ROCKER ARM—Part of the valve actuating mechanism of a reciprocating engine.

ROOT BLOWER—The blower supplies the fresh air needed for combustion and scavenging.

ROOT VALVE—A valve located where a branch line comes off the main line.

ROTARY PUMPS—These pumps have very small clearances between rotating parts to minimize slippage (leakage) from the discharge side back to the inlet of the pump.

ROTOR—The rotating element of a motor, pump, or turbine.

RUDDER STOCK—A vertical shaft that has a rudder attached to its lower end and a yoke, quadrant, or tiller fitted to its upper portion by which it may be turned.

RUDDER STOPS—Fittings attached to the ship structure or to shoulders on the rudder post to limit the swing of the rudder.

SAFETY VALVE—An automatic, quick opening and closing valve that has a reset pressure lower than the lift pressure.

SALINITY—The concentration of chemical salts in water; measured by electrical devices, or salinity cells, of either equivalents per million (epm) or parts per million (ppm).

SALINITY CELL—The cell measures the ability of water to conduct electrical current (conductivity).

SALINOMETER—A hydrometer that measures the concentration of salt in a solution.

SATURATED AIR—Air that attains the maximum amount of moisture it can hold at a specified temperature.

SATURATED STEAM—Steam at the saturation temperature.

SAYBOLT VISCOSMETER—An instrument that determines the fluidity or viscosity (resistance to flow) of an oil.

SCALE—Undesirable deposit, mostly calcium sulfate, which forms in the tubes of boilers.

SCAVENGING AIR—Increased amount of air available as a result of blower action used to fill an engine cylinder with a fresh charge of air and, during the process, to aid in clearing the cylinder of the gases of combustion.

SCHEMATIC DIAGRAM—A diagram using graphic symbols to show how a circuit functions electrically.

SCREEN—A component that prevents particles of foreign material from entering the engine.

SCREW PUMP—This pump is used primarily for pumping viscous fluids, such as F-76 and F-44. Hydraulic systems on some ships use the screw pump to supply pressure for the system.

SEA CHEST—An arrangement for supplying seawater to engines, condensers, and pumps and for discharging waste water from the ship to the sea. It is a cast fitting or a built-up structure located below the waterline of the vessel and having means for attachment of the piping. Suction sea chests are fitted with strainers or gratings.

SEA COCK, SEA CONNECTION—A sea valve secured to the plating of the vessel below the waterline for use in flooding tanks, magazines, and so forth, to supply water to pumps and for similar purposes.

SEAWATER—Seawater (also referred to as saltwater) is an aqueous solution of various minerals and salts (chlorides). In suspension also, but not dissolved in the water, may be various types of vegetable and animal growths, including, in many cases, bacteria and organisms harmful or actually dangerous to health.

SEDIMENT—An accumulation of matter that settles to the bottom of a liquid.

SENSIBLE HEAT—Heat that is given off or absorbed by a substance without changing its state.

SENSING POINT—The physical and/or functional point in a system at which a signal may be detected and monitored or may cause some automatic operation to result.

SENSITIVITY—The change in speed required before the governor will make a corrective movement of the fuel control mechanism; generally expressed as a percentage of the normal or average speed.

SENSOR—A component that senses physical variables and produces a signal to be observed or to actuate other elements in a control system.

SENTINEL VALVE—A relief valve designed to emit an audible sound; does not have substantial pressure-relieving capacity.

SEPARATOR—A purifier removes water from the lubricating oil.

SERVICE TANKS—Tanks in which fluids for use in the service systems are stored.

SERVO—A device used to convert a small movement into a greater movement or force.

SET POINT—The level or value at which a controlled variable is to be maintained.

SHAFT ALLEY—A watertight passage, housing the propeller shafting from the engine room to the bulkhead at which the stern tube commences.

SHAFT/SHAFTING—The cylindrical forging, solid or tubular, used for transmission of rotary motion from the source of power, the engine, to the propellers.

SHELL-AND-TUBE COOLER—Component consists principally of a bundle of tubes encased in a shell. The liquid to be cooled enters the shell at one end, is directed to pass over the tubes by baffles, and is discharged at the opposite end of the shell.

SHOCK ABSORBERS—Component used to absorb vibration forces that are greater than those originating in the engine.

SHORE WATER—A broad term for classifying water originating from a source ashore.

SHUT-OFF VALVE—A valve that operates fully open or fully closed.

SILENCER—A device that reduces air noise of the air passes through the silencer where it is reduced by a sound-absorbent, flameproof, felted cotton waste.

SIMPLE GEAR PUMP—The pump has two spur gears that mesh. Together they rotate in opposite directions; one is the driving gear, and the other is the driven gear.

SLIPPAGE—Occurs at a high engine speed when an engine is delivering the greatest torque, causing lower efficiency, loss of power, and rapid wear of the clutch friction surface.

SMOKE—Can be quite useful as an aid in locating some types of trouble, especially if used in conjunction with other trouble symptoms.

SOLENOID—An electromagnetic coil that contains a movable plunger.

SOLID COUPLING—A device that joins two shafts rigidly.

SOUNDING PIPE OR SOUNDING TUBE—A vertical pipe in an oil or water tank, used to guide a sounding device during measurement of the depth of liquid in the tank.

SPECIFIC GRAVITY—The relative weight of a given volume of a specific material as compared to the weight of an equal volume of water.

SPECIFIC HEAT—The amount of heat required to raise the temperature of 1 pound of a substance 1 °F. All substances are compared to water, which has a specific heat of 1 Btu/lb/°F.

SPECTROGRAPHIC ANALYSIS—A method of determining engine or equipment wear by analyzing engine oil and hydraulic oil samples for chemicals and particles.

SPEED DROOP—The decrease in speed of the engine from a no-load condition to a full-load condition.

SPEED-LIMITING GOVERNORS—Speed-control devices that serve to keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum speed.

SPEED-REGULATING GOVERNOR—A device that maintains a constant speed on an engine that is operating under varying load conditions.

SPLIT PLANT—A method of operating propulsion plants so they are divided into two or more separate and complete units.

SPRAG OVERRUNNING CLUTCH—A process by which the pinion, once engaged, the pinion will stay in mesh with the ring gear on the flywheel until the engine starts or the solenoid switch disengages. To protect the starter armature from excessive speed when the engine starts, the clutch "overruns" or turns faster than the armature, which permits the starter pinion to disengage itself from the ring gear.

SPRING BEARINGS—Bearings positioned at varying intervals along a propulsion shaft to help keep it in alignment and to support its weight.

SPRING-BALANCED INDICATOR—Instrument employs a spherical ball piston, which is held on its seat by the force of a helical spring actuated by the cylinder pressure, which acts against the bottom of the ball piston to oppose the spring tension.

SPRING-LOADED REDUCING VALVES—These valves use spring pressure against a diaphragm to open the valves.

STABILITY—The ability of the governor to maintain the desired engine speed without fluctuations or hunting.

STANDBY EQUIPMENT—When one auxiliary is running, the standby is so connected that it may be started if the first fails.

STEAMING ORDERS—Written orders issued by the Engineering Officer. They list the major machinery units and readiness requirements of the engineering department based upon the time set for getting the ship underway.

STEERING ENGINE—The machinery that turns the rudder.

STERN TUBE—(1) The bearing supporting the propeller shaft where it emerges from the ship. (2) A watertight enclosure for the propeller shaft.

STERN TUBE FLUSHING WATER—Water circulated through the stern tube from inboard to prevent accumulation of debris in the stern tube while the ship is at rest or backing down

STOP VALVES—These valves are used to shut off or, in some cases, control the flow of fluid.

STRIPPING SYSTEM—A system provided to strip all oil tanks and service systems of water and sediment.

STROBOSCOPE—A flashing light source used to measure the speed of fast-moving objects.

STRUT BEARINGS—These bearings are equipped with composition bushings that are split longitudinally into two halves.

STRUT-TUBE COOLER—This cooler provides considerable heat transfer in a smaller and more compact unit.

STUFFING BOX—A device to prevent leakage between a moving and a fixed part.

STUFFING TUBE—A packed tube that makes a watertight fitting for a cable or small pipe passing through a bulkhead.

SUBMERGED TUBE DISTILLING PLANTS—A process by which feed floods into the bottom of the unit and surrounds the tubes that contain circulating low-pressure steam. The steam in the tubes causes the surrounding feed to boil and produce steam (vapor).

SUMP—A container, compartment, or reservoir used as a drain or receptacle for engine oil.

SUPERCHARGER—A device for increasing the volume of the air charge of an internal combustion engine.

SUPERHEATED STEAM—A vapor that is not adjacent or next to its liquid source and has been heated to a temperature above its saturation temperature.

SUPPLY AIR—Compressed air required for the proper operation of pneumatic control components.

SURGES—Rhythmic variations of speed of large magnitude that can be eliminated by blocking the fuel linkage manually.

SWING CHECK VALVE—A valve that has a guide-mounted disk swung from the top by a horizontal pin.

SWITCHBOARD—A panel or group of panels with automatic protective devices, used to distribute the electrical power throughout the ship.

SYNCHRONIZE—(1) To make two or more events or operations occur at the proper time with respect to each other. (2) To adjust two engines to run at the same speed.

SYNTHRON SEAL—A rubber strip seal installed on the shaft to prevent seawater from leaking into the ship along the shaft.

TACHOMETER—An instrument for indicating revolutions per minute (rpm).

TAG-OUT PROGRAM—Provides a procedure to be used when a component, piece of equipment, system, or portion of a system must be isolated because of some abnormal condition.

TAIL SHAFT—The aft section of the shaft that receives the propeller.

TEFLON®—A plastic with excellent self-lubricating bearing properties.

TEMPER—To harden steel by heating and sudden cooling by immersion in oil, water, or other coolant.

TENSILE STRENGTH—The measure of a material's ability to withstand a tensile, or pulling, stress without rupture, usually measured in pounds or tons per square inch of cross section.

TEST VALVE—Valve is used to (1) vent the cylinder of any accumulated water or oil before an engine is started; (2) relieve cylinder pressure when the engine is being turned by hand; or (3) test compression and firing pressures.

THERMAL EFFICIENCY—The measurement of the efficiency and completeness of combustion of the fuel, or, more specifically, the ratio of the output or work being done by the working substance in the cylinder in a given time to the input or heat energy of the fuel supplied during the same time.

THERMAL ENERGY—Energy contained in or derived from heat.

THERMAL EXPANSION—The increase in volume of a substance due to temperature change.

THERMOCOUPLE—(1) A bimetallic device capable of producing an electromotive force roughly proportional to temperature differences on its hot and cold junction ends and used in the measurement of elevated temperatures. (2) A junction of two dissimilar metals that produces a voltage when heated.

THERMODYNAMIC LOSSES—Losses of this nature are a result of the following: loss to the cooling and lubricating systems, loss to the surrounding air, loss to the exhaust, and loss due to imperfect combustion.

THROTTLE VALVE—A type of valve especially designed to control rate of flow.

THROTTLEMAN—Person in the engine room who operates the throttles to control the main engines.

THROTTLING—Operating a valve partially open to produce a pressure drop with flow.

THRUST BEARINGS—Bearings that limit the axial (longitudinal) movement of the shaft.

TILLER—An arm attached to the rudder head for operating the rudder.

TIMING—Allowing fuel injection into each cylinder to start and stop at the proper time.

TIMING GEARS—Gears attached to the crankshaft, camshaft, idler shaft, or injection pump to provide a means to drive the camshaft and injection pump and to regulate the speed and performance.

TIMING MECHANISM—A separate drive mechanism that serves to transmit power to operate engine valve.

TOP DEAD CENTER (TDC)—The position of a reciprocating piston at its uppermost point of travel

TORQUE—A force or combination of forces that produces or tends to produce a twisting or rotary motion.

TOUGHNESS—The property of a material that enables it to withstand shock and to be deformed without breaking.

TRANSFER VALVE—A manually operated direction valve used to switch automatic control systems from automatic to manual operation and vice versa.

TRANSFORMER—An electrical device used to step up or down an alternating current (ac) voltage.

TRANSMISSION—A device that transmits power from the engine (driving unit) to the load (driven unit).

TRANSPARENCY TEST—The test is conducted only on auxiliary machinery oil samples that have failed the clear and bright criteria. The transparency test is conducted by placing a clean Planned Maintenance System card behind the sample bottle in a well-lighted area.

TREND ANALYSIS—A method of obtaining certain engine operating data and studying, analyzing, and comparing it with previous data. This information is then reduced to a form that all engineering personnel can interpret and decide whether the engine needs to be overhauled or just temporarily shut down for simple maintenance.

TRICK WHEEL—A steering wheel in the steering engine room or emergency steering station of a ship, used in case of emergency.

TUBING—A type of fluid line, the dimensions of which are designated by actual measured outside diameter (OD) and by actual measured wall thickness.

TURBOCHARGER—A forced induction device used to allow more power to be produced by an engine of a given size.

TURBULENCE—Air in the combustion space in motion.

TWIN-DISKS—These disks are equipped with a duplex clutch and a reverse and reduction gear unit, all contained in a housing at the after-end of the engine.

UNBURNABLE OIL—The quantity of oil below the stripping suction in storage tanks and below the service suction in service tanks.

UNIT INJECTOR—A diesel engine injector that combines a pump and a fuel-spray nozzle in a single unit.

UNLOADING SYSTEMS—Closing or throttling the compressor intake, forcing intake valves off their seats, relieving intercoolers to the atmosphere, and relieving the final discharge to the atmosphere.

UNSTABLE—The action of an automatic control system and controller process that is characterized by a continuous cycling of one or more system variables for a degree greater than a specified maximum.

VACUUM—Pressure less than atmospheric pressure.

VALVE—A mechanism that can be opened or closed to control or stop the flow of a liquid, gas, or vapor from one place to another place.

VALVE ACTUATING MECHANISM—The group of parts that, by changing the type of motion, causes the valves of an engine to operate; may include the camshaft, cam followers, pushrods, rocker arms.

VALVE GUIDE—A hollow-sized shaft pressed into the cylinder head to keep the valve in proper alignment.

VALVE KEEPER (valve retainer)—A device designed to lock the valve-spring retainer to the valve stem.

VALVE LIFT—The distance a valve moves from the fully closed to the fully open position.

VALVE SEAT—The surface, normally curved, against which the valve disk's operating face comes to rest to provide a seal against leakage of liquid, gas, or vapor.

VALVE SEAT INSERT—Metal ring inserted into a valve seat, made of a special metal that can withstand operating temperature satisfactorily

VALVE SPRINGS—Mechanisms that serve to close the valves.

VAPOR—The gaseous state of a substance that is usually a liquid or solid at atmospheric temperature and pressure.

VARIABLE DISPLACEMENT—The type of pump or motor in which the volume of fluid delivered per cycle can be varied.

VARIABLE-SPEED GOVERNORS—Governors that maintain any desired engine speed over a wide speed range and that can be set to maintain a desired speed in that range.

VARIABLE-STROKE AXIAL-PISTON PUMP—An uneven number of pistons is always used so that pulsations in the discharge flow can be avoided.

VARIABLE-STROKE PUMPS—Pumps that are used on anchor windlasses, cranes, winches, steering engines.

VARIABLE-STROKE RADIAL-PISTON PUMP—A pump that consists of plungers or pistons, which extend outward from each cylinder and are pinned at their outer ends to slippers, which slide around the inside of a rotating floating ring or housing

VELOCITY—Speed in a definite direction.

VENT—A valve in a system used primarily to permit air to escape.

VENTURI—A tube that has a narrowing throat or constriction to increase the velocity of fluid flowing through it. The flow through the venturi causes a pressure drop in the smallest section.

VIBRATION ISOLATORS—This component is designed to absorb the forces of relatively minor vibrations that are common to operating diesel engines.

VISCOSITY—The internal resistance of a fluid that tends to prevent it from flowing.

VITAL AIR—Air used primarily for engineering purposes, such as automatic boiler controls, water level controls, and air pilot-operated control valves.

VITAL CIRCUITS—Electrical circuits that provide power or lighting to equipment and spaces necessary for propulsion, ship control, and communications.

VOLUME OF FLOW—The quantity of fluid that passes a certain point in a unit of time. The volume of flow is usually expressed in gallons per minute (gpm) for liquids and in cubic feet per minute for gases.

VOLUMETRIC EFFICIENCY—The ratio between the charge that actually enters the cylinder and the amount that could enter under ideal conditions.

VOLUTE—(1) A gradually widening spiral. (2) A section or component of a centrifugal pump where velocity head becomes pressure head.

WATER JACKET—Internal passages and cavities cast into the cylinder block of engines and air compressors through which water is circulated around and adjacent to friction (heat) areas.

WATER METER—This direct-reading meter measures the production in gallons of acceptable distillate that is produced by the evaporator.

WIPED BEARINGS—Bearings in which the babbitt has melted because of excess heat.

WORK—The result of force moving through distance.

WORK REQUEST—Request issued to naval shipyard, tender, or repair ship for repairs.

YOKE—A frame or bar having its center portion bored and keyed or otherwise constructed for attachment to the rudder stock. Steering effort from the steering gear is applied to each end of the yoke for the purpose of turning the rudder.

ZERK FITTING—A small fitting to which a grease gun can be applied to force lubricating grease into bearings or moving parts of machinery.

ZERO SETTING—The output of a device when its input is minimum.

ZINC—A metal placed in salt water systems to counteract the effects of electrolysis.

APPENDIX II

REFERENCES

> **NOTE**
>
> Although the following references were current when this Rate Training Manual (RTM) was published, their continued currency cannot be assured. When consulting these references, keep in mind that they may have been revised to reflect new technology or revised methods, practices, or procedures; therefore, you need to ensure that you are studying the latest references.
>
> If you find an incorrect or obsolete reference, please use the RTM User Update Form provided at the end of each chapter to contact the SWOS Rate Training Manager.

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11-9.	C
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17-10.	A

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22-8.	B
22-9.	A
22-10.	A

22-11.	C
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24-3.	D
24-4.	C

24-5.	B
24-6.	A
24-7.	B
24-8.	C

24-9.	C
24-10.	C

Chapter 1

Introduction to the Engineman Rating

1-1. On diesel-driven ships “M” division is responsible for all the following equipment, except?

A. Main engines
B. Distillate plant
C. Reduction gears
D. Shaft bearings

1-2. Following orders exactly, observing safety precautions, and accepting responsibility are all signs of what kind of leadership?

A. On the job
B. Practical
C. General
D. Technical

1-3. As you move up the ladder in the Engineman rate, which of the following statements best describes your technical leadership responsibilities?

A. They will require only that you tell others what to do
B. They will include more military responsibilities than for personnel who hold other ratings
C. They will be more general in nature
D. They will be more directly related to your work

1-4. When talking to a group of trainees about diesel engines, why should you use precise technical and standard Navy terms?

A. To take advantage to the opportunity for self-improvement
B. To avoid criticism from trainees having higher formal education
C. To impress the trainees
D. To convey information accurately, simply, and clearly

1-5. Who does the Engineering Officer of the Watch make their reports to?

A. Main Propulsion Assistant
B. Officer of the Deck
C. Executive Officer
D. Damage Control Assistant

1-6. What kind of service is provided during the Auxiliary Watch?

A. General
B. Hotel services
C. Phone
D. Water

1-7. Under what normal condition is a cold-iron watch stood?

A. Underway
B. At anchor
C. Moored to a buoy
D. Alongside a tender

1-8. What is the purpose of the Navy Enlisted Classification Codes (NECs)?

A. To identify skills and training required for specific types of operations or equipment
B. To determine who will advance
C. To recruit Navy men and women
D. To qualify for officers programs

1-9. Which of the following can earn you advancement by satisfactorily completing an applicable course of instruction at a Navy school?

A. Bonus
B. Special assignment
C. NECs
D. Limited duty

1-10. What is contained in NAVPERS 18068 Section 11?

A. Occupational Standards
B. Description of rate
C. Job traits
D. NECs

1-11. What kind of control is the Navy Enlisted Classification Codes (NECs) coding system?

A. Management
B. Internal
C. External
D. Cross-reference

1-12. What is the watch called for any hot work (welding or burning) being performed onboard a Naval Vessel?

A. Sound and Security
B. Cold Iron
C. Fire Watch
D. Auxiliary Watch

1-13. What is Section One of NAVPERS 18068?

A. NEC
B. Occupational Standards
C. Jobs
D. Bibs

1-14. Occupational Standards are the __________requirements that are directly related to the work of each rating.

A. maximum task
B. Personal Qualification Standards (PQS)
C. minimum task
D. Total Quality Leadership (TQL)

1-15. How are mandatory rate training manuals marked in the NAVEDTRA 10052?

A. Underlined
B. Asterisk
C. Bold
D. In quotes

1-16. How often are NAVSEA publications updated?

A. Once every 5 years
B. Every time a new class of ship is commissioned
C. Once a year
D. Every six months

1-17. Which of the following hints for studying should help you get the most from your Navy training course?

A. Devote your time exclusively to important military topics
B. Make notes as you study, putting the main ideas in your own words; then review your notes
C. Try not to cover a complete unit in any one study period
D. Omit easy material; study only the most difficult and the unfamiliar

1-18. What primary source of information should you consult to locate onboard drawings?

A. Ship Drawing Index
B. Naval Sea Systems notices
C. BUPERS notices
D. Personal Qualification Standards (PQS)

1-19. All of these concepts are benefits of the Planned Maintenance System (PMS), except?

A. Commanding Officer can easily determine readiness of ship
B. It assures better record keeping
C. It is self-starting
D. It is a better management tool for scheduling

1-20. Which form is used by maintenance personnel to report deferred maintenance actions and completed maintenance actions?

A. OPNAV 4790/2C
B. OPNAVINST 5100.19
C. NAVPER 5100
D. OPNAV 4790/2K

1-21. How often does the Current Ship's Maintenance Project get updated?

A. Bi-weekly
B. Monthly
C. Bi-monthly
D. Quarterly

1-22. What is the purpose of the Current Ship's Maintenance Project (CSMP)?

A. To provide a list for preparing the ship's bills
B. To serve as a management tool for (PMS)
C. To provide a consolidated list of deferred corrective maintenance
D. To serve as a management tool for (PQS)

1-23. Where does the maintenance action form, OPNAV 4790/2K, originate?

A. In the captain's office
B. In the work center
C. In the engineer's office
D. In the 3-M coordinator's office

1-24. What are some of the steps that can be taken to reduce heat stress in Engineering spaces onboard naval vessels?

A. Remove all lagging and insulation
B. Tag-out ventilation system
C. Repair steam and hot water leaks
D. Increase the humidity in the work center

1-25. What is the long name of OPNAVINST 5100.19?

A. NAVSEA Publication
B. Ship's Maintenance and Material Management (3M) Manual
C. Basic Military Requirements
D. Navy Occupational Safety and Health Program Manual

1-26. At what temperature does the watch start taking hourly reading inside the Engineering spaces?

A. 70 °F
B. 100 °F
C. 105 °F
D. 110 °F

1-27. At what noise level must ear protection be worn to avoid noise hazard?

A. 48 dB
B. 84 dB
C. 114 dB
D. 200 dB

1-28. Where can you find the skills required of an Engineman?

A. NAVPERS 20024
B. NAVPERS 18068
C. NAVPERS 15005
D. NAVPERS 18087

1-29. What is the key factor in technical leadership?

A. Knowledge
B. Leadership
C. Experience
D. Integrity

1-30. On repair tenders ENs work in all of the following work centers, except?

A. Engine Overhaul
B. Governor Overhaul
C. Fuel Injector Shop
D. Air Conditioning and Refrigeration

1-31. Which of the following is a description of the Engineman rating?

A. A general rating in the engineering group
B. A specific rating that covers a narrow occupational field of duties and functions
C. A service rating within the Machinist's Mate rating
D. A special rating held by those who operate only one kind of engine

1-32. ENs must perform all the following technical duties for advancement in rank, except?

A. Conduct routine test and inspection on equipment
B. Operate and maintain internal combustion engines
C. Charge air conditioning plants
D. Perform overhaul and repair work on internal combustion engines

1-33. When does the Engineering Duty Officer assume the watch?

A. Underway
B. Sea and anchor
C. Coming along side of another ship
D. In port

1-34. What Engineering Watches are being stood when the ship is in the shipyard?

A. Cold-Iron Watch
B. Non-Operational Watch
C. Out of Commission Watch
D. Ship Yard Watch

1-35. Where can you find information about the Navy Enlisted Classification (NEC) Codes?

A. OPNAVINST 5100.19
B. NAVPERS 18086
C. NAVEDTRA 10045
D. NAVPERS 18068

1-36. Which of the following authorities details personnel with special NECs?

A. Chief of Naval Personnel
B. Chief of Naval Support Systems
C. Chief of Naval Operations
D. Naval Weapons Command

1-37. Where at your command can you find the complete package of information on NECs and qualification procedures?

A. Engineering Log Room
B. Technical Library
C. Career Counsel
D. Personnel Office

1-38. Who must sign the Engineering log and the Engineering Bell Book prior to being relieved of watch?

A. Officer of the Deck
B. Engineering Officer of the Watch
C. Engineering Duty Officer
D. Messenger of the Watch

1-39. Which of the following publications contains the occupational standards?

A. BUPERS 18068
B. NAVEDTRA 18068
C. NAVPERS 14104
D. NAVPERS 18068

1-40. Which pay grades are covered under Section I in NAVPERS 18068?

A. E7 through E-9
B. Officers
C. All pay grades
D. Warrant Officers

1-41. What publication lists the requirements for rate training manuals and other reference material to be used by personnel for advancement?

A. Advancement Progress Cards
B. Bibliography for Advancement Examination Study NAVEDTRA 10052
C. Rate Training Manual
D. Navy Technical Manual

1-42. What can you reference to find the most up-to-date training manual for advancement?

A. NAVEDTRA 10052
B. NAVEDTRA 10061
C. NAVPER 10068
D. NAVPER 10086

1-43. How often are changes made to Naval Ships' Technical Manual (NSTM)?

A. Monthly
B. Quarterly
C. Yearly
D. Every 2 years

1-44. Which courses listed in the Bibliography for Advancement for your rating must you complete to be eligible to take the advancement examination?

A. Only the course that that have letters after the chapter numbers
B. All courses listed for the engineering and hull group
C. All courses listed for the next higher pay grade
D. Courses marked with an asterisk for the next higher pay grade

1-45. What is the purpose of the Planned Maintenance System?

A. Increase the compatibility in the maintenance process
B. Keep maintenance actions general
C. Forecast and plan manpower and material requirements
D. Leave maintenance in the hands of the users

1-46. What is the OPNAVINST 4790.4?

A. Basic Military Requirements
B. Ship's Maintenance and Material Management (3M) Manual
C. Naval Occupational Safety and Health Program Manual
D. NAVSEA Publications

1-47. What is the one necessary step in a progressing Planned Maintenance Program?

A. Leadership
B. Planning
C. Material
D. Training

1-48. Where are warning signs posted for noise hazards?

A. In the area of noise hazard
B. Mess decks
C. General living area
D. Quarterdeck area

1-49. Which of the following can somewhat help control heat stress in an engine room?

A. Hot water leaks are corrected
B. Lagging and insulation is not hanging in its proper place
C. Keeping Ventilation off
D. Steam leaks to the bilge

1-50. Hearing protection must be worn where the noise level is above what maximum number of decibels?

A. 55 dB
B. 65 dB
C. 78 dB
D. 84 dB

Chapter 2

Basic Administration and Training

2-1. Which of the following entries is NOT required in the Engineering Log?

A. The total engine miles steamed for the day
B. Any injuries to engineering department personnel
C. The amount of the fuel consumed for the day
D. Draft and displacement upon getting underway

2-2. Instructions for making entries in the Engineering Logs are contained in which of the following references?

A. Naval Ships' Technical Manual, chapter 090
B. OPNAVINST 5100.23(series)
C. Log Form, NAVSHIP 3120.3G
D. Engineering Log Form, NAVSHIP 3120.7K

2-3. How are manual corrections made to the Engineering Bell Book?

A. By crossing out entry and rewriting it.
B. By erasing entry and rewriting it
C. By leaving original incorrect entry as is
D. By drawing a single line , initial , and rewriting correct entry on next line of log

2-4. When are checks and audits of all tag-outs usually done?

A. At the end of each workday
B. Every Friday
C. Every 2 weeks
D. At the end of each quarter

2-5. In proper tag-out procedure, what person verifies the completeness of the tag-out action?

A. The person initiating the tag-out
B. The authorizing officer
C. The Engineering officer of the watch (EOOW)
D. The second person that made an independent check

2-6. Where would you find the instructions for the Navy Tag-Out Program?

A. NAVPERS 5100.25
B. OPNAVINST 3120.23
C. OPNAVINST 3120.32
D. NAVPERS 5100.52

2-7. What documents are used to prohibit the operation of equipment that could jeopardize the safety of personnel or endanger equipment?

A. Out-of-Commission labels
B. Caution tags
C. Out-of-Calibration labels
D. Danger tags

2-8. What can be determined from a spectrographic analysis?

A. The rate of flow of cooling water to the lube oil cooler
B. The amount of oil the engine uses per month
C. The extent of accelerated wear of an internal combustion engine
D. The amount of oil pressure produced by the lube oil pump

2-9. When the shipyard or IMA laboratory receives the oil samples, which of the following tests is performed?

A. Acid
B. Bubble
C. Spectrometric
D. Gas

2-10. In addition to technical competence, which of the following characteristics should you possess before you can teach others about the Engineering rating?

A. Ability to organize information
B. Soft, caring voice
C. Ability to Informally train or shoot from the hip
D. Good sense of imagination

2-11. A newly assigned person to the engine room is not ready for messenger duty training until he or she becomes familiar with which of the following factors?

A. Duties of the throttleman
B. Technique of reading pressure gauges
C. Procedures of starting or securing main propulsion plant
D. Locations of all machinery, equipment, piping, and valves

2-12. What section of the PQS deals with the major working parts of the duties, assignments, and responsibilities needed for qualifications?

A. Fundamentals
B. Systems
C. Watchstations
D. Qualification cards

2-13. In addition to PQS, what other two requirements must you and your subordinates satisfy?

A. Air Warfare and Damage Control Underlined
B. 3-M and damage control
C. Air and Surface Warfare
D. 3-M and Surface Warfare

2-14. What is the main purpose of the Engineering Operational Sequencing System (EOSS)?

A. To restore plant operation after a casualty
B. To shorten communication lines to the bridge
C. To recognize the five levels of operation
D. To eliminate the flow of necessary communication

2-15. What is the best form of casualty control?

A. Restoring the casualty
B. Organizing effectively
C. Minimizing the casualty
D. Preventing the casualty

2-16. What is the best source for studying diesel engine casualty control procedures?

A. The Naval Ships' Technical Manual
B. This rate training manual
C. The Watch, Quarter, and Station Bill
D. The Ship's Engineering Casualty Control Manual

2-17. To be a successful watch stander, you must be able do all of the following EXCEPT……..

A. operate a torque wrench.
B. take appropriate and prompt corrective actions.
C. be ready, in emergency, to act quickly and independently.
D. know the ship's piping systems and how, where, and why they are controlled.

2-18. In which of the following ways would it be easiest to gain the respect and confidence of your supervisors and shipmates?

A. Be late to watch.
B. Turn over a bad watch.
C. Stand a good watch.
D. Give wrong information during turnover.

2-19. Which of the following conditions is NOT a sign of faulty operation machinery?

A. Water in the sight glass of the expansion tank
B. Unusual noises
C. Abnormal operating speeds
D. Vibrations

2-20. The QA program organization (Navy) begins with what officer(s)?

A. Type commanders
B. Commanding officers
C. Commander in chief of fleets
D. QA officers

2-21. Level A assurance provides which of the following levels of assurance?

A. The most stringent of restrictive verification
B. The least verification
C. Limited verification
D. Adequate verification

2-22. Which of the following statements is NOT correct about levels of essentiality?

A. They are codes assigned by supply.
B. They indicate the degree of impact on the ship's mission.
C. They indicate the impact on personnel safety.
D. They reflect the degree of confidence that procurement specifications have been met.

2-23. Which of following Engineering department's records must be preserved as permanent legal records?

A. Engineering Log/Fuel and Water Report
B. Engineering Bell Log/Monthly Summary
C. Engineering Log/Engineering Bell Book
D. Machinery History/Boiler Room Operating Record

2-24. What is the standard engine order telegraph symbol for back emergency speed?

A. Z
B. 1
C. BF
D. BEM

2-25. Which of the following documents indicates the amount of fuel on hand as of midnight, the previous day?

A. Daily Boat Fueling Report
B. Fuel and Water Account
C. Fuel and Water Report
D. Diesel Engine Operating Record

2-26. Information about engineering records that must be kept permanently, is contained in which of the following publications?

A. NSTM chapter 080
B. SECNAVINST P5212.5(series)
C. NAVSHIPS 5084
D. NAVSHIPS 3648

2-27. When a piece of equipment fails, you must take which of the following actions before repairs can begin?

A. Isolate and tag-out the system/equipment
B. Notify the Type Commander
C. Submit an OPNAV Form 4790K
D. Request permission the relieve pressure from the system before isolation

2-28. When repairs have been completed on a piece of equipment, what must be accomplished before the operational testing of equipment or system?

A. Complete the work request
B. Warm up the system
C. Align the equipment/system in accordance with EOP
D. Clear the tags

2-29. What documents are used as a precautionary measure, providing special instructions and warning of unusual measures that must be used to operate the tagged item?

A. DANGER TAGS
B. CAUTIONS TAGS
C. OUT-OF-CALIBRATION LABELS
D. OUT-OF-COMMISSION LABELS

2-30. What documents are used to identify instruments that will not give accurate readings because they are either defective or isolated from the system?

A. Danger Tags
B. Caution Tags
C. Out-of-Calibration Labels
D. Out-of-Commission Labels

2-31. What method is used to determine if an engine needs to be overhauled or just temporarily shut down for sample maintenance?

A. The current engine operating data is compared with the previous operating data.
B. The operating data of the engine is compared with same type.
C. The temperature of the lube oil entering the cooler is compared to that leaving the cooler.
D. The present amount of lube oil consumption is compared with the previous lube oil consumption.

2-32. If your ship is home-ported on the West Coast and you need additional information concerning trend analysis and oil spectrometric analysis, to what Navy instruction should you refer?

A. OPNAVINST 43P1
B. COMNAVSURFLANTINST 9000.1C
C. COMNAVSURFPACINST 4700.1B
D. SECNAVINST P5212.5

2-33. Where would you be able to find the most information about Engine Trend Analysis?

A. NAVSEA S9233-C3-HB-010.010
B. COMNAVSURFLANTINST 9000.1C
C. COMNAVSURFPACINST 4700.1B
D. SECNAVINST P5212.5

2-34. Which of the following factors does NOT help in determining the procedures for training a new person in engine-room operations?

A. Ship's operating schedule
B. Number of experienced personnel available
C. Condition of engine-room equipment
D. Trainee's manual skills level

2-35. What factors should be emphasized constantly throughout an engine-room training program?

A. Safety precautions
B. Trial and error techniques
C. Emergency repairs procedures
D. Machinery characteristics

2-36. What section of the PQS deals with the major working parts of the installation, organization, or equipment?

A. Fundamentals
B. Systems
C. Watchstations
D. Qualification Cards

2-37. What is required of all commands to have on hand for every piece of hazardous material in their inventory?

A. Material Safety Data Sheet
B. Material Safety Document Sheet
C. Material Safety Data List
D. Maintenance Safety Data Sheets

2-38. Which of the following is contained in the Engineering Operational Casualty Control (EOCC) subsystem?

A. Watch qualification
B. Casualty symptoms
C. Casualty reporting to the Type Commander
D. Casualty reports to Fleet Commander

2-39. When combatting an engine-room casualty, which of the following items would you use?

A. EOP
B. NSTM
C. EOCC
D. The Watch, Quarter, and Station Bill

2-40. In the Engineering Operational Procedures (EOPs), what level of operation is for the system operators?

A. 1
B. 2
C. 3
D. 4

2-41. If a major piece of equipment has any material failure, which of the following pieces of information is essential to the Engineering Officer?

A. If there is similar failure in other pieces of equipment
B. If it would be beneficial to exchange parts
C. If there is a spare keep it operational
D. If there are sufficient funds in the budget to cover the cost of repairs

2-42. To be a successful watch stander, you must be able do all of the following, EXCEPT……..

A. Operate equipment that you are qualified to operate.
B. Be able to read and interpret measuring instruments.
C. Recognize and remove hazards, stow gear that is adrift, and keep deck plates clean and dry.
D. Operate a pneumatic tool.

2-43. To get the best watch turnover information, when should you relieve the watch?

A. Right on time
B. 15 minutes late
C. A little early
D. Whenever you decide to take the watch

2-44. Which of the following duties is NOT the responsibility of the Quality Assurance Officer?

A. Coordinating the ship’s QA training program
B. Maintaining the ship’s record of test and inspection reports
C. Conducting QA audits as required
D. Monitoring work procedure for QA

2-45. Level B assurance provides which of the following levels of assurance?

A. Minimum verification
B. Limited verification
C. The most stringent verification
D. Adequate verification

2-46. In regards to Ship-to-Shop work, who is responsible for witnessing any test requirements?

A. The ship’s Quality Assurance (QA) personnel assigned to the Deck Department
B. The work center representative who requested the work to be completed
C. The repair facility supervisor
D. The repair facility QA representative

Chapter 3

Precision and Measuring Instruments

3-1. To ensure the accuracy when measuring crankshaft end play, take the measurement what minimum number of times?

A. 1
B. 2
C. 3
D. 4

3-2. Of the following statements about the bore gauge, which is incorrect?

A. It gives a direct measurement.
B. It has two stationary spring-loaded point and san adjustable point.
C. It is one of the most accurate tools for measuring a cylinders bore.
D. It checks the cylinder for out-of-roundness or tapering.

3-3. The strain/deflecting gauge is used for which of the following measurements?

A. Crankshaft run-out.
B. Crankshaft end play
C. Crank web clearance
D. Crankshaft alignment.

3-4. What is the preferred ratio of the torque multiplier?

A. 1 to 1
B. 2 to 1
C. 3 to 1
D. 4 to 1

3-5. When an engine has been repaired, and needs to be tested for proper operation and power output, what piece of test equipment is used?

A. Stroboscope
B. Dynamometer
C. Borescope
D. Fluxgauge

3-6. What must you do to the strain/deflection gauge after each reading?

A. Reset the gauge to zero
B. Reposition the gauge after rotation the crankshaft
C. Nothing, do not touch until all reading are completely taken
D. Mark crankshaft, and move gauge 180 degree to new position

3-7. A borescope is used to inspect which of the following diesel engine parts?

A. Engine base
B. Flywheel
C. Fuel racks
D. Cylinder heads

3-8. What must you do before handling the vernier caliper so that you do not damage it?

A. Put on rubber gloves.
B. Wrap the vernier caliper with protective cover.
C. Wash your hands.
D. Lightly cost vernier caliper with oil.

3-9. When using a snap gauge, why do you use the handle and avoid touching the gauge itself?

A. Body oil will damage the moving parts of the gauge.
B. The gauge is extremely sensitive.
C. The special oil on the snap gauge is hard to wash off your skin.
D. Your body heat may affect the reading of the gauge.

3-10. What kind of force would you use on the knurled thimble of a micrometer when taking a measurement?

A. Slight
B. Moderate
C. None
D. A lot

3-11. When you perform shaft runout using a micrometer, the total amount the pointer moves is called is (TIR), which stands for what?

A. Total indicator reading
B. Total indicator runout
C. Total index reading
D. True indicator reading

3-12. What is the normal electrical operating range for a strobescope?

A. 120 volt, 60 Hz, and direct current supply
B. 120 volt, 60 Hz, and alternating current supply
C. 240 volt, 60 Hz, and direct current supply
D. 240 volt, 60 Hz, and alternating current supply

3-13. What is the correct method to follow when opening a micrometer?

A. Twirl the frame.
B. Hold the knurled sleeve with both hands and twirl the frame.
C. Hold the frame with one hand and turn the knurled sleeve with the other hand.
D. Twirl the knurled sleeve.

3-14. Why must you expose the bore gauge and its special tools to the same environment before measuring?

A. Because it is a good practice to have all the tools and the parts measured in one place
B. Because doing so will give some time to read the bore gauge operating manual
C. Because by doing this, you can check what else you need before starting a measurement
D. Because the temperature differential may cause your reading to be inaccurate

3-15. When a strain/deflection gauge is used, readings are generally taken in how many crank positions?

A. 1
B. 2
C. 4
D. 6

3-16. If you use an extension to a torque adapter, how should the torque be applied to the part or fastener compared to the torque indicated on the torque wrench?

A. The same
B. Greater
C. Less
D. Negative

3-17. In what location would you most likely use a dynamometer?

A. Ship repair locker
B. Tender
C. Shore activity shop
D. Machine shop

3-18. When taking crankshaft End Play or Thrust Reading, which of the following steps is part of the procedure you must use?

A. Attach a dial indicator gauge as far possible away from the vibration damper.
B. Set the dial indicator to zero.
C. Position the dial indicator gauge so the contact point touches the back of the vibration damper.
D. Move the crankshaft away from the dial indicator.

3-19. How does the strain/deflection gauge check crankshaft alignment on large diesel engines?

A. Distance between crank web and journal
B. Distance between crank web and counterweight
C. Distance between counterweight and journal
D. Flexing motion of the web

3-20. Which of the following measurements of speed is not measured by a stroboscope?

A. In-line
B. Vibration
C. Reciprocating
D. Rotating

3-21. Ridge reamers are used to remove ridges on cylinders; how are these ridges formed?

A. Carbon build up from high exhaust temperatures
B. Dirty lube oil
C. Excessive lube oil
D. Piston rings moving up and down in the cylinder

3-22. Most micrometers read down to what fraction on an inch?

A. .00001
B. .0001
C. .001
D. .01

Chapter 4
Reciprocating Internal-Combustion Engine

4-1. In a diesel engine, internal combustion causes the piston to move by?

A. Pressure of gases produced by the burning of the fuel and air in the cylinder
B. The admission of fuel and air into the combustion space
C. Specially designed parts connected to a shaft
D. The concept of reciprocity

4-2. In describing engine operation, which of the following definitions refers to the term “cycle”?

A. One rotation of the engine crankshaft
B. One stroke of a piston
C. The rotation of the crankshaft that produces the turning of the jacking gear
D. The sequence of events that produces a power pulse

4-3. What factors determines the number of events occurring in a cycle of operation?

A. Crankshaft revolution
B. Distance a piston travels during a stroke
C. Number of pistons
D. Type of engines (diesel or gasoline)

4-4. The combustion cycle specifically refers to which of the following facts?

A. The mechanics of engine operation
B. Period of two combustion cycles
C. Cycles of two operation
D. Mechanical cycle of operation

4-5. The 2 strokes of a 2-stroke cycle engine are?

A. Power and intake
B. Compression and power
C. Intake and exhaust
D. Exhaust and compression

4-6. What is the relationship between the temperature developed in a combustion space and the compression ratio of the engine?

A. Higher compression ratios create higher temperatures
B. Higher temperatures create higher compression ratios
C. Lower temperatures creates higher compression ratios
D. Higher compression ratios create lower temperatures

4-7. An indicator card, or pressure-volume diagram, shows graphically the?

A. Compression ratio of the engine
B. Relationship between pressure and volume during one cycle of the engine
C. Volume of the engine
D. Relationship between pressure and volume during one stroke of the engine

4-8. In an opposed-piston engine, the term “crank lead” means that?

A. One crankshaft turns faster than the other
B. The two crankshafts turn in different directions
C. One piston in a cylinder reaches Inner Dead Center when the other reaches Outer Dead Center
D. One piston in a cylinder reaches Inner Dead Center before the other

4-9. The difference in crank lead between the upper and lower cranks of the engine cause the lower shaft to?

A. Operate most of the engine’s accessories
B. Longer combustion events
C. Exhaust events starting before scavenging events
D. Rotates faster than the upper shaft

4-10. A dye penetrant test meets the requirements for quality assurance when it is conducted by what person?

A. QA Inspector
B. Any qualified person
C. Certified nondestructive testing technician
D. Well-trained engineman

4-11. Which of the following conditions is NOT a cause for the liner to be improperly seated?

A. Metal chips
B. Nicks or burrs
C. Improper fillets
D. Oversized liner

4-12. Which of the following symptoms is an indication of scored cylinder?

A. Low compression pressures
B. High compression pressure
C. Rapid wearing out of strainer and liner parts
D. Cracked or broken piston rings

4-13. What condition is NOT a cause of abnormal liner wear?

A. Insufficient lubrication
B. Improper starting procedures
C. Dirt in the lube oil
D. High cooling water temperature

4-14. You are removing a cylinder liner from an engine. When fastening the special liner puller to the liner studs, why must you tighten the caps by hand instead of by wrench?

A. Because the nuts cannot be reached with a wrench
B. Because threads on both nuts and studs could be damaged by the wrench
C. Because the cylinder liner could be scratched with the wrench
D. Because there is some danger that the wrench could be left in the cylinder liner

4-15. The gaskets which are used between the mating surfaces of the heads and the blocks of an engine give this joint which of the following characteristics?

A. Acid resistance
B. Rigidity
C. Protection against leakage
D. Correct shape

4-16. What symptoms do NOT indicate fouling in the combustion chamber?

A. Excessive oil pumping
B. Low compression
C. Smoky exhaust
D. Loss of power

4-17. Which of the following conditions will NOT cause cracks on an engine’s cylinder head?

A. Obstruction in the combustion space
B. Restriction of the cooling passages
C. Addition of hot water to a cold engine
D. Improperly tightened studs

4-18. After inspecting the engine intake valves, you discovered that the surface of the valve head has damage. Which of the following casualties is the most probable cause?

A. It is sticking
B. It is bent
C. It has a weak spring
D. It has a loose valve seat

4-19. Minor pits and flaws may be removed from the valves seat by what method?

A. Buffing
B. Insert replacements
C. Hand grinding
D. Rubbing with Prussian blue

4-20. If the threads on a rocker arm adjusting screw become worn, what must you do?

A. Replace the screw only
B. Replace the screw and locknut only
C. Dress the threads on the screw
D. Replace the rocker arm, screw, and locknut

4-21. What is the most frequent maintenance requirement for rocker arms?

A. Reaming the bushing in the rocker arm
B. Inspecting the rocker arm ends for wear
C. Checking tappet clearance and locknut tightness
D. Replacing tappet adjusting screws and locknuts

4-22. When a lash adjuster is adequately supplied with oil, what will most likely cause it to operate noisily?

A. Excessive clearance
B. Broken parts
C. Dirt, resin, or abrasive particles
D. Missing check ball or spring

4-23. Why is it necessary to scrape around the top of a cylinder bore before pulling the piston?

A. To increase clearance for the piston
B. To remove any metal ridge and carbon deposits
C. To remove abrasive particles and gum
D. To free the piston rings

4-24. When using a brass drift to remove a frozen piston ring, you must avoid damaging which of the following parts?

A. The rings
B. The drift
C. The land
D. The camshaft

4-25. Operation of an internal combustion engine above the specified temperature limits may result in which of the following problems?

A. Low cylinder temperatures
B. Increased oil viscosity
C. Low oil temperature
D. Lack of lubrication of the cylinder walls

4-26. You are installing a new sleeve bearing. Which of the following procedures will make it easier to insert the new sleeve bearing?

A. Apply plenty of grease to the bushing
B. Shrink the sleeve bearing with dry ice
C. Shrink the piston with dry ice
D. Heat the sleeve bearing in the oven

4-27. To measure the clearance between a piston pin and its bushing, which of the following items should you use?

A. Feeler gauge
B. Micrometer
C. Leads
D. Prussian blue

4-28. Crankshaft journals that exceed the specified tolerance for out-of-roundness should be refinished by which of the following means?

A. Stoning
B. Grinding
C. Filing
D. Scraping

4-29. What instrument is used to take crankweb deflection reading?

A. Feeler gauge
B. Outside micrometer
C. Strain gauge
D. Gauge block

4-30. What is the recommended corrective action for journal bearing that have small raised surfaces or minor pits?

A. Replace the bearing
B. Stone down the raised surfaces
C. Grind the surfaces with a hand grinder
D. Smooth the surface with a bearing scraper

4-31. Which of the following senses is NOT used by the diesel engine troubleshooter?

A. Smell
B. Taste
C. Sight
D. Hearing

4-32. When a diesel engine can neither be cranked nor barred over, which of the following troubles is most probably indicated?

A. Depleted air supply
B. Open cylinder relief valve
C. Improperly engaged turning gear
D. Out-of time air-starting motor

4-33. An engine cannot be cranked, but it can be barred over. Which of the following is the most probable fault?

A. Improper throttle setting
B. Tripped overspeed
C. Engaged jacking gear interlock
D. Seized piston

4-34. In general, what should you do if a pressure-actuated air-starting valve is not functioning properly because of a weak return spring?

A. Placed another washer on top of the valve stem
B. Replace castellated nut with a heavier one
C. Restress the valve return spring
D. Install a new return spring

4-35. Metal fatigue in the nipple of a fuel system is usually caused by which of the following factors?

A. Leakage
B. High injection pressure
C. Vibration
D. Erosion

4-36. Which of the following problems is likely to cause failure of a diesel engine mechanical governor?

A. Faulty oil seal
B. Bound control linkage
C. Defective starting valve
D. Low oil level

4-37. Most diesel engines are equipped with a special means of cutting off their air or fuel supply in an emergency. In which of the following situations would the special means be used?

A. Engine cannot be cranked or barred over
B. Parts of the exhaust system are obstructed
C. Fuel oil injection system is not properly timed
D. Overspeed safety device does not operate when speed becomes excessive

4-38. A cylinder compression leak is indicated when the pressure in a particular cylinder of an engine signals which of the following conditions?

A. It is much higher than the pressure in the other cylinders
B. It is much lower than the pressure in the other cylinders
C. It fluctuates from normal to much below specified pressures
D. It fluctuates from normal to much above specified pressures

4-39. In the Fulton-Sylphon automatic temperature regulator, what happens if you decrease the spring tension?

A. The velocity of the cooling water decreases
B. The temperature range of the regulator increases
C. The temperature range of the regulator decreases
D. The velocity of the cooling water increases

4-40. Which of the following conditions is a major contributing factor to diesel engine power loss, starting failure, and frequent stalling?

A. High cooling water temperature
B. Faulty operation of the governor
C. Improperly engaged jacking gear
D. Faulty air-starting distributor

4-41. A leaking fuel injector may cause an engine to?

A. Stop
B. Overheat
C. Operate better
D. Continue to operate when you attempt to shut it down

4-42. What must you do an improperly operating safety valve when it is removed from an engine cylinder?

A. Reset the spring tension
B. Replace the shear pin
C. Machine and lap the valve
D. Replace it with a new one

4-43. When cleaning the cylinder ports of an engine, you can prevent carbon from entering the cylinder by performing which of the following actions?

A. Using a vacuum cleaner while brushing off the carbon
B. Jacking the engine over to a position that the piston ports are blocked
C. Covering the intakes of the cylinders
D. Blowing down the engine with air after you are finished

4-44. Which of the following problems can result from over-priming a gasoline engine?

A. Overheated engine
B. Inoperative engine
C. Stuck piston rings
D. Corrode piston crowns

4-45. Most oil used by the Navy can be heated to what maximum temperature without damaging the oil?

A. 180 °F
B. 185 °F
C. 190 °F
D. 195 °F

4-46. The size of the discharge rings used in a purifier is determined by which of the following factors?

A. Viscosity of the oil
B. Moisture content of the oil
C. Sediment of the oil
D. Specific gravity of the oil

4-47. Diesel engines are classified as reciprocating internal-combustion engines because which of the following actions?

A. Use energy from fuel burned outside their cylinder
B. Burn fuel in a combustion chamber that moves back and forth
C. Burns fuel in a confined chamber where the energy from the fuel moves a piston back and forth
D. Use a continuous combustion process to impart rotary motion to the piston

4-48. The thermal energy produced by thermal combustion in an engine is transformed into what kind of energy?

A. Expansion
B. Internal
C. External
D. Mechanical

4-49. One cycle of engine operation includes?

A. One combustion cycle
B. One mechanical cycle
C. Either a half of a mechanical or an entire mechanical cycle depending on the type of engine
D. One mechanical and one combustion cycle

4-50. When is fuel injected into a cylinder of a diesel engine?

A. Before air in the cylinder is compressed
B. After air in the cylinder is compressed
C. After combustion gases in the cylinder have expanded
D. As air is taken into the cylinder

4-51. What two events occur simultaneously in a 2-stroke cycle engine?

A. Scavenging and compression
B. Exhaust and scavenging
C. Ignition and expansion
D. Exhaust and compression

4-52. After ignition of the fuel and before the piston reaches Top Dead Center (TDC), there is little change in which of the following conditions in a diesel engine?

A. Pressure
B. Temperature
C. Energy
D. Volume

4-53. An engine having a combustion chamber located between a cylinder head and the crown of a piston is which of the following types?

A. Double-acting
B. Single-acting
C. Horizontal-acting
D. Opposed-acting

4-54. Crank lead is used to cause which of the following conditions?

A. Longer combustion events
B. Exhaust events lasting longer that scavenging events
C. Exhaust events starting before scavenging events
D. Higher combustion temperatures

4-55. Before you begin an inspection or test of an engine frame or block what should you do first?

A. Consult the manual because specific procedures vary with engines
B. Check the engine's preventive maintenance schedule
C. Clean the outside of the engine thoroughly
D. Warm up the engine

4-56. Broken piston rings will cause which of the following problems?

A. Scored cylinder liners
B. Connecting bearing failure
C. High lube-oil temperature
D. High freshwater temperature

4-57. How do you determine liner wear?

A. Take piston and liner measurement and get the difference
B. Take measurement at three levels in the liner
C. Compare wear of the piston rings
D. Compare compression readings

4-58. Under which of the following conditions are corrosive vapors most likely to condense on the cylinder liner walls of an engine?

A. While operating at temperatures exceeding normal
B. While operating with the lube- oil pressure below normal
C. While warming up after it is first started
D. While operating in such a way that normal lube-oil pressure is exceeded

4-59. You are inspecting a cylinder head for cracks. Which of the following is NOT a correct procedure to use?

A. Perform a compression test
B. After bringing the piston of each cylinder to TDC, apply compressed air
C. Examine by sight or with magnetic powder
D. Perform a hydrostatic test that is used on a water-jacket cylinder

4-60. What should you do if you discover a warped or distorted cylinder head during an inspection?

A. Machine the head to correct tolerance
B. Replace the head as soon as possible
C. Over-torque the head to compensate for the warpage
D. Reduce the load on the engine

4-61. What valve problems will cause a valve to hang open?

A. Burned
B. Floating
C. Sticking
D. Bent

4-62. What valve casualty is usually caused by resinous deposits left by improper lube-oil or fuel?

A. Burned
B. Sticking
C. Weak
D. Bent

4-63. Which of the following valve casualties will cause the valves to fail to close completely?

A. Burned
B. Floating
C. Sticking
D. A weak spring

4-64. When replacing a valve seat insert, which of the following procedures should you follow?

A. Plan the operation so that the insert is placed slowly and precisely
B. Use boiling water to heat the valve seat
C. Drive the insert down with a special tool
D. Shrink the valve guide or counterbore with dry ice

4-65. Which of the following defects does NOT warrant valve spring replacement?

A. Loss of 2 percent of length
B. Damage to protective coating
C. Hairline cracks
D. Rust pits

4-66. To adjust the intake valve tappet valve of a 4-stroke cycle engine, the piston must be in what position?

A. On the intake stroke
B. On the compression stroke
C. Between the compression and power stroke
D. Between the intake and compression stroke

4-67. After setting a tappet clearance and locking the adjusting screw with a locknut, what is your next step?

A. Recheck the clearance
B. Adjust the next tappet
C. Warm the engine and reset the clearance
D. Check the manufacture’s manual to see if the clearance is correct

4-68. Which of the following actions should you take to insert a camshaft into the camshaft recess?

A. Rotate as you push it in
B. Shake it up and down
C. Apply grease to it
D. Hit it with a sledge

4-69. To scour the top of a cylinder bore before pulling out the piston, you should use which of the following tools?

A. Power grinder
B. File
C. Metal scraper
D. Emery cloth

4-70. In addition to ring gap, what other factors must you measure to ensure correct ring fit?

A. Ring end gap
B. Ring-to-land-clearance
C. Ring width
D. Ring circumference

4-71. If the oil flow to a piston is restricted, where will the deposits be formed?

A. On the underside or the piston crown
B. Behind the compression ring
C. On the piston walls
D. On the topside of the piston crown

4-72. When inserting new piston pin bushing, what are the three things you must check?

A. Alignment, clearance, and appearance
B. Cleanliness, clearance, and appearance
C. Appearance, alignment, and cleanliness
D. Cleanliness, alignment, and clearance

4-73. A rough spot or slight score on a crankshaft journal should be removed by dressing with which of the following material?

A. Fine sandpaper
B. Rough sandpaper
C. Fine oilstone
D. Grinder

4-74. Impending bearing failures may be indicated by which of the following factors?

A. Higher than normal lube-oil pressure and lower than normal lube-oil temperature
B. Lower than normal lube-oil pressure and higher than normal lube-oil temperature
C. Higher than normal lube-oil pressure and temperature
D. Lower than normal lube-oil pressure and temperature

4-75. Which of the following means of determining clearances will NOT leave an impression in the soft bearing metal?

A. Leads
B. Shim stock
C. Feeler gauge
D. Plastigage

4-76. Which if the following actions will be the greatest aid in detecting minor leaking?

A. Standing watch
B. Conducting administrative inspection
C. Conducting material inspection
D. Conducting routine cleaning

4-77. Which of the following is a symptom of excessive clearance between a piston and its cylinder?

A. Piston slap
B. Less oil consumption
C. Minimal carbon deposits
D. Blue exhaust

4-78. If an engine cannot be cranked, but can be barred over, which of the following systems is most probable the source of trouble?

A. Starting
B. Fuel
C. Ignition
D. Lubrication

4-79. Which of the following practices tends to reduce or eliminate the formation of gummy deposits that cause upper and lower pistons of pressure-activated air-starting valves to stick in the cylinders?

A. Increasing the tension of the valve return spring
B. Draining the storage tank and water traps of the air-starting system
C. Jacking the engine over manually before starting to free any valves that may be stuck
D. Decreasing the tension of the valve return spring

4-80. What is the main reason for troubles in the fuel and injection pumps?

A. Contaminated fuel
B. Improper adjustments
C. Coated fuel lines
D. Excessive vibrations

4-81. What are the two main causes of leakage in fuel tanks?

A. Corrosion and excessive fuel line pressure
B. Metal fatigue and improper welds
C. Vibration and metal fatigue
D. Clogged fuel lines and corrosion

4-82. Which of the following actions will cause the overspeed safety device of an engine to become inoperative?

A. Trying to start the engine with low air-starting pressure
B. Tripping the device accidentally while trying to start the engine
C. Shutting off the fuel supply after starting the engine
D. Shutting off the air supply after starting the engine

4-83. What diesel engine system is likely to be at fault if a cylinder misfires regularly?

A. Lubrication
B. Fuel
C. Exhaust
D. Ignition

4-84. What corrective actions should you take if the water in the cooling system of a diesel emergency generator overheats because the thermostat fails to function?

A. Clean the bellows of the element
B. Adjust the tension of the regular spring
C. Clean the freshwater cooler
D. Replace the thermostat

4-85. Which of the following troubles in the engine exhaust system will cause back pressure?

A. Obstruction in the combustion space
B. Thermostat failure
C. Restricted exhaust
D. Restricted oil filter

4-86. How can you determine whether blower rotor gears are worn excessively?

A. Measure the clearance between the leading and the trailing edges of the rotor lobes
B. Measure the backlash of the gear sets
C. Measure the clearance between the rotor lobes and the casing
D. Check the timing of the rotors

4-87. What should you do immediately after disconnecting the linkage to the governor, if you are checking an engine for a stuck control rack?

A. Visually inspect the rack
B. Try to move the rack by hand
C. Test the return springs
D. Clean the remove rack

4-88. Which of the following is result of the engine having clogged exhaust ports during operation?

A. Low exhaust temperature
B. Overheating of the lube-oil
C. Popping of the cylinder safety valves
D. Dirty fuel oil

4-89. What kind of noise will most likely be coming from an engine operating with a broken engine part?

A. Rattling
B. Clicking
C. Pounding
D. Knocking

4-90. When the starting motor of a gasoline engine turns but fails to crank the engine, the trouble is usually found where?

A. Drive assembly
B. Engine timing
C. Fuel system
D. Ignition system

4-91. You are checking for trouble in a fuel system that has a wobble pump. If the pump feels or sounds dry, where is the most likely cause?

A. In the carburetor
B. In the line to the fuel pump
C. In the fuel pump
D. Between the fuel pump and the supply pump

4-92. Oil purifies are designed give maximum efficiency when you operate the purifier at what limits?

A. Minimum speed
B. A speed determined by prevailing conditions
C. A speed between minimum and maximum and below rated speed
D. Maximum designed speed and rated capacity

4-93. When the military symbol 9250 lube-oil is to be purified, it should be heated to what specific temperature?

A. 140 °F
B. 160 °F
C. 175 °F
D. 180 °F

4-94. What is the best method of determining the efficiency of a purifier?

A. Oil clarity test
B. Oil analysis
C. Batch process
D. Bowl sediment check

Chapter 5
Principal Stationary Parts of an Engine

5-1. How often should machinery space piping be marked with directional flow and system labeling?

A. Once
B. Twice
C. Three times
D. Four times

5-2. What is the standard color code for piping on lubricating oil system?

A. Green
B. Yellow
C. Orange
D. Yellow and black striped

5-3. What is the standard color code for piping on hydraulic oil systems?

A. Orange
B. Yellow
C. Green
D. Dark gray

5-4. What is the maximum shelf life, in years, for rubber hose?

A. 8
B. 12
C. 16
D. 4

5-5. From what type of construction are blocks for most large engines made?

A. Cast iron en bloc
B. Welded steel forgings and plates
C. Cast steel en bloc
D. Welded aluminum forging and plates

5-6. What part of the engine houses components such as gears, blowers, and attach pumps?

A. Sumps
B. End plates
C. Bases
D. Access covers

5-7. In a dry sump engine, the lubricating oil returns to what locations?

A. Purifier
B. Reservoir
C. Storage tank
D. Settling tank

5-8. Which of the following statements is most accurate in describing the dry-type cylinder liner?

A. A thick wall with integral cooling passages
B. A thick wall that is water jacketed
C. A thin wall without cooling passages
D. A thin wall that is integral with the block

5-9. On a wet-type cylinder liner, the static seals are generally constructed of what item on the crankshaft?

A. A gasket under a flange or machined fit
B. Rubber or neoprene rings
C. A labyrinth seal
D. A non-hardening sealing compound

5-10. To reduce wear resistance, some diesel engines are plated with what material?

A. Nickel
B. Steel
C. Cooper
D. Chromium

5-11. Which of the following conditions must be met with the design and material of a cylinder head, EXCEPT?

A. Rapid change in temperature
B. Rapid change in pressure
C. Mechanical stress
D. Constant contact with fluid

5-12. Compressibility is a common property of all gaskets. Which of the following materials can be used in the manufacturing of gaskets?

A. Plywood
B. Tin
C. Copper
D. Aluminum

5-13. What device is the supporting and connecting pedestal between an engine and the ship's structure?

A. Engine base
B. Subbase
C. Chock
D. Stud

5-14. Which of the following mechanisms is NOT mounted to the ship's structure by the shock absorbers and vibration isolators?

A. Small generators mounted near the hull
B. Engines that will receive shock loads from powerful explosions
C. Propulsion engines
D. Operating engines that develop high-frequency, small-amplitude vibrations

5-15. A vibration isolator with how many rings is used to support generator sets?

A. 1 spring
B. 2 springs
C. 3 springs
D. 4 or more springs

5-16. When tubular objects are measured, which of the following dimensions is NOT as important?

A. Outside diameter (OD)
B. Inside diameter (ID)
C. Wall thickness
D. Total diameter (TD)

5-17. What is the standard color code for piping on fuel system pipes?

A. Green
B. Yellow
C. Dark gray
D. Yellow with black stripes

5-18. What is the general reason that copper-nickel alloy material has become widely used in the Navy for seawater systems piping?

A. Lighter and easy to move around
B. Not as expensive
C. Resistance to seawater corrosion
D. Easier to weld

5-19. What Naval Ships' Technical Manual (NSTM) chapter would you use as a reference for information about hoses and fittings?

A. Chapter 100
B. Chapter 210
C. Chapter 505
D. Chapter 660

5-20. In a modern internal-combustion engine, the load-carrying part of the engine is referred to as the?

A. Bedplate or base
B. Sump or oil pan
C. Cylinder block
D. Frame

5-21. In the majority of large engines, what component serves to support the cylinder block?

A. Sump
B. Base
C. Bedplate
D. Oil pan

5-22. Why do main diesel engines have oil galleries drilled into their blocks?

A. To direct lubricating oil to the crankshaft main bearing
B. To direct oil to the rocker arm assembly
C. To direct lubricating oil to the piston crowns
D. To direct lubricating oil to the camshaft

5-23. Where does the lubricating oil go after it leaves the sump on an engine with a dry sump?

A. Back to the engine
B. To the reservoir
C. To the lube oil purifier
D. To the stripping pump

5-24. What is the name of the bearing that supports the crankshaft in a diesel engine?

A. Thrust bearing
B. Connecting rod bearing
C. Main bearing
D. Supporting bearing

5-25. By what means is the water jacket formed in a wet-type cylinder liner that does NOT have integral cooling passages?

A. An integral cooling passage in the block
B. A liner and a separate jacket that is part of the block
C. Individual tubes that are inserted in the block
D. A liner an integral cooling passage and is part of the block

5-26. The spark plugs of a gasoline engine are always found in the cylinder head. In a diesel engine, what engine part almost invariably is located in the cylinder head or heads?

A. Fuel injecting valves
B. Air starting valves
C. Intake valves
D. Rocker arm assembly

5-27. What Naval Ships' Technical Manual (NSTM) chapter can you find information on jacketwater liners?

A. Chapter 200
B. Chapter 233
C. Chapter 505
D. Chapter 660

5-28. Compressibility is a common property of all gaskets. Which of the following materials can be used in the manufacturing of gaskets?

A. Plywood
B. Tin
C. Copper
D. Aluminum

5-29. What device is the supporting and connecting pedestal between an engine and the ship’s structure?

A. Engine base
B. Subbase
C. Chock
D. Stub

5-30. What Naval Ships' Technical Manual (NSTM) chapter would you find information pertaining to gaskets?

A. Chapter 078
B. Chapter 100
C. Chapter 233
D. Chapter 660

Chapter 6
Principal Moving and Related Components

6-1. Why is low-alloy steels generally used for intake valves?

A. Because intake valves are exposed to the corrosive actions of hot exhaust gases
B. Because intake valves are not exposed to the corrosive action of hot exhaust gases
C. Because low-alloy steels resist corrosion
D. Because intake valves are larger and need a hard alloy surface

6-2. How is the rate and amount of valve lift determined?

A. The size of the cam
B. Cam timing
C. The number of cams
D. The shape of the cams

6-3. What is the function of the cam follower in a diesel engine?

A. To absorb friction from the camshaft
B. To reduce tappet clearances
C. To replace the tappet setscrew
D. To transmit rotary motion of the camshaft to reciprocating motion

6-4. What is the purpose of a diesel engine's valve bridges?

A. To operate two valves in sequence
B. To enables the rocker arm to operate two valves simultaneously
C. To replace rocker arms
D. To replace push rods

6-5. What is the name of the piston part that absorbs side thrust?

A. Crown
B. Boss
C. Land
D. Skirt

6-6. What serves as a mounting place for the bushing or bearing and supports the piston pins?

A. Crowns
B. Bosses
C. Lands
D. Skirts

6-7. What part of the piston is cooled while the assembly uses a “cocktail shaker” motion

A. Crown
B. Skirt
C. Rings
D. Lands

6-8. Which of the following is NOT a function of the piston rings?

A. Sealing against combustion gas leakage
B. Spreading oil on the cylinder walls
C. Keeping all oil off the combustion area
D. Transferring heat to the cylinder wall

6-9. How many sides on a properly working compression ring would be black from hot combustion gases?

A. One
B. Two
C. Three
D. Four

6-10. What type of ring set is composed of three separate pieces?

A. Firing ring
B. Compression ring
C. Oil control ring
D. Articulated ring

6-11. What device serves to reduce the damaging effects of torsional vibrations caused by the pulsation of the pistons against the crankshaft?

A. Torsional vibrational dampers
B. Counterweights
C. Flywheels
D. Crank webs

6-12. Why are crankshaft passages drilled so that two holes are in each journal?

A. To give twice the oil flow
B. In case one hole gets clogged
C. To give constant flow regardless of crank position
D. To provide more oil pressure to the connecting rod

6-13. How are crankshafts treated to increase the strength of their shafts and minimize wear?

A. Steel alloy forged
B. Nitride (heat treated)
C. Cooper Nickel coated
D. Zinc alloy embedded

6-14. Where are the connecting rod attachment points on the crankshaft?

A. Cranks
B. Webs
C. Dampers
D. Pins

6-15. Which of the following does NOT determine the number of cranks and their arrangement on the crankshaft?

A. Arrangement of cylinders
B. Number of cylinders
C. Operating cycle of engine
D. Type of lubricating oil used

6-16. What material is used for the construction of roller bearing?

A. Heat-treated chromium-steel alloy
B. Carbonized steel alloy
C. Carbonized iron alloy
D. Heat-treated alloy

6-17. What bearing metal is used in a trimetal bearing?

A. Iron
B. Babbitt
C. Bronze
D. Steel

6-18. Where is the oil distribution grooves located in the main bearing shells?

A. Around the caps
B. At the caps
C. Where shaft pressure is the least
D. All around the bearing

6-19. What is the name of the bearing that is use to control the back and forth movement of the crankshaft?

A. Main
B. Stationary
C. Thrust
D. Flex

6-20. During the power event, which component stores energy to be used during the rest of the combustion cycle?

A. Crank web
B. Flywheel
C. Camshaft
D. Crankshaft

6-21. How can the flywheel be used to determine the position of the crankshaft?

A. Looking through the sight glass on the flywheel
B. Use the degree marking
C. There is an automatic indicator that lets you know the position of the crankshaft
D. There is no way to determine the position of the crankshaft

6-22. When the engine's speed decreases, the flywheel gives up energy to the crankshaft for uniform rotation, the flywheel will?

A. Keeps variation in speed with desired limits at different loads
B. Increases in speed during sudden change of load
C. Decreases in speed during sudden change of load
D. Provides leverage or mechanical advantage for starting motor

6-23. What must be operating before jacking over the engine?

A. Fuel system
B. Hydraulic system
C. Jacket water system
D. Lubrication oil system

6-24. At a minimum, how long do you run the lubrication system for priming the diesel engine?

A. Five minutes
B. Until the operating temperature is reached
C. Until oil flow is observed at each site flow indicator
D. Until the engine turns over

6-25. What type of intake and exhaust valves are used on internal-combustion engines?

A. Gas-operated check
B. Spring-activated
C. Cone shaped seat
D. Poppet

6-26. In a 2-stroke cycle diesel engine, the camshaft does NOT carry a cam for actuating what component?

A. Exhaust valves
B. Intake valves
C. Unit injectors
D. Air start valves

6-27. What is the usual metallurgical makeup of valve bridge and serves to extend the life of valve seats?

A. Forged steel
B. Ground tempered steel
C. Annealed high-carbon steel
D. Chrome-plated alloy steel

6-28. Why is the crown of a piston smaller than a skirt?

A. It has more rings on it
B. It runs hotter
C. It absorbs no side thrust
D. It gets worn down faster

6-29. How are the pistons held in place on an engine?

A. Crowns
B. Bosses
C. Lands and grooves
D. Skirts

6-30. What is the maximum amount of combustion heat absorbed by the piston that is removed through the rings to the cylinder wall?

A. Approximately 20%
B. Approximately 30%
C. Approximately 40%
D. Approximately 50%

6-31. What are some of the ways that heat is transferred through the cylinder walls to cool a piston?

A. Intake air and lubricating oil
B. Intake air and exhaust
C. Piston speed and crankcase air
D. Lubricating oil and cooling fins

6-32. Which of the following characteristics does NOT apply to compression rings?

A. They commonly have a rectangular cross-section
B. Their diameter is slightly larger than the cylinder bores
C. Combustion gases act only on the combustion areas
D. They transfer heat to cylinder wall

6-33. How would you classify the shape of crankshaft?

A. Several flanges forged together
B. Several throws in a row formed as offsets
C. A shaft with a crank at the end
D. A series of bearing and weights

6-34. What is the function of the drilled passages in the crankshaft?

A. To relieve excess oil pressure at the connecting rods
B. To carry oil to the connecting rods
C. To carry lubricating oil to the piston pin and the piston
D. To lighten the crankshaft by the amount that offsets the weights of any counterweights used
E.

6-35. Where does the oil travel after passing the crankshaft?

A. Through the main journal and the connecting rod journal
B. Through the connecting rod bearing and the piston pin
C. Through the connecting rod bearing and the connecting rod
D. Through the connecting rod and the piston crown

6-36. What is the purpose for main journals on a crankshaft?

A. Used to ensure balance of rotation
B. Used as the attach point for the connecting rod
C. Used as the point of support and the center of rotation of the shaft
D. Used as the attachment for the flywheel

6-37. In addition to reducing the weight considerably, why is a crankshaft hollow in construction?

A. Provide passage for lubricating oil
B. Ensure timing of the engine
C. To balance the crankshaft
D. To offset the weight of the flywheel

6-38. What components do NOT use antifriction bearing?

A. Starters
B. Camshafts
C. Governors
D. Blowers

6-39. What type of bearing serves to hold the crankshaft in position axially?

A. Main
B. Thrust
C. Roller
D. Ball

6-40. What type of bearing is a precision bearing?

A. Fixed
B. Floating
C. Non-friction
D. Friction

6-41. What event during the combustion cycle does the flywheel store energy?

A. Intake
B. Compression
C. Power
D. Exhaust

6-42. What accessories are usually attached to an engine’s flywheel?

A. Lubricating oil pump
B. Governor
C. Water pump
D. Turning ring gear

6-43. When the engine’s speed decreases, the flywheel gives up energy to the crankshaft for uniform rotation, the flywheel will?

A. Keeps variation in speed within desired limits at all loads
B. Keeps variation in speed within desired limits different loads
C. Increases in speed during sudden change of load
D. Decreases in speed during sudden change of load

6-44. What measures are in place to ensure the engine doesn’t start while the jacking gear is engaged?

A. “DO NOT START” sign attached to gear
B. Area roped off
C. Engine safety devices
D. Engine can operate while engaged

6-45. What is the jacking gear used for on diesel engines?

A. To start the engine
B. To reverse the engine
C. Inspection of the crankshaft
D. To position the crankshaft for timing

6-46. What situation should the engine’s jacking gear be engaged and locked?

A. When adequate lubricating oil is unavailable
B. During trend analysis
C. During maintenance
D. During full power run

Chapter 7
Speed Controlling Devices

7-1. What term means the continuous fluctuation of the engine speed from the desired speed?

A. Jiggles
B. Hunting
C. Sensitivity
D. Stability

7-2. What term means the time normally taken in seconds for the fuel linkage to be moved from no-load to full-load position?

A. Jiggles
B. Promptness
C. Response time
D. Surges

7-3. Which classification of governors maintains one speed regardless of engine's load?

A. Constant-speed
B. Variable-speed
C. Speed-limiting
D. Load-limiting

7-4. Which classification of speed-control devices is used to keep an engine from exceeding a specified maximum speed and from dropping below a specified minimum speed?

A. Constant-speed governor
B. Variable-speed governor
C. Speed-limiting governor
D. Load-limiting governor

7-5. When reassembling a governor, what is the only kind of grease allowable to be used?

A. Soft
B. Natural
C. Neutral
D. Hard

7-6. Where would you see movement of the flyweights on a mechanical governor, if there were movement?

A. Power piston
B. Fuel linkage
C. Oil sight glass
D. Control rack

7-7. What device on the hydraulic governor will discontinue changing the fuel control setting slightly before the new settling has been actually reached?

A. Power piston
B. Servo piston
C. Compensating needle
D. Control rack.

7-8. What Naval program covers the testing of overspeed devices?

A. Planned Maintenance System (PMS)
B. Engineering Operational Procedures
C. Engineering Testing Procedures
D. Governors Operating Procedures

7-9. All of the following practices ensures the overspeed trip and its linkages are clean, EXCEPT which one?

A. Remove the source of binding
B. Maintain a proper oil level in the hydraulic overspeed trip
C. Adjust faulty parts
D. Adjust the speed- sensitive element according to the instruction manual

7-10. What is the maximum rated speed percent for high-speed engines', safety devices to operate at?

A. 10
B. 49
C. 110
D. 150

7-11. What would a stuck external fuel linkage cause in an engine?

A. Jiggles
B. Hunt
C. Speed droop
D. Isochronous governing

7-12. What term means the decrease in speed of the engine from no-load condition to a full load condition?

A. Jiggles
B. Isochronous governing
C. Hunting
D. Speed Droop

7-13. What controls the speed of a diesel engine that has mechanical governors?

A. Throttle setting
B. Spring pressure
C. Fuel delivery
D. Adjusting screw

7-14. How does the hydraulic oil reach the power piston of the hydraulic governor?

A. Through a small pilot valve
B. Oil leakage from the compensating needle
C. Through the buffer cylinder
D. Gravity from the oil sump

7-15. If an engine overspeeds and exceeds its rated revolutions per hour (RPM) trip setting, what must you do before restarting it?

A. Reset overspeed trips and restart engine
B. Able to restart engine immediately, no action required
C. Conduct internal inspection prior to restart engine
D. Get permission from ship's Engineering Officer to restart engine

7-16. All of the following factors are considered when determining the time interval between governor oil changes EXCEPT which one?

A. Flashpoint of the oil
B. Type of service the oil is going to be used for
C. Operating temperature of the oil
D. Quality of the oil

7-17. What is the maximum rated speed percent for large, slow-speed engines' safety devices to operate at?

A. 10
B. 49
C. 107
D. 150

7-18. What would an incorrectly adjusted compensating needle valve cause in an engine?

A. Speed droop
B. Surges
C. Jiggles
D. Isochronous governing

Chapter 8
Engine Drive Mechanisms

8-1. What diesel engine component that transmits power to operate specific parts and accessories may be related to more than one engine system?

A. Power system
B. Steering system
C. Drive mechanism
D. Combination power mechanism

8-2. Which of the following terms of motion does NOT apply to the relationship in the drive mechanism between the crankshaft and the camshaft?

A. Speed differential between crankshaft and camshaft
B. Ratio of revolutions between crankshaft and camshaft
C. Direction of rotation in one of the shafts
D. The type of motion of one of the shafts

8-3. Of the three types of mediums for drive mechanisms, which one is NOT commonly used for marine engines, but used often for gasoline engines?

A. Belts
B. Chains
C. Gears
D. Wire rope

8-4. What is the name of the drive that serves to transmit power to operate engine valves?

A. Rocker arms
B. Timing mechanism
C. Valve train
D. Camshaft

8-5. When the driving mechanism of a diesel engine consists only of gears, what is the mechanism called?

A. Gear chain
B. Gear belt
C. Gear train
D. Gear assembly

8-6. Why is an idler gear placed between two other gears?

A. To transfer motion from one gear to the other without changing their speed
B. To transfer motion from one gear to the other gear without changing their type of motion
C. To transfer motion from one gear to the other gear without changing their ratio of revolution
D. To transfer motion from one gear to the other gear without changing their direction of rotation

8-7. What other gear of the drive mechanism on a 2-stroke diesel engine operates at the same speed as the crankshaft and camshaft?

A. Accessory
B. Balancer
C. Blower
D. Lube-oil pump

8-8. What pump is mounted on the front end of the blower and is driven by the rotor shaft in the drive mechanism system on a 2-stroke diesel engine?

A. Fuel
B. Lube-oil
C. Starting air
D. Water

8-9. What is the primary purpose of the camshaft drive on opposed-piston diesel engine?

A. Operate the cylinder valves
B. Establish timing of the fuel injection pumps
C. Ensure balanced rotation of the crankshaft
D. Maintain proper timing of the lube-oil pumps

8-10. What is attached to the end of each camshaft on an opposed-piston diesel engine for timing and adjustment of the drive mechanism?

A. Adjustment screw
B. Sliding bar
C. Sprocket
D. Yoke

8-11. What gear is keyed to the crankshaft and absorbs the torsional oscillations transmitted by the crankshaft?

A. Accessory
B. Balancer
C. Flexible drive
D. Spacer

8-12. What component of the Fairbank Morse 38D8 1/8 diesel engine drives the majority of the accessories?

A. Lower crankshaft control end
B. Lower crankshaft free end
C. Upper crankshaft control end
D. Camshaft

8-13. Engine shock transmitted by the crankshaft is absorbed by the spring of what type of drive gear?

A. Flexible
B. Heat-treated
C. Hollow
D. Rigid

8-14. What component of an opposed-piston diesel engine does the shaft of the lubricating oil pump transmit power to?

A. Fuel pump
B. Governor
C. Start air solenoid
D. Water pump

8-15. What is the major difference on a 4-stroke cycle diesel engine's drive mechanism compared to a 2-stroke cycle diesel engine?

A. More gears
B. Different rotation of the gears
C. No mechanical drive
D. No accessories gears

8-16. How does the 2:1 ratio gear reduction get accomplished in a 4-stroke cycle diesel engine's drive mechanism?

A. Each shaft rotates at different speeds
B. The flywheel balances the ratio to 2:1
C. One or more idler gears between the crankshaft and camshaft gears balance the ratio
D. There is no gear reduction ratio on a 4-stroke diesel engine

8-17. What is the drive design for the camshaft to rotate at relative to the crankshaft speed on a 4-stroke cycle diesel engine?

A. Same speed as the crankshaft
B. Twice the speed of the crankshaft
C. Half the speed of the crankshaft
D. Three times the speed of the crankshaft

8-18. Of the following variation in design and arrangements of drive mechanisms found on diesel engines, which one is NOT considered?

A. Size of engine
B. Cycle of operation
C. Cylinder arrangement
D. Number of cylinders

8-19. What kind of teeth is frequently used for more uniform transmission of power in drive mechanisms?

A. Helical
B. Herring bone
C. Spur
D. Straight

8-20. Why do the camshaft and balance gear use counterweights in the drive mechanism on the 2-stroke in-line diesel engine?

A. Maintaining proper timing
B. Balancing the camshaft and balancer gear with the crankshaft
C. Balancing the camshaft with blower gear
D. Balancing the idler and accessories gears with the camshaft gear

8-21. What component in the drive mechanism of a 2-stroke cycle diesel engine transmits power to the blower, governor, water pump, and fuel pump?

A. Camshaft gear
B. Blower driver gear
C. Fuel pump gear
D. Lube-oil pump gear

8-22. What component is driven by idler gear in the front gear train of 2-stroke cycle V-type engine?

A. Fuel pump
B. Lube-oil pump
C. Start air solenoid
D. Water pump

8-23. How would someone know the correct way to place the gears on the gear train for the crankshaft and camshaft?

A. Wear patterns of old gears
B. Reading the technical manual
C. Timing marks
D. All gears are universal

8-24. Of what medium is the drive constructed that furnishes power to the camshaft and fuel injection equipment on an opposed-piston diesel engine?

A. Belts
B. Chains
C. Gears
D. Wire rope

8-25. Where does the power to drive the blower come from on an opposed-piston diesel engine drive mechanism?

A. Accessory drive
B. Camshaft
C. Lower crankshaft
D. Upper crankshaft

8-26. Which of following does NOT receive power from the accessory drive gear on an opposed-piston diesel engine drive mechanism?

A. Fuel pump
B. Governor
C. Start air solenoid
D. Water pump

8-27. What must a 4-stroke cycle engine's camshaft speed be, compared to the engines crankshaft's speed?

A. The same
B. Twice
C. Half
D. Four times

Chapter 9
Intake and Exhaust Systems

9-1. What component is used in all two-stroke and some four-stroke diesel engines to ensure the flow of air into the cylinder?

A. Air box
B. Blower
C. Silencer
D. Spark arrester

9-2. During the scavenging event of the combustion cycle, the valves and ports on a four-stroke diesel engine are in what position?

A. Valves and ports both open
B. Valves and ports both closed
C. Valves open and ports closed
D. Valves closed and ports open

9-3. What components should be added to the air-intake system of a four-stroke diesel engine that is supercharged?

A. Turbocharger
B. Silencer
C. Air ejectors
D. Blower

9-4. In addition to the speed of an engine, the actual length of the injection period of a specific engine depends on what factor?

A. Number of pistons on an engine
B. The alignment of the cylinders of an engine
C. Atmospheric conditions
D. Load of the engine

9-5. Why does a two-stroke diesel engine piston do little work during the intake and exhaust events of the combustion cycle?

A. Natural aspiration takes place in the air box
B. Turbochargers replace the exhaust gases and fill cylinder with fresh air.
C. Blowers force air into the cylinder and remove exhaust gases.
D. The air ejectors supply the air.

9-6. What material is used to reduce the incoming air's noise on a silencer?

A. Braided nylon and cotton pads
B. Insulted foam
C. Felted cotton waste
D. Rubber foam

9-7. How are centrifugal blowers driven?

A. By an exhaust gas turbine
B. Gear driven by the engine
C. Remotely activated when the engine starts
D. Sequenced with start of engine

9-8. What special feature of a roots blower prevents the meshing of rotor lobes from touching?

A. Helical timing gears
B. Two sets of idler gears
C. Offset rotation
D. Baffles between lobes

9-9. What component on a two-stroke diesel engine directs intake air to the cylinders?

A. Air bank
B. Air flask
C. Air cavity
D. Air box

9-10. Which of the following action is NOT a function of the cylinder test valve, safety, relief valve system?

A. To vent cylinder of accumulated water before starting the engine
B. To inspection of the cylinders
C. To relieve cylinder pressure when the engine is being turned by hand
D. To test compression and firing pressures

9-11. On the diesel engine exhaust manifold, what component traps burnt carbon particles and soot from the mufflers?

A. Silencer
B. Filter
C. Trap
D. Deflector

9-12. The fixed pyrometer measures the difference between electric currents produced by heat acting on dissimilar metals in what two surfaces?

A. Pistons and cylinder
B. Cylinder and exhaust manifold
C. Hot junction and cold junction
D. Hot junction and engine block

9-13. When the demand for increased horsepower is required, the pressure comes from what source?

A. Fuel system
B. Governor
C. Air-intake system
D. Exhaust system

9-14. What is the estimated percentage increase in power of a turbocharged engine?

A. 25
B. 50
C. 65
D. 75

9-15. What engine component does NOT have a drain attached to it?

A. Turbocharger
B. Air box
C. Header
D. Receiver

9-16. Which of the following components is part of the diesel engine air-intake system?

A. Muffler
B. Air box
C. Spark arrester
D. Silencer

9-17. What process involves using an increased amount of air to clear the cylinder of combustion exhaust gases?

A. Natural exhaust
B. Turbocharged
C. Supercharged
D. Scavenging

9-18. Supplying more air to the combustion space than can be supplied from atmospheric pressure or piston action, on a four-stroke diesel engine, is what process?

A. Supercharged
B. Turbocharged
C. Natural aspirated
D. Scavenging

9-19. Which of the following statements describes the timing difference between a supercharged and non-supercharged diesel engine compression and power events?

A. Longer in a supercharged engine
B. Shorter in a supercharged engine
C. No difference
D. Compression event longer, and power event shorter on a supercharged engine

9-20. What component is used on a diesel engine air-intake system to ensure the incoming air is as quiet and clean as possible?

A. Filter
B. Cleaner
C. Muffler
D. Silencer

9-21. What grade of oil is used on the viscous-type air cleaner?

A. Extra-duty weight
B. Heavy-duty weight
C. Light-duty weight
D. Medium-duty weight

9-22. What determines the location of the blower on a diesel engine?

A. Space allotment in the engine room
B. Cylinder arrangement
C. Placement of gears
D. Crankshaft web design

9-23. After the exhaust air leaves the turbocharger but before it enters the air-intake housing, the air passes through what component to compress its volume?

A. Strainer
B. Baffles
C. Aftercooler
D. Blower

9-24. Most marine engines exhaust manifolds are cooled by what method?

A. Force draft air
B. Shell and tube cooler
C. Water jacket surrounding manifold
D. Installed cooling coils

9-25. What instrument is used to measure exhaust gases?

A. Thermostat
B. Gasometer
C. Pyrometer
D. Thermometer

9-26. What action produces the minimum turbulence and improves the effectiveness of the scavenging action?

A. Direct line intake
B. Cross pattern intake
C. Steam line intake
D. Uniflow intake

9-27. From what source, if any, do the rotor lobes receive lubrication?

A. Main oil gallery
B. Governor drive assembly
C. Crankshaft oil passages
D. Lubrication not required

Chapter 10
Engine Cooling Systems

10-1. What term describes the measurement of the developed power of an engine's actual output in power?

A. Kinetic energy
B. Horsepower
C. Brake horsepower
D. Mechanical energy

10-2. What property is the major reason that lubricating oil creates a film on the metallic components of a diesel engine?

A. Lubricating oil sludge point
B. Lubricating oil drip point
C. Lubricating oil viscosity
D. Lubricating oil specific gravity

10-3. When there is inadequate cooling to a diesel engine during operation, it will cause what effect?

A. Pounding
B. Ignition lag
C. Knocking
D. Governor overspeed

10-4. What is the end result of lack of cooling to a diesel engine?

A. Low operating temperature
B. Low exhaust temperatures
C. Low compression temperatures
D. Engine seizure

10-5. What is the one important thing that must be accomplished when using a seawater open cooling system?

A. Keep it in operation
B. Prime before starting
C. Clean strainer often
D. Flush with freshwater

10-6. What is the correct path of freshwater in a heat exchanger cooling system?

A. Cold freshwater in, picks up heat as it is going through the engine
B. Hot freshwater in, cools off as it is going through the engine
C. Hot seawater in, picks up heat and never release it until discharged overboard
D. Both seawater and jacket water stay cool with support of installed ventilation

10-7. Where does the coolant go to after it complete its job in the closed cooling system?

A. Sump
B. Expansion tank
C. Reservoir
D. Suction side of pump

10-8. Where is the pump located that moves the coolant in the keel cooling system?

A. Attached to the hull of the ship
B. Connected to the flywheel
C. Bottom of the expansion tank
D. Before the freshwater pump

10-9. Where does the coolant go in the radiator and fan cooling system when the thermostat is closed?

A. Through the system
B. To the suction side of the pump
C. To the sump
D. To the expansion tank

10-10. Which classification of coolers is NOT typically used to identify coolers?

A. Direction of flow
B. Number of passes
C. Construction of cooler
D. Cooling medium

10-11. What is the header plates made of on the strut-tube coolers?

A. Tin
B. Iron
C. Aluminum
D. Nickel

10-12. What is the coolant-flow channel on the plate-tube cooler constructed of?

A. Tin
B. Copper-nickel
C. Iron
D. Aluminum

10-13. How many degrees above the rated temperate are thermostats when they are at fully open position?

A. 10 °F
B. 15 °F
C. 20 °F
D. 25 °F

10-14. What happens on a conventional thermostat when the power pellet becomes totally liquefied?

A. Expansions begins
B. Expansions stops
C. Bypass closes
D. Bypass open

10-15. What term is used for the collapsing of bubbles that form on the coolant side of an engine's component?

A. Vapor baskets
B. Vapor pockets
C. Natural erosion
D. Cavitation erosion

10-16. Which of the following is NOT a way that NALCOOL 2000 stops cavitation in diesel engines?

A. Forming a physical barrier
B. Creating an oil film
C. Strengthening the metal surface against cavitation
D. Reduce foaming and lessen air entrapment

10-17. What Naval Ships' Technical Manual (NSTM), chapter do you refer to before opening a heat exchanger?

A. Chapter 090
B. Chapter 110
C. Chapter 254
D. Chapter 600

10-18. What tool would you use on a heat exchanger tube for cleaning?

A. Soft bristle brush
B. Wire brush
C. Heavy sandpaper
D. Metal scraper

10-19. How do you plug tubes in a single-pass-tube sheet heat exchanger?

A. Cork plugs
B. Rubber plugs
C. Wood plugs
D. Phenolic plugs

10-20. How much heat energy from the fuel changed into mechanical energy leaves the engine in the form of brake horsepower?

A. One half
B. One third
C. One fourth
D. One fifth

10-21. What medium would be a suitable solution for removing heat from a diesel engine?

A. Lubricating oil
B. Heat resistant wool
C. Vacuum tubes
D. Paper filters

10-22. What condition will be occurring if the diesel engines cooling system reduces the temperature of the lubricating oil too low?

A. Oxidation
B. Knocking
C. Ignition lag
D. Governor overspeeding

10-23. Where is the water being drawn from and discharged to in an open loop cooling system?

A. Jacket water system
B. Main raw water system
C. Potable water system
D. Operational waters

10-24. What is the minimum boiling point of the coolant in a closed cooling system?

A. 32 °F
B. 100 °F
C. 212 °F
D. 250 °F

10-25. On larger diesel engines that provide propulsion, what is the means for emergency cooling?

A. Potable water
B. Firemain
C. Distillate
D. Jacket water

10-26. What component drives the fan in the radiator and fan cooling system?

A. Crankshaft
B. Camshaft
C. Governor drive
D. Accessories drive

10-27. What is the most common type of pump used in the diesel engine cooling system?

A. Worm gear drive
B. Positive displacement
C. Centrifugal
D. Lobe gear

10-28. What is use in a shell-and-tube cooler to keep the mixing of cooling medium and the liquid being cooled from happening?

A. Baffles
B. Seals
C. Gaskets
D. Packing joints

10-29. What function does NOT involve the freshwater expansion tank?

A. Provide room for expansion when water is warm
B. Provide room for contraction when water is cool
C. Adding water to the engine
D. Washing the engine

10-30. What is the maximum seawater cooling temperature needed on the discharge side of a seawater cooler, to prevent scale formation and erosion?

A. 100 °F
B. 130 °F
C. 160 °F
D. 190 °F

10-31. What inhibitor treatment is authorized for use on MCM ship?

A. MIL-A-53009
B. NALCOOL 2000
C. Nalfleet 9-111
D. Paxcool

10-32. In what Naval Ships' Technical Manual (NSTM) chapter can you find the listing of chemicals to correctly protect diesel engine against corrosion and scale formation?

A. Chapter 090
B. Chapter 233
C. Chapter 220 volume 1
D. Chapter 220 volume 3

10-33. What is the maximum percentage of plugged tubes a heat exchanger can have before replacement of the tubes is required?

A. 5%
B. 10%
C. 15%
D. 20%

Chapter 11
Engine Lubricating Oil Systems

11-1. By what means would you reduce the harmful effects of friction by changing sliding friction to fluid friction?

A. Hydropower
B. Lubrication
C. Gaskets
D. Spacers

11-2. What is the friction that exists between moving bodies called?

A. Kinetic
B. Immobile
C. Static
D. Motile

11-3. What is the property of a lubricant, in liquid form, which causes the lubricant to stick to the bodies being lubricated?

A. Cohesion
B. Viscosity
C. Demulsibility
D. Adhesion

11-4. What is one way you can determine the effectiveness of oil film lubrication?

A. Stationary clearance
B. Impurity of the lubricant
C. Flow rate
D. Freeze point

11-5. How are lubricants for reciprocating internal combustion engines commonly known as?

A. Unleaded
B. Petro
C. Detergent
D. Synthetic

11-6. What viscosity grade of lubricating oil do shipboard diesel engines operate satisfactory with?

A. MIL-L-9000
B. MIL-L-2104
C. MIL-L-2000
D. MIL-L-6000

11-7. What do the letters H, T, TH, or TEP mean when added to a basic viscosity grade of lubricating oil?

A. New
B. Substituted
C. Specific usage
D. Foreign source

11-8. What indicates the lubrication oils acid content and is defined as the number of milligrams of potassium hydroxide (KOH) required offset 1 gram of the oil?

A. Demulsibility
B. Neutralization number
C. Autoignition point
D. Viscosity

11-9. How many different grades of lubricating grease are used in the Navy?

A. 1
B. 2
C. 3
D. 4

11-10. What lubricating grease must be used for temperature application above 300 °F, high temperature, and electric motors?

A. MIL-G-17740
B. MIL-L-15719
C. MIL-G-24508A
D. VV-G-671

11-11. Which of the following is graphite grease?

A. MIL-G-17740
B. MIL-L-15719
C. MIL-G-24508A
D. VV-G-671

11-12. What Naval Ships' Technical Manual (NSTM) would you reference when working with lubrication greases?

A. Chapter 060
B. Chapter 100
C. Chapter 200
D. Chapter 262

11-13. What normally controls the operating pressures of the pumps in a lubrication oil system?

A. Pressure-regulating valves
B. Inlet pressure of the pump
C. Outlet pressure of the pump
D. Viscosity of the lubricating oil

11-14. What type of coolers is used to remove heat from the lubricating oil for diesel engine?

A. Plate
B. Strut tube
C. Shell and tube
D. Air cooled

11-15. Which of the following material is approved by the Navy for use in filters?

A. Cork
B. Felt
C. Cotton yarn
D. Paper rolls

11-16. What is a function of the lubrication oil system in a diesel engine?

A. Form a seal between the cooling passages in a diesel engine.
B. Reduce wear by preventing metal-to-metal contact between moving parts.
C. Stabilize the temperature in a piston.
D. Increase the amount of sludge for a better seal for moving parts.

11-17. What is known as the ability of the lubricating oil to resist oxidation and deterioration for long periods?

A. Viscosity
B. Adhesion
C. Stability
D. Neutralization number

11-18. What is a cause of lubricating oil overheating?

A. Overloading of the engine
B. Proper level of lubrication oil in diesel engine
C. Functioning lubrication oil strainers
D. Proper clearance between rotation parts

11-19. What is one of the dangers of fuel oil dilution in lubrication oil that could cause vapor to form in the diesel engines crankcase?

A. Fuel oil has a higher flash point than lubrication oil.
B. Fuel oil has a lower flash point than lubrication oil.
C. Fuel oil has a higher pour point than lubrication oil.
D. Fuel oil has a lower pour point than lubrication oil.

11-20. How does fuel dilution occur in lubricating oil when a diesel engine is operating at low speeds or under idling conditions?

A. Lack of lubricating oil pressure
B. Low temperature of the lubricating oil
C. Blow-by of unburned fuel
D. Bypass valves are open for the coolers

11-21. Where is oil transferred to during the batch purification process?

A. Centrifugal purifier
B. Disk-type purifier
C. Lubricating tank
D. Settling tank

11-22. Which of the following is used in the continuous purification process?

A. Centrifugal purifier
B. Bypass heater
C. Open transfer system to the diesel engine
D. Primer cutout switch

11-23. When a centrifugal purifier is used as a clarifier, what is the main source of contamination?

A. Seawater
B. Freshwater
C. Fuel
D. Sediment

11-24. What is the function of the three-wing device in the tubular-type centrifugal purifier?

A. To maintain a constant oil pressure
B. To restrain movement of the bottom of the bowl
C. To cause the liquid to rotate at bowl speed
D. To accelerate emulsification

11-25. Oil purifiers give maximum efficiency when operating at their rated capacity and at what speed?

A. A speed between minimum and maximum
B. A speed determined by prevailing conditions
C. The maximum design speed
D. The minimum design speed

11-26. When heating oil for purification, enough heat should be added to decrease its viscosity to what specified level?

A. 60 SSU
B. 75 SSU
C. 90 SSU
D. 120 SSU

11-27. What is a major point of the Lube Oil Quality Management (LOQM) Program?

A. Equipment not needing lubricating oil testing
B. Waste oil usage
C. The required logs and records you must maintain
D. Collection of new lubricating oil

11-28. What program does the Navy use to detect accelerated wear of machinery in lubricating oil?

A. Navy Oil Analysis Program (NOAP)
B. Joint Oil Analysis Program (JOAP)
C. LOQM
D. Damaged Equipment Oil Program (DEOP)

11-29. What is the maximum allowable fuel contamination in lubricating oil?

A. 5 percent
B. 10 percent
C. 15 percent
D. 20 percent

11-30. When cleaning the insides of lubricating oil tank, bearings, and other lubrication oil system parts, what material is authorized?

A. Simply green
B. Old T-shirts
C. Lint-free rags
D. Soap and water

11-31. Which of the following location is NOT authorized placement for lubrication oil that has been in the bilges?

A. Oily waste system
B. Used oil tank
C. Oil barge
D. Lubricating oil system

11-32. What is the friction between a body at rest and the surface upon which it is resting?

A. Kinetic
B. Immobile
C. Static
D. Motile

11-33. What is a presently accepted theory on lubrication?

A. Boyles
B. Einstein
C. Newton
D. Langmuir

11-34. What is the property of lubrication which holds the lubricants together and enables it to resist breakdown under extreme pressure?

A. Cohesion
B. Viscosity
C. Demusibility
D. Adhesion

11-35. Why do diesel engines' lubricating oils contain additives?

A. Increase the foaming of the lubricating oil
B. Reduce wear to engine parts
C. Increase the oxidation of metal surfaces
D. Increase the heat insulation in the combustion chamber

11-36. What determines the viscosity digits in the classification of lubricating material?

A. Standard code from the manufactory
B. Number of minutes required for a 60 milliliter (mL) sample of oil to flow through a standard orifice at a certain temperature
C. Number of seconds required for a 60 mL sample of oil to flow through a standard orifice at a certain temperature
D. The size of the orifice that is used during the viscosity test

11-37. What lubricating oil property is the oils tendency to resist flow or change shape?

A. Viscosity
B. Pour point
C. Neutralization number
D. Precipitation number

11-38. What lubricating oil property is a measure of the amount of solids classified as asphalts or carbon residue contained in the oil?

A. Viscosity
B. Pour point
C. Neutralization number
D. Precipitation number

11-39. What are simple mixtures of soaps and lubricating oils called?

A. Petroleum
B. Lubricating greases
C. Synthetic oil
D. Penetrating oil

11-40. What is the maximum operating temperature of ball and roller bearing grease?

A. 100°F
B. 200°F
C. 300°F
D. 400°F

11-41. When filling a grease cup with lubricating grease, what must be kept out of the cup?

A. Fresh grease
B. Dirt
C. Moisture
D. Air

11-42. Which of the following function is NOT an indication that a diesel engine lubricating oil system is effective?

A. Smooth starting of the diesel engine
B. Minimizes friction between bearing surfaces and moving parts
C. Removes heat from the surface area where friction is present
D. Keeps diesel engine parts clean

11-43. What must every approved lubricating oil strainer have built in?

A. Vent valve
B. Fill tube
C. Spring-loaded differential area
D. Sight glass

11-44. Where does the lubricating oil go from the bypass filter?

A. To the engine
B. Recirculated through the lubricating oil cooler
C. Returned to the sump tank
D. Bypassed to the settling tank

11-45. Where could combustible gases accumulate in the diesel engine if there was no way to vent the gases?

A. In the attached lubricating oil pump
B. In the emergency lubricating pump
C. On the sides of the combustion chamber
D. In the diesel engines crankcase

11-46. What would happen to the lubricating oil if it became overheated?

A. Formation of acids
B. Formation of sludge
C. The lubricating oil flash point would increase
D. The lubricating oil flash point would decrease

11-47. What is the normal temperature range for lubricating oil to prevent dilution?

A. 100°- 200°F
B. 200°- 300°F
C. 300°- 400°F
D. 600°- 700°F

11-48. What is the biggest source of contamination in lubricating oil?

A. Diesel fuel
B. Jet propulsion 5 (JP5) fuel
C. Sediments
D. Water

11-49. What oil is used in modern naval ships with forced-feed lubrication systems?

A. Hydraulic oil
B. Pure oil
C. Penetrating oil
D. Synthetic oil

11-50. When water must be removed from the lubricating oil, the purifier is called?

A. Clarifier
B. Separator
C. Filter
D. Strainer

11-51. What Naval Ships' Technical Manual (NSTM) would you refer to for additional shipboard tests and procedures to maintain the quality of lubricating oil?

A. Chapter 150
B. Chapter 220
C. Chapter 262
D. Chapter 358

11-52. What determines the size of the discharge rings on a purifier?

A. Viscosity
B. Pour point
C. Flash point
D. Specific gravity

11-53. What program is used by the Navy to ensure the properties of the lubricating oil are reliable and proper for use on naval equipment?

A. Lube Oil Quality Management (LOQM)
B. Navy Oil Analysis Program (NOAP)
C. Joint Oil Analysis Program (JOAP)
D. Engineering Operating Procedures (EOP)

11-54. What condition is NOT caused by a high lubricating oil level in a gear casing?

A. Churning
B. Demulsibility
C. Foaming
D. Emulsification

11-55. What must be done to newly received oil?

A. Store in storage tank
B. Store in settling tank
C. Carefully examine before bringing onboard
D. Send for Joint Oil Analysis Program (JOAP) testing

Chapter 12
Diesel Fuel System

12-1. In what form must diesel fuel be injected into the cylinders of an engine?

A. Fine Stream
B. Fine mist
C. Jet
D. Sprinkle

12-2. What does a high cetane number indicate about a fuel?

A. Slower burning
B. Quicker burning
C. Hard engine starts
D. Better in hot weather

12-3. Where is the turbulence created on some high speed engines before it enters the piston?

A. Compression area
B. Energy cell
C. Turbo bank
D. Intake port

12-4. What does a ship use to remove solids and water from diesel fuel before using it?

A. Heaters
B. Stripping pumps
C. Purifiers
D. Services tanks

12-5. What is the maximum percent capacity a fuel tank can be fill at sea, and in port?

A. 85, 95
B. 80, 95
C. 95, 90
D. 95, 80

12-6. What kind of pump is the engine-driven fuel transfer pump?

A. Centrifugal
B. Rotary
C. Positive-displacement
D. Variable-stroke

12-7. What is the maximum pressure drop across fuel oil strainers for a fuel pump in pounds per square inch (PSI)?

A. 1
B. 1.5
C. 3
D. 3.5

12-8. What is the force that impels a body or substance outwards from an axis of rotation?

A. Gravity
B. Rotation
C. Implosion
D. Centrifugal

12-9. What purification phase is considered the light phase?

A. Purified fuel
B. Solids
C. Water
D. Salt

12-10. Where does the purified fuel go after it has been purified and before it is used in the diesel engine?

A. Holding tank
B. Stripping tank
C. Storage tank
D. Service tank

12-11. What carries the weight of the bowl spindle of a disk-type purifier and absorbs any thrust created by the driving action?

A. The crankshaft
B. The camshaft
C. The radial thrust bearing
D. Counterweights

12-12. What rotates with the bowl of a tubular-type purifier and forces the liquid in the bowl to rotate at the same speed as the bowl?

A. The belt drive
B. The chain drive
C. The gear drive
D. The three wing

12-13. What is the range of fuel pressure in pounds per square inch (psi) at the beginning of injection on a diesel combustion engine?

A. 500-1000
B. 1000-1500
C. 1800-30000
D. 50000-100000

12-14. Where is the delivery valve assembly operated from on the Bosch APE fuel supply system?

A. Outside of the cylinder
B. Before the pre-combustion chamber
C. Directly above the plunger
D. In line with the plunger

12-15. How is the DPA fuel system pump lubricated?

A. Self-lubricated
B. From the governor
C. From the attached fuel pump
D. By leak-off from the injectors

12-16. What is NOT part of the unit fuel injector (UFI)?

A. Pumping and timing element
B. Fuel Control
C. Injection valve spray tip assemble
D. Bypass valve

12-17. What must the pressure in a fuel line be?

A. Lower than atmospheric
B. Greater than atmospheric
C. Equal to atmospheric
D. Equal to the volume of the piston

12-18. What is the ability of a liquid to change to vapor known as?

A. Gas
B. Volatility
C. Consternation
D. Motile

12-19. What is the fuel ignition quality, and the ease at which diesel fuel burns called?

A. Cetene number
B. Cetene index
C. Octane number
D. Octane index

12-20. What is the difference in fuel injection pressure on an engine with a pre-combustion chamber and an engine without a pre-combustion chamber?

A. Pre-combustion chamber engines require greater injection pressure.
B. Pre-combustion chamber engines require less injection pressure.
C. There is no difference in either engine.
D. Engines without pre-combustion chambers will naturally create more pressure.

12-21. In what Naval Ship's Technical Manuals (NSTM) chapters would you find detailed information on shipboard fuel testing?

A. 100, and 101
B. 250, and 251
C. 541, and 542
D. 754, and 755

12-22. What kind of pumps are most fuel service pumps?

A. Centrifugal
B. Vane
C. Variable-stroke
D. Rotary, positive displacement

12-23. What is the maximum allowable pressure drop, in pounds per square inch (psi), across a clean new fuel filter element?

A. 1.0
B. 3.5
C. 4.5
D. 6.0

12-24. What purification phase is the heavy phase?

A. Solids
B. Salt
C. Water
D. Purified fuel

12-25. What form(s) a seal between the top disc and the bowl top on the disc-type purifier?

A. Water
B. Fuel
C. Solids
D. Air

12-26. What happens when you decrease the viscosity of the fuel by heating it and speeding up the purification process?

A. The capacity of the purifier decreases.
B. The need for the purifier is removed.
C. The capacity of the purifier increases.
D. The purifier must be purged more.

12-27. What is NOT part of the jerk pump fuel injection system?

A. Rack and pinion control rack
B. High pressure pump
C. Pressure operated spray valves
D. Nozzles

12-28. What kind of nozzle injection system is used with the open type of combustion chamber?

A. Pintle
B. Unit
C. Crossfire
D. Multiple-hole

12-29. What is the corrective action when the diesel engine runs out of fuel?

A. Fill with fresh fuel
B. Purge air from engine
C. Use either to start engine
D. Pour fuel directly into the piston and crank engine

Chapter 13
Engine Starting Systems

13-1. What happens in a reverse-acting pilot when there is an increase in controlled pressure?

A. Nothing, everything equal out
B. A decrease in operating air pressure
C. An increase in operating air pressure
D. The diaphragm will override the pilot causing a surge in pressure

13-2. In a direct-acting control valve, an increase in pressure on the diaphragm does what to the pilot valve?

A. Shut the valve
B. Bypass the valve
C. Drain from the valve
D. Open the valve

13-3. From what two positions can control pilot air act on the valve diaphragm?

A. Open-shut
B. Up-down
C. Direct-reverse
D. Left-right

13-4. What do you use to monitor the charging system of an engine?

A. Ammeter
B. Tachometer
C. Strobometer
D. Voltmeter

13-5. When the engine starts, the flywheel drives the Bendix gear to rotate at a high speed. What cause the automatic disengagement of the drive pinion from the flywheel as soon as the engine starts?

A. A negative electrical force
B. Excess unnecessary speed
C. Rotation in opposite direction on the shaft spiral
D. Rotation in the same direction on the camshaft

13-6. Data from which of the following sensors is sent to the computer so it can analyze the data and change the timing for maximum engine efficiency?

A. Crankshaft web position sensor
B. Camshaft web position sensor
C. Engine heating temperature sensor
D. Throttle position sensor

13-7. What kind of drive has a nose housing mechanism that can be rotated so that a number of solenoid positions can be obtained with respect to the mounting flanges?

A. Sprag overrunning clutch
B. Blendix
C. Hydraulic
D. Dyer

13-8. What is the starting air relief valve normally set at?

A. 5 percent above required starting air pressure
B. 8 percent above required starting air pressure
C. 12 percent above required starting air pressure
D. 15 percent above required starting air pressure

13-9. What is the starting air pressure for motors driven by air?

A. 20-70 psi
B. 90-200 psi
C. 20-450 psi
D. 500-875 psi

13-10. What safety interlock will not allow control air to reach the main air start valve on a diesel engine when engaged, so that compressed air will not be admitted to the cylinders?

A. Air bleed valves
B. Cylinder bleed valves
C. Barring level assembly
D. Jacking gear interlock

13-11. Where is the glow plug located on each cylinder?

A. Top of the cylinder head
B. Above the injection nozzle
C. Below the injection nozzle
D. Bottom of cylinder head

13-12. In what Naval Ship's Technical Manual (NSTM) chapter will you find more information about diesel engine starting aids?

A. Chapter 100
B. Chapter 200
C. Chapter 233
D. Chapter 254

13-13. What kind of valve is used as an unloading valve to reduce pressure or to provide continuous regulation of pressure and temperature?

A. Hydraulic-pilot-operated diaphragm control
B. Air-pilot-operated diaphragm control
C. Steam-pilot-operated diaphragm control
D. Water-pilot-operated diaphragm control

13-14. Where does the pressure come from on the diaphragm control valve that acts on top of a diaphragm in the control pilot?

A. The inlet side
B. The bottom side
C. The discharge side
D. The top side

13-15. What voltage are most starting motors for small craft engines rated at?

A. 24-28 volts
B. 48-52 volts
C. 64-68 volts
D. 72-80 volts

13-16. What do starting motors that have Bendix drive use to open and close the motor-to-battery circuit?

A. Light-duty capacitor
B. Heavy-duty capacitor
C. Light-duty solenoid switch
D. Heavy-duty solenoid switch

13-17. What is connected by a linkage inside the solenoid to the pinion shift level that operates the Dyer drive?

A. Gear drive
B. Rack and pinion
C. Belt drive
D. Heavy-duty plunger

13-18. How is the pinion gear thrown out of mesh with the flywheel as the engine is started?

A. Reversing the torque
B. Reversing the rotation of the flywheel
C. Reversing the rotation of the engine
D. Reversing the rotation of the pinion gear

13-19. What kind of gas is used to actuate the piston that forces high pressure fluid out of the accumulator when the starter is engaged with the ring gear on the flywheel of the engine, and the control valve is opened?

A. Argon
B. Helium
C. Nitrogen
D. Oxygen

13-20. How does starting air enter into the cylinders?

A. Blowers
B. Fans
C. Controlled air
D. Pilot air

13-21. What is the operating range of glow plugs?

A. 1400-1600 °F
B. 1652-1832 °F
C. 1950-2150 °F
D. 2234-2434 °F

Chapter 14
Diesel Engine Operating Practices

14-1. When you have malfunctioning operating equipment, what must you pay particular and continuous attention to?

A. Normal noise
B. Abnormal pressures
C. Normal temperatures
D. Normal operating speeds

14-2. What should you be suspicious of with pressure-govern-controlled equipment?

A. Any changes in the operating speeds
B. Any changes in the operating temperatures
C. Any changes in the operating pressures
D. Bubbles in the sight glass

14-3. Which two Naval Ships' Technical Manual (NSTM) chapters provide additional information on symptoms of diesel engine trouble?

A. 114, and 300
B. 050, and 233
C. 079, and 502
D. 079, and 233

14-4. What abnormal noise is caused by loose, excessive worn or broken engine parts?

A. Clicking
B. Rattling
C. Hammering
D. Squealing

14-5. What must happen to test equipment that is suspect to inaccurate reading?

A. It must be tested
B. It must be replaced
C. It must be cleaned
D. It must have a caution tag on it

14-6. What is the color of the smoke that you would see coming from the exhaust of a normal operating diesel engine?

A. Gray
B. Black
C. Bluish
D. No color

14-7. How are the Navy small boat electrical systems generally wired?

A. One-wire, grounded, 24-volt
B. Two-wire, ungrounded, 24-volt
C. Two-wire, ungrounded, 12-volt
D. One-wire, grounded, 12-volt

14-8. What procedure is NOT part of the general operational checks for starting a diesel engine?

A. Start backup generator
B. Make pre-operational checks
C. Align supporting systems
D. Crank the engine with the starting equipment until ignition occurs and the engine is running

14-9. When starting a diesel engine, you want to operate it in idle until the lubricating oil reaches what temperature?

A. 85 °F
B. 100 °F
C. 115 °F
D. 130 °F

14-10. What additional check should you make to a diesel engine that has been overhauled or has been in a long period of idleness?

A. Keep all danger tags on until diesel engine runs satisfactorily
B. Start engine and inspect; fill according the freshwater system and vent air
C. Test the full range of the engine from no load to full load
D. Make a thorough check of the lubricating oil system

14-11. When on watch, operators should be aware of what type of direct or indirect unusual operating conditions?

A. Engine speed
B. Lubricating oil
C. Air
D. Fuel supply

14-12. When operating a diesel engine, what is the lowest percentage of power that you can operate for a prolonged period of time?

A. One-third
B. One-fourth
C. One-fifth
D. One-tenth

14-13. How often should you rotate the cleaning handles on the lubricating oil strainers in the diesel engine lubricating oil system?

A. Once a day
B. Every 12 hours
C. Every 8 hours
D. Once during a watch

14-14. How does the Navy maintain adequate supply of clean fuel for the diesel engine?

A. Transfers directly from storage tank
B. Transfers directly from stripping tank
C. Purifies day tank
D. Transfers directly from the settling tank

14-15. What must be done before tripping the overspeed trips of a diesel engine?

A. Stop supply of fuel to the governor
B. Stop supply of lubricating oil to diesel engine
C. Reduce the diesel engine speed to the specified idling speed
D. Stop the supply of air to the diesel engine

14-16. What must you NEVER do to a relief valve?

A. Clean
B. Calibrate
C. Label
D. Lock

14-17. What is essential for efficient operation and maintenance of a diesel engine?

A. Cleanliness
B. Practice
C. Equipment
D. Work

14-18. What check should be completed to ensure that the support systems and control systems are aligned and that the emergency generator is ready for operation?

A. Fuel system valves are correctly aligned
B. Fuel service tank is 75 percent
C. “Keep warm” system is in standby
D. Switchboard is set to standby

14-19. What percentage does a ship’s electrical load fall below causing the emergency generator starting mechanism to actuate?

A. 50 percent
B. 80 percent
C. 110 percent
D. 140 percent

14-20. What is NOT used for communication during Engineering Operational Casualty Control (EOSS) drills?

A. Sound-power circuit
B. Intercoms
C. 1-PK
D. Messengers

14-21. What is useful in the preliminary phases of training for imparting knowledge of casualty control procedures without endangering the ship’s equipment?

A. Practice on the pier
B. Dry run
C. Classroom training
D. Live scenario

14-22. What is the purpose of the split-plant design in the engineering plant?

A. Reduce the cost of operating a lot of equipment
B. Minimize battle damage that might result from a single hit
C. Reduce man hours
D. Reduce Planned Maintenance System (PMS)

14-23. When there is casualty in an engine room, who must the engineering officer of the watch (EOOW) notify as soon as possible?

A. Engineering officer and the Main Propulsion Assistant (MPA)
B. Main Propulsion Assistant (MPA) and the officer of the deck (OOD)
C. Engineering officer and the space supervisor
D. Engineering officer and the officer of the deck (OOD)

14-24. When emergency repairs have been made, what must be done before bringing the diesel engine back on line?

A. Account for all tools
B. Keep danger tags on until operational test is satisfactory
C. Do not tighten fasteners fully until operational test is satisfactory
D. Do not fill fluid completely until operational test is satisfactory

14-25. Why must you familiarize yourself with the specific temperatures, pressures, and operating speeds of equipment required for normal operations?

A. Easier to stand watch
B. Training new personnel
C. Detect any departure from normal operating conditions
D. Better training on aligning the systems

14-26. What should be done when collecting a lubricating oil sample from a piece of equipment that has been idle for some time?

A. Start the engine to warm the lubricating oil
B. Take the sample and wipe the area down
C. Drain a sufficient sample from the lowest part to remove all of the settled water
D. Tag out equipment and take the sample

14-27. What noise is associated with an improperly functioning valve mechanism or timing gear?

A. Clicking
B. Knocking
C. Pounding
D. Rattling

14-28. What does bluish-white exhaust smoke indicate from a diesel engine?

A. High exhaust back pressure (clogged exhaust ports, piping, or muffler)
B. Improperly timed or faulty injector
C. Low compression (burned valves or stuck piston rings)
D. Cracked pistons

14-29. What electrical system is necessary on a non-conducting boat hull of wood or plastic?

A. Grounded
B. Balanced
C. Two-wire
D. Three-wire

14-30. When you are starting or operating an engine or combating casualties in the engineering plant, what documentation should be used?

A. Naval Ships' Technical Manual (NSTM)
B. Engineering Operational Sequencing System (EOSS)
C. Naval Sea Systems Command (NAVSEA) technical manual
D. Engineering Operational Procedures (EOP)

14-31. What is the minimum temperature of the lubricating oil on a diesel engine that has been routinely secure that needs to be started?

A. 50 °F
B. 75 °F
C. 100 °F
D. 125 °F

14-32. What is the range of a normal load if applied to a diesel engine when the lubricating oil temperature reaches 120 °F?

A. 40 percent
B. 70 percent
C. 90 percent
D. 100 percent

14-33. When should a diesel engine be operated in an overload condition?

A. Emergency
B. Never
C. Break away
D. Exiting ports

14-34. When securing a diesel engine you want to leave a specified number of indicator cocks open for what reason?

A. Assist in cooling the diesel engine down
B. Inspect cylinder after shutdown
C. Clean cylinder after shutdown
D. Detect any water accumulation in the cylinder prior to starting the diesel engine

14-35. While an emergency generator furnishes power, what electrical auxiliary is NOT considered a vital source?

A. The internet
B. Steering gear
C. Ship's gyro
D. Casualty distribution system

14-36. How is communication established during Engineering Casualty Control drills?

A. From damage control
B. From the control station
C. From the bridge
D. From repair five

14-37. What system is NOT designed for split-plant operation?

A. Fuel
B. Oily waste
C. Starting air
D. Cooling-water

Chapter 15
Transmission of Engine Power

15-1. What propulsion-driven system components increase and decrease torque?

A. Couplings
B. Gears
C. Line shaft bearings
D. Strut bearings

15-2. What is equal to input horsepower minus any losses?

A. Total revolutions per minute (rpm)
B. Speed
C. Knots through water
D. Output horsepower

15-3. What engineering equipment uses indirect drive mechanisms for transmitting power?

A. Generators
B. Pumps
C. Marine engines
D. Air conditions units

15-4. What is the reduction ratio in most Navy diesel engine ships and propellers?

A. 3 to 1
B. 5 to 1
C. 7 to 1
D. 9 to 1

15-5. What coupling type does not allow for any misalignment between the input and output shaft, nor does it absorbs any of the torsional vibration transmitted from the engine’s crankshaft?

A. Hollow
B. Rigid
C. Solid
D. Flexible

15-6. What is the highest rated horse power (hp) diesel engine that friction clutches can be used on?

A. 1,000
B. 2,000
C. 3,000
D. 4,000

15-7. How does operating a diesel engine in an overloaded condition affect the clutches?

A. Sticking
B. Breakage
C. Slippage
D. Tearing

15-8. In what kind of transmission system would you have planetary gears?

A. Mechanical
B. Pneumatic
C. Nitrogen
D. Hydraulic

15-9. What cause the aeration of the hydraulic oil in the hydraulic transmission system?

A. Dirt
B. Improper level
C. Water
D. Air

15-10. At how many pounds per square inch (psi) does air get forced into the tubes of the airflex clutch, and the gear assembly friction blocks come in contact with the clutch drum?

A. 50
B. 75
C. 100
D. 125

15-11. Which of the following is a bearing type found in a main propulsion shaft?

A. Kingsburg
B. Thrust
C. Strut
D. Journal

15-12. How are the brass oiler rings positioned on a line shaft bearing?

A. In-line
B. Fee-floating
C. Semi-floating
D. Axial

15-13. Where is the oil scraper disc located on the line shaft bearing?

A. In the middle
B. On the top
C. On the bottom
D. On the outside

15-14. What is used to inflate the inflatable sealing ring in emergencies?

A. Nitrogen
B. Oxygen
C. Helium
D. Hydrogen

15-15. In a hydraulic coupling, what type of valve is used when extremely rapid declutching is NOT required?

A. Piston-type quick-dumping valve
B. Piston-type neutral directional valve
C. Needle-type quick-dumping valve
D. Needle-type neutral-dumping valve

15-16. How does the induction coupling limit maximum torque when excessive torque is applied?

A. Pulling out of step
B. Breaking circuit
C. Breaking loop
D. Disconnecting

15-17. What gives a ship excellent maneuverability and allow the propeller to develop maximum thrust at given shaft rpm?

A. Contained pitch propeller
B. Controllable pitch propeller
C. Connected pitch propeller
D. Combined pitch propeller

15-18. What is the most widely used means of providing the force required to change the pitch of a propeller?

A. Electricity
B. Diesel fuel
C. Hydraulic oil
D. Water

15-19. What station can NOT control the operation of the ship's propeller?

A. Local
B. Enclosed
C. Pilot-house
D. Shaft alley

15-20. What must be done to clutch plates if they come into contact with ethylene glycol antifreeze?

A. Clean with water
B. Wipe with dry cloth
C. Replace
D. Remove and use cleaning solvent

15-21. How is power transmitted from the drive mechanism on most Navy installations?

A. Fuel and oil
B. Fuel and gears
C. Gears and shafts
D. Shafts and oil

15-22. What drive mechanism is used by common marine engines?

A. Attached
B. Indirect
C. Direct
D. Detached

15-23. What component is used in indirect drives to connect the engine to the drive mechanism?

A. Flexible coupling
B. Solid coupling
C. Spring coupling
D. Rigid coupling

15-24. What is the condition called when the clutch fails to disengage because of water absorbed in the material that lines the clutch plates?

A. Wear
B. Slippage
C. Squealing
D. Frozen

15-25. What linkage on friction clutches engages when two friction surfaces are mechanically forced into contact with each other?

A. Toggle-action
B. Spring
C. Hydraulic
D. Pneumatic

15-26. What component on the airflex clutch control mechanism delays the inflation of the clutch to be engaged during the shifting from one direction of rotation to the other?

A. Time delay switch
B. Restricted plates
C. Restricted orifice
D. Pressure switch

15-27. What component of the main shaft ensures the proper guide and support of rotating elements, prevents free radial movement, and limits the axial movement of the shaft?

A. Foundations
B. Supports
C. Bearings
D. Hangers

15-28. Where is the stern tube located on the main shaft?

A. Through the hull of the ship
B. Between the bulkheads between spaces
C. Under the rudder
D. Before the propeller

15-29. A hydraulic coupling eliminates the need for a mechanical connection between the engine and which part?

A. Main shaft
B. Flywheel
C. Propeller
D. Reduction gear

15-30. How is the outer rotor of the induction coupling energized to lock in with the inner rotor?

A. Contact switch
B. Pressure switch
C. Pressure contact
D. Collector rings

15-31. What is the worst enemy of any hydraulic system?

A. Dirt
B. Grease
C. Water
D. Fuel

Chapter 16
Pumps and Valves

16-1. In what kind of rotary pump is pressure a result of resistance to flow in the system to which it discharges?

A. Non-positive
B. Positive
C. Indirect
D. Direct

16-2. What quality specific to a herringbone gear pump provides a steadier discharge pressure than that of simple gear pumps?

A. Overlapping of teeth
B. More lubrication needed
C. Less contact area
D. Smaller gear ratio

16-3. Where are the gibs located in lobe pumps?

A. In the middle of the lobes
B. Attached to the packing gland
C. Around the shaft
D. On the extremities of the lobes

16-4. What precaution is installed on some centrifugal pumps to prevent the pumps from becoming overheated and vapor bound?

A. Cooling fan
B. Internal cooling passage
C. Recirculating line
D. Special instruction for leakage

16-5. Why does the variable-stroke axial-piston pump have an uneven number of pistons in its cylinder casing?

A. It is a port side pump
B. It is a starboard side pump
C. To avoid pulsation during discharge
D. To maintain a neutral position

16-6. What part of the jet pump will show wear and require maintenance?

A. Impeller
B. Motor
C. Gears
D. Nozzle

16-7. What component is used in piping systems to control the amount and direction of the medium going through the pipes?

A. Valve
B. Connection
C. Flange
D. Union

16-8. What are the disks and seats of valves used in steam systems coated with?

A. Stelite
B. Chromium-copper
C. Chromium-nickel
D. Bronze-cobalt

16-9. What type of system are you most likely to find butterfly valves on?

A. Slow acting, positive flow
B. Quick acting, positive flow
C. Quick acting, non-positive flow
D. Slow acting, non-positive flow

16-10. How many degrees of turn are needed to open or close a butterfly valve?

A. 45
B. 90
C. 135
D. 180

16-11. What is the main purpose for a ball valve?

A. Circulate the medium in the system
B. Throttle system pressure
C. Regulate temperature of discharge medium
D. Start and stop flow of medium

16-12. What do relief valves have on them for manual test operation?

A. Pushbutton
B. Switch
C. Lever
D. Handwheel

16-13. Which of the following is NOT one of the ways to actuate a remote-operated valve?

A. Water
B. Electrical
C. Mechanical
D. Hydraulic

16-14. What kind of packing material has the capabilities for rapid heat dissipation, reduced wear, flexibility, and high resilience?

A. Corrugated ribbon packing (CRP)
B. Graphite filament yard (GFY)
C. Wool
D. Rubber

16-15. To find out about the health concerns associated with handling asbestos, what Naval Ships' Technical Manual (NSTM) chapter would you reference?

A. 150
B. 233
C. 450
D. 635

16-16. What material(s) are flange safety shields constructed of?

A. Plastic
B. Rubber
C. Aluminized glass cloth
D. Cotton and leather

16-17. What are the most numerous units of auxiliary machinery aboard ships?

A. Water foundation
B. Pumps
C. Unit coolers
D. Steam kettles

16-18. How is fluid trapped and forced through the screw pump?

A. Rotation of the screws
B. Gravity
C. Positive displacement
D. Centrifugal force

16-19. Why are centrifugal pumps provided with replaceable wearing rings?

A. Easier to replace than the shaft
B. Cheaper to replace than the whole pump
C. Easier to renew than the impeller
D. Always have spares on hand

16-20. What is considered an automatic-operated valve?

A. Deck washing connection
B. Fuel tank fill
C. Pressure regulating valve
D. Potable water tank fill

16-21. When is a gate valve used in a system?

A. When maximum flow restriction is needed
B. When throttling is needed
C. To bypass the relief valve in the system
D. When minimum flow restriction is needed

16-22. How many directions does the check valve allow the medium to flow through the system?

A. One
B. Two
C. Three
D. Four

16-23. How many valves should a reducing station have at minimum?

A. One
B. Two
C. Three
D. Four

16-24. What is NOT a basic design of a pressure-reducing valve?

A. Pneumatic
B. Fuel
C. Air-pilot
D. Spring

16-25. What do remote-operated valves have to show what their actual position is?

A. Alarms
B. Flags
C. Position indicators
D. Nothing

16-26. Where would you find information on how to select the right packing and gasket material?

A. Naval Sea Systems Command (NAVSEA), Mechanical Standard Drawing B0153
B. Naval Sea Systems Command (NAVSEA), Mechanical Standard Drawing F2355
C. Naval Sea Systems Command (NAVSEA), Mechanical Standard Drawing R7544 Naval Sea Systems Command (NAVSEA), Mechanical Standard Drawing Z6957

Chapter 17
Compressed Air Systems

17-1. Reciprocating air compressors consists of mechanical parts has the following?

A. Crankshafts
B. Camshafts
C. Pistons
D. Rocker arms

17-2. What kind of piston is fitted into special cylinders, arranged so that more than one stage of compression is achieved by a single upward stroke of the piston?

A. Differential
B. V-type
C. Opposing
D. Straight

17-3. When does lubrication start for reciprocating compressors?

A. Compressor has pre-lubrication system
B. 5 seconds after startup
C. Once vacuum is built up
D. Automatically as compressor starts up

17-4. What makes the start-stop design compressor start and stop automatically as the receiver pressure falls or rise?

A. Contact switches
B. Bourdon tubes
C. Predetermined set points
D. Energized plates

17-5. What type of valve is the unloaded valve on a helical screw compressor?

A. Gate
B. Butterfly
C. Needle
D. Ball

17-6. What is the operating range in pounds per square inch (psi) of a swashplate compressor?

A. 1,000-3,000
B. 3,000-5,000
C. 5,000-7,000
D. 7,000-9,000

17-7. What components are used in separator assemblies and the compressor assembly to prevent excess pressure buildup?

A. Contact switches
B. Pressure relief valves
C. Bypass valves
D. Cutoff valves

17-8. How much discharge pounds per square inch (psi) can a high-pressure air compressor (HPAC) produce in a continuous automatic operation mode?

A. 1,000
B. 2,000
C. 3,000
D. 4,000

17-9. What item allows monitoring of the water level within the separator assembly?

A. Sight glass
B. Water level Indicator
C. Check valve
D. Pressure gauges

17-10. The crossheads are constructed of what material?

A. Bronze
B. Titanium
C. Copper
D. Iron

17-11. What type of air compressor is mostly used for general-service use?

A. Rotary
B. Swivel
C. Swashplate
D. Helical screw

17-12. What system controls the compressor operation?

A. Air compressor starting
B. Compressor management system (CMS)
C. Refrigeration control
D. Start valve control

17-13. What component is a one-piece forging, accurately machined and balanced with removable counterweights to counteract shaking forces?

A. Connecting rod
B. Crankshaft
C. Camshaft
D. Piston

17-14. What component forms the link between the connecting rod and piston rod?

A. Crankshaft
B. Camshaft
C. Piston
D. Crosshead

17-15. The unloader valve is made of what material?

A. Aluminum
B. Brass
C. Bronze
D. Steel

17-16. What components are connected between the swashplate and the piston?

A. Connecting rods
B. Camshaft
C. Rocker arms
D. Journal bearings

17-17. The Worthington high-pressure air compressor (HPAC) has how many stages?

A. 2
B. 3
C. 4
D. 5

17-18. What does the counterweight provide on the swashplate assembly?

A. Smooth running balance
B. More lubricating oil distribution
C. Better cooling
D. Increase pressure ratio

17-19. What is NOT contained in a cylinder head of a standard Navy air compressor?

A. Piston
B. Suction valve
C. Discharge valve
D. Rocker arms

17-20. What connects the upper end of the connecting rod to fit directly to the trunk piston on an air compressor?

A. Stationary pin
B. Wrist pin
C. Free-floating pin
D. Semi-floating pin

17-21. What kind of pump moves oil from the reservoir in the compressor base and delivers it through a filter to a cooler to the cylinders?

A. Centrifugal
B. Lobe
C. Gear
D. Rotary

17-22. How would colder air from the intercooler affect the brake horsepower of the air compressor?

A. Lower it
B. Rise it
C. No change
D. Air compressors do not have brake horsepower

17-23. What component do vertical-mounted receivers have that permit proper draining of accumulated moisture, oil, and foreign matter?

A. Manual drain valve
B. Automatic drain valve
C. Relief valve
D. Convex bottoms

17-24. Air compressors are classified by what characteristics?

A. Amount of air supplied to the compressed
B. Capacity
C. Dimensions
D. Size of final stage cylinder

17-25. What is the discharge pressure rate of a low pressure air compressor (LPAC) in (a) cubic feet per minute and (b) pounds per square inch gauge?

A. (a) 100, (b) 105
B. (a) 200, (b) 125
C. (a) 200, (b) 145
D. (a) 400, (b) 165

17-26. The air inlet filter is capable of removing particles what size, in microns?

A. 10
B. 25
C. 50
D. 75

17-27. What component permits compression loads to be removed automatically during startup and applied automatically when the unit is back up to operating speed?

A. Air inlet filter
B. Water filter assembly
C. Heat exchanger
D. Suction unloader valve

17-28. What component uses a replaceable filter element to remove dirt and other solid particles of 20 microns or greater from the injection water?

A. Air inlet filter
B. Heat exchanger
C. Suction unloader valve
D. Water filter assembly

17-29. At what pounds per square inch gauge (psig) is the high pressure relief valve set from the manufacturer?

A. 150
B. 175
C. 200
D. 225

17-30. The drive elector motor on the RIX high pressure air compressor (HPAC) is how much horsepower (hp)?

A. 40
B. 60
C. 80
D. 100

17-31. What assembly houses the crankshaft, swashplate drive system, and connecting rods?

A. Base
B. Crankcase
C. Drive motor
D. Swashplate

17-32. What component is located at the motor-end of the compressor attached to the first stage suction port?

A. Suction relief valve
B. Suction gauge
C. Suction filter
D. Suction bypass valve

Chapter 18
Distilling Plants

18-1. Which of the following solutions is made up of water and various minerals and salts?

A. Distillate
B. Freshwater
C. Oxidation
D. Seawater

18-2. Distilling plants are NOT effective in removing which of the following contaminants?

A. Brine that has a high boiling point
B. Salt that has a lower boiling point than water
C. Volatile gases or liquids that have a lower boiling point than water
D. Water with a high boiling point

18-3. What happens to volatile gases in distilling plants?

A. They become purified
B. They boil into vapor and are combined with the freshwater
C. They oxidize and enrich freshwater with minerals
D. They explode

18-4. Which of the following devices is used to prevent carryover?

A. Dry separators
B. Moisture separators
C. Salinity purifier
D. Tube vaporizer

18-5. In what chapter of the Naval Ships' Technical Manual (NSTM) can you find details on carryover?

A. 531
B. 545
C. 631
D. 645

18-6. What term best describes the product of the evaporation of seawater feed?

A. Brine
B. Distillate
C. Feed
D. Vapor

18-7. What term best describes water in which the concentration of chemical salts is higher than it is in seawater?

A. Brine
B. Distillate
C. Feed
D. Vapor

18-8. What term best describes the product resulting from the condensation of the steam produced by the evaporation of seawater?

A. Brine
B. Distillate
C. Feed
D. Vapor

18-9. How many classifications, or arrangements, of submerged tube distilling plants are there?

A. One
B. Two
C. Three
D. Four

18-10. Which of the following is a classification of submerged tube distilling plants?

A. Double-effect
B. One-shell single-effect
C. Tri-shell effect
D. Two-shell single-effect

18-11. What component permits withdrawal and descaling of the salinity cells without securing the unit?

A. Condensation purifying tubes
B. Flange tubes
C. Shutoff valves
D. Vapor gate valves

18-12. What term best describes the process of boiling seawater, then cooling and condensing the resulting vapor to produce freshwater?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-13. What term best describes the process of cooling the freshwater vapor produced by evaporation to produce usable freshwater?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-14. What term best describes the process of boiling seawater to separate it into freshwater vapor and brine?

A. Condensation
B. Distillation
C. Evaporation
D. Salinity

18-15. What term best describes a vapor that is NOT adjacent or next to its liquid source and has been heated to a temperature above its saturation temperature?

A. Brine
B. Effect
C. Superheated steam
D. Vapor

18-16. How many major types of low pressure steam distilling units are there?

A. One
B. Two
C. Three
D. Four

18-17. What method is recommended to test for air leaks when the plant is secured?

A. Using an air-pressure or soapsuds test on the various component parts
B. Using a candle flame to test all joints and parts
C. Using the pressure from the main pump to test all parts
D. Visually inspecting the parts

18-18. Which of the following methods should you use to find a leak in a heat exchanger?

A. Candle test
B. Hydrostatic test
C. Non-destructive test
D. Visual test

18-19. Which of the following conditions is a primary cause of air ejector problems?

A. Clear nozzle
B. Obstructed nozzle
C. Scale formation
D. Low vacuum pressure

18-20. What condition does a complete flooding of the flash chamber gauge glass indicate?

A. Improper drainage
B. Inconsistent brine density
C. Insufficient circulating water
D. Vacuum loss in the two-stage flash

18-21. Which of the following pieces of equipment is used to produce pure water for drinking, cooking, and other freshwater uses?

A. Centrifugal purifier
B. Normal osmosis plant
C. Reverse osmosis (RO) plant
D. Zinc oxide purifier

18-22. In what chapter of the Naval Ships' Technical Manual (NSTM) is troubleshooting procedures for reverse osmosis (RO)?

A. 351
B. 431
C. 458
D. 531

18-23. Which of the following conditions can cause the high-pump discharge light to be illuminated?

A. Bound or clogged transducer airline
B. Defective pressure transducer
C. Oil reservoir level low
D. Operating with severely fouled membranes

Chapter 19
Environmental Pollution Program and Policies

19-1. The Oil Pollution Act of 1924 was repealed by which of the following acts?

A. Oil Pollution Act of 1954
B. Oil Pollution Act of 1961
C. Water Quality Improvement Act of 1979
D. Water Quality Improvement Act of 1989

19-2. What amendments set goals for the reduction of pollutant emissions from stationary sources and vehicles?

A. Clean Air Amendment of 1970
B. Clean Air Amendment of 1979
C. Water Quality Improvement Amendment 1979
D. Water Quality Improvement Amendment 1989

19-3. Which of the following acts requires Federal, State, and local governments to create and maintain conditions where man and nature can exist together?

A. Environmental Quality Improvement Act of 1972
B. Environmental Quality Improvement Act of 1979
C. National Environmental Policy Act of 1969
D. National Environmental Policy Act of 1983

19-4. You should NEVER raise fuel oil (FO) above what temperature, in degrees Fahrenheit?

A. 75
B. 80
C. 100
D. 120

19-5. What publication provides guidance on giving first aid to any person suffering from inhalation of fuel oil (FO) fumes?

A. Standard First Aid Training Course, NAVEDTRA 11082
B. Standard First Aid Training Course, NAVEDTRA 12081
C. Naval Ships' Technical Manual (NSTM), chapter 075
D. Naval Ships' Technical Manual (NSTM), chapter 220

19-6. To what temperature, in degrees Fahrenheit, should you heat fuel oil (FO), if the transfer pump is having difficulty moving the fuel?

A. 75
B. 80
C. 90
D. 95

19-7. How far in advance should you man fueling stations when preparing to take on fuel?

A. 15 minutes
B. 30 minutes
C. 1 hour
D. 2 hours

19-8. When fuel oil (FO) is received, who must furnish the commanding officer of the receiving ship with an analysis of the oil?

A. The executive officer (XO)
B. The oil king
C. The activity receiving the fuel
D. The activity supplying the fuel

19-9. When you start filling the first two tanks in each overflow group, you should start filling the others in the group at approximately what percent capacity?

A. 65
B. 75
C. 85
D. 95

19-10. While fuel oil (FO) is discharging, what color flags are placed over the side of the ship at the fueling stations?

A. Green
B. Orange
C. Red
D. Yellow

19-11. To reduce and control environmental pollution, what method is preferred?

A. Act quickly when notified of pollution
B. Prevent the pollution
C. Plan and train emergency response teams
D. Stop using pollutants aboard ship

19-12. All oil spills and slicks or sheens within the 50-mile prohibited zone of the United States shall be reported immediately according to what publication?

A. Environmental and Natural Resources Protection Manual, OPNAVINST 5090.1(series)
B. Environmental and Natural Resources Protection Manual, SECNAVINST 5090.1(series)
C. Naval Ships' Technical Manual *(*NSTM*)*, chapter 075
D. Naval Ships' Technical Manual (NSTM), chapter 220

19-13. In what year did Congress pass a law prohibiting the discharge of refuse in navigable waters of the United States?

A. 1812
B. 1899
C. 1928
D. 1942

19-14. What act prohibits the discharge of oil or oily mixtures, such as ballast, within the prohibited zones established by any nation, and those zones ranging from 50 to 150 miles seaward from the nearest land?

A. The Oil Pollution Act of 1961
B. The Oil Pollution Act of 1978
C. The Water Quality Act of 1961
D. The Water Quality Act of 1978

19-15. What instruction contains guidelines to prevent, control, and abate air and water pollution?

A. Clean Water and Air Program Manual, OPNAVINST 5090.1(series)
B. Clean Water and Air Program Manual, SECNAVINST 5190.2
C. Environmental and Natural Resources Protection Manual, SECNAVINST 5190.2
D. Environmental and Natural Resources Protection Manual, OPNAVINST 5090.1

19-16. Over how many miles from shore must you be in order to discharge trash and garbage?

A. 12
B. 15
C. 20
D. 22

19-17. The Navy replaced fuel oil (FO) with what fluid, which reduces air pollution because it has low sulfur content and burns more cleanly?

A. Distillate
B. Ethanol
C. Lube oil
D. Water

19-18. What publication lists safety precautions for closed or poorly ventilated compartments?

A. OPNAVINST 5090.1
B. OPNAVINST 5290.2
C. Naval Ships' Technical Manual (NSTM), chapter 074
D. Naval Ships' Technical Manual (NSTM), chapter 230

19-19. Safety precaution, when ships are refueled where the ambient temperature is below 40 °F, you should NOT fill storage tanks above what percent of capacity?

A. 65
B. 75
C. 85
D. 95

19-20. Regarding the immediate reporting of oil slicks and spills or sheens, the prohibited zone of the United States is how many miles?

A. 12
B. 25
C. 50
D. 75

19-21. What publication defines the policies and procedures for dealing with sewage discharge?

A. Clean Water and Air Program Manual, OPNAVINST 5090.1(series)
B. Clean Water and Air Program Manual, SECNAVINST 5190.2
C. Environmental and Natural Resources Protection Manual, SECNAVINST 5190.2
D. Environmental and Natural Resources Protection Manual, OPNAVINST 5090.1

19-22. What system is installed on Navy ships to comply with the sewage discharge standards without compromising mission capability?

A. Marine abatement controller (MAC)
B. Marine sanitation devices (MSDs)
C. Sanitation and waste purifier
D. Sewage storage and filtration

19-23. In what year did the Chief of Naval Operations (CNO) decide that the Navy would install the sewage collection, holding, and transfer (CHT) system?

A. 1948
B. 1965
C. 1972
D. 1978

Questions Chapter 20
Advanced Administration, Supervision, and Training

20-1. What is used to keep a daily record (midnight to midnight) of the ship's engineering department?

A. Engineering Operating Log
B. Engineroom Operating Log
C. Watch Operating Log
D. Engineering Log

20-2. Where can you obtain the forms issued to forces afloat for engineering logs?

A. Naval Sea Systems Command (NAVSEA)
B. Chief of Naval Operations (CNO)
C. Navy Stock List of Forms and Publications, NAVSUP 2002
D. Google

20-3. When does the commanding officer (CO) approve and sign the Engineering Log?

A. Every day
B. The last calendar day of the month only
C. The first calendar day of the month only
D. Every Monday only

20-4. What is the symbol "Z" used for in a Bell Book?

A. Ahead full speed
B. Stop
C. Back full speed
D. Back emergency speed

20-5. Which of the following items is NOT one of the engineer officer's night orders?

A. The night movies on site television
B. Operation of the engineering plant
C. Special orders or precautions concerning the speed and operation of the main engines
D. All orders for the night for the engineering officers of the watch (EOOWs)

20-6. The Engineering Log and Engineer's Bell Book each must be preserved as permanent records on board ship for what total number of years?

A. 1
B. 2
C. 3
D. 4

20-7. What kind of shipboard inspection involves the inspection team coming on board to determine if the department is operating in an intelligent, sound, and efficient manner?

A. General
B. Administrative
C. Routine
D. Focused

20-8. During an Engineering department inspection, the inspection team focuses on which of the following items?

A. Proper haircuts
B. Full sentence entries in logs
C. Length of time for watch standers to complete rounds
D. Proper posting of operating and safety precautions and instructions

20-9. What inspection is conducted to ensure that the ship is ready and able to perform the actions that might be required of it time of war?

A. Battle
B. Operation readiness
C. War time
D. Mission

20-10. What training exercise is considered the most profitable and significant of all peacetime training experiences because it demonstrates departmental readiness for combat by approximating actual battle conditions?

A. Battle problem
B. Computer animation
C. Dry run
D. Classroom walkthrough

20-11. Which of the following ship's trials is considered a routine trial?

A. Builder's
B. Final contract trails
C. Recommissioning
D. Tactical

20-12. What is the total duration of a full power trial?

A. 1 hour
B. 2 hours
C. 3 hours
D. 4 hours

20-13. Which of the following items is NOT included in the EOSS?

A. User's Guide
B. Correction form
C. The Engineering Operation Procedures (EOP)
D. The Engineering Operational Causality Control (EOCC)

20-14. What stage of the EOP is designed just for component operators?

A. 1
B. 2
C. 3
D. 4

20-15. To identify the repair parts for the equipment in your engineroom, you should NOT use which of the following documents?

A. Coordinated Shipboard Allowance List (COSAL)
B. Oil lab parts list
C. Manufacturer's technical manual
D. Blueprints

20-16. The COSAL contains information for which of the following items?

A. Allowance Part List (APL)
B. Raw material
C. Chemical composition
D. Special dyes

20-17. When you need to make a structure or equipment modification, you should use what accounting system?

A. 4790 KC
B. 4790 2L
C. 4790 CK
D. 4790 2Q

20-18. What Naval supply program provides shipboard maintenance managers with a consolidated listing of deferred corrected maintenance so they can manage and control its accomplishment?

A. Ship-to-shop
B. Ship Equipment Configuration Accounting System (SECAS)
C. COSAL
D. Current Ship's Maintenance Project (CSMP)

20-19. When specification cannot be met, what is the standard for the Quality Assurance (QA) program?

A. Notify the work center
B. Complete and report a departure-from-specification request
C. Put an out-of-calibration sticker on the piece of equipment
D. Put a caution tag on the piece of equipment

20-20. Who provides overall instruction, policy, and direction for implementation and operation of the force QA program?

A. CNO
B. TYCOM
C. Commander in chief of the fleets
D. Quality Assurance Officer (QAO)

20-21. What are the codes, assigned by the ship according to the QA manual, that indicate the degree to which the ship's system, subsystem, or components are necessary in the performance of the ship's mission?

A. Levels of essentiality
B. Levels of importance
C. Levels of priority
D. Degrees of essentially

20-22. What level of assurance provides for adequate verification techniques, normally requires limited quality control, and may not require test or inspection?

A. A
B. B
C. C
D. D

20-23. What maximum length of an extension cord, in feet, is permitted on board Navy vessels?

A. 25
B. 50
C. 75
D. 100

20-24. Who is responsible for notifying the commanding officer of a heat stress condition in the engineering spaces?

A. Watchstander
B. Messenger
C. EOOW
D. Engineer officer

20-25. Double hearing protection is mandatory at what decibel (dB) level?

A. Greater than 50 dB
B. Greater than 84 dB
C. Greater than 104 dB
D. Greater than 120 dB

20-26. What in the engineering department provides a means for the proper assignment of duties and proper supervision of personnel?

A. Watch bills
B. Training
C. Evaluation program
D. Administration organization

20-27. Which of the following engineering department records must be preserved as permanent legal records?

A. Engineering Log and Fuel and Water Report
B. Engineering Bell Book and Monthly Summary
C. Engineering Log and Engineer's Bell Book
D. Machinery History and Engineroom Operating Records

20-28. What is the standard engine order telegraph symbol for back emergency speed?

A. Z
B. 1
C. BEM
D. BF

20-29. What does the Engineering Officer use to list major machinery units and readiness of the engineering department based upon the time set for getting the ship underway?

A. Steaming orders
B. Night orders
C. Daily orders
D. Electronic orders

20-30. When computing the amount of burnable fuel on board, which of the following is NOT considered burnable fuel?

A. Fuel in the service tanks
B. Fuel in the storage tanks
C. Fuel below the suction line
D. Fuel in the purifiers

20-31. Who usually designates the type of inspection and when it will be held?

A. Commanding Officer (CO)
B. Chief of Naval Operations (CNO)
C. Fleet forces
D. Type Commander (TYCOM)

20-32. What kind of inspection determines whether proper procedures are being carried out in the care and operation of machinery and equipment?

A. Routine
B. Administration
C. Material
D. Daily

20-33. Which of the following ship’s trials is considered a routine trial?

A. Economy
B. Final contacts
C. Laying up
D. Standardization

20-34. What stage of Engineering Operational Procedures (EOP) is considered as the total engineering plant level under the direct cognizance of the engineering officer of the watch (EOOW)?

A. 1
B. 2
C. 3
D. 4

20-35. What level of assurance provides for minimum or “as necessary” verification techniques and normally requires very little quality controls, tests, or inspections?

A. A
B. B
C. C
D. D

20-36. Which of the following Training films has been included in the Navy’s heat stress training for the engineering department?

A. Heat Stress Monster
B. I Can Stand the Heat
C. It’s Not Hot I Have This
D. No Breaks for Me

20-37. At what decibel (dB) level must ear protection be worn and warning signs posted cautioning about noise hazard that may cause loss of hearing?

A. Greater than 50
B. Greater than 67
C. Greater than 74
D. Greater than 84

Chapter 21
Engine Maintenance

21-1. What must be done to a gauge, or other instrument for recording operating conditions of machinery, that gives an abnormal reading?

A. Fully investigate
B. Take the reading
C. Increase the flow of fluid
D. Decrease the flow of fluid

21-2. What kind of test is used to determine if there is saltwater present in lubrication oil?

A. Hardiness
B. Bromine
C. Scale
D. Chloride

21-3. When doing compression test on a diesel engine, what is the desired load of the engine?

A. One half
B. One third
C. One quarter
D. One eighth

21-4. Where is the cold junction of the thermocouple pyrometer exposed to?

A. Manifold of each cylinder
B. Intakes of each cylinder
C. Exhaust of each cylinder
D. Room temperature

21-5. What is used to tell the operator what is going on inside the diesel engine and how it is performing?

A. Logs
B. Graphic records
C. Lubricating oil samples
D. Filter samples

21-6. Where is the diesel engine temperature-control element bellows mounted?

A. Lubricating oil inlet
B. Cooling water discharge
C. Lubricating oil discharge
D. Cooling water inlet

21-7. When the temperature regulators are cooling lubricating oil in the seawater circuit, how many temperature regulators are required?

A. 1
B. 2
C. 3
D. 4

21-8. What does it mean when there is a gradual increase in the freshwater temperature?

A. Freshwater inlet fully open
B. Freshwater bypass valves closed
C. Excessive scale on cooler element
D. Saltwater inlet fully open

21-9. Which of the following should be used to clean the tubes of a shell-and-tube heat exchanger?

A. Compressed air
B. Steel brush
C. Air lance
D. High pressure air

21-10. What is the most common cause of lubricating oil pump failure?

A. Unbalance
B. Loose foundation
C. Misalignment
D. Wear

21-11. What kind of fuel delivery system uses a cam-actuated constant-stroke lapped plunger and barrel pump?

A. Individual pump
B. Unit injection
C. Cam actuated injector and nozzle assembly
D. Common rail

21-12. What kind of fuel delivery system contains one untimed, high-pressure pump that supplies fuel at injection pressure to a main header?

A. Unit injection
B. Cam-actuated injector and nozzle assembly
C. Common rail
D. Individual pump

21-13. How would you remove rust or pit marks on a plunger before reinstalling?

A. Grinding
B. Honing
C. Lapping
D. Stoning

21-14. What could be used to reduce casualties from accidentally dropping part on the work bench?

A. Rubber gloves
B. Linoleum
C. Cloth
D. Paper

21-15. What component is NOT the cause of backlash in a fuel control system?

A. Crankshaft
B. Gear
C. Rack
D. Control sleeve

21-16. If the governor's oil is foaming, what is this an indication of?

A. Dirt in the oil
B. Air in the oil
C. Water in the oil
D. Overheated oil

21-17. What malfunction in a hydraulic governor is indicated by a high frequency vibration fuel rod end or engine linkage?

A. Hunt
B. Surge
C. Rattle
D. Jiggle

21-18. What Naval Ships' Technical Manual (NSTM) chapter discusses the lubrication oil management program?

A. 100
B. 178
C. 262
D. 344

21-19. What term is used to describe the sample if solid particulate is not found in lubricating oil during a visual observation test?

A. Clear
B. Transparent
C. Filmy
D. Pellucid

21-20. What is the maximum sediment allowed in lubricating oil for the bottom sediment and water (BS&W) test?

A. 0.001 percent
B. 0.01 percent
C. 0.1 percent
D. 1 percent

21-21. What NSTM chapter discusses testing fuel in ships stowage and service tanks?

A. 202
B. 444
C. 486
D. 541

21-22. How are cracked lands caused on a piston?

A. Insufficient ring groove clearance
B. Insufficient ring groove lubricating
C. Insufficient ring groove material
D. Insufficient piston rings

21-23. What is the main cause for crankshaft and camshaft failure in diesel engines?

A. Overloaded conditions
B. Metal fatigue
C. Constant speed shifting
D. Cooling differential troubles

21-24. What is the most direct way for checking gear clearance on blower rotor gears?

A. Inside micrometer
B. Outside micrometer
C. Feeler gauge
D. Depth micrometer

21-25. How often, in hours, should compression and firing pressure readings be taken on diesel engine for trend analysis graphs?

A. 200
B. 250
C. 300
D. 350

21-26. A thermocouple pyrometer, is used in which principal engine system?

A. Intake
B. Exhaust
C. Saltwater
D. Freshwater

21-27. In what system is the temperature regulating valve located in on most diesel engines?

A. Fuel
B. Lubricating oil
C. Saltwater
D. Freshwater

21-28. What is used for making emergency repairs to the radiator-type heat exchanger?

A. Hard solder
B. Cooper nickel
C. Soft solder
D. Steel

21-29. What kind of pumps is used in diesel engine lubricating oil systems?

A. Gear
B. Jerk
C. Positive displacement
D. Centrifugal

21-30. How are pump casualties, and many other lube system failures indicated?

A. Increase of lubricating oil temperature
B. Decrease of lubricating oil temperature
C. Increase of lubricating oil pressure
D. Decrease of lubricating oil pressure

21-31. What kind of fuel delivery system embodies a cam-actuated constant-stroke lapped plunger and bushing, a high pressure pump, and an injection nozzle, all in one unit?

A. Individual pump system
B. Unit injection system
C. Common rail
D. Individual pump

21-32. What kind of fuel delivery system employs a common metering device that distributes a measured quality of fuel to each of the ejectors?

A. Cam-actuated injector and nozzle assembly
B. Individual pump system
C. Common rail
D. Individual pump

21-33. What causes the diesel engine to have uneven operation or vibrations?

A. Improper timing of the fuel system
B. Improper purification of the fuel system
C. Improper purification of the lubricating oil system
D. Improper cooling of the lubricating oil system

21-34. What information is found on the label of the lubricating oil sample bottle?

A. Sump level
B. Person taking sample
C. Equipment
D. Sample code

21-35. What is it called when the piston shifts its thrust from one side to the other side after it reach top dead center (TDC) and bottom dead center (BDC)?

A. Smack
B. Strike
C. Slap
D. Swipe

21-36. What condition causes oxidation, leaving carbon deposits on the rings and in the grooves of a diesel engine?

A. Low operating temperatures
B. Excessive operating temperatures
C. Low cooling temperatures
D. Excessive cooling temperatures

21-37. What is the first indication of a spalled or pitted roller or race in a frictionless bearing?

A. Smoke
B. Red color
C. Bubbling of oil
D. Noisy bearing

Chapter 22
Reduction Gears and Related Equipment

22-1. To what component are reduction gears coupled?

A. Propulsion gear
B. Propulsion shaft
C. Turbine gear
D. Turbine shaft

22-2. What is proportional to the diameters of the pinion and gears?

A. The ratio number of gears
B. The ratio number of pinions
C. The ratio of the speeds
D. The average speed

22-3. The turning gear is mounted on top and at the after end of what component?

A. Clutch
B. Reduction gear casing
C. Rotor
D. Shaft

22-4. Reduction gears are classified according to what?

A. The number of steps used to reduce speed and the arrangement of the gearing
B. The number of steps used to increase speed and the arrangement of the gearing
C. The number of gears used in the arrangement
D. The speed used to arrange the gears

22-5. Which of the following is one of the largest and most expensive units of machinery found in the engineering department?

A. Auxiliary bearing
B. Auxiliary reduction gear
C. Main bearing
D. Main reduction gear

22-6. What is the Navy symbol for the lubricating oil in the propulsion gears?

A. 9250 TEP
B. 2190 TEP
C. 2910 TEP
D. 9520 TEP

22-7. The mixture of metallic particles and what material causes gear tooth surface erosion?

A. Dirt
B. Fuel
C. Water
D. Air

22-8. Who should handle major repairs and major items of maintenance on a main reduction gear?

A. Main machinery (M) division
B. Manufacturer
C. Shipyard
D. Standard development team

22-9. To whom do you submit a request for a 10-year inspection?

A. Chief of engineering
B. Chief of naval operations
C. Naval shipyard
D. Type commander

22-10. What should not be opened immediately before trials?

A. Inspection plates
B. Nozzles
C. Teeth
D. Thrusts

22-11. Who must be present before any inspection or work on or around the reduction gear is done where access is possible?

A. Type commander (TYCOM)
B. Engineering officer
C. Commanding officer (CO)
D. Main Propulsion Assistant (MPA)

22-12. What is the normal temperature range of oil leaving the lube-oil cooler?

A. 100 to 110 °F
B. 120 to 130 °F
C. 140 to 160 °F
D. 180 to 200 °F

22-13. What controls the quantity of oil to each bearing?

- A. An orifice in the supply line
- B. The main feed pump
- C. The secondary supply line
- D. The stationary rotor

22-14. What percent of the total number of bearings are normally carried aboard as spares?

- A. 50
- B. 55
- C. 70
- D. 75

22-15. How many hours a day do you operate the lube-oil purifier while underway?

- A. 2 hours
- B. 8 hours
- C. 12 hours
- D. 24 hours

22-16. What is the maximum neutralization number for the reduction gear lubricating oil?

- A. 0.25
- B. 0.50
- C. 0.75
- D. 1.0

22-17. What causes wiped bearings and worn gear teeth?

- A. Low lubricating oil viscosity
- B. Emulsified lubricating oil
- C. Low lubricating oil neutralization number
- D. High lubricating oil neutralization number

22-18. What furnishes the propulsion and speed control for the ship?

- A. Auxiliary propulsion plant and the controllable pitch propeller (CPP) arrangement
- B. Main propulsion plant and the CPP arrangement
- C. Secondary steam plant
- D. Turbine shaft

22-19. What is a major component of the hydraulic oil power module (HOPM) assembly?

A. Crankshaft
B. Oil distribution (OD) box
C. Thrust bearing
D. Clutch

22-20. Where does the prairie air assembly tubing pass through the OD box?

A. Top
B. Under
C. Center
D. Control side

22-21. Which of the following should you use to prevent misunderstanding and confusion in preparing to get underway?

A. EOCC
B. EOSS
C. MRC
D. PMS

22-22. What is the first step in preparation to get underway?

A. Determine if circulating water is available at the lube-oil cooler
B. Inspect for water in the lube oil
C. Inspect the sump or supply to ensure there is enough oil for system operation
D. Make sure that oil is flowing freely and at the correct pressure

22-23. What is the most common cause of vibration in a main reduction gear?

A. Damaged propellers
B. Damaged turbine generators
C. Faulty oil supply
D. Incorrect oil used

22-24. In reference to reduction gears, the term axial float has what meaning?

A. The gears are not subject to excessive tooth loads due to mismatch of the journal bearing halves.
B. The gears are double-helical, and axial thrust is eliminated.
C. The gears are capable of free motion, neither supporting nor supported by other gears radially.
D. The gears are capable of free motion, neither supporting nor supported by other gears axially.

22-25. What is the term for play between the unloaded surfaces of the teeth in mesh on the pitch circle?

A. Spotting
B. Wear
C. Backlash
D. Contour

22-26. What is the purpose of the reduction gear?

A. To change rotary motion into linear action
B. To reduce high speed to low speed
C. To minimize thrust on the main diesel engines
D. To transmit thrust from the main shaft to the ship's hull

22-27. What is essential for the long life span of the reduction gear?

A. Low speed
B. Clean lubricating oil
C. Programming
D. Proper shifting

22-28. How does the operator keep the reduction gear and the diesel engine rotating slowly during cool down period?

A. Applying the clutch
B. Applying the brakes
C. Using the motor-driven turning gear
D. Backing down the engine speed

22-29. Who has the custody of and responsibility for the reduction gear keys?

A. Commanding Officer (CO)
B. Type Commander (TYCOM)
C. Main Propulsion Assistant (MPA)
D. Engineering Officer

22-30. In what Naval Ships' Technical Manual (NSTM) chapter can you find the list of requirements, suggested procedures, and precautions for accessing control to the main reduction gear?

A. 115
B. 187
C. 241
D. 302

22-31. What must you ensure has been done before engaging and starting the turning gear?

A. Plug it in
B. Lubricate properly
C. Align cooling
D. Secure heater

22-32. During the 10-year inspection, shipyard personnel perform which of the following inspections?

A. Lead reading on gear bearing
B. Lead reading on journals
C. Lead reading on gear teeth
D. Lead reading on gear thickness

22-33. What component in the main reduction gear provides a constant spray of lubricating oil that is directed over the gears?

A. Nozzle
B. Spray plate
C. Spray gun
D. Spray wheel

22-34. What component electronically controls, monitors, and actuates the display of the propellers pitch settings and changes?

A. Oil distribution (OD) box
B. Hydraulic oil power module (HOPM) assembly
C. Electrohydraulic servo control assembly
D. Hub assembly

22-35. What tool should you use to measure end play?

A. Dial indicator
B. Level
C. Micrometer
D. Torque wrench

22-36. What is the most common cause of vibration in a main reduction gear?

A. Damaged propeller
B. Damaged diesel engine
C. Faulty lubricating oil supply
D. Incorrect lubricating oil

Chapter 23
Engine Performance and Efficiency

23-1. What is limited by frictional heat and the inertia of moving parts?

A. Rotation of the crankshaft
B. Rotation of the camshaft
C. Speed of the piston
D. Speed of the governor

23-2. What instrument is used to determine the average pressure exerted on the piston during each power stroke?

A. Planimeter
B. Pressure indicator
C. Scale
D. Water gauge

23-3. What component regulates the maximum amount of fuel that can enter the cylinder and limits the maximum load of the cylinder on some engines?

A. Governor
B. Needle valve
C. Positive stop
D. Check valve

23-4. What is the main result of an unbalanced diesel engine?

A. Bubbling of lubricating oil
B. Loss of lubricating oil flow
C. Vibration
D. Overheating

23-5. Under what conditions is a balanced load produced in a diesel engine?

A. At least half the cylinders are producing their share of the total power developed
B. Every cylinder is producing its share of the total power developed
C. The inlet and outlet lubricating oil temperature are within the specifications
D. The cooling water differentials are within the specifications

23-6. How can an operator determine which cylinder is causing an unbalanced condition?

A. Open indicator cock and check exhaust
B. Open indicator cock see if water is present
C. Look at the fuel rack to determine if a cylinder is off
D. Touch the cylinders to feel if the cylinders is running hot

23-7. What is the term used for “the output divided by the input”?

A. Competence
B. Efficiency
C. Productivity
D. Proficiency

23-8. What determines the minimum value of a diesel engine’s compression ratio?

A. Type of cooling medium used
B. Type of fuel used
C. Type of lubrication used
D. Type of cylinder arrangement

23-9. When will the mechanical efficiency of a diesel engine be at its highest?

A. When the diesel engine produces maximum indicated horsepower (ihp)
B. When the diesel engine produces minimum ihp
C. When the diesel engine produces maximum brake horsepower (bhp)
D. When the diesel engine produces minimum bhp

23-10. To what engine type does volumetric efficiency NOT apply?

A. Opposed piston
B. 4-stroke
C. 2-stroke
D. Gasoline

23-11. What is the area of the piston crown that pressure acts on to create the driving force of the cylinder?

A. Boss
B. Bore
C. Crown
D. Seat

23-12. What is the amount of power available to do useful work?

A. Brake horsepower (bhp)
B. Indicated horsepower (ihp)
C. Actual horsepower (ahp)
D. True horsepower (thp)

23-13. When does the thermal efficiency of a diesel engine increase?

A. As the speed of the diesel engine decreases
B. As the speed of the diesel engine increases
C. As the compression ratio is increased
D. As the compression ratio is decreased

23-14. What is the term for the amount of power developed as compared to the energy input that is measured by the heating value of the fuel consumed?

A. Proficiency
B. Competence
C. Productivity
D. Engine efficiency

23-15. How is the work being done in the cylinder by the gases measured?

A. Actual thermal efficiency (ate)
B. True thermal efficiency (tte)
C. Proficient thermal efficiency (pte)
D. Indicated thermal efficiency (ite)

Chapter 24
Engineering Casualty Control

24-1. How is a complete propulsion plant designed to operate?

A. Isolated
B. Parallel
C. Split-plant
D. Congruent

24-2. What is the battle telephone circuit used during casualty control exercises?

A. 1-MC
B. 7-JC
C. 9-MC
D. 5-JC

24-3. When finding a gauge or other instrument that record operating conditions, the operator should accomplish what action first?

A. Calibrate equipment
B. Log out of calibration and place sticker on gauge
C. Commence full investigation of cause
D. Remove gauge and cap from connection

24-4. Who should have custody of a master Engineering Casualty Control Evaluation drill package?

A. Commanding Officer
B. Type Commander (TYCOM)
C. Engineer Officer
D. Main Propulsion Assistant (MPA)

24-5. When corrective actions are applied to an engineering casualty, which of the following attributes is of paramount importance?

A. Patience
B. Speed
C. Tolerance
D. Perseverance

24-6. When can the operation of equipment under casualty control be justified?

A. There is risk of even greater damage.
B. You have permission from the space supervisor.
C. You have permission from the Engineer Officer.
D. You have permission from Main Propulsion Assistant (MPA).

24-7. What phase of casualty control is concerned with the immediate control of the casualty so as to prevent further damage to the unit affected and to prevent the casualty from spreading?

A. One
B. Two
C. Three
D. Four

24-8. Why is it important to control minor casualties?

A. To reduce the single flow of communication from station to station
B. To reduce the amount of cleanup required
C. To reduce the amount of people involved
D. To keep a minor casualty from becoming a major casualty

24-9. How is a badly wiped or burned out main shaft bearing renewed?

A. Lapped
B. Scrapped
C. Replaced
D. Sanded

24-10. When the emergency generator is set up in automatic mode to supply emergency power to vital equipment, what circuits must be stripped from the electrical board?

A. Unnecessary
B. Propulsion
C. Communication
D. Electronic

24-11. As a general rule when handling casualties, you should first consider what factor?

A. Isolating equipment
B. Cross-connecting systems
C. Personnel safety
D. Restoring lighting

24-12. The emergency power system and transformers furnish power to which of the following systems?

A. Steering
B. Propulsion units
C. Lighting
D. Navigation controls

24-13. In the casualty power system, what components connect the casualty power terminals to the circuit breaker?

A. Two-prong connection
B. Bus bars
C. Three-prong connection
D. Quick disconnect

24-14. On larger deck ships, the bulkhead terminals for the power system are located on what deck?

A. Main
B. Second
C. Third
D. Fourth

24-15. To permit the transfer of power from one source to another source in the event of casualty, electrical power panels and terminals are equipped with what components?

A. Throws
B. Contacts
C. Knobs
D. Circuit breakers

24-16. Which of the following is a factor for obtaining engineering casualty control efficiency?

A. Careless inspections
B. On-time inspections
C. Ineffective training program
D. Sound design

24-17. Which of the following introduced a more methodical and organized approach to casualty control, resulting in increased control, less disabling of a plant, and increased overall safety to the plant and?

A. Engineering Operational Procedures (EOP)
B. Engineering Department Organizational Readiness Manual (EDORM)
C. Engineering Operational Casualty Control (EOCC)
D. Damage Control Procedures (DCP)

24-18. What is the second priority for Engineering Operational Casualty Control (EOCC) drills?

A. Main space fire
B. Diesel engine casualty
C. Main shaft casualty
D. Lube oil system casualty

24-19. On a ship, how is speed and knowledge of the systems and equipment achieved?

A. Constantly reading the
B. Standing under instruction (U/I) watches
C. Training repeatedly
D. Learning the content in “A” school

24-20. When a casualty occurs, who is the first person the equipment operator must notify?

A. Officer of the Deck (OOD)
B. Engineering officer of the watch (EOOW)
C. Main Propulsion Assistant (MPA)
D. Engineer Officer

24-21. A loud roaring noise coming from the reduction gears is an indication of what problem?

A. Tooth damage
B. Water in the lubricating oil
C. Hot bearing surface
D. Loss of lubricating pressure

24-22. The casualty power system is used for what equipment?

A. Internet
B. Site television
C. Emergency generator
D. Laundry

24-23. What is the purpose of using the triple outlet extension cable in the engineroom?

A. Extra source of electric power
B. Emergency lighting
C. Concentration of all submersible pumps in one area
D. More ventilation