ENGINEERING-PDH.com
ONLINE CONTINUING EDUCATION

FLUID POWER FUNDAMENTALS VOL 1 OF 3

Main Category:	Mechanical Engineering
Sub Category:	Hydraulics/Pneumatics
Course #:	MEC-118
Course Content:	102 pgs
PDH/CE Hours:	6

OFFICIAL COURSE/EXAM

(SEE INSTRUCTIONS ON NEXT PAGE)

WWW.ENGINEERING-PDH.COM
TOLL FREE (US & CA): 1-833-ENGR-PDH (1-833-364-7734)
SUPPORT@ENGINEERING-PDH.COM

MEC-118 EXAM PREVIEW

- TAKE EXAM! -

Instructions:

- At your convenience and own pace, review the course material below. When ready, click "Take Exam!" above to complete the live graded exam. (Note it may take a few seconds for the link to pull up the exam.) You will be able to re-take the exam as many times as needed to pass.
- Upon a satisfactory completion of the course exam, which is a score of 70% or better, you will be provided with your course completion certificate. Be sure to download and print your certificates to keep for your records.

Exam Preview:

1. Why are hydraulics and pneumatics extensively used to transmit power?
    a. They eliminate the need for complicated systems of gears, cams, and levers.
    b. They increase the need for complicated systems of gears, cams, and levers.
    c. They reduce the need for complicated systems of levers.
    d. They reduce the risk of fluid contamination.
2. What change, if any, will occur in the volume and weight of a substance if its temperature changes?
    a. Both its volume and weight will change
    b. Both its volume and weight will be unaffected
    c. Its volume will change, but its weight will remain constant
    d. Its weight will change, but its volume will remain constant
3. Pascal's Law is best described as pressure on a confined liquid is transmitted equally in all directions.
    a. True
    b. False
4. Specific gravity of a liquid is the ratio of its volume to the density of water.
    a. True
    b. False
5. Flow regime is the property of a material that is the measure of a material's resistance to flow?
    a. True
    b. False

6. The temperature at which a liquid gives off enough vapor to ignite or flash when a flame is applied is known as?
    a. Fire point
    b. Foam point
    c. Flashpoint
    d. Autoignition point
7. How many centistokes (cSt) equals 1 Stoke (St)?
    a. 1
    b. 10
    c. 100
    d. 1,000
8. In an internal gear pump the Crescent prevents liquid from flowing backwards from the outlet to the inlet port?
    a. True
    b. False
9. Tube sizes are listed by actual outside diameter (OD) and the wall thickness.
    a. True
    b. False
10. Copper, as a general rule, is used for exposed lines and lines subject to abrasion or intense heat.
    a. True
    b. False

CHAPTER 1

INTRODUCTION TO FLUID POWER

Fluid power is a term that describes the generation, control, and application of smooth, effective power of pumped or compressed fluids (either liquids or gases) to provide force and motion to mechanisms. This force and motion may be in the form of pushing, pulling, rotating, regulating, or driving. Fluid power includes hydraulics and pneumatics, which involve liquids and gases, respectively.

LEARNING OBJECTIVES

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

1. Recognize fundamentals of fluid power.
2. Explain the concept and history of hydraulics and pneumatics.
3. Identify the states of matter and the factors affecting them.

FLUID POWER

Advantages of Fluid Power

The extensive use of hydraulics and pneumatics to transmit power is due to the fact that properly constructed fluid power systems possess a number of favorable characteristics. They eliminate the need for complicated systems of gears, cams, and levers. Motion can be transmitted without the slack inherent in the use of solid machine parts. The fluids used are not subject to breakage as are mechanical parts, and the mechanisms are not subjected to great wear.

The different parts of a fluid power system can be conveniently located at widely separated points because the forces generated are rapidly transmitted over considerable distances with small loss. These forces can be conveyed up and down or around corners with small loss in efficiency and without complicated mechanisms. Very large forces can be controlled by much smaller ones and can be transmitted through comparatively small lines and orifices.

If the system is well adapted to the work it is required to perform, and if it is not misused, it can provide smooth, flexible, uniform action without vibration, and is unaffected by variation of load. In case of an overload, an automatic release of pressure can be guaranteed so that the system is protected against breakdown or strain. Fluid power systems can provide widely variable motions in both rotary and straight-line transmission of power. The need for control by hand can be minimized. In addition, fluid power systems are economical to operate.

The question may arise as to why hydraulics is used in some applications and pneumatics in others. Many factors are considered by the user and/or the manufacturer to determine which type of system to use in a specific application. There are no hard and fast rules to follow; however, past experience has provided some sound ideas that are usually considered when such decisions are made. If the application requires speed, a medium amount of pressure, and only fairly accurate control, a pneumatic system may be used. If the application requires only a medium amount of pressure and more accurate control, a combination of hydraulics and pneumatics may be used. If the application requires a great amount of pressure and/or extremely accurate control, a hydraulic system should be used.

Special Problems

The extreme flexibility of fluid power elements presents a number of problems. Because fluids have no shape of their own, they must be positively confined throughout the entire system. Special consideration must be given to the structural integrity of the parts of a fluid power system. Strong pipes and containers must be provided. Leaks, which are a serious problem with the high pressure obtained in many fluid power installations, must be prevented.

The operation of the system involves constant movement of the fluid within the lines and components. This movement causes friction within the fluid itself and against the containing surfaces, which, if excessive, can lead to serious losses in efficiency. Foreign matter must not be allowed to accumulate in the system, where it will clog small passages or score closely fitted parts. Chemical action may cause corrosion. Anyone working with fluid power systems must know how a fluid power system and its components operate, in terms of both the general principles common to all physical mechanisms and of the peculiarities of the particular arrangement at hand.

HYDRAULICS

The word hydraulics is based on the Greek word for water, and originally covered the study of the physical behavior of water at rest and in motion. Use has broadened its meaning to include the behavior of all liquids, although it is primarily concerned with the motion of liquids.

Hydraulics includes the manner in which liquids act in tanks and pipes, deals with their properties, and explores ways to take advantage of these properties.

Development of Hydraulics

Although the modern development of hydraulics is comparatively recent, the ancients were familiar with many hydraulic principles and their applications. The Egyptians and the ancient people of Persia, India, and China conveyed water along channels for irrigation and domestic purposes, using dams and sluice gates to control the flow. The ancient Cretans had an elaborate plumbing system. Archimedes studied the laws of floating and submerged bodies. The Romans constructed aqueducts to carry water to their cities.

After the breakup of the ancient world, there were few new developments for many centuries. Then, over a comparatively short period, beginning near the end of the 17^{th} century, Italian physicist Evangelista Torricelle, French physicist Edme Mariotte, and later Swiss physicist Daniel Bernoulli conducted experiments to study the elements of force in the discharge of water through small openings in the sides of tanks and through short pipes. During the same period, Blaise Pascal, a French scientist, discovered the fundamental law for the science of hydraulics.

Pascal's law states that an increase in pressure on the surface of a confined fluid is transmitted undiminished throughout the confining vessel or system (*Figure 1-1*).

For Pascal's law to be made effective for practical applications, it was necessary to have a piston that "fit exactly." It was not until the latter part of the 18^{th} century that methods were found to make these snugly fitted parts required in hydraulic systems. This manufacturing of parts was accomplished by the invention of machines that were used to cut and shape the necessary closely fitted parts and, particularly, by the development of gaskets and packings. Since that time, components such as valves, pumps, actuating cylinders, and motors have been developed and refined to make hydraulics one of the leading methods of transmitting power.

Use of Hydraulics

Today, hydraulic power is used to operate many different tools and mechanisms. In a garage, a mechanic raises the end of an automobile with a hydraulic jack. Dentists and barbers use hydraulic power, through a few strokes of a control lever, to lift and position their chairs to a convenient working height. Hydraulic doorstops keep heavy doors from slamming. Hydraulic brakes have been standard equipment on automobiles since the 1930s. Most automobiles are equipped with automatic transmissions that are hydraulically operated. Power steering is another application of hydraulic power. Construction workers depend upon hydraulic power for the operation of various components of their equipment. For example, the blade of a bulldozer is normally operated by hydraulic power.

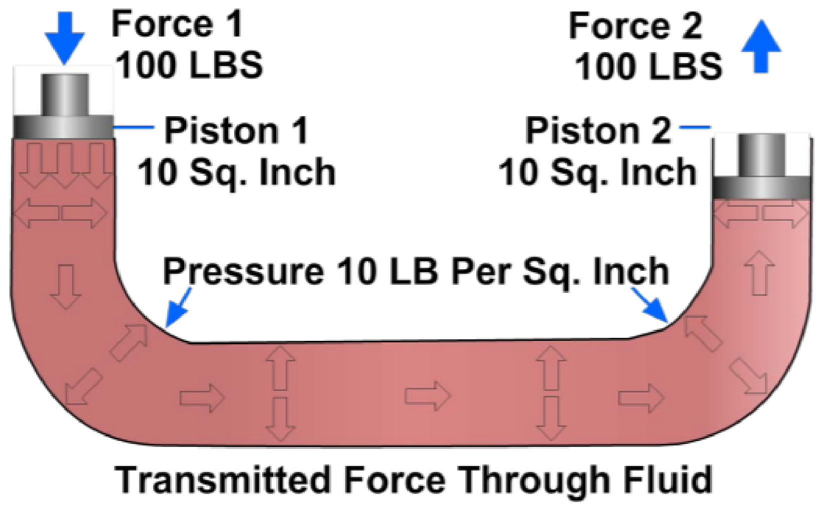


Figure 1-1 — Force transmitted through fluid.

During the period preceding World War II, the Navy began to apply hydraulics to naval mechanisms extensively. Since then, naval applications have increased to the point where many ingenious hydraulic devices are used in the solution of problems of gunnery, aeronautics, and navigation. Aboard ship, hydraulic power is used to operate such equipment as anchor windlasses, cranes, steering gear, remote control devices, and power drives for elevating and training guns and rocket launchers. Elevators on aircraft carriers use hydraulic power to transfer aircraft from the hangar deck to the flight deck and vice versa.

Hydraulics and pneumatics are combined for some applications. This combination is referred to as hydropneumatics. An example of this combination is equipment and machinery associated with underway replenishment (UNREP) systems and aircraft elevator systems. Air pressure is applied to the surface of hydraulic fluid in a reservoir. The air pressure forces the hydraulic fluid to raise the lift.

STATES OF MATTER

The material that makes up the universe is known as matter. Matter is defined as any substance that occupies space and has weight.

Matter exists in three states: solid, liquid, and gas; each has distinguishing characteristics. Solids have a definite volume and a definite shape; liquids have a definite volume but take the shape of their containing vessels; gases have neither a definite shape nor a definite volume. Gases not only take the shape of the containing vessel but also expand and fill the vessel, regardless of its volume. Examples of the states of matter are iron, water, and air.

Matter can change from one state to another. Water is a good example. At high temperatures it is in the gaseous state known as steam. At moderate temperatures it is a liquid, and at low temperatures it becomes ice, which is definitely a solid state. In this example, the temperature is the dominant factor in determining the state the substance assumes.

Pressure is another important factor that will effect changes in the state of matter. At pressures lower than atmospheric pressure, water will boil and thus change into steam at temperatures lower than 212 degrees Fahrenheit (°F). Pressure is also a critical factor in changing some gases to liquids or solids. Normally, when pressure and chilling are both applied to a gas, the gas assumes a liquid state. Liquid air, which is a mixture of oxygen and nitrogen, is produced in this manner.

In the study of fluid power, we are concerned primarily with the properties and characteristics of liquids and gases. However, you should keep in mind that the properties of solids also affect the characteristics of liquids and gases. The lines and components, which are solids, enclose and control the liquid or gas in their respective systems.

CHAPTER 2

FORCES IN LIQUIDS

The study of liquids is divided into two main parts: liquids at rest (hydrostatics) and liquids in motion (hydraulics).

The effects of liquids at rest can often be expressed by simple formulas. The effects of liquids in motion are more difficult to express due to frictional and other factors whose actions cannot be expressed by simple mathematics.

In chapter 1 we learned that liquids have a definite volume but take the shape of their containing vessel. There are two additional characteristics we must explore prior to proceeding.

Liquids are almost incompressible. For example, if a pressure of 100 pounds per square inch (psi) is applied to a given volume of water that is at atmospheric pressure, the volume will decrease by only 0.03 percent. It would take a force of approximately 32 tons to reduce its volume by 10 percent; however, when this force is removed, the water immediately returns to its original volume. Other liquids behave in about the same manner as water.

Another characteristic of a liquid is the tendency to keep its free surface level. If the surface is not level, liquids will flow in the direction that will tend to make the surface level.

LEARINING OBJECTIVES

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

1. Recognize the pressure characteristics of liquids.
2. Describe how pressure is caused by the weight of the atmosphere.
3. Explain how pressures are measured.
4. Identify terms and facts applicable to the physics of fluids.
5. Solve problems pertaining to density and specific gravity.
6. Recognize the principles and equations involved with the transmission of forces.
7. Solve problems and equations involved with the transmission of forces.
8. Recognize the characteristics and behavior of fluids in motion.
9. Explain the methods for measuring volume and velocity.
10. Relate the dynamic and static factors involved with fluid flow.
11. Describe the operating characteristics and component functions of basic fluid power systems.

LIQUIDS AT REST

A Substance confined in an enclosed container at rest, situated on a fixed part of earth's surface. In studying fluids at rest, we are concerned with the transmission of force and the factors that affect the forces in liquids. Additionally, pressure in and on liquids and factors affecting pressure are of great importance.

Pressure and Force

The terms force and pressure are used extensively in the study of fluid power. It is essential that we distinguish between the terms. Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams. Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in^2) or grams per square centimeter (g/cm^2). Pressure maybe exerted in one direction, in several directions, or in all directions.

Computing Force, Pressure, and Area

A formula is used in computing force, pressure, and area in fluid power systems. In these formulas, *P* refers to pressure, *F* indicates force, and *A* represents area.

$$Force_{(LBS)} = Pressure_{(PSI)}\ x\ Area_{(IN^2)}$$

Force equals pressure times area. Thus, the formula is written:

Equation 2-1: $F = PxA$

Pressure equals force divided by area. By rearranging the formula, this statement may be condensed into:

Equation 2-2: $P = \frac{F}{A}$

Since area equals force divided by pressure, the formula is written:

Equation 2-3: $A = \frac{F}{P}$

A memory device for recalling the different variations of this formula is shown in *Figure 2-1*. Any letter in the triangle may be expressed as the product or quotient of the other two, depending on its position within the triangle.

To determine the area, use the formula for finding the area of a circle. This is written A = where A is the area, 3.1416 (3.14 or 3 1/7 for most calculations), and r^2 indicates the radius squared. $A = \pi r^2$

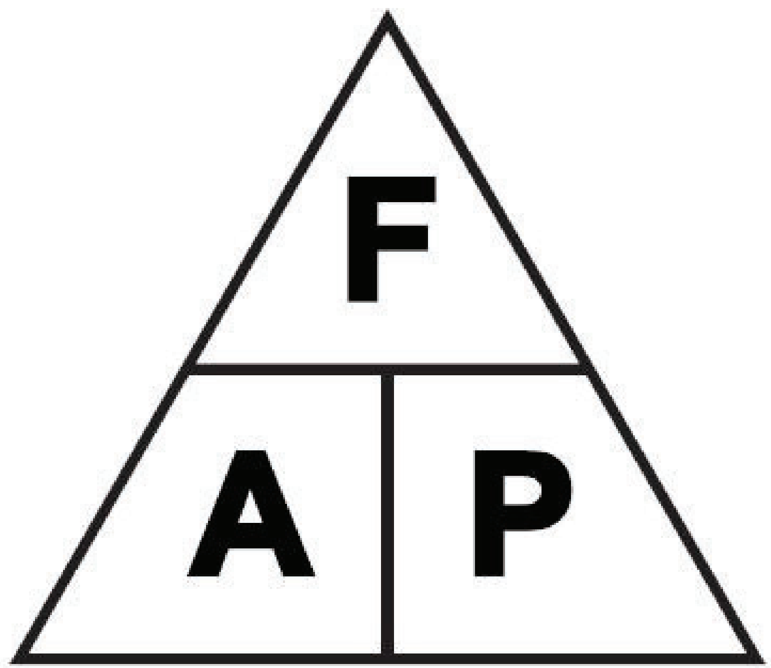


Figure 2-1 — Device for determining the arrangement of the force, pressure, and area formula.

NOTE

Sometimes the area may not be expressed in square units. If the surface is rectangular, you can determine its area by multiplying its length (say, in inches) by its width (also in inches). The majority of areas you will consider in these calculations are circular in shape. Either the radius or the diameter may be given, but you must know the radius in inches to find the area. The radius is one-half the diameter.

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 500 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

If a column of air 1-inch square extending all the way to the "top" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air only because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0 degrees Celsius (°C), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure (*Figure 2-2*). The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes more rapidly at lower altitudes because of the compressibility of the air, which causes the air layers close to the earth's surface to be compressed by the air masses above them. This effect, however, is partially counteracted by the contraction of the upper layers due to cooling. The cooling tends to increase the density of the air.

Atmospheric pressures are quite large, but in most instances practically the same pressure is present on all sides of objects so that no single surface is subjected to a great load.

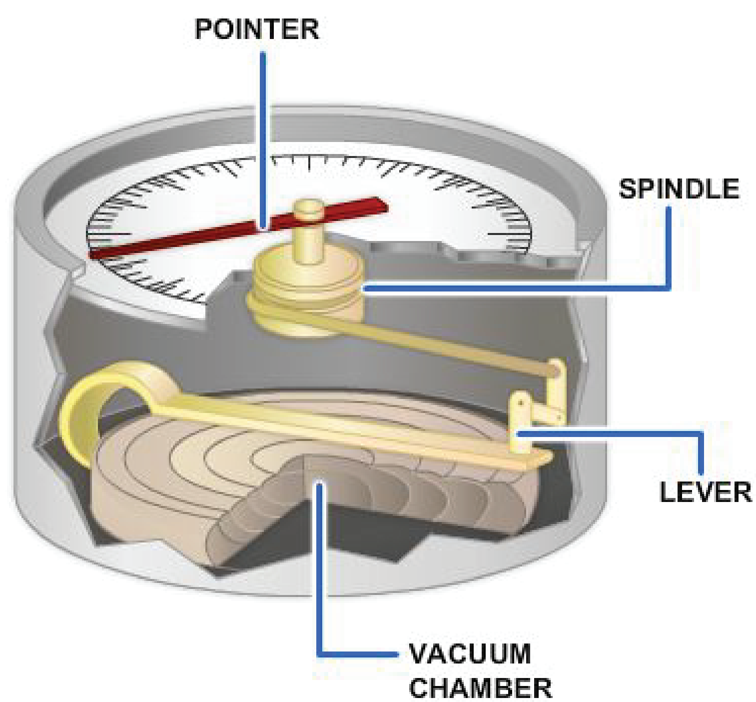


Figure 2-2 — Simple diagram of the aneroid barometer.

Atmospheric pressure acting on the surface of a liquid (*Figure 2-3, view A*) is transmitted equally throughout the liquid to the walls of the container, but is balanced by the same atmospheric pressure acting on the outer walls of the container. Atmospheric pressure acting on the surface of one piston is balanced (*Figure 2-3, view B*) by the same pressure acting on the surface of the other piston. The different areas of the two surfaces make no difference, since for a unit of area, pressures are balanced.

TRANSMISSION OF FORCES THROUGH LIQUIDS

When the end of a solid bar is struck, the main force of the blow is carried straight through the bar to the other end (*Figure 2-4, view A*). This happens because the bar is rigid. The direction of the blow almost entirely determines the direction of the transmitted force. The more rigid the bar, the less force is lost inside the bar or transmitted outward at right angles to the direction of the blow.

When a force is applied to the end of a column of confined liquid (*Figure 2-4, view B*), it is transmitted straight through to the other end and also equally and undiminished in every direction throughout the column—forward, backward, and sideways—so that the containing vessel is literally filled with pressure.

An example of this distribution of force is illustrated in *Figure 2-5*. The flat hose takes on a circular cross section when it is filled with water under pressure. The outward push of the water is equal in every direction.

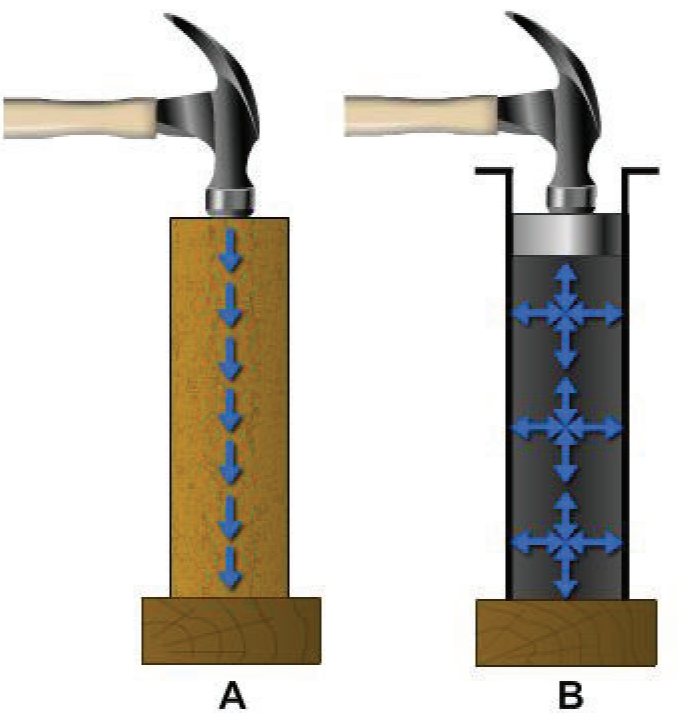


Figure 2-4 — Transmission of force: (A) solid; (B) fluid.

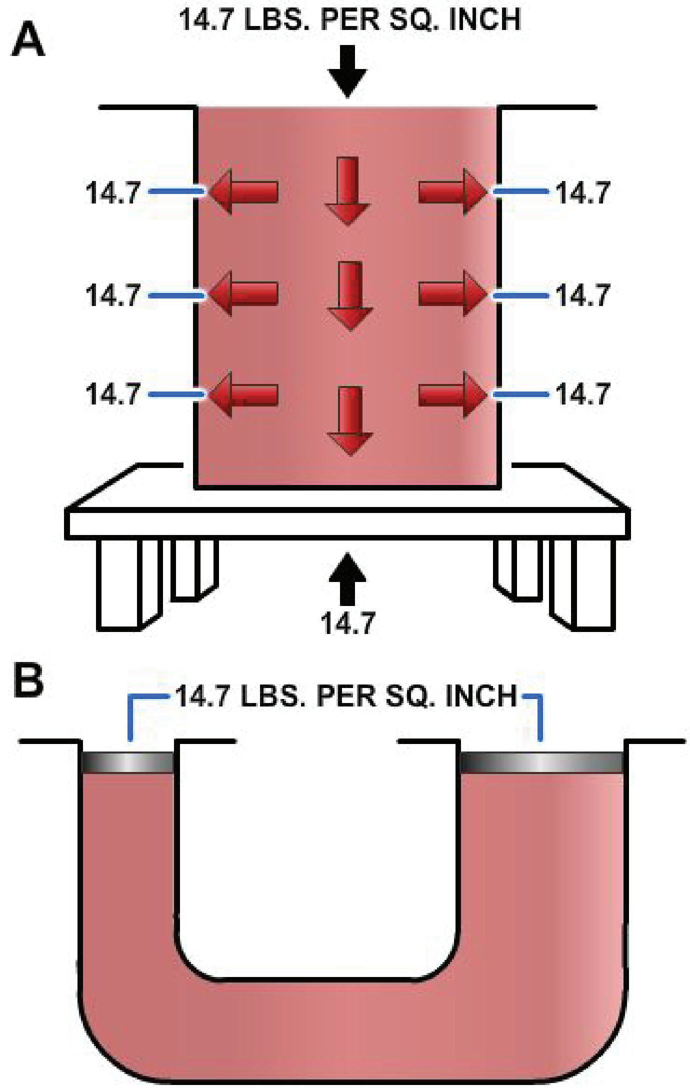


Figure 2-3 — Effects of atmospheric pressure.

So far we have explained the effects of atmospheric pressure on liquids and how external forces are distributed through liquids. Let us now focus our attention on forces generated by the weight of liquids themselves. To do this, we must first discuss density, specific gravity, and Pascal's law.

Density and Specific Gravity

The density of a substance is its weight per unit volume. The unit volume in the English system of measurement is 1 cubic foot. In the metric system it is the cubic centimeter; therefore, density is expressed in pounds per cubic foot or in grams per cubic centimeter.

To find the density (D) of a substance, you must know its weight (W) and volume (V). You then divide its weight by its volume to find the weight per unit volume. In equation form, this is written as:

Equation 2-4: $D = W/V$

EXAMPLE: The liquid that fills a certain container weighs 1,497.6 pounds. The container is 4 feet long, 3 feet wide, and 2 feet deep. Its volume is 24 cubic feet (4 ft x 3 ft x 2 ft). If 24 cubic feet of this liquid weighs 1,497.6 pounds, then 1 cubic foot weighs 62.4.

$$\frac{1,497.6}{24} = 62.4$$

Therefore, the density of the liquid is 62.4 pounds per cubic foot.

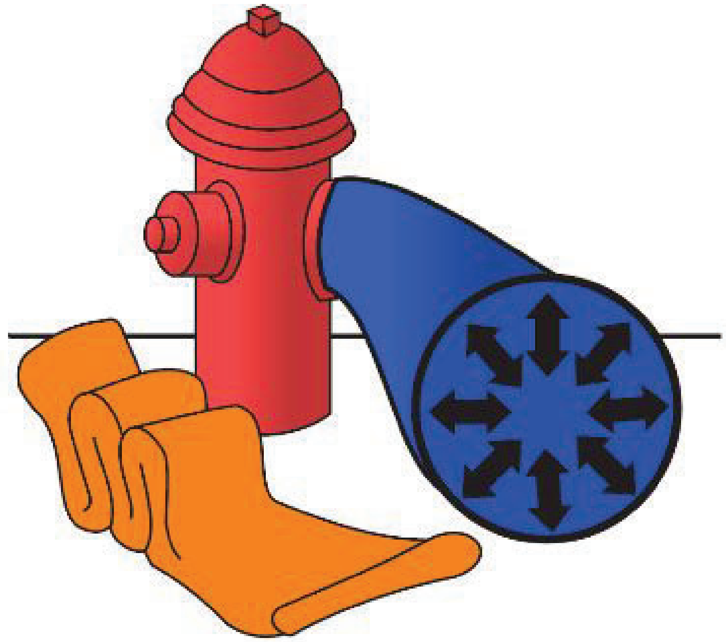


Figure 2-5 — Distribution of force.

This is the density of water at 4 °C and is usually used as the standard for comparing densities of other substances. The temperature of 4 °C was selected because water has its maximum density at this temperature. In the metric system, the density of water is 1 gram per cubic centimeter. The standard temperature of 4 °C is used whenever the density of liquids and solids is measured. Changes in temperature will not change the weight of a substance but will change the volume of the substance by expansion or contraction, thus changing the weight per unit volume.

In physics, the word specific implies a ratio. Weight is the measure of the earth's attraction for a body. The earth's attraction for a body is called gravity. Thus, the ratio of the weight of a unit volume of some substance to the weight of an equal volume of a standard substance, measured under standard pressure and temperature conditions, is called specific gravity. The terms specific weight and specific density are sometimes used to express this ratio.

The following formulas are used to find the specific gravity (sp gr) of solids and liquids, with water used as the standard substance.

$$sp\ gr = \frac{Weight\ of\ the\ substance}{Weight\ of\ an\ equal\ volume\ of\ water}$$

or,

$$sp\ gr = \frac{Density\ of\ the\ substance}{Density\ of\ water}$$

The same formulas are used to find the specific gravity of gases by substituting air, oxygen, or hydrogen for water.

The specific gravity of water is $1, \frac{62.4}{62.4}$.

If a cubic foot of a certain liquid weighs 68.64 pounds, then its specific gravity is 1.1, $\frac{68.64}{62.4}$.

Thus, the specific gravity of the liquid is the ratio of its density to the density of water. If the specific gravity of a liquid or solid is known, the density of the liquid or solid may be obtained by multiplying its specific gravity by the density of water. For example, if a certain hydraulic liquid has a specific gravity of 0.8, 1 cubic foot of the liquid weighs 0.8 times as much as a cubic foot of water—0.8 times 62.4, or 49.92 pounds. In the metric system, 1 cubic centimeter of a substance with a specific gravity of 0.8 weighs 1 times 0.8, or 0.8 grams. (Note that in the metric system the specific gravity of a liquid or solid has the same numerical value as its density, because water weighs 1 gram per cubic centimeter.)

Specific gravity and density are independent of the size of the sample under consideration and depend only on the substance of which it is made.

A device called a hydrometer is used for measuring the specific gravity of liquids.

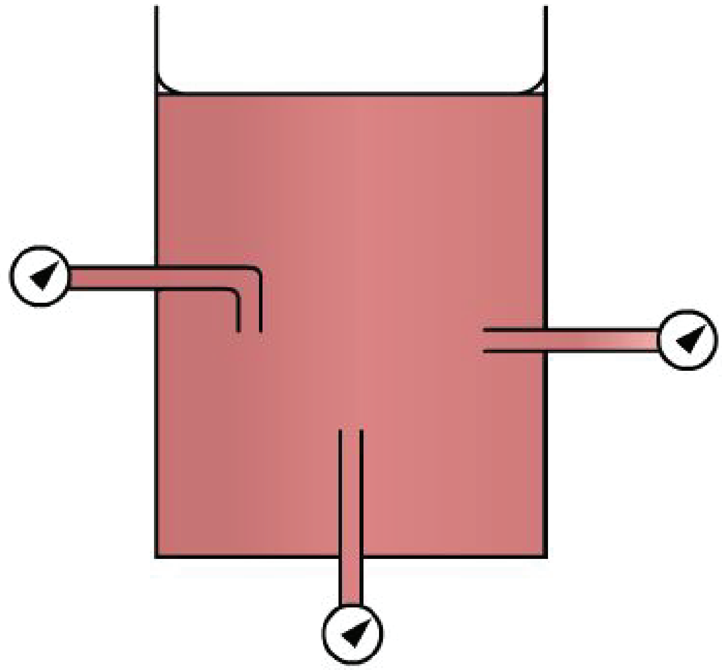


Figure 2-6 — Pressure of a liquid is independent of direction.

Pascal's Law

Recall from chapter 1 that the foundation of modern hydraulics was established when Pascal discovered that pressure in a fluid acts equally in all directions. This pressure acts at right angles to the containing surfaces. If some type of pressure gauge, with an exposed face, is placed beneath the surface of a liquid (*Figure 2-6*) at a specific depth and pointed in different directions, the pressure will read the same. Thus, we can say that pressure in a liquid is independent of direction.

Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the surface. If the exposed face of the pressure gauges (*Figure 2-6*) is moved closer to the surface of the liquid, the indicated pressure will be less. When the depth is doubled, the indicated pressure is doubled. Thus the pressure in a liquid is directly proportional to the depth.

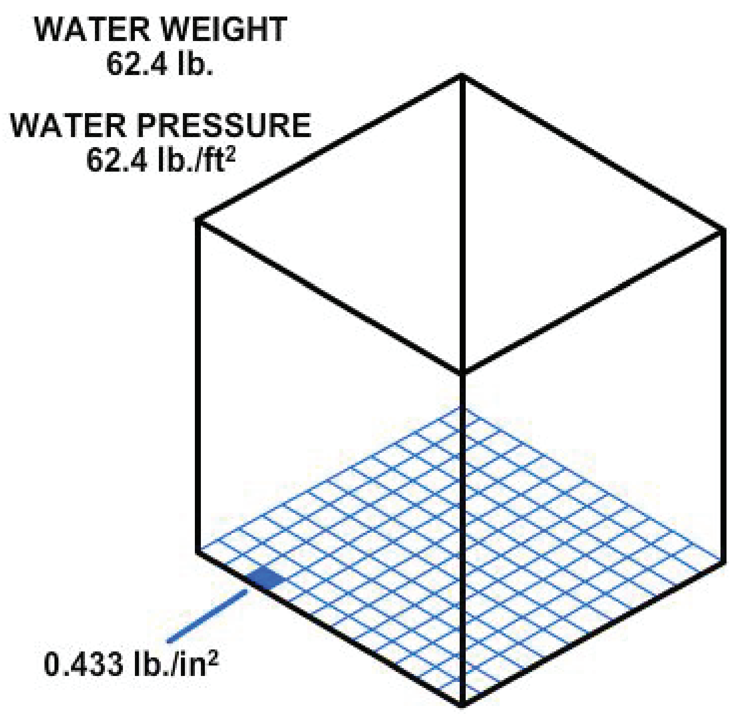


Figure 2-7 — Water pressure in a 1-cubic-foot container.

Consider a container with vertical sides (*Figure 2-7*) that is 1 foot long and 1 foot wide. Let it be filled with water 1 foot deep, providing 1 cubic foot of water. We learned earlier in this chapter that 1 cubic foot of water weighs 62.4 pounds. Using this information and equation 2-2, $\boldsymbol{P = \frac{F}{A}}$, we can calculate the pressure on the bottom of the container.

$$\boldsymbol{P = \frac{F}{A}}$$

$$\boldsymbol{= \frac{62.4\ lbs}{1\ ft^2}}$$

$$\boldsymbol{= 62.4\ lb/ft^2}$$

Since there are 144 square inches in 1 square foot,

$$\boldsymbol{P_{(PSI)} = \frac{62.4\ lbs}{144\ in^2} = 0.433\ PSI}$$

This equation can be stated as follows: the weight of a column of water 1 foot high, having a cross-sectional area of 1 square inch, is 0.433 pound.

If the depth of the column is tripled, the weight of the column will be 3 x 0.433, or 1.299 pounds, and the pressure at the bottom will be 1.299 (psi), since pressure equals the force divided by the area. Thus, the pressure at any depth in a liquid is equal to the weight of the column of liquid at that depth divided by the cross-sectional area of the column at that depth. The volume of a liquid that produces the pressure is referred to as the fluid head of the liquid. The pressure of a liquid due to its fluid head is also dependent on the density of the liquid.

If we let *A* equal any cross-sectional area of a liquid column and *h* equal the depth of the column, the volume becomes *Ah*. Using equation 2-4, $\boldsymbol{D = W/V}$, the weight of the liquid above area *A* is equal to *AhD*.

$$\boldsymbol{D = W/V,\ D = \frac{W}{Ah}, W = AhD}$$

Since pressure is equal to the force per unit area, set *A* equal to 1. Then the formula pressure becomes

Equation 2-5: $\boldsymbol{P = hD}$

It is essential that *h* and *D* be expressed in similar units. That is, if *D* is expressed in pounds per cubic foot, the value of *h* must be expressed in feet. If the desired pressure is to be expressed in pounds per square inch, the pressure formula, equation 2-5, becomes

Equation 2-6: $\boldsymbol{P = \frac{hD}{144}}$

Pascal was also the first to prove by experiment that the shape and volume of a container in no way alters pressure. Thus in *Figure 2-8*, if the pressure due to the weight of the liquid at a point on horizontal line

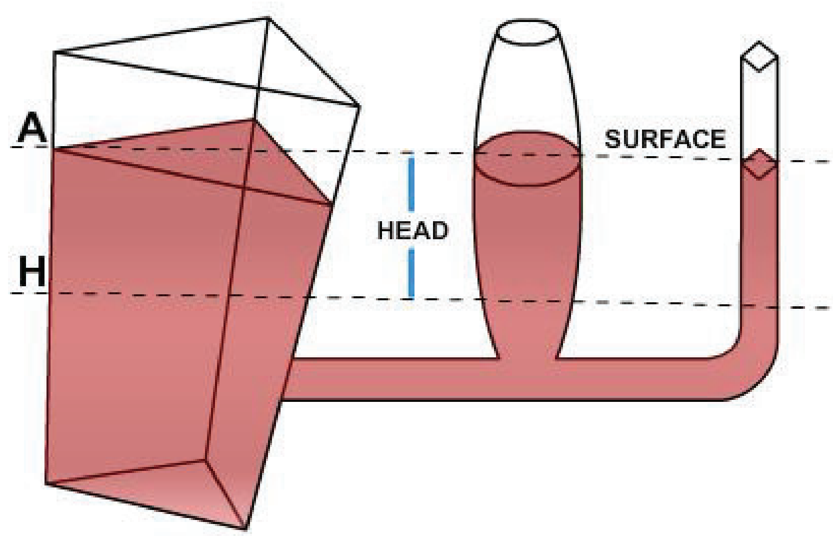


Figure 2-8 — Pressure relationship with shape.

H is 8 psi, the pressure is 8 psi everywhere at level H in the system. Equation 2-5 also shows that the pressure is independent of the shape and volume of a container.

Pressure and Force in Fluid Power Systems

Recall that, according to Pascal's law, any force applied to a confined fluid is transmitted in all directions throughout the fluid regardless of the shape of the container. Consider the effect of this in the system shown in *Figure 2-9*. If there is a resistance on the output piston and the input piston is pushed downward, a pressure is created through the fluid, which acts equally at right angles to surfaces in all parts of the container.

If force 1 is 100 pounds and the area of the input piston is 10 square inches, then the pressure in the fluid is 10 psi:

$$\frac{100\ lb}{10\ (in^2)}$$

NOTE

Fluid pressure cannot be created without resistance to flow. In this case, resistance is provided by the equipment to which the output piston is attached. The force of resistance acts against the top of the output piston. The pressure created in the system by the input piston pushes on the underside of the output piston with a force of 10 pounds on each square inch.

In this case, the fluid column has a uniform cross section, so the area of the output piston is the same as the area of the input piston, or 10 square inches. Therefore, the upward force on the output piston is 100 pounds (10 psi x 10 in^2), the same as the force applied to the input piston. All that was accomplished in this system was to transmit the 100-pound force around the bend. However, this principle underlies practically all mechanical applications of fluid power.

At this point you should note that since Pascal's law is independent of the shape of the container, it is not necessary that the tube connecting the two pistons have the same cross-sectional area of the pistons. A connection of any size, shape, or length will do, as long as an unobstructed passage is provided. Therefore, the system

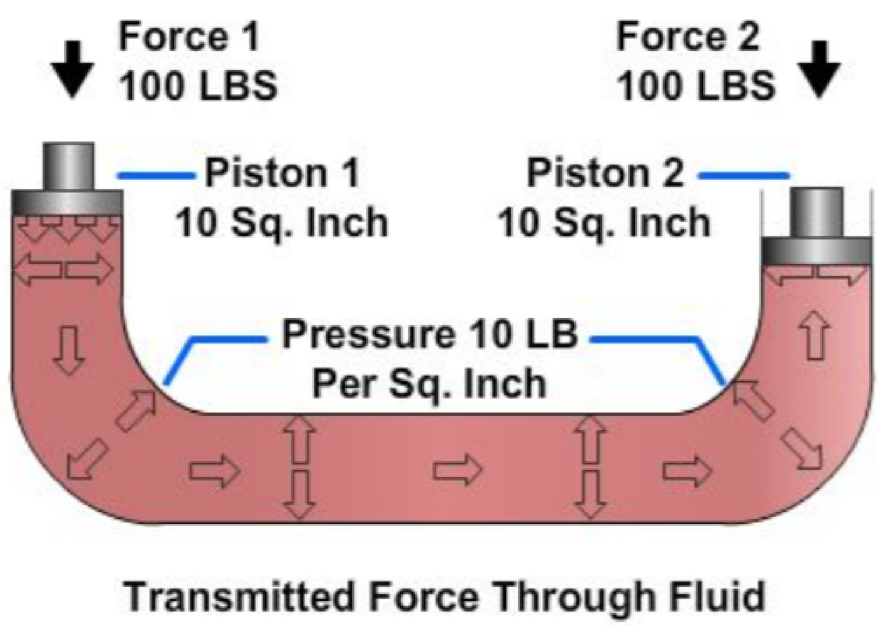


Figure 2-9 — Force transmitted through fluid.

shown in *Figure 2-10*, with a relatively small, bent pipe connecting two cylinders, will act exactly the same as the system shown in *Figure 2-9*.

Multiplication of Forces

Consider the situation in *Figure 2-11*, where the input piston is much smaller than the output piston. Assume that the area of the input piston is 2 square inches. With a resistant force on the output piston, a downward force of 20 pounds acting on the input piston creates a pressure of 10 psi in the fluid. Although this force is much smaller than the force applied in *Figures 2-9 and 2-10*, the pressure is the same. This is because the force is applied to a smaller area.

This pressure of 10 psi acts on all parts of the fluid container, including the bottom of the output piston. The upward force on the output piston is 200 pounds (10 pounds of pressure on each square inch). In this case, the original force has been multiplied tenfold while using the same pressure in the fluid as before. In any system with these dimensions, the ratio of output force to input force is always 10 to 1, regardless of the applied force. For example, if the applied force of the input piston is 50 pounds, the pressure in the system will be 25 psi. This will support a resistant force of 500 pounds on the output piston.

The system works the same in reverse. If we change the applied force and place a 200-pound force on the output piston (*Figure 2-11*), making it the input piston, the output force on the input piston will be one-tenth the input force, or 20 pounds. (Sometimes such results are desired.) Therefore, if two pistons are used in a fluid power system, the force acting on each piston is directly proportional to its area, and the magnitude of each force is the product of the pressure and the area of each piston.

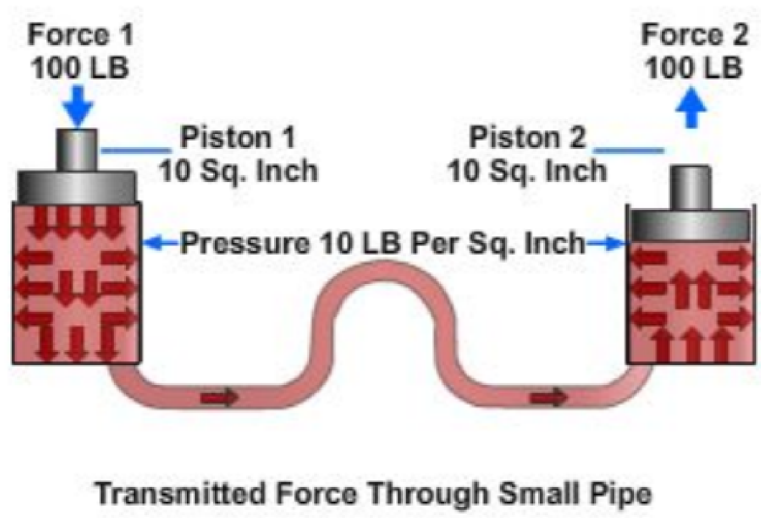


Figure 2-10 — Transmitting force through a small pipe.

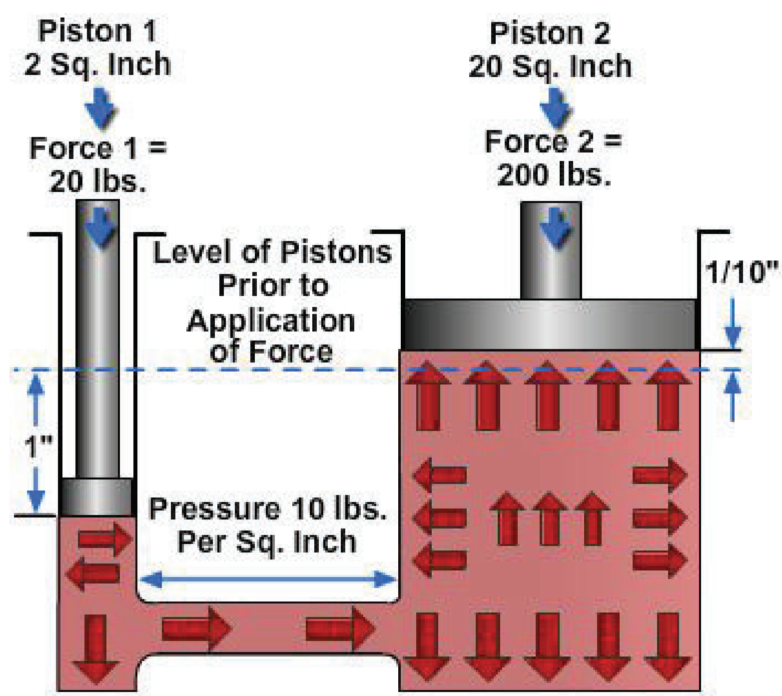


Figure 2-11 — Multiplication of forces.

Differential Areas

Consider the special situation shown in *Figure 2-12*. Here, a single piston (1) in a cylinder (2) has a piston rod (3) attached to one of its sides. The piston rod extends out of one end of the cylinder. Fluid under pressure is admitted equally to both ends of the cylinder. The opposed faces of the piston (1) behave like two pistons acting against each other. The area of one face is the full cross-sectional area of the cylinder, say 6 square inches, while the area of the other face is the area of the cylinder minus the area of the piston rod, which is 2 square inches. This leaves an effective area of 4 square inches on the right face of the piston. The pressure on both faces is the same, in this case, 20 psi. Recall that, according to Pascal's Law, a pressure exerted on a piston produces an equal increase in pressure on another piston in the system. If the second piston has an area 10 times that of the first, the force on the second piston is 10 times greater, though the pressure is the same as that on the first piston. This rule is shown in *Figure 2-12*, as the force pushing the piston to the right is its area times the pressure, or 120 pounds (20 x 6). Likewise, the force pushing the piston to the left is its area times the pressure, or 80 pounds (20 x 4). Therefore, there is a net unbalanced force of 40 pounds acting to the right, and the piston will move in that direction. The net effect is the same as if the piston and the cylinder had the same cross-sectional area as the piston rod.

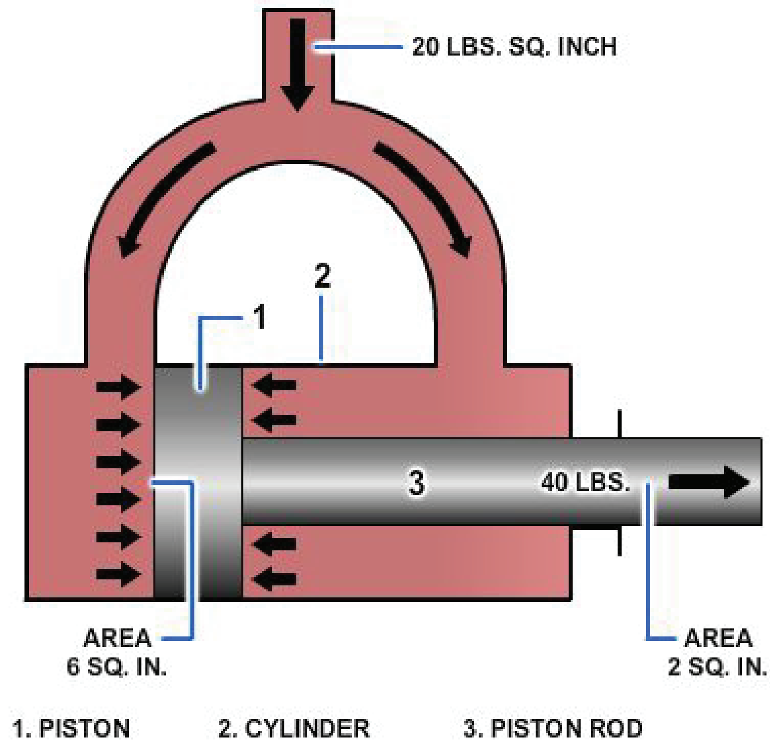


Figure 2-12 — Differential areas on a piston.

Volume and Distance Factors

You have learned that if a force is applied to a system and the cross-sectional areas of the input and output pistons are equal, as in *Figures 2-9 and 2-10*, the force on the input piston will support an equal resistant force on the output piston. The pressure of the liquid at this point is equal to the force applied to the input piston divided by the piston's area. Let us now look at what happens when a force greater than the resistance is applied to the input piston.

In the system illustrated in *Figure 2-9*, assume that the resistance force on the output piston is 100 psi. If a force slightly greater than 100 pounds is applied to the input piston, the pressure in the system will be slightly greater than 10 psi. This increase in pressure will overcome the resistance force on the output piston. Assume that the input piston is forced downward 1 inch. The movement displaces 10 cubic inches of fluid. The fluid must go somewhere. Since the system is closed and the fluid is practically incompressible, the fluid will move to the right side of the system. Because the output piston also has a cross-sectional area of 10 square inches, it will move 1 inch upward to accommodate the 10 cubic inches of fluid. You may generalize this by saying that if two pistons in a closed system have equal cross-sectional areas and one piston is pushed and moved, the other piston will move the same distance, though in the opposite direction. This is because a decrease in volume in one part of the system is balanced by one equal increase in volume in another part of the system.

Apply this reasoning to the system in *Figure 2-11*. If the input piston is pushed down a distance of 1 inch, the volume of fluid in the left cylinder will decrease by 2 cubic inches. At the same time, the volume in the right cylinder will increase by 2 cubic inches. Since the diameter of the right cylinder cannot change, the piston must move upward to allow the volume to increase. The piston will move a distance equal to the volume increase divided by the surface area of the piston (equal to the surface area of the cylinder). In this example, the piston will move one-tenth of an inch (2 cu in ÷ 20 in^2). This leads to the second basic rule for a fluid power system that contains two pistons: The distances the pistons move are inversely proportional to the areas of the pistons. Or more simply, if one piston is smaller than the other, the smaller piston must move a greater distance than the larger piston any time the pistons move.

LIQUIDS IN MOTION

In the operation of fluid power systems, there must be a flow of fluid. The amount of flow will vary from system to system. To understand fluid power systems in action, it is necessary to understand some of the characteristics of liquids in motion.

Liquids in motion have characteristics different from liquids at rest. Frictional resistances within a fluid (viscosity) and inertia contribute to these differences. (Viscosity is discussed in chapter 3.) *Inertia,* which means the resistance a mass offers to being set in motion, will be discussed later in this section. There are other relationships of liquids in motion with which you must become familiar. Among these is volume of flow (flow rate), velocity of flow (velocity of fluid), streamline (laminar) and, turbulent flow that occur in flow.

Volume and Velocity of Flow

The volume of a liquid passing a point in a given time is known as its volume of flow or flow rate. The volume of flow is usually expressed in gallons per minute (gpm) and is associated with relative pressures of the liquid, such as 5 gpm at 40 psi.

The velocity of flow or velocity of the fluid is defined as the average speed at which the fluid moves past a given point. It is usually expressed in feet per second (fps) or feet per minute (fpm). Velocity of flow is an important consideration in sizing the hydraulic lines.

Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases. For example, the velocity of flow is slow at wide parts of a stream and rapid at narrow parts, yet the volume of water passing each part of the stream is the same.

In *Figure 2-13*, if the cross-sectional area of the pipe is 16 square inches at point A and 4 square inches at point B, we can calculate the relative velocity of flow using the flow equation

Equation 2-7 $Q = vA$

where Q is the volume of flow, v is the velocity of flow, and A is the cross-sectional area of the liquid. Since the volume of flow at point A, Q_1, is equal to the volume of flow at point B, Q_2, we can use equation 2-7 to determine the ratio of the velocity of flow at point A, v_1, to the velocity of flow at point B, v_2.

Since $Q_1 = Q_2, A_1 v_1 = A_2 v_2$

From *Figure 2-13*; $A_1 = 16\ in^2, A_2 = 4\ in^2$

Substituting: $16v_1 = 4v_2 \text{ or } v_2 = 4v_1$

Therefore, the velocity of flow at point B is four times the velocity of flow at point A.

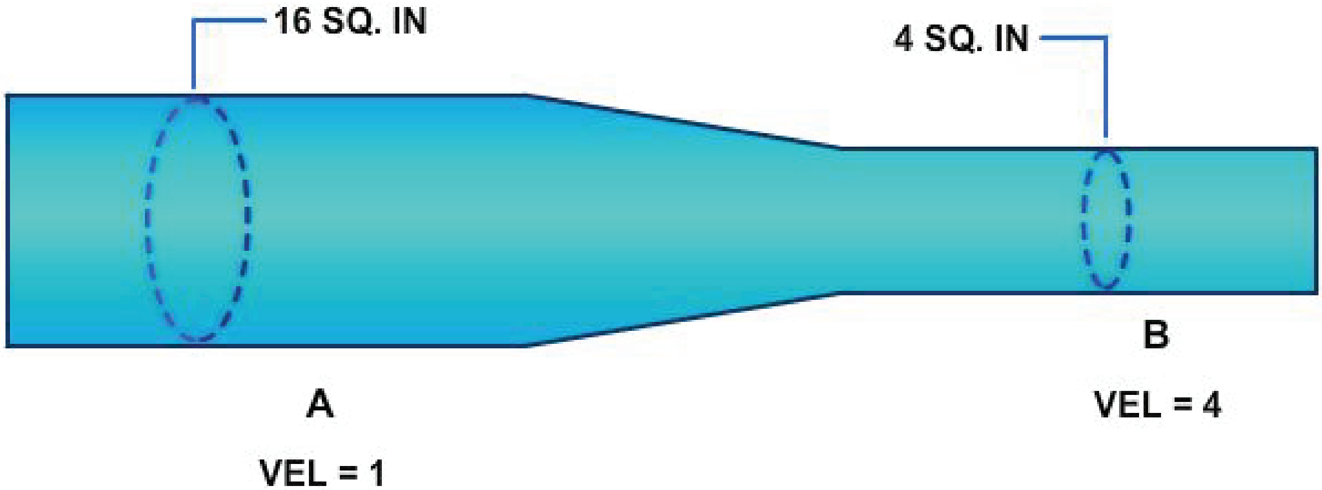


Figure 2-13 — Volume and velocity of flow.

Volume of Flow and Speed

If you consider the cylinder volume you must fill and the distance the piston must travel, you can relate the volume of flow to the speed of the piston. The volume of the cylinder is found by multiplying the piston area by the length the piston must travel (stroke).

Suppose you have determined that two cylinders have the same volume and that one cylinder is twice as long as the other. In this case, the cross-sectional area of the longer tube will be half of the cross-sectional area of the other tube. If fluid is pumped into each cylinder at the same rate, both pistons will reach their full travel at the same time. However, the piston in the longer cylinder must travel twice as fast because it has twice as far to go.

There are two ways of controlling the speed of the piston: (1) by varying the size of the cylinder and (2) by varying the volume of flow (gpm) to the cylinders. (Hydraulic cylinders are discussed in detail in chapter 10.)

Streamline and Turbulent Flow

At low velocities or in tubes of small diameter, flow is streamlined. This means that a given particle of fluid moves straight forward without bumping into other particles and without crossing their paths. Streamline flow is often referred to as laminar flow, which is defined as a flow situation in which fluid moves in parallel laminae or layers. As an example of streamline flow, consider *Figure 2-14*, which illustrates an open stream flowing at a slow, uniform rate.

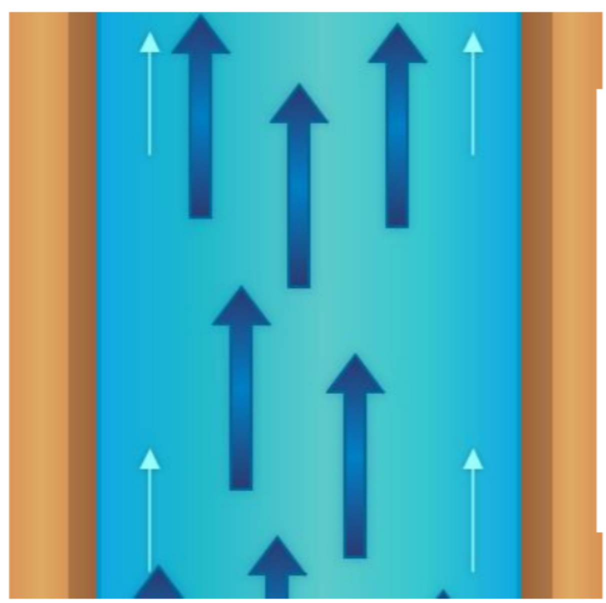


Figure 2-14 — Streamline flow.

Figure 2-14 — Streamline flow.

If the stream narrows, however, and the volume of flow remains the same, the velocity of flow increases. If the velocity increases sufficiently, the water becomes turbulent (*Figure 2-15*). Swirls, eddies, and cross-motions are set up in the water.

Particles of fluid flowing in pipes act in the same manner. The flow is streamlined if the fluid flows slowly enough, and remains streamlined at greater velocities if the diameter of the pipe is small. The flow of a fluid is turbulent as velocity is increased and the center of flow shifts from the center to the walls of the pipe. Turbulent flow will occur when its velocity is greater than critical velocity. Critical velocity of a fluid is that velocity up to which the fluid flow is streamlined and above which its flow becomes turbulent. When the velocity of a fluid exceeds the critical velocity, the paths and velocities of the fluid particles begin to change continuously and randomly. The flow loses all its orderliness and is called turbulent flow.

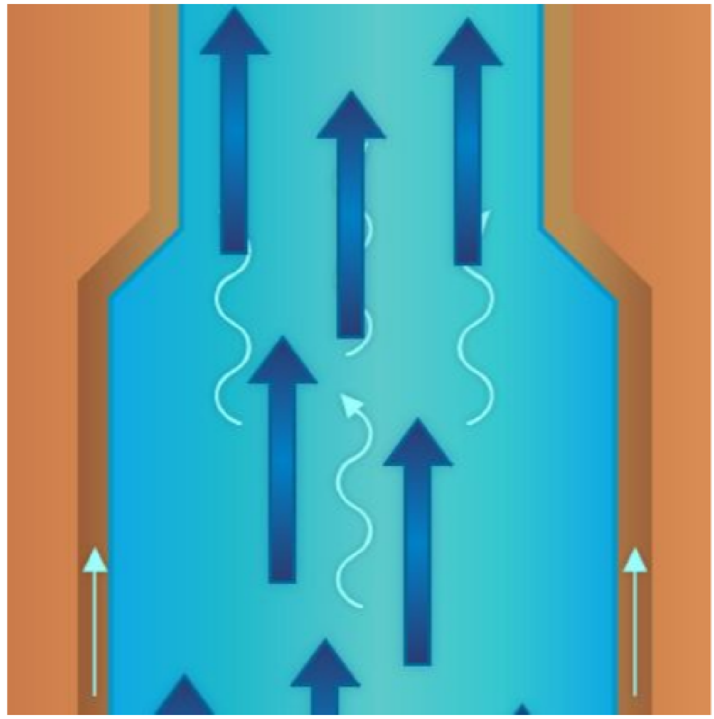


Figure 2-15 — Turbulent flow.

While a high velocity of flow will produce turbulence in any pipe, other factors contribute to turbulence. Among these are the roughness of the inside of the pipe, obstructions, the degree of curvature of bends, and the number of bends in the pipe. In setting up or maintaining fluid power systems, care should be taken to eliminate or minimize as many causes of turbulence as possible, since the energy consumed by turbulence is wasted.

While designers of fluid power equipment do what they can to minimize turbulence, it cannot be avoided. For example, at 68 degrees Fahrenheit (°F), flow becomes turbulent at velocities over approximately 6 inches per second in a 4-inch pipe or about 3 inches per second in a 6-inch pipe. These velocities are far below those commonly encountered in fluid power systems, where velocities of 5 feet per second and above are common. In streamlined flow, losses due to friction increase directly with velocity. With turbulent flow these losses increase much more rapidly.

Factors Involved in Flow

An understanding of the behavior of fluids in motion, or solids for that matter, requires an understanding of the term inertia*.* Inertia is the term used by scientists to describe the property possessed by all forms of matter that makes the matter resist being moved if it is at rest, and likewise, resist any change in its rate of motion if it is moving.

The basic statement covering inertia is Newton's first law of motion—inertia. Sir Isaac Newton was a British philosopher and mathematician. His first law states: *A body* at *rest tends to remain at rest, and a body in motion tends to remain in motion at the same speed and direction, unless acted on by some unbalanced force.* This simply says what you have learned by experience—that you must push an object to start it moving and push it in the opposite direction to stop it again.

A familiar illustration is the effort a pitcher must exert to make a fast pitch and the opposition the catcher must put forth to stop the ball. Similarly, considerable work must be performed by the engine to make an automobile begin to roll; although, after it has attained a certain velocity, it will roll along the road at uniform speed if just enough effort is expended to overcome friction, while brakes are necessary to stop its motion. Inertia also explains the kick or recoil of guns and the tremendous striking force of projectiles.

Inertia and Force

To overcome the tendency of an object to resist any change in its state of rest or motion, some force that is not otherwise canceled or unbalanced must act on the object. Some unbalanced force must be applied whenever fluids are set in motion or increased in velocity; while conversely, forces are made to do work elsewhere whenever fluids in motion are retarded or stopped.

There is a direct relationship between the magnitude of the force exerted and the inertia against which it acts. This force is dependent on two factors: (1) the mass of the object (which is proportional to its weight), and (2) the rate at which the velocity of the object is changed. The rule is that the force in pounds required to overcome inertia is equal to the weight of the object multiplied by the change in velocity, measured in feet per second, and divided by 32 times the time in seconds required to accomplish the change. Thus, the rate of change in velocity of an object is proportional to the force applied. The number 32 appears because it is the conversion factor between weight and mass.

There are five physical factors that can act on a fluid to affect its behavior. All of the physical actions of fluids in all systems are determined by the relationships of these five factors to each other. Summarizing, these five factors are as follows:

1. Gravity, which acts at all times on all bodies, regardless of other forces.
2. Atmospheric pressure, which acts on any part of a system exposed to the open air.
3. Specific applied forces, which may or may not be present, but which, in any event, are entirely independent of the presence or absence of motion.
4. Inertia, which comes into play whenever there is a change from rest to motion or the opposite, or whenever there is a change in direction or in rate of motion.
5. Friction, which is always present whenever there is motion.

A possible relationship of these factors with respect to a particle of fluid (P) in a system is shown in *Figure 2-16*. The different forces are shown in terms of head, or in other words, in terms of vertical columns of fluid required to provide the forces. At the particular moment under consideration, a particle of water (P) is being acted on by applied force (A), by atmospheric pressure (B), and by gravity (C) produced by the weight of the fluid standing over it. The particle possesses sufficient inertia or velocity head to rise to level P1, since head equivalent to F was lost in friction as P passed through the system. Since atmospheric pressure (B) acts downward on both sides of the system, what is gained on one side is lost on the other.

If all the pressure acting on P to force it through the nozzle could be recovered in the form of elevation head, it would rise to level Y. If account is taken of the balance in atmospheric pressure, in a frictionless system, P would rise to level X, or precisely as high as the sum of the gravity head and the head equivalent to the applied force.

Kinetic Energy

It was previously pointed out that a force must be applied to an object in order to give it a velocity or to increase the velocity it already has. Whether the force begins or changes velocity, it acts over a certain distance. A force acting over a certain distance is work. Work and all forms into which it can be changed are classified as energy. Obviously then, energy is required to give an object velocity. The greater the energy used, the greater the velocity will be.

Disregarding friction, for an object to be brought to rest or for its motion to be slowed down, a force opposed to its motion must be applied to it. This force also acts over some distance. In this way energy is given up by the object and delivered in some form to whatever opposes its continuous motion. The moving object is therefore a means of receiving energy at one place (where its motion is increased) and delivering it to another point (where it is stopped or retarded). While it is in motion, it is said to contain this energy as energy of motion or kinetic energy.

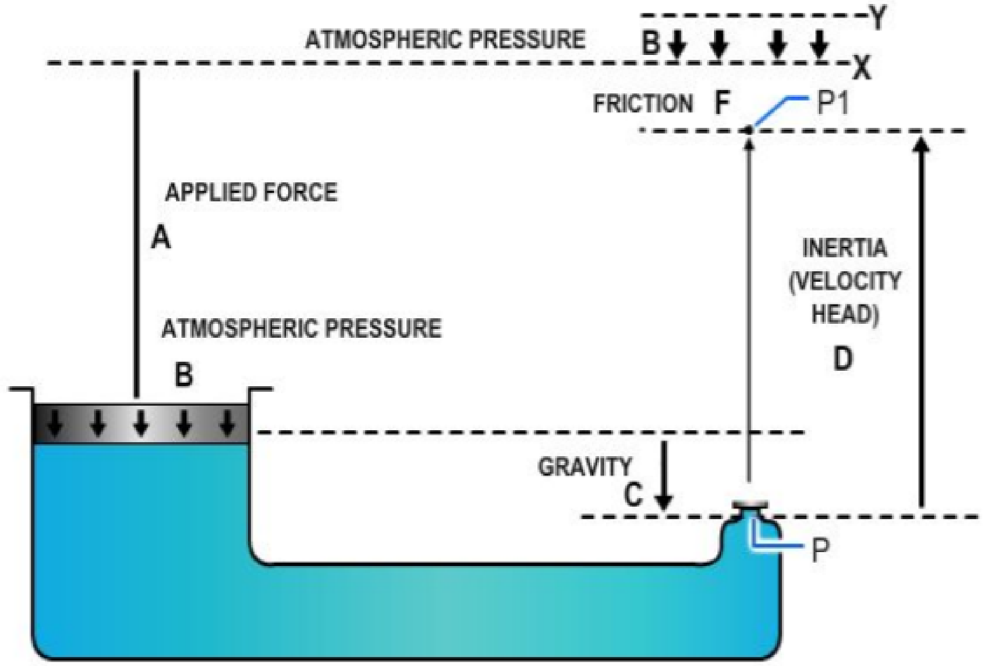


Figure 2-16 — Physical factors governing fluid flow.

Since energy can never be destroyed, it follows that if friction is disregarded the energy delivered to stop the object will exactly equal the energy that was required to increase its speed. At all times the amount of kinetic energy possessed by an object depends on its weight and the velocity at which it is moving.

The mathematical relationship for kinetic energy is stated in the following rule: "Kinetic energy in foot-pounds is equal to the force in pounds which created it, multiplied by the distance through which it was applied, or to the weight of the moving object in pounds, multiplied by the square of its velocity in feet per second, and divided by 64.

The relationship between inertia forces, velocity, and kinetic energy can be illustrated by analyzing what happens when a gun fires a projectile against the armor of an enemy ship (*Figure 2-17*). The explosive force of the powder in the breach pushes the projectile out of the gun, giving it a high velocity. Because of its inertia, the projectile offers opposition to this sudden velocity and a reaction is set up that pushes the gun backward (kick or recoil). The force of the explosion acts on the projectile throughout its movement in the gun. This is force acting through a distance producing work. This work appears as kinetic energy in the speeding projectile. The resistance of the air produces friction, which uses some of the energy and slows down the projectile. Eventually, however, the projectile hits its target and, because of the inertia, tries to continue moving. The target, being relatively stationary, tends to remain stationary because of its inertia. The result is that a tremendous force is set up that either leads to the penetration of the armor or the shattering of the projectile. The projectile is simply a means of transferring energy, in this instance for destructive purpose, from the gun to the enemy ship. This energy is transmitted in the form of energy of motion or kinetic energy.

A similar action takes place in a fluid power system in which the fluid takes the place of the projectile. For example, the pump in a hydraulic system imparts energy to the fluid, which overcomes the inertia of the fluid at rest and causes it to flow through the lines. The fluid flows against some type of actuator that is at rest. The fluid tends to continue flowing, overcomes the inertia of the actuator, and moves the actuator to do work. Friction uses up a portion of the energy as the fluid flows through the lines and components.

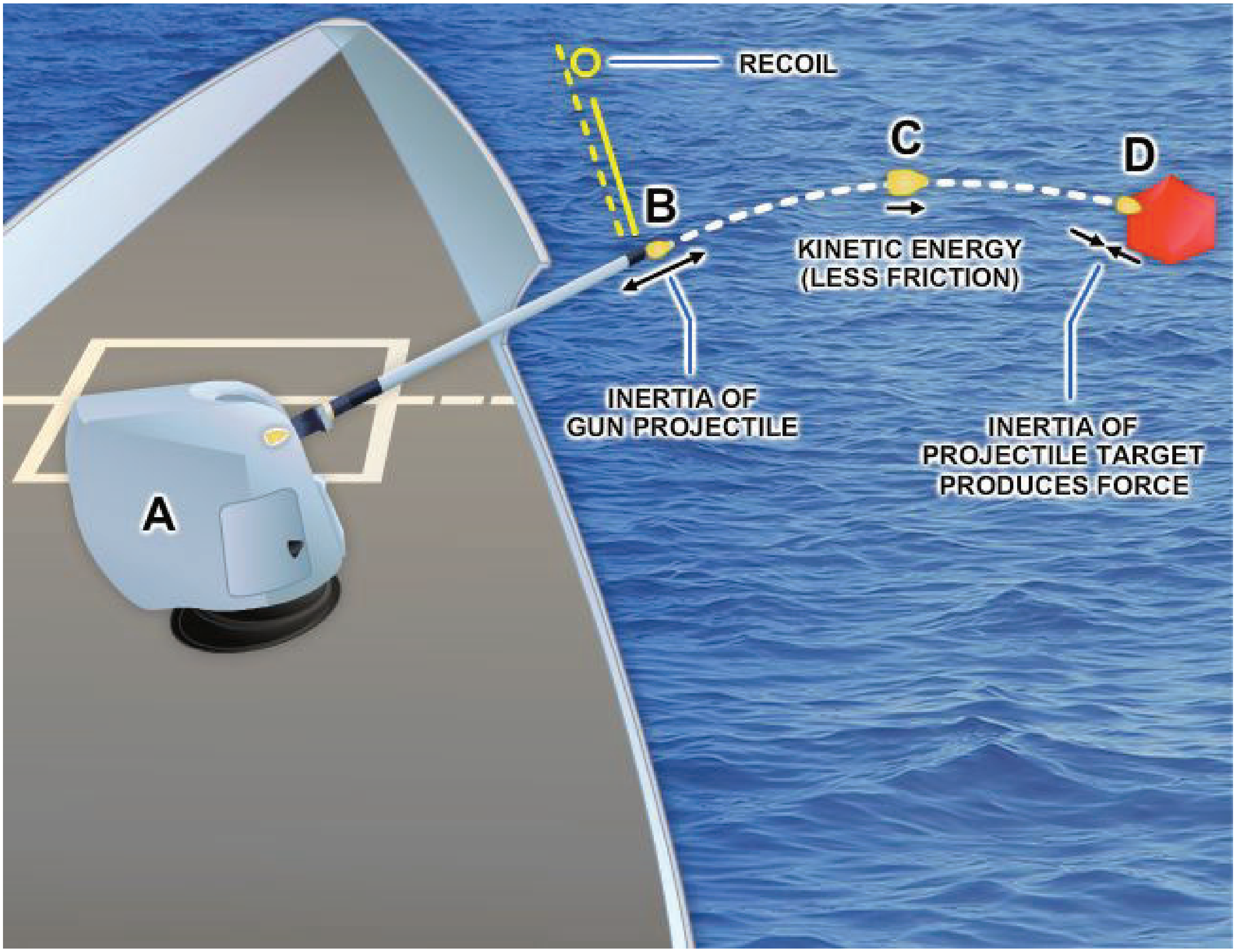


Figure 2-17 — Relationship of inertia, velocity, and kinetic energy.

RELATIONSHIP OF FORCE, PRESSURE, AND HEAD

In dealing with fluids, forces are usually considered in relation to the areas over which they are applied. As previously discussed, a force acting over a unit area is a pressure, and pressure can alternately be stated in pounds per square inch or in terms of head, which is the vertical height of the column of fluid whose weight would produce that pressure.

In most of the applications of fluid power in the Navy, applied forces greatly outweigh all other forces, and the fluid is entirely confined. Under these circumstances it is customary to think of the forces involved in terms of pressures. Since the term head is encountered frequently in the study of fluid power, it is necessary to understand what it means and how it is related to pressure and force.

All five of the factors that control the actions of fluids can, of course, be expressed either as force, or in terms of equivalent pressures or head. In each situation, the different factors are referred to in the same terms, since they can be added and subtracted to study their relationship to each other.

At this point you need to review some terms in general use. Gravity head, when it is important enough to be considered, is sometimes referred to as head. The effect of atmospheric pressure is referred to as atmospheric pressure. (Atmospheric pressure is frequently and improperly referred to as suction.) Inertia effect, because it is always directly related to velocity, is usually called velocity head; and friction, because it represents a loss of pressure or head, is usually referred to as friction head.

Static and Dynamic Factors

Gravity, applied forces, and atmospheric pressure are static factors that apply equally to fluids at rest or in motion, while inertia and friction are dynamic factors that apply only to fluids in motion. The mathematical sum of gravity, applied force, and atmospheric pressure is the static pressure obtained at any one point in a fluid at any given time. Static pressure exists in addition to any dynamic factors that may also be present at the same time.

Remember, Pascal's law states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces. This covers the situation only for fluids at rest or practically at rest. It is true only for the factors making up static head. Obviously, when velocity becomes a factor it must have a direction, and as previously explained, the force related to the velocity must also have a direction, so that Pascal's law alone does not apply to the dynamic factors of fluid power.

The dynamic factors of inertia and friction are related to the static factors. Velocity head and friction head are obtained at the expense of static head. However, a portion of the velocity head can always be reconverted to static head. Force, which can be produced by pressure or head when dealing with fluids, is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is arrested; therefore, whenever a fluid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.

Bernoulli's Principle

Consider the system illustrated in *Figure 2-18*. Chamber A is under pressure and is connected by a tube to chamber B, which is also under pressure. The pressure in chamber A is static pressure of 100 psi. The pressure at some point (X) along the connecting tube consists of a velocity pressure of 10 psi exerted in a direction parallel to the line of flow, plus the unused static pressure of 90 psi, which still obeys Pascal's law and operates equally in all directions. As the fluid enters chamber B, it is slowed down, and its velocity is changed back to pressure. The force required to absorb its inertia equals the force required to start the fluid moving originally, so that the static pressure in chamber B is equal to that in chamber A.

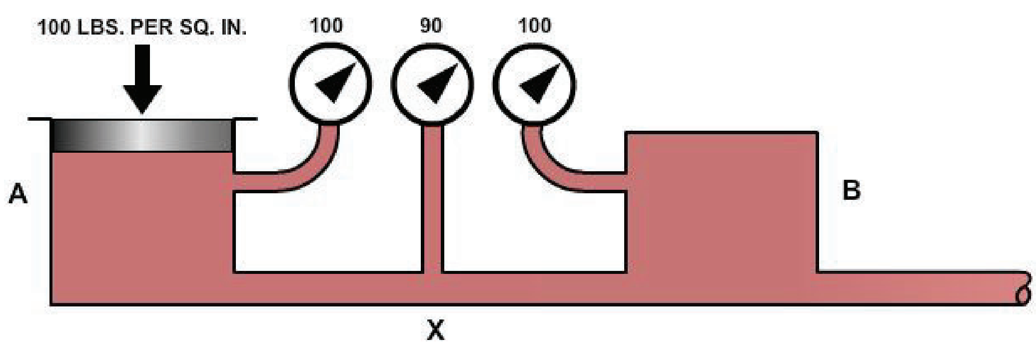


Figure 2-18 — Relationship of static and dynamic factors (Bernoulli's principle).

This situation (*Figure 2-18*) disregards friction; therefore, it would not be encountered in actual practice. Force or head is also required to overcome friction but, unlike inertia effect, this force cannot be recovered again, although the energy represented still exists somewhere as heat. Therefore, in an actual system the pressure in chamber B would be less than in chamber A by the amount of pressure used in overcoming friction along the way.

At all points in a system the static pressure is always the original static pressure, less any velocity head at the point in question and less the friction head consumed in reaching that point. Since both the velocity head and the friction head represent energy that came from the original static head, and since energy cannot be destroyed, the sum of the static head, the velocity head, and the friction head at any point in the system must add up to the original static head. This is known as Bernoulli's principle, which states: For the horizontal flow of fluid through a tube, the sum of the pressure and the kinetic energy per unit volume of the fluid is constant. This principle governs the relations of the static and dynamic factors concerning fluids, while Pascal’s law states the manner in which the static factors behave when taken by themselves.

Minimizing Friction

Fluid power equipment is designed to reduce friction to the lowest possible level. Volume and velocity of flow are made the subject of careful study. The proper fluid for the system is chosen. Clean, smooth pipe of the best dimensions for the particular conditions is used, and it is installed along as direct a route as possible. Sharp bends and sudden changes in cross-sectional areas are avoided. Valves, gauges, and other components are designed to interrupt flow as little as possible. Careful thought is given to the size and shape of the openings. The systems are designed so they can be kept clean inside and variations from normal operation can easily be detected and remedied.

OPERATION OF HYDRAULIC COMPONENTS

To transmit and control power through pressurized fluids, an arrangement of interconnected components is required. Such an arrangement is commonly referred to as a system. The number and arrangement of the components vary from system to system, depending on the particular application. In many applications, one main system supplies power to several subsystems, which are sometimes referred to as circuits. The complete system may be a small compact unit; more often, however, the components are located at widely separated points for convenient control and operation of the system.

The basic components of a fluid power system are essentially the same, regardless of whether the system uses a hydraulic or a pneumatic medium. There are five basic components used in a system. These basic components are as follows:

1. Reservoir or receiver (depending on system type).
2. Pump or compressor.
3. Lines (pipe, tubing, or flexible hose).
4. Directional control valve.
5. Actuating device.

Several applications of fluid power require only a simple system; that is, a system that uses only a few components in addition to the five basic components. A few of these applications are presented in the following paragraphs. We will explain the operation of these systems briefly at this time so you will know the purpose of each component and can better understand how hydraulics is used in the operation of these systems.

Hydraulic Jack

The hydraulic jack is perhaps one of the simplest forms of a fluid power system. By moving the handle of a small device, an individual can lift a load weighing several tons. A small initial force exerted on the handle is transmitted by a fluid to a much larger area. To understand this better, study *Figure 2-19*. The small input piston has an area of 5 square inches and is directly connected to a large cylinder with an output piston having an area of 250 square inches. The top of this piston forms a lift platform.

If a force of 25 pounds is applied to the input piston, it produces a pressure of 5 psi in the fluid, that is, of course, if a sufficient amount of resistant force is acting against the top of the output piston. Disregarding friction loss, this pressure acting on the 250-square-inch area of the output piston will support a resistance force of 1,250 pounds. In other words, this pressure could overcome a force of slightly under 1,250 pounds. An input force of 25 pounds has been transformed into a working force of more than half a ton; however, for this to be true, the distance traveled by the input piston must be 50 times greater than the distance traveled by the output piston. Thus, for every inch that the input piston moves, the output piston will move only one-fiftieth of an inch.

This would be ideal if the output piston needed to move only a short distance. However, in most instances, the output piston would have to be capable of moving a greater distance to serve a practical application. The device shown in *Figure 2-19* is not capable of moving the output piston farther than that shown; therefore, some other means must be used to raise the output piston to a greater height.

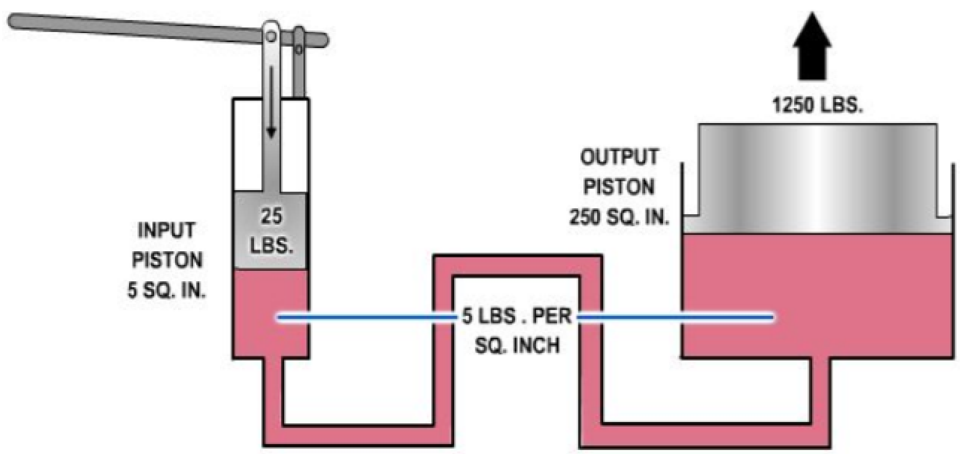


Figure 2-19 — Hydraulic jack.

The output piston can be raised higher and maintained at this height if additional components are installed as shown in *Figure 2-20*. In this illustration the jack is designed so that it can be raised, lowered, or held at a constant height. These results are attained by introducing a number of valves and also a reserve supply of fluid to be used in the system.

Notice that this system contains the five basic components—the reservoir; cylinder 1, which serves as a pump; valve 3, which serves as a directional control valve; cylinder 2, which serves as the actuating device; and lines to transmit the fluid to and from the different components. In addition, this system contains two valves, 1 and 2, whose functions are explained in the following discussion.

As the input piston is raised (*Figure 2-20, frame 1*), valve 1 is closed by the back pressure from the weight of the output piston. At the same time, valve 2 is opened by the head of the fluid in the reservoir. This forces fluid into cylinder 1. When the input piston is lowered (*Figure 2-20, frame 2*), a pressure is developed in cylinder 1. When this pressure exceeds the head in the reservoir, it closes valve 2. When it exceeds the back pressure from the output piston, it opens valve 1, forcing fluid into the pipeline. The pressure from cylinder 1 is thus transmitted into cylinder 2, where it acts to raise the output piston with its attached lift platform. When the input piston is again raised, the pressure in cylinder 1 drops below that in cylinder 2, causing valve 1 to close. This prevents the return of fluid and holds the output piston with its attached lift platform at its new level. During this stroke, valve 2 opens again, allowing a new supply of fluid into cylinder 1 for the next power (downward) stroke of the input piston. Thus, by repeated strokes of the input piston, the lift platform can be progressively raised. To lower the lift platform, valve 3 is opened, and the fluid from cylinder 2 is returned to the reservoir.

Hydraulic Brakes

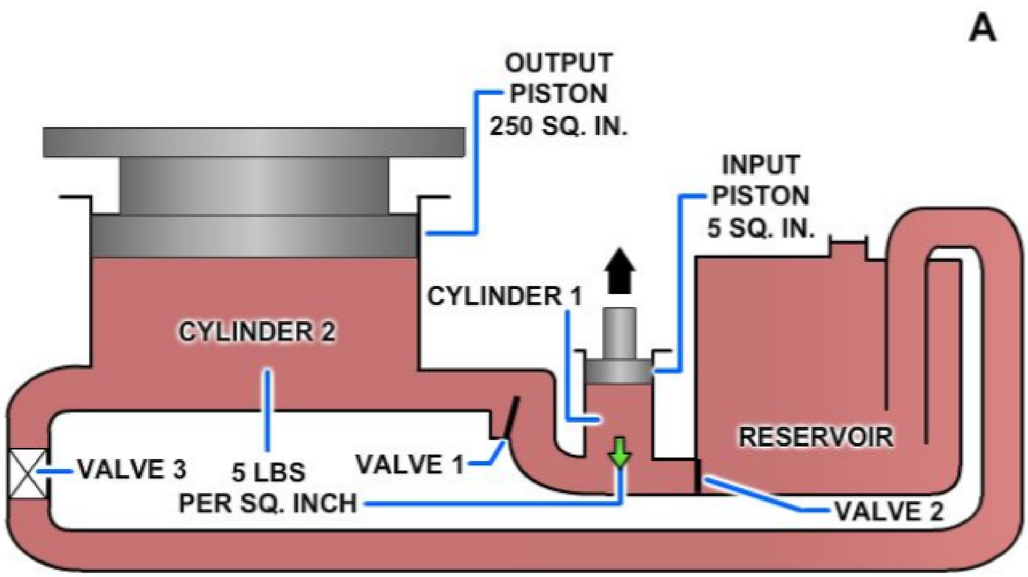


Figure 2-20 — Hydraulic jack; (A) up stroke; (B) downstroke.

The hydraulic brake system used in the automobile is a multiple piston system. A multiple piston system allows forces to be transmitted to two or more pistons in the manner indicated in *Figure 2-21*. Note that the pressure set up by the force applied to the input piston (1) is transmitted undiminished to both output pistons (2 and 3), and that the resultant force on each piston is proportional to its area. The multiplication of forces from the input piston to each output piston is the same as that explained earlier.

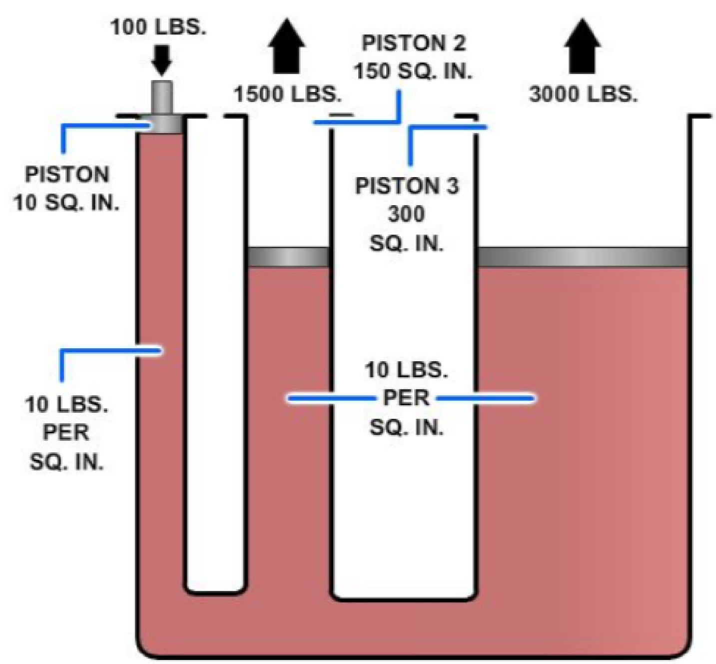


Figure 2-21 — Multiple piston system.

The hydraulic brake system from the master cylinders to the wheel cylinders on most automobiles operates in a way similar to the system illustrated in *Figure 2-22*.

When the brake pedal is depressed, the pressure on the brake pedal moves the piston within the master cylinder, forcing the brake fluid from the master cylinder through the tubing and flexible hose to the wheel cylinders. The wheel cylinders contain two opposed output pistons, each of which is attached to a brake shoe fitted inside the brake drum. Each output piston pushes the attached brake shoe against the wall of the brake drum, thus retarding the rotation of the wheel. When pressure on the pedal is released, the springs on the brake shoes return the wheel cylinder pistons to their released positions. This action forces the displaced brake fluid back through the flexible hose and tubing to the master cylinder.

The force applied to the brake pedal produces a proportional force on each of the output pistons, which in turn apply the brake shoes frictionally to the turning wheels to retard rotation.

As previously mentioned, the hydraulic brake system on most automobiles operates in a similar way, as shown in *Figure 2-22*. It is beyond the scope of this manual to discuss the various brake systems.

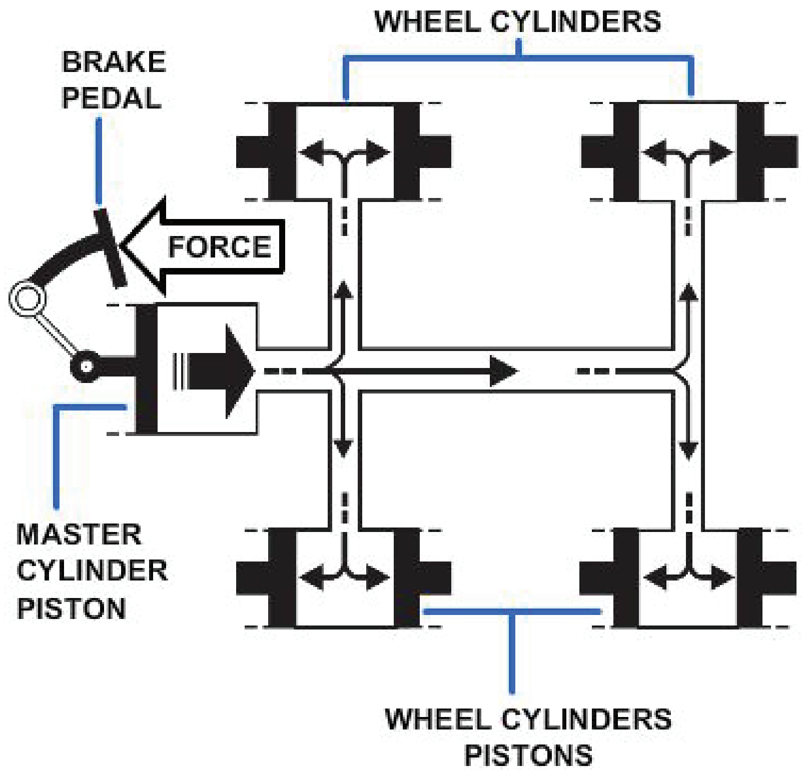


Figure 2-22 — An automobile brake system.

CHAPTER 3

HYDRAULIC FLUIDS

During the design of equipment that requires fluid power, many factors are considered in selecting the type of system to be used—whether hydraulic, pneumatic, or a combination of the two. Some of the factors include required speed and accuracy of operation, surrounding atmospheric conditions, economic conditions, availability of replacement fluid, required pressure level, operating temperature range, contamination possibilities, cost of transmission lines, limitations of the equipment, lubricity, safety to the operators, and expected service life of the equipment.

After the type of system has been selected, many of these same factors must be considered in selecting the fluid for the system. This chapter is devoted to hydraulic fluids. Included in it are sections on the properties and characteristics desired of hydraulic fluids; types of hydraulic fluids; hazards and safety precautions for working with, handling, and disposing of hydraulic liquids; types and control of contamination; and sampling.

LEARNING OBJECTIVES

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

1. Identify the characteristics of liquid that make it desirable for use in hydraulic systems.
2. Describe the properties and characteristics that must be considered in selecting a hydraulic liquid for a particular system, including related data.
3. Recognize various types of hydraulic liquids and their particular characteristics and uses.
4. Identify types, characteristics, and origin for various hydraulic system contaminants.
5. Describe the controls and checks for various hydraulic system contaminants.

PROPERTIES

If fluidity (the physical property of a substance that enables it to flow) and incompressibility were the only properties required, any liquid not too thick might be used in a hydraulic system. However, a satisfactory liquid for a particular system must possess a number of other properties. The most important properties of hydraulic fluid and some of its characteristics are discussed in the following paragraphs.

Viscosity

Viscosity is one of the most important properties of hydraulic fluids. It is a measure of a fluid's resistance to flow. A liquid that flows easily, such as gasoline, has a low viscosity; and a liquid that flows slowly, such as tar, has a high viscosity. The viscosity of a liquid is affected by changes in temperature and pressure. As the temperature of a liquid increases, its viscosity decreases. That is, a liquid flows more easily when it is hot than when it is cold. The viscosity of a liquid increases as the pressure on the liquid increases.

A satisfactory liquid for a hydraulic system must be thick enough to give a good seal at pumps, motors, valves, and so on. These components depend on close fits for creating and maintaining pressure. Any internal leakage through these clearances results in loss of pressure, instantaneous control, and pump efficiency. Leakage losses are greater with thinner liquids (low viscosity). A liquid that is too thin will also allow rapid wearing of moving parts, or of parts that operate under heavy loads. On the other hand, if the liquid is too thick (viscosity too high), the internal friction of the liquid will cause an increase in the liquid's flow resistance through clearances of closely fitted parts, lines, and internal passages. This resistance of flow will result in pressure drops throughout the system, sluggish operation of the equipment, and an increase in power consumption.

Measurement of Viscosity

Viscosity is normally determined by measuring the time required for a fixed volume of a fluid (at a given temperature) to flow through a calibrated orifice or capillary tube. The instruments used to measure the viscosity of a liquid are known as viscometers or viscometers.

Several types of viscometers are in use today. The Saybolt viscometer, shown in *Figure 3-1*, measures the time required, in seconds, for 60 milliliters of the tested fluid at 100 degrees Fahrenheit (°F) to pass through a standard orifice. The time measured is used to express the fluid's viscosity, in Saybolt universal seconds or Saybolt furol seconds.

The glass capillary viscometers, shown in *Figure 3-2*, are examples of the second type of viscometer used. These viscometers are used to measure kinematic viscosity. Kinematic viscosity is the ratio of absolute or dynamic viscosity to density—a quantity in which no force is involved.

Kinematic viscosity can be obtained by dividing the dynamic viscosity of a fluid by its density:

$v = \mu/\rho$, where

v = kinematic viscosity

μ = absolute or dynamic viscosity

ρ = density

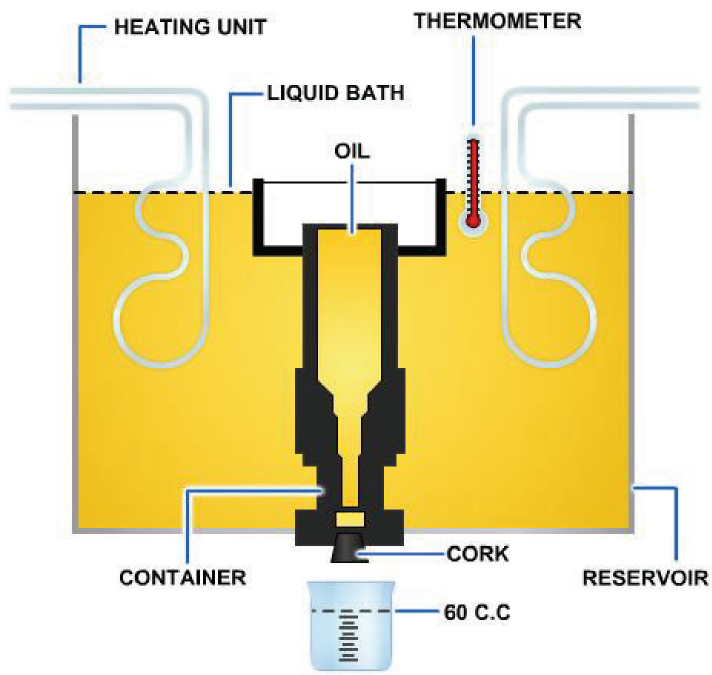


Figure 3-1 — Saybolt viscometer.

Like the Saybolt viscometer, the glass capillary measures the time in seconds required for the tested fluid to flow through the capillary. This time is multiplied by the temperature constant of the viscometer in use to provide the viscosity, expressed in centistokes.

In the International System of Units (SI-system), the theoretical unit is m^2/s or commonly used stoke (St), where:

$$1\ St = 10^{-4}\ m^2/s$$

Because the Stoke is an impractical large unit, it is usually divided by 100 to give the unit called centistokes (cSt), where:

$$1\ St = 100\ cSt$$

$$1\ cSt = 10^{-6}\ m^2/s$$

Because the specific gravity of water at 68.4 °F (20.2 degrees Celsius (°C)) is almost 1, the kinematic viscosity of water at 68.4 °F is, for all practical purposes, 1.0 cSt.

The following formulas may be used to convert centistrokes (cSt units) to approximate Saybolt universal seconds (*SUS* units).

For SUS values between 32 and 100:

$$cST = 0.253xSUS - \frac{194.4}{SUS}$$

For *S*US values greater than 100:

$$cST = 0.220xSUS - \frac{135}{SUS}$$

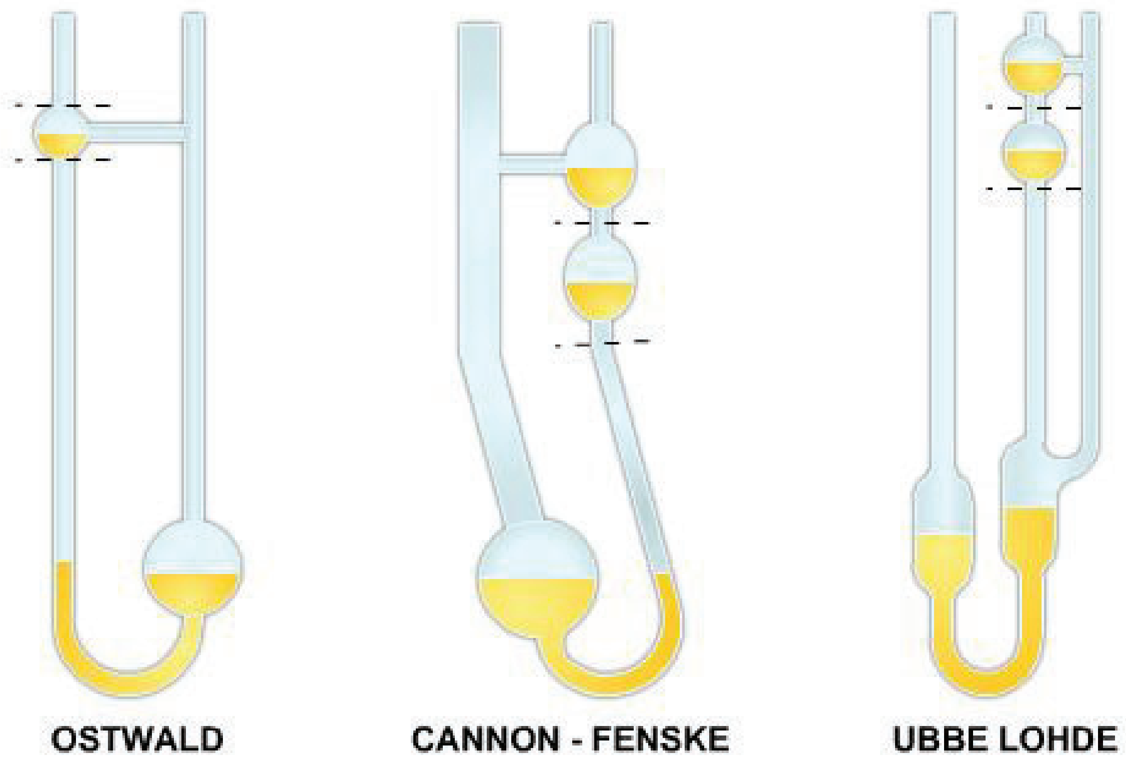


Figure 3-2 — Various styles of glass capillary viscometers.

Although the viscometers discussed above are used in laboratories, other viscometers in the supply system are available for local use. These viscometers can be used to test the viscosity of hydraulic fluids either prior to their being added to a system or periodically after they have been in an operating system for a while.

Refer to the Naval Aircraft Carrier and Amphibious Assault Ships Metrology and Calibration (METCAL) Program Manual, NAVAIR 17-35QAL-15 for additional information on the various types of viscometers and their operation.

Viscosity Index

Viscosity index (VI) is an arbitrary measure for the change of viscosity with variations in temperature. The lower the VI, the greater the change of viscosity of the oil with temperature and vice versa. It is used to characterize viscosity changes with relation to temperature in lubricating oil. The viscosity of liquids decreases as temperature increases. The viscosity of a lubricant is closely related to its ability to reduce friction. Generally, the least viscous lubricant which still forces the two moving surfaces apart is desired. If the lubricant is too viscous, it will require a large amount of energy to move (as in honey); if it is too thin, the surfaces will come in contact and friction will increase.

An ideal oil for most purposes is one that maintains a constant viscosity throughout temperature changes. The importance of the VI can be shown easily by considering automotive lubricants. An oil with a high VI resists excessive thickening when the engine is cold, consequently promoting rapid starting and prompt circulation. It also resists excessive thinning when the motor is hot, thus providing full lubrication and preventing excessive oil consumption.

Another example of the importance of the VI is the need for a high-VI hydraulic oil for military aircraft because hydraulic control systems may be exposed to temperatures ranging from below –65 °F at high altitudes to over 100 °F on the ground. For the proper operation of the hydraulic control system, the hydraulic fluid must have a sufficiently high VI to perform its functions at the extremes of the expected temperature range.

Liquids with a high viscosity have a greater resistance to heat than low-viscosity liquids, which have been derived from the same source. The average hydraulic liquid has a relatively low viscosity. Fortunately, there is a wide choice of liquids available for use in the viscosity range required of hydraulic liquids.

The VI of an oil may be determined if its viscosity at any two temperatures is known. The American Society for Testing and Materials (ASTM) issues tables that are based on a large number of tests. These tables permit calculation of the VI from known viscosities.

LUBRICATING CHARACTERISTICS

If motion takes place between surfaces in contact, friction tends to oppose the motion. When pressure forces the liquid of a hydraulic system between the surfaces of moving parts, the liquid spreads out into a thin film, which enables the parts to move more freely. Different liquids, including oils, vary greatly not only in their lubricating ability but also in film strength. Film strength is the capability of a liquid to resist being wiped or squeezed out from between the surfaces when spread out in an extremely thin layer. A liquid will no longer lubricate if the film breaks down because the motion of part against part wipes the metal clean of liquid.

Lubricating power varies with temperature changes; therefore, the climatic and working conditions must enter into the determination of the lubricating qualities of a liquid. Unlike viscosity, which is a physical property, the lubricating power and film strength of a liquid is directly related to its chemical nature. Lubricating qualities and film strength can be improved by the addition of certain chemical agents.

CHEMICAL STABILITY

Chemical stability is another property that is exceedingly important in the selection of a hydraulic liquid. It is defined as the liquid's ability to resist oxidation and deterioration for long periods. All liquids tend to undergo unfavorable changes under severe operating conditions.

Excessive temperatures, especially extremely high temperatures, have a great effect on the life of a liquid. The temperature of the liquid in the reservoir of an operating hydraulic system does not always indicate the operating conditions throughout the system. Localized hot spots occur on bearings, on gear teeth, or at other points where the liquid under pressure is forced through small orifices. Continuous passage of the liquid through these points may produce local temperatures high enough to carbonize the liquid or turn it into sludge, yet the liquid in the reservoir may not indicate an excessively high temperature.

Liquids may break down if exposed to air, water, salt, or other impurities, especially if they are in constant motion or subjected to heat. Some metals, such as zinc, lead, brass, and copper, have undesirable chemical reactions with certain liquids.

These chemical reactions result in the formation of sludge, gums, carbon, or other deposits that clog openings, cause valves and pistons to stick or leak, and give poor lubrication to moving parts. Once a small amount of sludge or other deposits is formed, the rate of formation generally increases more rapidly. As these deposits are formed, certain changes in the physical and chemical properties of the liquid take place. The liquid usually becomes darker, the viscosity increases, and damaging acids are formed.

The extent to which changes occur in different liquids depends on the type of liquid, type of refining, and whether it has been treated to provide further resistance to oxidation. The stability of liquids can be improved by the addition of oxidation inhibitors. Inhibitors selected to improve stability must be compatible with the other required properties of the liquid.

ACIDITY

An ideal hydraulic liquid should be free from acids that cause corrosion of the metals in the system. Most liquids cannot be expected to remain completely noncorrosive under severe operating conditions. The degree of acidity of a liquid, when new, may be satisfactory; but after use, the liquid may tend to become corrosive as it begins to deteriorate.

Many systems are idle for long periods after operating at high temperatures. This permits moisture to condense in the system, resulting in rust formation.

Certain corrosion- and rust-preventive additives are added to hydraulic liquids. Some of these additives are effective only for a limited period. Therefore, the best procedure is to use the liquid specified for the system for the time specified by the system manufacturer and to protect the liquid and the system as much as possible from contamination by foreign matter, from abnormal temperatures, and from misuse.

FLASHPOINT

Flashpoint is the temperature at which a liquid gives off vapor in sufficient quantity to ignite momentarily or flash when a flame is applied. A high flashpoint is desirable for hydraulic liquids because it provides good resistance to combustion and a low degree of evaporation at normal temperatures. Required flashpoint minimums vary from 300 °F for the lightest oils to 510 °F for the heaviest oils.

FIRE POINT

Fire point is the temperature at which a substance gives off vapor in sufficient quantity to ignite and continue to burn when exposed to a spark or flame. Like flashpoint, a high fire point is required of desirable hydraulic liquids.

TOXICITY

Toxicity is defined as the quality, state, or degree of being toxic or poisonous. Some liquids contain chemicals that are a serious toxic hazard. These toxic or poisonous chemicals may enter the body through inhalation, by absorption through the skin, or through the eyes or the mouth. The result is sickness and, in some cases, death. Manufacturers of hydraulic liquids strive to produce suitable liquids that contain no toxic chemicals. As a result, most hydraulic liquids are free of harmful chemicals. Some fire-resistant liquids are toxic, and suitable protection and care in handling must be provided.

DENSITY AND COMPRESSIBILITY

A fluid with a specific gravity of less than 1.0 is desired when weight is critical, although with proper system design, a fluid with a specific gravity greater than 1 can be tolerated. Where avoidance of detection by military units is desired, a fluid that sinks rather than rises to the surface of the water is desirable. Fluids having a specific gravity greater than 1.0 are desired because leaking fluid will sink, allowing the vessel with the leak to remain undetected.

Under extreme pressure, a fluid may be compressed up to 7 percent of its original volume. Highly compressible fluids produce sluggish system operation. This effect does not present a serious problem in small, low-speed operations, but it must be considered in the operating instructions.

FOAMING

Foam is an emulsion of gas bubbles in the fluid. Foam in a hydraulic system results from compressed gases in the hydraulic fluid. A fluid under high pressure can contain a large volume of air bubbles. When this fluid is depressurized, as when it reaches the reservoir, the gas bubbles in the fluid expand and produce foam. Any amount of foaming may cause pump cavitation and produce poor system response and spongy control. Therefore, defoaming agents are often added to fluids to prevent foaming. Minimizing air in fluid systems is discussed later in this chapter.

CLEANLINESS

Cleanliness in hydraulic systems has received considerable attention recently. Some hydraulic systems, such as aerospace hydraulic systems, are extremely sensitive to contamination. Fluid cleanliness is of primary importance because contaminants can cause component malfunction, prevent proper valve seating, cause wear in components, and increase the response time of servo valves. Fluid contaminants are discussed later in this chapter.

The inside of a hydraulic system can only be kept as clean as the fluid added to it. Initial fluid cleanliness can be achieved by observing stringent cleanliness requirements (discussed later in this chapter) or by filtering all fluid added to the system.

TYPES OF HYDRAULIC FLUIDS

Many liquids have been tested for use in hydraulic systems. Currently, liquids being used include mineral oil, water, phosphate ester, water-based ethylene glycol compounds, and silicone fluids. The three most common types of hydraulic liquids are petroleum-based, synthetic fire-resistant, and water-based fire-resistant.

Petroleum-Based Fluids

The most common hydraulic fluids used in shipboard systems are the petroleum-based oils. These fluids contain additives to protect the fluid from oxidation (antioxidant), to protect system metals from corrosion (anticorrosion), to reduce tendency of the fluid to foam (foam suppressant), and to improve viscosity.

Petroleum-based fluids are used in surface ships' electrohydraulic steering and deck machinery systems; submarines' hydraulic systems; and aircraft automatic pilots, shock absorbers, brakes, control mechanisms, and other hydraulic systems using seal materials compatible with petroleum-based fluids.

Synthetic Fire-Resistant Fluids

Petroleum-based oils contain most of the desired properties of a hydraulic liquid. However, they are flammable under normal conditions and can become explosive when subjected to high pressures and a source of flame or high temperatures. Nonflammable synthetic liquids have been developed for use in hydraulic systems where fire hazards exist.

Phosphate Ester Fire-Resistant Fluid

Phosphate ester fire-resistant fluid for shipboard use is covered by specification MIL-H-19457. Tertiary butylated triphenyl phosphate fluids per MIL-H-19457 have been used in aircraft elevators and other surface ship hydraulic systems where a fire-resistant fluid is required. These fluids will be delivered in containers marked MIL-H-19457C or a later specification revision. Phosphate ester in containers marked by a brand name without a specification identification must not be used in shipboard systems because they may contain toxic chemicals.

These fluids will burn if sufficient heat and flame are applied, but they do not support combustion. Drawbacks of phosphate ester fluids are that they will attack and loosen commonly used paints and adhesives, deteriorate many types of insulations used in electrical cables, and deteriorate many gasket and seal materials. Therefore, specific materials are used to manufacture gaskets and seals for systems in which phosphate ester fluids are used. Naval Ships' Technical Manual (NSTM), chapter 556, specifies paints to be used on exterior surfaces of hydraulic systems and components in which phosphate ester fluid is used and on ship structure and decks in the immediate vicinity of this equipment. NSTM, chapter 078, specifies gasket and seal materials used. The Aviation Hydraulics Manual, NAVAIR 01-1A-17 also contains a list of materials resistant to phosphate ester fluids.

Trade names for phosphate ester fluids that do not conform to MIL-H-19457 include Pydraul, Skydrol, and Fyre Safe.

Phosphate Ester Fluid Safety

As a maintenance person, operator, supervisor, or crew member of a ship, squadron, or naval shore installation, you must understand the hazards associated with hydraulic fluids to which you may be exposed.

Phosphate ester fluid conforming to specification MIL-H-19457 is used in aircraft elevators, ballast valve operating systems, and replenishment-at-sea systems. This type of fluid contains a controlled amount of neurotoxic material. Because of the neurotoxic effects that can result from ingestion, skin absorption, or inhalation of these fluids, be sure to use the following precautions:

1. Avoid contact with the fluids by wearing protective clothing.
2. Use chemical goggles or face shields to protect your eyes.
3. If you are expected to work in an atmosphere containing a fine mist or spray, wear a continuous-flow airline respirator.
4. Thoroughly clean skin areas contaminated by this fluid with soap and water.
5. If you get any fluid in your eyes, flush them with running water for at least 15 minutes and seek medical attention.

If you come in contact with MIL-H-19457 fluid, report the contact when you seek medical aid and whenever you have a routine medical examination.

NSTM, chapter 556, contains a list of protective clothing, along with national stock numbers (NSNs), for use with fluids conforming to MIL-H-19457. It also contains procedures for repair work and for low-level leakage and massive spills cleanup.

Phosphate Ester Fluid Disposal

Waste fluids and refuse (rags and other materials) must not be dumped at sea. Fluid should be placed in bung-type drums. Rags and other materials should be placed in open-top drums for shore disposal. These drums should be marked with a warning label stating their content, safety precautions, and disposal instructions. Refer to NSTM chapter 556 and OPNAVINST 5090.1, Environmental Readiness Program Manual for detailed instructions on phosphate ester fluids disposal.

Synthetic Fire-Resistant Fluids (Silicone)

Synthetic fire-resistant fluids are frequently used for hydraulic systems that require fire resistance but have only marginal requirements for other chemical or physical properties common to hydraulic fluids. Silicone fluids do not have the detrimental characteristics of phosphate ester fluids, nor do they provide the corrosion protection and lubrication of phosphate ester fluids, but they are excellent for fire protection. Silicone fluid conforming to MIL-S-81087 is used in the missile holddown and lockout system aboard submarines.

Lightweight Synthetic Fire-Resistant Fluids

In applications where weight is critical, lightweight synthetic fluid is used in hydraulic systems. MIL-H-83282 is a synthetic, fire-resistant hydraulic fluid used in military aircraft and hydrofoils where the requirement to minimize weight dictates the use of a low-viscosity fluid. It is also the most commonly used fluid in aviation support equipment. NAVAIR 01-1A-17 contains additional information on fluids conforming to specification MIL-H-83282.

Water-Based Fire-Resistant Fluids

The most widely used water-based hydraulic fluids may be classified as water-glycol mixtures and water-synthetic base mixtures. The waterglycol mixture contains additives to protect it from oxidation, corrosion, and biological growth and to enhance its load-carrying capacity.

Fire resistance of the water mixture fluids depends on the vaporization and smothering effect of steam generated from the water. The water in water-based fluids is constantly being driven off while the system is operating. Therefore, frequent checks to maintain the correct ratio of water are important.

The water-based fluid used in aircraft handling machinery (catapults), catapult retracting engines, and jet blast deflectors conforms to MIL-H-22072.

The safety precautions outlined for phosphate ester fluid and the disposal of phosphate ester fluid also apply to water-based fluid conforming to MIL-H-22072.

CONTAMINATION

Hydraulic fluid contamination may be described as any foreign material or substance whose presence in the fluid is capable of adversely affecting system performance or reliability. It may assume many different forms, including liquids, gases, and solid matter of various compositions, sizes, and shapes. Solid matter is the type most often found in hydraulic systems and is generally referred to as particulate contamination. Contamination is always present to some degree, even in new, unused fluid, but must be kept below a level that will adversely affect system operation. Hydraulic contamination control consists of requirements, techniques, and practices necessary to minimize and control fluid contamination.

Classification

Many types of contaminants are harmful to hydraulic systems and liquids. These contaminants may be divided into two different classes—particulate and fluid.

Particulate Contamination

This class of contaminants includes organic, metallic solid, and inorganic solid contaminants. These contaminants are discussed in the following paragraphs.

Organic Contamination

Organic solids or semisolids found in hydraulic systems are produced by wear, oxidation, or polymerization. Minute particles of O-rings, seals, gaskets, and hoses are present due to wear or chemical reactions. Synthetic products, such as neoprene, silicones, and hypalon, though resistant to chemical reaction with hydraulic fluids, produce small wear particles. Oxidation of hydraulic fluids increases with pressure and temperature, although antioxidants are blended into hydraulic fluids to minimize such oxidation. The ability of a hydraulic fluid to resist oxidation or polymerization in service is defined as its oxidation stability. Oxidation products appear as organic acids, asphaltics, gums, and varnishes. These products combine with particles in the hydraulic fluid to form sludge. Some oxidation products are oil soluble and cause the hydraulic fluid to increase in viscosity; other oxidation products are not oil soluble and form sediment.

Metallic Solid Contamination

Metallic contaminants are almost always present in a hydraulic system and will range in size from microscopic particles to particles readily visible to the naked eye. These particles are the result of wearing and scoring of bare metal parts and plating materials, such as silver and chromium. Although practically all metals commonly used for parts fabrication and plating may be found in hydraulic fluids, the major metallic materials found are ferrous, aluminum, and chromium particles. Because of their continuous high-speed internal movement, hydraulic pumps usually contribute most of the metallic particulate contamination present in hydraulic systems. Metal particles are also produced by other hydraulic system components, such as valves and actuators, due to body wear and the chipping and wearing away of small pieces of metal plating materials.

Inorganic Solid Contamination

This contaminant group includes dust, paint particles, dirt, and silicates. Glass particles from glass bead peening and blasting may also be found as contaminants. Glass particles are very undesirable contaminants due to their abrasive effect on synthetic rubber seals and the very fine surfaces of critical moving parts. Atmospheric dust, dirt, paint particles, and other materials are often drawn into hydraulic systems from external sources. For example, the wet piston shaft of a hydraulic actuator may draw some of these foreign materials into the cylinder past the wiper and dynamic seals, and the contaminant materials are then dispersed in the hydraulic fluid. Contaminants may also enter the hydraulic fluid during maintenance when tubing, hoses, fittings, and components are disconnected or replaced. It is therefore important that all exposed fluid ports be sealed with approved protective closures to minimize such contamination.

Fluid Contamination

Air, water, solvent, and other foreign fluids are in the class of fluid contaminants.

Air Contamination

Hydraulic fluids are adversely affected by dissolved, entrained, or free air. Air may be introduced through improper maintenance or as a result of system design. Any maintenance operation that involves breaking into the hydraulic system, such as disconnecting or removing a line or component, will invariably result in some air being introduced into the system. This source of air can and must be minimized by prefilling replacement components with new filtered fluid prior to their installation. Failing to prefill a filter element bowl with fluid is a good example of how air can be introduced into the system. Although prefilling will minimize introduction of air, it is still important to vent the system where venting is possible.

Most hydraulic systems have built-in sources of air. Leaky seals in gas-pressurized accumulators and reservoirs can feed gas into a system faster than it can be removed, even with the best of maintenance. Another lesser known but major source of air is air that is sucked into the system past actuator piston rod seals. This usually occurs when the piston rod is stroked by some external means while the actuator itself is not pressurized.

Water Contamination

Water is a serious contaminant of hydraulic systems. Hydraulic fluids are adversely affected by dissolved, emulsified, or free water. Water contamination may result in the formation of ice, which impedes the operation of valves, actuators, and other moving parts. Water can also cause the formation of oxidation products and corrosion of metallic surfaces.

Solvent Contamination

Solvent contamination is a special form of foreign-fluid contamination in which the original contaminating substance is a chlorinated solvent. Chlorinated solvents or their residues may, when introduced into a hydraulic system, react with any water present to form highly corrosive acids.

Chlorinated solvents, when allowed to combine with minute amounts of water often found in operating hydraulic systems, change chemically into hydrochloric acids. These acids then attack internal metallic surfaces in the system, particularly those that are ferrous, and produce a severe rustlike corrosion. NAVAIR 01-1A-17 and NSTM, chapter 556, contain tables of solvents for use in hydraulic maintenance.

Foreign-Fluids Contamination

Hydraulic systems can be seriously contaminated by foreign fluids other than water and chlorinated solvents. This type of contamination is generally a result of lube oil, engine fuel, or incorrect hydraulic fluid being introduced inadvertently into the system during servicing. The effects of such contamination depend on the contaminant, the amount in the system, and how long it has been present.

NOTE

It is extremely important that the different types of hydraulic fluids are not mixed in one system. If different type hydraulic fluids are mixed, the characteristics of the fluid required for a specific purpose are lost. Mixing the different types of fluids usually will result in a heavy, gummy deposit that will clog passages and require a major cleaning. In addition, seals and packing installed for use with one fluid usually are not compatible with other fluids, and damage to the seals will result.

Origin of Contamination

Recall that contaminants are produced from wear and chemical reactions, introduced by improper maintenance, and inadvertently introduced during servicing. These methods of contaminant introduction fall into one of the four major areas of contaminant origin.

Particles Originally Contained in the System

These particles originate during the fabrication and storage of system components. Weld spatter and slag may remain in welded system components, especially in reservoirs and pipe assemblies. The presence is minimized by proper design. For example, seam-welded overlapping joints are preferred, and arc welding of open sections is usually avoided. Hidden passages in valve bodies, inaccessible to sand blasting or other methods of cleaning, are the main source of introduction of core sand. Even the most carefully designed and cleaned casting will almost invariably free some sand particles under the action of hydraulic pressure. Rubber hose assemblies always contain some loose particles. Most of these particles can be removed by flushing the hose before installation; however, some particles withstand cleaning and are freed later by the action of hydraulic pressure.

Particles of lint from cleaning rags can cause abrasive damage in hydraulic systems, especially to closely fitted moving parts. In addition, lint in a hydraulic system packs easily into clearances between packing and contacting surfaces, leading to component leakage and decreased efficiency. Lint also helps clog filters prematurely. The use of the proper wiping materials will reduce or eliminate lint contamination. The wiping materials to be used for a given application will be determined by:

- Substances being wiped or absorbed
- The amount of absorbency required
- The required degree of cleanliness

These wiping materials are categorized for contamination control by the degree of lint or debris that they may deposit during use. For internal hydraulic repairs, this factor itself will determine the choice of wiping material. NAVAIR 01-1A-17 and NSTM*,* chapter 556, provide information on low-lint wiping cloths.

Rust or corrosion initially present in a hydraulic system can usually be traced to improper storage of materials and component parts. Particles can range in size from large flakes to abrasives of microscopic dimensions. Proper preservation of stored parts is helpful in eliminating corrosion.

Particles Introduced from Outside Sources

Particles can be introduced into hydraulic systems at points where either the liquid or certain working parts of the system (for example, piston rods) are at least in temporary contact with the atmosphere.

The most common contaminant introduction areas are at the refill and breather openings, cylinder rod packings, and open lines where components are removed for repair or replacement. Contamination arising from carelessness during servicing operations is minimized by the use of filters in the system fill lines and finger strainers in the filler adapter of hydraulic reservoirs. Hydraulic cylinder piston rods incorporate wiper rings and dust seals to prevent the dust that settles on the piston rod during its outward stroke from entering the system when the piston rod retracts. Caps and plugs are available and should be used to seal off the open lines when a component is removed for repair or replacement.

Particles Created Within the System During Operation

Contaminants created during system operation are of two general types—mechanical and chemical. Particles of a mechanical nature are formed by the wearing of parts in frictional contact, such as pumps, cylinders, and packing gland components. These wear particles can vary from large chunks of packings down to steel shavings that are too small to be trapped by filters.

The major source of chemical contaminants in hydraulic liquid is oxidation. These contaminants are formed under high pressure and temperatures and are promoted by the chemical action of water and air and of metals such as copper and iron oxides. Liquid-oxidation products appear initially as organic acids, asphaltines, gums, and varnishes—sometimes combined with dust particles as sludge. Liquid-soluble oxidation products tend to increase liquid viscosity, while insoluble types separate and form sediments, especially on colder elements such as heat exchanger coils.

Liquids containing antioxidants have little tendency to form gums and sludge under normal operating conditions. However, as the temperature increases, resistance to oxidation diminishes. Hydraulic liquids that have been subjected to excessively high temperatures (above 250 °F for most liquids) will break down, leaving minute particles of asphaltines suspended in the liquids. The liquid changes to brown in color and is referred to as decomposed liquid. This process explains the importance of keeping the hydraulic liquid temperature below specific levels.

The second contaminant-producing chemical action in hydraulic liquids is one that permits these liquids to react with certain types of rubber. This reaction causes structural changes in the rubber, turning it brittle and finally causing its complete disintegration. For this reason, the compatibility of system liquid with seals and hose material is a very important factor.

Particles Introduced by Foreign Liquids

One of the most common foreign-fluid contaminants is water, especially in hydraulic systems that require petroleum-based liquids. Water, which enters even the most carefully designed system by condensation of atmospheric moisture, normally settles to the bottom of the reservoir. Oil movement in the reservoir disperses the water into fine droplets, and agitation of the liquid in the pump and in high-speed passages forms an oil-water-air emulsion. This emulsion normally separates during the rest period in the system reservoir; but when fine dust and corrosion particles are present, the emulsion is chemically changed by high pressures into sludge. The damaging action of sludge explains the need for effective filtration, as well as the need for water separation qualities in hydraulic liquids.

Contamination Control

Maintaining hydraulic fluid within allowable contamination limits for both water and particulate matter is crucial to the care and protection of hydraulic equipment.

Filters will provide adequate control of the particular contamination problem during all normal hydraulic system operations if the filtration system is installed properly and filter maintenance is performed properly. Filter maintenance includes changing elements at proper intervals. Control of the size and amount of contamination entering the system from any other source is the responsibility of the personnel who service and maintain the equipment. During installation, maintenance, and repair of hydraulic equipment, the retention of cleanliness of the system is of paramount importance for subsequent satisfactory performance.

Adhere to the following maintenance and servicing procedures at all times to provide proper contamination control:

1. Keep all tools and the work area (workbenches and test equipment) in a clean, dirt-free condition.
2. Ensure a suitable container is always provided to receive the hydraulic liquid that is spilled during component removal or disassembly.

> **NOTE**
>
> After draining liquid from these systems for reuse, store it in a clean and suitable container. Strain and/or filter the liquid when returning it to the system reservoir.

3. Before disconnecting hydraulic lines or fittings, clean the affected area with an approved dry-cleaning solvent.
4. Cap or plug all hydraulic lines and fittings immediately after disconnection.
5. Before assembling any hydraulic components, wash their parts with an approved dry-cleaning solvent.
6. After cleaning the parts in dry-cleaning solvent, dry them thoroughly with clean, low-lint cloths and lubricate with the recommended preservative or hydraulic liquid before assembling.

> **NOTE**
>
> Only use clean, low-lint type I or II cloths as appropriate to wipe or dry component parts.

7. Replace all packings and gaskets during the assembly procedures.
8. Connect all parts with care to avoid stripping metal slivers from threaded areas. Install and torque all fittings and lines according to applicable technical instructions.
9. Keep all hydraulic servicing equipment clean and in good operating condition.

Some hydraulic fluid specifications, such as MIL-H-6083, MIL-H-46170, and MIL-H-83282, contain particle contamination limits that are so low that the products are packaged under clean room conditions. Very slight amounts of dirt, rust, and metal particles will cause them to fail the specification limit for contamination. Because these fluids are usually all packaged in hermetically sealed containers, the act of opening a container may allow more contaminants into the fluid than the specification allows. Therefore, take extreme care in the handling of these fluids. In opening the container for use, observation, or tests, it is extremely important to open and handle the can in a clean environment. Flush the area of the container to be opened with filtered solvent (petroleum ether or isopropyl alcohol), and thoroughly rinse the device used for opening the container with filtered solvent. After opening the container, pour a small amount of the material from the container and disposed of it before pouring the sample for analysis. Once you have opened a container, if the contents are not totally used, discard the unused portion. Because the level of contamination of a system containing these fluids must be kept low, perform maintenance on the system's components in a clean environment commonly known as a controlled environment work center. Refer to Aviation Hydraulics Manual, NAVAIR 01-1A-17, for specific information about the controlled environment work center.

Hydraulic Fluid Sampling

The condition of a hydraulic system, as well as its probable future performance, can best be determined by analyzing the operating fluid. Of particular interest are any changes in the physical and chemical properties of the fluid and excessive particulate or water contamination, either of which indicates impending trouble. Excessive particulate contamination of the fluid indicates that the filters are not keeping the system clean. This impediment can result from improper filter maintenance, inadequate filters, or excessive ongoing corrosion and wear.

Sample operating equipment according to instructions given in the operating and maintenance manual for the particular equipment or as directed by the Maintenance Requirement Cards (MRCs).

1. Take all samples from circulating systems, or immediately upon shutdown, while the hydraulic fluid is within 5 °C (9 °F) of normal system operating temperature. Systems not up to temperature may provide nonrepresentative samples of system dirt and water content. Discard the first oil coming from the sampling point because it can be dirty and does not represent the system. Either avoid such samples or indicate the status on the analysis report. As a general rule, a volume of oil equivalent to one to two times the volume of oil contained in the sampling line and valve should be drained before the sample is taken.
2. Ideally, take the sample from a valve installed specifically for sampling. When sampling valves are not installed, avoid taking samples from locations where sediment or water can collect, such as dead ends of piping, tank drains, and low points of large pipes and filter bowls, if possible. If taking samples from pipe drains, drain sufficient fluid before taking the sample to ensure that the sample actually represents the system. Do not take samples from the tops of reservoirs or other locations where the contamination levels are normally low.
3. Unless otherwise specified, take a minimum of one sample for each system located wholly within one compartment. For ships' systems extending into two or more compartments, a second sample is required. An exception to this requirement is submarine external hydraulic systems, which require only one sample. Original sample points should be labeled and the same sample points used for successive sampling. If possible, the following sampling locations should be selected: Label original sample points, and use the same sample points for successive sampling. If possible, select the following sampling locations:
    a. A location that provides a sample representative of fluid being supplied to system components
    b. A return line as close to the supply tank as practical but upstream of any return line filter
    c. For systems requiring a second sample, a location as far from the pump as practical

Operation of the sampling point should not introduce any significant amount of external contaminants into the collected fluid. For additional information on hydraulic fluid sampling, refer to NAVAIR 01-1A-17.

Most fluid samples are submitted to shore laboratories for analysis. Refer to NAVAIR 17-15-50-1, NSTM chapter 556, and NSTM 226 for additional information on collection, labeling, and shipping samples.

CHAPTER 4

PUMPS

Pumps are used for some essential services in the Navy. Pumps supply water to the boilers, draw condensation from the condensers, supply sea water to the firemain, circulate cooling water for coolers and condensers, pump out bilges, transfer fuel, supply water to the distilling plants, and serve many other purposes. Although the pumps discussed in this chapter are used primarily in hydraulic systems, the principles of operation apply as well to the pumps used in other systems.

LEARNING OBJECTIVES

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

1. Explain the functions, operating characteristics, and related data pertinent to hydraulic pumps.
2. Identify operating principles and construction features of rotary pumps.
3. Recognize functions and principles of operation of various types of reciprocating pumps.
4. Describe the construction features of various types of reciprocating pumps.

PURPOSE

The purpose of a hydraulic pump is to supply a flow of fluid to a hydraulic system. The pump does not create system pressure, since pressure can be created only by a resistance to the flow. As the pump provides flow, it transmits a force to the fluid. As the fluid flow encounters resistance, this force is changed into a pressure. Resistance to flow is the result of a restriction or obstruction in the path of the flow. This restriction is normally the work accomplished by the hydraulic system, but can also be restrictions of lines, fittings, and valves within the system. Thus, the pressure is controlled by the load imposed on the system or the action of a pressure-regulating device.

OPERATION

A pump must have a continuous supply of fluid available to the inlet port to supply fluid to the system. As the pump forces fluid through the outlet port, a partial vacuum or low-pressure area is created at the inlet port. When the pressure at the inlet port of the pump is lower than the local atmospheric pressure, atmospheric pressure acting on the fluid in the reservoir forces the fluid into the pump's inlet. If the pump is located at a level lower than the reservoir, the force of gravity supplements atmospheric pressure on the reservoir. Aircraft and missiles that operate at high altitudes are equipped with pressurized hydraulic reservoirs to compensate for low atmospheric pressure encountered at high altitudes.

PERFORMANCE

Pumps are normally rated by their volumetric output and pressure. Volumetric output is the amount of fluid a pump can deliver to its outlet port in a certain period of time at a given speed. Volumetric output is usually expressed in gallons per minute. Since changes in pump speed affect volumetric output, some pumps are rated by their displacement. Pump displacement is the amount of fluid the pump can deliver per cycle. Since most pumps use a rotary drive, displacement is usually expressed in terms of cubic inches per revolution.

As a pump does not create pressure, however, pressure develops by the restrictions in the system affecting the volumetric output of the pump. As the system pressure increases, the volumetric output decreases. This drop in volumetric output is the result of an increase in the amount of internal leakage from the outlet side to the inlet side of the pump. This leakage is referred to as pump slippage and is a factor that must be considered in all pumps. This explains why most pumps are rated in terms of volumetric output at a given pressure.

CLASSIFICATION OF PUMPS

Many different methods are used to classify pumps. Terms such as positive-displacement, nonpositive-displacement, fixed-displacement, variable-displacement, fixed delivery, variable delivery, constant volume, and others are used to describe pumps. The first two of these terms describe the fundamental division of pumps; that is, all pumps are either positive-displacement or nonpositive-displacement.

Basically, pumps that discharge liquid in a continuous flow are referred to as nonpositive-displacement, and those that discharge volumes separated by a period of no discharge are referred to as positive-displacement.

NOTE

Nonpositive-displacement pumps impart velocity to the liquid resulting in a pressure at the discharge (pressure is created and flow is the result).

Positive-displacement pumps capture confined amounts of liquid and transfer it from the suction to the discharge (flow is created and pressure is the result).

The nonpositive-displacement pump can be classified as centrifugal or propeller.

Centrifugal

The centrifugal pump is a nonpositive-displacement pump which delivers a continuous flow produced by a rotating impeller. Centrifugal pumps are widely used aboard ship for pumping nonviscous liquids. In the engine room you will find several important centrifugal pumps: the feed booster pump, the fire and flushing pump, condensate pumps, auxiliary circulating pumps, and the main feed pump. They have several advantages over reciprocating pumps; they are simpler, more compact, lighter, and easily adapted to a high-speed prime mover. Centrifugal pumps also have disadvantages; they have poor suction lift characteristics and they are sensitive to variations in head and speed.

The centrifugal pump uses the throwing force of a rapidly revolving impeller. The liquid is pulled in at the center or eye of the impeller and is discharged at its outer rim. By the time the liquid reaches the outer rim of the impeller, it has acquired a considerable velocity (kinetic energy). The liquid is then slowed down by being led through a volute or through a series of diffusing passages. As the velocity of the liquid decreases, its pressure increases and thus its kinetic energy is transformed into potential energy.

A centrifugal pump does not provide a positive seal against slippage; therefore, the output of the pump varies as system pressure varies. In other words, the volume of fluid delivered for each cycle depends on the resistance to the flow. This type of pump produces a force on the fluid that is constant for each particular speed of the pump. Resistance in the discharge line produces a force in a direction opposite the direction of the force produced by the pump. When these forces are equal, the fluid is in a state of equilibrium and does not flow.

Types of Centrifugal Pumps

There are many different types of centrifugal pumps, but the two which are most likely encountered aboard ship are the volute pump and the volute turbine, or diffuser pump.

Volute Pump

In the volute pump shown in *Figure 4-1*, the impeller discharges into a volute. As the liquid passes through the volute (a gradually widening spiral channel in the pump casing) and into the discharge nozzle, a great part of its kinetic energy is converted into potential energy.

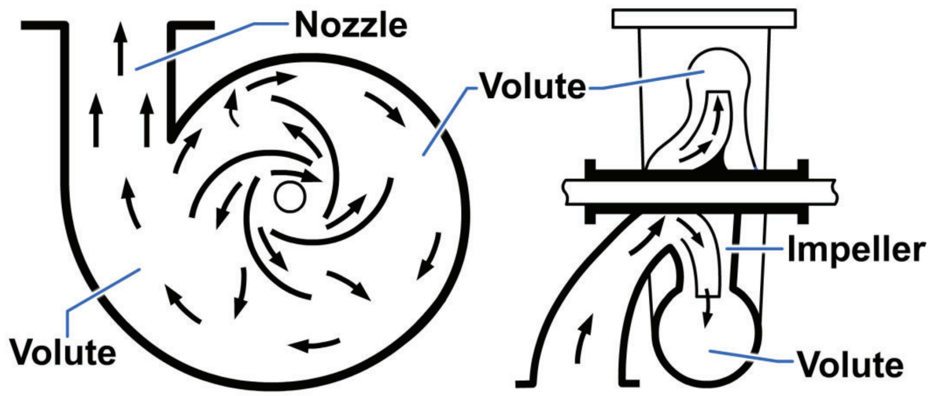


Figure 4-1 — Simple volute pump.

Diffuser Pump

In the diffuser pump shown in *Figure 4-2*, the liquid leaving the impeller is first slowed down by the stationary diffuser vanes which surround the impeller. The liquid is forced through gradually widening passages in the diffuser ring (not shown) and into the volute. 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.

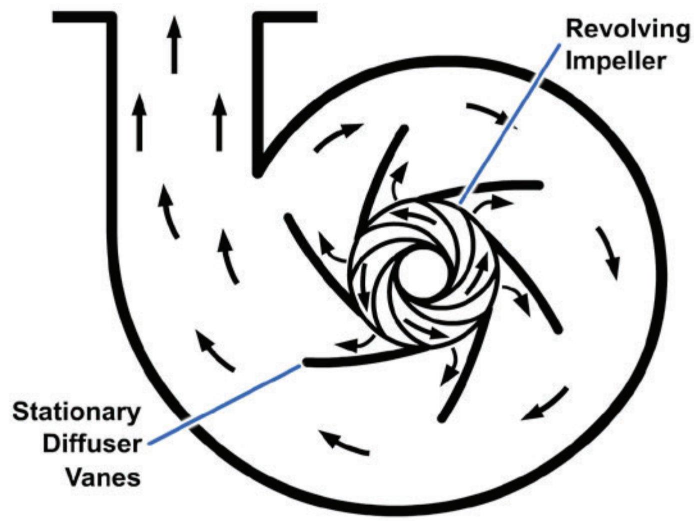


Figure 4-2 — Diffuser (volute turbine) pump.

Propeller Pumps

A propeller pump is another type of nonpositive-displacement pump. This pump is used primarily where there is a large volume of liquid with a relatively low total head requirement. This pump is usually limited to where the total head does not exceed 40 to 60 feet.

The chief use of the propeller pump is for the main condenser circulating pump. In most ships this has an emergency suction for pumping out the engine room.

The main condenser circulating pump is of the vertical propeller type. The pump unit consists of three major parts: the propeller, together with its bearings and shaft; the pump casing; and the driving unit, which may be an auxiliary steam turbine or electric motor.

The propeller is a multibladed screw propeller having a large pitch. The blades are thick at the roots and flare out toward the tips. The blades and hubs are cast or forged in one piece and are then machined and balanced. The lower shaft bearing is a water-lubricated sleeve bearing. The shaft packing gland prevents excessive leakage of water between the casing and the shaft.

If the discharge valve of a nonpositive-displacement pump is completely shut, the discharge pressure will increase to the maximum for that particular pump at a specific speed. Nothing more will happen except that the pump will churn the fluid and produce heat.

The positive-displacement pump can be classified as:

- Reciprocating pumps - piston, plunger, and diaphragm
- Variable-stroke pumps
- Rotary pumps - gear, lobe, screw, and vane

A positive-displacement pump is one in which a definite volume of liquid is delivered for each cycle of pump operation. Positive-displacement pumps use two opposing, rotating elements to displace liquid from the suction side of the pump to the discharge side of the pump. As the elements rotate, the chamber formed between the rotors, housing, and cover collects the liquid on the inlet side of the pump and carries the liquid to the discharge side of the pump. Positive-displacement pumps are used for low flow and high-pressure applications.

Positive-displacement pumps sometimes do not pump the full displacement for which they are rated because of slippage. To allow a positive pump's rotors to rotate, small clearances must be maintained between the rotors and housing. The liquid that slips by will partially fill the inlet cavity. This amount of liquid must be repumped, preventing the pump from reaching its full rated capacity and decreasing its volumetric efficiency.

Positive-displacement pumps physically displace the fluid; therefore, shutting a valve downstream of a positive-displacement pump will result in a continual buildup in pressure resulting in severe damage to the pipeline or pump.

Positive-displacement pumps are further classified as fixed-displacement or variable-displacement. The fixed-displacement pump delivers the same amount of fluid on each cycle.

The variable-displacement pump is constructed so that the displacement per cycle can be varied. The displacement is varied through the use of an internal controlling device.

Pumps may also be classified according to the specific design used to create the flow of fluid. Practically all hydraulic pumps fall within three design classifications–centrifugal, rotary, and reciprocating. The use of centrifugal pumps in hydraulics is limited and will not be discussed in this text.

ROTARY PUMPS

All rotary pumps have rotating parts which trap the fluid at the inlet (suction) port and force it through the discharge port into the system. Gears, screws, lobes, and vanes are commonly used to move the fluid. Rotary pumps are positive-displacement of the fixed-displacement type. The rotary pump tree is illustrated in *Figure 4-3*.

Rotary pumps (*Figure 4-4 through Figure 4-7*) are designed with very small clearances between rotating parts and stationary parts to minimize slippage from the discharge side back to the suction side. These types of pumps are designed to operate at relatively moderate

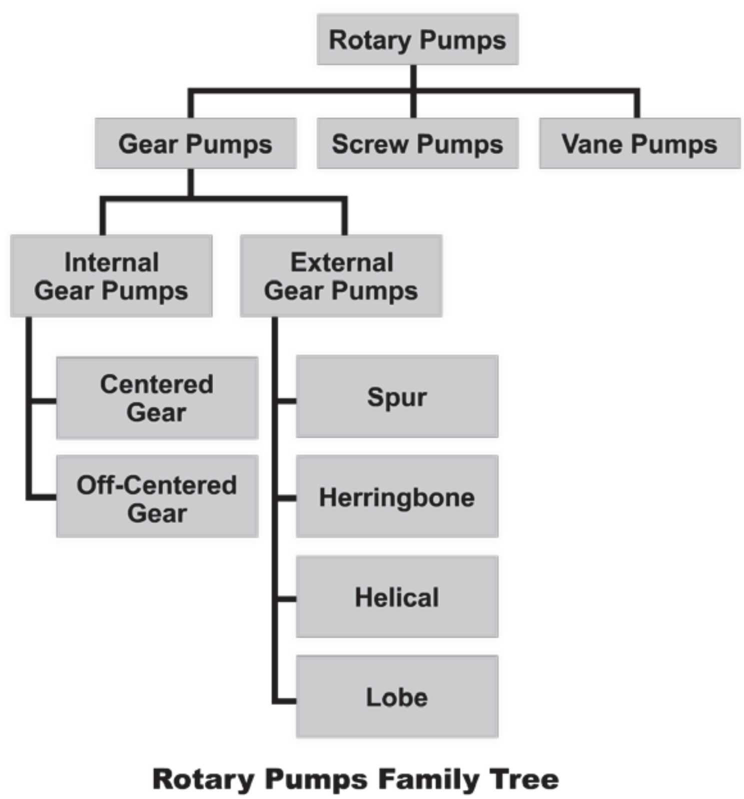


Figure 4-3 — Rotary pump tree.

speeds. Operating at high speeds causes erosion and excessive wear which results in increased clearances.

There are numerous types of rotary pumps and various methods of classification. They may be classified by the shaft position—either vertically or horizontally mounted; the type of drive—electric motor, gasoline engine, and so forth; their manufacturer's name; or their service application. However, classification of rotary pumps is generally made according to the type of rotating element. A few of the most common types of rotary pumps are discussed in the following paragraphs.

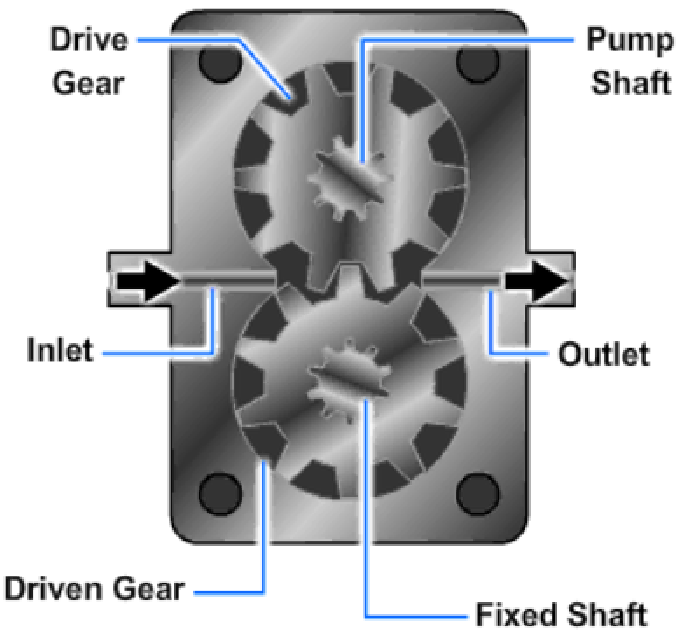


Figure 4-4 — Gear-driven hydraulic pump.

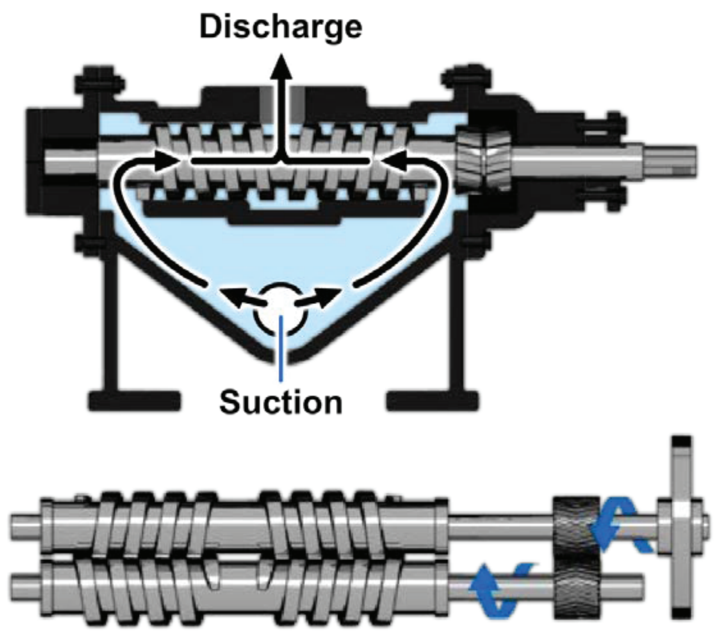


Figure 4-5 — Screw-driven hydraulic pump.

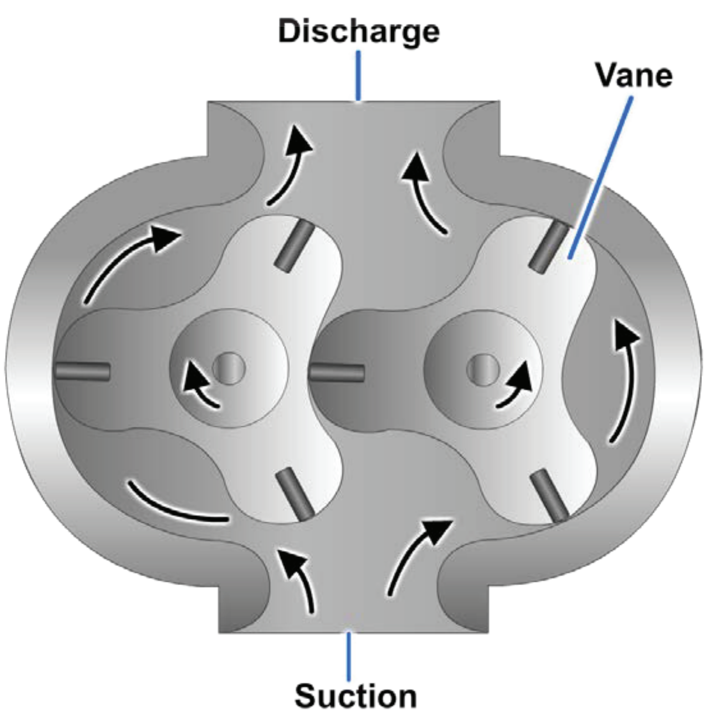


Figure 4-6 — Lobe-driven hydraulic pump.

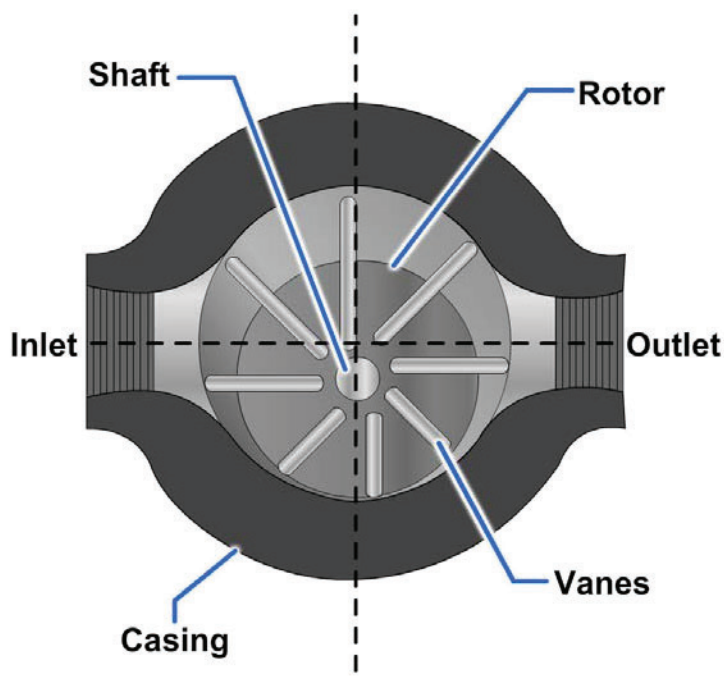


Figure 4-7 — Vane-driven hydraulic pump.

Internal Gear Pumps

Internal gear pumps deliver fluid between the gear teeth from the inlet to outlet ports. The outer gear (rotor) drives the inner or idler gear on a stationary pin. The gears create voids as they come out of mesh and fluid flows into the cavities. As the gears come back into mesh, the volume is reduced and the liquid is forced out of the discharge port. The crescent prevents liquid from flowing backwards from the outlet to the inlet port. Internal gear pumps may be either centered or off-centered. Internal gear pumps may be further divided into those with a crescent and those with no crescent.

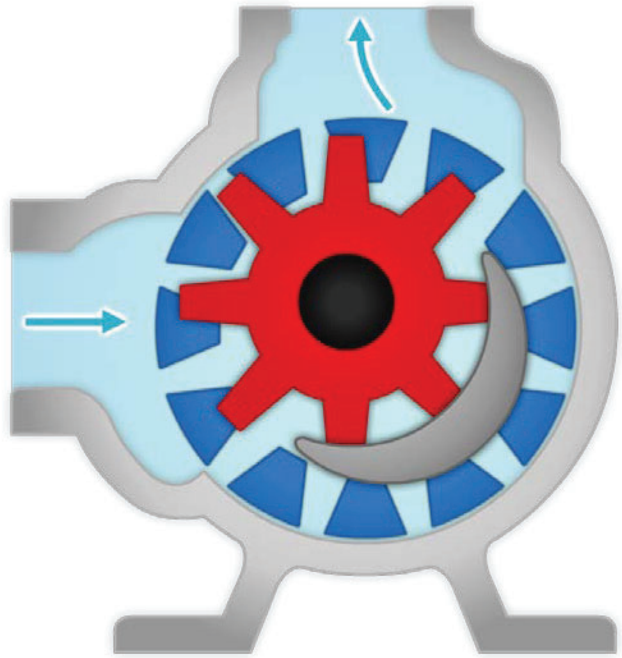


Figure 4-8 — Off-centered internal gear pump.

Off-Centered Internal Gear Pump

This pump is illustrated in *Figure 4-8*. The drive gear is attached directly to the drive shaft of the pump and is placed off-center in relation to the internal gear. The two gears mesh on one side of the pump, between the suction (inlet) and discharge ports. On the opposite side of the chamber, a crescent-shaped form fitted to a close tolerance fills the space between the two gears.

The rotation of the center gear by the drive shaft causes the outside gear to rotate, since the two are meshed. Everything in the chamber rotates except the crescent. This rotation causes liquid to be trapped in the gear spaces as they pass the crescent. The liquid is carried from the suction port to the discharge port where it is forced out of the pump by the meshing of the gears. The size of the crescent that separates the internal and external gears determines the volume delivery of the pump. A small crescent allows more volume of liquid per revolution than a larger crescent.

Internal Gear Pump with No Crescent

In contrast to the internal gear pump with a crescent, the internal gear pump without crescent consists of a gear within a gear. This pump consists of a pair of gear-shaped elements—one within the other—located in the pump chamber. The inner gear is connected to the drive shaft of the power source.

The operation of this type of internal gear pump is illustrated in *Figure 4-9*. The tooth design of each gear is related to that of the other in such a way that each tooth of the inner gear is always in sliding contact with the surface of the outer gear. Each tooth of the inner gear meshes with the outer gear at just one point during each revolution. As the gears continue to rotate in a clockwise direction, the inner gear teeth approach and mesh with the outer gear teeth. Note that the inner gear has one less tooth than the outer gear. As a result, the outer gear rotates at just six-sevenths the speed of the inner gear. For example, if the inner gear rotates at 1,400 revolutions per minute (rpm), the outer gear rotates at 1,200 rpm.

At one side of the point of mesh, pockets of increasing size are formed as the gears rotate; simultaneously, the pockets decrease in size on the other side. The pockets on the right-hand side of the drawings increase in size as you move down the illustration, while those on the left-hand side decrease in size. The motion of the gears draws fluid in on one side of the pump and pushes it out of the other side.

Internal Gear Pump Operation

The operation of this type of internal gear pump is illustrated in *Figure 4-10*. To simplify the explanation, the teeth of the inner gear and the spaces between the teeth of the outer gear are numbered. Note that the inner gear has one less tooth than the outer gear. The tooth form of each gear is related to that of the other in such a way that each tooth of the inner gear is always in sliding contact with the surface of the outer gear. Each tooth of the inner gear meshes with the outer gear at just one point during each revolution. In the illustration, this point is at the X. In *view A*, tooth 1 of the inner gear is meshed with space 1 of the outer gear. As the gears continue to rotate in a clockwise direction and the teeth approach point X, tooth 6 of the inner gear will mesh with space 7 of the outer gear, tooth 5 with space 6, and so on. During this revolution, tooth 1 will mesh with space 2; and during the following revolution, tooth 1 will mesh with space 3. As a result, the outer gear will rotate at just six-sevenths the speed of the inner gear.

At one side of the point of mesh, pockets of increasing size are formed as the gears rotate, while on the other side the pockets decrease in size. In *Figure 4-10*, the pockets on the right-hand side of the drawings are increasing in size toward the bottom of the illustration, while those on the left-hand side are decreasing in size toward the top of the illustration. The intake side of the pump would therefore be on the right and the discharge side on the left.

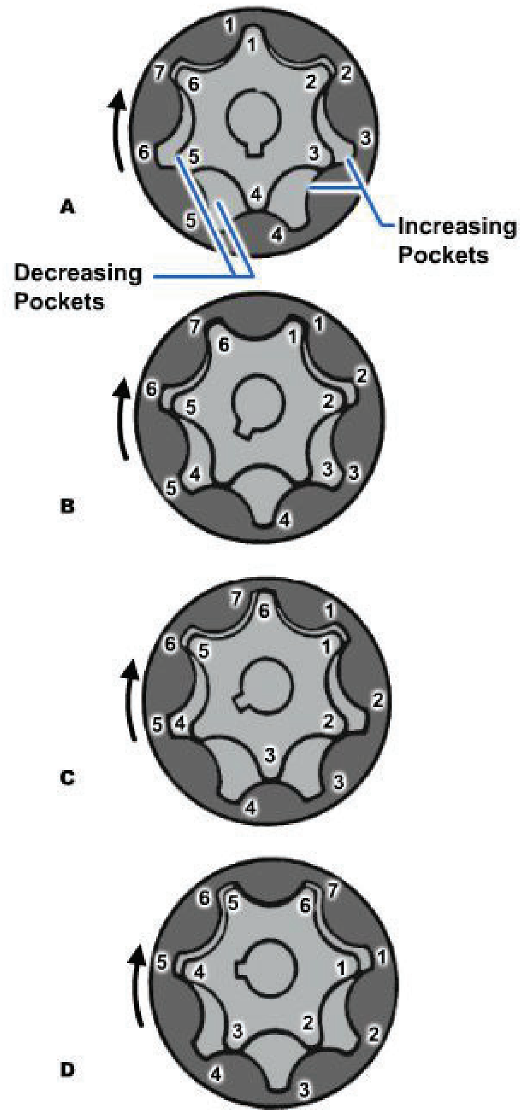


Figure 4-9 — Internal gear pump with no crescent.

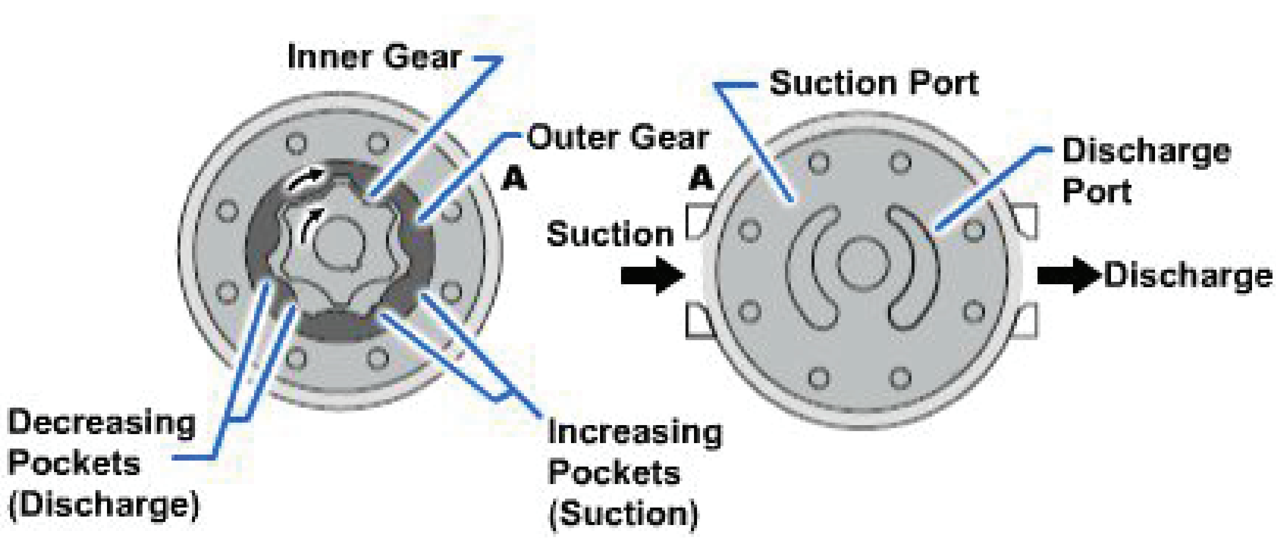


Figure 4-10 Internal gear pump operation.

External Gear Pumps

External gear pumps (*Figure 4-11*) are similar to internal gear pumps in that two gears come into and out of mesh to produce flow. In the external gear pump, one gear (drive gear) is driven by a motor and in turn drives the other gear (driven gear). As the gears mesh, the fluid, which is trapped in the gear teeth spaces between the housing and the outside of the gears, are transferred from the suction side of the pump to the discharge side. As the gears come out of mesh, they create expanding volume on the inlet side of the pump.

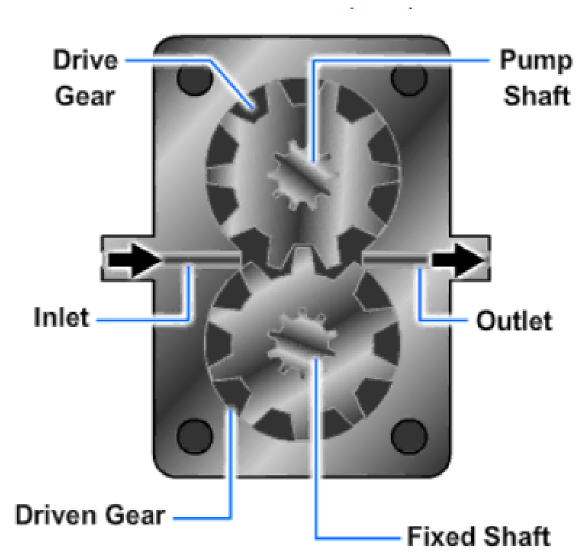


Figure 4-11 — Gear-type rotary pump.

Because the gears are supported on both sides, external gear pumps are quiet-running and are routinely used for high-pressure applications such as hydraulic applications. With no overhung bearing loads, the rotor shaft can't deflect and cause premature wear.

Spur Tooth Gear Pump

The spur gear pump (*Figure 4-12*) consists of two meshed gears which revolve in a housing. The drive gear in the illustration is turned by a drive shaft which is attached to the power source. The clearances between the gear teeth as they mesh and the pump housing are very small.

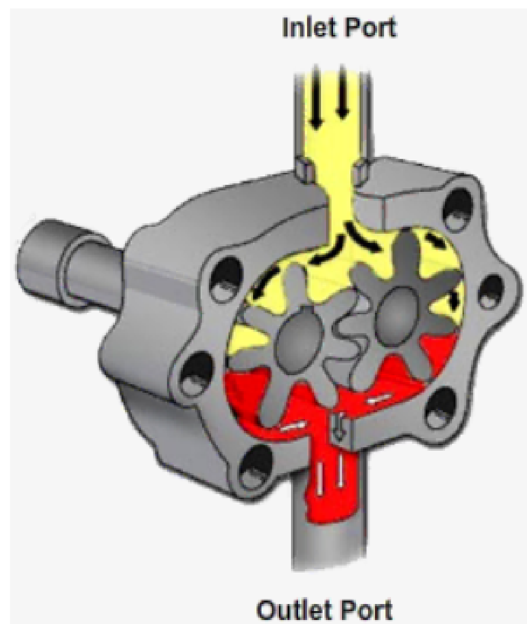


Figure 4-12 — Spur Tooth Gear pump.

Herringbone Gear Pump

The herringbone gear pump (*Figure 4-13*) is a modification of the spur gear pump. A herringbone gear is composed of two helixes spiraling in different directions from the center of the gear. The liquid is pumped in the same manner as in the spur gear pump; however, the herringbone pump has two sets of teeth (double helical) set in a V-shape. Each set of teeth begins its fluid discharge phase before the previous set of teeth has completed its discharge phase. This overlapping of teeth and the relatively larger space at the center of the gears tend to minimize pulsations and give a steadier flow than the spur gear pump.

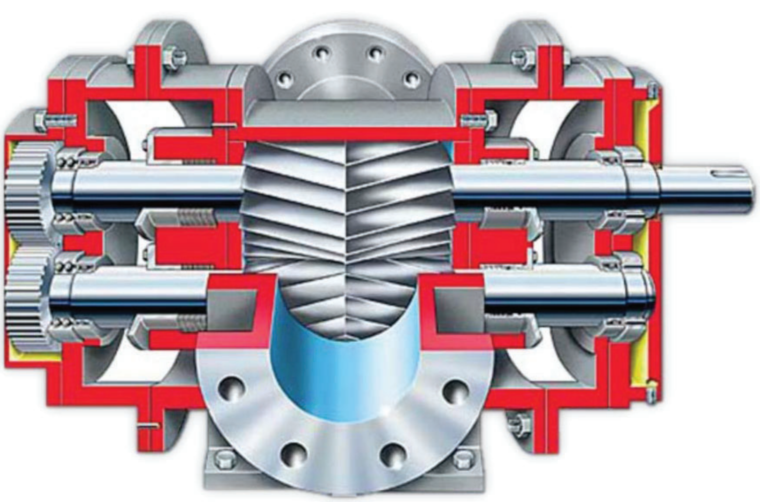


Figure 4-13 — Herringbone gear pump.

Helical Gear Pump

The helical gear pump (*Figure 4-14*) is another type of rotary pump. A helix is the curve produced when a straight line moves up or down the surface of a cylinder. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth produces a smooth discharge flow in the helical pump. In this type of pump, the gears can be designed with a small number of large teeth—thus allowing increased capacity without sacrificing smoothness of flow.

The pumping gears of this type of pump are driven by a set of timing and driving gears that help maintain the required close clearances without actual metallic contact of the pumping gears (metallic contact between the teeth of the pumping gears would provide a tighter seal against slippage; however, it would cause rapid wear of the teeth, because foreign matter in the liquid would be present on the contact surfaces).

Roller bearings at both ends of the gear shafts maintain proper alignment and minimize the friction loss in the transmission of power. Suitable packings are used to prevent leakage around the shaft.

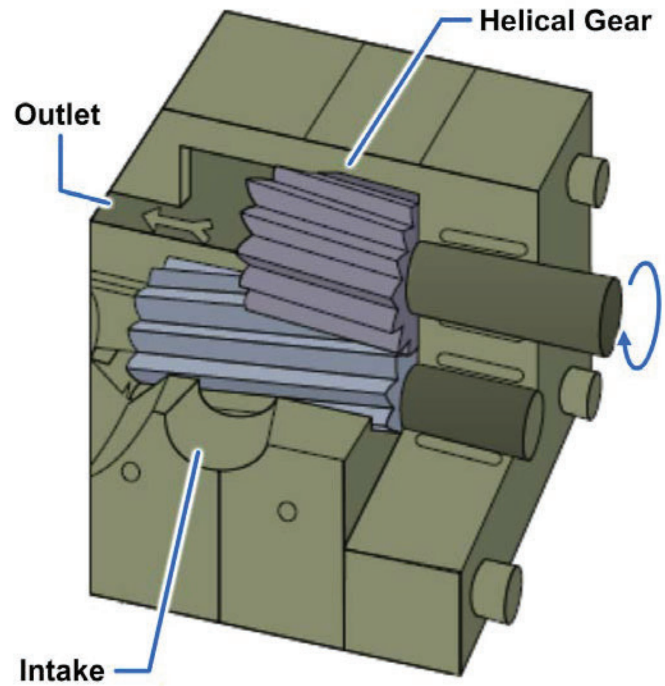


Figure 4-14 — Helical gear pump.

LOBE PUMP

The lobe pump uses the same principle of operation as the external gear pump described previously. The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. A three-lobe pump is illustrated in *Figure 4-15*. The two elements are rotated—one directly driven by the source of power and the other through timing gears. As the elements rotate, liquid is trapped between two lobes of each rotor and the walls of the pump chamber and carried around from the suction side to the discharge side of the pump. As liquid leaves the suction chamber, the pressure in the suction chamber is lowered and additional liquid is forced into the chamber from the reservoir.

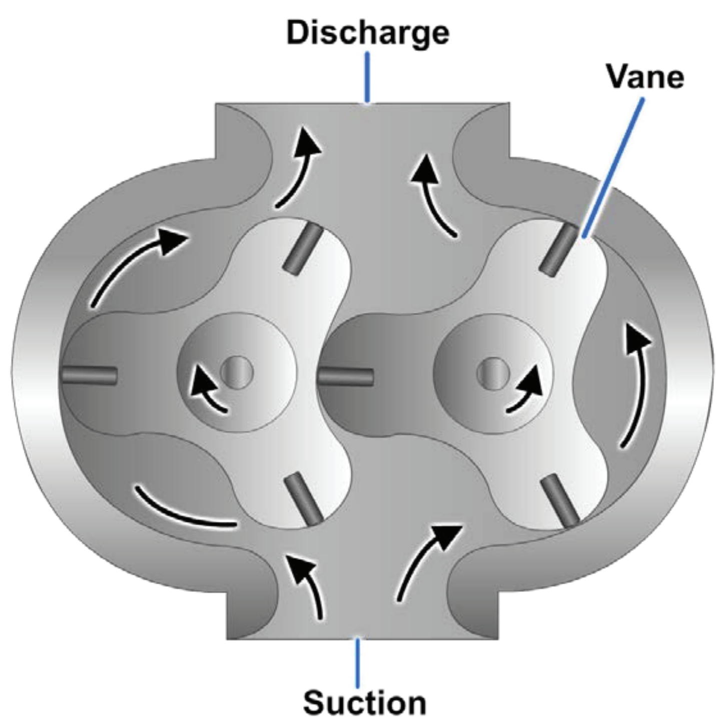


Figure 4-15 — Lobe pump.

The lobes are constructed so there is a continuous seal at the points where they meet at the center of the pump. The lobes of the pump illustrated in *Figure 4-15* are fitted with small vanes at the outer edge to improve the seal of the pump. Although these vanes are mechanically held in their slots, they are, to some extent, free to move outward. Centrifugal force keeps the vanes snug against the chamber and the other rotating members.

SCREW PUMP

Screw pumps are primarily used for pumping all viscous fluids such as JP-5 and diesel oil. Hydraulic systems on some ships use the screw pump as the pressure supply for the system. The pump may be either motor-driven or turbine-driven.

There are several types of screw pumps. The main points of difference between the various types are the number of intermeshing screws and the pitch of the screws. A positive-displacement, double-screw, low-pitch pump is illustrated in *Figure 4-16.* The two-screw, low-pitch screw pump has two rotors—one drive and one driven—and relies on the pumped fluid to fill the clearances between the rotor and rotors and liner. The pumped fluid seals the individual pumping chambers of the screw profiles, allowing the pump to maintain prime. One rotor has a right-handed thread, and the other rotor has a left-handed thread. One shaft is the driving shaft and drives the other shaft through a set of herringbone timing gears. Liquid is trapped at the outer end of each pair of screws. As the first space between the screw threads rotates away from the opposite screw, liquid is enclosed when the end of the screw again meshes with the opposite screw. The enclosures formed by the meshing of the rotors inside the close clearance housing contain the fluid being pumped. As the rotors turn, these enclosures move axially, providing a continuous flow. Effective performance is based on the following factors:

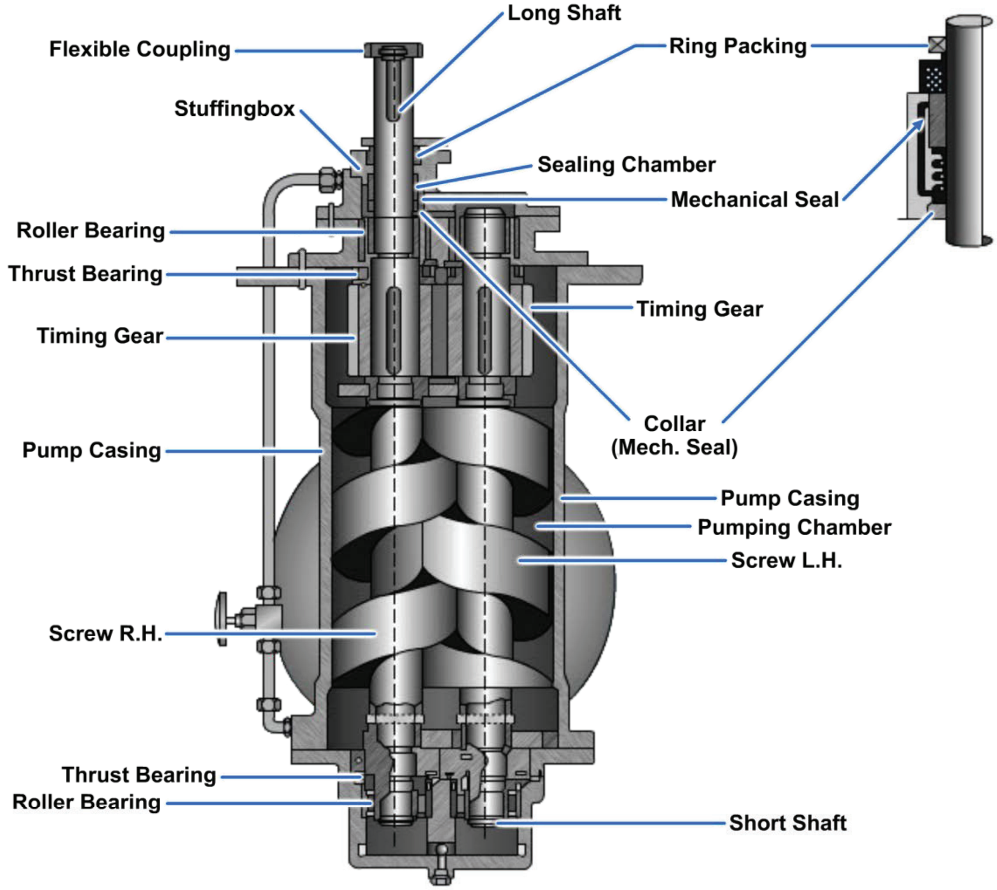


Figure 4-16 — Screw pumps.

- The rolling action obtained with the thread design of the rotors is responsible for the very quiet pump operation. The symmetrical pressure loading around the power rotor eliminates the need for radial bearings because there are no radial loads. The cartridge-type ball bearing in the pump positions the power rotor for proper seal operation. The axial loads on the rotors created by discharge pressure are hydraulically balanced.
- The key to screw pump performance is the operation of the idler rotors in their housing bores. The idler rotors generate a hydrodynamic film to support themselves in their bores like journal bearings. Since this film is self-generated, it depends on three operating characteristics of the pump—speed, discharge pressure, and fluid viscosity. The strength of the film is increased by increasing the operating speed, by decreasing pressure, or by increasing the fluid viscosity. This is why screw pump performance capabilities are based on pump speed, discharge pressure, and fluid viscosity.

Information on the operation may be obtained from the Engineering Operating Sequencing Systems (EOSS); Naval Ships' Technical Manual (NSTM), Chapter 503; and the manufacturers' manuals. Maintenance should be performed according to Planned Maintenance System (PMS) requirements.

VANE PUMP

Vane-type hydraulic pumps generally have a circular- or elliptical-shaped interior and flat end plates. *Figure 4-17* illustrates a vane pump with a circular interior. A slotted rotor is fixed to a shaft that enters the housing cavity through one of the end plates. A number of small rectangular plates or vanes are set into the slots of the rotor. As the rotor turns, centrifugal force causes the outer edge of each vane to slide along the surface of the housing cavity as the vanes slide in and out of the rotor slots. The numerous cavities, formed by the vanes, end plates, housing, and rotor, enlarge and shrink as the rotor and vane assembly rotates. An inlet port is installed in the housing so fluid may flow into the cavities as they enlarge. An outlet port is provided to allow the fluid to flow out of the cavities as they become small.

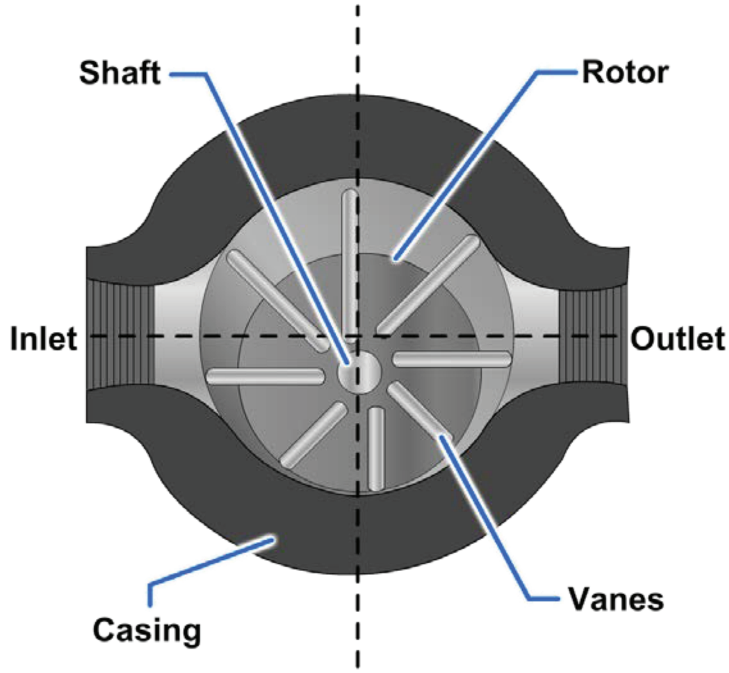


Figure 4-17 — Vane pump.

The pump shown in *Figure 4-17* is referred to as an unbalanced pump because all of the pumping action takes place on one side of the rotor. This causes a side load on the rotor. Some vane pumps are constructed with an elliptical-shaped housing that forms two separate pumping areas on opposite sides of the rotor. This cancels out the side loads; such pumps are referred to as balanced vane.

Usually vane pumps are fixed-displacement and pump in only one direction. There are, however, some designs of vane pumps that provide variable flow. Vane pumps are generally restricted to service where pressure demand does not exceed 2,000 pounds per square inch (psi). Wear rates, vibration, and noise levels increase rapidly in vane pumps as pressure demands exceed 2,000 psi.

RECIPROCATING PUMPS

The term reciprocating is defined as back-and-forth motion. In the reciprocating pump it is this back-and-forth motion of pistons inside of cylinders that provides the flow of fluid. Reciprocating pumps, like rotary pumps, operate on the positive principle—that is, each stroke delivers a definite volume of liquid to the system.

The master cylinder of the automobile brake system is an example of a simple reciprocating pump. Several types of power-operated hydraulic pumps, such as the radial piston and axial piston, are also classified as reciprocating pumps. These pumps are sometimes classified as rotary pumps, because a rotary motion is imparted to the pumps by the source of power. However, the actual pumping is performed by sets of pistons reciprocating inside sets of cylinders.

Hand Pumps

There are two types of manually operated reciprocating pumps—the single-action and the double-action. The single-action pump provides flow during every other stroke, while the double-action provides flow during each stroke. Single-action pumps are frequently used in hydraulic jacks.

A double-action hand pump is illustrated in *Figure 4-18*. This type of pump is used in some aircraft hydraulic systems as a source of hydraulic power for emergencies, for testing certain subsystems during preventive maintenance inspections, and for determining the causes of malfunctions in these subsystems.

This pump (*Figure 4-18*) consists of a cylinder, a piston containing a built-in check valve (A), a piston rod, an operating handle, and a check valve (B) at the inlet port. When the piston is moved to the left, the force of the liquid in the outlet chamber and spring tension cause valve A to shut. This movement causes the piston to force the liquid in the outlet chamber through the outlet port and into the system. This same piston movement causes a low-pressure area in the inlet chamber. The difference in pressure between the inlet chamber and the liquid (at atmospheric pressure) in the reservoir acting on check valve B causes its spring to compress; thus, opening the check valve. This allows liquid to enter the inlet chamber.

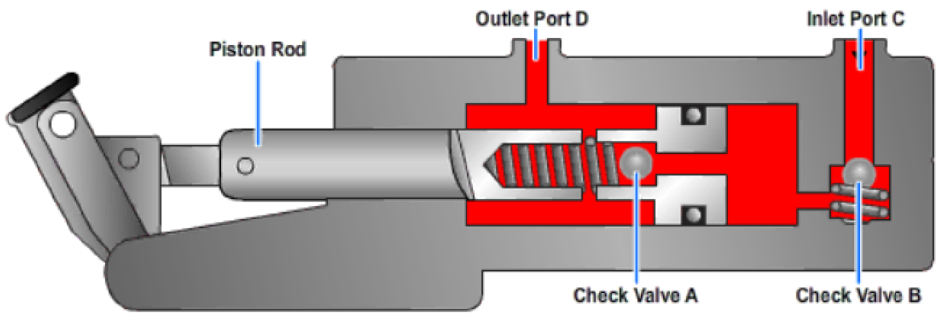


Figure 4-18 — Double-action hydraulic hand pump.

When the piston completes this stroke to the left, the inlet chamber is full of liquid. This eliminates the pressure difference between the inlet chamber and the reservoir, thereby allowing spring tension to shut check valve B.

When the piston is moved to the right, the force of the confined liquid in the inlet chamber acts on check valve A. This action compresses the spring and opens check valve A which allows the liquid to flow from the intake chamber to the outlet chamber. Because of the area occupied by the piston rod, the outlet chamber cannot contain all the liquid discharged from the inlet chamber. Since liquids do not compress, the extra liquid is forced out of the outlet port into the system.

Piston Pumps

Piston pumps are made in a variety of types and configurations. A basic distinction is made between axial and radial pumps. The axial piston pump has the cylinders parallel to each other and the drive shaft. The radial piston design has the cylinders extending radially outward from the drive shaft like the spokes of a wheel. A further distinction is made between pumps that provide a fixed delivery and those able to vary the flow of the fluid. Variable delivery pumps can be further divided into those able to pump fluid from zero to full delivery in one direction of flow and those able to pump from zero to full delivery in either direction.

All piston pumps used in Navy shipboard systems have the cylinders bored in a cylinder block that is mounted on bearings within a housing. This cylinder block assembly rotates with the pump drive shaft.

Radial Piston Pumps

A radial pump has the pistons arranged radially in a cylinder block. The pump consists of a stationary pintle inside a circular reaction ring or rotor. As the block rotates, centrifugal force, charging pressure, or some form of mechanical action causes the pistons to follow the inner surface of the ring, which is offset from the centerline of the cylinder block. A port in the pintle permits the pistons to take in fluid as they move outward and discharge it as they move in. Pump displacement is determined by the size and number of pistons (there may be more than one bank in a single cylinder block) and the length of their stroke. A slide block is used to control the length of the piston strokes. The slide block does not revolve but houses and supports the rotor, which does revolve due to the friction set up by the sliding action between the piston heads and the reaction ring. The cylinder block is attached to the drive shaft.

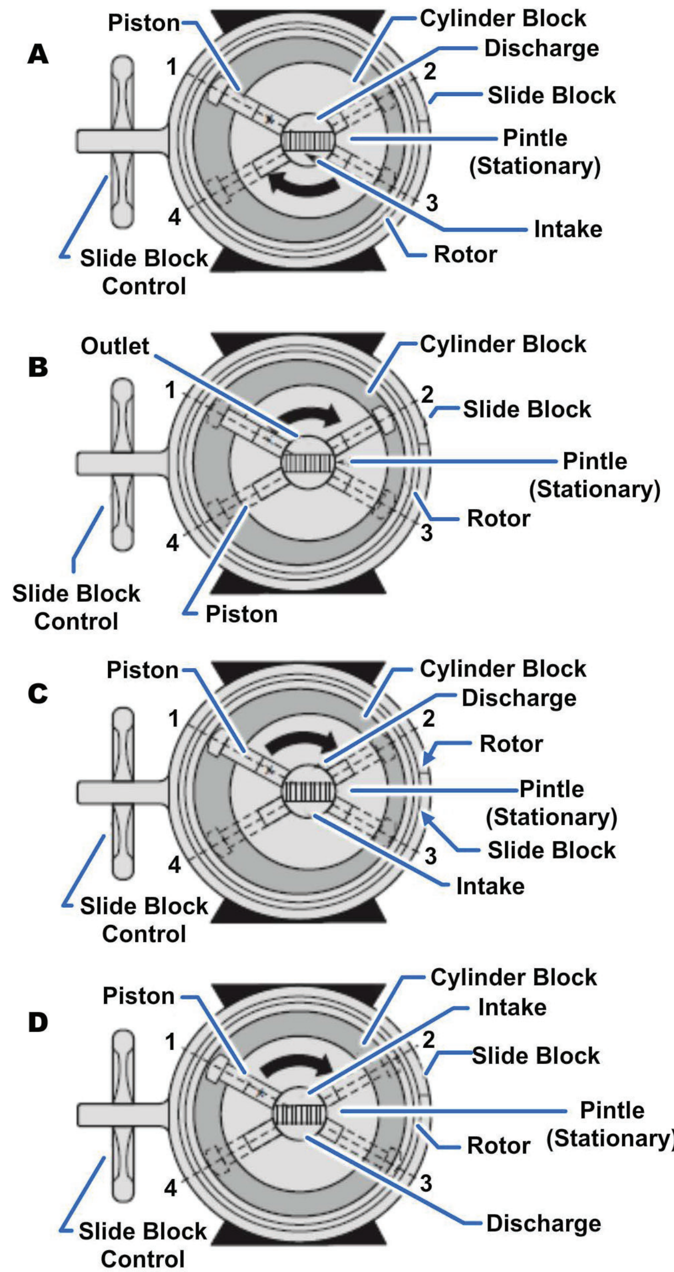


Figure 4-19 — Principles of operation of the radial piston pump.

Referring to *Figure 4-19, view B*, assume that space X in one of the cylinders of the cylinder block contains liquid and that the respective piston of this cylinder is at position 1. When the cylinder block and piston are rotated in a clockwise direction, the piston is forced into its cylinder as it approaches position 2. This action reduces the volumetric size of the cylinder and forces a quantity of liquid out of the cylinder and into the outlet port above the pintle. This pumping action is due to the rotor being off-center in relation to the center of the cylinder block.

In *Figure 4-19, view B*, the piston has reached position 2 and has forced the liquid out of the open end of the cylinder through the outlet above the pintle and into the system. While the piston moves from position 2 to position 3, the open end of the cylinder passes over the solid part of the pintle; therefore, there is no intake or discharge of liquid during this time. As the piston and cylinder move from position 3 to position 4, centrifugal force causes the piston to move outward against the reaction ring of the rotor. During this time, the open end of the cylinder is open to the intake side of the pintle and, therefore, fills with liquid. As the piston moves from position 4 to position 1, the open end of the cylinder is against the solid side of the pintle and no intake or discharge of liquid takes place. After the piston has passed the pintle and starts toward position 2, another discharge of liquid takes place. Alternate intake and discharge continues as the rotor revolves about its axis-intake on one side of the pintle and discharge on the other, as the piston slides in and out.

Notice in *Figure 4-19, view A and view B,* the center point of the rotor is different from the center point of the cylinder block. The difference of these centers produces the pumping action. If the rotor is moved so that its center point is the same as that of the cylinder block, as shown in *Figure 4-11*, *view*

C, there is no pumping action, since the piston does not move back and forth in the cylinder as it rotates with the cylinder block.

The flow in this pump can be reversed by moving the slide block—and therefore the rotor—to the right so the relation of the centers of the rotor and the cylinder block is reversed from the position shown in *Figure 4-19, views A and B.* Liquid enters the cylinder as the piston travels from position 1 to position 2 and is discharged from the cylinder as the piston travels from position 3 to 4.

In the illustrations the rotor is shown in the center, on the extreme right, or the extreme left in relation to the cylinder block. The amount of adjustment in distance between the two centers determines the length of the piston stroke, which controls the amount of liquid flow in and out of the cylinder. Thus, this adjustment determines the displacement of the pump; that is, the volume of liquid the pump delivers per revolution. This adjustment may be controlled in different ways. Manual control by a handwheel is the simplest. The pump illustrated in *Figure 4-19* is controlled in this way. For automatic control of delivery to accommodate varying volume requirements during the operating cycle, a hydraulically controlled cylinder may be used to position the slide block. A gear-motor controlled by a push button or a limit switch is sometimes used for this purpose. Four pistons are shown in *Figure 4-19* for the sake of simplicity.

Radial pumps are actually designed with an odd number of pistons (*Figure 4-20*). This is to ensure that no more than one cylinder is completely blocked by the pintle at any one time. If there were an even number of pistons spaced evenly around the cylinder block (for example, eight), there would be occasions when two of the cylinders would be blocked by the pintle, while at other times none would be blocked. This would cause three cylinders to discharge at one time and four at one time, causing pulsations in flow. With an odd number of pistons spaced evenly around the cylinder block, only one cylinder is completely blocked by the pintle at any one time. This reduces pulsations of flow.

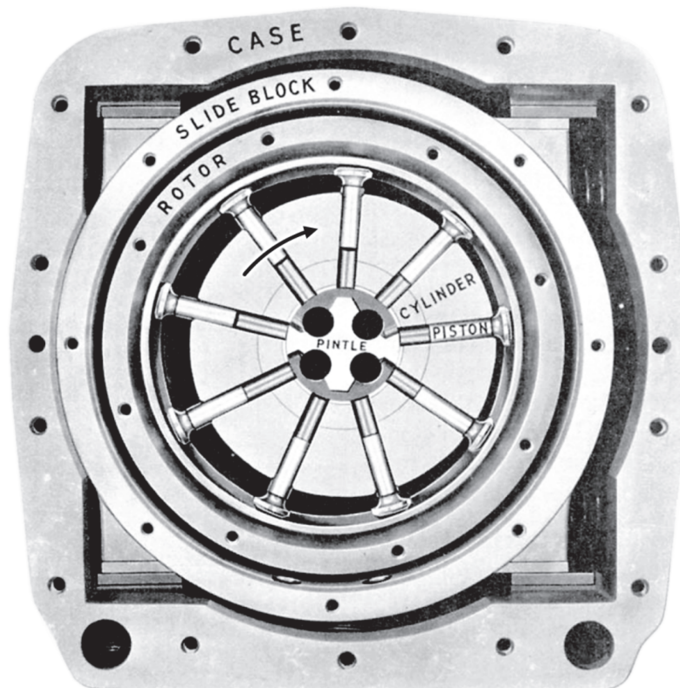


Figure 4-20 — Nine-piston radial piston pump.

Axial Piston Pumps

The variable stroke axial-piston pump usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. An uneven number of pistons are always used in order to avoid pulsations in the discharge flow. (Note that the term "cylinder barrel," as used here, actually refers to a cylinder block which holds all the cylinders.) 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; therefore, no pumping takes place. When the box is tilted away from a right angle, however, the pistons reciprocate and the liquid is pumped.

The variable stroke axial-piston pump is often used as a part of a variable speed gear such as electrohydraulic anchor windlasses, cranes, winches, and the power transmitting unit in electrohydraulic steering engines. In those cases, the tilting box is so arranged 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-line Axial-Piston Pump

In axial piston pumps of the in-line type where the cylinders and the drive shaft are parallel *(Figure 4-21)*, the reciprocating motion is created by a cam plate, also known as wobble plate, tilting plate, or swash plate. This plate lies in a plane that cuts across the center line of the drive shaft and cylinder barrel and does not rotate. In a fixed-displacement pump, the cam plate will be rigidly mounted in a position so that it intersects the center line of the cylinder barrel at an angle approximately 25 degrees from perpendicular. Variable delivery axial piston pumps are designed so the angle the cam plate makes is perpendicular to the center line of the cylinder barrel and may be varied from zero to 20 or 25 degrees to one or both sides. One end of each piston rod is held in contact with the cam plate as the cylinder block and piston assembly rotates with the drive shaft. This causes the pistons to reciprocate within the cylinders. The length of the piston stroke is proportional to the angle that the cam plate is set from perpendicular to the center line of the cylinder barrel.

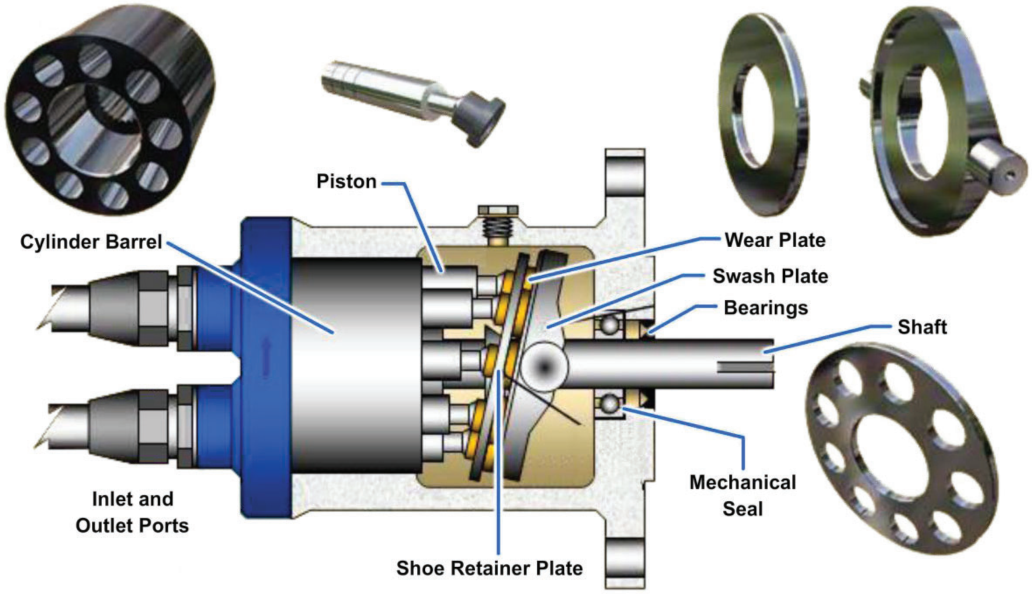


Figure 4-21 — Axial piston pump.

Bent Axis Piston Pump

A variation of the axial piston pump is the bent-axis type shown in *Figure 4-22*. This type does not have a tilting cam plate as the in-line pump. Instead, the cylinder block axis is varied from the drive shaft axis. The ends of the connecting rods are retained in sockets on a disc that turn with the drive shaft. The cylinder block is turned with the drive shaft by a universal joint assembly at the intersection of the drive shaft and the cylinder block shaft. In order to vary the pump displacement, the cylinder block and valve plate are mounted in a yoke and the entire assembly is swung in an area around a pair of mounting pintles attached to the pump housing.

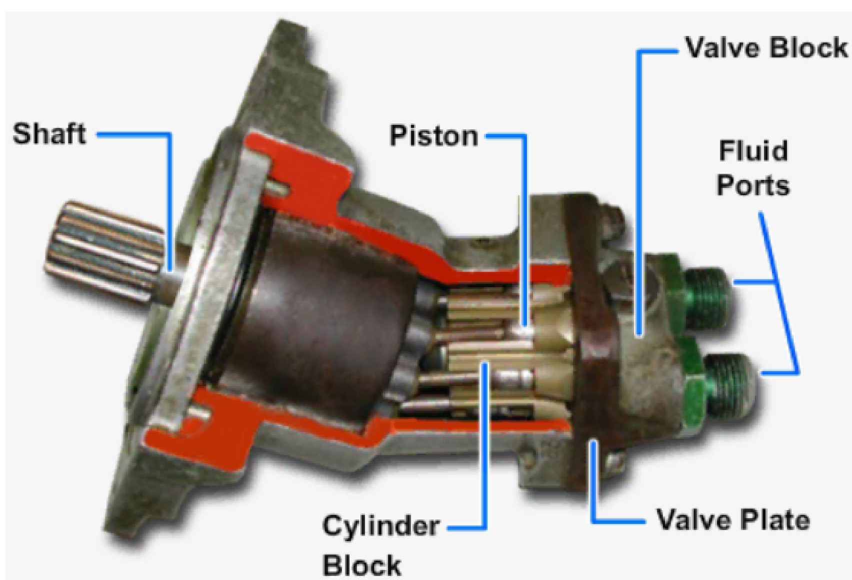


Figure 4-22 — Bent-axis axial piston pump.

The bent axis piston pump is capable of operating at variable conditions of flow, pressure, speed, and torque. The major elements of bent axis piston pump are pistons, connecting rods, universal joint, flanges, input shaft, output shaft, bearings, and motor.

Bent axis piston pumps tend to be slightly more volumetrically efficient. One end of each piston is held in contact with the cam plate as the cylinder block and piston assembly rotates with the drive shaft. This causes the pistons to reciprocate within the cylinders. The length of the piston stroke is proportional to the angle that the cam plate makes with the pump center line. Another characteristic of a piston-type pump is that the displacement can be changed simply by changing the angle of the swash plate. Any displacement between zero and maximum is achieved with simple actuators to change the swash plate angle. The displacement-varying mechanism and power-to-weight ratio of the variable displacement piston pump makes them most suitable for control of high power levels.

First, a rocker arm is installed on a horizontal shaft (*Figure 4-23, view A*). The arm is joined to the shaft by a pin so that it can be swung back and forth, as indicated in *Figure 4-23, view B*. Next, a ring is placed around the shaft and secured to the rocker arm so the ring can turn from left to right as shown in *Figure 4-23, view C*. This provides two rotary motions in different planes at the same time and in varying proportions as may be desired. The rocker arm can swing back and forth in one arc, and the ring can simultaneously move from left to right in another arc, in a plane at right angles to the plane in which the rocker arm turns.

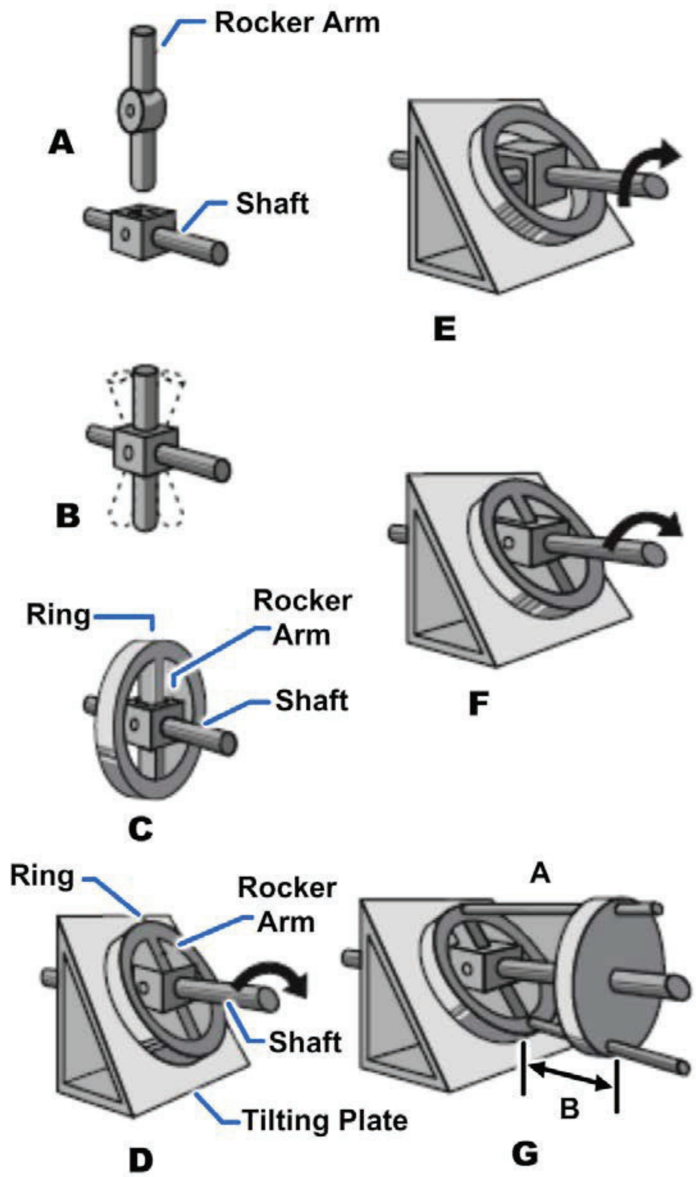


Figure 4-23 — Relationship of the universal joint in operation of the axial piston pump.

Next, a tilting plate is added to the assembly. The tilting plate is placed at a slant to the axis of the shaft, as depicted in *Figure 4-23, view D*. The rocker arm is then slanted at the same angle as the tilting plate, so that it lies parallel to the tilting plate. The ring is also parallel to, and in contact with, the tilting plate. The position of the ring in relation to the rocker arm is unchanged from that shown in *Figure 4-23, view C*.

Figure 4-23, view E, shows the assembly after the shaft—still in a horizontal position—has been rotated a quarter turn. The rocker arm is still in the same position as the tilting plate and is now perpendicular to the axis of the shaft. The ring has turned on the rocker pins, so that it has changed its position in relation to the rocker arm, but it remains parallel to—and in contact with—the tilting plate.

Figure 4-23, view F, shows the assembly after the shaft has been rotated another quarter turn. The parts are now in the same position as shown in *Figure 4-23, view D*, but with the ends of the rocker arm reversed. The ring still bears against the tilting plate.

As the shaft continues to rotate, the rocker arm and the ring turn about their pivots, with each changing its relation to the other and with the ring always bearing on the plate.

Figure 4-23, view G, shows a wheel added to the assembly. The wheel is placed upright and fixed to the shaft, so that it rotates with the shaft. In addition, two rods (A and B) are loosely connected to the tilting ring and extend through two holes standing opposite each other in the fixed wheel. As the shaft is rotated, the fixed wheel turns perpendicular to the shaft at all times. The tilting ring rotates with the shaft and always remains tilted, since it remains in contact with the tilting plate. Referring to *Figure 4-23, view G*, the distance along rod A from the tilting ring to the fixed wheel, is greater than the distance along rod B. As the assembly is rotated, however, the distance along rod A decreases as its point of attachment to the tilting ring moves closer to the fixed wheel, while the distance along rod B increases. These changes continue until after a half revolution, at which time the initial positions of the rods have been reversed. After another half revolution, the two rods will again be in their original positions.

As the assembly rotates, the rods move in and out through the holes in the fixed wheel. This is the way the axial piston pump works. To get a pumping action, pistons are placed at the ends of the rods beyond the fixed wheel, and inserted into cylinders. The rods must be connected to the pistons and to the wheel by ball and socket joints. As the assembly rotates, each piston moves back and forth in its cylinder. Suction and discharge lines can be arranged so that liquid enters the cylinders while the spaces between the piston heads and the bases of the cylinders are increasing, and leaves the cylinders during the other half of each revolution when the pistons are moving in the opposite direction.

The main parts of the pump are the drive shaft, pistons, cylinder block, and valve and swash plates. There are two ports in the valve plate. These ports connect directly to openings in the face of the cylinder block. Fluid is drawn into one port and forced out the other port by the reciprocating action of the pistons.

Stratopower Pump

Another type of axial piston pump, sometimes referred to as an in-line pump, is commonly referred to as a Stratopower pump. This pump is available in either the fixed-displacement type or the variable-displacement type.

Two major functions are performed by the internal parts of the fixed-displacement Stratopower pump. These functions are mechanical drive and fluid displacement.

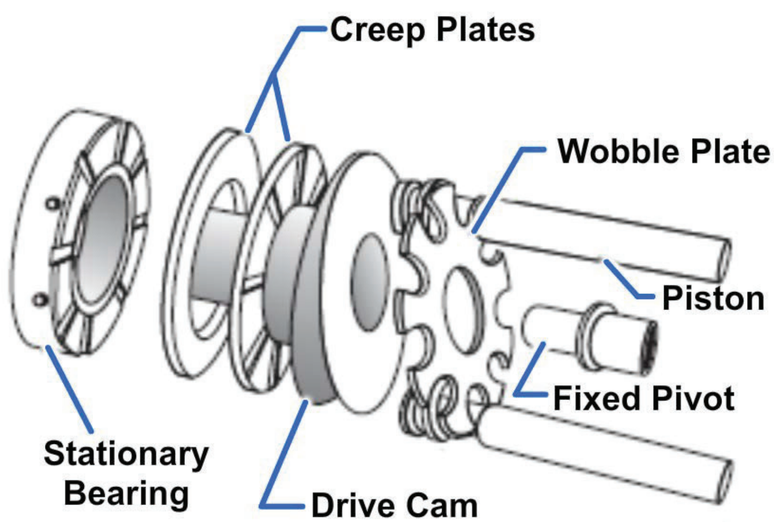


Figure 4-24 — Mechanical drive-Stratopower pump.

The mechanical drive mechanism is shown in *Figure 4-24*. In this type of pump, the pistons and block do not rotate. Piston motion is caused by rotating the drive cam, displacing each piston the full height of the drive cam during each revolution of the shaft. The ends of the pistons are attached to a wobble plate supported by a freed center pivot and are held in constant contact with the cam face. As the high side of the rotating drive cam depresses one side of the wobble plate, the other side of the wobble plate is withdrawn an equal amount, moving the pistons with it. The two creep plates are provided to decrease wear on the revolving cam.

A schematic diagram of the displacement of fluid is shown in *Figure 4-25*. Fluid is displaced by axial motion of the pistons. As each piston advances in its respective cylinder block bore, pressure opens the check valve and a quantity of fluid is forced past it. Combined back pressure and check valve spring tension shut the check valve when the piston advances to its foremost position. The low-pressure area occurring in the cylinder during the piston return causes fluid to flow from the reservoir into the cylinder.

The internal features of the variable-displacement Stratopower pump are illustrated in *Figure 4-26*. This pump operates similarly to the fixed-displacement Stratopower pump; however, this pump provides the additional function of automatically varying the volume output.

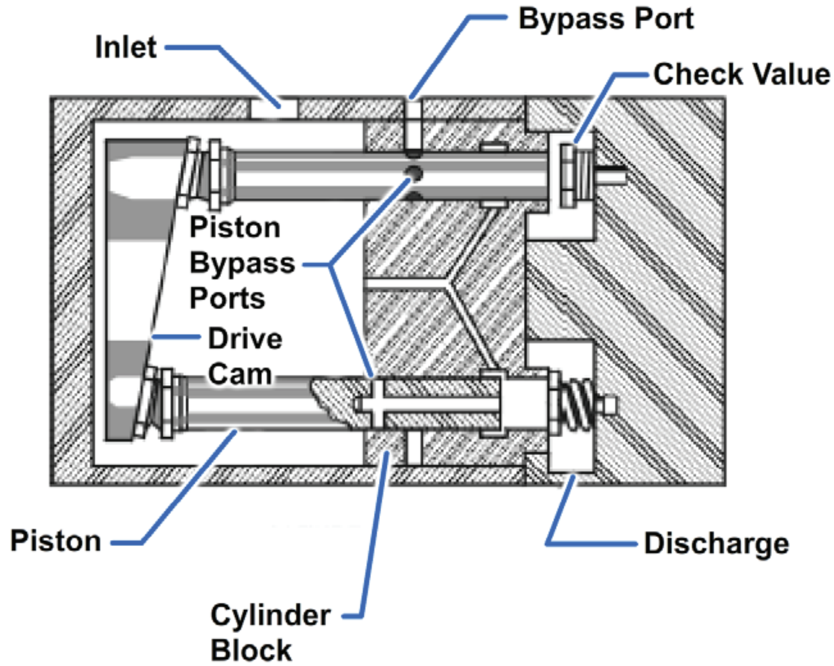


Figure 4-25 — Fluid displacement—Stratopower pump.

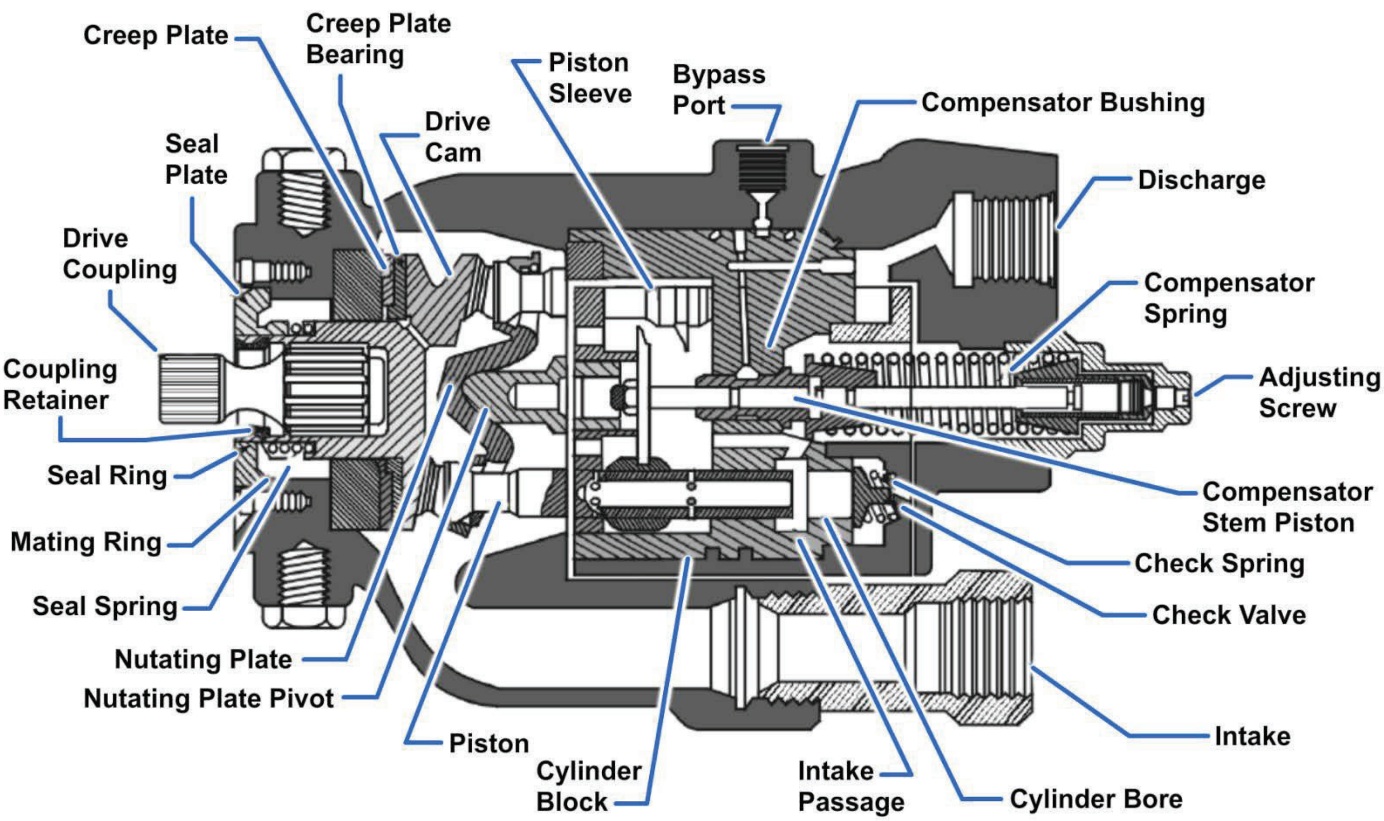


Figure 4-26 — Internal features of Stratopower variable-displacement pump.

This function is controlled by the pressure in the hydraulic system. For example, a pump rated at 3,000 psi provides flow to a 3,000 psi system. As system pressure approaches 2,850 psi, the pump begins to unload (delivering less flow to the system) and is fully unloaded (zero flow) at 3,000 psi.

The pressure regulation and flow are controlled by internal bypasses that automatically adjust fluid delivery to system demands.

The bypass system is provided to supply self-lubrication, particularly when the pump is in nonflow operation. The ring of bypass holes in the pistons are aligned with the bypass passage each time a piston reaches the very end of its forward travel. This pumps a small quantity of fluid out of the bypass passage back to the supply reservoir and provides a constant change of fluid in the pump. The bypass is designed to pump against a considerable back pressure for use with pressurized reservoirs.

EDUCTORS

Eductors (*Figure 4-27*) are designed to pump large volumes of water. In modern ships, 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 fire main, and water from the fire main is used to actuate 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.

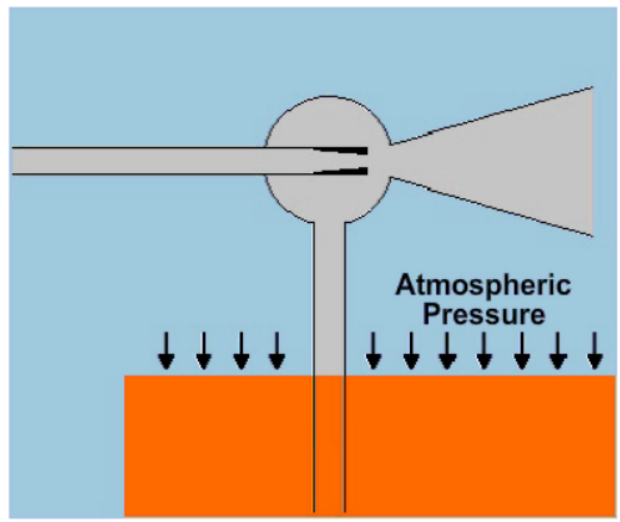


Figure 4-27 — Eductor.

⚠ CAUTION ⚠

Improper lighting off and securing of an eductor can cause rapid flooding of the space being pumped. Always follow the proper procedure!

CHAPTER 5

FLUID LINES AND FITTINGS

The control and application of fluid power would be impossible without suitable means of transferring the fluid between the reservoir, the power source, and the points of application. Fluid lines are used to transfer the fluid, and fittings are used to connect the lines to the power source and the points of application.

LEARNING OBJECTIVES

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

1. Identify the basic requirements for fluid power system lines.
2. Recognize pertinent facts concerning identification, and sizing of pipe and tubing.
3. Recognize the uses and construction features of pipe and tubing.
4. Recognize the characteristics, uses, and construction features of flexible hose.
5. Identify the installation procedures for flexible hose.
6. Recognize the uses and construction features of fluid power system connectors.
7. Identify the operational characteristics and functions of fluid power system and connectors.
8. Recognize the precautionary measures associated with fluid power system connectors.

TYPES OF LINES

The three types of lines used in fluid power systems are pipe (rigid), tubing (semirigid), and hose (flexible). A number of factors are considered when the type of line is selected for a particular fluid system. These factors include the type of fluid, the required system pressure, and the location of the system. For example, heavy pipe might be used for a large stationary fluid power system, but comparatively lightweight tubing must be used in aircraft and missile systems because weight and space are critical factors. Flexible hose is required in installations where units must be free to move relative to each other.

PIPES AND TUBING

There are three important dimensions of any tubular product—outside diameter (OD), inside diameter (ID), and wall thickness. Sizes of pipe are listed by the nominal (or approximate) ID and the wall thickness. Sizes of tubing are listed by the actual OD and the wall thickness.

Selection of Pipes and Tubing

The material, ID, and wall thickness are the three primary considerations in the selection of lines for a particular fluid power system.

The ID of a line is important, since it determines how much fluid can pass through the line in a given time period (rate of flow) without loss of power due to excessive friction and heat. The velocity of a given flow is less through a large opening than through a small opening. If the ID of the line is too small for the amount of flow, excessive turbulence and friction heat cause unnecessary power loss and overheated fluid.

Sizing of Pipes and Tubing

Pipes are available in three different weights: standard (STD) or Schedule 40, extra strong (XS) or Schedule 80, and double extra strong (XXS). The schedule numbers range from 10 to 160 and cover 10 distinct sets of wall thickness (*Table 5-1*). Schedule 160 wall thickness is slightly thinner than double extra strong.

Table 5-1 — Wall thickness schedule designations for pipe

NOMINAL SIZE	PIPE OD	INSIDE DIAMETER									
		SCHED. 10	SCHED. 20	SCHED. 30	SCHED. 40	SCHED. 60	SCHED. 80	SCHED. 100	SCHED. 120	SCHED. 140	SCHED. 160
1/8	.405				.269		.215				
1/4	.540				.364		.302				
3/8	.675				.493		.423				
1/2	.840				.622		.546				.466
3/4	1.050				.824		.742				.614
1	1.315				1.049		.957				.815
1 1/4	1.660				1.380		1.278				1.160
1 1/2	1.900				1.610		1.500				1.388
2	2.375				2.067		1.939				1.689

As mentioned earlier, the size of pipes is determined by the nominal (approximate) ID. For example, the ID for a 1/4-inch Schedule 40 pipe is 0.364 inch, and the ID for a 1/2-inch Schedule 40 pipe is 0.622 inch.

It is important to note that the IDs of all pipes of the same nominal size are not equal. This difference is because the OD remains constant and the wall thickness increases as the schedule number increases. For example, a nominal size 1-inch Schedule 40 pipe has a 1.049 ID. The same size Schedule 80 pipe has a 0.957 ID, while Schedule 160 pipe has a 0.815 ID. In each case the OD is 1.315 (*Table 5-1*) and the wall thicknesses are 0.133 ($\frac{\mathbf{1.315}-\mathbf{1.049}}{2}$), 0.179 ($\frac{\mathbf{1.315}-9.\mathbf{957}}{2}$), and 0.250 ($\frac{\mathbf{1.315-0.815}}{\mathbf{2}}$) respectively. Note that the difference between the OD and ID includes two wall thicknesses and must be divided by 2 to obtain the wall thickness.

Tubing differs from pipe in its size classification. Tubing is designated by its actual OD (*Table 5-2*). Thus, 5/8-inch tubing has an OD of 5/8 inch. As indicated in the table, tubing is available in a variety of wall thicknesses. The diameter of tubing is often measured and indicated in 16ths of an inch. Thus, No. 6 tubing is 6/16 or 3/8 inch, No. 8 tubing is 8/16 or 1/2 inch, and so forth.

The wall thickness, material used, and ID determine the bursting pressure of a line or fitting. The greater the wall thickness in relation to the ID and the stronger the metal, the higher the bursting pressure. However, the greater the ID for a given wall thickness, the lower the bursting pressure, because force is the product of area and pressure.

Materials

The pipe and tubing used in fluid power systems are commonly made from steel, copper, brass, aluminum, and stainless steel. Each of these metals has its own distinct advantages or disadvantages in certain applications.

Steel pipe and tubing are relatively inexpensive and are used in many hydraulic and pneumatic systems. Steel is used because of its strength, suitability for bending and flanging, and adaptability to high pressures and temperatures. Its chief disadvantage is its comparatively low resistance to corrosion.

Copper pipe and tubing are sometimes used for fluid power lines. Copper has high resistance to corrosion and is easily drawn or bent. However, it is unsatisfactory for high temperatures and has a tendency to harden and break due to stress and vibration.

Aluminum has many of the characteristics and qualities required for fluid power lines. It has high resistance to corrosion and is easily drawn or bent. In addition, it has the outstanding characteristic of light weight. Since weight elimination is a vital factor in the design of aircraft, aluminum alloy tubing is used in the majority of aircraft fluid power systems.

Stainless steel tubing is used in certain areas of many aircraft fluid power systems. As a general rule, exposed lines and lines subject to abrasion or intense heat are made of stainless steel.

An improperly piped system can lead to serious power loss and possible harmful fluid contamination. Therefore, in maintenance and repair of fluid power system lines, the basic design requirements must be kept in mind. Two primary requirements are as follows:

Table 5-2 — Tubing size designation

TUBE OD	WALL THICKNESS	TUBE ID
1/8	.028 .032 .035	.069 .061 .055
3/16	.32 .035	.1235 .1175
1/4	.035 .042 .049 .058 .065	.180 .166 .152 .134 .120
5/16	.035 .042 .049 .058 .065	.2425 .2285 .2145 .1965 .1825
3/8	.035 .042 .049 .058 .065	.305 .291 .277 .259 .245
1/2	.035 .042 .049 .058 .065 .072 .083 .095	.430 .416 .402 .384 .370 .358 .334 .310

TUBE OD	WALL THICKNESS	TUBE ID
5/8	.035	.555
	.042	.541
	.049	.527
	.058	.509
	.065	.495
	.072	.481
	.083	.459
	.095	.435
3/4	.049	.652
	.058	.634
	.065	.620
	.072	.606
	.083	.584
	.095	.560
	.109	.532
7/8	.049	.777
	.058	.759
	.065	.745
	.072	.731
	.083	.709
	.095	.685
	.109	.657
1	.049	.902
	.058	.884
	.065	.870
	.072	.856
	.083	.834
	.095	.810
	.109	.782
	.120	.760
1 1/4	.049	1.152
	.058	1.134
	.065	1.120
	.072	1.106
	.083	1.084
	.095	1.060
	.109	1.032
	.120	1.010
1 1/2	.065	1.370
	.072	1.356
	.083	1.334
	.095	1.310
	.109	1.282
	.120	1.260
	.134	1.232

TUBE OD	WALL THICKNESS	TUBE ID
1 3/4	.065	1.620
	.072	1.606
	.083	1.584
	.095	1.560
	.109	1.532
	.120	1.510
	.134	1.482
2	.065	1.870
	.072	1.856
	.083	1.834
	.095	1.810
	.109	1.782
	.120	1.760
	.134	1.732

1. The lines must have the correct ID to provide the required volume and velocity of flow with the least amount of turbulence during all demands on the system.
2. The lines must be made of the proper material and have the wall thickness to provide sufficient strength to both contain the fluid at the required pressure and withstand the surges of pressure that may develop in the system.

Preparation of Pipes and Tubing

Fluid power systems are designed as compactly as possible, to keep the connecting lines short. Every section of line should be anchored securely in one or more places so that neither the weight of the line nor the effects of vibration are carried on the joints. The aim is to minimize stress throughout the system.

Lines should normally be kept as short and free of bends as possible. However, tubing should not be assembled in a straight line, because a bend tends to eliminate strain by absorbing vibration and also compensates for thermal expansion and contraction. Bends are preferred to elbows, because bends cause less of a power loss. A few of the correct and incorrect methods of installing tubing are illustrated in *Figure 5-1*.

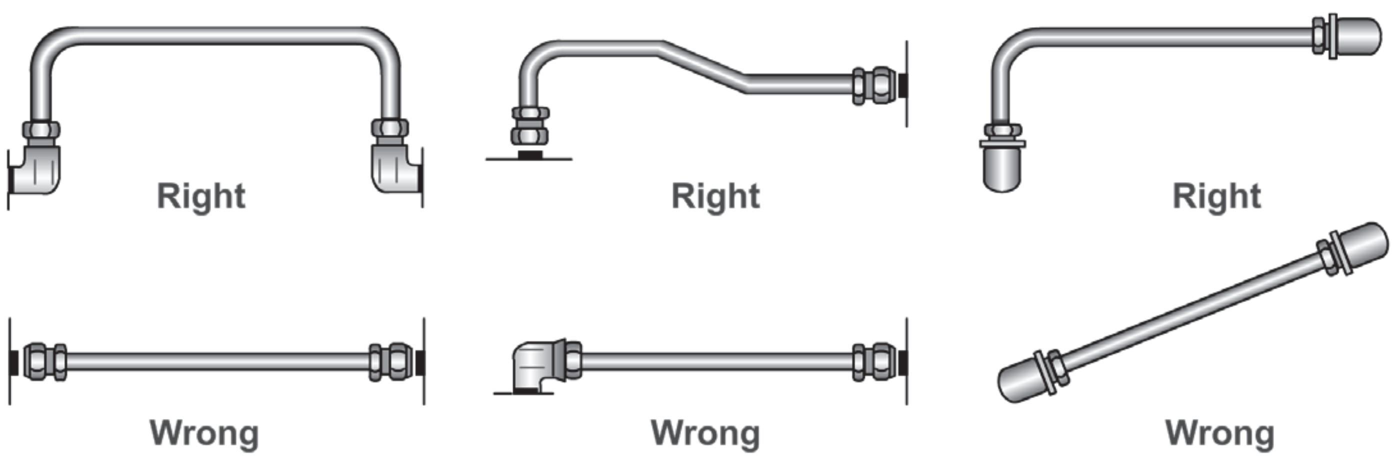


Figure 5-1 — Correct and incorrect methods of installing tubing.

Bends are described by their radius measurements. The ideal bend radius is 2 1/2 to 3 times the ID, as shown in *Figure 5-2*. For example, if the ID of a line is 2 inches, the radius of the bend should be between 5 and 6 inches.

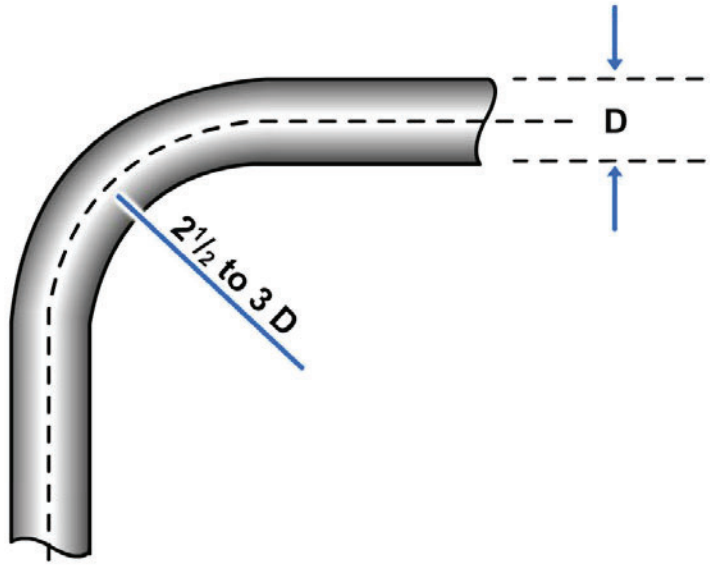


Figure 5-2 — Ideal bend radius.

While friction increases significantly for sharper curves than this, it also tends to increase up to a certain point for gentler curves. The increases in friction in a bend with a radius of more than 3 pipe diameters results from increased turbulence near the outside edges of the flow. Particles of fluid must travel a longer distance in making the change in direction. When the radius of the bend is less than 2 1/2 pipe diameters, the increased pressure loss is due to the abrupt change in the direction of flow, especially for particles near the inside edge of the flow.

At times, new tubing may need to be fabricated to replace damaged or failed lines. Fabrication of tubing consists of four basic operations: cutting, deburring, bending, and joint preparation.

Tube Cutting and Deburring

The objective of cutting tubing is to produce a square end that is free from burrs. Tubing may be cut using a tube cutter *(Figure 5-3*), or a chipless cutter (*Figure 5-4*).

Figure 5-3 — Tube cutter.

Tubing should be cut with a tubing cutter, when available. The tubing should be marked where it is to be cut and the cutter should be installed so the cutter wheel is over the mark and the cutting wheel can be seen from the top view of the pipe, as shown in *Figure 5-3*. The adjustment wheel or handle should be turned clockwise to force the cutter wheel against the copper. The cutter should be revolved around the tubing and turn the adjustment wheel 1/4 turn per rotation until the copper is cut through and separates.

Tubing may be cut with a hacksaw, although a tubing cutter is preferable. It is important to be careful to cut the tubing square if it is to be flared. A fine-toothed hacksaw blade, with 32 teeth per inch, should be used when cutting copper.

The following steps should be taken when using a chipless cutter:

1. Select the chipless cutter according to tubing size.

2. Rotate the cutter head to accept the tubing in the cutting position. Check that the cutter ratchet is operating freely and that the cutter wheel is clear of the cutter head opening (*Figure 5-4*).
3. Center the tubing on two rollers and the cutting blade.
4. Use the hex key provided to turn the drive screw in until the cutter touches the tube.
5. Tighten the drive screw 1/8 to 1/4 turn. Do not overtighten the drive screw. Overtightening can damage soft tubing or cause excessive wear or breakage of the cutter wheel in hard tubing.
6. Swing the ratchet handle back and forth through the available clearance until there is a noticeable ease of rotation. Avoid putting side force on the cutter handle. Side force will cause the cutter wheel to break.
7. Tighten the drive screw an additional 1/8 to 1/4 turn and swing the ratchet handle back and forth, retightening the drive screw as needed until the cut is completed. The completed cut should be 1/2 degree square to the tube centerline.

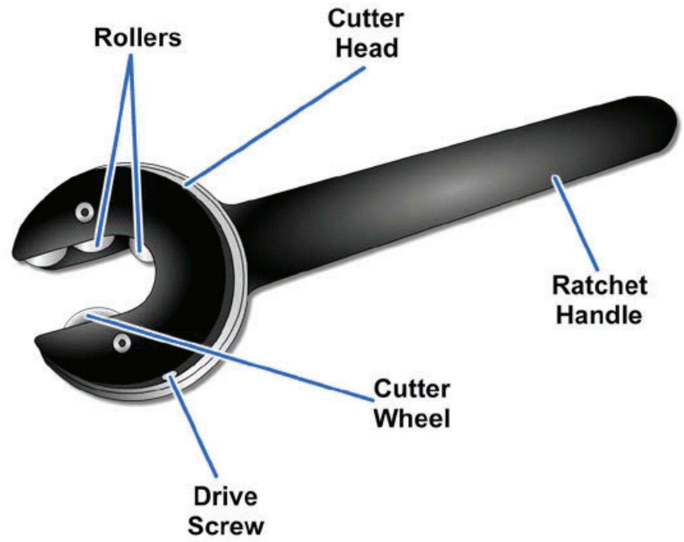


Figure 5-4 — Chipless cutter.

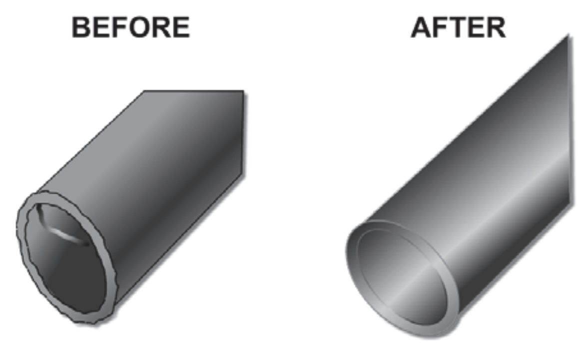


Figure 5-5 — Properly burred tubing.

After the tubing is cut, all burrs and sharp edges should be removed from inside and outside of the tube (*Figure 5-5*) with deburring tools. The tubing should be cleaned to make sure there are no foreign particles remaining. A convenient method for cutting tubing with a hacksaw is to place the tube in a flaring block and clamp the block in a vice. After cutting the tubing with a hacksaw, all saw marks should be removed by filing.

Tube Bending

The objective in tube bending is to obtain a smooth bend without flattening the tube. Tube bending is usually done with either a hand tube bender or a mechanically-operated bender.

Hand Tube Bender

The hand tube bender shown in *Figure 5-6* consists of a handle, a radius block, a clip, and a slide bar. The handle and slide bar are used as levers to provide the mechanical advantage necessary to bend the tubing. The radius block is marked in degrees of bend ranging from 0 to 180 degrees. The slide bar has a mark which is lined up with the zero mark on the radius block. The tube is inserted in the tube bender, and after the marks are lined up, the slide bar is moved around until the mark on the slide bar reaches the desired degree of bend on the radius block. The six procedural steps in tube bending with the hand-operated tube bender are shown in *Figure 5-6, frames 1 through 7*.

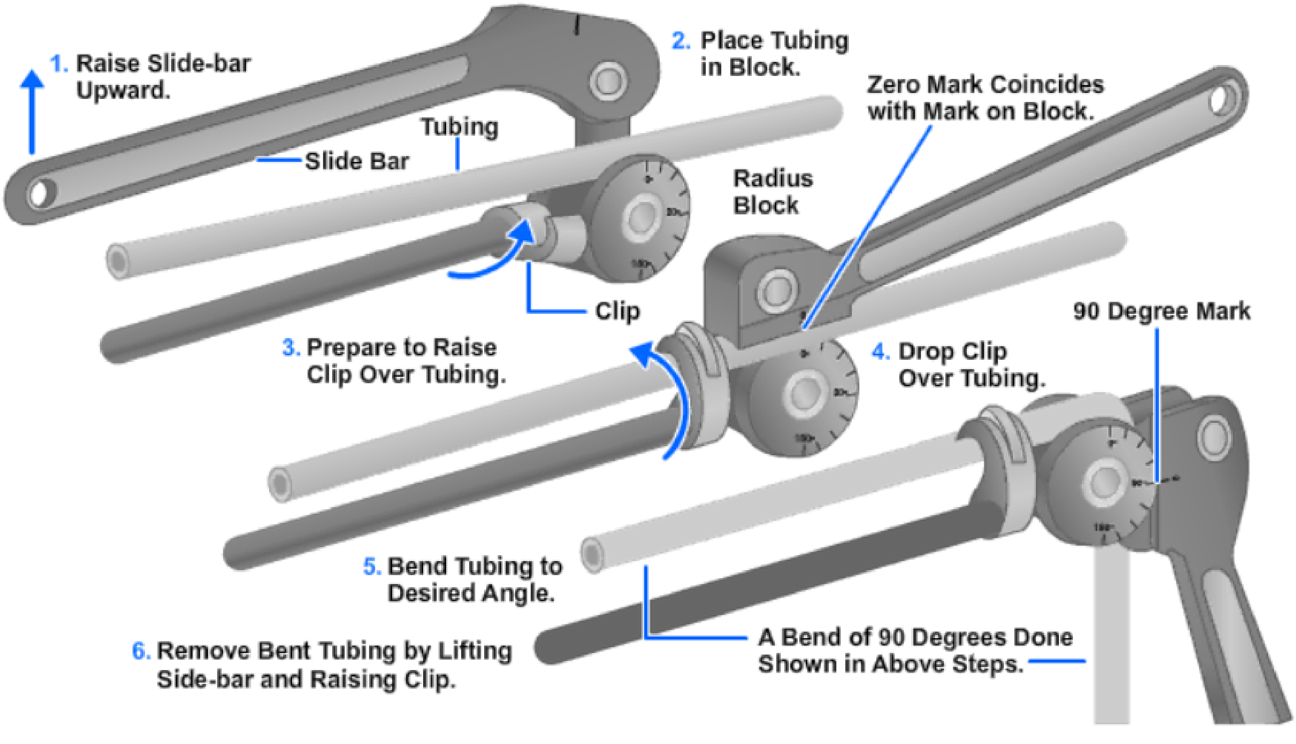


Figure 5-6 — Bending tubing with hand-operated tube bender.

Mechanical Tube Bender

Mechanical tube benders (*Figure 5-7*) are considered the most practical and most accurate method of bending copper tubing. These benders are manufactured in many different sizes. When a tube is placed in the bender, the right handle of the bender should be raised as far as it will go so that it rests in a horizontal position. The clip should be raised and the tubing placed in the space between the handle and slide block and the bending form. The slip should now be placed over the tubing and the handle slide bar turned about its pin and to the right. The zero mark on the bending form will line up with the mark on the slide bar. Next, the handle should continue to be pulled to the right (clockwise), until the tubing is bent to the desired angle. When using the mechanical bending tool, bends may be made up to 180° without buckling or kinking the tubing.

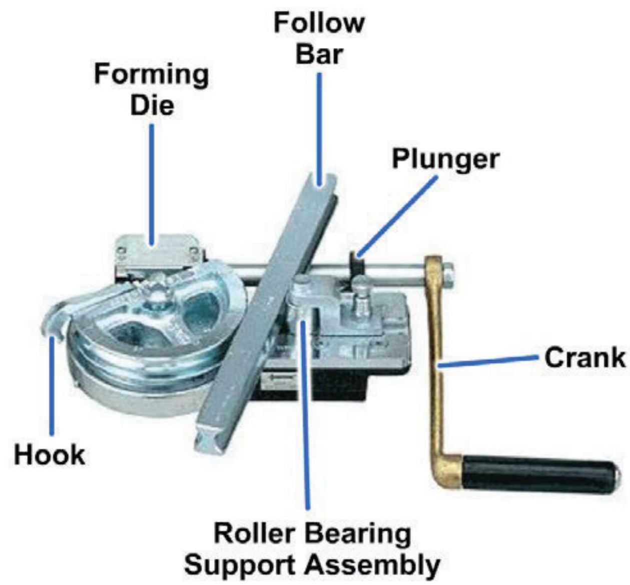


Figure 5-7 — Mechanical tube bender.

Tube Flaring

Flaring is an easy and satisfactory method of joining copper tubing. The ends of the tubing should be flared and pressed against the tapered surface of the flared fitting. Next, the flare nut should be screwed over the end of the fitting.

An advantage of this type of connection is that it is easily disassembled when repairs are necessary. The only thing required to disassemble this connection is to select the correct size wrench, unscrew the flare nut that makes up the compression-type connection, and separate the fittings. When a flare is made on tubing, every precaution should be taken to produce an airtight and watertight joint. First, the tubing should be measured and cut to the proper length with a tubing cutter or hacksaw. Then, the burr within the tubing should be removed by reaming. Tubing can be flared with a flaring type tool (*Figure 5-8, frames 1 through 3*).

Before a flare is made, the flare nut should be slipped on the tubing and the end of the tubing inserted into the correct size hole in the flaring block. Then, the end of the tubing should be extended above the face of the block twice the wall thickness of the tubing.

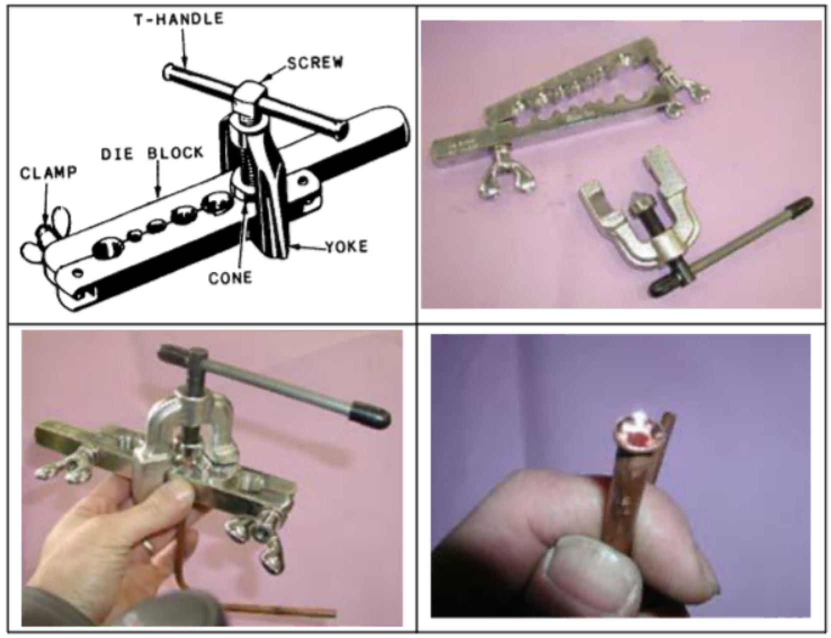


Figure 5-8 — Flaring tool.

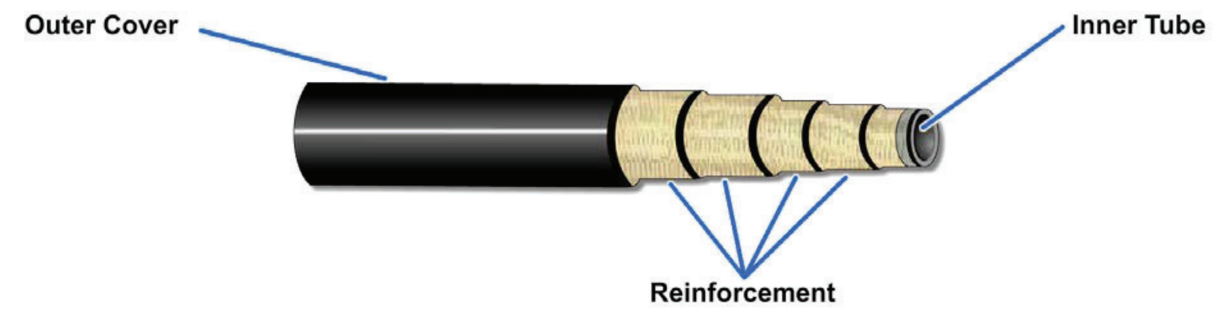
Next, the flaring yoke should be attached to the flaring block and the flaring cone centered over the end of the tubing. The cone should be forced against the flaring block by rotating the handle on the flaring yoke clockwise. After the tubing has been flared properly, assembly of the joint is simple. After placing the flare against the fitting, the compression nut should be slipped against the flare and screwed on the fitting. This operation compresses the flare of the tubing between the fitting and nut.

FLEXIBLE HOSE

Shock-resistant, flexible hose assemblies are required to absorb the movements of mounted equipment under both normal operating conditions and extreme conditions. They are also used for their noise-attenuating properties and to connect moving parts of certain equipment. There are two basic types of hoses used in military aircraft and related equipment. They are synthetic rubber and polytetrafluoroethylene (PTFE), commonly known as Teflon®.

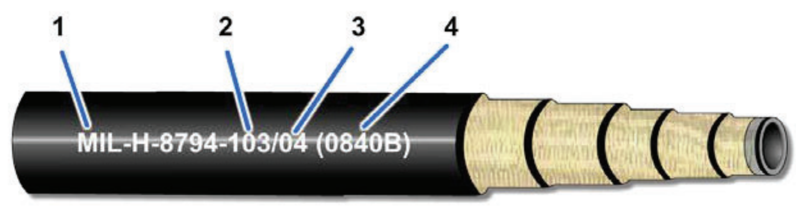
Rubber hoses are designed for specific fluid, temperature, and pressure ranges and are provided in various specifications. Rubber hoses (*Figure 5-9*) consist of a minimum of three layers; a seamless synthetic rubber tube reinforced with one or more layers of braided or spiraled cotton, wire, or synthetic fiber; and an outer cover. The inner tube is designed to withstand the attack of the fluid that passes through it. The braided or spiraled layers determine the strength of the hose; the greater the number of these layers, the greater the pressure rating. Hoses are provided in three pressure ranges: low, medium, and high. The outer cover is designed to withstand external abuse and contains identification markings.

Synthetic rubber hose (if rubber-covered) is identified by the indicator stripe and markings that are stenciled along the length of the hose. The indicator stripe (also called the lay line because of its use in determining the straightness or lie of a hose) is a series of dots or dashes. The markings (letters and numerals) contain the military specification, hose size, cure date, and manufacturer's Federal supply code number. This information is repeated at intervals of 9 inches (*Figure 5-10*).



Construction material			Intended Use	Cautions	Use To Fabricate Hose Assy
Inner Tube	Reinforcement	Outer Cover			
Synthetic rubber compound, seamless construction, resistant to: petroleum base fuel, lubricating oil, hydraulic fluid	Inner cotton braid and wire braid	Synthetic rubber impregnated cotton braid, resistant to: oil (petroleum base)	Medium-pressure hydraulic, fuel, and petroleum base oil system applications		MIL-DTL-8795

Figure 5-9 — Medium pressure synthetic rubber hose.



Synthetic Rubber Hose

1. Military specification of hose
2. Size indicated by a dash (-) No. or fraction of an inch for MIL-DTL-6000 hose
3. Cure date for age control
4. Manufacturer's Federal Supply Code No.

Wire Braid Covered Synthetic Rubber Hose

Manufacturer	ACME
Manufacturer's code	0840B
Part No. with dash (size) No.	AB123-10
Lot No.	16160
Operating pressure	3000 PSI
Military specification	MIL-H-83298

Wire Braid Covered PTFE Hose Label

Figure 5-10 — Synthetic rubber hose identification.

Size is indicated by a dash followed by a number (referred to as a dash number). The dash number does not denote the inside or outside diameter of the hose. It refers to the equivalent outside diameter of rigid tube size in sixteenths (1/16) of an inch. A dash 8 (-8) mates to a number 8 rigid tube, which has an outside diameter of one-half inch (8/16). The inside of the hose will not be one half inch, but slightly smaller to allow for tube thickness. The cure date is provided for age control. It is indicated by the quarter of the year and year. The year is divided into four quarters.

- 1st quarter — January, February, March
- 2rd quarter — April, May, June
- 3rd quarter — July, August, September
- 4th quarter — October, November, December

The cure date is also marked on bulk hose containers in accordance with Military Standard 129 (MIL-STD-129).

Synthetic rubber hose (if wire-braid covered) is identified by bands wrapped around the hose at the ends and at intervals along the length of the hose. Each band is marked with the same information (*Figure 5-10*).

Acceptance Life

The acceptance life for synthetic rubber hoses is the period of time from the cure date to the acceptance by the organizational-, Intermediate-, or Depot-level activity. Synthetic rubber hose and hose assemblies must have at least 8 1/2 years (34 quarters) of the shelf life remaining upon acceptance from the first Government activity receiving the material from the manufacturer.

Polytetrafluoroethylene (PTFE) (Teflon®) Hose

The PTFE hose is a flexible hose designed to meet the requirements of higher operating pressures and temperatures in present fluid power systems. This type of hose is made from a chemical resin, which is processed and extruded into a tube shaped to a desired size. It is reinforced with one or more layers of braided stainless steel wire or with an even number of spiral wrap layers with an outer wire braid layer.

A PTFE hose is unaffected by all fluids presently used in fluid power systems. It is inert to acids, both concentrated and diluted. Certain PTFE hose may be used in systems where operating temperatures range from –100 to +500 degrees Fahrenheit (°F). PTFE is nonflammable; however, where the possibility of open flame exists, a special asbestos fire sleeve should be used.

A PTFE hose will not absorb moisture. This, together with its chemical inertness and antiadhesive characteristics, makes it ideal for missile fluid power systems where noncontamination and cleanliness are essential.

In lieu of layline marking, PTFE hoses are identified by metal or pliable plastic bands at their ends and at intervals along their length. Usually the only condition that will shorten the life of PTFE hose is excessive temperature. For this reason there is no manufacture date listed on the identification tag.

Application

As mentioned earlier, flexible hose is available in three pressure ranges: low, medium, and high. When replacing hoses, it is important to ensure that the replacement hose is a duplicate of the one removed in length, OD, material, type and contour, and associated markings. In selecting hose, several precautions must be observed. The selected hose must:

1. Be compatible with the system fluid,
2. Have a rated pressure greater than the design pressure of the system,

3. Be designed to give adequate performance and service for infrequent transient pressure peaks up to 150 percent of the working pressure of the hose, and
4. Have a safety factor with a burst pressure at a minimum of 4 times the rated working pressure.

There is temperature restrictions applied to the use of hoses. Rubber hose must not be used where the operating temperature exceeds 200 °F with the exception of MIL-H-24135/12 and MIL-H024135/13, which may be used up to 300 °F. PTFE hoses in high-pressure air systems must not be used where the temperature exceeds 350 °F. PTFE hoses in water and steam drain applications must not be used where the operating temperature exceeds 380 °F.

Fabrication and Testing

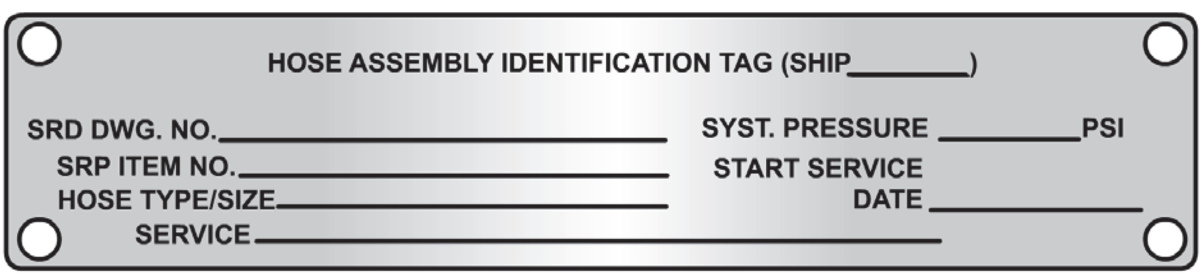
The fabrication of flexible hose assemblies is covered in applicable training manuals, technical publications, and the Aviation Hose and Tube Manual, NAVAIR 01-1A-20. After a hose assembly has been completely fabricated, it must be cleaned, visually inspected for foreign materials, and proof tested.

A hose assembly is proof tested by the application of a nondestructive pressure for a minimum of 1 minute but not longer than 5 minutes to ensure that it will withstand normal working pressures. The test pressure, known as normal proof pressure, is twice the rated working pressure. While the test pressure is being applied, the hose must not burst, leak, or show signs of fitting separation. NAVAIR 01-1A-20 and NAVSEA S6430-AE-TED-010, Volume 1, provide detailed instructions on cleaning of hoses, cleaning and test media, proof pressure, and proof testing.

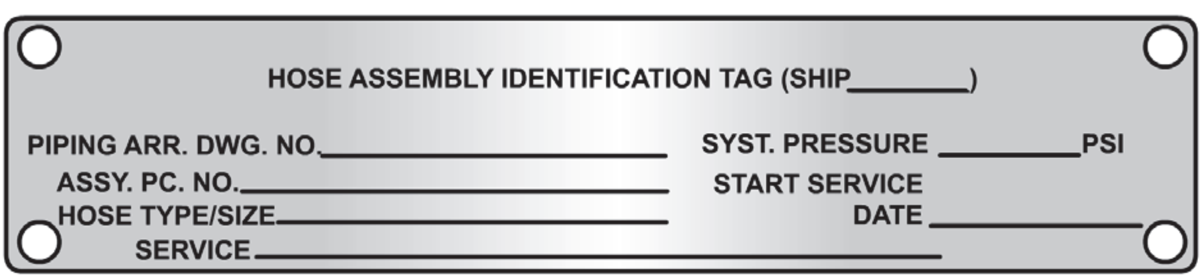
After proof testing is completed, the hose must be flushed and dried and the ends capped or plugged to keep dirt and other contaminants out of the hose.

Identification

The final step after fabrication and satisfactory testing of a hose assembly is the attachment of identification tags as shown in *Figure 5-11* (for ships). Hose assemblies to be installed in aircraft fuel and oil tanks are marked with an approved electric engraver on the socket-wrench flats with the required information.



ID Tag When Selected Record Drawing Is Available



ID Tag When Selected Record Drawing Does Not Exist

Figure 5-11 — Hose assembly identification tags (ships).

Installation

Flexible hose must not be twisted during installation, since this reduces the life of the hose considerably and may cause the fittings to loosen as well. To determine whether a hose is twisted or not, the layline that runs along the length of the hose should be straight. If the layline does not spiral around the hose, the hose is not twisted. If the layline does spiral around the hose, the hose is twisted (*Figure 5-12*) and must be untwisted.

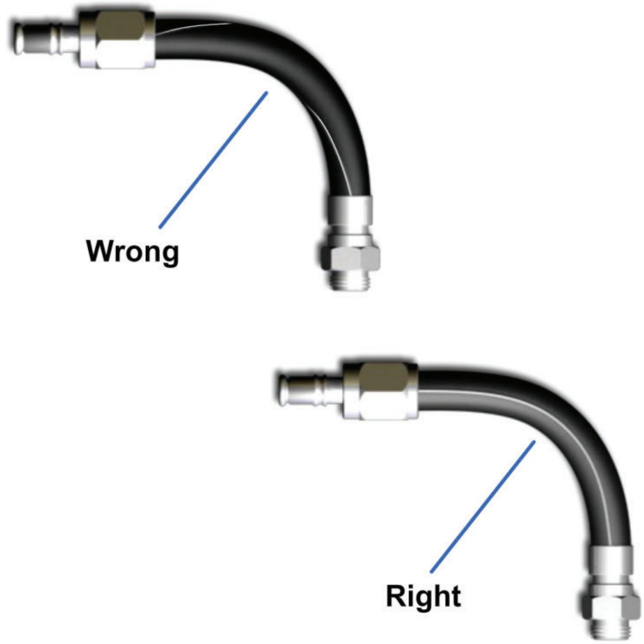


Figure 5-12 — Hose twist.

Flexible hose should be protected from chafing by using a chafe-resistant covering wherever necessary.

The minimum bend radius for flexible hose varies according to the size and construction of the hose and the pressure under which the system operates. Current applicable technical publications contain tables and graphs showing minimum bend radii for the different types of installations. Bends that are too sharp will reduce the bursting pressure of flexible hose considerably below its rated value.

Flexible hose should be installed so that it will be subjected to a minimum of flexing during operation. Support clamps are not necessary with short installations; but for hose of considerable length (48 inches, for example), clamps should be placed not more than 24 inches apart. Closer supports are desirable and in some cases may be required.

A flexible hose must never be stretched tightly between two fittings. About 5 to 8 percent of the total length must be allowed as slack to provide freedom of movement under pressure. When under pressure, flexible hose contracts in length and expands in diameter. Examples of correct and incorrect installations of flexible hose are illustrated in *Figure 5-13*.

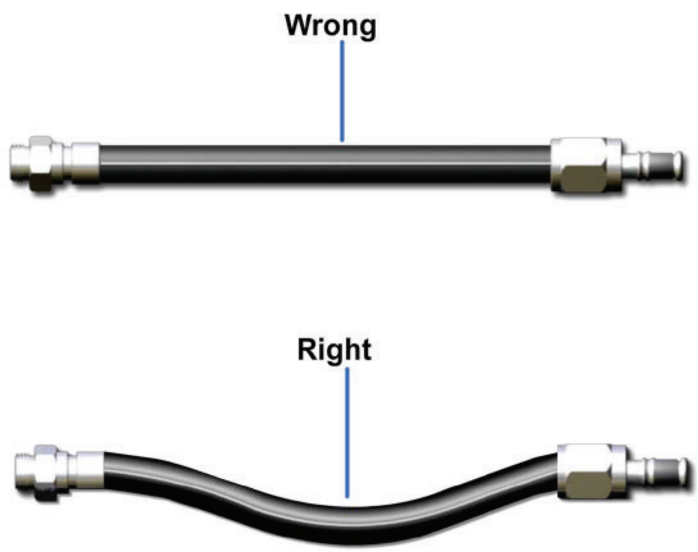


Figure 5-13 — Hose slack.

PTFE hose should be handled carefully during removal and installation. Some PTFE hose is preformed during fabrication. This type of hose tends to form itself to the installed position in the system. To ensure its satisfactory function and reduce the likelihood of failure, anyone who works with PTFE hose should observe the following rules:

1. Do not exceed recommended bend limits.
2. Do not exceed twisting limits.
3. Do not straighten a bent hose that has taken a permanent set.
4. Do not hang, lift, or support objects from PTFE hose.

Once flexible hose assemblies are installed, there are no servicing or maintenance requirements other than periodic inspections. These inspections are conducted according to maintenance instruction manuals (MIMs), maintenance requirement cards (MRCs), and depot-level specifications.

TYPES OF FITTINGS AND CONNECTORS

Some type of connector or fitting must be provided to attach the lines to the components of the system and to connect sections of line to each other. There are many different types of connectors and fittings provided for this purpose. The type of connector or fitting required for a specific system depends on several factors. One determining factor, of course, is the type of fluid line (pipe, tubing, or flexible hose) used in the system. Other determining factors are the type of fluid medium and the maximum operating pressure of the system. Some of the most common types of fittings and connectors are described in the following paragraphs.

Threaded Connectors

There are several different types of threaded connectors. In the type discussed in this section, both the connector and the end of the fluid line (pipe) are threaded. These connectors are used in some low-pressure fluid power systems and are usually made of steel, copper, or brass, and are available in a variety of designs.

Threaded connectors are made with standard pipe threads cut on the inside surface. The end of the pipe is threaded with outside threads. Standard pipe threads are tapered slightly to ensure tight connections. The amount of taper is approximately 3/4-inch in diameter per foot of thread.

Metal is removed when a pipe is threaded, thinning the pipe and exposing new and rough surfaces. Corrosion agents work more quickly at such points than elsewhere. If pipes are assembled with no protective compound on the threads, corrosion sets in at once and the two sections stick together so that the threads seize when disassembly is attempted. The result is damaged threads and pipes.

To prevent seizing, a suitable pipe thread compound is sometimes applied to the threads. The two end threads must be kept free of compound so that it will not contaminate the fluid. Pipe compound, when improperly applied, may get inside the lines and components and damage pumps and control equipment.

Another material used on pipe threads is sealant tape. This tape, which is made of PTFE, provides an effective means of sealing pipe connections and eliminates the necessity of torqueing connections to excessively high values in order to prevent pressure leaks. It also provides for ease of maintenance whenever it is necessary to disconnect pipe joints. The tape is applied over the male threads, leaving the first thread exposed. After the tape is pressed firmly against the threads, the joint is connected.

Flange Connectors

Bolted flange connectors (*Figure 5-14*) are suitable for most pressures now in use. The flanges are attached to the piping by welding, brazing, tapered threads (for some low-

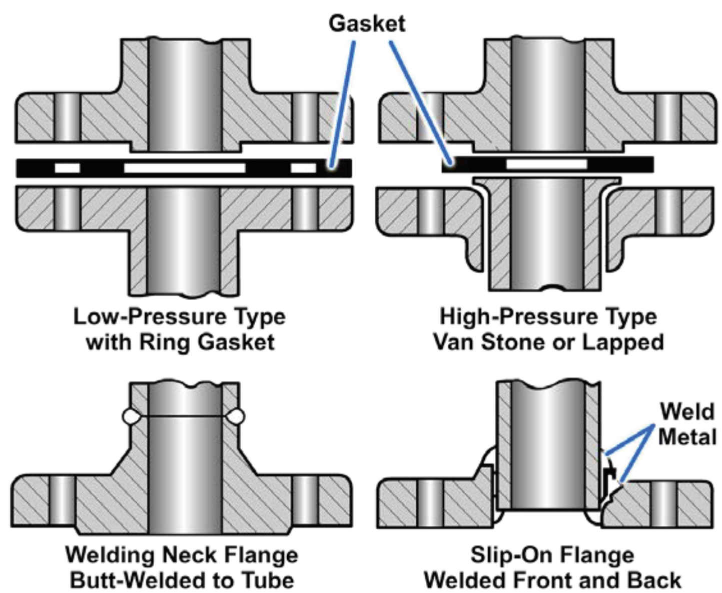


Figure 5-14 — Four types of bolted flange connectors.

pressure systems), or rolling and bending into recesses. Those illustrated are the most common types of flange joints used. The same types of standard fitting shapes (tee, cross, elbow, and so forth) are manufactured for flange joints. Suitable gasket material must be used between the flanges.

Welded Connectors

The subassemblies of some fluid power systems are connected by welded joints, especially in high-pressure systems which use pipe for fluid lines. The welding is done according to standard specifications which define the materials and techniques.

Brazed Connectors

Silver-brazed connectors are commonly used for joining nonferrous (copper, brass, and soon) piping in the pressure and temperature range where their use is practical. Use of this type of connector is limited to installations in which the piping temperature will not exceed 425 °F and the pressure in cold lines will not exceed 3,000 pounds per square inch (psi). The alloy is melted by heating the joint with an oxyacetylene torch. This causes the alloy insert to melt and fill the few thousandths of an inch annular space between the pipe and the fitting.

A fitting of this type, which has been removed from a piping system, can be rebrazed into a system, as in most cases sufficient alloy remains in the insert groove for a second joint. New alloy inserts may be obtained for fittings which do not have sufficient alloy remaining in the insert for making a new joint.

Flared Connectors

Flared connectors are commonly used in fluid power systems containing lines made of tubing. These connectors provide safe, strong, dependable connections without the need for threading, welding, or soldering the tubing. The connector consists of a fitting, a sleeve, and a nut (*Figure 5-15*).

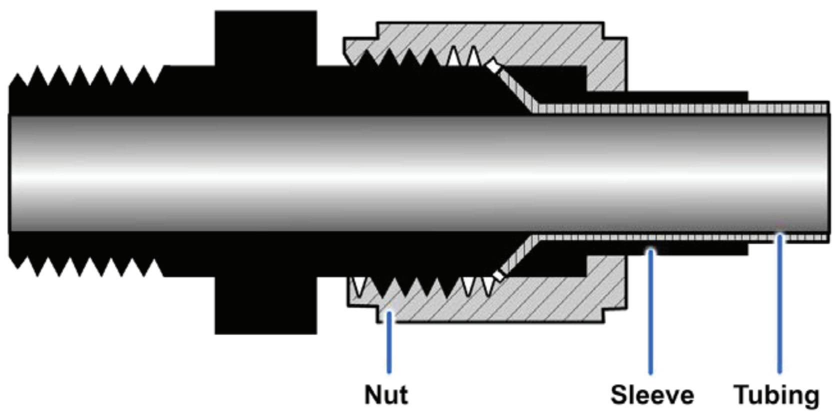


Figure 5-15 — Flared-tube fitting.

The fittings are made of steel, aluminum alloy, or bronze. The fitting used in a connection should be made of the same material as that of the sleeve, the nut, and the tubing. For example, steel connectors should be used with steel tubing and aluminum alloy connectors with aluminum alloy tubing. Fittings are made in union; 45-degree and 90-degree elbow, tee, and various other shapes (*Figure 5-16*).

Tees, crosses, and elbows are self-explanatory. Universal and bulkhead fittings can be mounted solidly with one outlet of the fitting extending through a bulkhead and the other outlet(s) positioned at any angle. Universal means the fitting can assume the angle required for the specific installation. Bulkhead means the fitting is long enough to pass through a bulkhead and is designed so it can be secured solidly to the bulkhead.

For connecting to tubing, the ends of the fittings are threaded with straight machine threads to correspond with the female threads of the nut. In some cases, however, one end of the fitting may be threaded with tapered pipe threads to fit threaded ports in pumps, valves, and other components.

Tubing used with flare connectors must be flared prior to assembly. The nut fits over the sleeve and when tightened, it draws the sleeve and tubing flare tightly against the male fitting to form a seal.

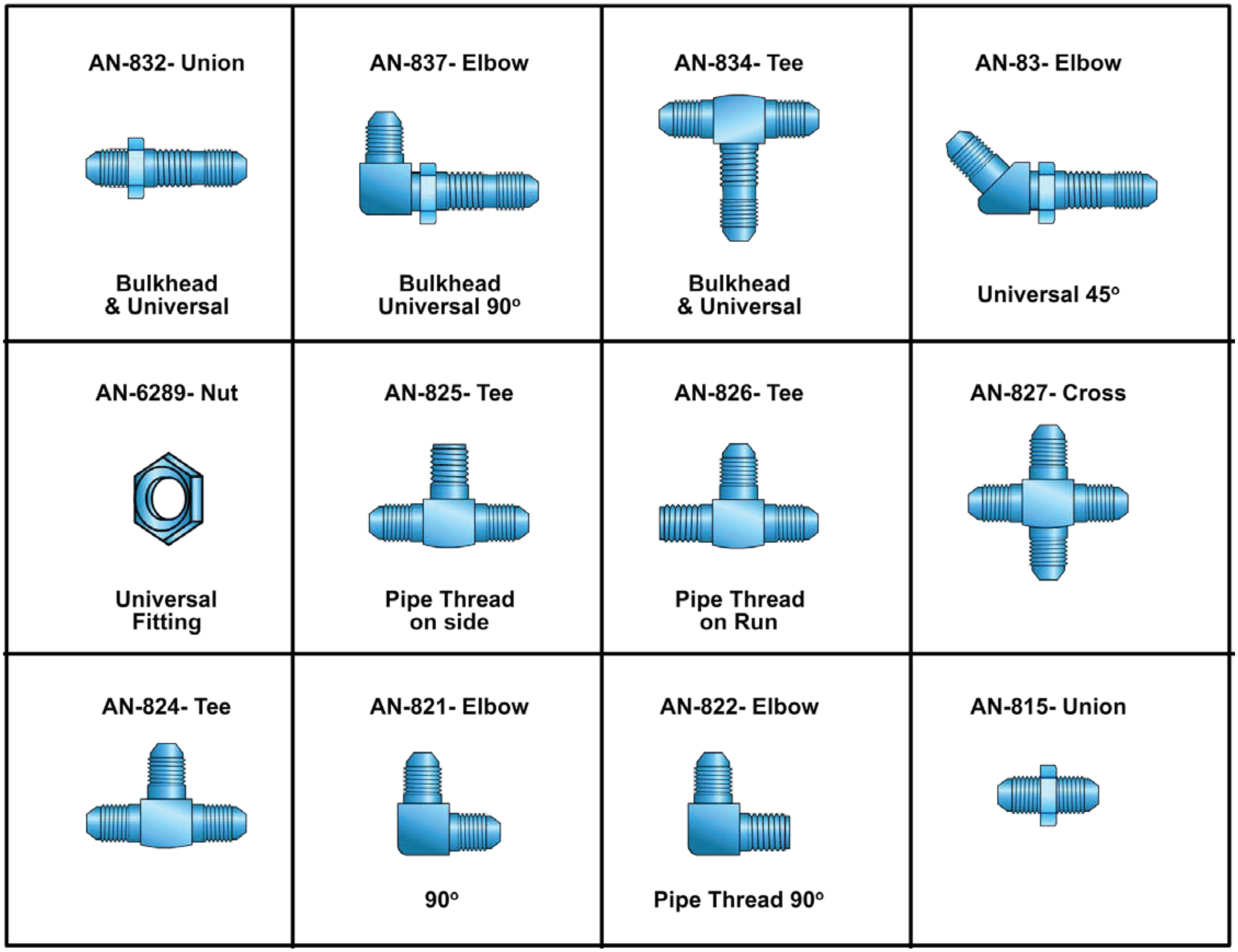


Figure 5-16 — Flared-tube fittings.

The male fitting has a cone-shaped surface with the same angle as the inside of the flare. The sleeve supports the tube so vibration does not concentrate at the edge of the flare, and distributes the shearing action over a wider area for added strength.

Correct and incorrect methods of installing flared-tube connectors are illustrated in *Figure 5-17*. Tubing nuts should be tightened with a torque wrench to the value specified in applicable technical publications.

If an aluminum alloy flared connector leaks after being tightened to the required torque, it must not be tightened further. Overtightening may severely damage or completely cut off the tubing flare or may result in damage to the sleeve or nut. The leaking connection must be disassembled and the fault corrected.

If a steel tube connection leaks, it may be tightened 1/6 turn beyond the specified torque in an attempt to stop the leakage; then if it still leaks, it must be disassembled and repaired.

Undertightening of connections may be serious, as this can allow the tubing to leak at the connector because of insufficient grip on the flare by the sleeve. The use of a torque wrench will prevent undertightening.

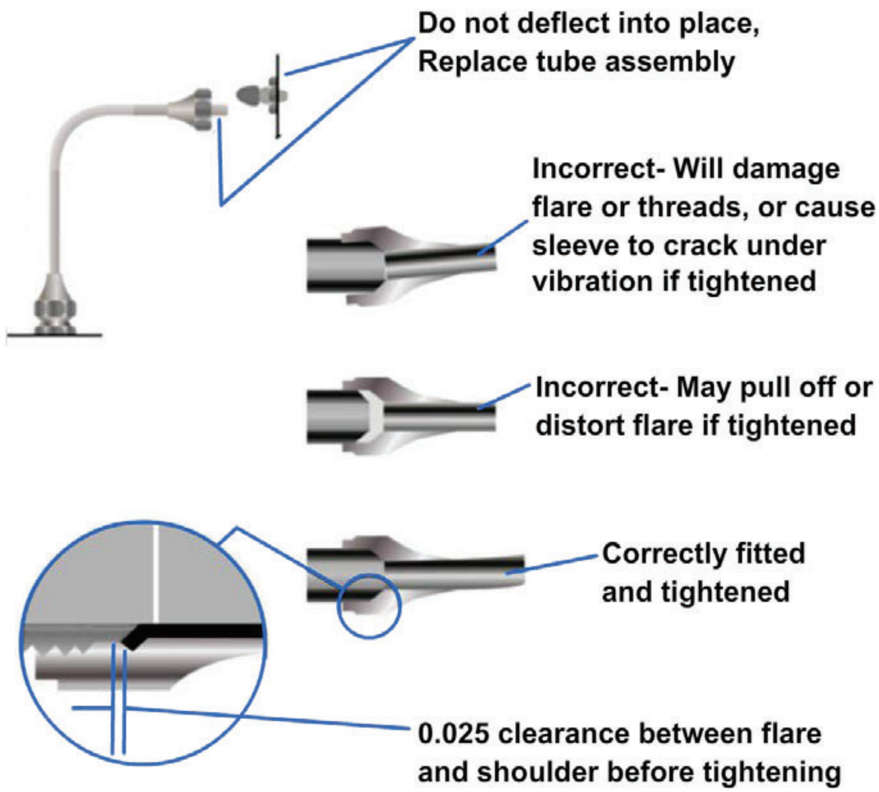


Figure 5-17 — Correct and incorrect methods of installing flared fittings.

> ⚠ **CAUTION** ⚠
>
> Never tighten a nut when there is pressure in the line; damage to the connection may occur without adding any appreciable torque to the connection.

Flareless-Tube Connectors

This type of connector eliminates all tube flaring, yet provides a safe, strong, and dependable tube connection. This connector consists of a fitting, a sleeve or ferrule, and a nut. (*Figure 5-18*).

> **NOTE**
>
> Although the use of flareless tube connectors is widespread, NAVSEA policy is to reduce or eliminate use of flareless fittings in newly designed ships; the extent to which flareless fittings are approved for use in a particular ship is reflected in applicable ship drawings.

Flareless-tube fittings are available in many of the same shapes and thread combinations as flared-tube fittings. The fitting has a counterbore shoulder for the end of the tubing to rest against. The angle of the counterbore causes the cutting edge of the sleeve or ferrule to cut into the outside surface of the tube when the two are assembled.

The nut presses on the bevel of the sleeve and causes it to clamp tightly to the tube. Resistance to vibration is concentrated at this point rather than at the sleeve cut. When fully tightened, the sleeve or ferrule is bowed slightly at the midsection and acts as a spring. This spring action of the sleeve or ferrule maintains a constant tension between the body and the nut and thus prevents the nut from loosening.

Prior to the installation of a new flareless-tube connector, the end of the tubing must be square, concentric, and free of burrs. For the connection to be effective, the cutting edge of the sleeve or ferrule must bite into the periphery of the tube (*Figure 5-19*). This is ensured by presetting the sleeve or ferrule on the tube.

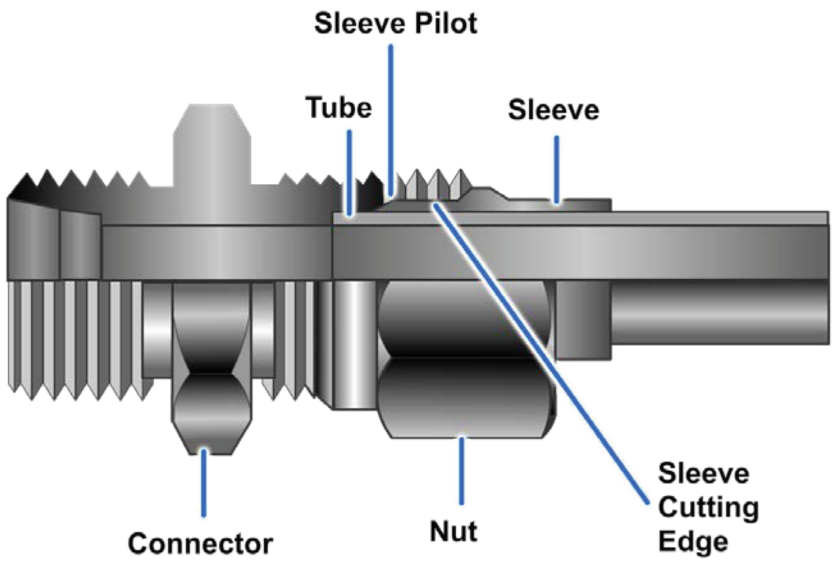


Figure 5-18 — Flareless-tube connector.

Presetting

Presetting consists of deforming the ferrule to bite into the tube OD and deforming the end of the tube to form a shallow conical ring seating surface. The tube and ferrule assembly should be preset in a presetting tool that has an end section identical to a fitting body but which is made of specially hardened steel. This tool hardness is needed to ensure that all deformation at the tube end seat goes into the tube.

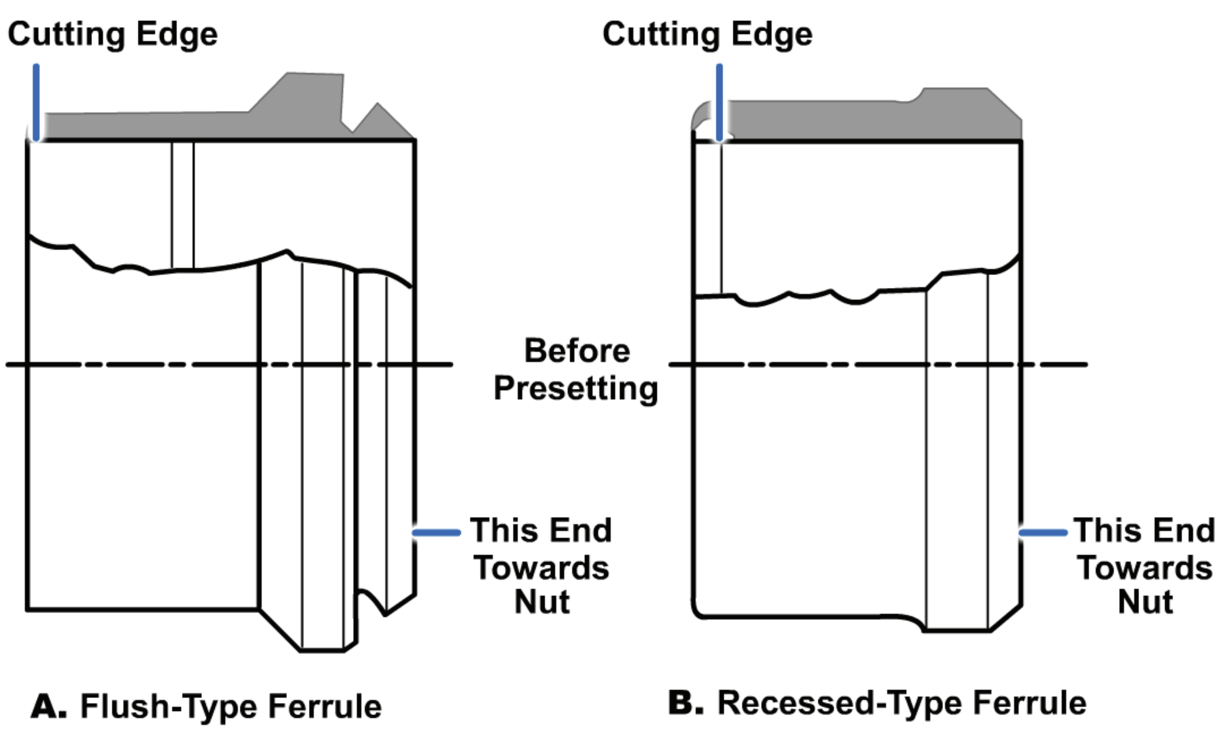


Figure 5-19 — Unused ferrules.

Presetting is done with a hydraulic presetting tool or a manual presetting tool, either in the shop or aboard ship. The tool vendor's instructions must be followed for the hydraulic presetting tool. If a presetting tool is not available, the fitting body intended for installation is used in the same manner as the manual presetting tool. (If an aluminum fitting is used, it should not be reused in the system.) The manual tool is used as follows:

WARNING

Failure to follow these instructions may result in improperly preset ferrules with insufficient bite into the tube. Improperly preset ferrules have resulted in joints that passed hydrostatic testing and operated for weeks or years, then failed catastrophically under shock, vibration, or normal operating loads. Flareless fitting failures have caused personnel injury, damage to equipment, and unnecessary interruption of propulsion power.

1. Cut the tubing square and lightly deburr the inside and outside corners. For corrosion resisting steel (CRES) tubing, use a hacksaw rather than a tubing cutter to avoid work hardening the tube end. For CRES, and if necessary for other materials, dress the tube end smooth and square with a file. Tube ends with irregular cutting marks will not produce satisfactory seating surface impressions.
2. Test the hardness of the ferrule by making a light scratch on the tubing at least 1/2 inch back from the tube end, using a sharp corner on the ferrule. If the ferrule will not scratch the tube, no bite will be obtained. This test may be omitted for flush-type ferrules where the bite will be visible. Moderate hand pressure is sufficient for producing the scratch.
3. Lubricate the nut threads, the ferrule leading and trailing edges, and the preset tool threads with a thread lubricant compatible with the system. Slide the nut onto the tubing so the threads face the tube end. Note whether the ferrule is a flush-type or recessed-type (*Figure 5-19*), and slide the ferrule onto the tube so the cutting edge is toward the tube end (large end toward the nut).
4. Bottom the end of the tubing in the presetting tool. Slide the ferrule up into the presetting tool, and confirm that the nut can be moved down the tube sufficiently to expose at least 1/8 of an inch of tubing past the ferrule after the presetting operation (*Figure 5-20*) to allow for inspection of the ferrule.

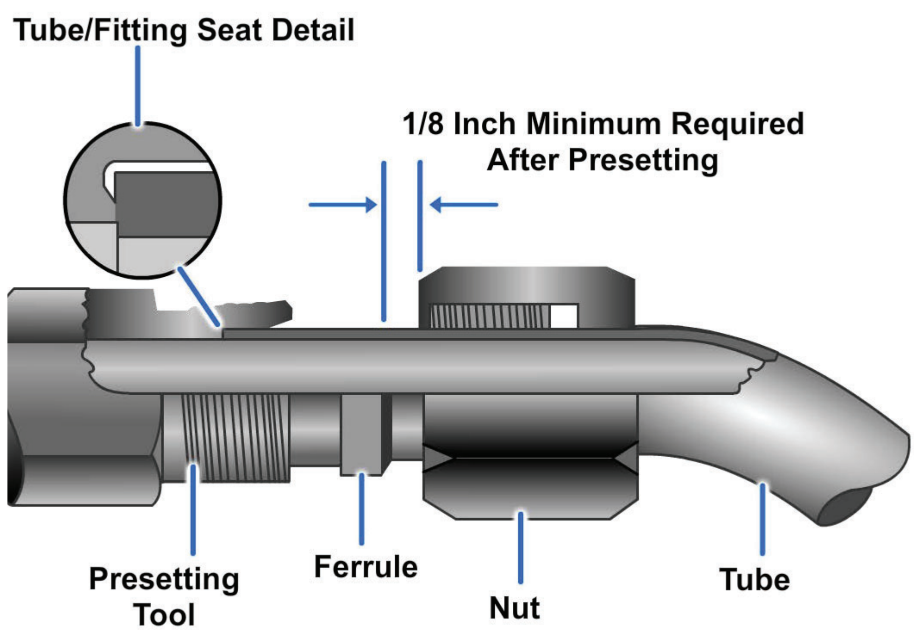


Figure 5-20 — Tube and ferrule assembled for presetting, showing nut position required for inspecting ferrule.

5. While keeping the tube bottomed in the presetting tool, tighten the nut onto the fitting body until the ferrule just grips the tube by friction. This ring grip point may be identified by lightly turning the tube or the presetting tool and slowly tightening the nut until the tube cannot be turned in the presetting tool by hand. Mark the nut and the presetting tool at this position.
6. Tighten the nut according to the number of turns given in *Table 5-3*, depending on tube size.

Table 5-3 — Number of turns

TUBE OD INCHES	NUMBER OF TURNS
1/8 to 1/2	1-1/6 (seven flats of the nut)
5/8 to 7/8	1 (six flats)
1	5/6 (five flats)
1-1/4 to 2	1 (six flats)

Inspection

Disassemble and inspect the fitting as follows (mandatory):

1. Ensure that the end of the tubing has an impression of the presetting tool seat surface (circular appearing ring) for 360 degrees. A partial circle, a visibly off-center circle, or a circle broken by the roughness of the tube end is unsatisfactory.
2. Check for proper bite:
   a. For flush-type ferrules, a raised ridge (*Figure 5-21*) of tube metal must be visible completely around the tube at the leading edge of the ferrule. The best practice is to obtain a ridge about 50 percent of the ferrule edge thickness.

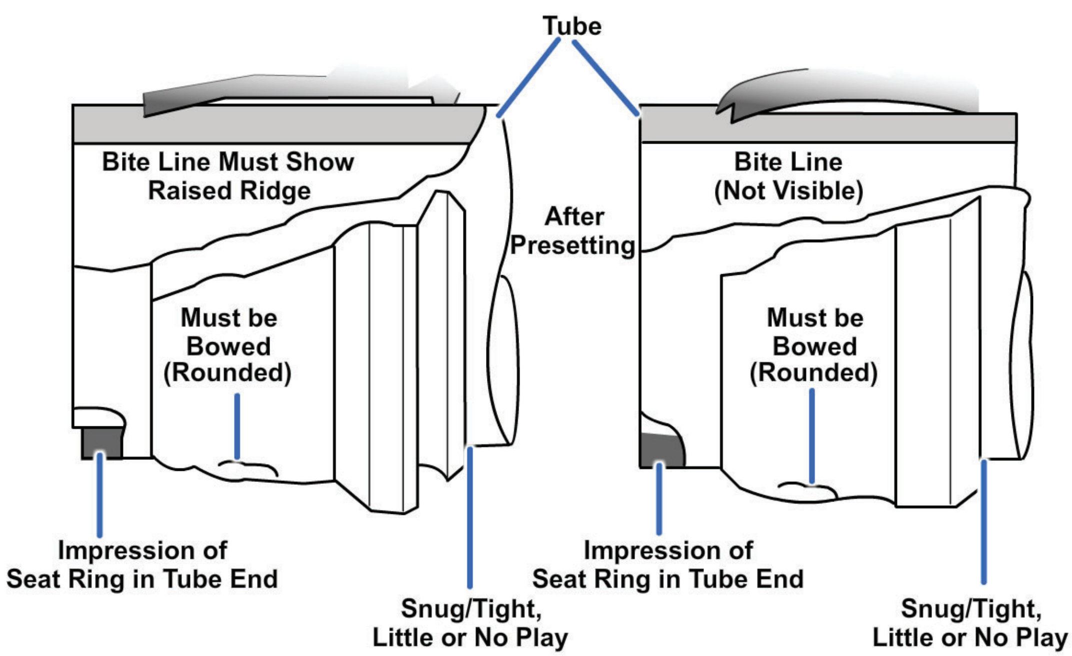


Figure 5-21 — Ferrules installed on tube, preset and removed for inspection.

b. For recessed-type ferrules, the leading edge must be snug against the tube OD. Determine this visually and by attempting to rock the ferrule on the tube.

3. Ensure that the nut end of the ferrule (both types) is collapsed around the tube to provide support against bending loads and vibration.
4. The ferrule (both types) must have little or no play along the direction of the tube run. Check this by trying to move the ferrule back and forth by hand. The ferrule will often be free to rotate on the tubing; this does not affect its function.
5. For flush-type ferrules, check that the gap between the raised metal ridge and the cutting end of the ferrule stays the same while the ferrule is rotated. (Omit this check for recessed-type ferrules or if the flush-type ferrule will not rotate on the tube).
6. Check that the middle portion of the ferrule (both types) is bowed or sprung into an arc. The leading edge of the ferrule may appear flattened into a cone shape; this is acceptable as long as there is a bowed section near the middle of the ferrule. If the whole leading section of the ferrule is flattened into a cone with no bowed section, the ferrule (and possibly the fitting body, if used) has been damaged by overtightening and will not seal reliably.

Final Assembly

The following installation procedure should be used to make a final assembly in the system:

1. Lubricate all threads with a liquid that is compatible with the fluid to be used in the system.
2. Place the tube assembly in position and check for alignment.
3. Tighten the nut by hand until you feel an increase in resistance to turning. This indicates that the sleeve or ferrule pilot has contacted the fitting.
4. If possible, use a torque wrench to tighten flareless tubing nuts. Torque values for specific installations are usually listed in the applicable technical publications. If it is not possible to use a torque wrench, the following discussion describes a process for tightening the nuts:

   After the nut is handtight, turn the nut 1/6 turn (one flat on a hex nut) with a wrench. Use a wrench on the connector to prevent it from turning while tightening the nut. After you install the tube assembly, have the system pressure tested. Should a connection leak, you may tighten the nut an additional 1/6 turn (making a total of 1/3 turn). If, after tightening the nut a total of 1/3 turn, leakage still exists, remove the assembly and inspect the components of the assembly for scores, cracks, presence of foreign material, or damage from overtightening.

NOTE

Overtightening a flareless-tube nut drives the cutting edge of the sleeve or ferrule deeply into the tube, causing the tube to be weakened to the point where normal vibration could cause the tube to shear.

⚠ CAUTION ⚠

Do not (in any case) tighten the nut beyond 1/3 turn (two flats on the hex nut); this is the maximum the fitting may be tightened without the possibility of permanently damaging the sleeve or the tube.

CONNECTORS FOR FLEXIBLE HOSE

As stated previously, the fabrication of flexible hose assemblies is covered in applicable training manuals, technical publications, and NAVAIR 01-1A-20. There are various types of end fittings for both the piping connection side and the hose connection side of hose fittings (*Figure 5-22*).

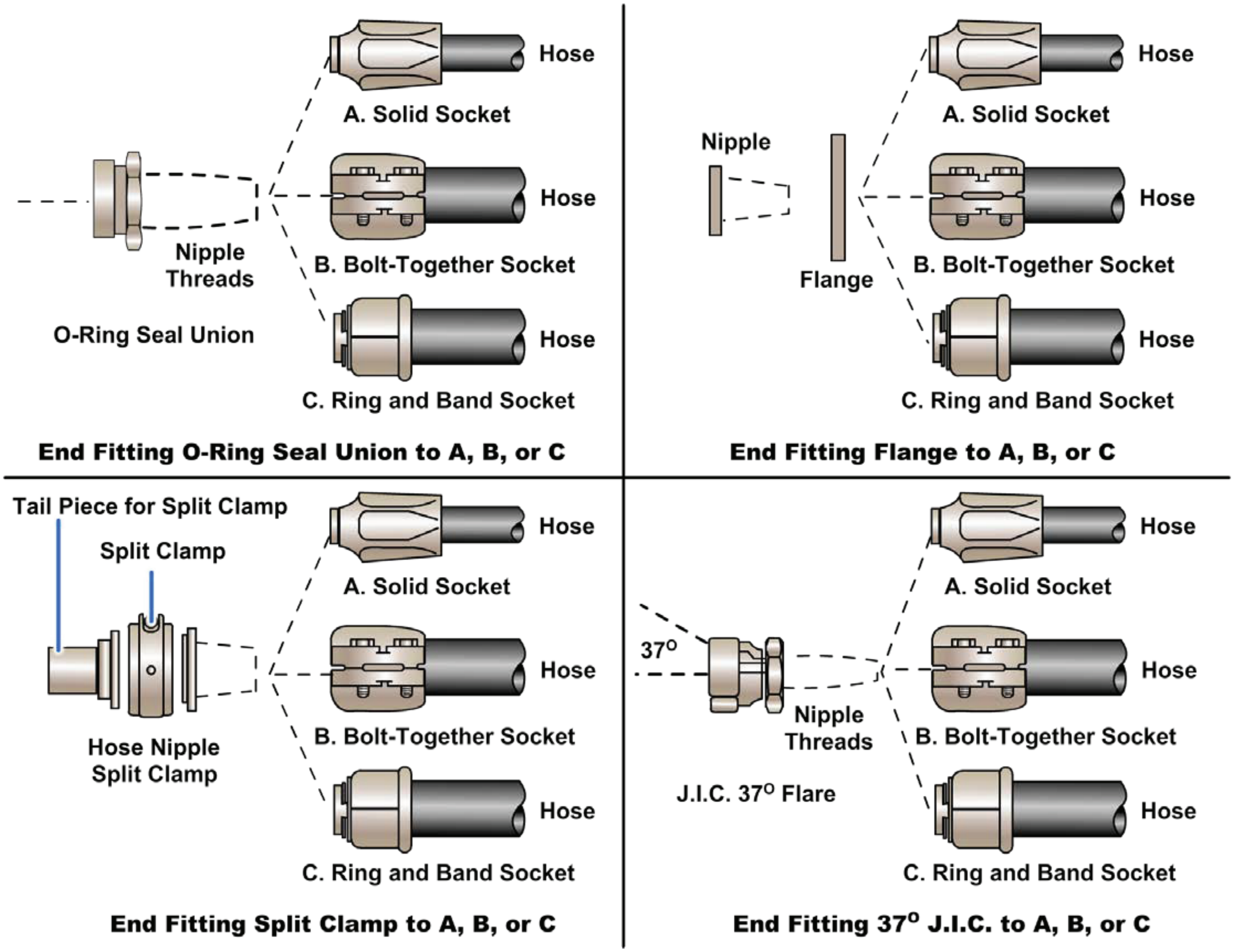


Figure 5-22 — End fittings and hose fittings.

Piping Connection Side of Hose Fitting

The piping side of an end fitting comes with several connecting variations: flange, Joint Industry Council (JIC) 37-degree flare, O-ring union, and split clamp, to name a few. Not all varieties are available for each hose. Therefore, installers must consult the military specification and manufacturer's data to determine the specific end fittings available.

Hose Connection Side of Hose Fitting

Hose fittings are attached to the hose by several methods. Each method is determined by the fitting manufacturer and takes into consideration such things as size, construction, wall thickness, and pressure rating. Hoses used for flexible connections use one of the following methods for attachment of the fitting to the hose.

One-Piece Reusable Socket

The socket component of the fitting is fabricated as a single piece. One-piece reusable sockets are screwed or rocked onto the hose OD, followed by insertion of the nipple component.

Segmented, Bolted Socket

The segmented, bolted socket consists of two or more segments which are bolted together on the hose after insertion of the nipple component.

Segmented Socket, Ring and Band Attached

The segmented, ring and band attached socket consists of three or more segments. As with the bolt-together segments, the segments, ring and band are put on the hose after insertion of the nipple. A special tool is required to compress the segments.

Segmented Socket, Ring and Bolt Attached

The segmented, ring and bolt attached socket consists of three or more segments. As with other segmented socket-type fittings, the segments, ring, and nuts and bolts are put on the hose after insertion of the nipple.

Solid Socket, Permanently Attached

This type of socket is permanently attached to the hose by crimping or swaging. It is not reusable and is only found on hose assemblies where operating conditions preclude the use of other fitting types. Hose assemblies with this type of fitting attachment are purchased as complete hose assemblies from the manufacturer.

QUICK-DISCONNECT COUPLINGS

Self-sealing, quick-disconnect couplings are used at various points in many fluid power systems. These couplings are installed at locations where frequent uncoupling of the lines is required for inspection, test, and maintenance. Quick-disconnect couplings are also commonly used in pneumatic systems to connect sections of air hose and to connect tools to the air pressure lines. This provides a convenient method of attaching and detaching tools and sections of lines without losing pressure.

Quick-disconnect couplings provide a means for quickly disconnecting a line without the loss of fluid from the system or the entrance of foreign matter into the system. Several types of quick-disconnect couplings have been designed for use in fluid power systems. A coupling that is used with portable pneumatic tools is illustrated in *Figure 5-23*. The male section is connected to the tool or to the line leading from the tool. The female section, which contains the shutoff valve, is installed in the pneumatic line leading from the pressure source. These connectors can be separated or connected by very little effort on the part of the operator.

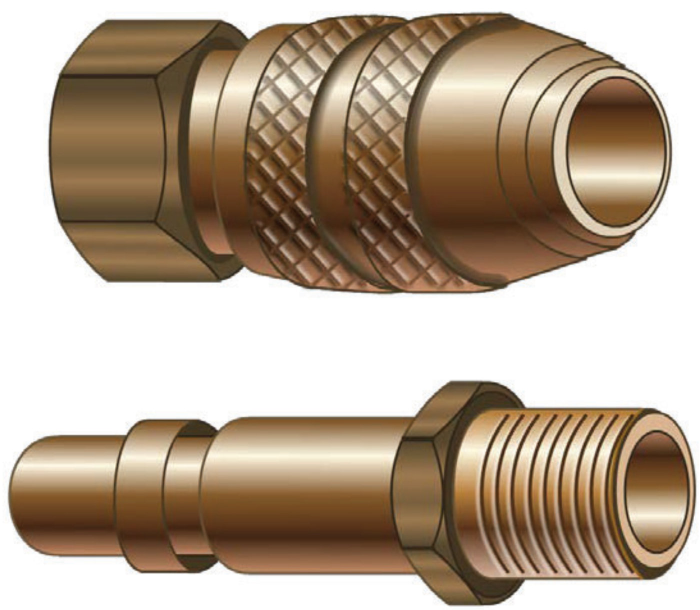


Figure 5-23 — Quick-disconnect coupling for air lines.

The most common quick-disconnect coupling for hydraulic systems consists of two parts, held together by a union nut. Each part contains a valve which is held open when the coupling is connected, allowing fluid to flow in either direction through the coupling. When the coupling is disconnected, a spring in each part closes the valve, preventing the loss of fluid and entrance of foreign matter.

MANIFOLDS

Some fluid power systems are equipped with manifolds in the pressure supply and/or return lines. A manifold is a fluid conductor that provides multiple connection ports. Manifolds eliminate piping, reduce joints (which are often a source of leakage), and conserve space. For example, manifolds may be used in systems that contain several subsystems. One common line connects the pump to the manifold. There are outlet ports in the manifold to provide connections to each subsystem. A similar manifold may be used in the return system. Lines from the control valves of the subsystem connect to the inlet ports of the manifold, where the fluid combines into one outlet line to the reservoir. Some manifolds are equipped with the check valves, relief valves, filters, and so on, required for the system. In some cases, the control valves are mounted on the manifold in such a manner that the ports of the valves are connected directly to the manifold.

Manifolds are usually one of three types—sandwich, cast, or drilled. The sandwich-type is constructed of three or more flat plates. The center plate (or plates) is machined for passages, and the required inlet and outlet ports are drilled into the outer plates. The plates are then bonded together to provide a leakproof assembly. The cast-type of manifold is designed with cast passages and drilled ports. The casting may be iron, steel, bronze, or aluminum, depending upon the type of system and fluid medium. In the drilled-type of manifold, all ports and passages are drilled in a block of metal.

A simple manifold is illustrated in *Figure 5-24*. This manifold contains one pressure inlet port and several pressure outlet ports that can be blocked off with threaded plugs. This type of manifold can be adapted to systems containing various numbers of subsystems. A thermal relief valve may be incorporated in this manifold. In this case, the port labeled T is connected to the return line to provide a passage for the relieved fluid to flow to the reservoir.

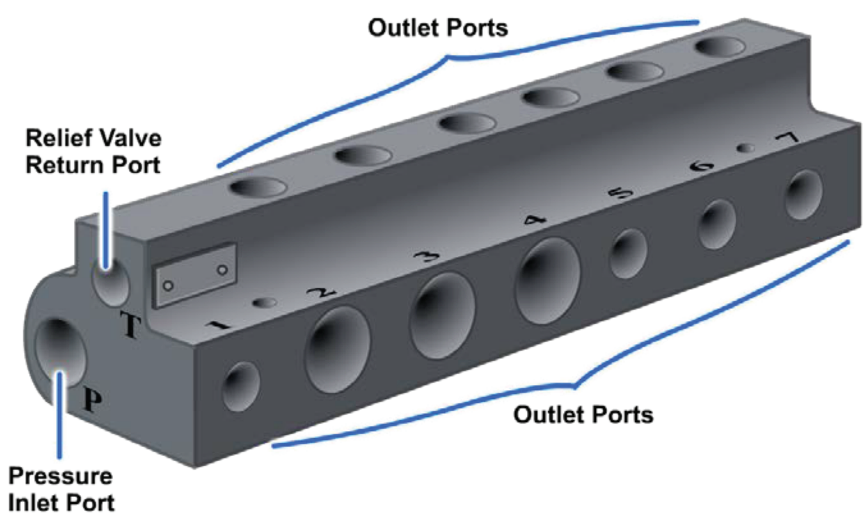


Figure 5-24 — Fluid manifold.

A flow diagram in a manifold (*Figure 5-25*) shows both pressure and return passages. One common line provides pressurized fluid to the manifold, which distributes the fluid to any one of five outlet ports. The return side of the manifold is similar in design. This manifold is provided with a relief valve, which is connected to the pressure and return passages. In the event of excessive pressure, the relief valve opens and allows the fluid to flow from the pressure side of the manifold to the return side.

PRECAUTIONARY MEASURES

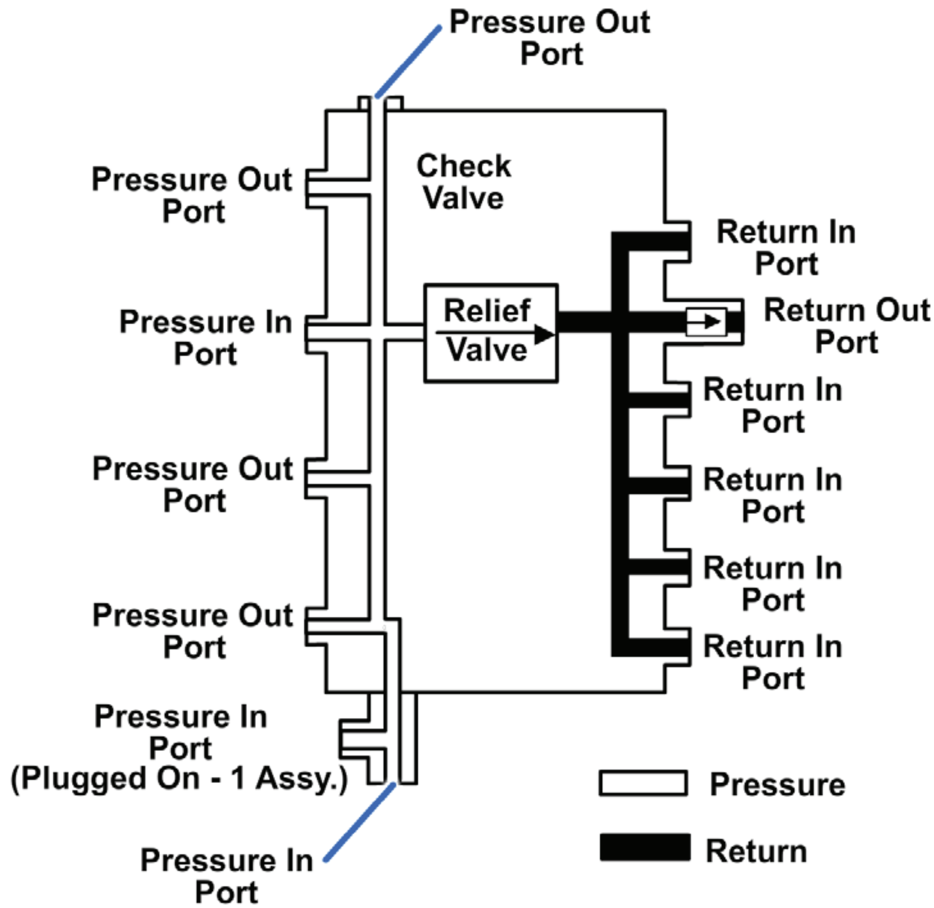


Figure 5-25 — Fluid manifold—flow diagram.

The fabrication, installation, and maintenance of all fluid lines and connectors are beyond the scope of this training manual. However, there are some general precautionary measures that apply to the maintenance of all fluid lines.

Regardless of the type of lines or connectors used to make up a fluid power system, they must be the correct size and strength and perfectly clean on the inside. All lines must be absolutely clean and free from scale and other foreign matter. Iron or steel pipes, tubing, and fittings can be cleaned with a boiler tube wire brush or with commercial pipe cleaning apparatus. Rust and scale can be removed from short, straight pieces by sandblasting, provided there is no danger that sand particles will remain lodged in blind holes or pockets after the piece is flushed. In the case of long pieces or pieces bent to complex shapes, rust and scale can be removed by pickling (cleaning metal in a chemical bath). Parts must be degreased prior to pickling. The manufacturer of the parts should provide complete pickling instructions.

Open ends of pipes, tubing, hose, and fittings should be capped or plugged when they are to be stored for any considerable period. Rags or waste must not be used for this purpose, because they deposit harmful lint which can cause severe damage to the fluid power system.

APPENDIX I

GLOSSARY

ABSOLUTE TEMPERATURE—The temperature measured using absolute zero (-273.16 degrees Celsius or -459.69 degrees Fahrenheit) as a reference.

ACCELERATION—The increase in the rate or speed of an object.

ACCUMULATOR—A device for storing liquid under pressure. It usually consists of a chamber separated into a gas compartment and a liquid compartment by a piston or diaphragm. An accumulator also serves to smooth out pressure surges in a hydraulic system.

ACTUATOR—A device that converts fluid power into mechanical force and motion.

ADDITIVE—A chemical compound or compounds added to a fluid to change its properties.

AIR, COMPRESSED—Air at any pressure greater than atmospheric pressure.

AMBIENT—Surrounding, such as ambient air, meaning surrounding air.

BAROMETER—An instrument that measures atmospheric pressure.

BAROMETER, ANEROID—Uses the change in shape of an evacuated metal cell (aneroid) to measure variations in atmospheric pressure.

BERNOULLI'S PRINCIPLE—If a fluid flowing through a tube reaches a constriction, or narrowing of the tube, the velocity of the fluid flowing through the constriction increases and the pressure decreases.

BOYLE'S LAW—The absolute pressure of a fixed mass of gas varies inversely with the volume, provided the temperature remains constant.

CAVITATION—A localized gaseous condition within a liquid stream that occurs where the pressure is reduced to the vapor pressure.

CELSIUS—The temperature scale using the freezing point of water as zero and the boiling point as 100, with 100 equal divisions between, called degrees. This scale was formerly known as the centigrade scale.

CENTIGRADE—(See Celsius.)

CENTRIFUGAL FORCE—A force exerted on a rotating object in a direction outward from the center of rotation.

CHARLES' LAW—If the pressure is constant, the volume of dry gas varies directly with the absolute temperature.

CHEMICAL CHANGE—A change that alters the composition of the molecules of a substance.

CIRCUIT—An arrangement of interconnected component parts.

CLOSED-CENTER SYSTEM—A type of fluid power system in which fluid is pressurized any time a power pump is operated.

COMPRESSIBILITY—The change in volume of a unit volume of a fluid when it is subjected to a unit change of pressure.

COMPRESSOR—A device that converts mechanical force and motion into pneumatic fluid power.

COMPUTER—A device capable of accepting information, applying prescribed processes to the information, and supplying the results of these processes.

CONDENSATION—The change from a gaseous (or vapor) state to a liquid state.

CONTAMINATION—Any foreign material or substance whose presence in a fluid is capable of adversely affecting system performance or reliability.

CONTINUITY EQUATION—The mass rate of fluid flow into any fixed space is equal to the mass flow rate out. Therefore, the mass flow rate of fluid past all cross sections of a conduit is equal.

CONTROL—A device used to regulate the function of a component or system.

CONTROL, CYLINDER—A control in which a fluid cylinder is the actuating device.

CONTROL, ELECTRIC—A control actuated electrically.

CONTROL, HYDRAULIC—A control actuated by a liquid.

CONTROL, MANUAL—A control actuated by the operator.

CONTROL, MECHANICAL—A control actuated by linkages, gears, screws, cams, or other mechanical elements.

CONTROL, PNEUMATIC—A control actuated by air or other gas pressure.

CONTROL, SERVO—A control actuated by a feedback system that compares the output with the reference signal and makes corrections to reduce the difference.

CONTROLS, PUMP—Controls applied to positive-displacement variable delivery pumps to adjust their volumetric output or direction of flow.

CONVERGENT—That which inclines and approaches nearer together, as the inner walls of a tube that is constricted.

COOLER—A heat exchanger, which removes heat from a fluid.

COOLER, AFTERCOOLER—A device that cools a gas after it has been compressed.

COOLER, INTERCOOLER—A device that cools a gas between the compressive steps of a multiple stage compressor.

COOLER, PRECOOLER—A device that cools a gas before it is compressed.

CORROSION—The slow destruction of materials by chemical agents and electromechanical reactions.

CYCLE—A single complete operation consisting of progressive phases starting and ending at the neutral position.

CYLINDER—A device that converts fluid power into linear mechanical force and motion. It usually consists of a movable element, such as a piston and piston rod, plunger, or ram, operating within a cylindrical bore.

CYLINDER, CUSHIONED—A cylinder with a piston-assembly deceleration device at one or both ends of the stroke.

CYLINDER, DOUBLE-ACTING—A cylinder in which fluid force can be applied to the movable element in either direction.

CYLINDER, DOUBLE-ROD—A cylinder with a single piston and a piston rod extending from each end.

CYLINDER, DUAL-STROKE—A cylinder combination that provides two working strokes.

CYLINDER, PISTON—A cylinder in which the movable element has a greater cross-sectional area than the piston rod.

CYLINDER, PLUNGER—A cylinder in which the movable element has the same cross-sectional area as the piston rod.

CYLINDER, SINGLE-ACTING—A cylinder in which the fluid force can be applied to the movable element in only one direction.

CYLINDER, SINGLE-ROD—A cylinder with a piston rod extending from one end.

CYLINDER, SPRING-RETURN—A cylinder in which a spring returns the piston assembly.

CYLINDER, TANDEM—Two or more cylinders with interconnected piston assemblies.

CYLINDER, TELESCOPING—A cylinder with nested multiple tubular rod segments, which provide a long working stroke in a short retracted envelope.

DENSITY—The weight per unit volume of a substance.

DIAGRAM, COMBINATION—A drawing using a combination of graphical, cutaway, and pictorial symbols.

DIAGRAM, CUTAWAY—A drawing showing principal internal parts of all components, controls, and actuating mechanisms, all interconnecting lines, and functions of individual components.

DIAGRAM, GRAPHICAL—A drawing or drawings showing each piece of apparatus, including all interconnecting lines, by approved standard symbols.

DIAGRAM, PICTORIAL—A drawing showing each component in its actual shape according to the manufacturer's installation.

DIAGRAM, SCHEMATIC—See **DIAGRAM, GRAPHICAL.**

DIAPHRAGM—A dividing membrane or thin partition.

DIFFUSER—A duct of varying cross section designed to convert a high-speed gas flow into low-speed flow at an increased pressure.

DISPLACEMENT—The volume of fluid that can pass through a pump, motor, or cylinder in a single revolution or stroke.

DIVERGENT—Moving away from each other, as the inner wall of a tube that flares outward.

EDUCTOR—A jet-type pump with no moving parts that is designed to pump large volumes of water.

EFFICIENCY—The ratio of the output power to the input power, generally expressed as a percentage.

ENERGY—The ability or capacity to do work.

EQUILIBRIUM—A state of balance between opposing forces or actions.

FAHRENHEIT—The temperature scale using the freezing point of water as 32 and the boiling point as 212, with 180 equal divisions between, called degrees.

FEEDBACK—A transfer of energy from the output of a device to its input.

FILTER—A device whose primary function is the retention by a porous media of insoluble contaminants from a fluid.

FILTER ELEMENT—The porous device that performs the actual process of filtration.

FILTER MEDIA—The porous materials that perform the actual process of filtration.

FILTER MEDIA, SURFACE—Porous materials that primarily retain contaminants on the influent face.

FIRE POINT—The temperature at which a substance gives off vapor in a sufficient quantity to ignite and continue to burn when exposed to a spark or flame.

FLASHPOINT—The temperature to which a liquid must be heated under specified test conditions to give off sufficient vapor to form a mixture with air that can be ignited momentarily by a specified flame.

FLOW, LAMINAR—A flow situation in which fluid moves in parallel layers (also referred to as streamline flow).

FLOW, METERED—Flow at a controlled rate.

FLOW, TURBULENT—A flow situation in which the fluid particles move in a random manner.

FLOW RATE—The volume, mass, or weight of a fluid passing through any conductor per unit of time.

FLOWMETER—An instrument used to measure quantity or the flow rate of a fluid motion.

FLUID—A liquid or a gas.

FLUID FLOW—The stream or movement of a fluid, or the rate of its movement.

FLUID FRICTION—Friction due to the viscosity of fluids.

FLUID, FIRE-RESISTANT—A fluid, difficult to ignite, which shows little tendency to propagate flame.

FLUID, HYDRAULIC—A fluid suitable for use in a hydraulic system.

FLUID, PETROLEUM—A fluid composed of petroleum oil. It may contain additives.

FLUID, PHOSPHATE ESTER BASE—A fluid that contains a phosphate ester as one of the major components.

FLUID, SILICONE—A fluid composed of silicones. It may contain additives.

FLUID, WATER-GLYCOL—A fluid whose major constituents are water and one or more glycols or polyglycols.

FLUID STABILITY—Resistance of a fluid to permanent change in properties.

FLUID POWER—Energy transmitted and controlled through the use of fluids under pressure.

FLUID POWER SYSTEM—A system that transmits and controls power through use of a pressurized fluid within an enclosed circuit.

FOAMING—An emulsion of gas bubbles in a fluid. Foaming in a hydraulic system results from compressed gases in the hydraulic fluid.

FOOT-POUND—The amount of work accomplished when a force of 1 pound produces a displacement of 1 foot.

FORCE—The action of one body on another tending to change the state of motion of the body acted upon.

FREE FLOW—Flow that encounters negligible resistance.

FRICTION—The action of one body or substance rubbing against another, such as fluid flowing against the walls of pipe; the resistance to motion caused by this rubbing.

FRICTION PRESSURE DROP—The decrease in the pressure of a fluid flowing through a passage attributable to the friction between the fluid and the passage walls.

GAS—The form of matter that has neither a definite shape nor a definite volume.

GASKET—A class of seals that provides a seal between two stationary parts.

GAUGE—An instrument or device for measuring, indicating, or comparing a physical characteristic.

GAUGE PRESSURE—Pressure above atmospheric pressure.

GAUGE SNUBBER—A device installed in the line to the pressure gauge used to dampen pressure surges and thus provide a steady reading and protection for the gauge.

GAUGE, BELLOWS—A gauge in which the sensing element is a convoluted closed cylinder. A pressure differential between the outside and the inside causes the cylinder to expand or contract axially.

GAUGE, BOURDON TUBE—A pressure gauge in which the sensing element is a curved tube that tends to straighten out when subjected to internal fluid pressure.

GAUGE, DIAPHRAGM—A gauge in which the sensing element is relatively thin and its inner portion is free to deflect with respect to its periphery.

GAUGE, PRESSURE—A gauge that indicates the pressure in the system to which it is connected.

GAUGE, VACUUM—A pressure gauge for pressures less than atmospheric.

GRAVITY—The force that tends to draw all bodies toward the center of the earth. The weight of a body is the resultant of gravitational force acting on the body.

HEAD—The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the fluid.

HEAD, FRICTION—The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type, and condition of conductors and fittings, and fluid characteristics.

HEAD, STATIC—The height of a column or body of fluid above a given point.

HEAD, VELOCITY—The equivalent head through which the liquid would have to fall to attain a given velocity. Mathematically it is equal to the square of the velocity (in feet) divided by 64.4 feet per second squared.

HEAT EXCHANGER—A device that transfers heat through a conducting wall from one fluid to another.

HYDRAULICS—Engineering science pertaining to liquid pressure and flow.

HYDRAULIC POWER DRIVE SYSTEM—Typically consists of an outside power source, hydraulic pump, hydraulic motor, control signal, and mechanical shafting and gearing.

HYDROMETER—An instrument for determining the specific gravities of liquids.

HYDROPNEUMATICS—Pertaining to the combination of hydraulic and pneumatic fluid power.

HYDROSTATICS—Engineering science pertaining to the energy of liquids at rest.

IMPACT PRESSURE—The pressure of a moving fluid brought to rest that is in excess of the pressure the fluid has when it does not flow; that is, total pressure less static pressure. Impact pressure is equal to dynamic pressure in incompressible flow; but in compressible flow, impact pressure includes the pressure change owing to the compressibility effect.

IMPINGEMENT—The striking or dashing upon with a clash or sharp collision, as air impinging upon the rotor of a turbine or motor.

IMPULSE TURBINE—A turbine driven by a fluid at high velocity under relatively low pressure.

INERTIA—The tendency of a body at rest to remain at rest, and a body in motion to continue to move at a constant speed along a straight line, unless the body is acted upon in either case by an unbalanced force.

INHIBITOR—Any substance that slows or prevents chemical reactions such as corrosion or oxidation.

INVERSE PROPORTION—The relation that exists between two quantities when an increase in one of them produces a corresponding decrease in the other.

KELVIN SCALE—The temperature scale using absolute zero as the zero point and divisions that are the same size as centigrade degrees.

KINETIC ENERGY—The energy that a substance has while it is in motion.

KINETIC THEORY—A theory of matter that assumes that the molecules of matter are in constant motion.

LINE—A tube, pipe, or hose that is used as a conductor of fluid.

LIQUID—A form of matter that has a definite volume but takes the shape of its container.

LOAD—The power that is being delivered by any power-producing device. Also, the equipment that uses the power from the power-producing device.

LUBRICATOR—A device that adds controlled or metered amounts of lubricant into a fluid power system.

MANIFOLD—A type of fluid conductor that provides multiple connections ports.

MANOMETER—A differential pressure gauge in which pressure is indicated by the height of a liquid column of known density. Pressure is equal to the difference in vertical height between two connected columns multiplied by the density of the manometer liquid. Some forms of manometers are U-tube, inclined tube, well, and bell types.

MATTER—Any substance that occupies space and has weight.

MECHANICAL ADVANTAGE—The ratio of the resisting weight to the acting force. The ratio of the distance through which the force is exerted divided by the distance the weight is raised.

METER-IN—To regulate the amount of fluid into a system or an actuator.

METER-OUT—To regulate the flow of fluid from a system or actuator.

MICRON—A millionth of a meter or about 0.00004 inch.

MOLECULE—A small natural particle of matter composed of two or more atoms.

MOTOR—A device that converts fluid power into mechanical force and motion. It usually provides rotary mechanical motion.

MOTOR, FIXED-DISPLACEMENT—A motor in which the displacement per unit of output motion cannot be varied.

MOTOR, LINEAR—(See Cylinder.)

MOTOR, ROTARY—A motor capable of continuous rotary motion.

MOTOR, ROTARY LIMITED—A rotary motor having limited motion.

MOTOR, VARIABLE-DISPLACEMENT— A motor in which the displacement per unit of output motion can be varied.

NEOPRENE—A synthetic rubber highly resistant to oil, light, heat, and oxidation.

NEUTRALIZATION NUMBER—A measure of the total acidity or basicity of an oil; this includes organic or inorganic acids or bases or a combination of them.

OPEN-CENTER SYSTEM—A type of fluid power system that circulates fluid from a reservoir, through selector valves, and then back to a reservoir.

OXIDATION—The process by which oxygen unites with some other substance, causing rust or corrosion.

PACKING—A class of seal that is used to provide a seal between two parts of a unit that move in relation to each other.

PASCAL'S LAW—A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

PERIPHERY—The outside surface, especially that of a rounded object or body.

PIPE—A type of fluid line whose dimensions are designated by nominal (approximate) inside diameter and wall thickness.

PNEUMATICS—Engineering science pertaining to gaseous pressure and flow.

PORT—An internal or external terminus of a passage in a component.

POTENTIAL ENERGY—The energy a substance has because of its position, its condition, or its chemical composition.

POUR POINT—The lowest temperature at which a liquid will flow under specified conditions.

POWER UNIT—A combination of pump, pump drive, reservoir, controls, and conditioning components that may be required for the unit's application.

POWER—The rate of doing work or the rate of expanding energy.

PRESSURE—The amount of force distributed over each unit of area, usually expressed in pounds per square inch.

PRESSURE, ABSOLUTE—The sum of atmospheric and gauge pressures.

PRESSURE, ATMOSPHERIC—Pressure exerted by the atmosphere at any specific location.

PRESSURE, BACK—The pressure encountered on the return side of a system.

PRESSURE, DIFFERENTIAL—The difference in pressure between any two points of a system or a component.

PRESSURE, HEAD—The pressure due to the height of a column or body of fluid. It is usually expressed in feet.

PRESSURE, OPERATING—The pressure at which a system operates.

PRESSURE, PRECHARGE—The pressure of compressed gas in an accumulator prior to the admission of a liquid.

PRESSURE, PROOF—The nondestructive test pressure in excess of the maximum rated operating pressure.

PRESSURE, STATIC—The pressure in a fluid at rest.

PRESSURE SWITCH—An electrical switch operated by the increase or decrease of fluid pressure.

PRIME MOVER—The source of mechanical power used to drive the pump or compressor.

PUMP—A device that converts mechanical force and motion into hydraulic fluid power.

RANKINE SCALE—A thermometer scale based on absolute zero of the Fahrenheit scale, in which the freezing point of water is approximately 492 degrees Rankine (°R).

RATIO—The value obtained by dividing one number by another, indicating their relative proportions.

RECEIVER—A container in which gas is stored under pressure as a supply source for pneumatic power.

RECIPROCATING—Moving back and forth, as in a piston reciprocating in a cylinder.

RESERVOIR—A container for storage of liquid in a fluid power system.

RESPONSE TIME—The time lag between a signal input and the resulting change of output.

RESTRICTOR—A device that reduces the cross-sectional flow area.

RESTRICTOR, ORIFICE—A restrictor, the length of which is relatively small with respect to its cross-sectional area. The orifice may be fixed or variable. Variable types are non-compensated, pressure compensated, or pressure and temperature compensated.

RETURN LINE—A line used for returning fluid back into the reservoir or atmosphere.

SEPARATOR—A device whose primary function is to isolate undesirable fluids and or contaminants by physical properties other than size.

SERVO—A device used to convert a small movement into a greater movement of force.

SOLID—The form of matter that has a definite shape and a definite volume.

SPECIFIC GRAVITY—The ratio of the weight of a given volume of a substance to the weight of an equal volume of some standard substance.

STEADY FLOW—A flow in which the velocity, pressure, and temperature at any point in the fluid do not vary with time.

STRAINER—A coarse filter.

STUFFING BOX—A cavity and closure with manual adjustment for a sealing device.

SUPPLY LINE—A line that conveys fluid from the reservoir to the pump.

SURGE—A momentary rise of pressure in a circuit.

SYNCHRONIZE—To make two or more events or operations occur at the proper time with respect to each other.

SYNTHETIC MATERIAL—A complex chemical compound that is artificially formed by the combining of two or more simpler compounds or elements.

TANK—A container for the storage of fluid in a fluid power system.

THEORY—A scientific explanation, tested by observations and experiments.

THERMAL EXPANSION—The increase in volume of a substance due to temperature change.

TORQUE—A force or combination of forces that produces or tends to produce a twisting or rotary motion.

TOXICITY—The quality, state, or degree of being toxic or poisonous. Some liquids contain chemicals that are a serious hazard.

TUBING—A type of fluid line whose dimensions are designated by actual measured outside diameter and by actual measured wall thickness.

TURBINE—A rotary motor actuated by the reaction, impulse, or both, of a flow of pressurized fluid.

VALVE—A device that controls fluid flow direction, pressure, or flow rate.

VELOCITY—The rate of motion in a particular direction. The velocity of fluids is usually expressed in feet per second.

VENTURI—A tube having 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, the amount being a function of the velocity of flow.

VISCOSITY—A measure of the internal friction or resistance of a fluid to flow.

VISCOSITY INDEX—A measure of the viscosity-temperature characteristics of a fluid as referred to that of two arbitrary reference fluids.

VISCOSITY, SAYBOLT UNIVERSAL SECONDS (SUS)—The time in seconds for 60 milliliters of oil to flow through a standard orifice at a given temperature.

VISCOSITY, KINEMATIC—The absolute viscosity divided by the density of the fluid. It is usually expressed in centistokes.

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 for liquids and cubic feet per minute for gases.

WORK—The transference of energy from one body or system to another. That which is accomplished by a force acting through a distance.

APPENDIX II

REFERENCES

> **NOTE**
>
> Although the following references were current when this NRTC 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 Rate Training Manual User Update Form provided at the end of each chapter to contact the SWOS Rate Training Manager.

Chapter 1

Airman, NAVEDTRA 14014A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, December 2012.

Construction Mechanic Basic, NAVEDTRA 14264A, Center for Seabees and Facilities Engineering (CSFE), Port Hueneme, CA, October 2010.

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

Chapter 2

Airman, NAVEDTRA 14014A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, December 2012.

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

Construction Mechanic Basic, NAVEDTRA 14264A, Center for Seabees and Facilities Engineering (CSFE), Port Hueneme, CA, October 2010.

"Hydraulic Equipment (Power Transmission and Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command (NAVSEA), Washington, DC, December 2012.

Chapter 3

"Afloat Hazardous Material Control and Management Guidelines Hazardous Material Users Guide (HMUG)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 670, Volume 2, Naval Sea Systems Command, Washington, DC, June 2012.

Aviation Hydraulics Manual, NAVAIR 01-1A-17, Commander, Naval Air Systems Command, Patuxent River, MD, August 2008.

Environmental Readiness Program, OPNAVINST 5090.1(series), Chief of Naval Operations, Washington, DC, 10 January 2014.

"Gaskets and Packing," *Naval Ships' Technical Manual* (*NSTM*), Chapter 078, Volume 2, Naval Sea Systems Command (NAVSEA), Washington, DC, September 1998.

"Hydraulic Equipment (Power Transmission and Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command (NAVSEA), Washington, DC, December 2012.

Navy Safety and Occupational Health (*SOH*) *Program Manual for Forces Afloat*, OPNAVINST 5100.19(series), Volume 1, Chief of Naval Operations, Washington, DC, May 2007.

Chapter 4

Engineman, NAVEDTRA 14075A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

"Pumps," *Naval Ships' Technical Manual* (*NSTM*), Chapter 503, Naval Sea Systems Command (NAVSEA), Washington, DC, January 2009.

Chapter 5

Aviation Hydraulics Manual, NAVAIR 01-1A-17, Naval Air Systems Command, Patuxent River, MD, August 2008.

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

Hull Maintenance Technician, NAVEDTRA 14119, Surface Warfare Officers School (SWOS), Newport, RI, June 1995.

"Piping Systems," *Naval Ships' Technical Manual* (*NSTM*), Chapter 505, Naval Sea Systems Command (NAVSEA), Washington, DC, April 2013.

Chapter 6

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

"Piping Systems," *Naval Ships' Technical Manual* (*NSTM*), Chapter 505, Naval Sea Systems Command (NAVSEA), Washington, DC, April 2013.

"Pressure, Temperature and other Mechanical and Electromechanical Measuring Instruments," *Naval Ships' Technical Manual* (*NSTM*), Chapter 504, Naval Sea Systems Command (NAVSEA), Washington, DC, September 2012.

Chapter 7

Construction Mechanic Basic, NAVEDTRA 14264A, Center for Seabees and Facility Engineering (CSFE), Port Hueneme, CA, October 2010.

"Gaskets and Packing," *Naval Ships' Technical Manual* (*NSTM*), Chapter 078, Volume 2, Naval Sea Systems Command (NAVSEA), Washington, DC, September 1998.

"Hydraulic Equipment (Power and Transmission Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command (NAVSEA), Washington, DC, December 2012.

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

Chapter 8

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), Newport, RI, September 2013.

"Pressure, Temperature and other Mechanical and Electromechanical Measuring Instruments," *Naval Ships' Technical Manual* (*NSTM*), Chapter 504, Naval Sea Systems Command (NAVSEA), Washington, DC, September 2012.

Chapter 9

Aviation Hydraulics Manual, NAVAIR 01-1A-17, Commander, Naval Air Systems Command (NAVAIR), Patuxent River, MD, August 2008.

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

"Hydraulic Equipment (Power Transmission and Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command (NAVSEA), Washington, DC, December 2012.

Chapter 10

Airman, NAVEDTRA 14014A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, December 2012.

Construction Mechanic Basic, NAVEDTRA 14264A, Center for Seabees and Facility Engineering (CSFE), Port Hueneme, CA, October 2010.

"Hydraulic Equipment (Power Transmission and Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command, (NAVSEA), Washington, DC, December 2012.

Chapter 11

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

Machinist's Mate (*Surface*), NAVEDTRA 14150A, Surface Warfare Officers School (SWOS), September 2013.

"Pressure, Temperature and other Mechanical and Electromechanical Measuring Instruments," *Naval Ships' Technical Manual* (*NSTM*), Chapter 504, Naval Sea Systems Command (NAVSEA), Washington, DC, September 2012.

Chapter 12

"Afloat Hazardous Material Control and Management Guidelines Hazardous Materials Users Guide (HMUG)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 670, Volume 2, Naval Sea Systems Command (NAVSEA), Washington, DC, June 2012.

Aviation Structural Mechanic, NAVEDTRA 14315A, Center for Naval Aviation Technical Training (CNATT), Pensacola, FL, March 2011.

Engineering Drawing and Related Documentation Practices, ASME Y14.100, The American Society of Mechanical Engineers (ASME), 22 Law Drive, P O, Box 2900, Fairfield, NJ 07007-2900.

"Hydraulic Equipment (Power Transmission and Control)," *Naval Ships' Technical Manual* (*NSTM*), Chapter 556, Naval Sea Systems Command (NAVSEA), Washington, DC, December 2012.

Navy Blueprint Reading and Sketching, NAVEDTRA 14040, Surface Warfare Officers School (SWOS), Newport, RI, October 2003.

Navy Safety and Occupational Health (*SOH*) *Program Manual for Forces Afloat*, OPNAVINST 5100.19(series), Volume 1, Chief of Naval Operations, Washington, DC, May 2007.

"Propulsion Reduction Gears, Couplings, Clutches, and Associated Components," Naval Ships' Technical Manual (NSTM), Chapter 241, Naval Sea Systems Command (NAVSEA), Washington, DC, March 2012.

Ships' Maintenance and Material Management (*3-M*) *Manual*, NAVSEAINST 4790.8C, Naval Sea Systems Command (NAVSEA), Washington, DC, 14 March 2013.

Ships' Maintenance and Material Management (*3-M*) *System Policy*, Chief of Naval Operations, Washington, DC, 31 October 2007.

APPENDIX III

GRAPHIC SYMBOLS FOR FLUID POWER DIAGRAMS

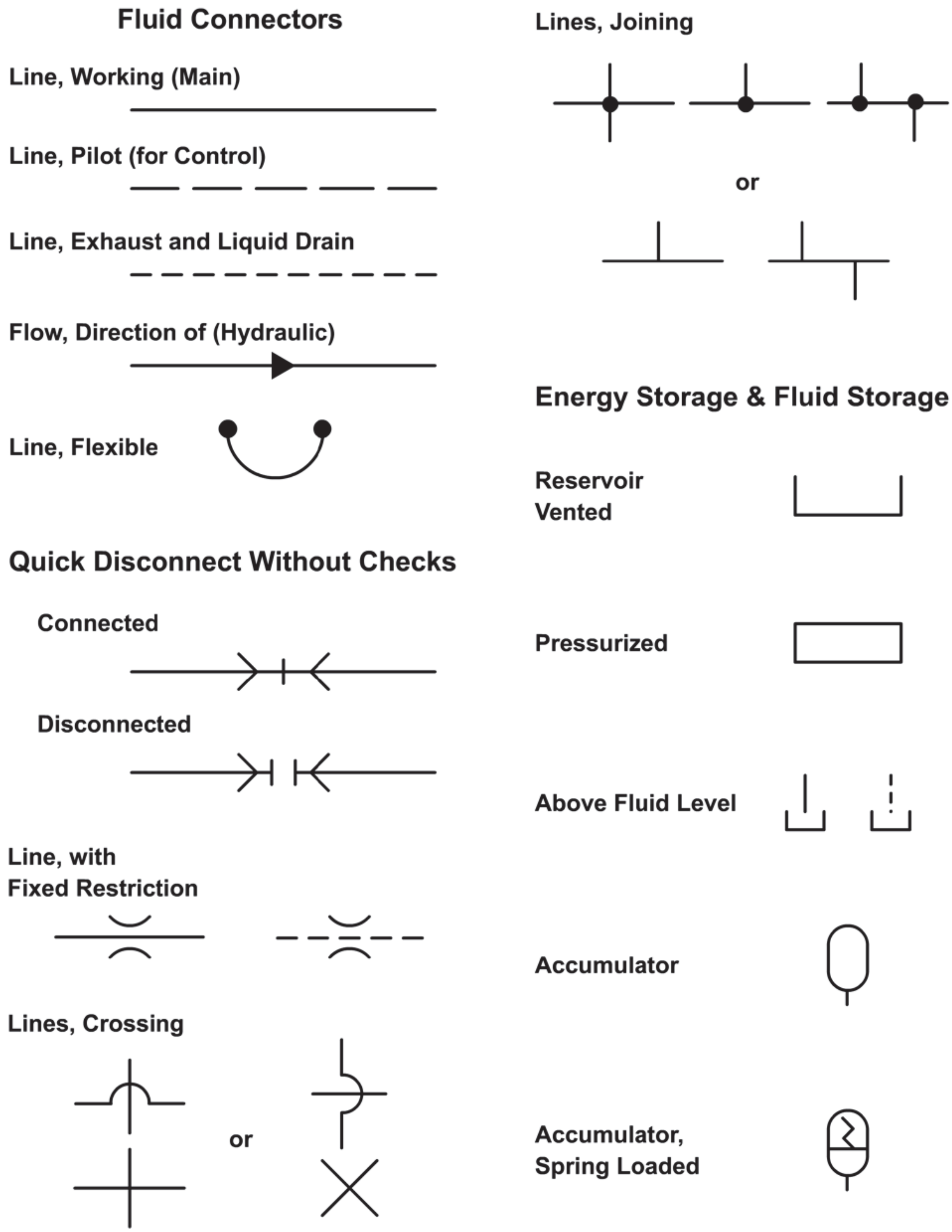


Figure AIII-1 — Fluid power graphic symbols.

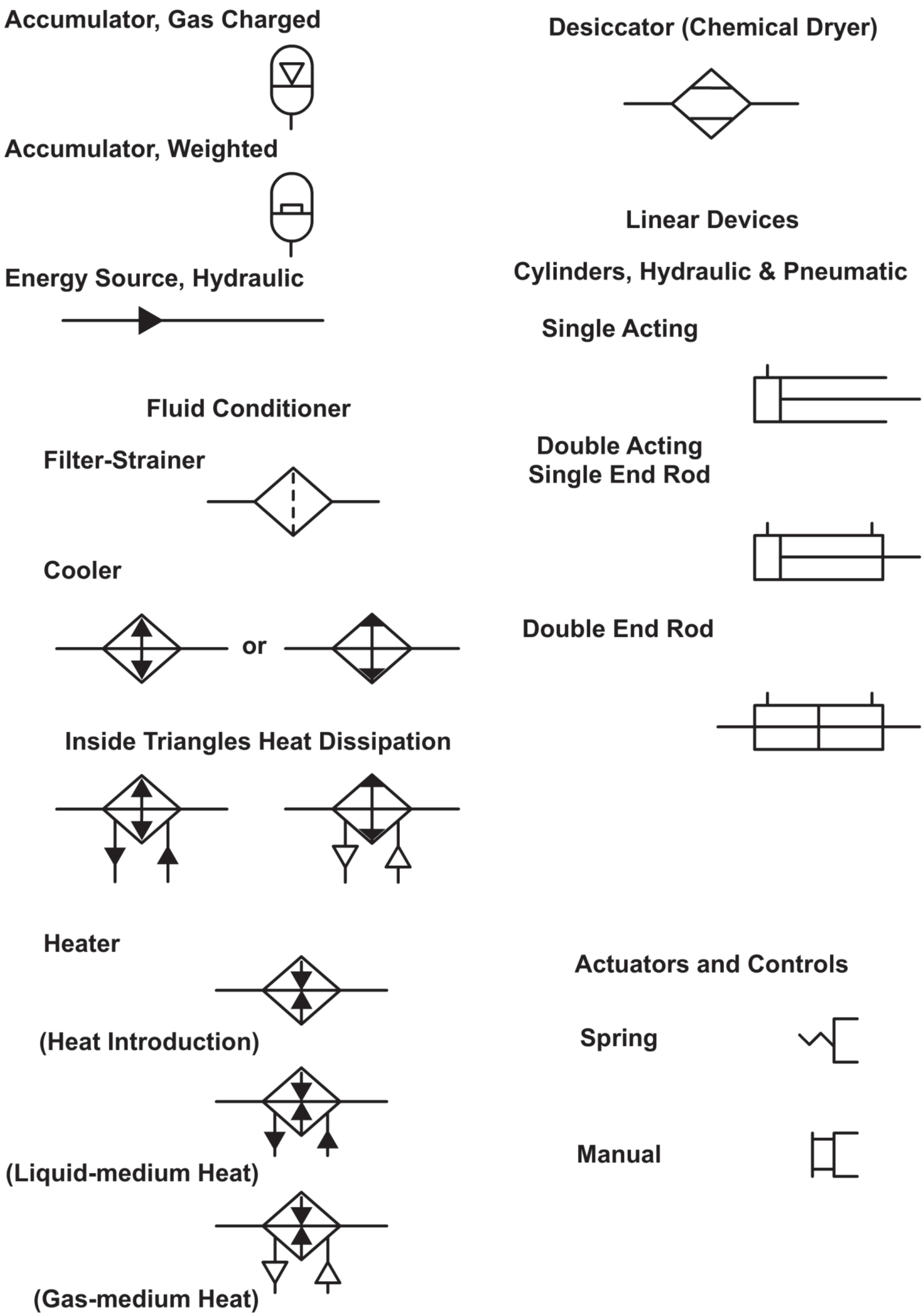


Figure AIII-1 — Fluid power graphic symbols (continued).

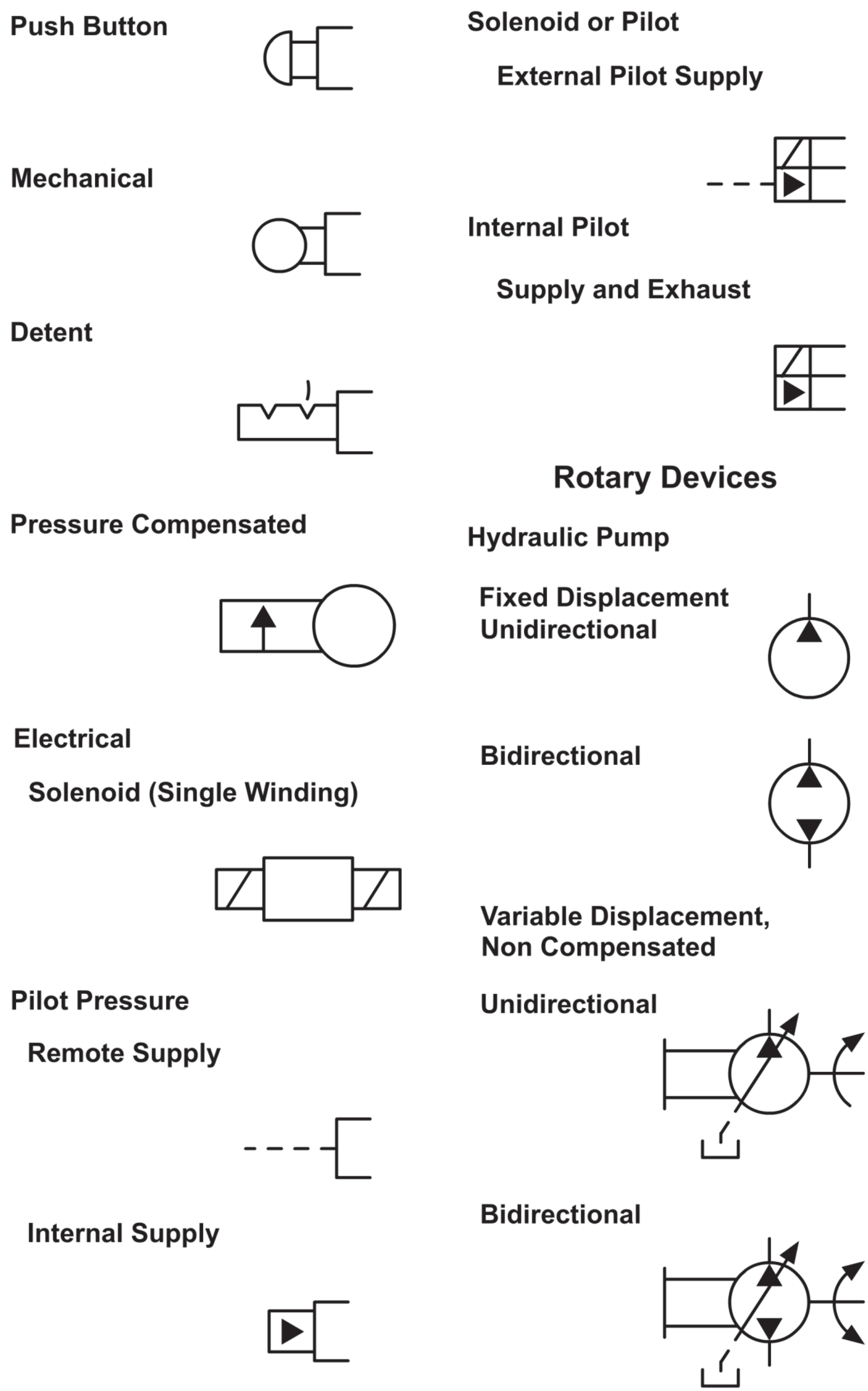


Figure AIII-1 — Fluid power graphic symbols (continued).

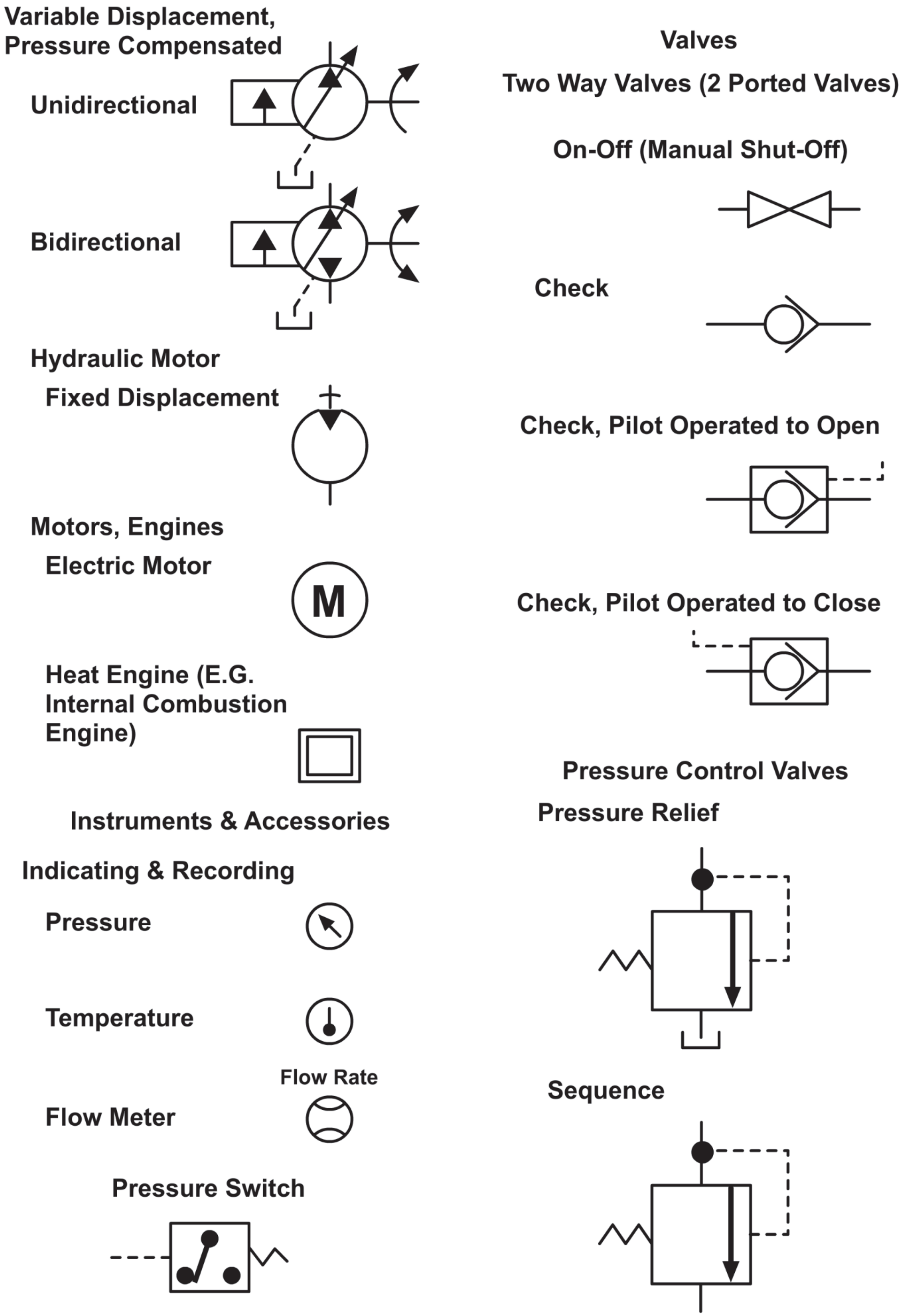


Figure AIII-1 — Fluid power graphic symbols (continued).

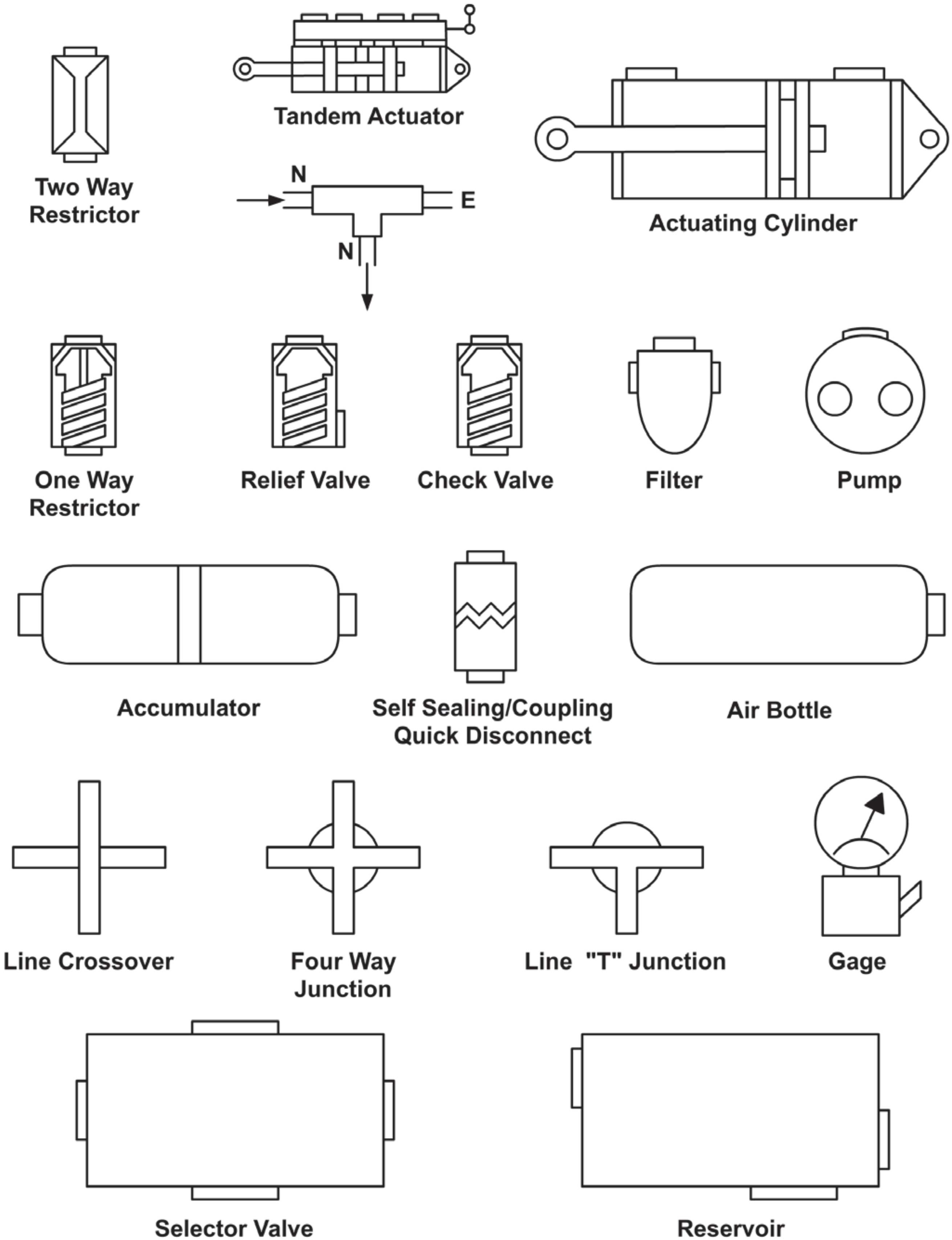


Figure AIII-1 — Fluid power graphic symbols (continued).

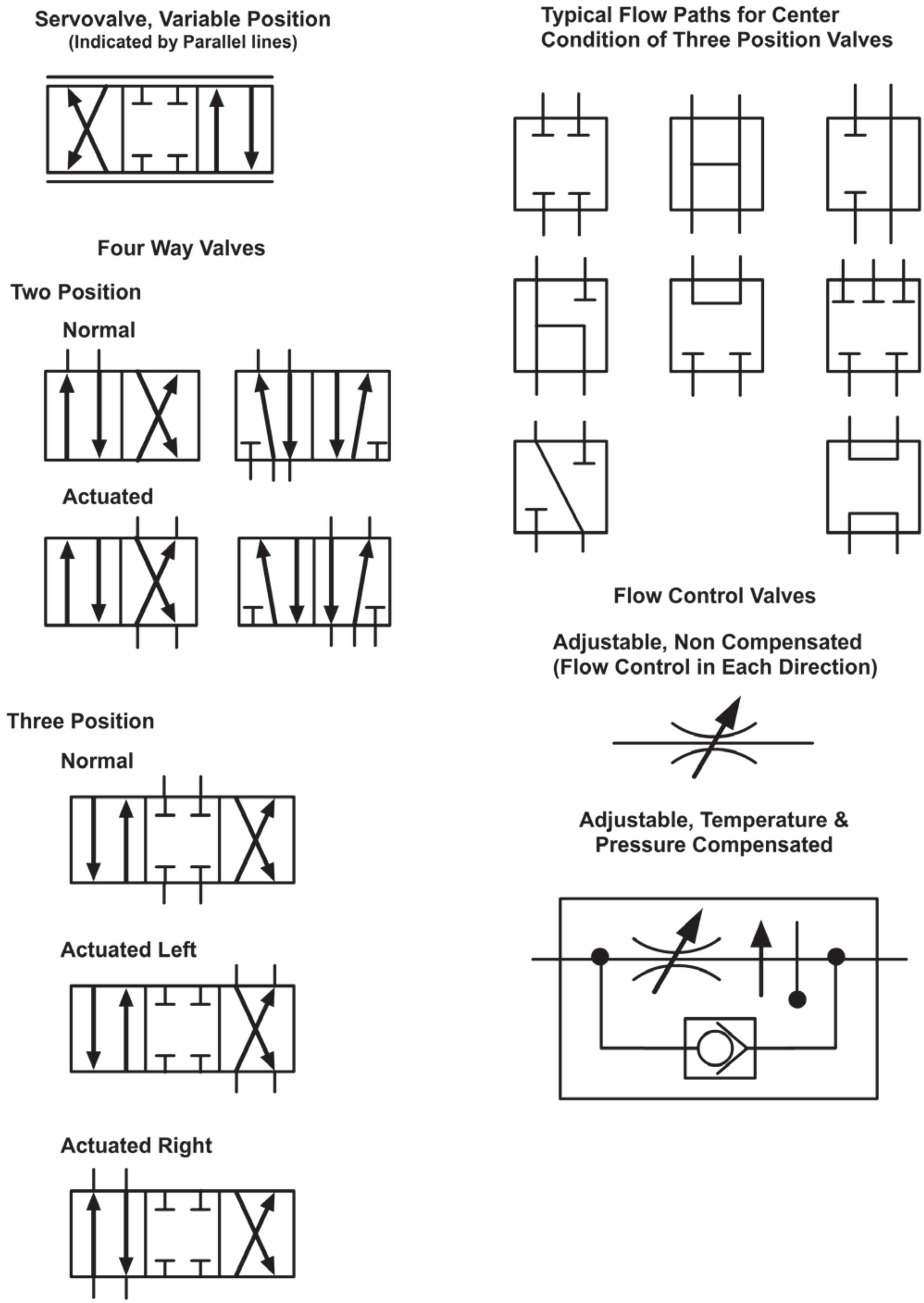


Figure AIII-1 — Fluid power graphic symbols (continued).