Chapter 1

Introduction to Gear Engineering

1.1 INTRODUCTION AND HISTORY OF GEARS

1.1.1 Introduction

A gear is basically a toothed wheel that works in tandem with another gear (or gears) to transmit power and/or motion to change speed and/or direction of motion. Dudley defined a gear as "a geometric shape that has teeth uniformly spaced around the circumference and is made to mesh its teeth with another gear" [1]. Slipping is a major problem during transmission of motion and power between two shafts by rope or belt drive and consequently may affect the precision and efficiency of the system adversely. This slipping phenomenon is largely avoided by means of gear drives. The compact layout, flexibility, high efficiency, and reliability are the most important features that make gears and gear drives the first choice in many applications. Gear sizes range from nanometers (nanogears) to meters (macrogears) with corresponding application areas from nanoelectromechanical systems (NEMS) to large mills and wind turbines. A wide range of materials ranging from plastics and ceramics to ultrahigh strength steels are used in gear manufacture.

Gears and subsequently the gear manufacturing industry plays an integral role in many industrial sectors as it is one of the basic mechanical components used for transmission of motion and/or power in equipment, machines, and instruments. Several conventional and advanced methods of gear manufacture are available for use in specialized applications to produce gears that are fit for purpose. Technological advancements in gear engineering over the last few decades have enabled the gear industry to produce near-net shaped and high-quality gears by short process chains and a lower environmental footprint.

1.1.2 History

The writings of Aristotle (4th century B.C.) reflect some of the earliest reference to gears and their use [2]. He specifically noted that the direction of rotation is reversed when one gear wheel drives another. Water-lifting devices, in the form of 'Persian wheels', were used in the 3rd century B.C. Animals such

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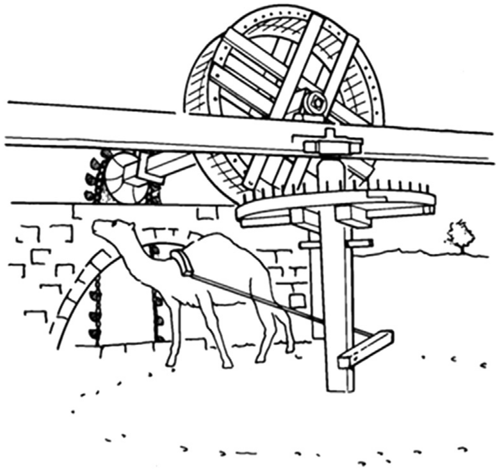


FIGURE 1.1 'Persian wheel': A water-lifting gearing mechanism used during 3rd century. *Source: Reproduced with permission from P.L. Fraenkel, Water lifting devices, FAO irrigation and Drainage Paper 43, Corporate Document Repository, Food and Agriculture Organization of the United Nations, Rome, 1986 [4].*

as camels, bullocks, and buffaloes were used to drive these devices that were typically associated with open wells. In this arrangement, an animal driven horizontal toothed wheel was meshed into a vertical toothed wheel that was then used to lift water containers that were attached to another geared mechanism (Fig. 1.1). Later on, this method was successfully adopted for use in water-driven grain mills and other devices. During the 3rd century, Archimedes also developed a device (Antikythera mechanism) that was equipped with numerous gears to simulate positions of astronomical bodies [3]. The sketchbooks of Leonardo da Vinci, dating to the mid 1400s, depict various unique gear mechanisms. Initially, wood was the material of choice for gear manufacture until it was subsequently replaced by cast iron.

A more advanced approach to gear engineering came into being at around 1400 with more comprehensive use of science and mathematics in gear design and the associated mechanisms. The first major investigation into gear design as regards to proving the benefits of the involute curve over a cycloidal was conducted by Philip de la Hire in France and later confirmed by a Swiss mathematician Leonard Euler who was responsible for the law of conjugate action [1]. The industrial revolution in England during the 18th century led to the use of cycloidal gears for clocks, irrigation devices, water mills, and powered machines. Further uses were rapidly developed and explored with the invention of the locomotive, vehicles, and other machines. Gear hobbing and shaping technologies were developed in the early 19th century providing the foundation for fabrication of better quality commercial gears. Various new gear types, materials, and surface treatment techniques were introduced during the 19th century. Further advancement in gear manufacturing, measurement techniques, and testing technologies during the late 19th and in early 20th centuries led the way for significant growth in its application in industry.

1.2 CLASSIFICATION AND GEAR TYPES

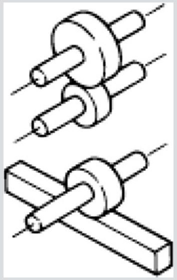
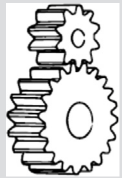
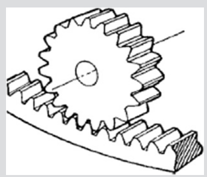
A wide range of gear types exist to fulfill various different application requirements. Gears and gear systems are usually classified according to the orientation/arrangement of its associated rotational axes. Gears are therefore classified as parallel-shaft gears, intersecting-shaft gears and nonparallel nonintersecting-shaft gears (refer Table 1.1). The details regarding these three categories and the corresponding gear types are discussed in detail in the following subsections.

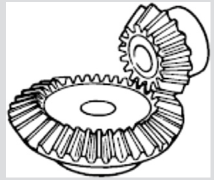
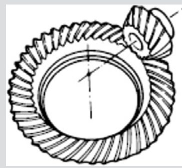
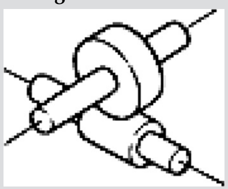
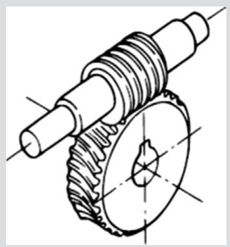
1.2.1 Parallel-Shaft Gears

The first and most common class of the gear is where the shaft axes are in the same plane and parallel to one another. The gear teeth may be either cut straight (spur gear) or inclined (helical) and may be of either external or internal configurations. These gears can be either cylindrical or linear-shaped gears, and are used in three main transmission arrangements: External, internal, and rack and pinion.

Spur gears are one of the most extensively used types of parallel-shaft gears. These gears have straight teeth cut parallel to the shaft axis. Engagement by spur gears occurs between two parallel shafts or between a shaft and a rack. The larger of two engaged gears are referred to as the 'gear,' while the smaller is referred to as the 'pinion' regardless of which gear is being driven or acting as the driver. The external configuration of spur gears implies that the driver gear rotates in an opposite direction to the driven gear. A **rack-and-pinion** configuration is a special category of parallel-shaft gears, where transmission occurs by meshing a rack (shaftless linear-shaped gear) and a pinion (cylindrical gear wheel). The rack-and-pinion configuration is extensively used in machine tools and other devices to convert linear motion into rotary motion and vice versa. A s**pur rack** is essentially a gear wheel with an infinite radius (Fig. 1.2) that engages a spur gear (pinion) with any number of teeth. An internal spur gear is made with the teeth cut on the inside face of a cylindrical gear which engages with an externally configured gear of matching teeth pattern with both rotating in the same direction (Fig. 1.3). The internal gear is usually referred to as the ring gear or annulus and is often used in planetary gear systems. The best functional performance requires that the diameter of ring gear be at least 1.5 times that of the mating external gear.

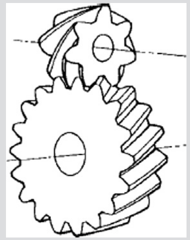
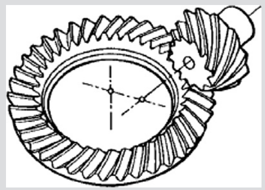
TABLE 1.1 The Three Major Categories of Gear Classification and Corresponding Gear Types

Categories of Gears (Based on the Orientation of Gear Shafts)	Types of Gears	Representation	Features, Applications and Methods of Manufacture
Parallel-shaft gears 	**Spur gears**		Features: Simple to design and manufacture, highest efficiency, easy to assemble, offer excellent precision, high wear and noisy operation
			Applications: Automotive transmission; Industrial drives; Machine tools; Motors and pumps; Agriculture equipment; Scientific instruments; Electronic devices; Large mills
			Methods of Manufacture: Hobbing, shaping, milling, broaching, casting, extrusion, stamping, powder metallurgy, forging, rolling, grinding, shaving, lapping, honing
	Helical gears		Features: High strength, smooth action, silent operation, offer good precision, axial thrust complications
			Applications: Automotive transmission; High-speed drives and machines; Rolling mills; Robotics; Agricultural equipment
			Methods of Manufacture: Hobbing, milling, shaping, casting, extrusion, stamping, powder metallurgy, forging, rolling, grinding, shaving, honing, lapping
	Rack and pinion		Features: Efficiently convert rotary motion to linear and vice versa; Flexibility
			Applications: Materials handling, linear actuators, power-steering system, machine tools, traveling gantries, robots, positioning systems, stair lifts
			Methods of Manufacture: Milling, shaping, broaching, casting, grinding, shaving, honing

Intersecting-shaft gears  	**Straight bevel gears**		Features: Greater flexibility, permit angular transmission, suitable for low-speed drives, significant thrust loads, noisy
			Applications: Differential gear systems of machines and automobiles, hand and power tools, marine transmission, power plants, steel plants, railway track inspection machines, textile machines, cooling towers, cement mixers, material-handling equipments, robotics
			Methods of Manufacture: Face milling, face hobbing, two-tool generating, Revacycle method, planning, powder metallurgy, shell molding (casting), forging, grinding, lapping
	Spiral bevel gears		Features: Greater load-carrying capacity; Smoother, quieter, and preferred over straight bevel gears at greater speeds, high overall contact ratio, complex tooth shape, high thrust loads
			Applications: Vehicle differential, rotary-wing aircraft drive system, mining machines, mobile cranes, dumpers, cone crushers, locomotives, machine tools
			Methods of Manufacture: Face-milling, face-hobbing, two-tool generating, planning, forging, grinding, lapping
Nonparallel nonintersecting-shaft gears 	**Worm and worm wheel**		Features: Compact, high ratio speed reduction, minimum backlash, low efficiency, high thrust loads
			Applications: Speed reducers, antibacklash drives, indexing devices, machine tools, rolling mills, presses, conveyor systems, marine transmission
			Methods of Manufacture: Milling, hobbing, shaping, grinding, lapping

(*Continued*)

TABLE 1.1 (Continued)

Categories of Gears (Based on the Orientation of Gear Shafts)	Types of Gears	Representation	Features, Applications and Methods of Manufacture
	Cross-helical (screw) gears		Features: Poor precision rating, allows wide range of speed ratios without changing gear size and center distance, high sliding loads between the teeth
			Applications: Light-load applications; Speed reducers; Agriculture equipment; Tractors; Electric motors, pump drives, substitute for bevel gears
			Methods of Manufacture: Hobbing, shaping, milling, grinding, shaving, lapping, honing
	Hypoid gears		Features: High strength and rigidity, stronger, and quieter than spiral bevel gears, withstand shock-loads, large speed reduction is possible, high reliability, uniform motion, high contact pressure between teeth requires extreme lubrication
			Applications: Industrial machines, automobile differential, speed reducers, agricultural equipment
			Methods of Manufacture: Face hobbing, Face milling, planing, powder metallurgy, grinding, lapping

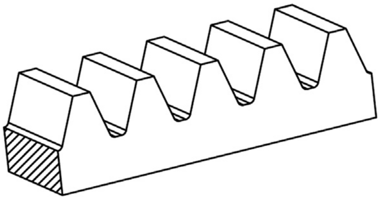


FIGURE 1.2 Spur rack.

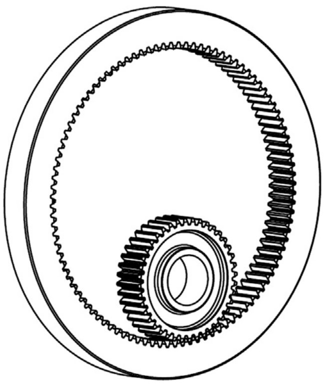


FIGURE 1.3 Internal spur gear.

Because of the straight-tooth nature of spur gears, they are simple in configuration and easy to manufacture. When engaged, spur gears make line contact; whereas during rotation, the contact is mostly of a rolling nature. The mechanical efficiency of spur gears is therefore high. However, these gears suffer from a major drawback in the form of noise and vibration that is the result of the simultaneous contact of teeth upon engagement that results in a continuous shock loading across the entire tooth face. Therefore, spur gears are mostly suitable for low to medium speed applications.

Helical gears are the second most extensively used parallel-shaft gear type. The teeth of these gears are cut in the form of a helix and at an angle to the shaft axis. Typically, helix angles of between 8 to 30° are used with maximum values up to 45° employed in applications where large resultant axial thrust forces are to be avoided [5]. Helix angles may be of either right-hand or left-hand orientation. The teeth of a left-hand gear lean to the left and the teeth of a right-hand gear lean to the right when the gear is placed on a flat surface (as shown in Fig. 1.4A and B). The helix angles of two engaged helical gears must be the same but of opposite orientation for

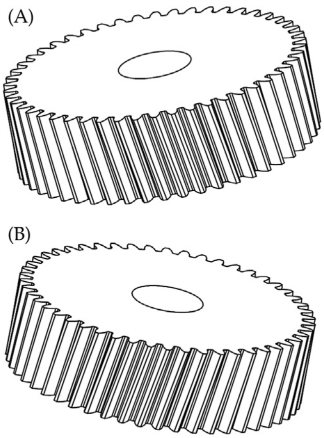


FIGURE 1.4 (A) Left-hand helical gear; (B) right-hand helical gear.

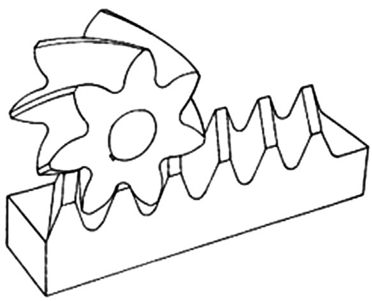


FIGURE 1.5 Helical rack-and-pinion arrangement.

engagement to be possible. Fig. 1.5 illustrates the engagement of a liner-shaped **helical rack** and pinion of same helix angle but of opposite orientation.

Because of the inclined teeth pattern, two or more teeth remain in contact at any given instant during engagement of a pair of helical gears ensuring gradual contact, which provides a smooth and quiet operation. In general, the mechanical strength of helical gears is also higher when compared with spur gears. Despite the advantage of higher strength and therefore greater load-carrying capacity along with lower noise and vibration than an equivalent-size spur gear, the associated thrust force along the rotational axis present major difficulties. It may lead to increased power losses, increased design complications (need for thrust bearings), and reduced system life due to untimely failure.

Double helical gears overcome the problem of thrust loads by counter-balancing them. A double helical gear incorporates two opposite orientated

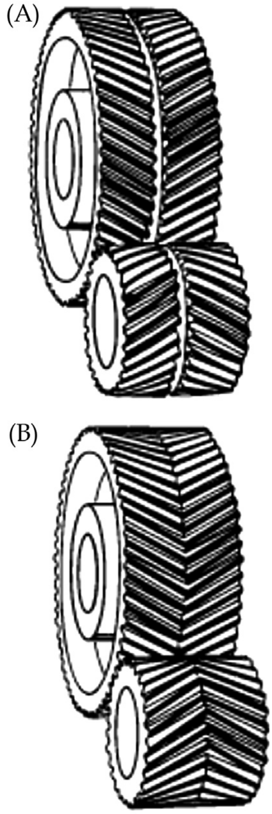


FIGURE 1.6 (A) Double helical gear; (B) herringbone gear.

helical gears of the same helix angle together such that the two opposing thrust forces annihilates one another. The two opposing helixes permit multiple tooth engagement and eliminate end thrust. There are two important configurations for this gear: A double helical gear (Fig. 1.6A), where a small gap exists in between the two opposing helixes and a herringbone gear (Fig. 1.6B), where the opposing helical gears are joined together without this gap.

Internal helical gear arrangements are also possible and comprises of a ring gear with helical teeth cut onto its inside face along with a small external gear (pinion) of same helix angle and orientation.

1.2.2 Intersecting-Shaft Gears

In this gear arrangement, the shaft axes intersect although they are in same plane. The most extensively used configuration is the right angle system, where the two engaged gear shafts are at 90° to each other. This right-angled arrangement is best accomplished by conical-shaped **bevel gears**. There are two basic classes of bevel gears i.e., straight bevel gear and spiral bevel gear. The tapered nature of the bevel gear implies an axial thrust onto the support bearings similar to helical gears.

Straight bevel gears are the simplest to produce and the most widely applied conical gear type. These gears have straight teeth cut along the pitch cone that if extended would intersect with the shaft axis (as shown in Fig. 1.7A and B). Moreover, the teeth are tapered in thickness along the face width and may have either constant or tapered height [6]. The areas of application of straight bevel gears are generally limited to low-speed drives, where vibration and noise may not be significant. These gears are however used for automobile differential gear system and other industrial applications.

Spiral bevel gears are more complex to manufacture because of the spiral (curved) teeth with helical angles (Fig. 1.8). Nonetheless, the curved and oblique teeth ensure gradual engagement with higher contact ratio when engaged and therefore results in smoother and quieter operation than equivalent straight-tooth bevel gears. A typical spiral angle used for these gears is 35° [5]. Spiral bevel gears are usually employed for high-speed applications (typically above 300 m/min) and large speed reduction ratio applications [7].

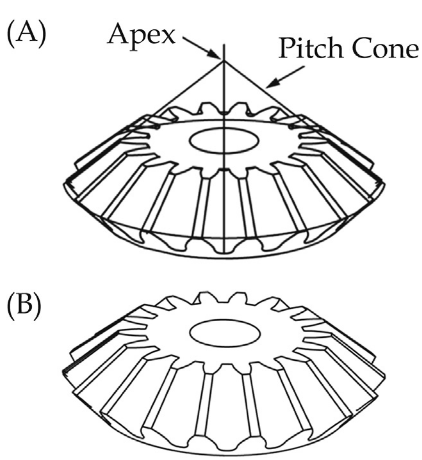


FIGURE 1.7 (A) Direction of teeth cut in straight bevel gear; (B) straight bevel gear.

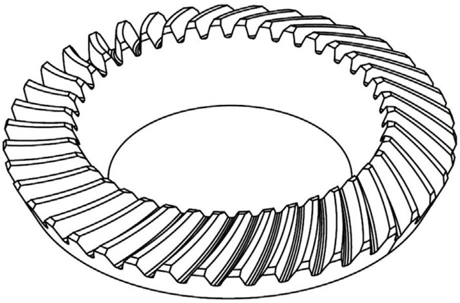


FIGURE 1.8 Spiral bevel gear.

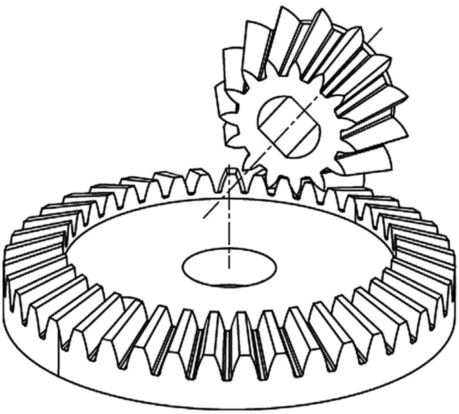


FIGURE 1.9 Zero bevel gear.

Zero bevel gears are another important type of bevel gear with curved teeth with zero spiral angles, which means that the teeth are not oblique (Fig. 1.9). In essence, this implies that the two tooth ends are in the same plane as the gear axis (coplanar). They possess characteristics of both straight and spiral bevel gears. Strength wise, they fall in between straight bevel and spiral gears and are therefore generally employed for medium-load applications. A typical choice of pressure angle for zero bevel gears ranges from 14.5 to 25°.

Miter bevel gears are a special class of bevel gear, where the gear shafts intersect at 90° (each of the two gears has a 45° pitch angle) and both gears have the same number of teeth i.e., the gear ratio is 1:1. Fig. 1.10 depicts a typical miter gear arrangement. Miter gears may be of straight or spiral tooth profile.

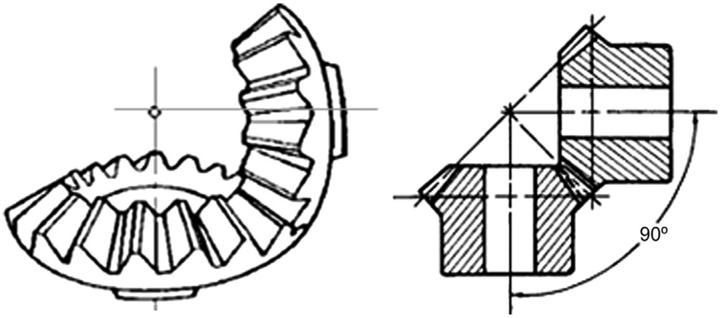


FIGURE 1.10 Miter bevel gear.

1.2.3 Nonparallel Nonintersecting-Shaft Gears

These are noncoplanar gears whose shaft axes can be aligned at any angle between 0 and 90°. Worm gears, hypoid gears, and cross-helical gears are the important gear types in this category.

Worm gears: A worm gearset consists of a worm wheel and a worm whose shafts are placed at a right angle to one other. Worm gears are mainly employed for high-ratio speed reduction in a limited space. The worm resembles a screw thread and meshes with a larger gear referred to as a worm gear (also called worm wheel) with teeth cut at various angles to be driven by the worm. This arrangement implies that large reduction ratios can be obtained with this gearset as a full rotation of the worm only advances the worm gear by the circumference associated with one tooth on the gear wheel. Although the transmission efficiency of worm gears is poor due to significant sliding motion, the screw action of this drive results in quiet and smooth operation. Speed reducers, indexing devices, machine tools, and antireversing gear drives are some of the important applications where worm gears are used.

The **Cylindrical Worm Gear** is the simplest form of worm gear where a straight cylindrical worm engages with a simple helical gear. Two other improved forms of worm gearsets also exist. These are single-enveloping and double-enveloping worm gears which differ as regards to the axial profile of the worm. A **single-enveloping worm gear** is shown in Fig. 1.11A, in which a straight-sided cylindrical worm meshes with a worm wheel which is essentially a throated helical gear and tends to wrap around the worm. This results in greater tooth contact area and thus smoother transmission with high load-carrying capacity. On the other hand, in a **double-enveloping worm gear** both gears are throated and wrap around each other (Fig. 1.11B). This mutual (two-sided) enveloping brings more teeth into contact and provides higher load-carrying capacity as compared with the other worm gear types mentioned above. The shape of the worm for a double-enveloping arrangement is referred to as an "hourglass".

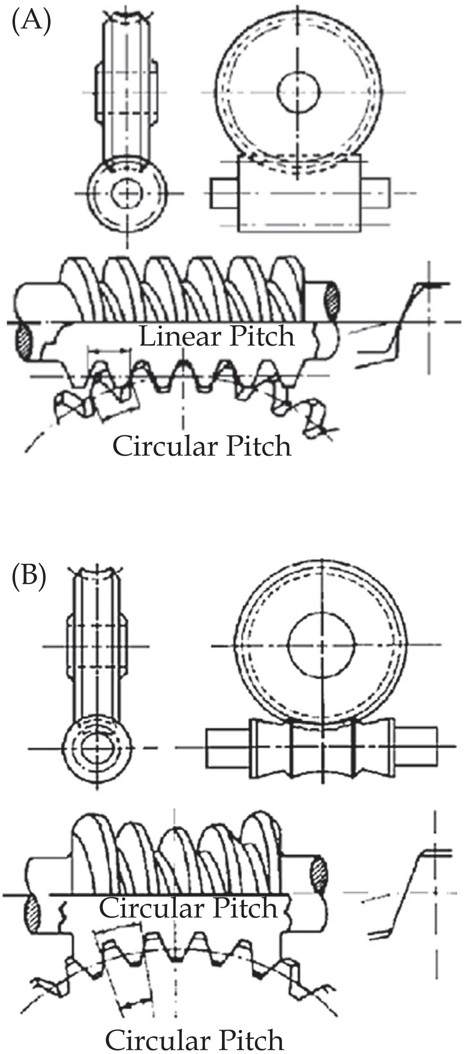


FIGURE 1.11 (A) A single-enveloping worm gearing; (B) a double-enveloping worm gearing.

Hypoid gears are similar to spiral bevel gears except that their pitch surfaces are hyperboloids rather than cones and the pinion axis is somewhat offset from the gear axis i.e., gear-shaft axes do not intersect. The general form of a pair of hypoid gears are shown in Table 1.1. Hypoid gears exhibit improved smoothness and lower noise when compared with spiral bevel gears due to the higher overall contact ratio. These gears find extensive applications in differential gear units in rear axles of automobiles with rear-wheel drives (Fig. 1.12).

Crossed-helical gears or **screw gears** resemble a gearing arrangement where two helical gears of either the same or opposite orientation meshes with

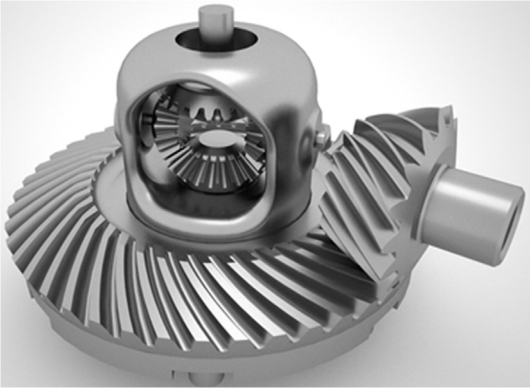


FIGURE 1.12 A typical bevel gear differential unit with straight bevel and hypoid gears.

their axes crossed at an angle. When installed in a crossed arrangement, they are also referred to as screw gears. Both of the engaged helical gears must have the same normal pressure angle and diametral pitch but may have different helix angles and orientations. Because of the sliding action and limited tooth contact area (point contact), the application domain for screw gears is limited to light loads only. These are not suitable for high-power transmission requirements. A typical arrangement of crossed-helical gearing is depicted in Table 1.1. Automatic machines that require intricate movements, pump drives, electrical motors, and cam-shafts of engines are some common applications of these gears.

1.2.4 Some Special Gear Types

Noncircular gears are specially designed gears used to transmit a unique motion and/or to convert speed in a nonconstant manner between two parallel axes shafts. These gears find applications in flow meters, textile machines, high-torque hydraulic engines, Geneva-mechanism, printing press equipment, pumps, packaging machines, potentiometers, conveyors, windshield wipers, robotic-mechanisms etc. The main purposes of these gears are to improve the function, versatility, and simplicity of the mechanical operations. Noncircular gears such as triangular, rectangular, square, elliptical, and oval-shaped gears are employed (as shown in Fig. 1.13) to perform a variety of mechanical functions, including complex displacement and velocity changes. Noncircular gears are also used as a viable substitute for cam-follower mechanism as they may provide a more compact and more accurate solution. Conversion of constant input speed into a variable output speed and stop-and-dwell motion requirements are efficiently handled by these gears. To fulfill these unique requirements noncircular gears of any particular shape can be assembled or meshed with gears of any other shape. Noncircular planetary gears are also used as effective motion convertors.

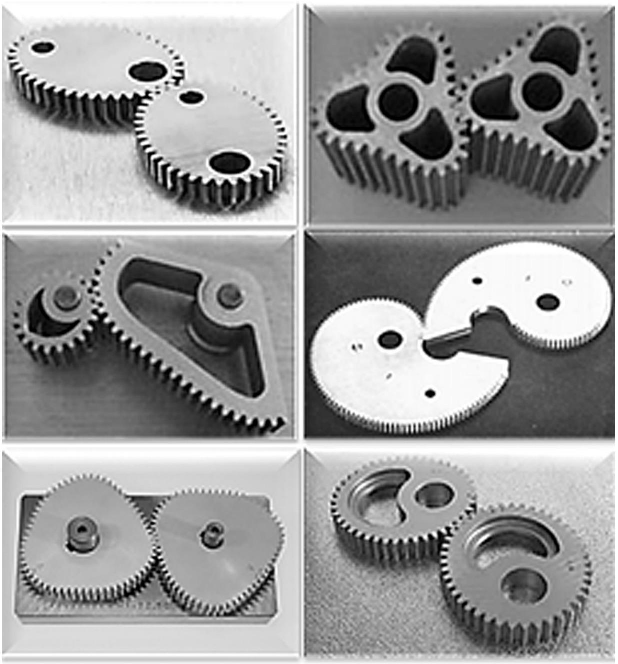


FIGURE 1.13 Various shapes of noncircular gears.

FIGURE 1.14 Close-up of a sector gear.

A **Sector gear** is a gear that has teeth cut along a section of its circumference only. The remaining portion of the gear is smooth without any teeth (Fig. 1.14). This arrangement may save space, material, and manufacturing costs. Sector gears are used in applications when less than 360° of rotation is required. These gears are typically used in applications such as valve actuators that only require 90° to open or close aircraft radar that scans through a limited angular range and X-ray machines etc. Spur, helical, bevel, and/or even worm gears may be used as sector gears and may be fabricated from most materials commonly used in gear manufacture.

A **Ratchet wheel** is a circular wheel provided with saw-shaped teeth (Fig. 1.15) that allows continuous rotational or intermittent motion in one direction but limits it in the other. Ratchets are widely used in machinery and tools. When used in a **pawl-and-ratchet mechanism**, as the ratchet wheel turns, the pawl which is a spring-loaded, finger-shaped element falls into the tooth cavity that then effectively "locks" the gear wheel from rotation in the opposite direction. A ratchet wheel can also be used to arrest motion. Common applications of this mechanism include mechanical clocks, ratchet spanners, winders, and jacks.

Splines are mechanical elements that have ridges or teeth on a shaft and that mesh with grooves cut in a hub in order to transfer torque and/or motion along the same axis. These are used in many mechanical drive systems. A splined shaft usually has equally spaced teeth around the circumference, which are most often parallel to the shaft's axis of rotation. These teeth can be straight sided, at an included angle, or of involute form. The externally splined shaft mates with an internal spline that has slots or spaces formed to

FIGURE 1.15 A ratchet wheel.

FIGURE 1.16 A typical splined connector.

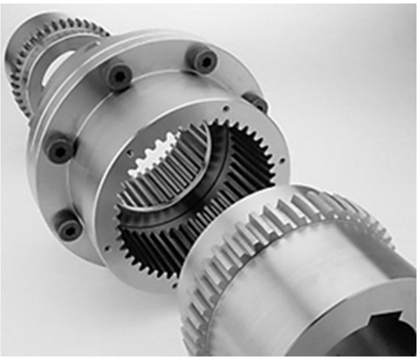


FIGURE 1.17 A flange-type gear coupling.

the reverse of the shaft's teeth. In other words, splines are always used as a combination of one external and one internal element. Fig. 1.16 shows a typical splined connector.

Splines are generally used in three types of applications: For coupling shafts when significant torque are to be transmitted without slippage; for transmitting power to gears, pulleys, and other rotating elements that are either fixed or mounted such that linear motion is possible (slide); and for attaching parts that may require removal for indexing or adjustment in angular position [8]. Hobbing, shaping, broaching, and cold rolling are the methods used for manufacturing of splines.

Gear coupling is a mechanical device used to transmit torque between two noncolinear shafts. It consists of a flexible joint (which comprises of two hubs and a sleeve) fixed to each shaft (as shown in Fig. 1.17). Both the hubs mounted on the shafts have external gear teeth that engage with internal teeth cut into a sleeve which is fitted over both hubs. The primary purpose of couplings is to join two elements of rotating equipment while permitting a certain degree of misalignment or linear end movement or both. Fig. 1.17 shows a typical flange-type gear coupling. Gear couplings are the most widely used flexible-type shaft coupling.

1.3 GEAR TERMINOLOGY

Gears are generally specified by their types (e.g., spur, bevel, spiral, etc.), size or dimensions, geometry, materials, and special features (if any). This section discusses some common and general gear terms, some special terms with reference to the dimensions and the geometry and meshing conditions.

Involute and Cycloidal Profile

The gear tooth profile is mainly based on two engineering curves i.e., involute curve and cycloidal curve. An involute of a circle is essentially a plane curve generated by a point on a tangent that rolls on the circle without slipping. In other words, an involute curve is developed by tracing a point on a cord as it unwinds from a circle which is the base circle. In cycloidal gears, the face section of a gear tooth profile is constructed by an epicycloid which is the curve traced by a point on the circumference of a circle that rolls without slipping on the outside of a fixed circle i.e., pitch circle; and the flank section is constructed by a hypocycloid, where the circle rolls inside of the pitch circle.

Cycloidal gears are specifically used in clocks and watches, while involute gears have widespread uses such as in machine tools, vehicle gear boxes, robotics, home appliances, scientific instruments etc.

Involute gears have certain advantages over cycloidal gears i.e., easy to manufacture as face and flank are both generated by a single curve; the center distance for a pair of involute gears can be varied within limits without changing the velocity ratio; and the pressure angle remains constant from the start to the end of the engagement. Involute gears does however have the disadvantage that interference may occur in which the root of one tooth undercuts the tip of another during meshing; whereas with cycloidal gears interference does not occur. In general, cycloidal gears are stronger than involute gears due to their wider flanks.

The following terms are commonly applied to the various classes of gears (refer Fig. 1.18):

Pitch circle or reference circle: It is an imaginary circle which by pure rolling action, would give the same motion as the actual gear produces. This imaginary circle also passes through the center of each tooth on the gear and has the gear axis as its center.

Pitch circle diameter or reference circle diameter (*d*): It is the diameter of the pitch circle and an important term to specify the size of the gear.

Module (*m*): It is the ratio of the pitch circle (reference) diameter of a gear to the number of teeth. It defines the size of a tooth in the metric system and is usually denoted by m. The unit of modules should be in millimeters (mm).

$$m = \frac{d}{N},$$

where N is the number of teeth

Preferred module values are 0.5, 0.8, 1, 1.25, 1.5, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40, and 50. Fig. 1.19 depicts the relative size of teeth machined in a rack with module values ranging from 0.5 to 6 mm.

Diametral pitch (*DP*): It is the number of teeth per inch of pitch diameter. In English system, it is a measure of tooth size. The higher the value of diametral pitch, the lower is the tooth size. The diametral pitch usually varies between 200 to 1 [9].

Transformation from diametral pitch to module

$$m = \frac{25.4}{DP}$$

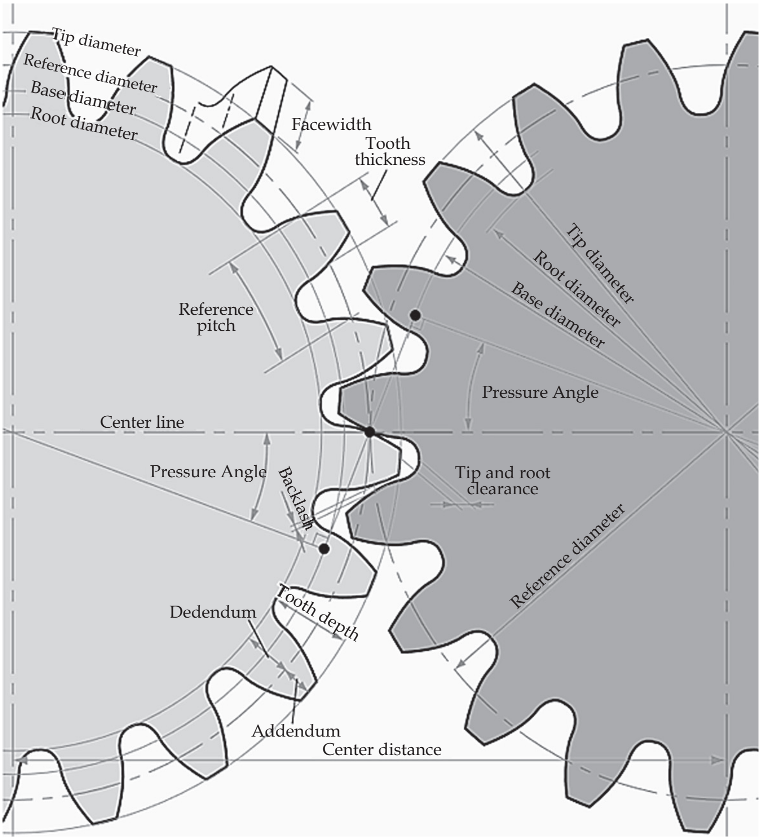


FIGURE 1.18 Schematic showing principal terminology of gears.

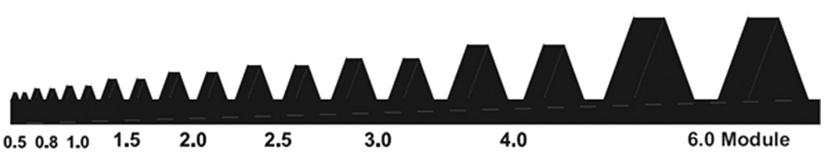


FIGURE 1.19 Gear tooth size as a function of the module.

Base diameter: It is the diameter of the base circle where the involute portion of a tooth profile starts.

Root diameter: It is the diameter of the circle that contains the roots or bottom land of the tooth spaces. In other words, it is the diameter at the base/bottom of the tooth space.

Tip diameter: It is the diameter of the circle that contains the tops of the teeth or top land of external gears. It is also called the outside diameter.

Addendum: It is the height by which a tooth projects beyond the pitch circle or pitch line. It can also be described as the portion of the tooth between the tip diameter and the pitch circle.

Dedendum: It is the depth of the tooth below the pitch circle or the portion of the tooth between the pitch circle and the bottom land of the tooth.

Working depth: It is the depth of engagement of two gears, that is, the sum of their addendums.

Whole depth: It is the total depth of a tooth space and equal to the sum of addendum and dedendum.

Circular pitch or reference pitch (p): It is the distance measured along the pitch circle or pitch line from any point on a gear tooth to the corresponding point on the next tooth. It is also equal to the circumference of the pitch circle divided by the total number of teeth on the gear and consequently formulated as:

$$p = \pi m,$$

where m is the gear module.

Center distance: It is the distance between the center of the shaft of one gear to the center of the shaft of the other gear. It can be calculated by dividing the sum of the pitch diameters by two.

Tooth thickness: It is also called the chordal thickness and is the width of the tooth measured along the pitch circle.

Top land: It is the surface of the top of a tooth along the face width.

Face of the tooth: It is the portion of the tooth surface above the pitch surface.

Flank of the tooth: It is the portion of the tooth surface below the pitch surface.

Face width: It is the length of a tooth in an axial plane and measured parallel to the gear axis.

Pressure angle (ϕ): Pressure angle is the angle at which the pressure from the tooth of one gear is passed on to the tooth of another gear. Geometrically, it is the angle between the common normal between two gear teeth at the point of contact and the common tangent at the pitch point. It is also called the angle of obliquity. The standard pressure angles are 14½ and 20°.

Clearance: It is the amount by which the dedendum in a given gear exceeds the addendum of its mating gear.

Backlash: It can be defined as the amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles.

Contact ratio: To assure continuous smooth tooth action, as one pair of teeth disengages a subsequent pair of teeth must already have come into engagement. It is desirable to have as much overlap as possible. Contact ratio is the measure of this overlapping and simply indicates the number of tooth pairs engaged at any given time. Higher contact ratios are always desirable and if it becomes less than 1.0, the gears disengage.

1.3.1 Standard Gear Tooth Proportions

Four systems of gear tooth proportions are used to achieve engineering interchangeability between gears belonging to the same category and therefore having the same pitch and pressure angle. These four systems are:

1. 14½° Composite system;
2. 14½° Full-depth involute system;
3. 20° Full-depth involute system; and
4. 20° Stub involute system.

The 14½° composite system has a cycloidal tooth profile for both top and bottom regions with an involute profile in the center. This system is used for general purpose gears. As the name implies, the 14½° full-depth involute system has an involute shaped tooth profile. The 20° full-depth involute system has a wider base and is therefore used in applications that require increased strength. The 20° stub involute system is used for applications that requires maximum strength to sustain exceptionally high loads. These systems imply specific gear geometry descriptors, including the addendum, dedendum, tooth thickness, and depth. The standard proportions for these (as a function of the module, *m*) are presented in Table 1.2.

TABLE 1.2 Standard Proportions of Systems for Spur Gear [5,6]

Term	14½° Composite system or Full-Depth Involute System (*m*)	20° Full-Depth Involute System (*m*)	20° Stub Involute System (*m*)
Addendum	1	1	0.8
Minimum dedendum	1.25	1.25	1
Working depth	2	2	1.60
Minimum whole depth	2.25	2.25	1.80
Basic tooth thickness	1.5708	1.5708	1.5708
Minimum clearance	0.25	0.25	0.2
Fillet radius at root	0.4	0.4	0.4

1.4 GEAR MATERIALS

The selection of a suitable material for any gear type is influenced by a number of technical and commercial factors which include transmission requirements in terms of power, speed, and torque; working environment, i.e., temperature, vibration, and chemical conditions; ease of manufacture; cost of processing and manufacture etc. An appropriate material choice is required for a gear to achieve its intended performance with adequate reliability throughout its intended service life. High strength, toughness, and resistance to fatigue and wear are some important and desirable characteristics for gear materials. Gears are extensively manufactured in both metallic and nonmetallic materials. Cast iron, plain carbon steels, and special alloy steels are important ferrous gear materials used for heavy-duty applications, whereas brass, aluminum, and bronze are frequently used nonferrous materials for medium to light-duty applications. Nonmetallic materials such as plastics are generally used for light-duty service applications in noise sensitive environments. Both the material properties and application requirements should be considered for appropriate final material selection. Table 1.3 presents special features and typical applications of some important gear materials which are also discussed in greater detail in the following sections.

1.4.1 Ferrous Metals and Alloys

1.4.1.1 Cast Iron

Properties such as low cost, good machinability, excellent noise-damping characteristics, and superior performance under dynamic conditions make cast iron eminently suitable as a gear material. The three basic grades of cast iron used for gears are gray, ductile, and malleable cast iron. Due to low shock resistance, gray cast iron cannot be used in gears that are subjected to shock load applications. Ductile iron has good impact strength and sufficient ductility. The fatigue strength of ductile iron is on par with steel of equal hardness [10]. The bending strength of cast iron are between 34 and 172 MPa while the surface fatigue strength ranges between 345 and 793 MPa [7]. Cast iron gears have good corrosion resistance and are generally quieter in operation than steel gears. These gears are also a good replacement for bronze worm gear drives due to their low cost and good sliding properties. Cast iron is commonly used in applications, including equipment and machinery used for mining, earthmoving, agriculture, construction, and machine tools.

1.4.1.2 Steel

Because of its high strength-to-weight ratio and relatively low cost, various different grades of steel are regularly used in applications requiring medium to heavy-duty power transmission, high-strength applications, and precision requirements. Both plain carbon and alloy steels are used in various different applications even though the latter may be difficult to machine. Typical commercial grades of plain carbon steels used are mild steel (AISI 1020, EN3), AISI 1040 (EN 8) and EN 9. These are used in applications requiring

TABLE 1.3 Summary of Properties and Applications of Some Important Gear Materials [6,9,10]

			Properties	Applications
Cast iron	Gray iron		Good machinability, sound dampening properties, good resistance to wear, low impact strength	Large-size mill gears; moderate power-rating applications; low shock applications; and machine tools
	Ductile iron		Fair to good machinability, sound dampening properties, better impact and fatigue strength than gray iron	Transportation; railroad and military vehicles; girth gears for mills
Plain carbon steels	Carburizing gear steels	Low-carbon steels (1010, 1015, 1020, 1021, 1022, 1025)	Excellent machinability, good combination of strength and ductility, heat treatable, can be case carburized	Low to medium duty applications
	Through-hardening gear steels	Medium-carbon steel (1035, 1040, 1045)	Good machinability	Moderate to high power-ratings application
		High-carbon steel (1060)	High strength and durability	High-power rating applications
Alloy steels	Carburizing steel	Nickel–chrome–molybdenum carburizing steel (SAE8620)	Good wear characteristics/ high wear resistance	Automotive transmissions; farm machineries; earth movers
		20MnCr5 (SAE5120)	Case-hardening imparts hard case with good wearing properties and tough core	Automobile gear boxes; heavy-duty transmission gears; hoisting; and cranes
	Through-hardening gear steels	Chrome–molybdenum alloy steel (4140)	High toughness, good torsional strength, good fatigue strength	Differential systems of automobiles; and tractors

(*Continued*)

TABLE 1.3 (Continued)

			Properties	Applications
		Nickel–chrome–molybdenum alloy steel (4340)	Can be hardened easily, toughness and high strength in heat-treated condition, good fatigue strength	Industrial drives; mining equipment, paper mills; steel mills
Stainless steels	300 series	303, 304, 316	Fair machinability, high strength, high corrosion resistance, nonmagnetic, cannot be heat treated	Precision applications; low-duty applications; antibacklash gears; juice extractors; fishing reels; gear reducers; underwater applications; gear pumps; crushers; medical instruments; and microgears
	400 series	416, 440 C	Fair machinability, heat treatable, nonmagnetic, high resistance to corrosion, good hardness and wear resistance	Low-to-medium duty applications; precision applications; and miniaturized devices
	Precipitation hardening	17-4PH, 17-7PH	High strength, moderate corrosion resistance, high-fracture toughness	Precision applications and microgears
Brass alloys	Free-cutting brass, yellow brass (die-cast alloy), naval brass		Good machinability, light weight, good corrosion resistance, good wear resistance	Low-duty applications; miniature motors; hydroservice applications; and precision motion transmission applications
Bronze alloys	Phosphor bronze		High toughness and hardness, high fatigue resistance, high wear resistance, good machinability, good corrosion resistance, and nonmagnetic	Used to make gears operate in mesh with steel worm gears for medium-duty applications
	Manganese bronze			
	Aluminum bronze			
	Silicon bronze			Low-duty applications

Aluminum alloys		2024, 6061, 7075	Light weight, excellent machinability, corrosion resistant	Extreme low-duty applications and instrument gears
Magnesium die-cast alloys		AZ91B, AZ91A, AM60, AS41	Light weight, corrosion resistant	Light-load applications
Zinc die-cast alloys			Good impact strength	Light-loading and low-temperature applications; and small-gear trains
Plastics	Thermoplastics	Nylons, acetals (derlin), polysters, polycarbonates, polytetrafluoroethylene (teflon)	Good corrosion resistance, low cost, and silent operation; thermoplastics have greater toughness than thermosetting plastics	Light-load and precision applications; instruments; printers; electronic devices; appliances; and clocks
	Thermosets	Polyurethanes, polyamides, phenolics, and laminated phenolics,		
Ceramics	Alumina		Good corrosion resistance and can withstand high-temperature conditions	Microgears for watches; instruments; microgearboxes; microactuators; and microreducers
	Zirconia			

medium to high toughness and strength requirements. Low and medium-carbon steels are good choices for gear stamping.

Plain carbon and alloy steels are generally heat treatable which implies that certain desirable mechanical characteristics may be imparted on the gears by an appropriate heat treatment. Hardenability, which is primarily a function of the alloy content, may be an important aspect to consider when selecting a gear steel. Surface (case) hardening and through hardening are two important heat treatment operations that may dramatically improve the strength, toughness, endurance limit, and shock resistance of steels. Through-hardened low-alloy steels are suitable for medium duty and moderate operating conditions. Heavy-duty and/or severe operating conditions usually necessitate case-hardened high-alloy steels. Typically, case-hardened gears are produced in a two-stage process (carburizing) by initially enriching the carbon content of the surface locally (up to 0.85%). This is followed by an appropriate quenching and tempering process that produces a hardened case (up to 64 HRC) of required thickness. The core remains largely unchanged and retains its inherent ductility and toughness. Localized quenching and tempering of appropriate steel (containing sufficient carbon usually more than 0.4%) may produce similar results (selective hardening). Elements other than carbon, such as nitrogen and boron, may also be used albeit in a slightly different technique. Generally, case-hardened gears have improved fatigue life and wear resistance. Carburizing, nitriding, laser hardening, and induction hardening are the most important case-hardening techniques employed for steel gears. Typical case depths are between 0.075 to 8.25 mm [10]. Case-hardened gears can withstand higher loads than through-hardened gears, whereas the latter are usually quieter and less expensive [10]. A wide range of steels that are eminently case hardenable exist. These include carburizing steels such as AISI 1015, 1018, 1020, 1022, 1025, 1117, 1118, 4020, 4026, 8720, 9310 etc.; and nitriding steels namely AISI 4140, 4340, 6140, 8740, and nitralloy. Nitralloy N and type 135 are suitable materials for highly stressed heavy-duty gears.

20MnCr5, 16MnCr5, and SAE 8620 are the most important case-hardening steels preferred for automobile gears. In general, alloy steels are preferred over plain carbon steels because of the increased hardness and effective depth of the case for a similar carbon content, finer grain size, lower distortion, increased toughness, and improved wear resistance.

Stainless steels (SS) are important alloy steels eminently suitable for gears exposed to high temperature and corrosive environments such as equipment and machines used in chemical, petrochemical, and the food and beverage-processing industries. Steel is usually designated “stainless” if it contains more that 12% chromium. The chromium reacts with oxygen in the air to form a homogeneous passive oxide layer that protects the core material against corrosion. Austenitic (types 303, 304, and 316), ferritic (type 430), martensitic (type 440 C), and precipitation hardening (17-4PH and 17-7PH) are the major stainless steel types [10]. The austenitic grades are popular for use in extreme environments because of their superior corrosion resistance. They are nonmagnetic, nonheat treatable, and generally difficult to machine. Type 304 (18Cr-8Ni) is one of the most widely used stainless steels for gears employed in extreme corrosion conditions.

Various types of stainless steel namely 303, 304, 316 L, 420, 440, and 17-4 PH steels are also extensively used for manufacturing of high-accuracy miniature gears employed in precision and high-torque transfer applications such as microharmonic drives, robot mechanisms, micromotors, micropumps, speed reducers, medical instruments, and electronic equipment. Types 303 and 17-4 PH are extensively used to fabricate ratchet wheels as used in pawl-and-ratchet mechanisms.

Gears manufactured by the casting process from **casting steels** are used for service conditions involving multidirectional loading in machines such as large mills, crane wheels, and wind turbine gearbox components. Common through-hardening cast steels include AISI grades 4135, 8630, 8640, and 4340, whereas AISI grades 1020, 8620, and 4320 are some important case-hardening cast steels.

Sintered steels are used to manufacture gears by the powder-pressing process. Iron–copper and iron–nickel steels are the two most important sintered steels available in powder form and used to manufacture helical, spur, and bevel gears that are exposed to high-strength applications. Powders of Type 316 L stainless steel and a powder mixture of nickel steel and bronze are also frequently used to manufacture gears by powder-pressing technique.

1.4.2 Nonferrous Metals and Alloys

A wide range of nonferrous metals such as copper, brass, bronze, aluminum, and magnesium are used to manufacture machined, die-cast, and formed gears. Depending on the alloy, they may have good manufacturability, low density, and good corrosion resistance while being nonmagnetic.

1.4.2.1 Copper Alloys

Bronze (copper–tin alloy) and brass (copper–zinc alloy) are the two most extensively used copper alloys. Several types of bronze and brass alloys are used in gearing. **Bronze** alloys are mostly used in worm gear applications, where low-sliding friction, wear resistance, and high-reduction ratios are the prime requirements. The four main types of bronze alloys used are aluminum bronze, manganese bronze, phosphorous bronze, and silicon bronze. All bronze alloys possess good machinability, wear and corrosion resistance, and have yield strengths ranging between 138–414 MPa [7].

A wide variety of **brass** that includes free-cutting brass, yellow brass, and naval brass are used in machined, die-cast, and formed gears of different shapes and size. Die-casting of brass is usually more expensive when compared with the other nonferrous metals. Brass gears are light weight and corrosion resistant. Brass alloys are one of the best choices for manufacturing miniature gears through various conventional and advanced processes for light-load applications as found in precision instruments, miniaturized products, and slow-speed machines.

Zinc and zinc–aluminum alloys are preferentially used to die-cast gears of good finish and accuracy at low cost. **Zn–22Al** alloy in powder form is a good choice to manufacture microgears by extrusion and hot-embossing methods.

1.4.2.2 Aluminum Alloy

Gears made from Al-alloys have the advantage of light weight combined with moderate strength. They are also corrosion resistant, easy to machine, and provide a good surface finish. A major disadvantage of aluminum is its large coefficient of thermal expansion compared to steel. High-strength wrought aluminum alloys (2024, 6061, and 7075) are used for machined gears and aluminum silicon alloys (A360, 383, 384, and 413) are used as die-cast alloys.

Magnesium alloys including ASTM AZ91A; AZ91B; AM60; AS41 are used in light weight die-casted gears for low load applications.

1.4.3 Nonmetals

Plastics including nylon, polyacetal, polyamide, polycarbonate, polyurethane, phenolic laminates etc. are extensively used to manufacture gears. Plastic gears offer light weight, smooth and quiet operation, wear and corrosion resistance, and may be manufactured at relatively low cost. In certain applications, they may be economic substitutes for metallic gears as they are easier to manufacture, require minimum or no finishing, are able to run with minimal or no lubrication, and generally have extended life spans. Hobbing, injection molding, and rapid prototyping techniques are the most popular techniques to manufacture plastic gears. Plastics are specifically preferred for miniature gear manufacture requiring precision and quite operation. In many instances, they may perform markedly better than their metallic equivalents.

Two broad categories of plastic materials are available for gear manufacture i.e., thermosets (polyurethanes, polyamides, phenolics, and laminated phenolics) and thermoplastics (nylons, acetals, polyesters, polycarbonates, fluoropolymers such as polytetrafluoroethylene etc.). Polyamides and polycarbonates are extensively used in selective laser sintering, stereolithography and 3D printing-type additive layer manufacturing techniques for rapid prototyping of gears.

Additives such as mica, carbon powders, kevlar, glass beads and fibers, graphite, ethylene vinyl acetate, acrylics etc. are introduced into plastics with the aim to improve their performance. Plastic gears are used in various different applications, including printers, computer memory devices, robots, toys, electronic devices, micromotors, clocks, small power tools, appliances, speedometers, automotive actuators, medical instruments etc.

Advancements in materials engineering have extended the use of plastic gears into the high-speed and high-torque transmission domains for certain applications.

Ceramics such as zirconia powder (ZrO_2), alumina (Al_2O_3) etc. are the key materials for precise microgears formed by metal powder injection molding techniques and are widely used in watches, microplanetary mechanisms, and microgearboxes. Ceramic gears are viable substitutes for plastic gears for high-temperature conditions and corrosive environments that require high mechanical strength.

The LIGA (a German acronym for Lithographie, Galvanoformung, and Abformung; lithography, electroplating and molding) process uses ceramics, electroplated metals, and photosensitive resins reinforced with ceramic nanoparticles, polymers, and silicon-based materials for fabrication of micro and nanogears that find applications in NEMS-MEMS, actuators, microsystems, and medical devices [11].

1.5 GEAR MANUFACTURE

Conventional metallic gear manufacture usually comprises of several sequential operations depending upon the gear type, material, and desired quality. These operations include preparation of the blank i.e., preforming the blank by casting or forging, heat treatment of the preformed blank (if required), shaping the blank to the required dimensions by machining, producing the teeth in gear blank, heat treatment of the gear (teeth), and finally finishing of the teeth, if required.

In case of large gears, the blank is produced by casting or forging, whereas medium-sized and small gears are produced by cutting and machining a cylindrical billet of the selected gear material to the required size. Sand casting is used for large cast iron gear blanks; while centrifugal casting is frequently used to form the blank for worm gears in cast iron, bronze, or steel. The preformed blank is subjected to a machining operation to produce the required shape and size and removal of excess material from its surface (if any) before teeth machining commences. Other casting techniques such as shell molding, die-casting, metal mold casting, and sometimes even sand casting may also be used to create a preform that may include gear teeth also instead of forming the blank only.

In general, “gear manufacturing” refers to the process required up to the production of the teeth, whereas “gear finishing” refers to the finishing and refinement of the teeth to final requirements.

Certain gear manufacturing techniques may not require blank preparation. Methods other than machining such as die-casting, powder metallurgy, and injection molding may shape the gear teeth close to the final required geometry and dimensions without requiring separate blanks.

A wide range of gear manufacturing and finishing processes exists, including both conventional and advanced types to produce gears of various types, shapes, sizes, and materials.

1.5.1 Conventional Gear Manufacturing

The conventional processes of producing gear teeth are grouped into the following major classes:

I **Subtractive or material removal processes**

Techniques belong to this group can be classified as:

i **Form-cutting processes**

Gear cutting by milling
Gear cutting by broaching
Gear cutting by shaper

ii **Generative processes**

Gear generation with hob cutter: Gear hobbing
Gear generation with rotary cutters: Gear shaping
Gear generation by planing
Generative processes for conical gears

II **Forming processes**

Stamping and fine blanking
Extrusion and cold drawing
Gear rolling
Forging

III **Additive processes**

Gear casting
Powder metallurgy
Injection molding for plastic gears

The first and one of the most important gear manufacturing techniques for cutting teeth of required geometry in prepared gear blanks is the **subtractive or material removal process**. All these material removal process types make use of an appropriately shaped tool, according to the gear geometry, to cut the required geometry into the blanks. These processes can further be subdivided in two main groups, namely form-cutting and generative processes.

Form-cutting processes are those where the teeth profiles are obtained as a replica of the geometry of the cutting tool (edge) e.g., milling, broaching, and teeth cutting on shaper.

The **generative process** produces gear teeth as the result obtained (generated) of relative motion between the gear blank and the cutting tool with the cutting tool being of the same geometry as the teeth to be cut. Generally, a cutter reciprocates and/or rotates against a rotating gear blank to cut the teeth. Hobbing, shaping, planning, and other conical gear generative processes such as face-mill cutting, face-hob cutting, Revacycle process, two-tool generators, planning generators etc. fall under this category. Subsequent chapters of this book present a more detailed description of these material removal type gear-manufacturing processes.

A number of forming methods such as stamping and fine blanking, extrusion and cold drawing, and rolling and forging are used to make gears either by forming a complete gear from the raw material or by forming teeth in the blank using dies of appropriate geometry.

Another important class of gear manufacturing is **additive processes** which includes various casting methods i.e., sand casting, die-casting, investment casting etc.; powder metallurgy to make gears from metal powders, injection molding for plastic gears.

The aforementioned conventional processes used to manufacture cylindrical gears are discussed in Chapter 2, Conventional Manufacturing of Cylindrical Gears, whereas manufacturing of conical and noncircular gears is discussed in Chapter 3, Manufacturing of Conical and Noncircular Gears.

1.5.2 Conventional Gear Finishing

The type and quantity of the microgeometry errors of gears determines their quality which consequently influences the functional performance in terms of noise generation, load-carrying ability, and accuracy in transmission. Errors in microgeometry of gears can be classified in two main types, i.e., form errors and location errors. Profile error and lead error are the main types of form errors, whereas pitch error and runout are types of location errors. In addition, the surface finish quality of the teeth also determines the tribology behavior and wears characteristics. High-surface roughness and the presence of nicks, burrs, cracks, and other surface defects may lead to early failure of gears.

Fundamentally, most conventional gear manufacturing processes is limited to shaping of the required teeth geometry and is unable to impart a good-quality surface finish. Precision applications necessitate high-quality gears for smooth and low-noise operation. This entails inclusion of finishing techniques to obtain the required gear tooth surface finish with acceptable accuracy of the microgeometry. Grinding, shaving, honing, and lapping are material removal-based finishing techniques, whereas rolling is a form-finishing technique. All these techniques are fundamentally used to obtain an adequate surface finish while shaping the teeth to the required geometry while also removing burrs and nicks. Chapter 5, Conventional and Advanced Finishing of Gears, introduces the working principles, mechanisms, and salient features of all the important conventional gear-finishing processes.

1.5.3 Advances in Gear Manufacturing and Finishing

Inherent limitations of conventional processes of gear manufacturing, namely high manufacturing costs, limited quality, and the inability to deal with a wide variety of shapes, sizes, and materials were the main factors behind the development of advanced/modern gear-manufacturing processes. Most conventional manufacturing processes alone cannot produce gears of acceptable quality and therefore requires a finishing technique to further improve the quality. Besides quality aspects, processing of advanced gear tooth geometries and materials are also major concerns where performance of conventional processes is restricted. Conventional gear manufacturing and finishing operations implies extended process chains which are costly and may be less environmentally friendly that desirable.

Advanced processes of gear manufacturing comprise modern methods/processes and advancements to some conventional processes to deal with the abovementioned challenges. Laser beam machining, abrasive water jet machining, spark-erosion machining, metal injection molding, additive layer manufacturing, LIGA etc. are just some of the modern processes used to manufacture high-quality gears from a wide range of materials and of various types and sizes. Their perceived ability to manufacture net-shaped gears can eliminate the need of further finishing, which thereby shortens the process chain, minimizes the production cost, and ensures environmental sustainability. Advancements in conventional methods increase their efficiency to manufacture gears with tight tolerances and improved surface finish. In addition, the concept of environmentally benign green or sustainable manufacturing (i.e., dry hobbing and minimum quantity lubrication-assisted machining etc.) has been introduced in gear manufacturing to produce gears of good quality while maintaining energy, resource, and economic efficiency at the same time. These advanced processes as applied to gear manufacturing are introduced and discussed in Chapter 4, Advances in Gear Manufacturing.

Gear finishing implies removing burrs and nicks, refining teeth surfaces, and achieving geometric tolerance. Manufacturing competitiveness and certain inherent limitations of conventional finishing techniques are the main drivers for the development and use of advanced/modern gear finishing processes. Electrochemical honing (a state-of-art method), abrasive flow finishing, water jet deburring, electrolytic deburring, Thermal deburring, brush deburring, vibratory surface finishing, and black oxide finishing are some of the significant advanced processes for gear finishing. These are presented and discussed in Chapter 5, Conventional and Advanced Finishing of Gears.

The processes such as surface hardening, peening, and coating are used to enhance the surface properties of gears for their improved performance in aspects such as surface hardness, tribology, and residual stress state with the ultimate aim to improve operation in terms of service life and dynamic performance (noise) etc. Chapter 6, Surface Property Enhancement of Gears, presents the aim, methodology, and advantages of various advanced surface modification processes/methods currently employed in gear engineering.

The assessment of the geometric accuracy is an important aspect of the gear manufacturing process. The methods and corresponding instruments employed to measure macro and microgeometry parameters of gears in order to assess their accuracy are presented in Chapter 7, Measurement of Gear Accuracy.

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