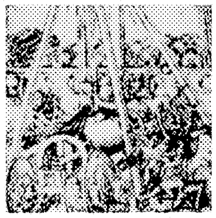
GEARS, SHAFTS, AND BEARINGS

Chapter 19



LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Recognize mechanical devices that are designed to transmit motion from one machine element to another.
2. Analyze gear blank stock material, types of hubs, and methods of attaching gears to shafts.
3. Define the various gear categories and basic specifications for manufacture and inspection.
4. Explain common gear terms and symbols.
5. Demonstrate an understanding of gear, shaft, and bearing drawing practices.
6. Communicate gear, shaft, and bearing data by means of ANSI-standard dimensioning and notation.
7. Describe the types and purposes of bearings and their respective housings and mountings.
8. Explore the use of CAD in gear design.

19.1 INTRODUCTION

This chapter covers mechanical devices designed to transmit motion from one machine element to another. Most gears (Fig. 19.1) are mounted on shafts, which, in turn, are secured by **bearings** installed in a variety of housings. **Gears** are designed to transfer rotary motion from one **shaft** to another. The speed of the motion is increased or decreased by changing the size of the *drive gear* and the *driven gear*.

The selection of gear types is based on the relative position of the shafts. The shafts will be either intersecting, nonintersecting, or parallel. Shafts can be positioned perpendicular, parallel, or at any given angle to each other, depending on the design application. Figure 19.2 shows two spur gears mounted on parallel shafts. Shaft A holds the drive gear; shaft B holds the driven gear. Spur gears are commonly used to transfer motion from one parallel shaft to another. In this example, the drive gear is smaller than the driven gear; therefore, the driven gear will take longer to complete one revolution and its speed will be less than that of the drive gear.

Some gears are designed to change rotary motion into reciprocating (linear—back-and-forth) motion. These machine elements are called **pinions** and **gear racks.** Another method of transmitting rotary motion into reciprocating (linear—up-and-down) motion utilizes a cam-and-follower assembly. This method is discussed in Chapter 20.

Whether the transfer of motion is rotary-to-rotary or rotary-to-linear, the rotary element must be mounted on some kind of a shaft and that shaft must rotate freely. Therefore, shafts ride on bearings [Fig. 19.3(a)]. The gear itself may have an integral keyseat to provide a positive connection to the shaft [Fig. 19.3(b)].

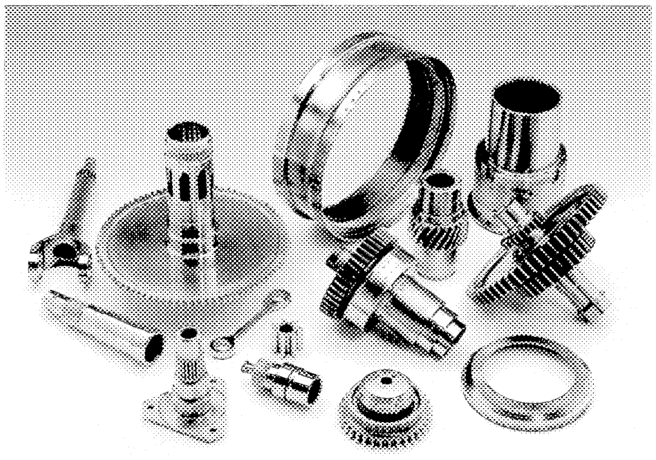


FIGURE 19.1 Gears

19.2 GEARS

This chapter introduces the most common types of gears, shows how they are represented on drawings, and presents methods for calling out their specifications. **Gear specifications** are the most important information that is supplied to the gear manufacturer. Gears come in many styles, including spur gears, pinions, ring gears, worm gears, bevel gears, miter gears, hypoid bevel gears, and racks, among others. Gears are made of metals and nonmetals. Spur gears are the most common type manufactured.

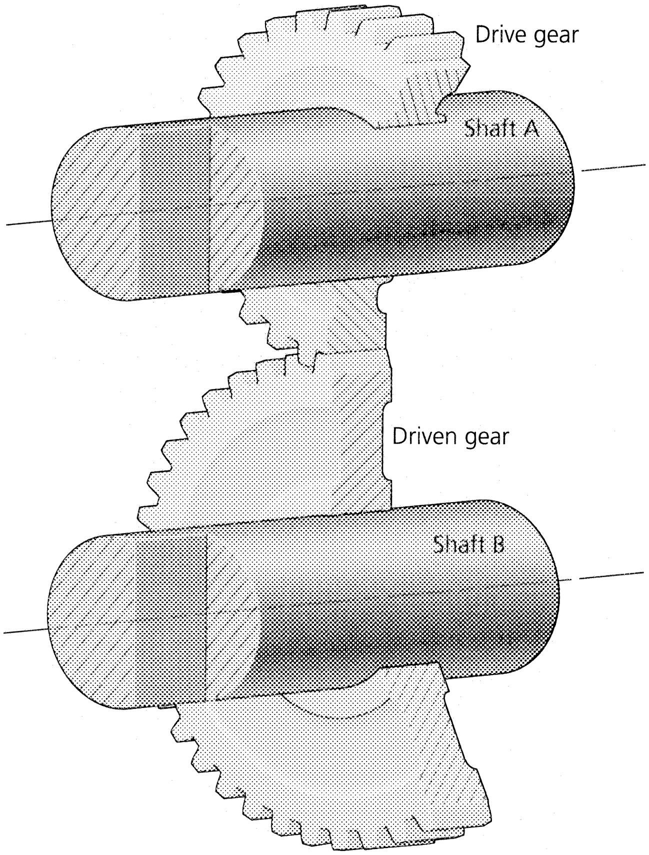
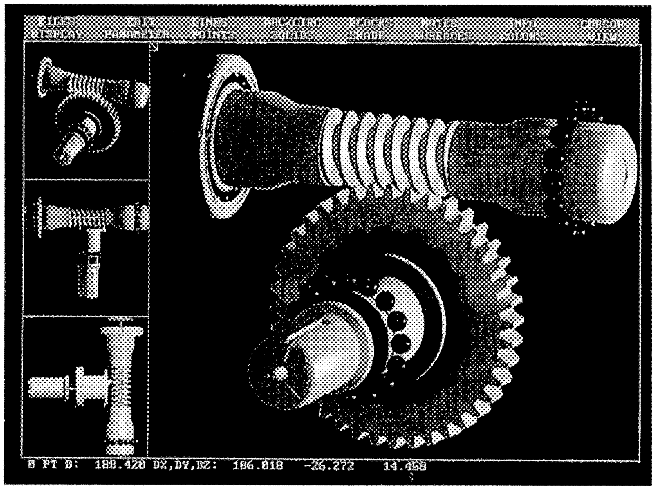
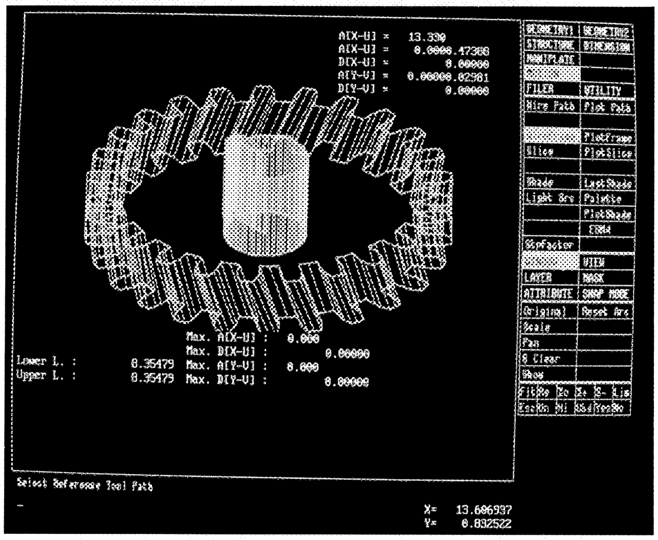


FIGURE 19.2 Gears and Shafts



(a) Gears, shafts, and bearings



(b) Gear

FIGURE 19.3 Gear Design Using CAD

19.2.1 Gear Teeth

Gear teeth are projections designed to fit into the tooth spaces of mating gears and to contact mating teeth along a common line known as the **pressure line**, also called the **line of action** (Fig. 19.4). The most common form for the tooth flank is involute. The pressure line determines the particular involute shape. The American National Standards Institute (ANSI) has standardized two pressure angles: $14\frac{1}{2}^\circ$ (now rarely used) and 20° (Fig. 19.5).

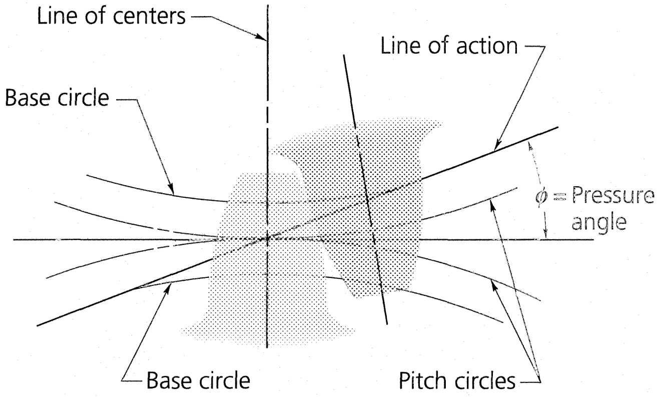


FIGURE 19.4 Pressure Angle and Line of Action

19.2.2 Gears, Splines and Serrations, and Racks

The following terms and descriptions define the general gear categories covered in the chapter.

Spur gears Gears connecting parallel shafts and having straight teeth elements (parallel to the axis of the shafts). The smaller gear of a pair of gears is called a **pinion.**

Helical gears Gears connecting shafts with projected nonintersecting centerlines. Helical gear teeth elements are spiral, or helical, in shape.

Bevel and miter gears Gears that are conical in form and that operate on shafts having projected intersecting centerlines. When the gears are different sizes, they are called bevel gears. Bevel gears of the same size (one-to-one ratio) and with shafts intersecting at right angles are called miter gears.

Internal gears Gears connecting parallel shafts, with teeth elements that are either straight or helical and with a pitch circle that is tangent internally to the mating spur or spiral gear.

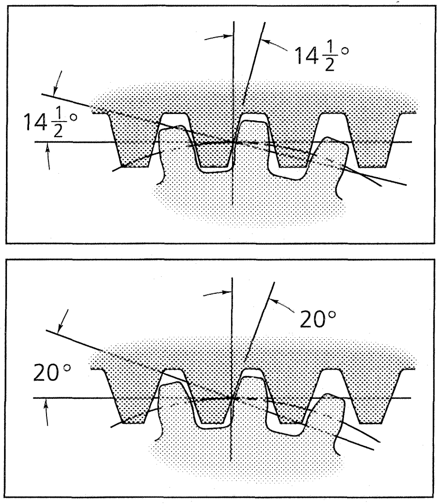


FIGURE 19.5 $14\frac{1}{2}°$ and 20° Pressure Angles

Worm gears Gears connecting nonparallel, nonintersecting shafts. They have teeth elements that are helical. Worm gearing generally is composed of a worm (screw) and a worm wheel (gear), in matched sets.

Rack gear A rack can be considered a gear of infinitely long pitch radius. The pitch line of a rack is a straight line; the pitch is described as linear pitch. A rack gear is a flat spur gear.

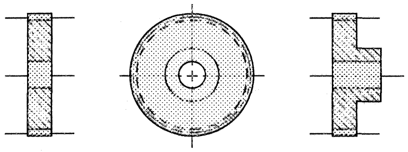
Splines and serrations Splines and serrations are multiple keys used to prevent relative rotation between two members, in the general form of internal and external gear teeth. Splines act primarily to transmit torque.

19.2.3 Gear Blanks

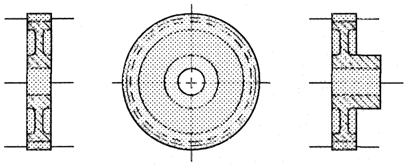
The **gear blank** is the stock material from which the gear is cut. The blank must have sufficient rigidity to prevent distortion during tooth cutting. The type of *hub* (split, solid, or hubless) and the type of gear (spoked, flanged, or flat) must also be determined. Hub variations are shown in Figure 19.6. Still another factor to consider in selecting the gear blank is the method of attaching the gear to its shaft. Here are some of the more common methods employed.

Key Permits easy assembly and disassembly. The design must ensure that the key is captive when the assembly is complete.

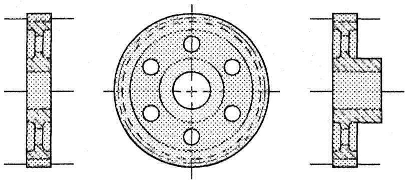
(a) Plain



(b) Web



(c) Web with cutouts



(d) Spoke

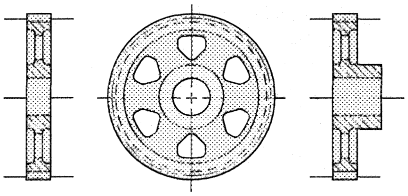


FIGURE 19.6 Hub Options

Pin Requires drilling at assembly. This tends to weaken small shafts and does not permit replacement of gear or shaft. This method provides a positive engagement between gear and shaft.

Set screw Permits easy assembly and disassembly. This method should always use two set screws at 45°–90° to each other. Set screws at a 60° angle are the strongest. The design of the shaft should provide flats on the shaft as a bearing surface for the set screw. Some method of retaining the set screw must be provided. This method is inappropriate when large torque loads are transmitted.

Adhesive bond Requires considerable care at assembly to ensure a good bond. Adhesive has temperature and torque limitations. Disassembly is very difficult without destroying parts of the assembly. The adhesive chosen must be compatible with gear and shaft materials.

Mechanical stake This method has moderate torque-transmitting capacity and may not permit replacement of gear or shaft.

Clamp Can only be used with split hub gears, is bulky in size, and has only moderate torque capacity. This method allows for easy assembly and disassembly.

Press This method is unacceptable when the shaft cannot be isolated from the bearings, as in a motor. Disassembly is difficult. Materials must not expand or contract and cause a loose fit at temperature extremes.

19.3 SPUR GEARS

Two friction wheels with surfaces in contact are shown in Figure 19.7. If one of the wheels is turned—and no slippage occurs—the other one will turn. To prevent slipping, gear teeth may be added to both wheels, with corresponding recesses in each wheel. In Figure 19.8 the spaces are being cut on a spur gear by a machine tool. **Spur gears** are mounted on parallel axes and are manufactured in both internal and external versions. Terms are given in Figure 19.9 for gears with the involute form of gear teeth. A gear and pinion are shown in this figure. A **pinion** is the smaller of two gears in a mating set. The **pitch circles** in Figure 19.9(a) are tangent and might be thought of as representing the friction wheels. The pitch circles on spur gears are tangent circles.

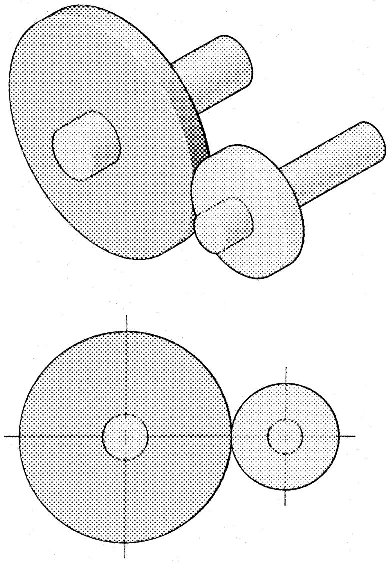


FIGURE 19.7 Friction Wheels

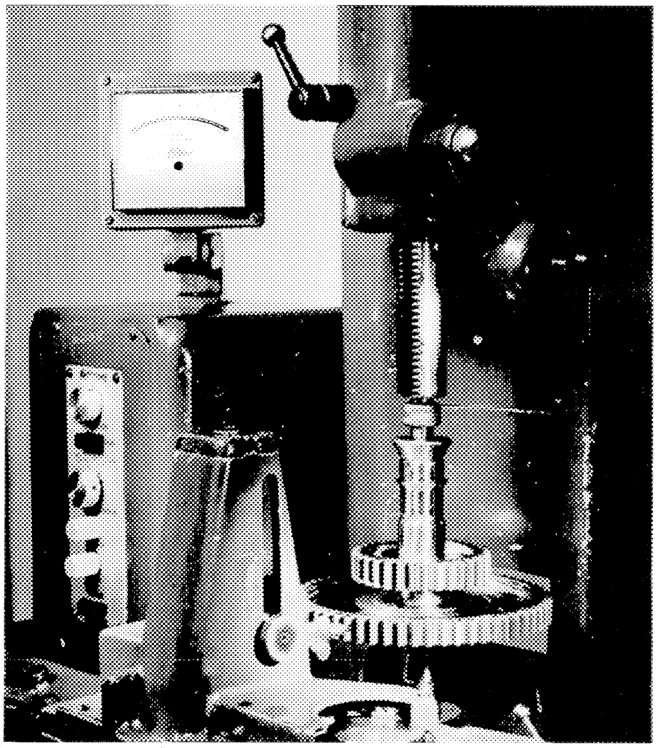


FIGURE 19.8 Machining Gear Teeth

19.3.1 Internal Spur Gear (Ring Gear)

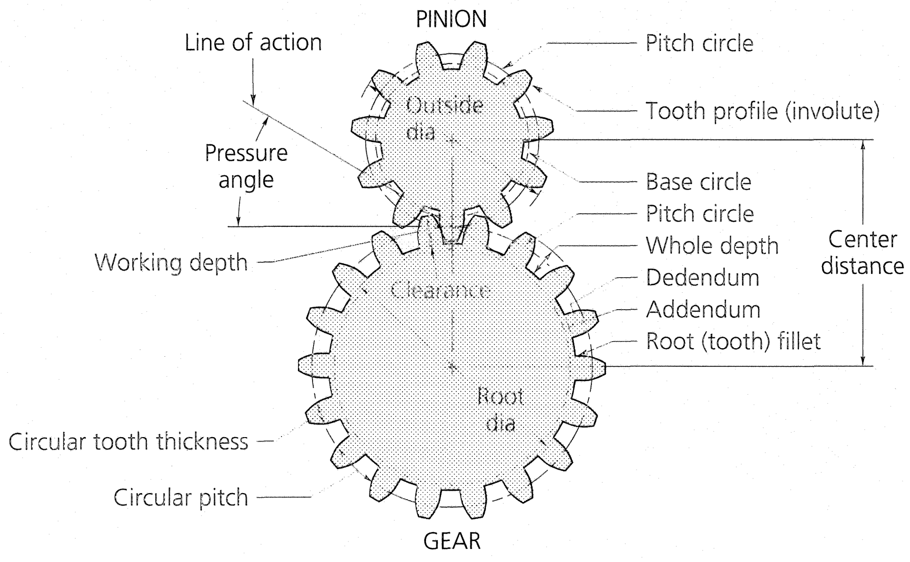
An **internal gear** has greater tooth strength for a given tooth size. Internal spur gears permit a closer *center distance* that may enable a more compact design and allow input (drive) and output (driven) shafts to rotate in the same direction. Figure 19.10 illustrates the center-to-center distance between a **ring gear** and a **pinion gear.** Ring gears can have spur or helical tooth forms. Figure 19.11(a) shows an internal spur gear; Figure 19.11(b) shows a pinion. This matching set was designed on a CAD system and physically modeled via stereolithography.

19.3.2 External Spur Gear

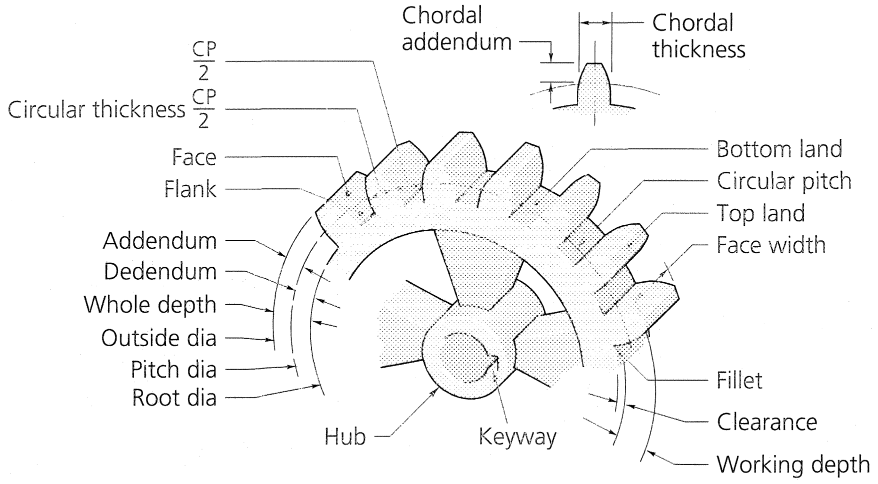
The **external spur gear** (Fig. 19.12) is the most common and best-known type of gear. It transmits motion between

FIGURE 19.9 Gear Teeth

(a) Spur gear and pinion



(b) Spur gear terminology



parallel shafts that rotate in opposite directions. Spur gears generate radial bearing loads. Because of their availability and ease of manufacture, they should be given first consideration as the choice of gear type.

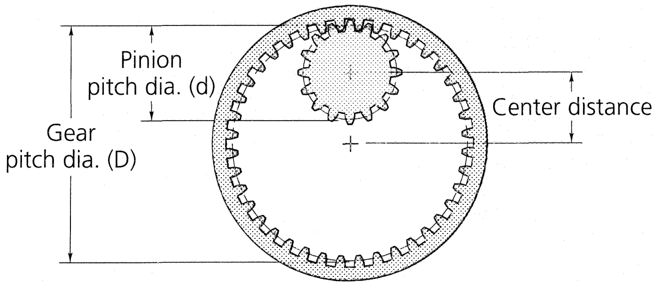


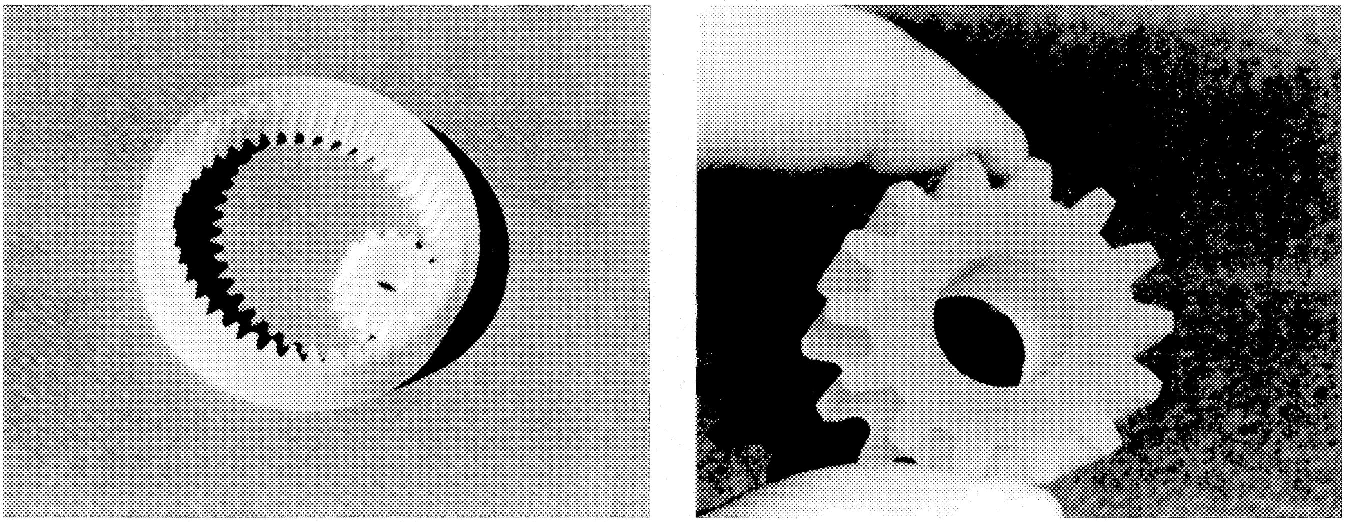
FIGURE 19.10 Ring Gear and Pinion

19.3.3 Spur Gear Specifications

The basic specifications for both manufacturing and inspection for a spur gear are as follows.

- Pressure angle
- Tooth form
- AGMA quality number
- Diametral pitch
- Tooth thickness, circular
- Measuring-wire size
- Total composite error
- Testing pressure
- Outside diameter
- Number of pinion teeth
- Material
- Number of gear teeth
- Face width
- Pitch diameter
- Measurement over wires
- Gear testing radius
- Surface finish

To provide these required data, the application requirements must be known. This information should include speed, ratio, power, accuracy, life, temperature, and application.

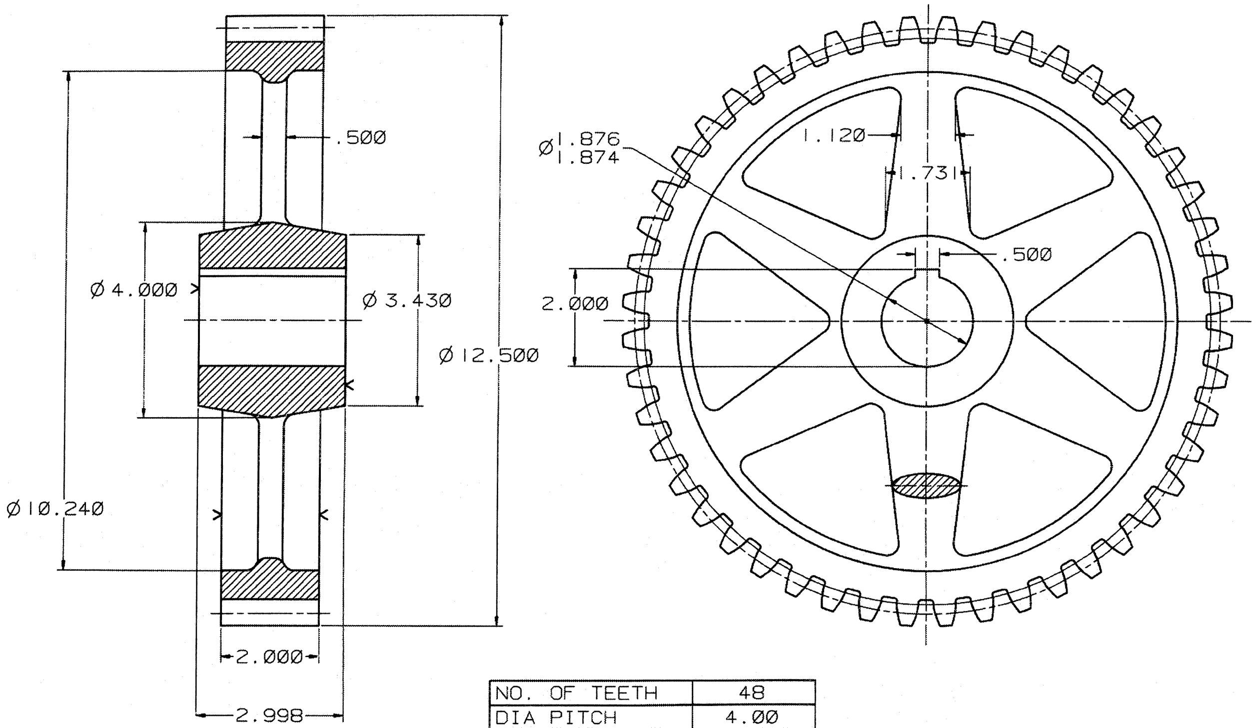


(a) Ring gear and pinion

(b) Pinion

FIGURE 19.11 Gears Modeled using Stereolithography

NOTES:
1. ALL FILLETS AND ROUNDS R.375



NO. OF TEETH	48
DIA PITCH	4.00
TOOTH FORM	14.5 INV
WHOLE DEPTH	0.5393
CHORDAL ADD	0.2532
CHORD. THICK	0.3926
PITCH DIA	12.000
CIRC THICK.	0.3927
WORK. DEPTH	0.5000

IGURE 19.12 Detail Drawing of a Spur Gear

19.3.4 Spur Gear Terms and Symbols

Many terms will be understood by an examination of Figure 19.9. The addendum is the height of the tooth, from the pitch circle to the outside circle. The **base circle** is used to generate the involute curve. The **line of action** is the line along which the contact between the teeth takes place. Symbols used for gears include the following:

a = addendum
c = clearance
OD = outside diameter
P = diametral pitch
b = dedendum
D = pitch diameter
N = number of teeth
p = circular pitch

The following terms are used throughout the chapter to describe spur and helical gears.

Addendum The height that a tooth projects beyond the pitch circle or pitch line.

Base diameter The diameter of the base cylinder from which the involute portion of a tooth profile is generated.

Backlash The amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles.

Center distance The distance between the parallel axis of spur gears and parallel helical gears, or the crossed axes of crossed helical gears.

Circular pitch The distance along the pitch circle or pitch line between corresponding profiles of adjacent teeth.

Dedendum The depth of a tooth space below the pitch line; normally greater than the addendum of the mating gear, to provide clearance.

Diametral pitch The ratio of the number of teeth to the pitch diameter, in inches.

Face width The length of the teeth in an axial plane.

Hub diameter The outside diameter of a gear, sprocket, or coupling hub.

Hub projection The distance the hub extends beyond the gear face.

Involute teeth The teeth of spur gears, helical gears, and worms where the active portion of the profile in the transverse plane is the involute of a circle.

Lead The axial advance of a helix for one complete turn, as in the threads of cylindrical worms and the teeth of helical gears.

Normal diametral pitch The value of the diametral pitch as calculated in the normal plane of a helical gear or worm.

Normal plane The plane normal to the tooth surface at a pitch point and perpendicular to the pitch plane.

Outside diameter The diameter of the addendum (outside) circle of a gear.

Pinion A machine part with gear teeth. When two gears run together, the one with the smaller number of teeth is called the pinion.

Pitch circle The circle derived from a number of teeth and a specified diametral or circular pitch; the circle on which spacing or tooth profiles is established and from which the tooth proportions are constructed.

Pitch diameter The diameter of the pitch circle. In parallel shaft gears, the pitch diameters can be determined directly from the center distance and the number of teeth.

Pressure angle The angle between a tooth profile and a radial line at its pitch point. In involute teeth, pressure angle is often described as the angle between the line of action and the line tangent to the pitch circle.

Root diameter The diameter at the base of the tooth space.

Transverse diametral The ratio of the number of teeth to the pitch diameter, in inches, for a helical gear.

Whole depth The total depth of a tooth space, equal to addendum plus dedendum, which is equal to working depth plus variance.

Working depth The depth of engagement of two gears.

19.3.5 Diametral Pitch System

All stock gears are made in accordance with the diametral pitch system. The **diametral pitch** of a gear is the number of gear teeth for each inch of pitch diameter. Therefore, the diametral pitch specifies the size of the gear tooth; a smaller diametral pitch indicates a larger tooth. An eight-pitch gear has eight teeth for each inch of pitch diameter (for a 6-in. pitch diameter, $6 \times 8 = 48$ teeth). The **circular pitch** is the distance from a point on one tooth to the corresponding point on the next tooth, measured along the pitch circle.

Gear teeth can be manufactured in a wide variety of shapes and profiles. The **involute profile** is the most common system for gearing today, and most standard spur and helical gears are of involute form. An **involute** is a curve that is traced by a point on a taut cord unwinding from a circle, called a **base circle.** The involute is a form of spiral, the curvature of which becomes straighter as it is drawn from a base circle. Eventually, if drawn far enough, it would become a straight line.

Focus On . . .

ELEVATORS

If asked, the average person would tell you that an elevator is a mechanical device for moving people or objects to a higher or lower level. They might also tell you that it is a rectangular car that moves up and down on guides in a shaft, has doors that open onto each floor, has a mechanism of some sort, has controls, and uses safety devices. Virtually no one would think to tell you that the elevator is the world's most used and safest method of transportation. Many would consider automobiles, planes, and trains before the elevator. Most would not even consider the elevator at all.

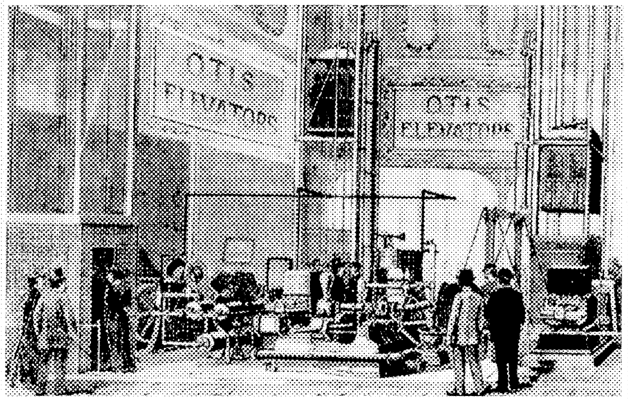
The total number of passengers riding in elevators in any two-week period is more than the world's population. Records show that there are fewer than 1000 accidents per year that involve elevators. However, if you have ever been stranded in an elevator during a malfunction, you know that the elevator is the kind of important technology no one notices until it malfunctions.

Elevators are based on the principle of the counterweight. The weight of one object balances the weight of another object.

In the early nineteenth century, the English were the first to hook up a steam engine to a pulley, but it was not until 1853 that Elisha Graves Otis really improved the safety of the elevator. He displayed his spring safety elevator at the World's Fair in New York City at the Crystal Palace. He invented a governor that allowed the cable holding the car to be cut without moving the car. Everyone was amazed and wanted to know how he stopped the elevator from plunging to the ground.

In 1857, Otis installed the first commercial passenger elevator in a department store. This elevator took fifteen minutes to arrive at the top of a skyscraper (back then that was fast!). The elevator was one of the key factors in the development of our cities. Otis, because of his patents on the steam elevator, created the Otis Elevator Company—a familiar name because their products are very visible in our modern tall buildings.

Today, the manufacturing, installation, and use of elevators are regulated by the national code of the American Society of Mechanical Engineers, the American Institute of Architects, and the National Institute of Standards and Technology. One wonders if Otis could have imagined the impact his invention would have on us when he first exhibited it at the 1853 World's Fair. It's one of those inventions you don't notice until you have to climb stairs to the twenty-fifth story of your office building. Then you know how important Otis is to your life.



An early steam elevator.

A modern elevator.

19.3.6 Pressure Angle

ressure angle (PA) (Fig. 19.5) is defined as the angle ormed between the normal to the tooth profile at the pitch ircle and the tangent to the pitch circle at that point.

Standard gears are manufactured in both $14\frac{1}{2}^\circ$ and 20° PA nvolute full-depth system gears. Although a 20° PA has a higher load-carrying capacity, $14\frac{1}{2}^\circ$ PA gears are still in existence. The spur gear detail shown in Figure 19.12 has a pressure angle of $14\frac{1}{2}^\circ$, a pitch diameter of 12.00 in., and a diametral pitch of 4; therefore, the gear has $12 \times 4 = 48$ teeth. *For gears to mesh, they must have the same diametral pitch.*

19.3.7 Spur Gear Formulas

Table 19.1 shows a complete set of spur gear formulas for full-depth involute teeth.

Tooth Proportions for Standard 20° Fine-Pitch System

N = number of teeth
P = diametral pitch = N/D
a = addendum = $1.000/P$
b = dedendum = $1.200/P + 0.002$
c = clearance = $0.200/P + 0.002$
h_k = working depth of tooth = $2.000/P$
h_l = total depth of tooth = $2.200/P + 0.002$
D = pitch diameter = N/P
OD = D_O (or D_o) = outside diameter = $D + 2/P$

Tooth Proportions for Standard $14\frac{1}{2}$° Full-Depth Involute System

N = number of teeth
P = diametral pitch = N/D
a = addendum = $1/P$
b = dedendum = $1.157/P$
c = clearance = $0.157/P$
h_k = working depth = $2/P$
h_l = total depth = $2.157/P$
D = pitch diameter = N/P
OD = outside diameter = $D + 2/P$

TABLE 19.1 Spur Gear Teeth Formulas (20° Pressure Angle) for Full-Depth Involute Teeth

To Obtain:	Having:	Formula
Diametral pitch (P)	Circular pitch (p)	$P = \frac{3.1416}{p}$
	Number of teeth (N) and pitch diameter (D)	$P = \frac{N}{D}$
	Number of teeth (N) and outside diameter (D_o)	$P = \frac{N + 2}{D_o}$
Circular pitch (p)	Diametral pitch (P)	$p = \frac{3.1416}{P}$
Pitch diameter (D)	Number of teeth (N) and diametral pitch (P)	$D = \frac{N}{P}$
	Outside diameter (D_o) and Diametral pitch (P)	$D = D_o - \frac{2}{P}$
Base diameter (D_b)	Pitch diameter (D) and pressure angle (ø)	$D_b = D \cos ø$
Number of teeth (N)	Diametral pitch (P) and pitch diameter (D)	$N = P \times D$
Tooth thickness (t) @ pitch diameter (D)	Diametral pitch (P)	$t = \frac{1.5708}{P}$
Addendum (a)	Diametral pitch (P)	$a = \frac{1}{P}$
Outside diameter (D_o)	Pitch diameter (D) and addendum (a)	$D_o = D + 2a$
Whole depth (h_t) (20P and finer)	Diametral Pitch (P)	$h_t = \frac{2.2}{P} + .002$
Whole depth (h_t) (coarser than 20P)	Diametral pitch (P)	$h_t = \frac{2.157}{P}$
Working depth (h_k)	Addendum (a)	$h_k = 2a$
Clearance (c)	Whole depth (h_t) and addendum (a)	$c = h_t - 2a$
Dedendum (b)	Whole depth (h_t) and addendum (a)	$b = h_t - a$
Contact ratio (M_c)	Outside radii,* base radii,* center distance (C), and pressure angle (ø)	$M_c = \frac{\sqrt{R_o^2 - R_b^2} + \sqrt{r_o^2 - r_b^2} - C \sin ø}{P_c \cos ø}$
Root diameter (D_r)	Pitch diameter (P) and dedendum (b)	$D_r = D - 2b$
Center distance (C)	Pitch diameter (D)	$C = \frac{D_1 + D_2}{2}$
	Number of teeth (N) and pitch (P)	$C = \frac{N_1 + N_2}{2P}$

*R_o = outside radius, gear; r_o = outside radius, pinion; R_b = base circle radius, gear; r_b = base circle radius, pinion.

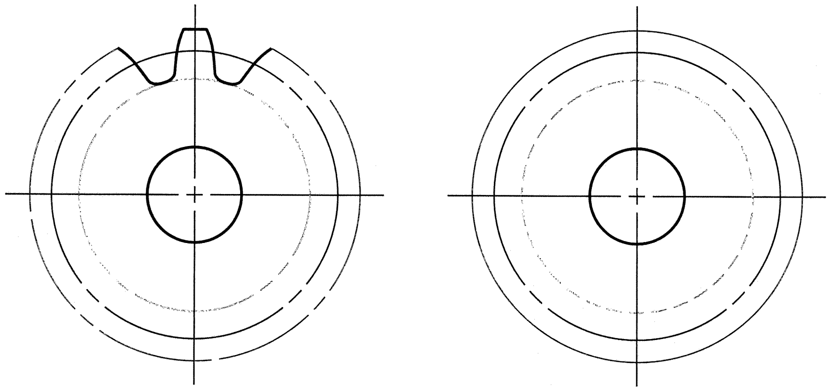


FIGURE 19.13 Representing Gear Teeth

(a) One tooth shown

(b) Teeth not shown

19.3.8 Spur and Helical Gear Teeth Representation

Views of external spur and helical gears are drawn as shown n Figure 19.13. Gear tooth outlines can normally be omitted from the drawing. Outlines are shown where needed for orientation with other features of the gear or where details, such as tip chamfers or reliefs, require dimensioning. Where required, one tooth may be shown [Fig. 19.13(a)]. Notice that all the teeth are shown in Figure 19.12. This is because a CAD system was used to draw the gear detail. The designer constructed only one tooth and hen rotated and copied (**ARRAY** on AutoCAD) the tooth he required number of times (48 in the example). When gears are drawn manually, a template is almost always used o construct the gear teeth.

19.3.9 Gear Tooth Thickness

Circular or arc **tooth thickness** is the preferred specification; chordal tooth thickness may be used. Tooth thickness s normally specified at the referenced pitch circle. Figure 9.14 shows gear teeth terminology in detail. If measurements such as with pins or balls (Fig. 19.14) are specified in ddition to the actual tooth thickness, these measurements must be labeled "reference," or labeled as in Figure 19.15, where the dimension is given **OVER PIN**. The diameter of pins or balls (Fig. 19.15) must be expressed beyond four decimal places as appropriate. The diameter of pins or balls is basic.

Tooth thickness must be designated "actual" or "functional." Functional tooth thickness is a specification at the referenced pitch circle for definitive backlash control. It may be used in place of, or in addition to, actual tooth thickness. However, if the actual tooth thickness is critical, it should be specified in addition to the functional tooth thickness. Table 19.2 shows standard tooth dimensions for spur gears.

19.3.10 Backlash on Spur Gears

Backlash is the motion of a meshed gear when its mate is held fixed. An increase or decrease in center distance will cause an increase or decrease in backlash. Stock spur gears are cut to operate at **standard center distances** (Figs. 19.9 and 19.10). The standard center distance is defined as follows:

$$\text{Standard center distance} = \frac{\text{pinion pitch diameter} + \text{gear pitch diameter}}{2}$$

19.4 HELICAL GEARS

The information already given for spur gears is also applicable to helical gears, with the addition of helix angle and lead. **Helix angle** is the angle between any helix and an

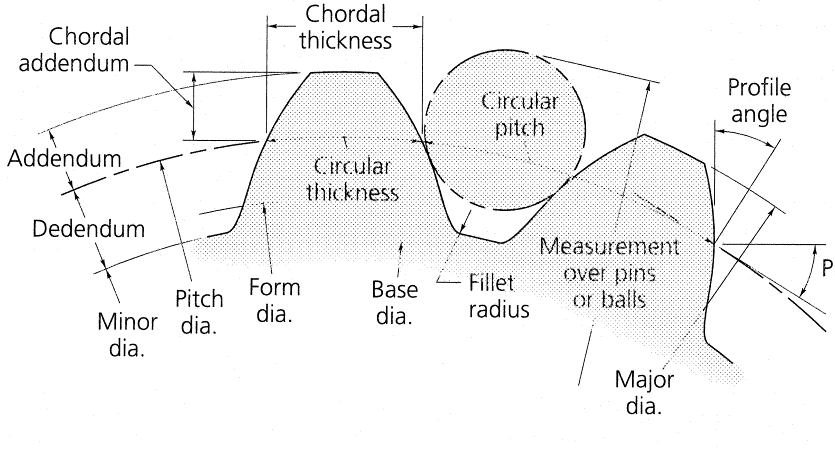
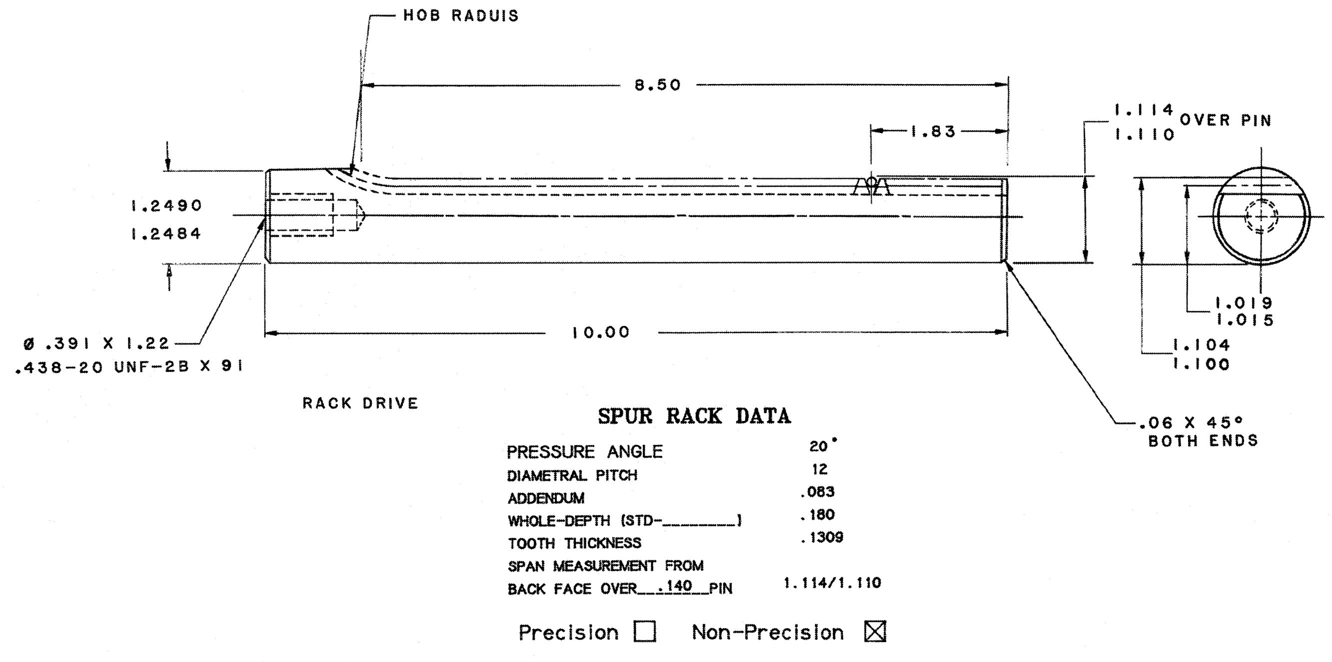


FIGURE 19.14 Spur Gear Teeth erminology



SPUR RACK DATA

PRESSURE ANGLE	20°
DIAMETRAL PITCH	12
ADDENDUM	.083
WHOLE-DEPTH (STD-________)	.180
TOOTH THICKNESS	.1309
SPAN MEASUREMENT FROM BACK FACE OVER__.140__PIN	1.114/1.110

Precision ☐ Non-Precision ☒

FIGURE 19.15 Spur Rack Detail

element of its cylinder; in **helical gears** (Fig. 19.16) it is at the pitch diameter, unless otherwise specified. **Lead** for helical gears is the axial advance of a helix for one complete turn, for instance, as in the threads of cylindrical worms and the teeth of helical gears. Figure 19.17 presents helical gear terminology.

Many standard helical gears are cut to the diametral pitch system. This results in a normal pitch that is smaller than the diametral pitch. **Normal diametral pitch** is the diametral pitch calculated in the normal plane.

Helical gears of the same hand operate at right angles. Helical gears of opposite hands run on parallel shafts.

TABLE 19.2 Spur Gear Tooth Dimensions

Diametral Pitch	Circular Pitch (inches)	Thickness of Tooth on Pitch Line (inches)	Depth to Be Cut in Gear (inches) (Hobbed Gears)	Addendum (inches)
3	1.0472	.5236	.7190	.3333
4	.7854	.3927	.5393	.2500
5	.6283	.3142	.4314	.2000
6	.5236	.2618	.3565	.1667
8	.3927	.1963	.2696	.1250
10	.3142	.1571	.2157	.1000
12	.2618	.1309	.1798	.0833
16	.1963	.0982	.1348	.0625
20	.1517	.0785	.1120	.0500
24	.1309	.0654	.0937	.0417
32	.0982	.0491	.0708	.0312
48	.0654	.0327	.0478	.0208
64	.0491	.0245	.0364	.0156

The helical tooth form is involute in the plane of rotation and can be developed in a manner similar to that for the spur gear. However, unlike the spur gear, which may be viewed as two-dimensional, the helical gear must be viewed as three-dimensional to show changes in axial features. Formulas for helical gears are provided in Table 19.3.

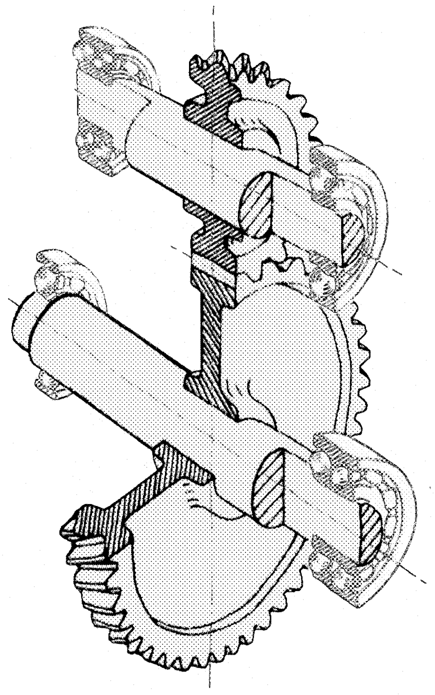
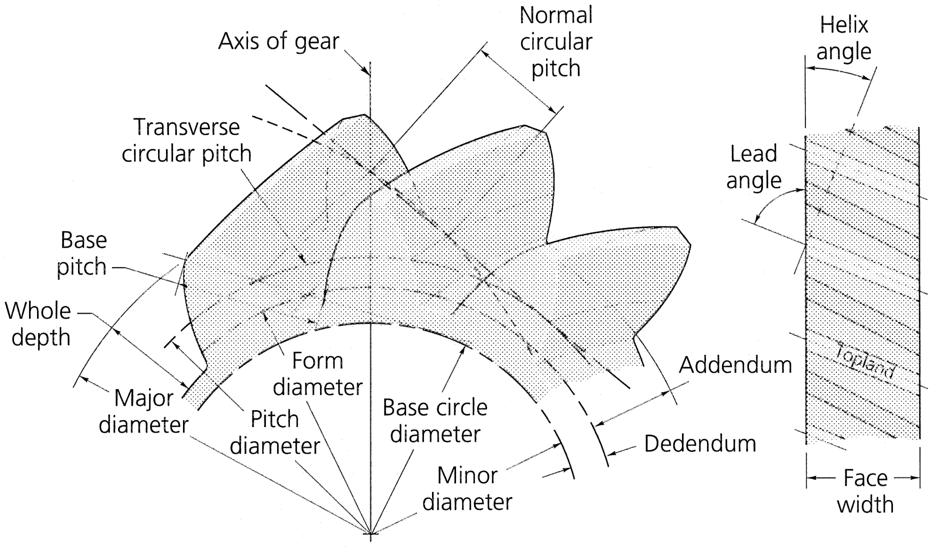


FIGURE 19.16 Mating Helical Gears



IGURE 19.17 Helical Gear eeth Terminology

19.5 RACKS AND PINIONS

rack may be considered a gear of infinitely long pitch adius. The pitch line of a rack is a straight line; the pitch is lescribed as the **linear pitch.** Racks can have spur or helical eeth. Figure 19.18 shows a standard rack detail. Racks are lesigned to mate with a **pinion** (gear) and are used to onvert rotary motion into linear motion or the reverse.

ABLE 19.3 Helical Gear Teeth Formulas

To Obtain:	Having:	Formula
Transverse diametral pitch (P)	Number of teeth (N) and pitch diameter (D)	$P = \frac{N}{D}$
	Normal diametral pitch (P_N) and helix angle (ψ)	$P = P_N \cos \psi$
Pitch diameter (D)	Number of teeth (N) and transverse diametral pitch (P)	$D = \frac{N}{P}$
Normal diametral pitch (P_N)	Transverse diametral pitch (P) and helix angle (ψ)	$P_N = \frac{P}{\cos \psi}$
Normal circular tooth thickness (τ)	Normal diametral pitch (P_N)	$\tau = \frac{1.5708}{P_N}$
Transverse circular pitch (p_t)	Diametral pitch (P) (transverse)	$p_t = \frac{\pi}{P}$
Normal circular pitch (p_n)	Transverse circular pitch (p_t) and pitch helix angle (ψ)	$p_n = p_t \cos \psi$
Lead (L)	Pitch diameter (D) and pitch helix angle (ψ)	$L = \frac{\pi D}{\tan \psi}$

19.6 SPLINES

Splines are multiple keys, in the general form of internal and external gear teeth, used to prevent relative rotation between two members. Splines act primarily to transmit torque and are usually integral with shafts that include other features, as in Figure 19.19, where the end of the shaft is a spline and the center is a worm screw. Splines (Fig. 19.20) normally have three applications:

- For coupling shafts when heavy torques are transmitted without slippage
- For attaching parts that require removal for indexing or for change of angular position
- For transmitting power to permanently fixed gears, pulleys, or other rotating devices

Involute splines (Fig. 19.20) are similar in form to external or internal involute gears. The general graphic format for depicting spline teeth is the same as for spur gears. Standard involute splines are manufactured with 30°, $37\frac{1}{2}$°, and 45° pressure angles.

19.7 GEAR DRAWING PRACTICES

An axial view and a plane of rotation view are generally sufficient to illustrate a gear. Additional views may be used to show construction and special features or relations. The axial view is usually made in section, on a plane parallel to the axis (Fig. 19.12). A helical gear or a gear, pinion, or worm integral with a shaft is shown in full view, on a plane parallel to the axis (Fig. 19.19). The pitch diameter is shown by conventional centerlines and the root diameter by hidden

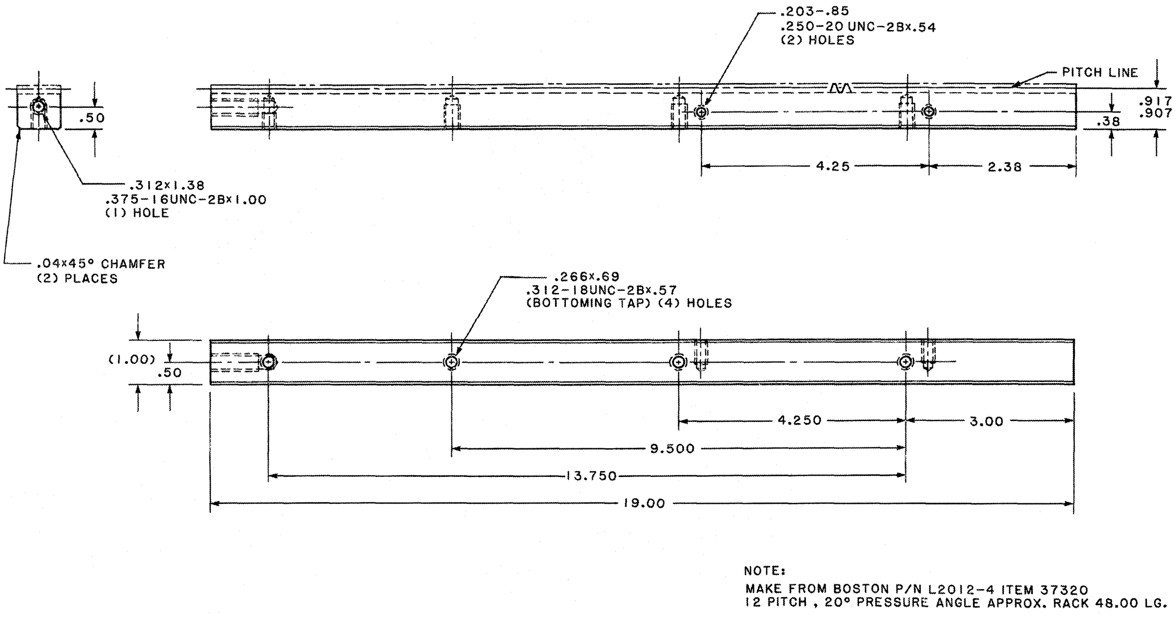


FIGURE 19.18 Rack Detail

lines. In an axial section view, visible lines represent the outside and root diameters, and centerlines show the pitch diameter.

In views representing planes of rotation, the outside and root diameters are shown by phantom lines and, when several teeth are shown, the pitch diameter is shown by a centerline [Fig. 19.13(a)]. *When no teeth are shown,* the outside diameter is represented by a visible object line and the root diameter by a hidden line [Fig. 19.13(b)]. The pitch diameter is still represented by a centerline. Figure 19.21 is an actual industry detail drawing of a gear.

In most cases, it is not necessary to draw all gear teeth when detailing gears. When it is necessary to illustrate a relation to some other feature, such as a keyseat or a bolt hole, or to show dimensions across pins, one or more teeth may be shown. An enlarged view or section can show special

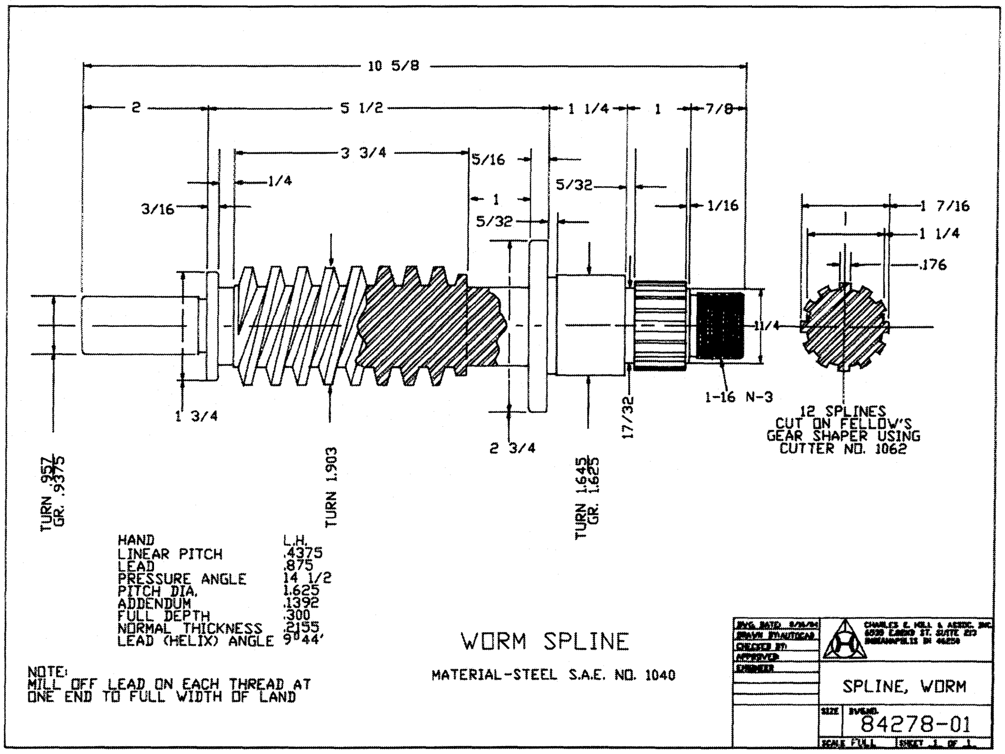
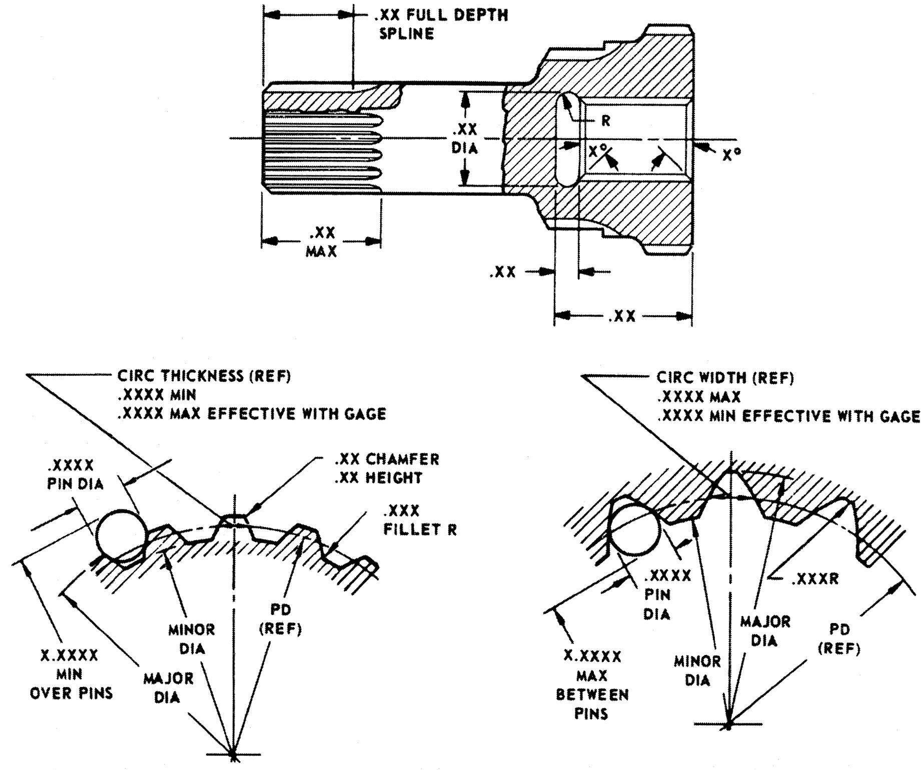


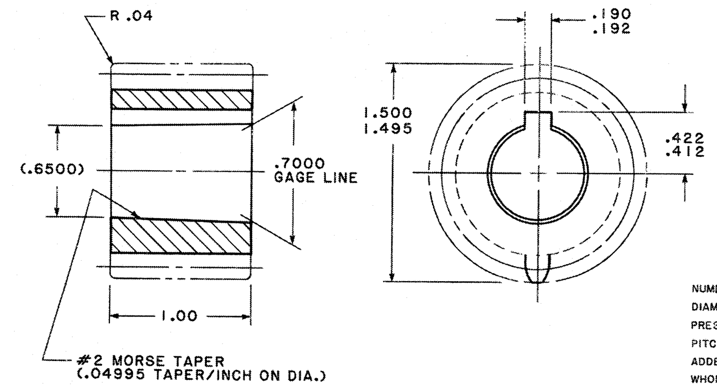
FIGURE 19.19 Worm Spline



INVOLUTE SPLINE DATA – EXTERNAL	
NUMBER OF TEETH	XX
DIAMETRAL PITCH	XX/XX
PRESSURE ANGLE	XX°
PITCH DIA (REF)	X.XXXX
MAJOR DIA	X.XXXX – X.XXXX
MINOR DIA	X.XXXX – X.XXXX
TRUE INVOLUTE FORM DIA	X.XXXX
*MAX LEAD ERROR	.XXXX

INVOLUTE SPLINE DATA – INTERNAL	
NUMBER OF TEETH	XX
DIAMETRAL PITCH	XX/XX
PRESSURE ANGLE	XX°
PITCH DIA (REF)	X.XXXX
MAJOR DIA	X.XXXX – X.XXXX
MINOR DIA	X.XXXX – X.XXXX
TRUE INVOLUTE FORM DIA	X.XXXX
*MAX LEAD ERROR	.XXXX

FIGURE 19.20 Spline Dimensioning



SPUR GEAR DATA

NUMBER OF TEETH	16
DIAMETRAL PITCH	12
PRESSURE ANGLE	20°
PITCH DIAMETER	1.333
ADDENDUM	.0833
WHOLE DEPTH	.1798
CIRCULAR TOOTH THICKNESS	.1309
SPAN MEASUREMENT OVER .140 TEETH	1.5179
MAXIMUM PITCH LINE VELOCITY	40 FT/MIN
CM QUALITY NO.	5

IGURE 19.21
pur Gear Detail

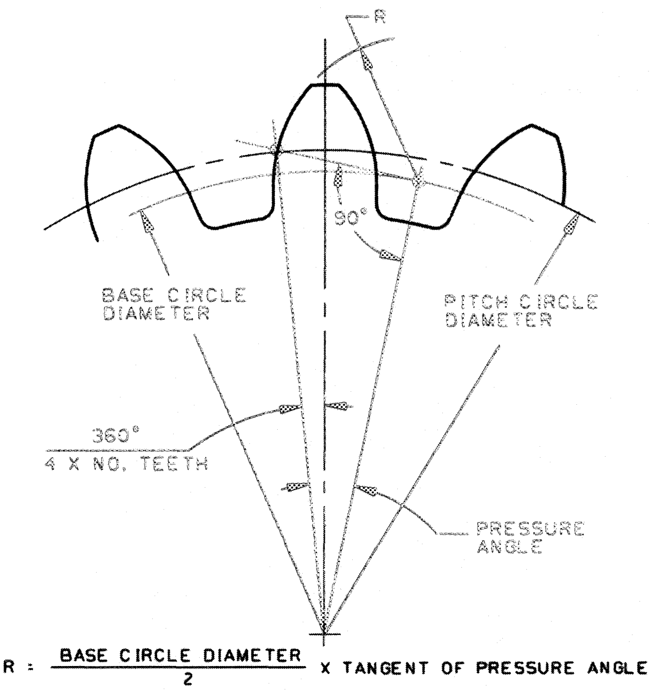


FIGURE 19.22 Drawing an Approximate Involute for Construction of Gear Teeth

features of gear teeth or a gear profile. Gear teeth may be drawn by the approximate method shown in Figures 19.22 and 19.23. The relative size of gear teeth in terms of diametral pitch is illustrated full size in Figure 19.24.

19.7.1 Dimensioning and Notes

Gear data must be grouped as shown in Figures 19.12 and 19.15. The location of the gear data on the drawing is arbitrary. However, if more than one gear is depicted on a drawing, the groups of gear data must be clearly referenced to the appropriate gear.

The major diameter may be specified as the outside diameter; the minor diameter may be specified as the root diameter. This is for external gears only. On internal gears, the major diameter may be specified as the root diameter and the minor diameter as the inside diameter.

Illustrations show only those dimensions that control the gear teeth and their relation to the specified mounting. All other dimensions and specifications must conform to recommended drafting practice (ANSI). For the rack in Figure 19.25, dimensional values are indicated by X's that show the number of decimal places recommended in each instance.

A completely defined rack or gear contains two sets of dimensions: those of the gear blank and those of the gear teeth. This information is shown as a composite on one set of views. Information required for the production of a gear blank is shown on the face of the gear drawing, integral with the graphic depiction. Information required for the production of the gear teeth is shown on the same drawing in a data block. Local and general notes are added as required. Angular dimensions are expressed in degrees and decimal portions thereof (where desired, the angle may be given in degrees, minutes, and seconds). Figure 19.26 shows a matching set of spur gears, along with all dimensions required for manufacture.

19.8 BEVEL GEARS

Portions of two cones in frictional contact (Fig. 19.27) might be used to transmit motion from one shaft to another. However, to prevent slipping, teeth may be used. The cones then become **bevel gears** (Fig. 19.28). Two bevel gears of the same size, with shafts at right angles, are called **miter gears** (Fig. 19.29). Bevel gears are the most common way to transmit motion between shafts with intersecting axes. The addendum and dedendum are measured the same as for a spur gear, and measurements are taken on a cone called the **back cone.** The diametral pitch, circular pitch, etc. are the same as for a spur gear.

The shafts for bevel gears may make any angle, called the

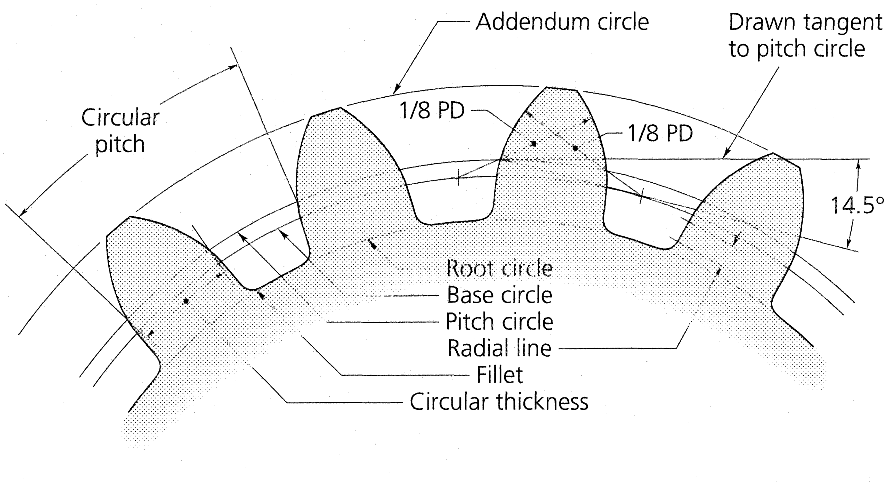


FIGURE 19.23 Simplified Gear Tooth Construction

Applying Parametric Design . . .

SPLINE GEAR TEETH AND PATTERNING

Patterns are multiple features created from a single feature (see Fig. A). After it is created, a pattern behaves as if it was a single feature. When you create a pattern, you create instances (copies) of the selected feature.

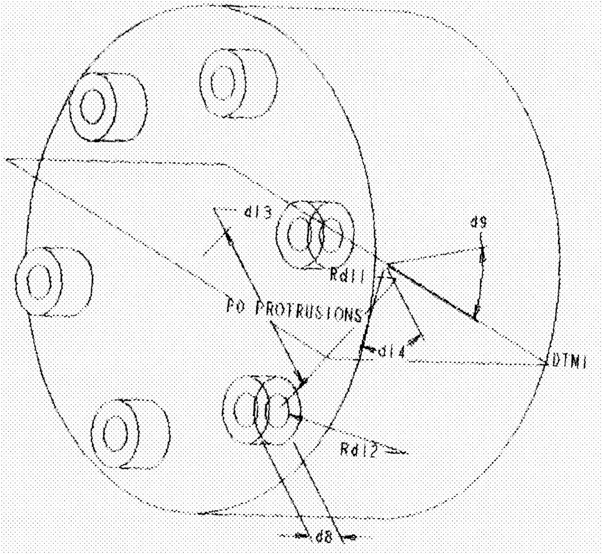


FIGURE B A Rotational Pattern of Sketched Features

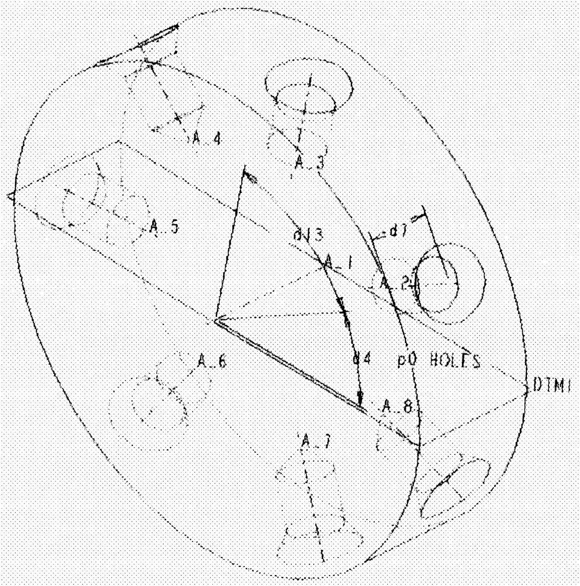


FIGURE A A Rotational Pattern of Radially Placed Holes

Patterns have many uses. Creating a pattern is a quick way to reproduce a feature (Fig. B). Manipulating a pattern may be more advantageous than operating individual features. In fact, you can easily suppress a pattern (temporarily remove it from the screen) or add it to a layer.

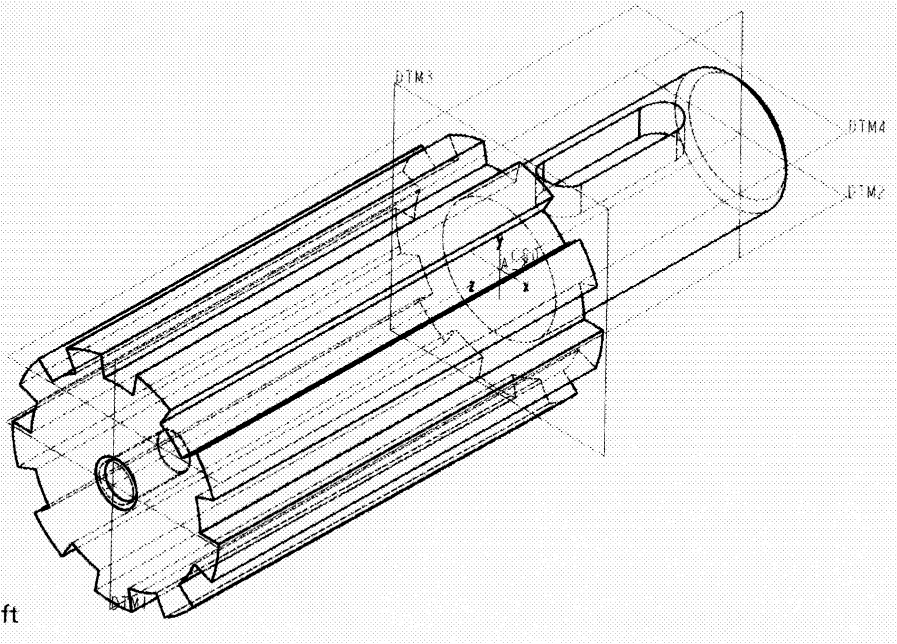


FIGURE C Completed Spline Shaft

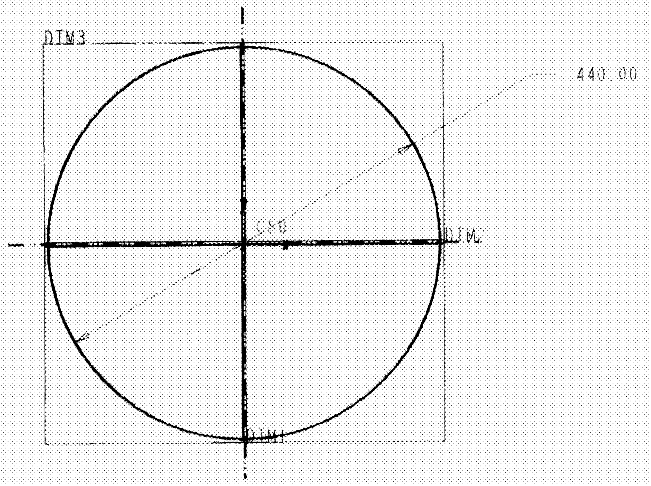


FIGURE D **Sketched Circle OD**

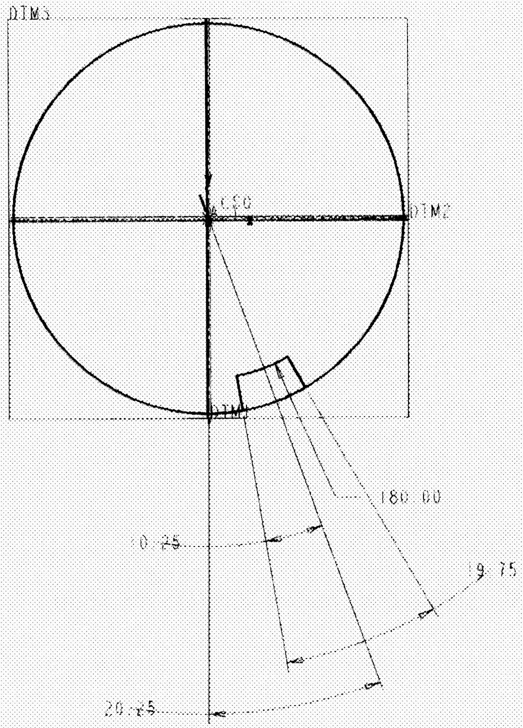


FIGURE E **Sketched Spline Tooth**

Modifying patterns is more efficient than modifying individual features. In a pattern, when you change dimensions of the original feature, the whole pattern will be updated automatically. Because a pattern is controlled parametrically, it can be modified by changing pattern parameters, such as the number of instances, spacing between instances, and the original feature dimensions.

The following features can be patterned:

Slots
Holes
Flanges
Ears
Thin features
Gear teeth
Cuts
Shafts
Ribs
Local pushes
Surface features
Spline teeth
Protrusions
Necks
Cosmetics
Datum planes
Datum point arrays
Features copied by translation

To create a gear spline on a parametric design system involves a simple set of commands. The following figure sequence and description presents the creation of a spline and shaft (see Figure C):

1. Sketch the circle representing the OD of the spline using the system's default datum planes (see Fig. D). The depth of the spline surface is given after the circle is dimensioned and regenerated.
2. Sketch the dimensions for one spline tooth. Make the tooth at an angle to one of the datum planes—here DTM1 (see Figs. E and F). This will allow you to use the angle dimension when

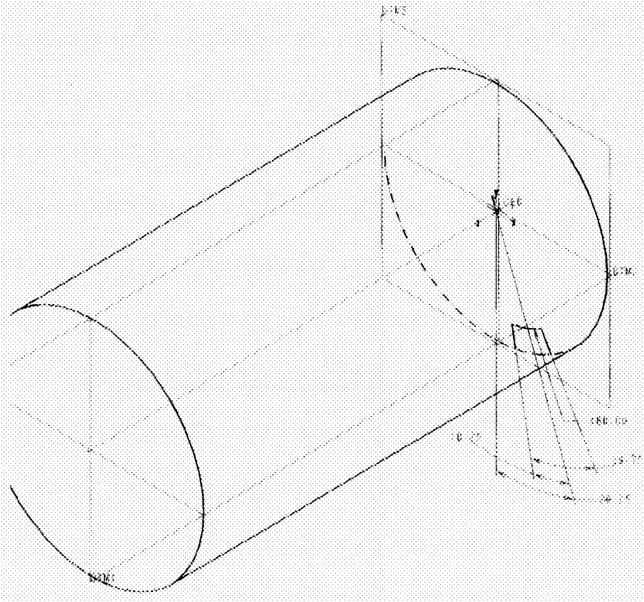


FIGURE F **Dimensioned Sketch of the Spline Tooth**

(*Continues*)

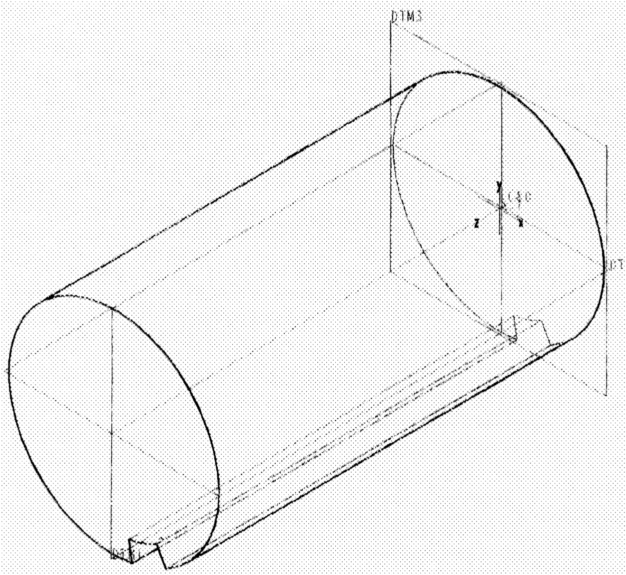


FIGURE G **Spline Cut Created Through the Shaft**

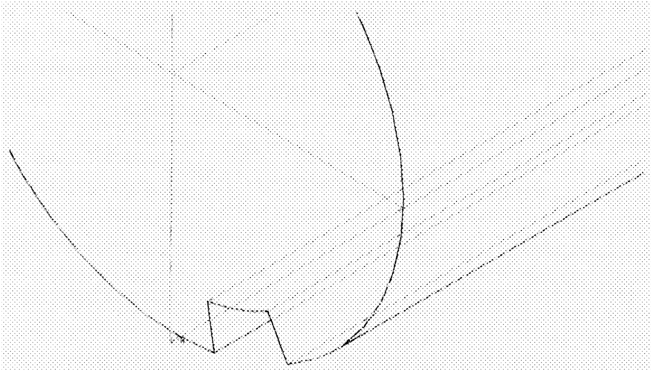


FIGURE H **Close-Up View of Cut Feature**

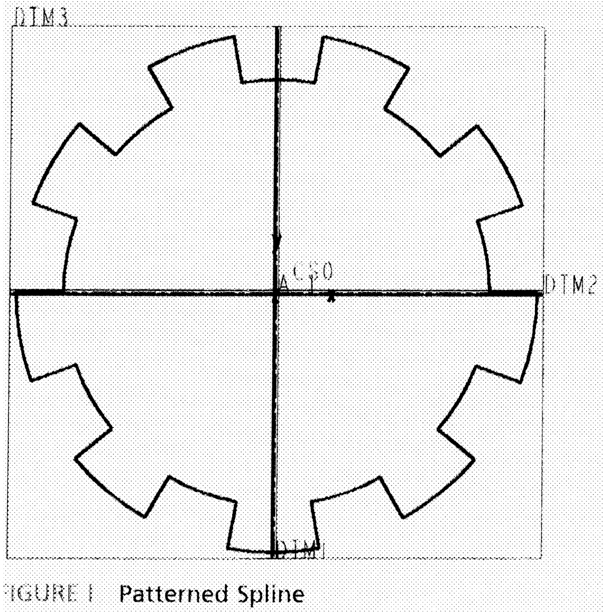


FIGURE I **Patterned Spline**

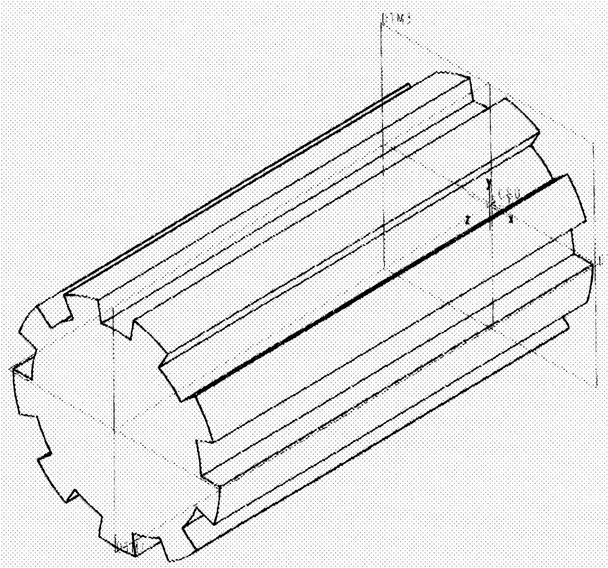


FIGURE J **Spline Shaft**

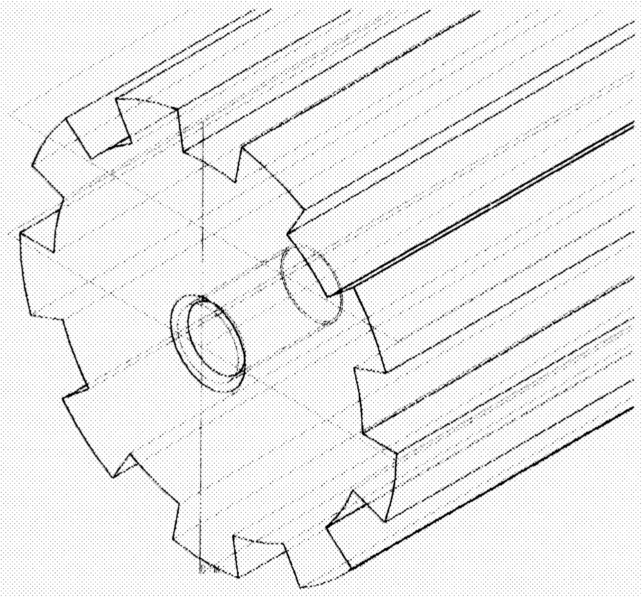


FIGURE K **Countersunk Hole and Cosmetic Threads**

patterning the feature. The depth of the spline tooth is given after its shape is sketched, aligned, regenerated, and dimensioned (see Figs. G and H).

3. Create the pattern by selecting the feature to be patterned, providing the angle for the radial displacement, and the number of instances (see Figs. I and J).
4. Model the shaft, keyseat, and countersunk hole last (see Figure C).
5. Add cosmetic threads to complete the part (see Fig. K).

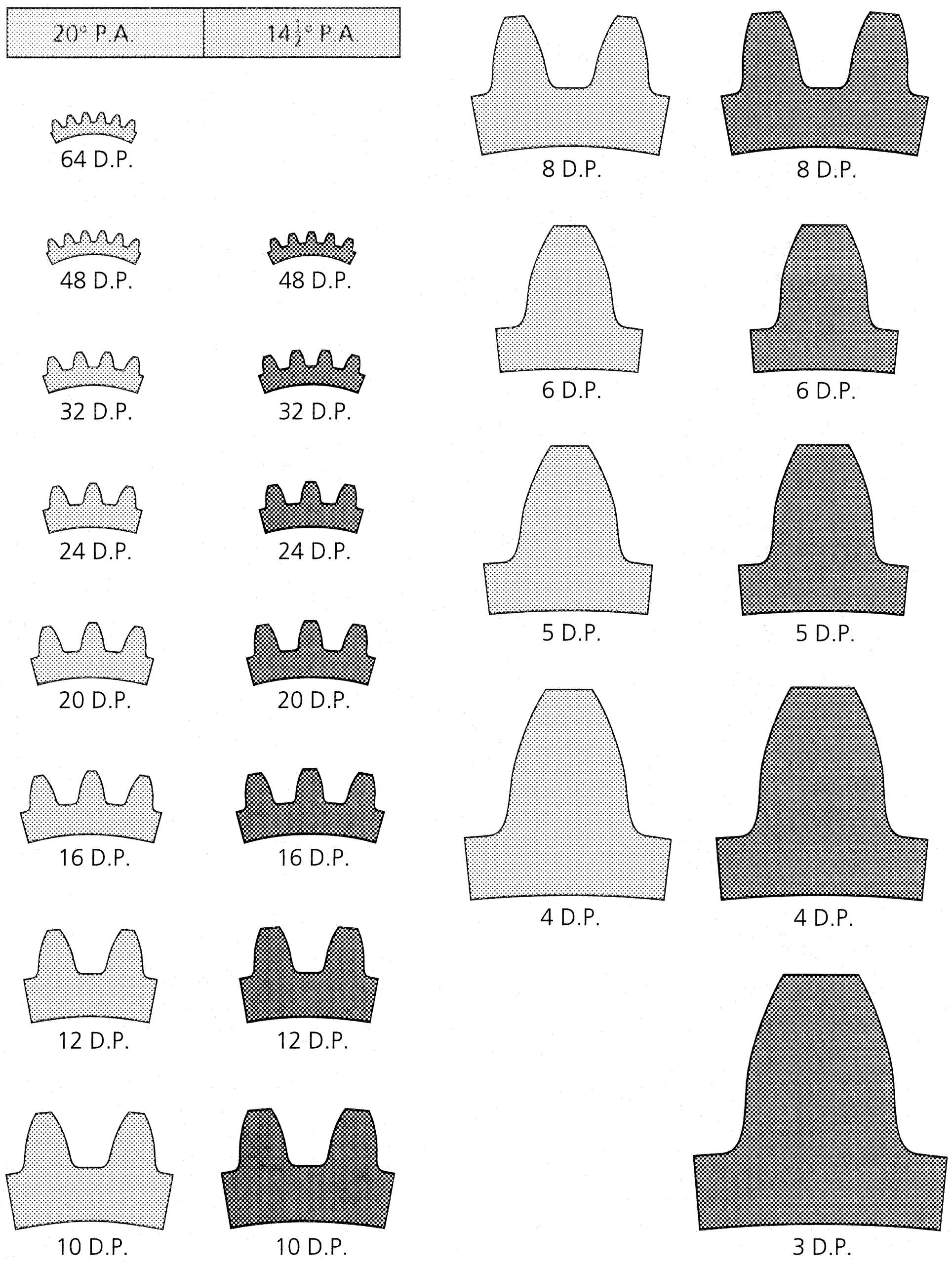


FIGURE 19.24 Spur Gear Teeth Outlines (shown full size)

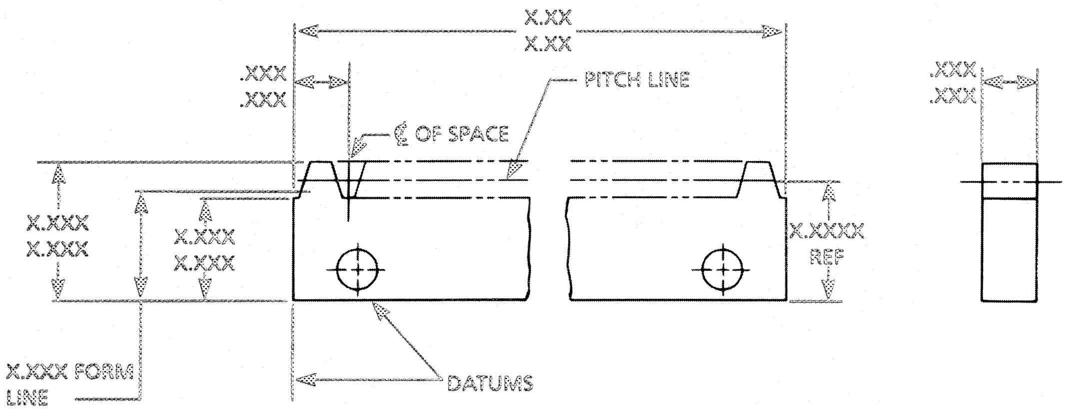
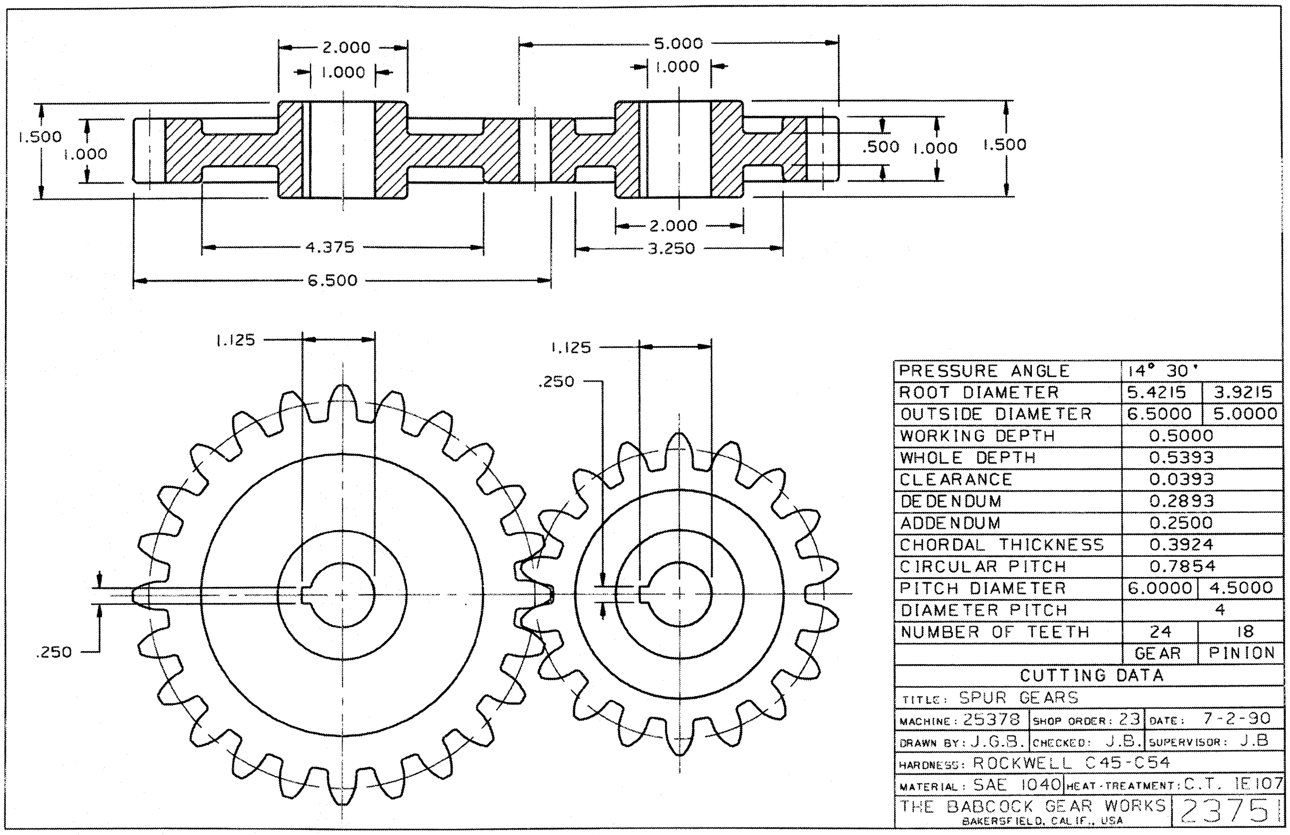


FIGURE 19.25 Rack Dimensioning



PRESSURE ANGLE	14° 30'	
ROOT DIAMETER	5.4215	3.9215
OUTSIDE DIAMETER	6.5000	5.0000
WORKING DEPTH	0.5000	
WHOLE DEPTH	0.5393	
CLEARANCE	0.0393	
DEDENDUM	0.2893	
ADDENDUM	0.2500	
CHORDAL THICKNESS	0.3924	
CIRCULAR PITCH	0.7854	
PITCH DIAMETER	6.0000	4.5000
DIAMETER PITCH	4	
NUMBER OF TEETH	24	18
	GEAR	PINION

CUTTING DATA

TITLE: SPUR GEARS
MACHINE: 25378 SHOP ORDER: 23 DATE: 7-2-90
DRAWN BY: J.G.B. CHECKED: J.B. SUPERVISOR: J.B
HARDNESS: ROCKWELL C45-C54
MATERIAL: SAE 1040 HEAT-TREATMENT: C.T. 1E107
THE BABCOCK GEAR WORKS 23751
BAKERSFIELD, CALIF., USA

FIGURE 19.26 Detail of Mating Spur Gears

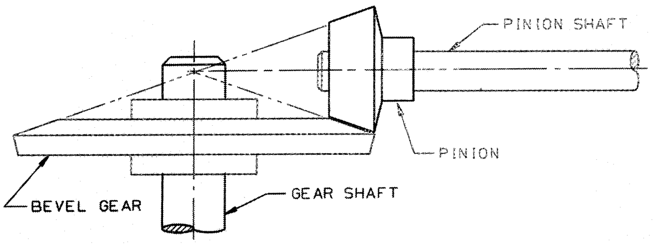


FIGURE 19.27 Bevel Gear Cones

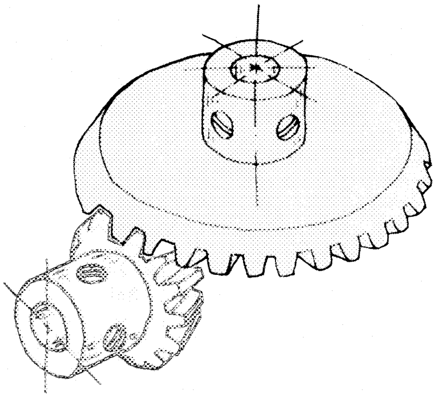


FIGURE 19.28 Bevel Gears

shaft angle, with each other. The terms used for bevel gears are given in Figure 19.29.

19.8.1 Bevel Gear Terminology and Formulas

Bevel gears (Fig. 19.30) are frequently matched in sets or pairs during sequence of the manufacturing process. They are maintained as a matched set in assembly. Formulas for straight bevel gears are given in Table 19.4. Since bevel gears differ from spur gears, the gear tooth nomenclature that follows is presented to familiarize you with general terms used on the bevel gear drawings.

Addendum The distance from the pitch cone to the top of the tooth, as measured at the large end of the tooth.

Axial plane A plane that contains the gear axis.

Back angle distance The perpendicular distance from the intersection of the gear axis with the locating surface at the back of a bevel gear to the back cone element.

Circular thickness The length of arc between the two sides of a gear tooth on the pitch circle.

Face angle distance The perpendicular distance from the intersection of the gear axis with the locating surface at the back of a bevel gear to the face cone element.

FIGURE 19.29 **Bevel and Miter Gear Terminology**

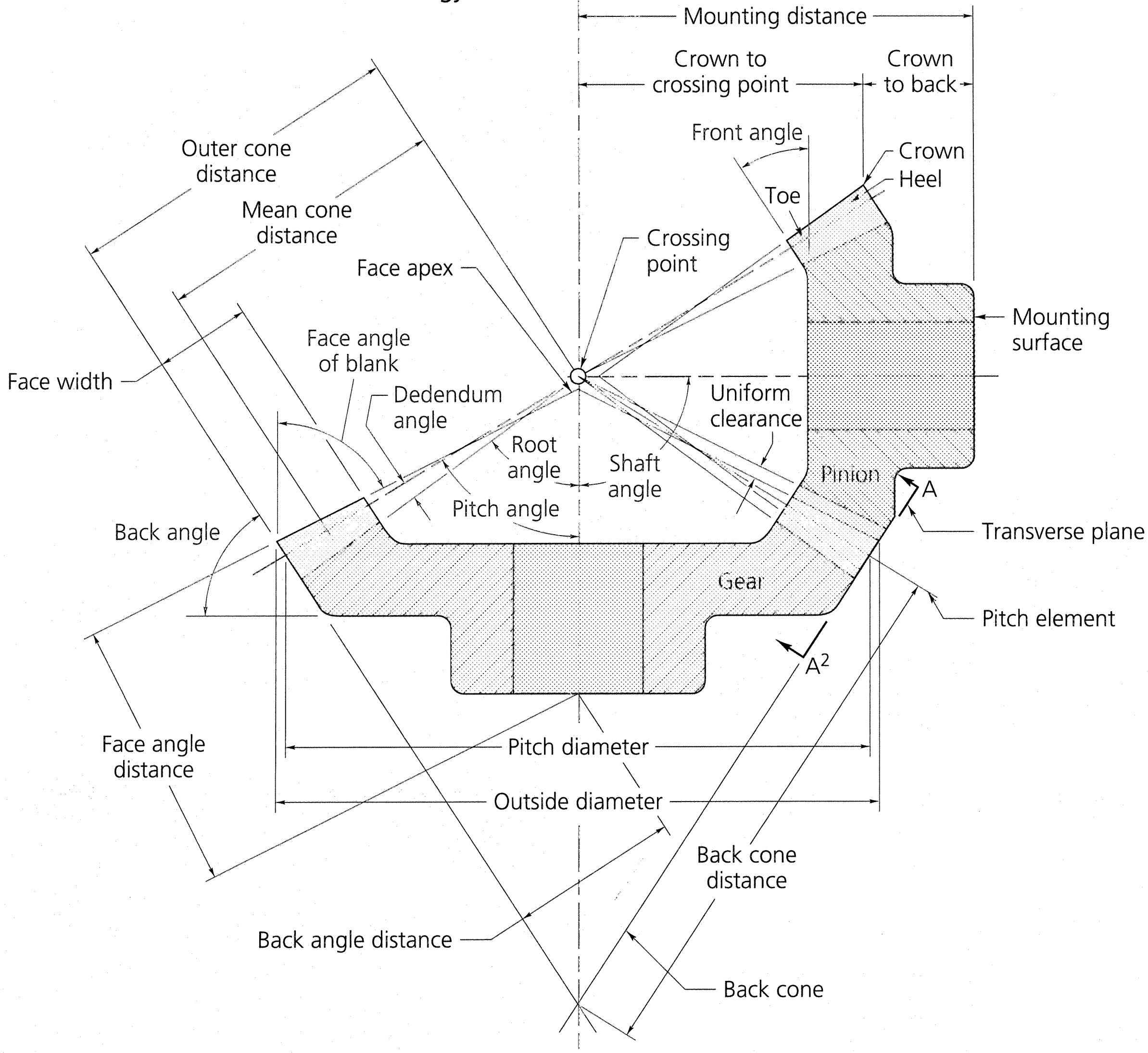
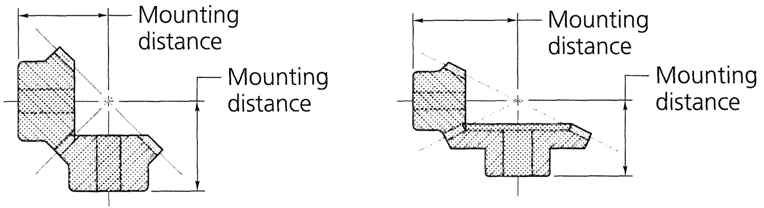


TABLE 19.4 **Straight-Tooth Miter and Bevel Gear Formulas**

To Obtain:	Having:	Formula Pinion	 Gear
Pitch diameter (D, d)	Number of teeth (N) and diametral pitch (P)	$d = \frac{N}{P}$	$D = \frac{N}{P}$
Whole depth (h_T)	Diametral pitch (P)	$h_T = \frac{2.188}{P} = .002$	$h_T = \frac{2.188}{P} = .002$
Addendum (a)	Diametral pitch (P)	$a = \frac{1}{P}$	$a = \frac{1}{P}$
Dedendum (b)	Whole depth (h_T) and addendum (a)	$b = h_T - a$	$b = h_T - a$
Clearance (c)	Whole depth (h_T) and addendum (a)	$c = h_T - 2a$	$c = h_T - 2a$
Circular tooth thickness (τ)	Diametral pitch (P)	$\tau = \frac{1.5708}{P}$	$\tau = \frac{1.5708}{P}$
Pitch angle (L_P, L_G)	Number of teeth in pinion (N_P) and gear (N_G)	$L_P = \tan^{-1}\left(\frac{N_P}{N_G}\right)$	$L_G = 90 - L_P$
Outside diameter (D_O, d_O)	Pinion and gear pitch diameter ($D_p + D_G$), addendum (a), and pitch angle ($L_P + L_G$)	$d_O = D_P + 2a(\cos L_P)$	$D_o = D_G + 2a(\cos L_G)$

FIGURE 19.30 Gear Sets



(a) Miter gears

(b) Bevel gears

Mounting distance (MD) The distance from the end of the hub of one gear to the centerline of its mating gear (Fig. 19.30).

Pitch plane A plane tangent to the gear pitch surface. For bevel gears, the pitch plane is tangent to the pitch cone.

Pressure angle The angle at the pitch point between a line normal to the tooth profile and the pitch plane.

Spiral angle The angle between the tooth trace and an element of the pitch cone.

Tooth form The shape of the tooth profile. Since bevel gears are manufactured with a variety of tooth forms, it is essential to specify the desired form on the gear drawing.

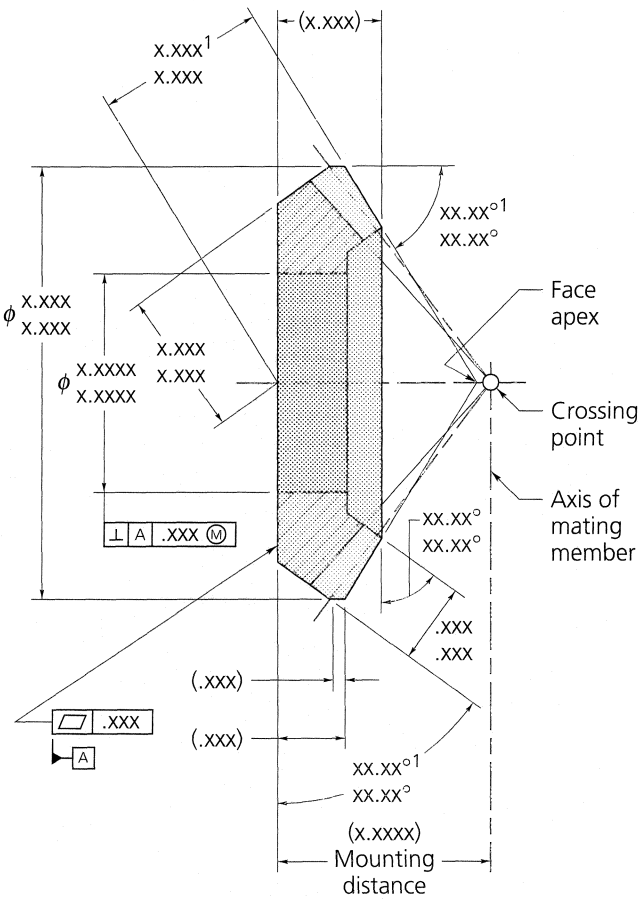


FIGURE 19.31 Dimensions Required for Spiral Bevel Gears

19.8.2 Drawing and Dimensioning Bevel Gears

A bevel gear drawing consists of a side view or axial section illustrating the general configuration and tabulated gear tooth data. Generally, only one view is needed. A front view is added where necessary to show the relationship of the gear teeth to other features.

The spiral bevel gear illustration in Figure 19.31 shows only those dimensions that control the gear teeth and their relation to the mounting surfaces. Dimensional values are indicated by X's, to show the number of decimal places recommended in each instance.

19.9 WORMS AND WORM GEARS

Worm gears (Fig. 19.32) transmit motion from one shaft to another at a high speed. **Worm gears** (wheel) and **worm screws** are designed to transmit motion between nonintersecting, perpendicular shafts. A worm is, in effect, a screw. When a worm wheel (similar to a spur gear) has teeth shaped to fit the threads on the worm, the worm will turn the wheel. The worm may have single, double, or multiple threads. A large speed ratio is possible with this type of

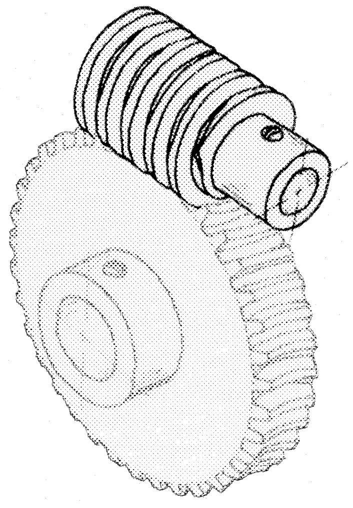


FIGURE 19.32 Worm and Worm Gear

gearing; however, a worm drive only works as a reducer. When the worm gear drives the worm screw (speed increases), the drive locks up.

Specifications and dimensions required for a worm gear set are provided in Figure 19.33. A detail of a worm wheel and a worm gear are shown in Figure 19.34. Sometimes a worm gear is combined with a pinion.

Standard stock worms and worm gears transmit motion and/or power between nonintersecting shafts at right angles (90°). Worm gear drives are considered the smoothest and quietest form of gearing. In most cases, a worm and a worm wheel are detailed on separate sheets. Worm and worm gear formulas are provided in Table 19.5.

19.10 CAD AND GEARS

CAD systems can be used to design and detail gears. Since the system can rotate and copy graphics (even in 3D), only one tooth is drawn and then time-saving commands are used. Figure 19.34 was drawn on a CAD system. The designer in Figure 19.35 is working at his terminal creating a 3D surface model of a spur gear tooth.

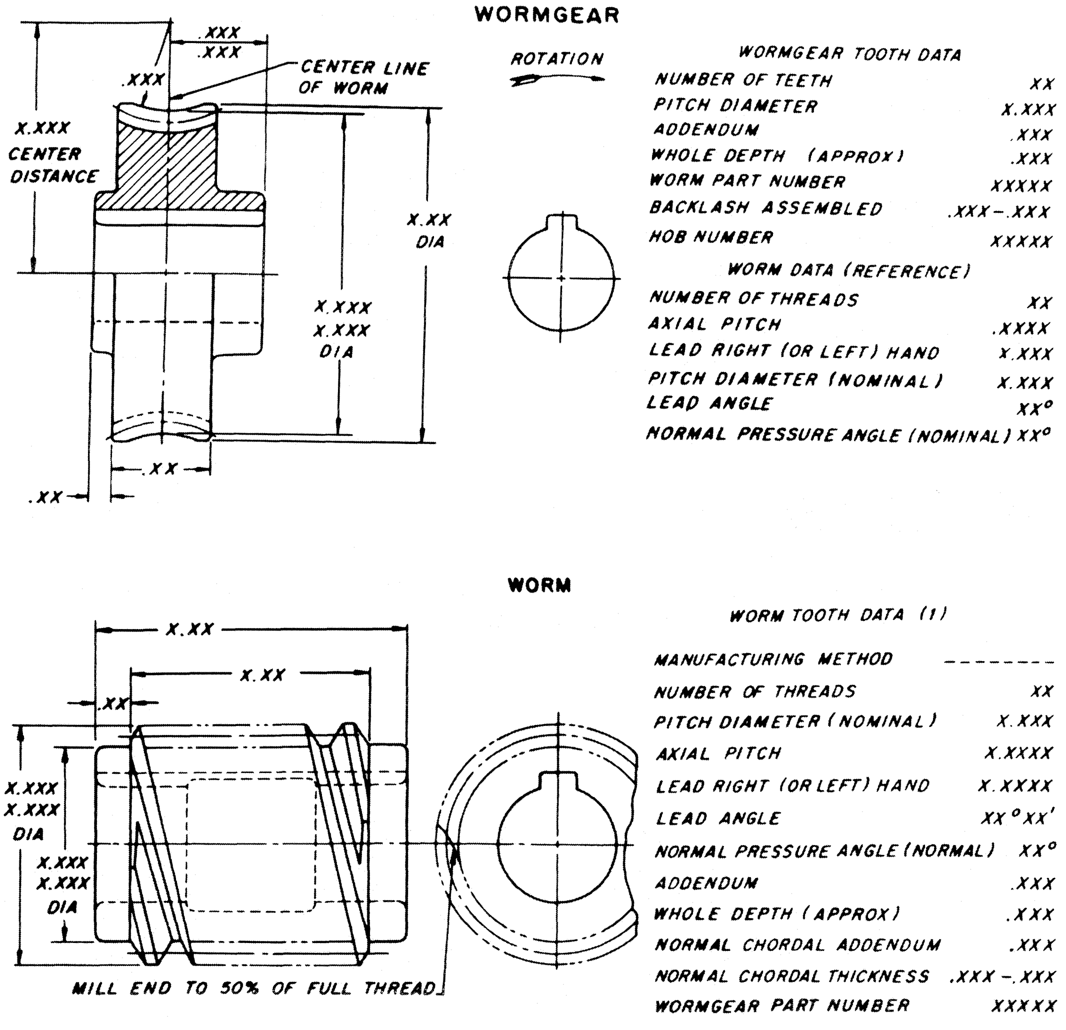
If a CAD system had not been involved, only one tooth would have been drawn for each gear. For AutoCAD the **ARRAY** command with the `Polar` option is used to rotate and copy the gear teeth:

```
Command: ARRAY Select Objects: Window the
tooth that was drawn.
Rectangular or Polar Array (R/P): P
Center point of array: Pick the center of the gear.
Number of items: 32
Angle to fill (+=CCW, -=CW) <360>:
<Return> to choose 360° default.
Rotate objects as they are copied? <y>:
<Return> for default.
```

You May Complete Exercises 19.1 Through 19.4 at This Time

TABLE 19.5 Worm and Worm Gear Formulas

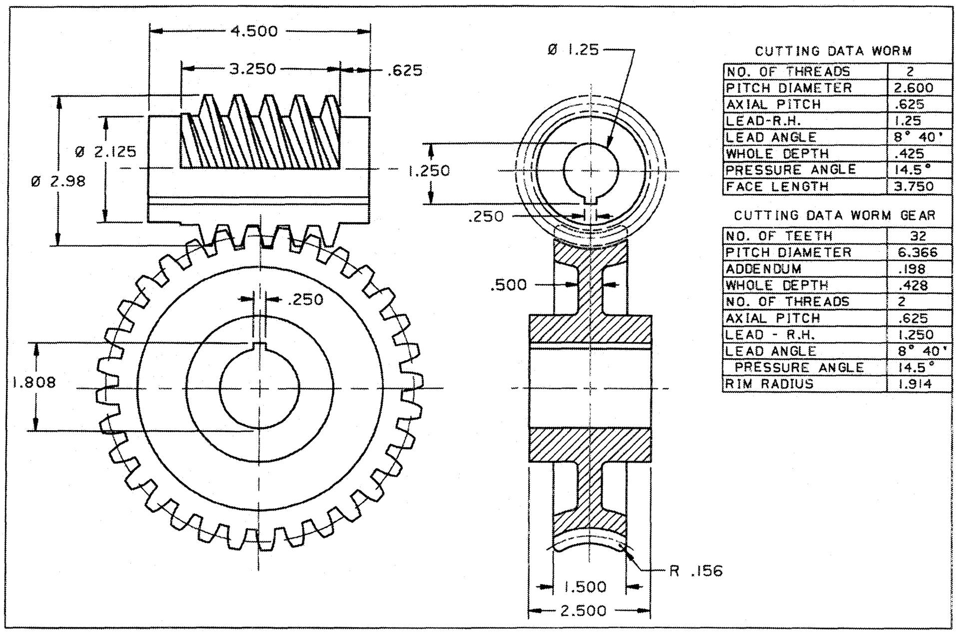
To Obtain:	Having:	Formula
Circular pitch (*p*)	Diametral pitch (*P*)	$P = \frac{3.1416}{P}$
Diametral pitch (*P*)	Circular pitch (*p*)	$P = \frac{3.1416}{P}$
Lead (of worm) (*l*)	Number of threads in worm and circular pitch (*p*)	$L = p \times$ (No. threads)
Addendum (*a*)	Diametral pitch (*P*)	$a = \frac{1}{P}$
Pitch diameter of Worm (D_W)	Outside diameter (*dO*) and addendum (*a*)	$D_W = d_O - 2a$
Pitch diameter of worm gear (D_G)	Circular pitch (*p*) and number of teeth (*N*)	$D_G = \frac{N_p}{3.1416}$
Center distance between worm and worm gear (CD)	Pitch diameter of worm (*DW*) and of worm gear (*DG*)	$CD = \frac{P_W + D_G}{2}$
Whole depth of teeth (*hT*)	Circular pitch (*p*)	$h_T = .6866p$
	Diametral pitch (*P*)	$h_T = \frac{2.157}{P}$
Bottom diameter of worm (*dr*)	Whole depth (*hT*) and outside diameter (*dO*)	$d_r = d_O - 2h_T$
Throat diameter of worm gear (*DT*)	Pitch diameter of worm gear (D_G) and addendum (*a*)	$D_T = D_G + 2a$
Lead angle of worm	Pitch diameter of worm (D_W) and the lead (*L*)	$Angle = \tan^{-1}\left(\frac{L}{3.1416\,D_W}\right)$
Ratio	No. of teeth on gear (*NG*) and number of threads on worm	$Ratio = \frac{N_G}{No.\ threads}$



WORMGEAR TOOTH DATA	
NUMBER OF TEETH	XX
PITCH DIAMETER	X.XXX
ADDENDUM	.XXX
WHOLE DEPTH (APPROX)	.XXX
WORM PART NUMBER	XXXXX
BACKLASH ASSEMBLED	.XXX-.XXX
HOB NUMBER	XXXXX
WORM DATA (REFERENCE)	
NUMBER OF THREADS	XX
AXIAL PITCH	.XXXX
LEAD RIGHT (OR LEFT) HAND	X.XXX
PITCH DIAMETER (NOMINAL)	X.XXX
LEAD ANGLE	XX°
NORMAL PRESSURE ANGLE (NOMINAL)	XX°

WORM TOOTH DATA (1)	
MANUFACTURING METHOD	--------
NUMBER OF THREADS	XX
PITCH DIAMETER (NOMINAL)	X.XXX
AXIAL PITCH	X.XXXX
LEAD RIGHT (OR LEFT) HAND	X.XXXX
LEAD ANGLE	XX° XX'
NORMAL PRESSURE ANGLE (NORMAL)	XX°
ADDENDUM	.XXX
WHOLE DEPTH (APPROX)	.XXX
NORMAL CHORDAL ADDENDUM	.XXX
NORMAL CHORDAL THICKNESS	.XXX -.XXX
WORMGEAR PART NUMBER	XXXXX

FIGURE 19.33 Dimensions Required for Worms and Worm Gears



CUTTING DATA WORM	
NO. OF THREADS	2
PITCH DIAMETER	2.600
AXIAL PITCH	.625
LEAD-R.H.	1.25
LEAD ANGLE	8° 40'
WHOLE DEPTH	.425
PRESSURE ANGLE	14.5°
FACE LENGTH	3.750

CUTTING DATA WORM GEAR	
NO. OF TEETH	32
PITCH DIAMETER	6.366
ADDENDUM	.198
WHOLE DEPTH	.428
NO. OF THREADS	2
AXIAL PITCH	.625
LEAD - R.H.	1.250
LEAD ANGLE	8° 40'
PRESSURE ANGLE	14.5°
RIM RADIUS	1.914

FIGURE 19.34 Worm and Worm Gear Detail

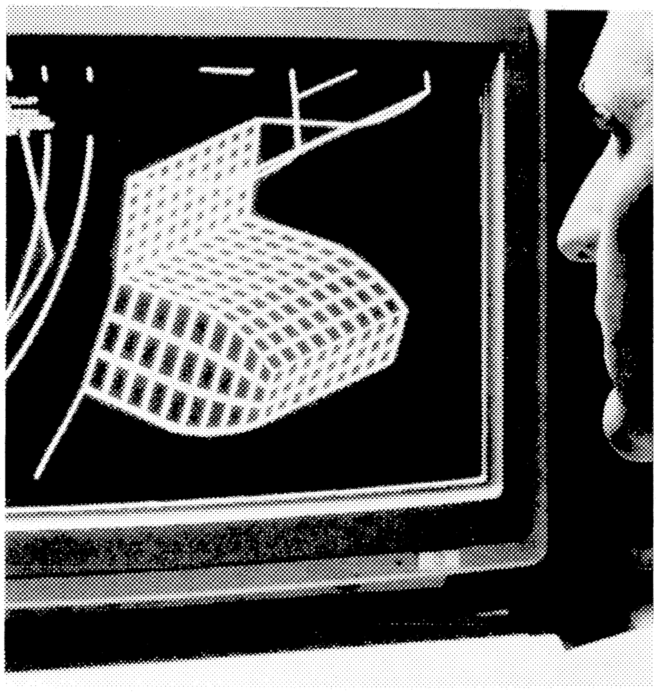


FIGURE 19.35 Spur Gear Teeth Design using CAD

19.11 SHAFTS

Shafts are rotating machine elements that are subjected to torsional stress (twisting) during operation. Shafts rotate freely when held by bearings at each end (Fig. 19.36). The shaft in Figure 19.37 is secured in a housing with a bearing.

Gears and cams are normally mounted on a shaft. The shaft is rotated by a drive mechanism, such as an electric motor. Gears are secured to the shaft by a collar set screw, keys, a dowel pin, a taper pin, threaded bearings, housing caps, or a bolted bearing flange.

Most shafts transmit power and must be sufficiently strong and rigid to avoid interfering with bearing and gear operation. Figure 19.16 shows a gearing assembly in which a helical gear on one shaft is being used to turn a mating helical gear on a parallel shaft. The shafts are held in place by bearings at both ends. Each shaft has a single-row ball bearing at one end and a double-row ball bearing at the other end. Double-row ball bearings carry a greater load than single-row ball bearings. The two gears are of different sizes; therefore, they provide reduced or increased shaft speed, depending on which shaft is the drive shaft and which the driven shaft.

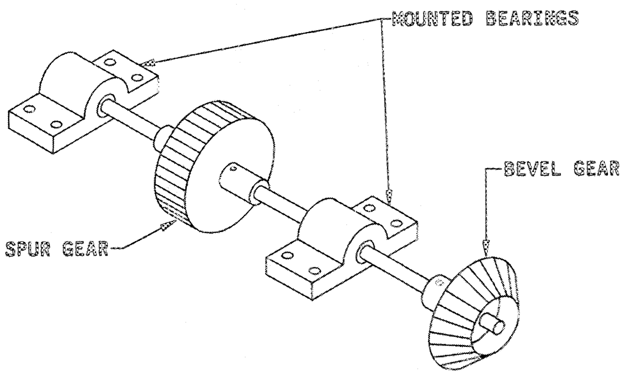


FIGURE 19.36 Shaft, Bearings, and Gears

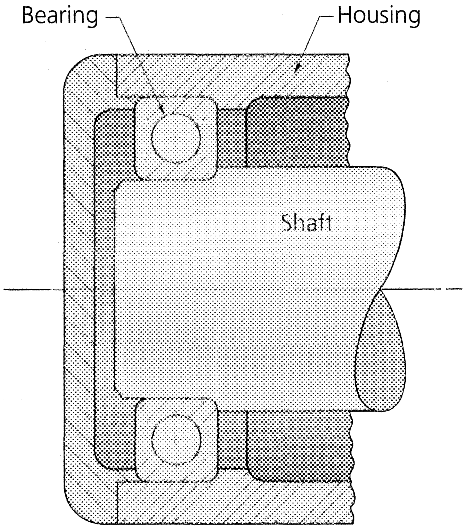


FIGURE 19.37 Bearing, Shaft, and Housing

19.12 BEARINGS

Bearings (Fig. 19.38) are designed to take radial loads, axial loads, or a combination of the two. Bearings designed to resist a load perpendicular to the axis of the shaft are **radial**

FIGURE 19.38 Bearings and Housings

bearings. Those designed to resist an axial load (along the axis) are **thrust bearings**. Plain radial bearings are sometimes called **journal bearings** (bushing type). The portion of a shaft that is in contact with the bearing is called a **journal**. Figure 19.39 shows the difference between axial (thrust) load and radial load. Bearings are manufactured from a variety of metals and plastics.

Bearing selection is based on shaft size, application, speed of rotation, required design life, load requirements, physical geometry, cost, and mounting requirements. When specifying bearings, you must consider the method of retaining the bearings, lubrication requirements, and sealing of the housing and the bearing. Shaft tolerance and diameter, shaft shoulder diameter, and the housing's internal bore and tolerance are also important. Many types of bearings are on the market, and they can be divided into two categories: **plain bearings** and **rolling contact bearings.**

19.12.1 Plain Bearings

When two mechanical members rest on one another and move in relation to one another, they create a *bearing surface.* In general, bearings are separate mechanical devices that reduce friction between moving parts. The two basic types of **plain bearings** are those in which the parts in contact slide and those in which the members revolve. Since the surfaces of each part or member make contact, bearings that do not incorporate some form of roller or ball are plain surface bearings.

Bearings that provide sliding contact between mating surfaces fall into three general classes: **radial bearings,** which support rotating shafts or journals; **thrust bearings** which support axial loads on rotating members; and **guide (slipper) bearings,** which guide moving parts along a straight line.

Radial sliding bearings, more commonly called **sleeve bearings,** may be of several types, the most common being the plain full journal bearing, which has 360° contact with its mating journal, and the partial journal bearing, which has less than 180° contact. Plain bearings look like bushings and, in many cases, what is referred to as a bushing is actually a plain bearing. Since the bearings in Figure 19.39 (drawn sectioned) do not have balls or rollers, they would be considered plain bearings. Plain bearings are manufactured both with and without flanges.

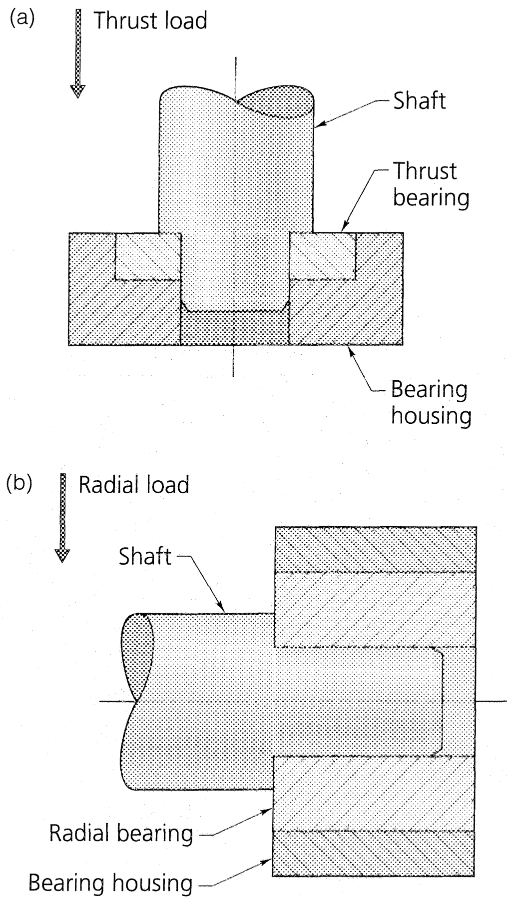
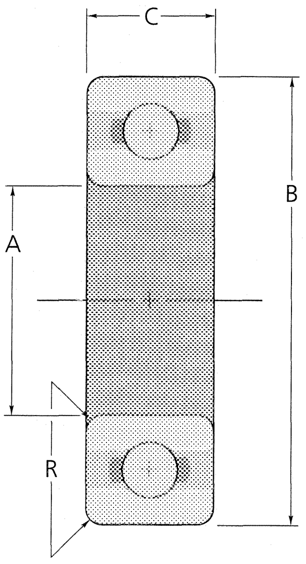


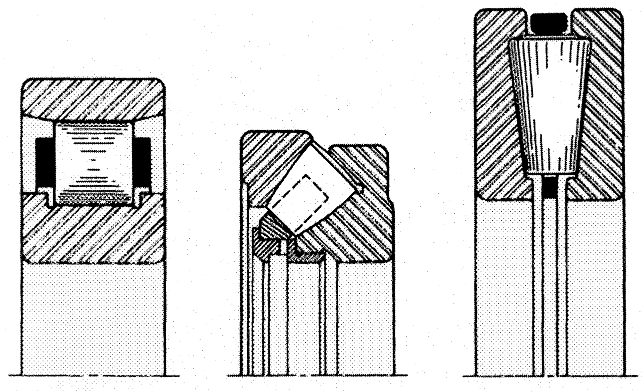
FIGURE 19.39 Bearing Loading



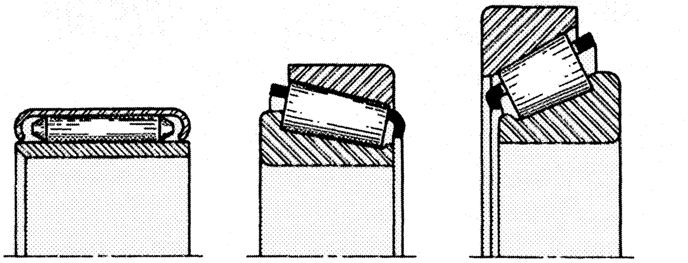
Dimensions	A	B	C	R	Balls	Ball dia.
	.500	1.125	.375	.025	7	.187
	1.000	2.000	.562	.035	10	.250
	1.312	2.562	.687	.035	9	.375

FIGURE 19.40 Ball Bearing

FIGURE 19.41 Roller Bearings



(a) Straight (b) Spherical thrust (c) Tapered thrust



(d) Needle radial (e) Tapered radial (f) Steep-angle tapered

19.12.2 Rolling-Contact Bearings

Rolling-contact bearings substitute a rolling element, a ball (Fig. 19.40), or a roller for a hydrodynamic or hydrostatic fluid film to carry an impressed load without wear and with reduced friction. Because of their greatly reduced starting friction compared to the conventional journal bearing, they have acquired the common designation of *antifriction bearings*. The balls of a rolling ball bearing can be any size from 0.05 to 320 mm and can be manufactured from a wide variety of metals and plastics.

The most common antifriction bearing application is the deep-groove **ball bearing** (Fig. 19.40) with a ribbon-type separator in which sealed-grease lubrication helps to support a shaft with radial and thrust loads in rotating equipment. The two basic types of rolling bearings are those that use a **ball** as the rolling element and those that use a **roller.** Rollers may be either cylindrical, tapered, spherical, or needle shaped (Fig. 19.41). The internal construction of a typical tapered roller bearing is illustrated in Figure 19.42.

19.12.3 Thrust Bearings

Thrust bearings, as the name implies, either absorb axial shaft loads or position vertical shafts. Thrust bearings are designed to take thrust loads either alone or, in some cases, in combination with radial loads. Thrust bearings (Fig. 19.43) have been manufactured in sizes up to 8 m in diameter.

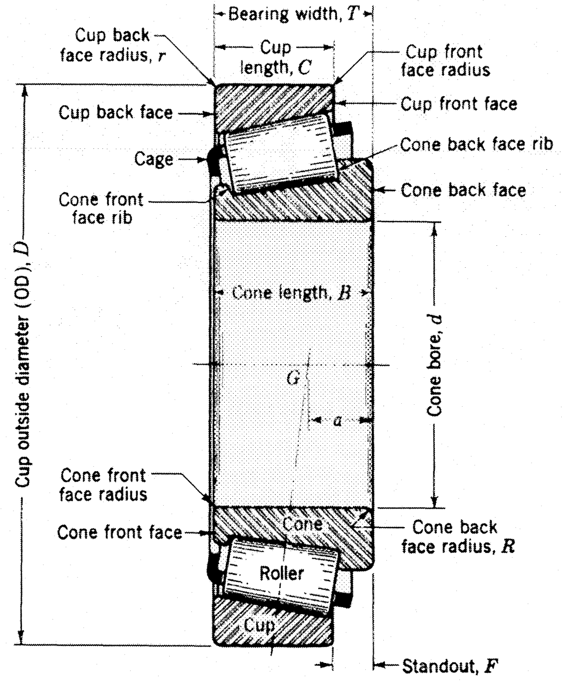


FIGURE 19.42 Tapered Roller Bearing

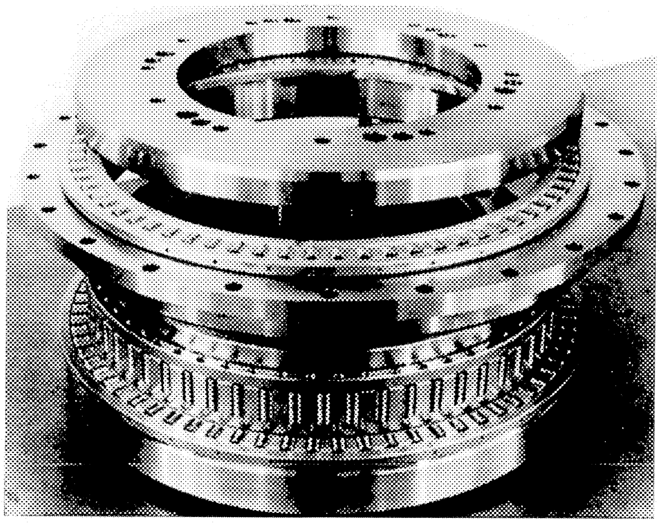


FIGURE 19.43 Large-Diameter Thrust Roller Bearing

19.12.4 Housings and Mountings

A number of methods are available to ensure that a bearing remains in place within a housing (Fig. 19.44). One common technique for retaining the bearing is to press or shrink the bearing in the housing with a light interference fit.

In applications where lubricants or process fluids are utilized in operation, provision must be made to prevent leakage. This is accomplished with a seal. All seals perform two functions: preventing the escape of fluid, and preventing the introduction of foreign matter.

You May Complete Exercise 19.5 at This Time

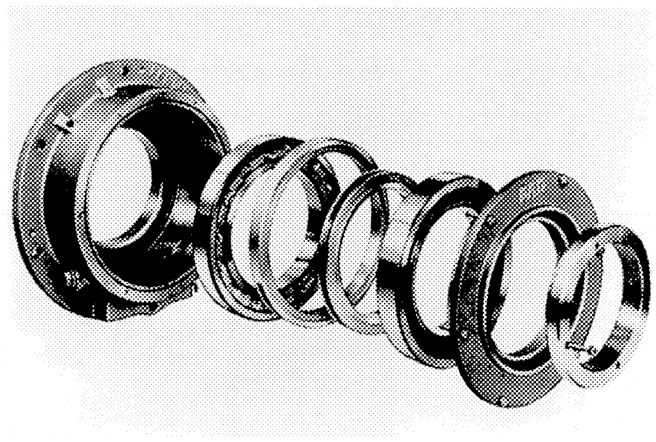


FIGURE 19.44 Bearing and Housing

QUIZ

True or False

1. The shaft relationship for mating spur gears is for them always to be perpendicular to one another.
2. A journal is that portion of a bearing that touches the balls or rollers.
3. The center distance for an internal spur gear (ring spur gear) and a pinion is closer than for external gears.
4. All needle bearings provide sealed housings.
5. Gear teeth are seldom drawn on the gear detail unless the gear is a special order.
6. Some thrust bearings can carry a radial load.
7. A pressure angle of 20° has a higher load-carrying capacity than one of $14\frac{1}{2}°$.
8. Thrust bearings are limited to smaller sizes (.5 in. to 6.00 in. diameter) and are found on high-speed machinery.

Fill in the Blanks

9. __________ bearings are the most common type of bearing found in industry.
10. A __________ is a straight machine element that has teeth cut into its surface that engage with a __________ gear to produce linear movement.
11. __________ gears connect parallel shafts, __________ gears connect shafts whose axes intersect, and __________ gears connect shafts whose axes are not parallel and do not intersect.
12. __________ are used to support and align.
13. A __________ gear is the same as a spur gear, but is usually smaller and has less __________ .
14. A __________ is designed to transmit power and is under __________ stress.
15. __________ are used to secure bearings.

Answer the Following

16. Describe the difference between a thrust bearing and a radial bearing.
17. What information is needed on a bevel gear drawing in addition to the graphical representation?
18. How are gears attached to shafts?
19. Why do plain bearings require special lubrication?
20. What are the three classes of bearings that provide sliding contact?
21. How do worm screws and worm gears work, and what type of motion is transmitted during operation?
22. What are the types of roller bearings?
23. Describe four common gear types.

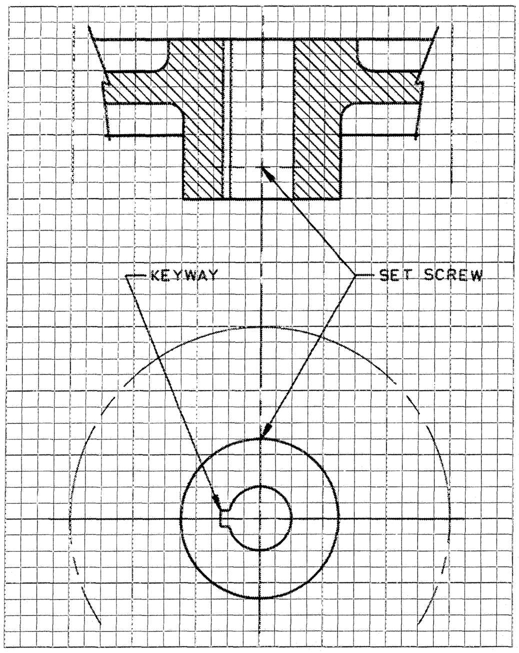
EXERCISES

Exercises may be assigned as sketching, instrument, or CAD projects. Transfer the given information to an "A"-size sheet of .25 in. grid paper. Complete all views, and solve for proper visibility, including centerlines, object lines, and hidden lines. Exercises that are not assigned by the instructor can be sketched in the text to provide practice and to enhance understanding of the preceding material.

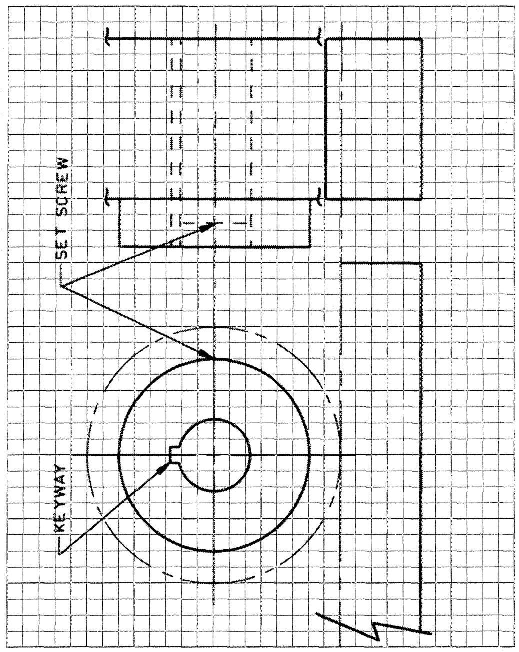
After Reading the Chapter Through Section 19.14.1 You May Complete the Following Four Exercises

Exercise 19.1 Draw a standard spur gear. Show three teeth. The cast-iron spur gear has a pressure angle of 20°, 48 teeth, 6.000 pitch diameter, 1.00 bore diameter, 2.00 hub diameter (1.00 hub projection), 8 diametral pitch, with a gear face width of 1.50 and a total width of 2.50. Design the gear to have a standard keyseat per the shaft diameter (see Chapter 17). The gear hub is to have a set screw at 90° to the keyseat. Determine the set screw size based on the shaft diameter (see Chapter 18).

Exercise 19.2 Draw the spur gear and rack. Show three teeth on the rack and the gear. Design the gear's keyseat and set screw per Exercise 19.1. The steel rack has the following specifications: 20° pressure angle, 5 diametral pitch, 1.500 overall thickness, 1.300 pitch line to back, 2.500 face width. The steel gear has the following specifications: 20° pressure angle, 5 diametral pitch, 1.125 shaft bore diameter, 20 teeth, .750 hub projection, 2.500 face width, 3.25 total width, and a 3.00 hub diameter.



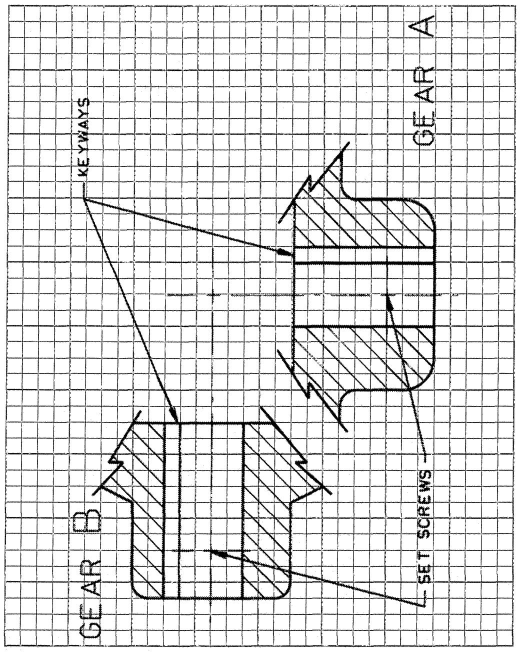
EXERCISE 19.1



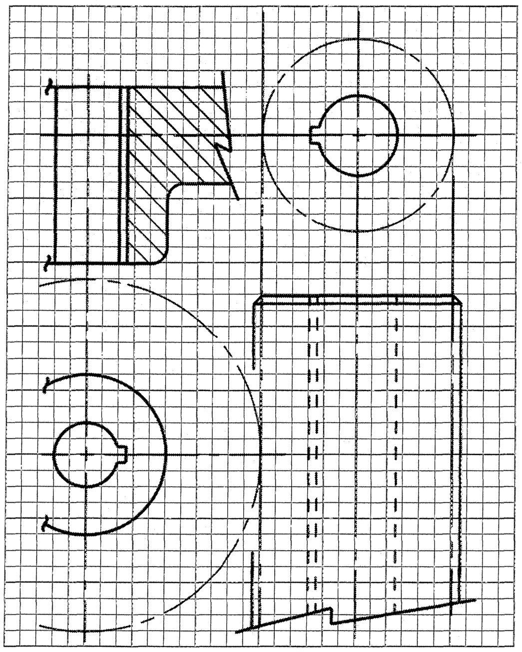
EXERCISE 19.2

Exercise 19.3 Design and draw bevel gears with the following specifications:

Gear A		Gear B
6	Diametral pitch	6
18	Teeth	36
2:1	Ratio	2:1
1.06	Face width	1.25
3.500	Mounting distance	4.750
2.25	Gear width	2.75
2.50	Hub diameter	3.25
6.00	Pitch diameter	3.00
1.125	Hub bore diameter	1.125
Calculate	Keyseat	Calculate
Calculate	Set screw	Calculate



EXERCISE 19.3

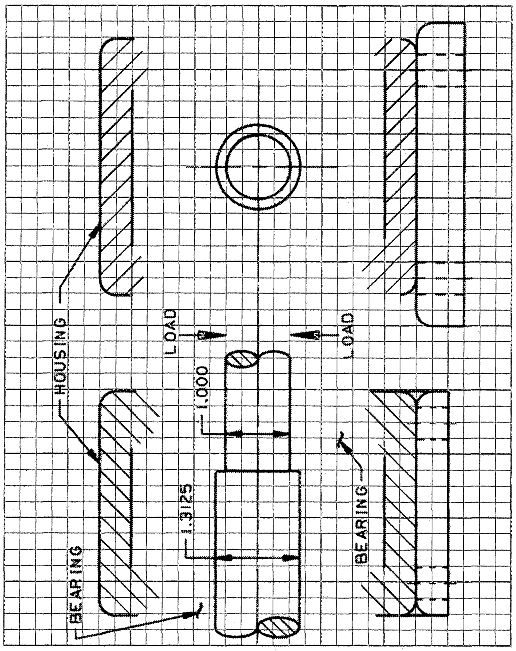


EXERCISE 19.4

Exercise 19.4 Design and draw the worm and the worm gear as in Figure 19.34. The worm (screw) is to have a $14\frac{1}{2}^\circ$ pressure angle, 4 diametral pitch, 3.500 face width, .7854 lead, 4.76° lead angle, 1.250 bore shaft diameter, 3.000 pitch diameter. Design the keyseat per the shaft size. The worm gear is to have a $14\frac{1}{2}^\circ$ pressure angle, 4 diametral pitch, 20 teeth, 5.000 pitch diameter, 1.00 diameter bore for a shaft, 2.50 hub diameter, 1.250 hub projection, and a face width of 1.500. Design an appropriate-size keyseat for the shaft

After Reading the Chapter Through Section 19.12.4 You May Complete the Following Exercise

Exercise 19.5 Using the bearing dimensions from Figure 19.40, design and draw a bearing housing to retain the bearings and support the stepped shaft.



EXERCISE 19.5

PROBLEMS

For gear problems completed manually, show only one tooth. For projects drawn on a CAD system, show all teeth.

Problem 19.1 Redraw the spur gear detail in Figure 19.12.

Problem 19.2 Draw the spur rack detail shown in Figure 19.15.

Problem 19.3 Detail the rack shown in Figure 19.18.

Problem 19.4 Draw the worm spline detail provided in Figure 19.19.

Problem 19.5 Detail each of the spur gears in Figure 19.26.

Problem 19.6 Redraw the worm and worm gear shown in Figure 19.34. Split the two into separate details and also draw an assembly. Use Figure 19.33 as a guide for dimensioning.

Problem 19.7 Design a spur gear rack and mating gear with the following specifications. Compute the required specifications for the rack and gear. Show all information data blocks on the drawing. Draw an assembly of the gear and rack using appropriate ANSI dimensioning.

1. **Gear**—6 in. pitch diameter

   20° pressure angle (20° involute teeth)
   2.00 in. face width
   Keyseat in hub
   1.25 diameter shaft
   Spoked gear blank

2. **Rack**—will move laterally 5 in.

Problem 19.8 Using the same format as in Problem 19.7, complete a spur gear and rack assembly with 20° involute teeth, gear face width of .75 in., solid gear blank, shaft diameter of 2.00 in., 7 in. pitch diameter for the gear, 56 teeth, and diametral pitch of 8. The rack will move 8 in. laterally.

Problem 19.9 Design spur gears with the following specifications:

Gear A—Spur Gear
- 44 teeth
- 20° full-depth involute teeth
- Diametral pitch of 12
- Spoke gear blank
- 1.00 face width
- Keyseat in hub
- 2.00 diameter shaft

Gear B—Spur Gear
- 18 teeth
- 20° full-depth involute teeth
- Diametral pitch of 8
- Webbed hub with lightning holes
- .750 face width
- Keyseat in hub
- 1.00 diameter of shaft

Gear C—Internal Ring Gear
- 32 teeth
- 14½° teeth
- 32 diametral pitch
- 2.00 pitch diameter
- 2.75 OD
- 1.96 ID
- .315 face width

Problem 19.10 Design bevel gears with the following specifications. Show all dimensions. Design the appropriate keyseat for each gear.

	Gear A	*Gear B*	*Gear C*	*Gear D*
Teeth	20	45	19	20
Pitch diameter	2.000	7.500	4.000	50 mm
Diametral pitch	10	6	4	1
Face	.570	1.070	1.400	18 mm
Bore	.750	1.125	1.125	30 mm
Hub diameter	1.750	3.250	3.250	40 mm
Hub projection	1.000	1.250	1.875	24 mm
Hub width	1.500	2.125	3.500	30 mm

Problem 19.11 Design mating miter gears with the following specifications. Show all dimensions. Design the appropriate keyseat for each gear.

	Set A	*Set B*	*Set C*
Teeth	36	32	30
Pitch diameter	1.500	2.000	2.500
Diametral pitch	24	19	12
Face	.220	.400	.540
Bore	.3125	.500	.625
Hub diameter	.6875	1.250	1.625
Hub projection	.3125	.375	.843
Hub width	.609	.875	.484
Mounting distance	1.188	1.562	2.312

Problem 19.12 Design and detail a worm gear set with the following specifications: *worm*—1.250 pitch diameter, diametral pitch of 10, 14½° pressure angle; *worm gear*—40 teeth, .750 face width.

Problem 19.13 Design and detail a worm gear set with the following specifications: *worm*—1.000 pitch diameter, diametral pitch of 12, 14½° thread; *worm gear*—30 teeth, .625 face width, .750 bore, 2.50 pitch diameter.

Problem 19.14 Design and detail a helical gear with the following specifications: normal diametral pitch = 12, 20° pressure angle, 48 teeth, face width = 1.75, helix angle = 45°.

Problem 19.15 Design and lay out a shaft-and-bearing assembly capable of supporting any of the gear sets described in Problems 19.7, 19.8, 19.11, or 19.12. Use standard mounted bearings or design a housing for the bearings.