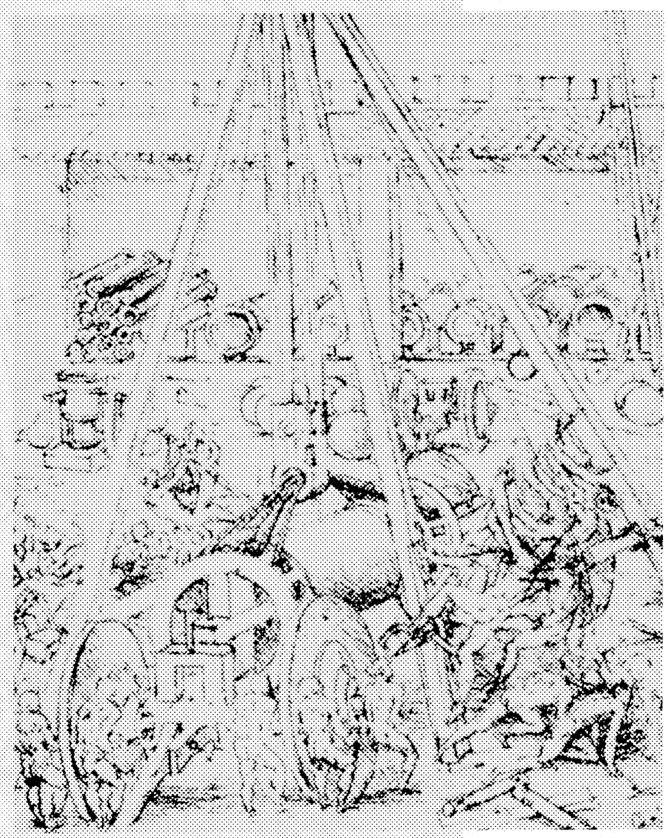
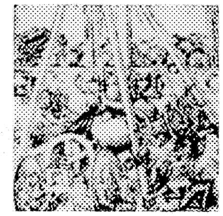
Part Three

MECHANICAL PARTS, PROCEDURES, AND LAYOUT



THREADS AND FASTENERS

Chapter 17



LEARNING OBJECTIVES

Upon completion of this chapter you will be able to:

1. Identify the variables, requirements, and considerations necessary for fastener selection.
2. Understand thread function while recognizing standard thread forms, series, terms, and parts.
3. Differentiate between and produce ANSI-standard detailed, schematic, and simplified screw thread representations.
4. Identify and compare Acme, buttress, metric, and pipe threads.
5. Understand bolt, nut, and screw representation.
6. Identify quick-release and semi-permanent pins.
7. Discuss key and keyseat variations and design considerations.
8. Understand the use of CAD libraries of fasteners and other standard mechanical parts to produce engineering drawings.

17.1 INTRODUCTION

Fasteners (Fig. 17.1) are used to join components in an assembly. They are interchangeable, readily available as standard parts, and manufactured to specific requirements to maintain a high degree of precision and quality. Most, but not all, fasteners have threads. There are more than a million types of fasteners. This chapter presents the common types of fasteners, covers thread specifications, and discusses nonthreaded types of fasteners.

17.1.1 Fastener Selection

There are many factors to consider when selecting the proper fastener. Design for manufacturability (DFM) concepts are considered at this stage, including:

- Use off-the-shelf, readily available standard fasteners.
- Use the minimum number of fasteners.
- Use fewer large fasteners rather than many small fasteners.
- Avoid separate washers.
- Design for automated assembly.
- Design for drop-in assembly.
- Eliminate separate fasteners by design (for example, snap fits).

The selection of the proper fastener for a project involves:

- Assembly requirements for assembly and disassembly during manufacturing, shipping, installation, service, and maintenance
- Conditions of operation: temperature, vibration, movement, corrosion, and impact
- Quantity of fasteners required to secure the parts adequately
- Variety of fasteners on the assembly
- Function of the fasteners in the assembly: location and fastening

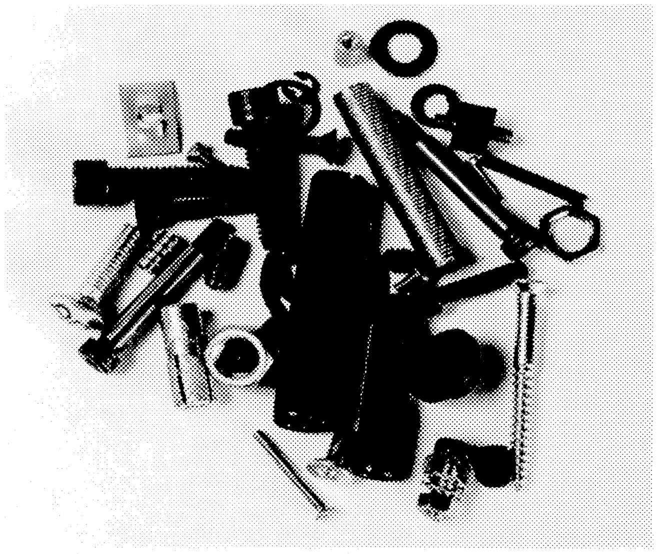


FIGURE 17.1 Fasteners and Threads

17.2 SCREW THREADS

A **thread** is a helical or spiral groove formed on the outside (external) surface or inside (internal) surface of a cylinder. Screw threads support and transfer loads and transmit power. A variety of thread styles are found in the valve shown in Figure 17.2. Threads on round parts such as shafts and bolts are external threads [Fig. 17.3(a)]; threads on interior surfaces of a cylindrical hole are internal threads [Fig. 17.3(b)]. A die is used to cut external threads; a tap is used to cut internal threads.

In many cases, threads are modeled in a simplified form when designing on a CAD system. These threads, called cosmetic threads on some systems, will contain all the thread information on an imbedded thread file attached to the geometry (Fig. 17.4).

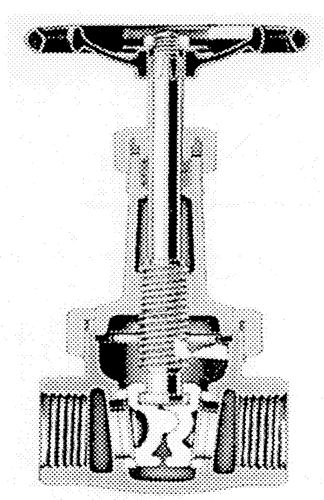
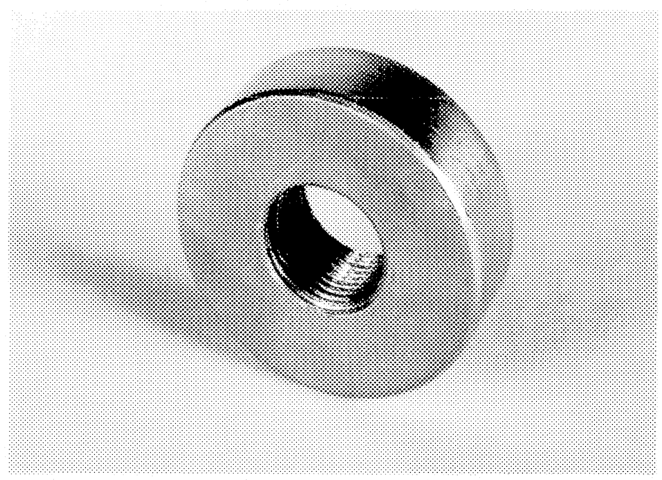


FIGURE 17.2 UNC, Acme, and NPT Threads Used in the Design of This Rising Stem Gate Valve

(a) External threads



(b) Internal threads

FIGURE 17.3 Threads

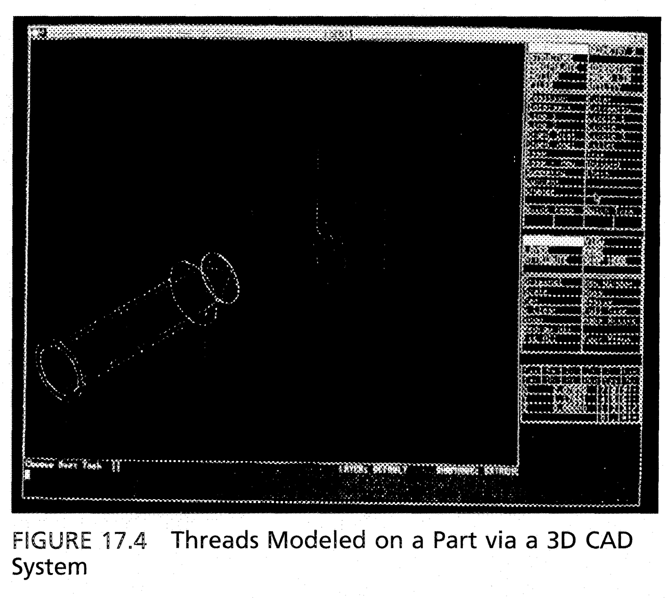


FIGURE 17.4 Threads Modeled on a Part via a 3D CAD System

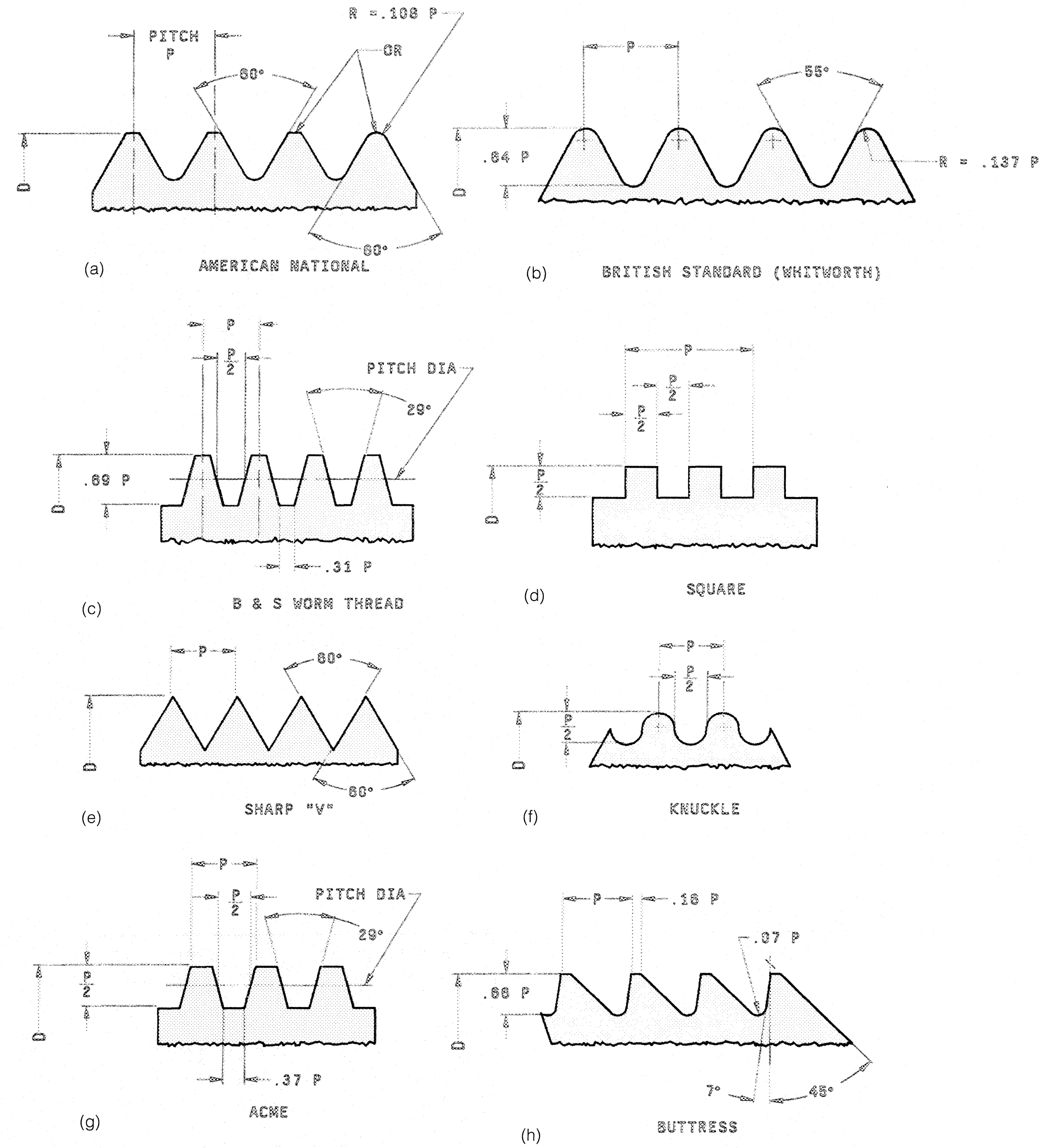


FIGURE 17.5 **Standard Thread Forms**

The different forms of threads are selected based on the requirements of the design. Eight standard styles are presented in Figure 17.5: (a) American National thread form, (b) the British Standard (Whitworth) thread form, (c) the worm thread form, (d) the square thread form, (e) the sharp V thread form, (f) the knuckle thread form, (g) the Acme thread form, and (h) the buttress thread form. The ISO metric thread form is shown in Figure 17.6, and the Unified National (UN) thread form is shown in Figure 17.7.

The Acme and square thread forms serve to transmit power. Acme threads (Fig. 17.2) function to move the valve stem up and down to open and close the valve. Worm

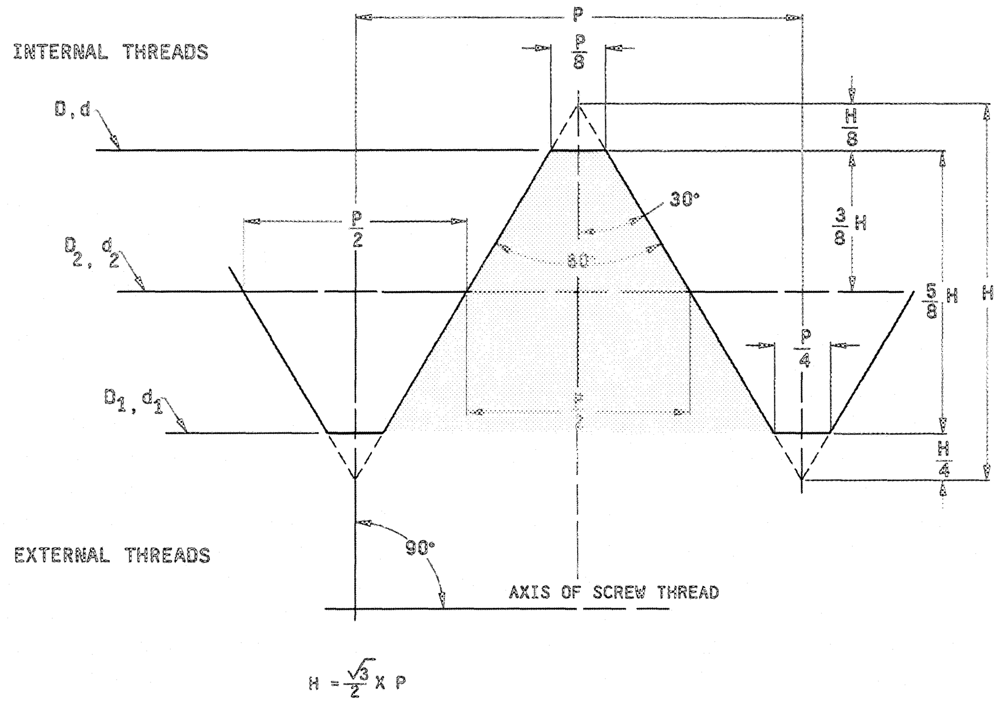


FIGURE 17.6 Basic M Thread Profile (ISO 68 Basic Profile)

threads are similar to Acme threads and also are used to transmit power.

The knuckle thread form is for sheet metal products such as the base of a light bulb, bottle and jar tops, and plastic bottles and caps. Buttress threads are found in high-stress designs and can transmit power along the axis in one direction.

ISO metric threads (Fig. 17.6) are the internationally recognized standard for thread forms. The ISO thread is very similar to the UN thread form except that its thread depth is not as great. The ISO thread has the same basic profile as the UN thread form.

The Unified National thread form (Fig. 17.7) is used in the United States and is practically identical to the obsolete American National thread form. In fact, threads manufactured to either form are functionally interchangeable. American National threads are designated as N, NC, NF, NEF, or NS. Unified National threads are designated similarly: UN, UNC, UNF, UNR, UNEF, UNS, or UNM.

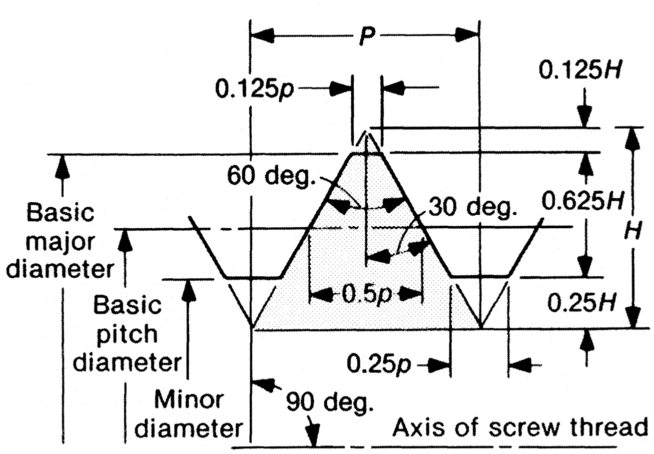


FIGURE 17.7 Basic Profile for UN and UNR Screw Threads

17.2.1 Thread Terms

The following terms are used throughout the chapter.

Class of thread An alphanumerical designation to indicate the standard grade of tolerance and allowance specified for a thread

Crest The top surface joining the two sides of the thread

Depth of thread engagement The radial distance, crest to crest, by which the thread forms overlap between two assembled mating threads

Major diameter The diameter of the major cylinder, that is, the distance across the crests of the thread

Minor diameter The diameter of the minor cylinder, that is, the root diameter of the thread

Nominal size The designation used for general identification of a thread, based on the major diameter

Pitch The axial distance from a point on one screw thread to the corresponding point on the next screw thread; equals the lead divided by the number of thread starts

Profile of thread The contour of a screw thread ridge and groove delineated by a cutting plane passing through the thread axis; also called *form of thread*

Root The bottom surface joining the two sides of the thread

Root diameter The diameter of an imaginary cylinder bounding the bottom of the roots of a screw thread (minor diameter of the thread)

Thread designations A capital letter abbreviation of names used to designate various thread forms and thread series

Thread series Groups of diameter/pitch combinations distinguished from each other by the number of threads per unit of measurement

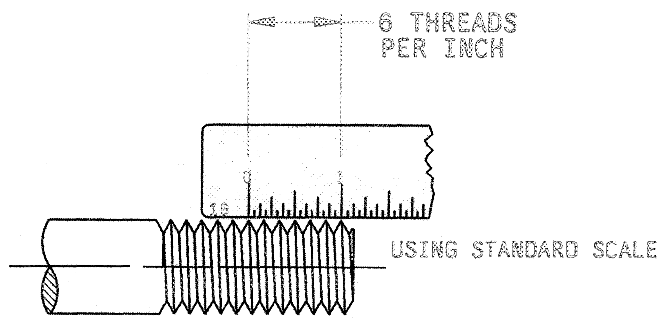


FIGURE 17.8 Using a Scale to Measure Threads per Inch

17.2.2 Thread Parts

The configuration of the thread in an axial plane is the **thread form** (profile). The three parts that make the form of a thread are the crest, the root, and the flank (Fig. 17.7). The **crest** of a thread is at the top, the **root** is on the bottom, and the **flank** joins them. The **fundamental triangle** (shaded part of Fig. 17.7) is the triangle formed when the thread profile is extended to a sharp **V** at both the crest and the root. The height of the fundamental triangle (*H*) is the distance between the crest and the root diameters (for Unified threads, $H = 0.866025 \times$ thread pitch).

A thread having full form at both the crests and the roots is a complete or **full-form thread.** When either the crest or the root is not fully formed, it is an **incomplete thread.** Incomplete threads occur at the ends of externally threaded fasteners that are pointed (conical), at thread runouts where the threaded length blends into the unthreaded shank, and at the countersinks on the faces of nuts and tapped holes.

Thread pitch (*P*) is the distance, measured parallel to the thread axis, between corresponding points on adjacent threads. Unified screw threads are designated in **threads per inch,** which is the number of complete threads occurring in one inch of threaded length. Thread pitch is the reciprocal of threads per inch. The standard inch scale can be placed along the threads when a screw thread pitch gage is unavailable (Fig. 17.8). Counting the number of threads in one inch will give the threads-per-inch measurement.

The **pitch diameter** is the diameter of a theoretical cylinder that passes through the threads such that the widths of the thread ridges and the thread widths would each equal one-half of the thread pitch (Fig. 17.9).

The combination of allowances and tolerances in mating threads, called the **fit,** is a measure of tightness or looseness between them. A **clearance fit** is one that always provides a free-running assembly. An **interference fit** is one that always results in a positive interference between the threads.

When assembling externally threaded fasteners into internally threaded nuts or tapped holes, the axial distance of contact of the fully formed threads is the **length of thread engagement** (Fig. 17.10). The distance these threads overlap in a radial direction is the **depth of thread engagement.**

17.2.3 Right-Hand and Left-Hand Threads

Unless otherwise specified, threads are right-hand. A left-hand thread turns counterclockwise to advance (Fig. 17.11). Figure 17.12 shows a turnbuckle that is designed with both right-hand and left-hand threads. When the buckle is turned in one direction, it will pull both rods together, thus tightening the connection.

17.2.4 Thread Lead

The **lead** of a thread is the axial distance it travels in one complete turn (the axial distance between two consecutive crests). Since the lead is the axial distance a crest will

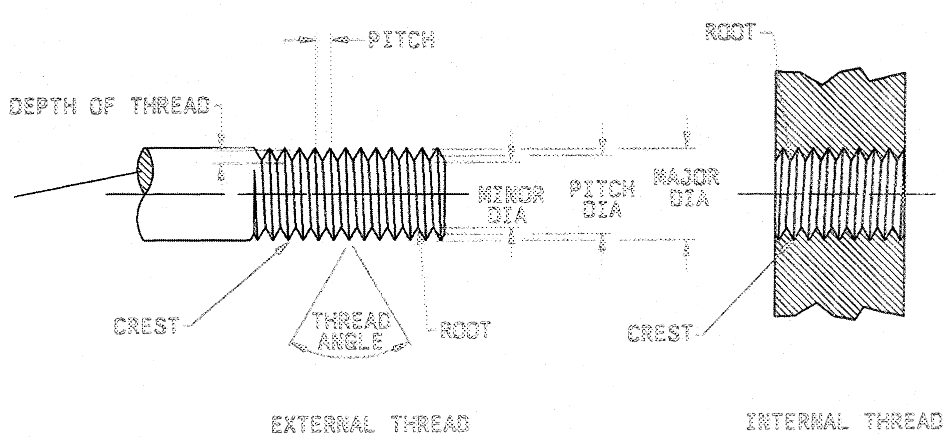


FIGURE 17.9 Unified National Thread Terminology

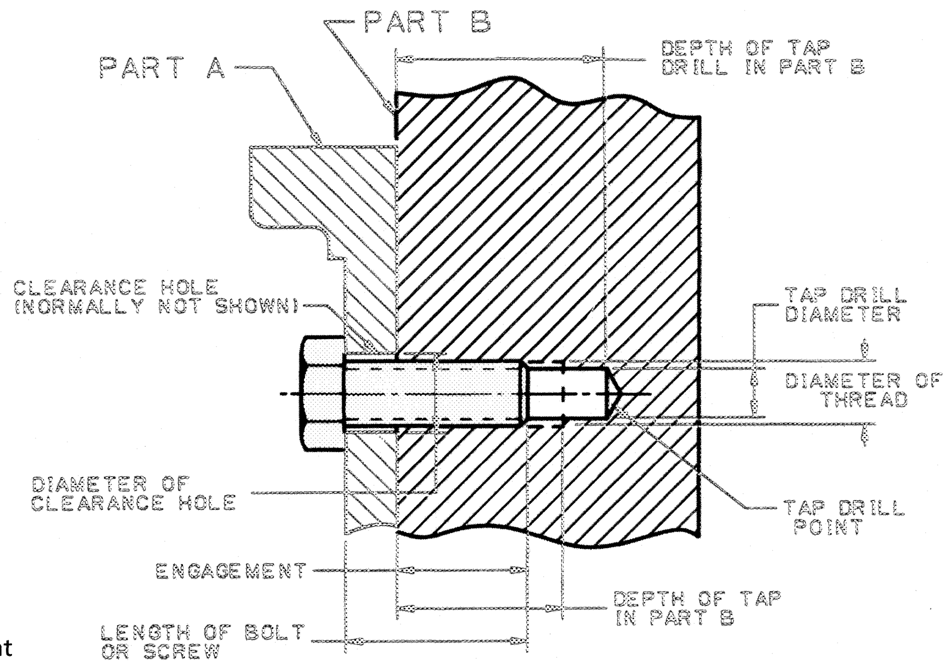


FIGURE 17.10 Thread Engagement

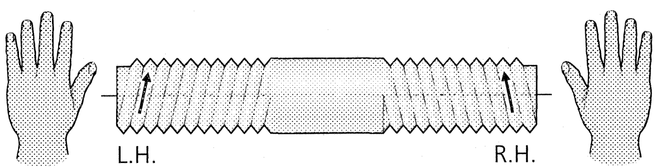


FIGURE 17.11 Right-Hand and Left-Hand Threads

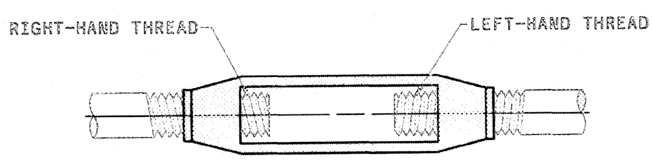


FIGURE 17.12 Turnbuckle

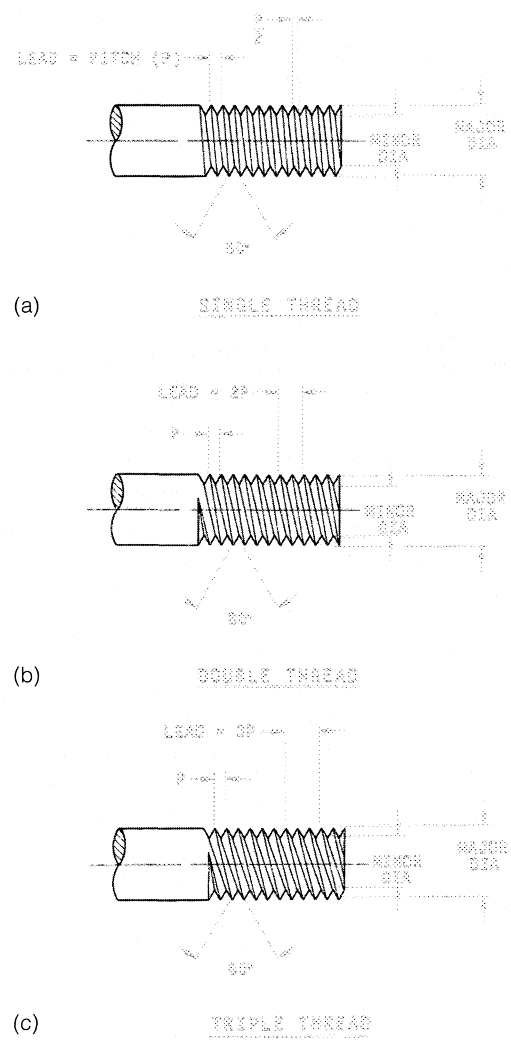


FIGURE 17.13 Single, Double and Triple Threads

advance in one complete turn, **single threads** have a lead equal to the pitch, **double threads** have a lead equal to twice the pitch, and **triple threads** have a lead of thrice the pitch (Fig. 17.13).

17.3 UNIFIED NATIONAL THREAD SERIES

Thread series are groups of diameter–pitch combinations that differ by the number of threads per inch. For fasteners, the popular thread series are Unified coarse, fine, and 8-pitch. The two general series classifications are *standard* and *special*.

The standard series consist of three series with graded pitches (coarse, fine, and extra-fine) and eight series with constant pitches (4, 6, 8, 12, 16, 20, 28, and 32 threads per inch).

17.3.1 Constant-Pitch Thread Series Applications

The various constant-pitch series (UN/UNR), with 4, 6, 8, 12, 16, 20, 28, and 32 threads per inch, offer a comprehensive range of diameter–pitch combinations where the threads in the coarse, fine, and extra-fine series do not meet the particular requirements of the design.

The **8-thread series** (8UN) is a uniform-pitch series for large diameters or is a compromise between coarse and fine thread series. Although originally intended for high-pressure-joint bolts and nuts, it is now widely used as a substitute for the coarse thread series for diameters larger than 1 inch.

The **12-thread series** (12UN) is a uniform-pitch series for large diameters requiring threads of medium-fine pitch. Although originally intended for boiler applications, it now serves as a continuation of the fine thread series for diameters larger than 12 inches.

The **16-thread series** (16UN) is a uniform-pitch series for large diameters requiring fine-pitch threads. It is suitable for adjusting collars and retaining nuts, and also serves as a continuation of the extra-fine thread series for diameters larger than $1\frac{11}{16}$ inch.

17.4 SCREW THREAD SELECTION

The first consideration in selecting a screw thread is the length of thread engagement required between threaded components (Fig. 17.10). For fastening applications, the lengths of engagement are derived from thread formulas based on the basic major diameter, the nominal size of the thread, and the material of the internal threaded part. The basic diameter of the thread is D. For steel screws, the length of engagement in mating materials should equal D for steel; 1.50 × D for cast iron, brass, bronze, or zinc; 2.00 × D for forged aluminum; 2.50 × D for cast aluminum and forged magnesium; and 3.00 × D for cast magnesium or plastic.

Thread form is the second consideration. Normally, the choice is limited to UNC, UNF, or SI metric for fasteners. Other thread forms, such as square, Acme, buttress, knuckle, and worm, are used for special applications.

Thread series is the third consideration. The Unified Screw Thread Standard Series gives preference to the coarse and fine thread series.

The **class of thread fit** is the fourth consideration. The class of threads determines the degree of looseness or tightness between mating threads.

17.4.1 Thread Form

There are dozens of screw thread forms. However, for inch series mechanical fasteners, only three have significance: UN, UNR, and UNJ. All are 60° symmetrical threads with essentially the same profile. The principal difference between them is the contour at the root of the external thread. For metric fasteners, SI metric threads are designated.

UNR applies only to external threads. The difference between UN and UNR threads, in addition to designation, is that a flat or optional rounded root contour is specified for UN threads, while only a rounded root contour is specified for UNR threads. The design of UNJ threads developed from a search for an optimum thread form. This thread has root radius limits of 0.150 to 0.180 × thread pitch.

17.5 STANDARD THREAD FITS

Thread fit is a measure of looseness or tightness between mating threads. **Classes of fit** are specific combinations of allowances and tolerances applied to external and internal threads.

Unified inch screw threads have three thread classes for external threads, 1A, 2A, and 3A, and three for internal threads, 1B, 2B, and 3B. All are clearance fits, which means they assemble without interference. *The higher the class number, the tighter the fit.* The designator "A" denotes an external thread; "B" denotes an internal thread. The mating of Class 1A and 1B threads provides the loosest fit; the mating of Class 3A with 3B the tightest.

Additionally, there is a Class 5 thread fit. This is an interference fit, which means that the external and internal threads are toleranced so that a positive interference occurs when they are assembled. Class 5 interference fits are standard only for coarse thread series in sizes 1 in. and smaller.

The requirements of screw-thread fits are determined by use and should be specified by indicating the proper classes for the components. For example, a Class 2A external thread should be used with a Class 2B internal thread. When choosing a class fit for threads, no tighter thread fit should be selected than the function of the parts requires.

Classes 1A and 1B are very loosely toleranced threads, with an allowance applied to the external thread. These classes are ideally suited when quick and easy assembly and disassembly are a prime design consideration. They are standard only for coarse and fine thread series in sizes $\frac{1}{4}$ in. and larger. They are rarely specified for mechanical fasteners.

Classes 2A and 2B are by far the most popular thread classes specified for inch series mechanical fasteners. Approximately 90% of all commercial and industrial fasteners produced in North America have this class of thread fit.

Classes 3A and 3B are suited to closely toleranced fasteners, such as socket cap screws, set screws, and other high-strength fasteners. Classes 3A and 3B have restrictive tolerances and no allowance.

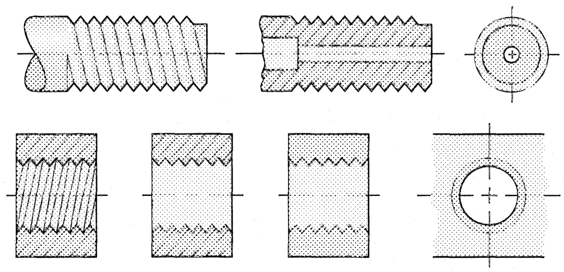


FIGURE 17.14 Detailed Thread Representation

17.6 THREAD REPRESENTATION

On working drawings, threads are seldom drawn as they would actually appear; instead, notes and specifications are given. The American National Standards Institute (ANSI) recognizes three conventions for representing screw threads on drawings: **detailed** (Fig. 17.14), **schematic** (Fig. 17.15), and **simplified** (Fig. 17.16) representations.

The detailed representation is an approximation of the actual appearance of screw threads. Minor modification includes showing the thread profile as a sharp **V**, where the actual thread has flat crest and root. Also, the normal helices are shown as straight lines connecting the thread, crest to crest and root to root. The detailed conventional representation is limited to cases in which the basic diameter is more than 1 in. and where detail or relation of component parts could be confused by less realistic thread representation. When internal holes are drawn by the detailed method, the lines representing the threads are sometimes omitted.

The **simplified method** showing internal threads and the simplified method to represent internal threads in a section are shown in Figure 17.17. Figure 17.18(b) shows how the simplified method represents external threads.

The **schematic method** is used only for external threads [Fig. 17.18(a)] or sectioned internal threads (Fig. 17.19), *not* for internal nonsectioned threads.

Figure 17.20 shows the **detailed method** of representing internal threads in a section. Notice that the detailed method can include or exclude the lines of the threads. External threads drawn with detailed representation are shown in Figure 17.18(c).

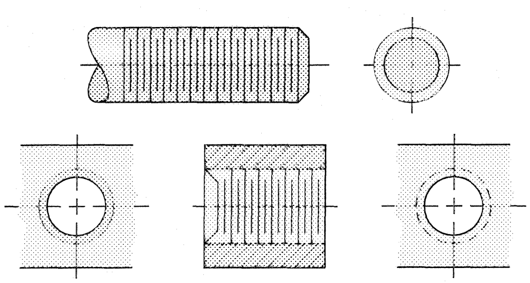


FIGURE 17.15 Schematic Thread Representation

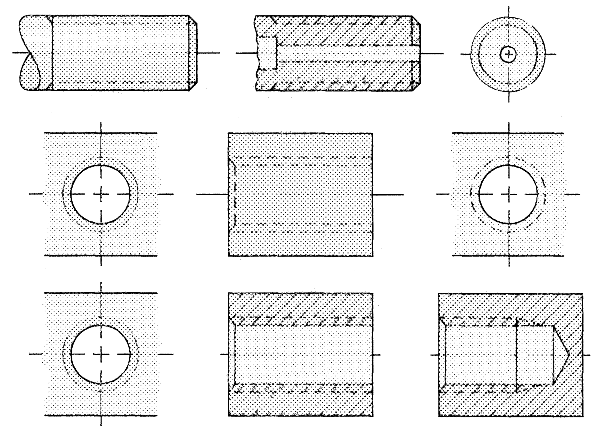


FIGURE 17.16 Simplified Thread Representation

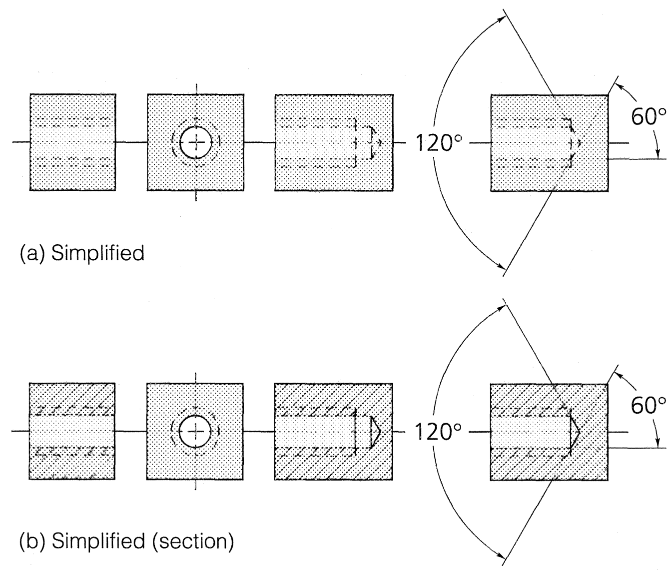


FIGURE 17.17 Internal Simplified Thread Representation

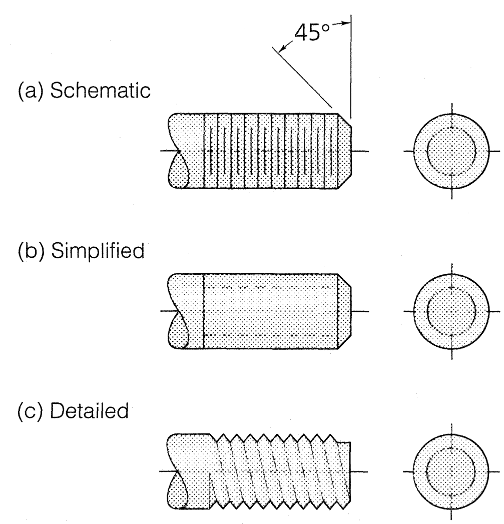


FIGURE 17.18 External Thread Representation

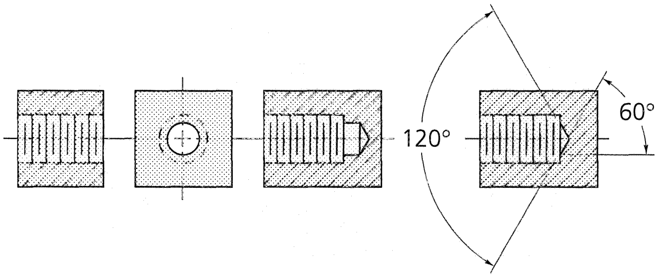


FIGURE 17.19 Internal Schematic Thread Representation

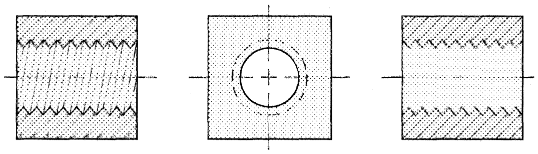


FIGURE 17.20 Internal Detailed Thread Representation

17.6.1 Drawing Threads Using Simplified Representation

The simplified method is executed by following the steps shown in Figure 17.21. Both internal and external threads are drawn by this method. Here, external threads are being constructed. The diameter of the screw is drawn and its end established [Fig. 17.21(a)]. The pitch (*P*) is measured as shown in Figure 17.21(b). Lines are drawn at 60° through the pitch measurements. The thread depth is where the 60° lines cross. The thread depth is used to draw the chamfered end. The chamfer is drawn at 45° and the threaded length is established [Fig. 17.21(c)]. The thread depth is used to draw the dashed lines that represent the minor diameter of the thread [Fig. 17.21(d)].

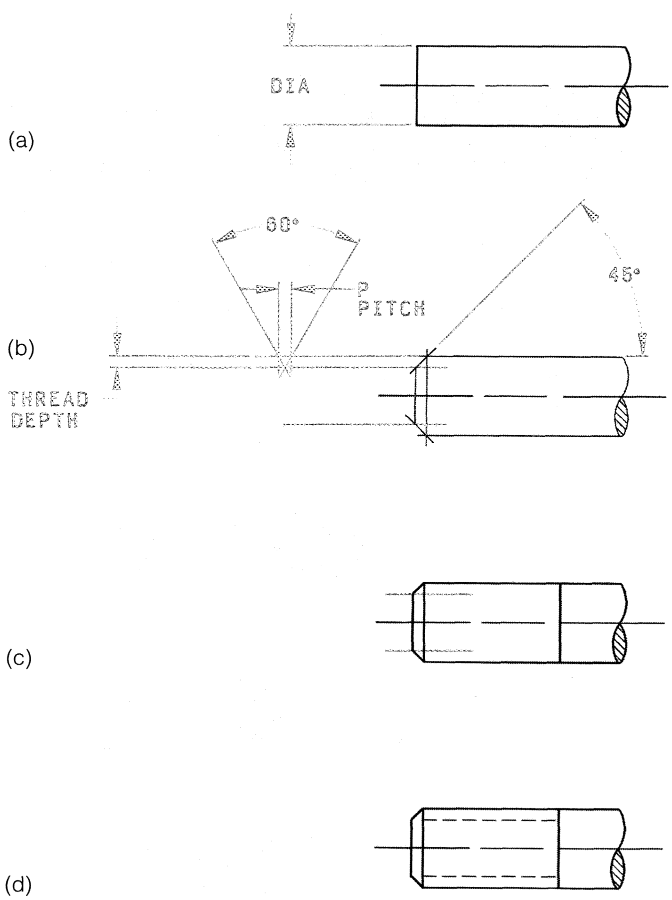


FIGURE 17.21 Drawing Threads Using Simplified Thread Representation

17.6.2 Drawing Threads Using Schematic Representation

Schematic representation is almost as effective as detailed representation and is much easier to draw. The alternating lines, symbolic of the thread roots and crests, are usually drawn perpendicular to the axis of the thread or sometimes slanted to the approximate angle of the thread helix. This construction should not be used for internal threads or sections of external threads.

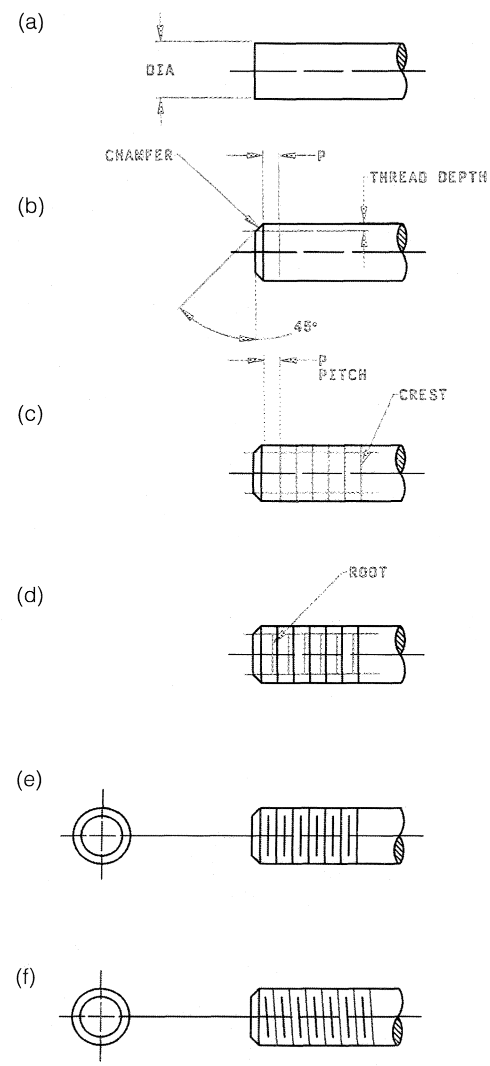


FIGURE 17.22 Drawing Threads Using Schematic Thread Representation

Drawing schematic threads is similar to the simplified method. The screw diameter and end are drawn first [Fig. 17.22(a)]. The chamfer is completed using 45° and the thread depth [Fig. 17.22(b)]. The pitch (*P*) is used to establish the spacing of the thread crests [Fig. 17.22(c)]. The root lines are drawn up to the thread depth [Fig. 17.22(d)]. The thread is completed by darkening in the lines [Fig. 17.22(e)]. This is called the **uniform-line method.** The slope-line representation is shown in [Fig. 17.22(f)]. The slope angle is equal to one-half the pitch. In actual industrial practice, drafters draw the screw diameter, construct a 45° chamfer, and use the chamfer depth to locate the thread root.

17.6.3 Drawing Threads Using Detailed Representation

The detailed thread representation is drawn only when a mechanical advantage must be calculated or analyzed graphically (or for illustrations). Figure 17.23 shows four steps in drawing threads with detailed representation. Step (a) is the same as for simplified and schematic thread representation. The diameter of the screw thread is layed out and one-half of the pitch is measured. Using the pitch (*P*), the top and the bottom lines of the shaft are divided along its length into the required number of threads. The sloped lines (crest lines) are drawn with an angle of one-half the pitch. The threads are drawn as sharp V's at 60°, as in Figure 17.23(b). The ends of the root lines will be established where the thread lines cross at the root. The root lines are drawn by connecting the roots [Fig. 17.23(c)]. Figure 17.23(d) shows the threads darkened.

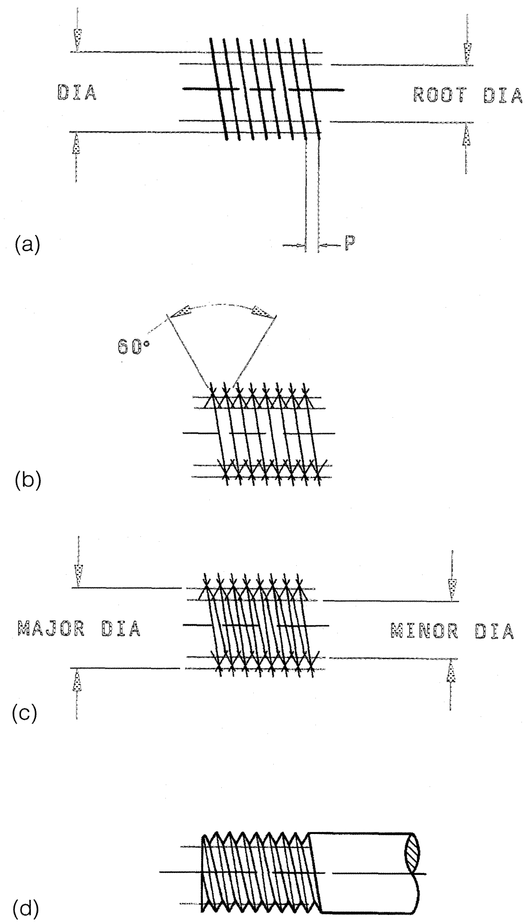


FIGURE 17.23 Drawing Threads Using Detailed Thread Representation

17.6.4 How to Draw Acme Threads

A step-by-step procedure for drawing Acme threads is given in Figure 17.24. The Acme thread has a depth equal to one-half its pitch. The drawing is begun by sketching the shaft diameter (major diameter), the minor diameter, and the pitch diameters with construction lines [Fig. 17.24(a)].

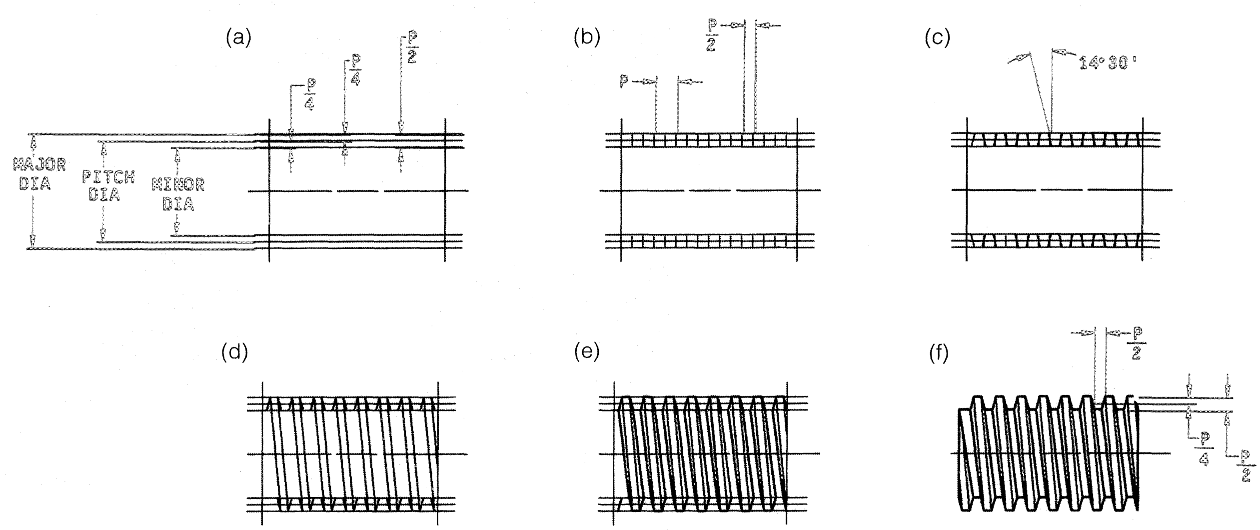


FIGURE 17.24 Drawing Acme Threads Using Detailed Thread Representation

The pitch diameter lines are divided into segments equaling one-half the pitch [Fig. 17.24(b)]. The angle of the thread profile is one-half of 29° ($14\frac{1}{2}$°). Usually, 15° is used to simplify the procedure. The 15° lines are drawn through the half-pitch distances established along the pitch diameter lines [Fig. 17.24(c)]. The angled lines will fall between the major diameter and the minor diameter [Fig. 17.24(d)]. The crests are completed and the root lines are then drawn [Fig. 17.24(e)]. The ends of the threads are completed, the construction lines are erased, and the drawing is darkened [Fig. 17.24(f)]. Detailed Acme threads are shown in Figure 17.25.

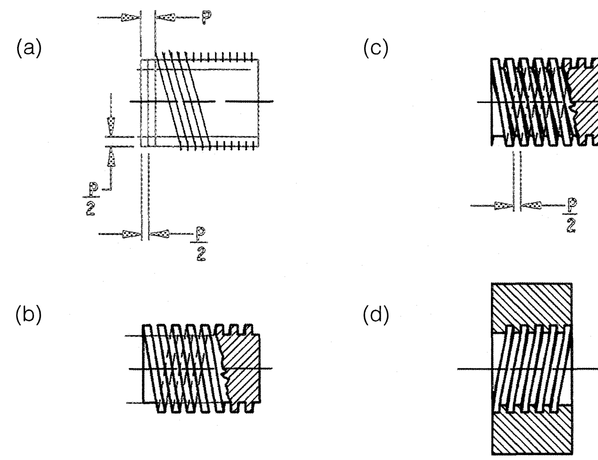


FIGURE 17.25 Detailed Acme Threads

17.6.5 Tap Drills

Threaded holes are first drilled and then tapped (Fig. 17.26). Because the tapping tool extends far enough into the hole to thread the required length of full threads, the tap drill must extend beyond the required thread depth. The major diameter represents the outside diameter of the thread, and the minor diameter represents the tap drill diameter.

Figure 17.27 shows how to represent tapped holes by the simplified method. The drilled hole is drawn accurately, with its diameter and depth as shown. The drill tip is 118°, but for simplicity it is drawn at 170° (30° from the horizontal). The tap drill is represented the same for holes. For drilled and tapped holes, the depth of the full thread is drawn accurately. The tap drill is drawn 3 × the pitch below the threaded portion. This distance includes a number of incomplete threads created by the chamfer end of the tapping tool. Although normally drawn at 3 × the pitch, this distance is actually determined by the drill size as to whether to use a bottoming tap or a plug tap. In some cases, the thread will

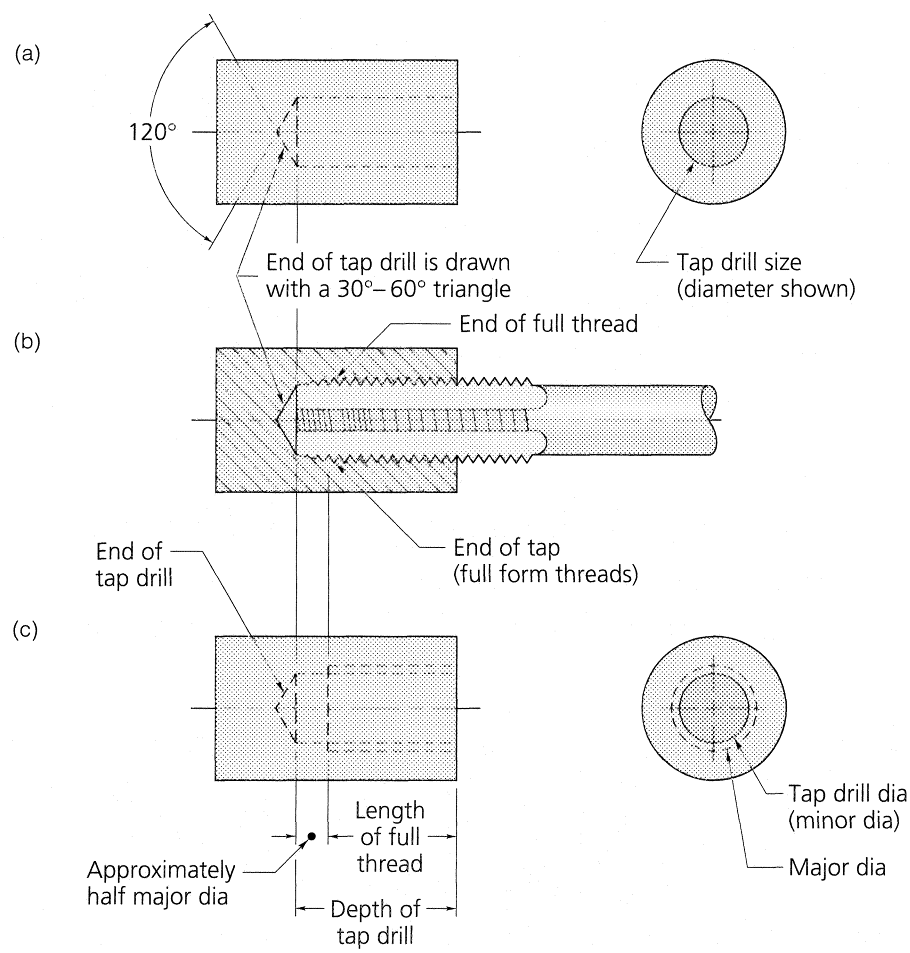


FIGURE 17.26 Blind Holes and Taps

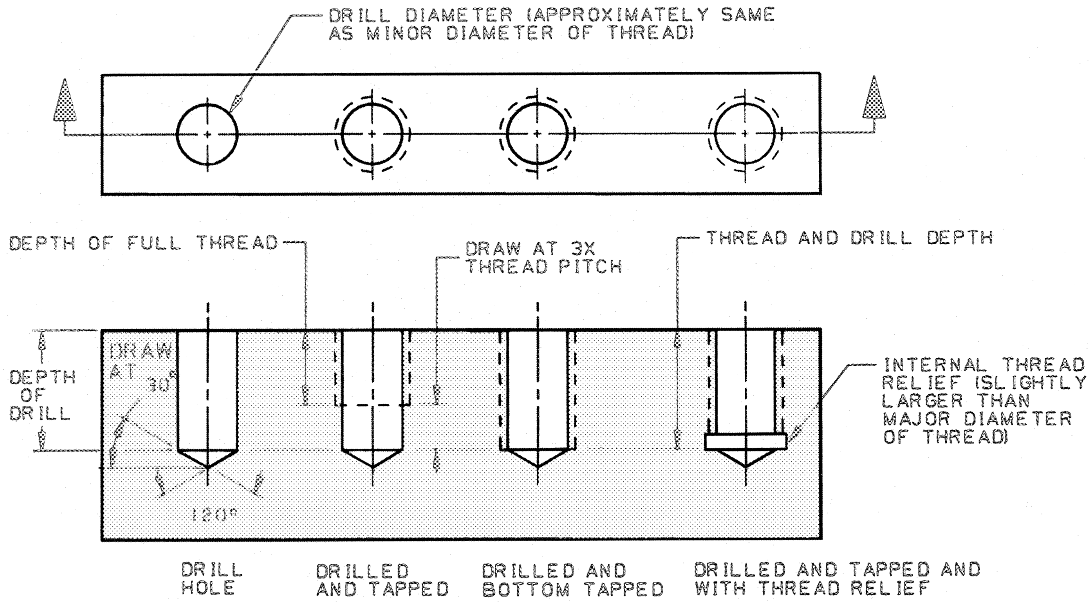


FIGURE 17.27 Drilling and Tapping Holes

extend to the bottom of the drilled hole, or a **thread relief** will be required.

An internal thread relief is slightly larger than the major diameter of the thread (Fig. 17.27). The circular views of the threaded holes show the tap drill as a solid line and the major thread (major diameter) as a dashed line.

17.7 DESIGNATING THREADS AND THREAD NOTES

The thread designation includes the nominal diameter, the number of threads per inch (or the pitch and lead), the letter symbol of the thread series, the number and letter of the thread class, and any qualifying information. The thread length, the hole size, and the chamfer or countersink may be included in the note or dimensioned on the drawing of the part.

The series symbols and the class numbers identify the controlling thread standard and define the details of thread design, dimensions, and tolerances not specifically covered on the drawing.

Series, Class, and Dimensional Letters in Thread Designations

A	external, American, aeronautical
B	internal
C	coupling, coarse, centralizing
EXT	external
EF	extra-fine
F	fine, fuel and oil
G	general purpose, gas, pitch allowance
H	house
I	intermediate
INT	internal
J	controlled radius root
L	lead, locknut
LE	length of engagement
LH	left-hand (absence of LH indicates RH, or right-hand)
M	metric, mechanical, microscope, miniature
MOD	modified
N	national
O	outlet, objective
P	pipe, pitch
R	railing, rounded root, American National Class 1 allowance
RH	right-hand
S	straight
SE	special engagement
SPL	special
T	taper
UN	unified

17.7.1 Thread Designation Examples

The designation and the pitch diameter limits are in note form and referenced to the drawing of the thread with a leader line. The following example illustrates the elements of a designation of the screw thread:

.250-20 UNC-2A

where

.250 = nominal diameter in decimal form
20 = number of threads per inch of pitch and lead

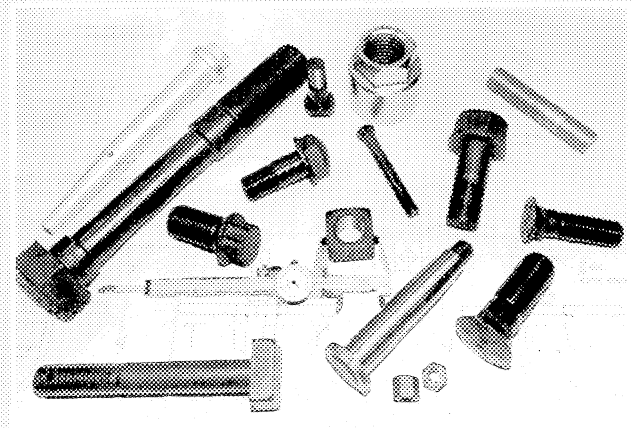
Focus On . . .

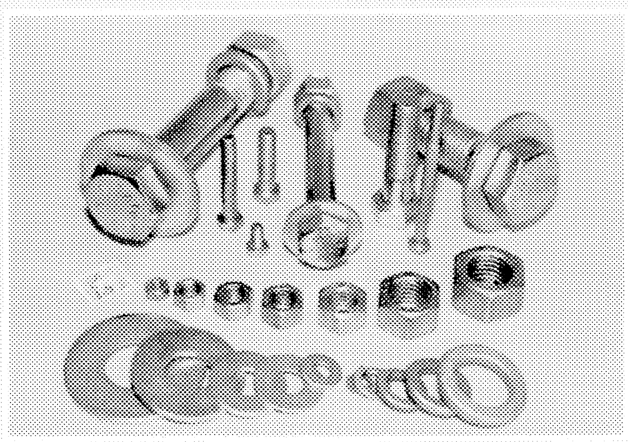
FASTENERS

How a product is fastened together is important to both the manufacturer and the customer or user of the product. We have all complained about the difficulty and cost to replace some minor component in an assembled product. Obviously, if rapid and easy disassembly were considered early in the design stage of the product, everyone would save time and money.

A fastener is any kind of device or method that is used to hold parts together. The permanent fastener choices are soldering, brazing, riveting, welding, and adhesives. Removable fasteners include nuts and bolts, screws, studs, pins, rings, and keys. Snap fits can also be designed into the part itself, eliminating the need for separate fasteners.

The choice of a suitable material for the fastener is also important. Because new materials, like carbon-fiber composites, are being employed, the choice of fastener material is becoming increasingly complex. Also, fasteners used on assemblies (for instance, aircraft and automobiles) must function in all weather conditions without deteriorating in a reasonable amount of time.


Various fasteners.


Industrial fasteners.

One of the most popular removable fasteners is the screw. Archimedes, the Greek mathematician, first used the idea in a screw conveyor to raise water. The threads on a screw provide a fast and easy method for fastening two parts together. However, screws are not the method of choice in automated assembly because of the complex motion required for insertion. Standards are being established to unify screw threads throughout the world. These standards would cut the costs of parts, reduce paperwork, simplify the inventory process, and improve quality control.

The selection of the proper fastening method and material is crucial for a product to be an economic success. The cost of the fastener itself is small compared to the costs associated with that fastener over the lifetime of the assembly. Every designer and drafter in industry knows how complicated the proper selection of a fastener can be, particularly when design for disassembly might be as important or more important than design for assembly.

UNC = thread form, series, and tolerance formulation symbol
2 = class number
A = internal or external symbol (A is external)

Thread sizes are shown as decimal callouts, except for fractional sizes. When specifying decimal sizes, a minimum of three or a maximum of four decimal places, omitting any zero in the fourth decimal place, should be shown as the nominal size:

1.000-8 UNC-2A

$1\frac{3}{4}$-8 UN-2A

Numbered sizes may also be shown; the decimal equivalent should be in parentheses:

No. 10(.190)-32 UNF-2A

Unless otherwise specified, threads are right-hand; a left-hand thread is designated LH:

$\frac{1}{4}$-20 UNC-3A-LH

17.8 ACME THREADS

There are four classes of general-purpose Acme threads and five classes of centralizing Acme threads. The general-purpose Acme threads have clearances on all diameters for free movement and may be used in assemblies where both internal and external members are supported to prevent movement.

There is only one class of stub Acme thread for general usage. It is the Class 2G (general-purpose) thread, which uses two threads with modified thread depths. Stub Acme threads are for power applications.

When designating Acme threads, the designation covers the nominal size, the number of threads per inch, the thread form symbol, and the thread class symbol:

1.750-4 ACME-2G

where

1.750 = nominal decimal size
4 = number of threads per inch
ACME = thread form and series symbol
2G = thread class symbol

17.9 BUTTRESS THREADS

Buttress threads are for high-stress applications where the stress is along its axis in only one direction. The buttress thread is designated either **butt** or **push-butt.** Since the design of most components having buttress threads is so special, no diameter–pitch series is recommended. The two classes of buttress threads are Class 2 (standard grade) and Class 3 (precision grade).

When only the "butt" designation is used, the thread is a "pull"-type buttress, with the clearance flank angle of 45° leading and the pressure flange angle of 7° following. In thread designations on drawings and in specifications, the designation should be shown as in the following example:

2.500-8 BUTT-2A-LH

where

2.500 = nominal size (basic major diameter in inches)
8 = threads per inch (TPI)
BUTT = buttress form of thread, pull-type
2 = class 2 (medium) thread
A = external thread
LH = left-hand

17.10 METRIC THREADS

A wide variety of threaded fasteners are manufactured with metric threads. This section contains general metric standards for a 60° symmetrical screw thread with a basic ISO 68 profile designated "M."

The simplified, schematic, and detailed methods of thread representation also apply to metric screw threads. The following additional definitions apply to metric threads: In ISO metric thread standards, **bolt thread (external thread)** describes all external threads. All symbols associated with external threads are designated with lowercase letters.

In ISO metric thread standards, **nut thread (internal thread)** describes all internal threads. All symbols associated with internal threads are designated with uppercase letters.

17.10.1 Metric Classes of Fit

There are two recognized classes of thread fit. One is for general-purpose applications and contains tolerance classes 6H/6g; the other is used where closer thread fits are required and contains tolerance classes 6H/4g to 6g.

The **tolerance grade** is indicated by a number. The system provides for a series of tolerance grades for each of the four screw thread parameters: minor diameter, internal thread (4, 5, 6, 7, 8); major diameter, external thread (4, 6, 8); pitch diameter, internal thread (4, 5, 6, 7, 8); and pitch diameter, external thread (3, 4, 5, 6, 7, 8, 9).

The **tolerance position,** the allowance, is indicated by a letter. A capital letter is for internal threads and a lowercase letter for external threads. The system provides a series of tolerance positions for internal and external threads:

Internal threads	G, H
External threads	g, h

The tolerance grade is given first, followed by the tolerance position—for example, 4g or 5H. To designate the tolerance class, the grade and position of the pitch diameter is shown first followed by the major diameter (external thread) or the minor diameter (internal thread)—for example, 4g6g for an external thread and 5H6H for an internal thread. If the two grades and positions are identical, it is not necessary to repeat the symbols. Thus, 4g alone stands for 4g4g, and 5H alone means 5H5H.

17.10.2 Designation of Metric Screw Threads

Metric screw threads are identified by the letter M for the thread form profile, followed by the nominal diameter size and the pitch, expressed in millimeters, separated by a × sign and followed by the tolerance class separated by a dash (-) from the pitch.

The simplified international practice for designating coarse-pitch M-profile metric screw threads is to leave off the pitch. Thus, an M14 × 2 thread is designated just M14. However, to prevent misunderstanding, it is mandatory to use the value for pitch in all designations shown on drawings.

The thread acceptability gaging system requirements of ANSI B1.3M may be added to the thread size designation. The numbers are shown in parentheses: (22), (21). The following is an example of a close-tolerance external thread designation:

M8 × 1.25-4g6g (22)

Here are two examples of internal thread designation:

M6 × 1-6H (21)

M6 × 1-5H6H (21)

Unless otherwise specified in the designation, the screw thread helix is right-hand. When a left-hand thread is specified, the tolerance class designation is followed by a dash and **LH**. The following is an example of a left-hand external thread with an **M** profile:

M6 × 1-4969-LH

where

- M = metric thread symbol, ISO 68 metric thread form
- 6 = nominal size in millimeters
- 1 = pitch in millimeters
- 4g6h = tolerance class
- 4g = major diameter tolerance symbol (4 = tolerance position; G = tolerance grade)
- 6g = pitch diameter tolerance symbol (6 = tolerance position; G = tolerance grade)
- LH = left-hand

A fit between *mating threads* is indicated by the internal hread tolerance class, followed by the external thread olerance class, separated by a slash, for example:

M6 × 1-6H/6g

M6 × 1-6H/4g6g

17.11 DIMENSIONING THREADS

'he thread length dimensioned on the drawing should be ie gaging length, or the length of threads having full form. 'hat is, the incomplete threads are outside or beyond the ength specified.

Should there be reason to control or limit the number of icomplete threads on parts having a full-body diameter hank, the overall thread length, including the vanish runout or incomplete) threads, are represented and dimensioned on the drawing, in addition to the full thread length Fig. 17.28). All representation of fully formed threads hould indicate the *thread runout* (incomplete threads), as hown in the figure. Overall thread length should be represented and dimensioned on the drawing, and should include ie thread runout.

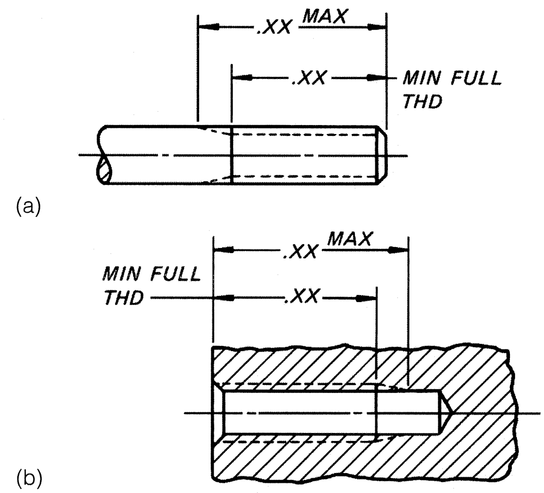


FIGURE 17.28 Dimensioning Thread Length

17.11.1 Thread Chamfers

If required, thread **chamfers,** or **countersinks,** should be specified on the drawing. It is preferable to specify the chamfer by length and diameter, to avoid confusion. Figure 17.29 shows three methods of dimensioning an external chamfer. The chamfer length should be 0.75 to 1.25 times the pitch, rounded off to a two- or three-place decimal.

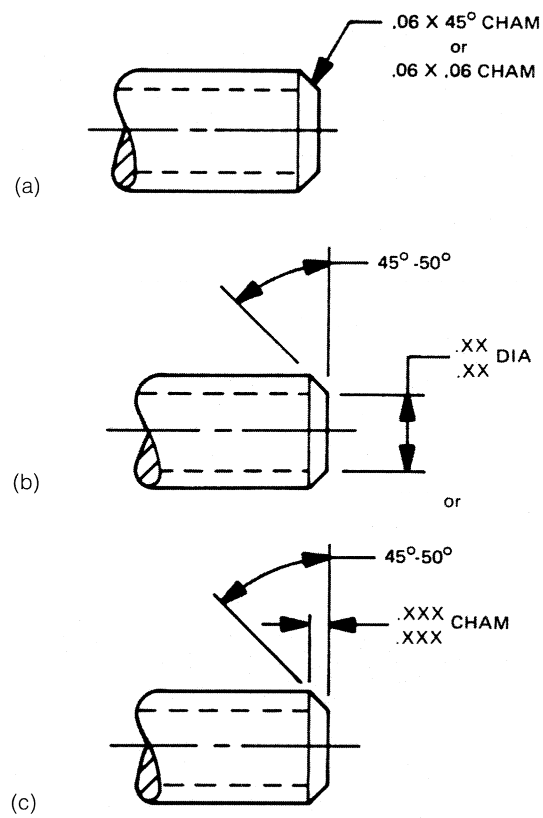


FIGURE 17.29 Dimensioning Chamfers at the End of External Threads

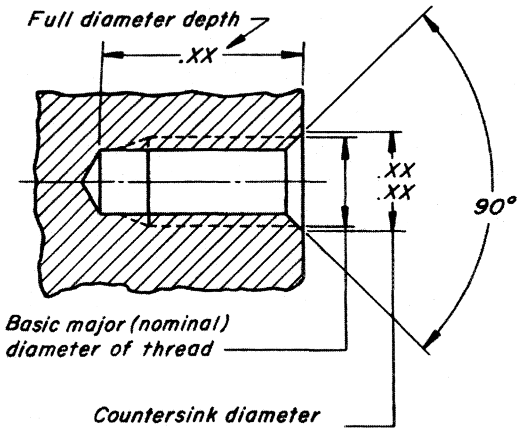


FIGURE 17.30 Dimensioning Countersink, Drill Depth, and Size on Internal Threaded Holes

When a callout cannot properly or clearly designate an internal threaded hole, the depth, size, and countersink (chamfer) are dimensioned (Fig. 17.30). If the chamfer and minor diameter are very close to being the same, the minor diameter of a thread may be eliminated to improve clarity. On end views of countersunk threaded holes where countersunk diameters and the major diameters of threads are close to being the same, the major diameter may be eliminated for clarity.

17.11.2 Threads on Drawings

Holes are located by their centers. Leaders have the arrowheads pointing toward the center in the circular views.

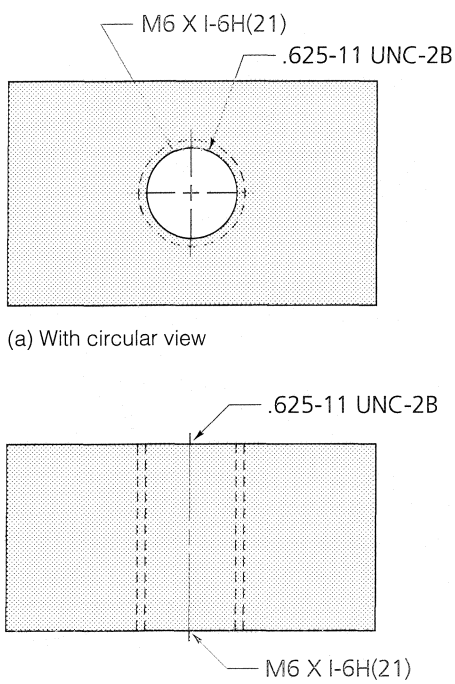


FIGURE 17.31 Calling Out Threads on a Drawing

When the circular view is not available, the arrow of the leader line should touch the axial centerline of the hole. Figure 17.31 shows an example of UN thread callouts (they are not meant to be equivalents in the example).

The full depth of the drilled hole for **blind tapped holes** should be specified on the drawing (Figs.17.27 and 17.30). Blind holes do not go all the way through the part. If the wall at the drill point is the limiting consideration in addition to, or instead of, the full-diameter depth, the drill point depth or the *wall thickness* may be dimensioned or stated in a note. In some cases, the depth may be specified as a minimum full-diameter depth and the note DO NOT BREAK THRU should be added. Hole size limits should be shown on the drawing.

17.12 PIPE THREADS

The American National Standard taper pipe thread is tapered $\frac{1}{16}$ in. per inch ($\frac{3}{4}$ in. per ft) to ensure a tight joint at the fitting (Fig. 17.32). The crest of the thread is flattened, and the root is filled so that the depth of the thread is equal to 80% of the pitch. The number of threads per inch for a given nominal diameter can be found in Appendix C.1.

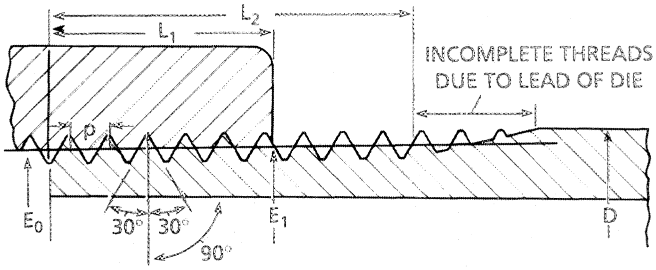
Pipe threads are designated in established trade sizes that signify a nominal diameter only. The designation of tapered threads includes the nominal size, the number of threads per inch, the thread form, and thread series symbols as shown in the following examples:

6-8 NPT	*Explanation*	**.125-27 NPT**
6 =	nominal pipe diameter in inches	= .125
8 =	number of threads per inch	= 27
N =	American Standard National thread	= N
P =	pipe	= P
T =	taper	= T

.750-14 NPSL	*Explanation*	**12-8 NPTR**
.750 =	nominal pipe diameter in inches	= 12
14 =	number of threads per inch	= 8
N =	American National Standard thread	= N
P =	pipe	= P
S =	straight	
	taper	= T
L =	locknuts and locknut pipe threads	
	rail fittings	= R

17.12.1 Drawing Pipe Threads

Figure 17.33 shows a male (external) and female (internal) pipe thread drawn in simplified representation. The taper on a pipe thread is so slight that it does not show up on



$E_0 = D - (0.050D + 1.1)p$ p = Pitch

$^*E_1 = E_0 + 0.0625\,L_1$ Depth of thread = $0.80p$

$L_2 = (0.80D + 6.8)p$ Total Taper 3/4-inch per Foot

FIGURE 17.32 American National Pipe Thread (NPT)

Nominal Pipe Size	D	TPI	P	E0	E1	L1	L2
.750	.840	14	.071	.758	.778	.320	.533
3.000	3.500	8	.125	3.340	3.388	.766	1.200

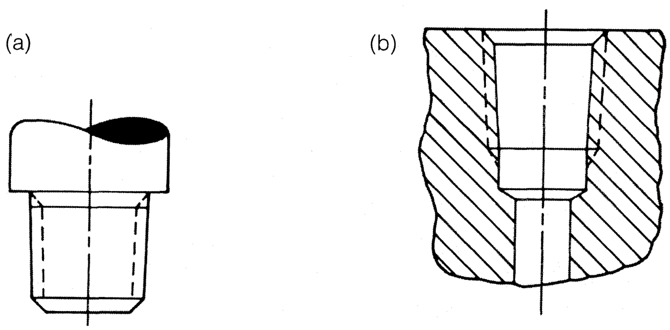


FIGURE 17.33 Internal and External Pipe Thread Representation

drawings unless it is exaggerated. It is drawn to 8 in. taper per inch. The ANSI recommendation for representing pipe threads is the same as for all other threads. The simplified form is the most common, the detailed form the least.

You May Complete Exercises 17.1 Through 17.4 at This Time

17.13 FASTENERS

Basic industrial **fasteners** (Fig. 17.34) include square and hex bolts, cap screws, carriage bolts, machine screws, plow bolts, lag screws, studs, nuts, and rivets. Other fasteners have also been standardized over the years as to type, style, usage, properties, dimensions, and tolerances.

Semipermanent assembly fasteners include bolts, screws, studs, nuts, washers, snap rings, nails, and pins. Rivets are considered **permanent fasteners**. Fastener selection is made by considering strength, appearance, durability, corrosion resistance, materials to be joined, total cost of assembly parts, and assembly and disassembly labor involved or machines and power tools required. Whenever possible, design for automated assembly with common standard parts.

The *installed cost* is far more important than the initial cost of the fastener. For example, a rivet is much cheaper than the high-strength bolt, nut, and washer that replaced it, but the greater holding power and the lower installed cost of the high-strength bolting system has for all practical purposes displaced riveting as standard fastening for structural joints.

When designating fasteners on a drawing, provide the following:

- Product name
- Nominal or actual size in fractions, decimal-equivalent, or metric units
- Thread specification, if appropriate
- Length in fractions, decimal-equivalent, or metric units
- Material and protective coating, if applicable
- Finish, where required

17.13.1 Representing Fasteners

In general, a template is employed for constructing standard fasteners. With a CAD system, a standard library of parts is normally available.

Figure 17.35 shows a sketch of two typical fasteners. The *head styles* shown are the **hex** and **socket** varieties. The *bearing surface* is that portion of the fastener that is in contact with the part being fastened (or a washer when one is used). The *point* is at the opposite end from the head and is normally chamfered. The *threaded* part of the *body* extends from the point toward the bearing surface. Some fasteners are completely threaded (the whole body) and some are partially threaded.

17.13.2 Studs

Studs are fasteners with no head but with threads at both ends of the shank. Studs come in *continuous threaded* types and *double-ended* varieties. In most applications, the stud is screwed into a workpiece on one end, and a nut is used on the other end (Fig. 17.36). In other applications, the stud has a nut on both ends and is used to secure two pieces. In Figure 17.37 the cover plate for the check valve has eight studs and sixteen nuts.

Continuous threaded studs are threaded from end to end and are often used for flange bolting with two nuts. Continuous threaded studs come in two types: Type 1, for general purpose, and Type 2, for pressure piping. If a stud is to be inserted into a tapped hole (Fig. 17.36), it is recommended that it be held in place by jamming it against the bottom of the hole. A Class 5 fit is recommended for such service. The thread engagement should be $1\frac{1}{4}$ times the diameter of the stud for steel, $1\frac{1}{2}$ times for cast iron, and $2\frac{1}{2}$ times for softer materials.

Double-ended studs come in four types: Type 1 is unfinished, Type 2 is finished and has an undersize body,

Description	Military Reference	Description	Military Reference	Description	Military Reference
–1– Pan head	MS 35204 thru MS 35219 and MS 35221 thru MS 35236	–12– Socket head cap screw	MS 35455 thru MS 35461	–23– Flat washer	MS 15795
80° to 82° –2– 82° Flat head	MS 35188 thru MS 35203 and MS 35237 thru MS 35251 and MS 35262	–13– Set screw	AN 565	–24– Lockwasher-spring	MS 35337 MS 35338 MS 35339 MS 35340
99° to 101° –3– 100° Flat head	AN 507	–14– Self-locking	Plastic pellet can be applied to all types of screws	–25– Lockwasher-ext. tooth	MS 35335
–4– Fillister head	MS 35361 and MS 35366	–15– Hex nut	MS 35649 MS 35650 MS 35690	–26– Lockwasher-int. tooth	MS 35333 MS 35334
–5– Drilled fillister head	MS 35263 thru MS 35278	–16– Self-locking nut (non-metallic collar)	Can be supplied with fibre or plastic collar. All sizes and material	–27– Lockwasher-csk. tooth	MS 35336 MS 35790
–6– Slotted hex head	Made to order in 1020 Bright. 1035 Heat Treat and Alloy Steel	–17– Self-locking nut (deflected beam)	Can be supplied in Steel, Brass, Stainless - all sizes	–28– Spring pin	MS 9047 MS 9048 MS 171401
–7– Tapping screw-Type 1	AN 504 AN 506	–18– Clinch nut	Supplied to order for special applications	–29– Grooved pin	MS 35671 thru MS 35679
–8– Tapping screw-Type 23	AN 504 AN 506	–19– Clinch nut	Supplied with fibre locking collar in various shank lengths	–30– Taper pin	AN 385
–9– Tapping screw-Type 25	AN 530 AN 531	–20– Self-locking nut	Made with Nylon pellets in standard and special sizes	–31– Weld stud	Supplied with welding nibs under and top of head
–10– Drive screw	AN 535	–21– Semi-tubular	MS 20450	–32– Weld nut (self locating)	Supplied with standard thread sizes
–11– Sems	Supplied with all types of heads, also with Internal and External Lockwashers	–22– Shoulder	Made to specifications in steel and brass	–33– Weld nut	Supplied with standard thread sizes

FIGURE 17.34 Industrial Fasteners

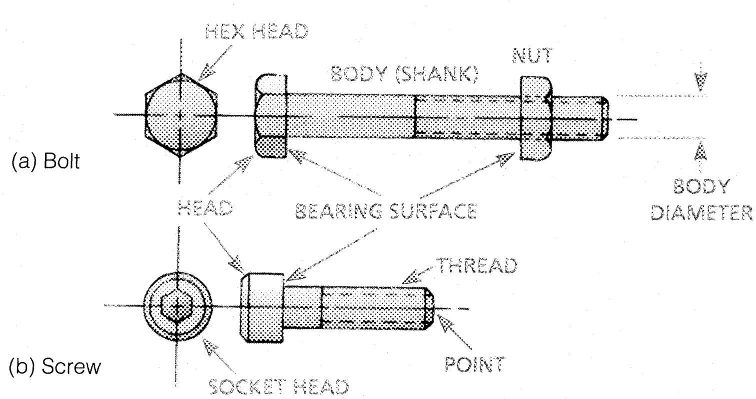


FIGURE 17.35 Bolt and Screw Terminology

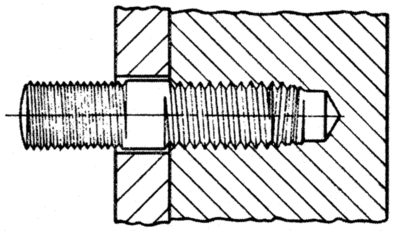


FIGURE 17.36 Threaded Stud in Blind Hole

FIGURE 17.37 Check Valve

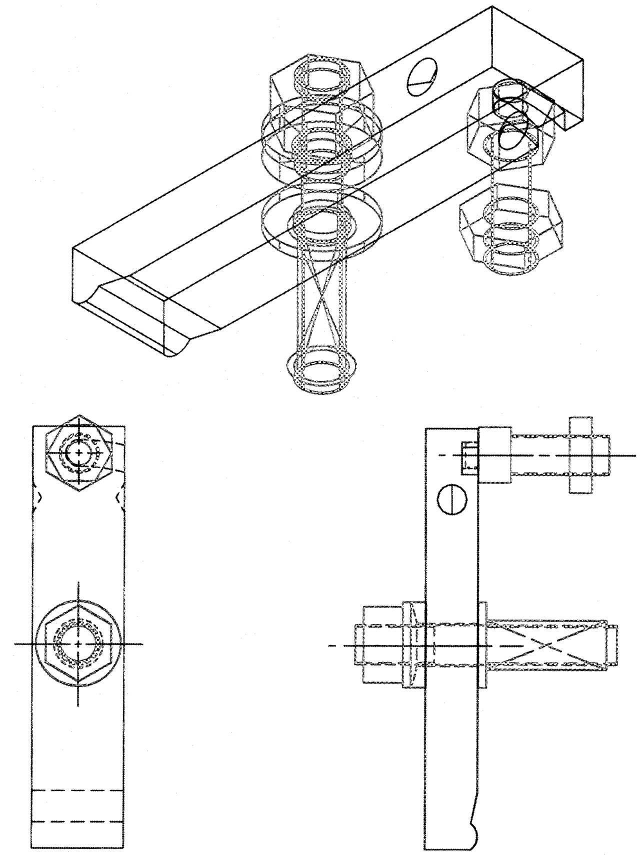


FIGURE 17.38 Swing Clamp for Tooling

Type 3 is full bodied and finished, and Type 4 is finished and is close-body, milled to specifications.

A typical stud application is shown in Figure 17.38 (a swivel-heel clamp assembly). Here, two studs are used in the design of this tooling component. Studs are designated on drawings as in the following examples.

For Type 1 continuous:
CONTINUOUS THREAD STUD, $\frac{1}{2}$-13 × 8, ASTM A307, ZINC PLATED

For Type 2 continuous:
ANSI/ASME B16.5 STUD BOLT, .875-9 × 12, ASTM A 354, GRADE BD

For metric continuous:
CONTINUOUS THREAD STUD, M24 × 3 × 200, ASTM F568 CLASS 8.8, ZINC PHOSPHATE AND OIL

For double-ended:
TYPE 4 DOUBLE END STUD $\frac{3}{4}$ - 10 × 8.50, ASTM A499, CADMIUM PLATED

TYPE 2 DOUBLE END STUD, M10 × 1.5 × 90, ASTM F568 CLASS 9.8, ZINC PLATED

17.13.3 Bolts

A **bolt** is a device with a head on one end of a shank and a thread on the other end. Designed for insertion through holes in assembly parts, it is mated with a tapped nut. The diameter of all bolts is measured as the outside (major) diameter of the thread; the length of a headed bolt is measured from under the head to the end of the bolt. The length of a bolt with a countersunk (flat) head is the overall length. The point (tip) of a bolt is always included in the measured length.

Figure 17.39 illustrates the common types of bolts available. **Hexagon bolts** (Fig. 17.40) can be used in a threaded hole or with a nut. A typical application of a hexagon bolt is shown in Figure 17.41. Hexagon bolts are available with either plain or slotted heads, and also come in metric sizes.

Square-head bolts (Fig. 17.42) and **round-head bolts** (Fig. 17.43) are usually made of low-carbon steel and are referred to as "black bolts." They are available in an unfinished style and with coarse threads. Square-head bolts are adequate for heavy machinery, conveyors, and fixtures. Round-head bolts have various-shaped necks under the head that are embedded in wood or metal and act as a locking device. **Countersunk bolts** are shown in Figure 17.44.

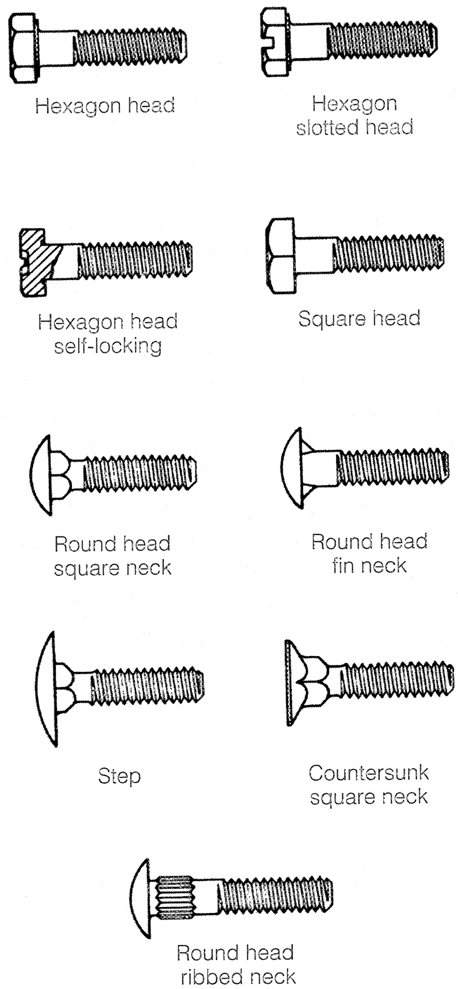


FIGURE 17.39 Bolt Head Types

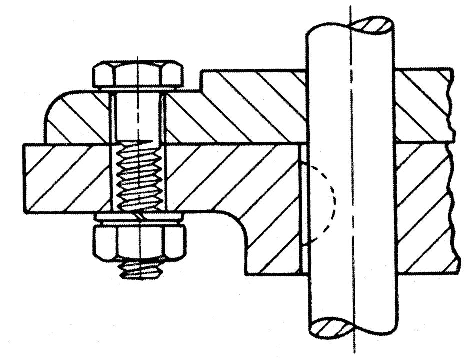


FIGURE 17.41 Hex Bolt Used on Assembly

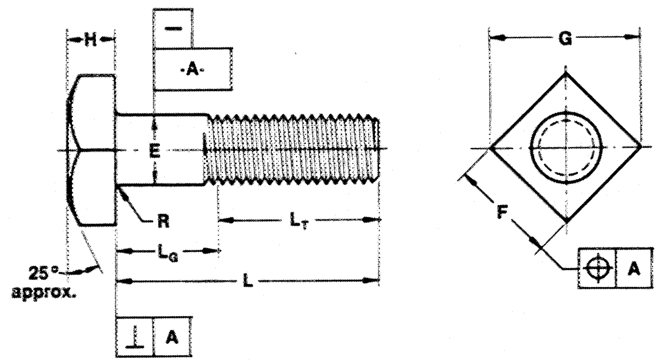


FIGURE 17.42 Square-Head Bolt

Nominal Size	E	F	G	LT	L
.875	.875	1.312	1.856	2.00	6.00 or less
1.500	1.50	2.250	3.182	3.25	6.00 or less

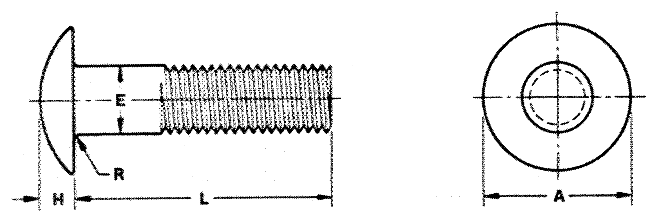


FIGURE 17.43 Round-Head Bolts

Nominal Size	A	E	H
.312	.719	.312	.176
.625	1.344	.625	.344

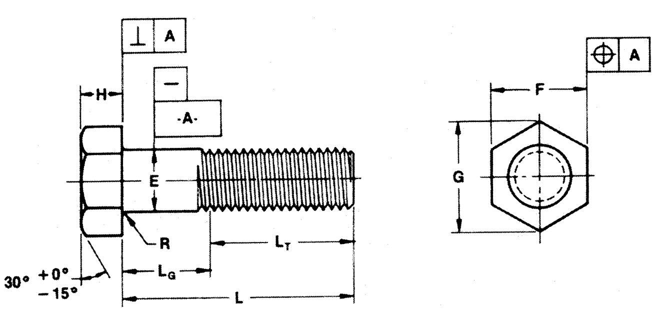


FIGURE 17.40 Hex Bolt

Nominal Size	E	F	G	LT	L
.627	.627	.938	1.08	1.50	6.00 or less
1.000	1.000	1.500	1.73	2.25	6.00 or less

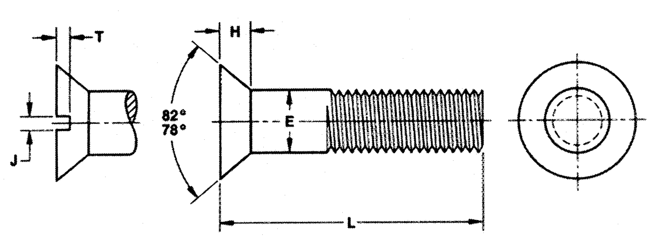


FIGURE 17.44 Countersunk Bolts

Nominal Size	Head Dia	E	H	J	T
.750	1.16	.750	.40	.14	.17
1.25	2.33	1.250	.67	.22	.29

Bolts are designated on drawings as in the following examples:

$\frac{1}{2}$-13 × 3$\frac{1}{2}$ HEX CAP SCREW, SAE GRADE 8 STEEL

.625-11 × 2 ROUND HEAD SQUARE NECK BOLT, STEEL

For metric:

HEX BOLT, M20 × 2.5 × 160, CLASS 4.6, ZINC PLATED

HEAVY HEX STRUCTURAL BOLT, M22 × 2.5 × 160, ASTM A325M

17.13.4 Screws

A **screw** is a threaded fastener used without a nut. Screws are inserted through a clearance hole and into an internally tapped hole in the mating part. The clearance hole is only slightly larger than the screw diameter; therefore, it is not shown on the assembly drawing. Only the body diameter of the screw is shown, as is the outside diameter of the threads. When sectioning assemblies, screws and other fasteners are not sectioned.

17.13.5 Machine Screws

Machine screws differ from cap screws mainly in the range of basic diameters, head shapes, and driver provisions. Machine screws are so named because they are machined completely from bar stock. They are usually restricted to light assemblies, such as instrument panel mountings, moldings, and clip fasteners. The size selection is determined by the tightness required of the parts to be fastened. Machine screws can be assembled into a nut or into a threaded hole in a functional part. Figure 17.45 shows various screw head shapes available as standard parts. Screw selection is made by considering design needs such as surface condition, appearance, size of hole, cover clearance, driving provisions, and expected environmental exposure.

Machine screws come in either fine or course thread and are normally confined to light assembly applications. Machine screw sizes are divided into two categories: fractional sizes and numbered sizes. Numbered sizes are confined to those below $\frac{1}{4}$ in. diameter. Fractional sizes range between $\frac{1}{4}$ and $\frac{3}{4}$ in. diameter. Number 0 has a diameter of .06 inches; .013 inches is added to each numbered size above number #0. Figure 17.46 shows a slotted flat-countersunk-head machine screw. Machine screws 2 in. and under in length come fully threaded. All lengths greater than 2 in. have a 1$\frac{3}{4}$ inch thread.

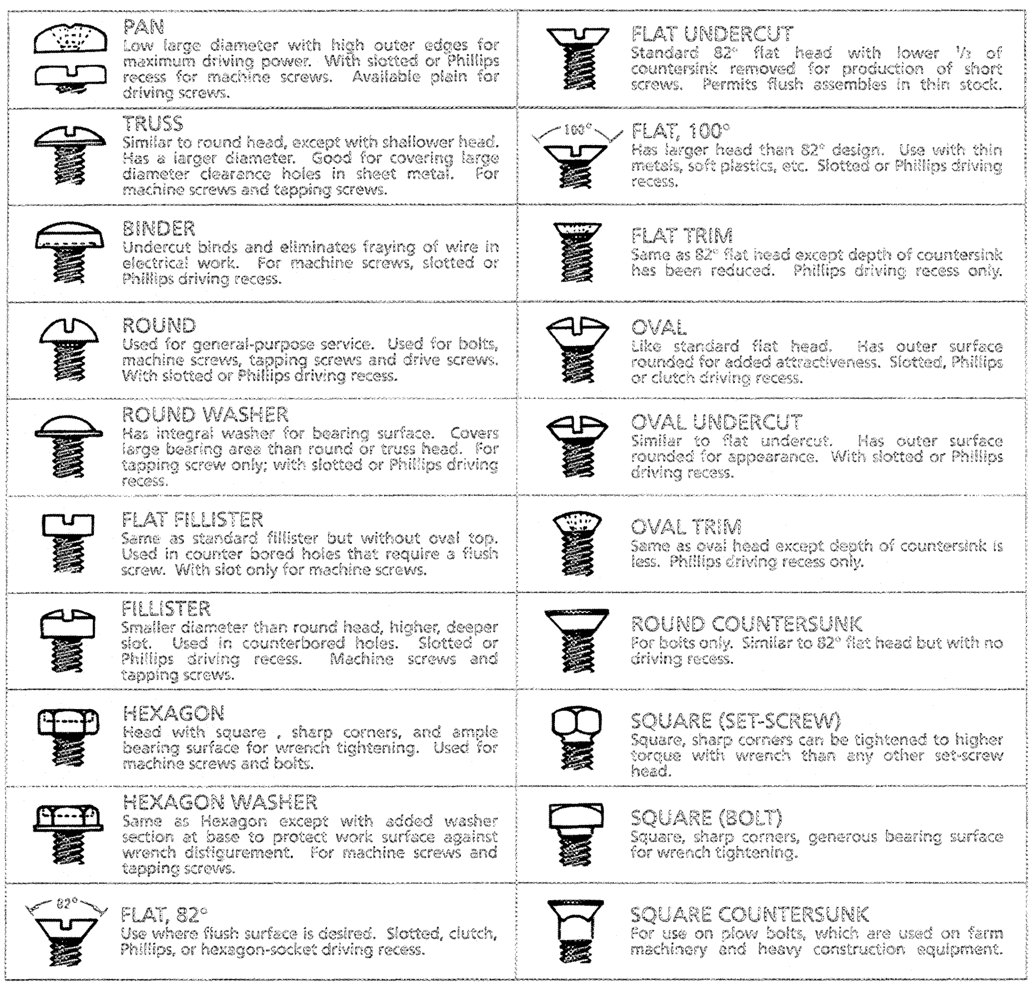


FIGURE 17.45 Machine Screw Head Styles

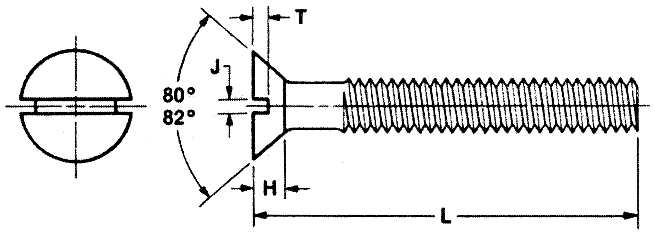


FIGURE 17.46 Slotted Flat-Countersunk-Head Machine Screw

Nominal Size	Head Dia	H	J	T
#5 (.125)	.25	.075	.04	.03
.500	.875	.223	.10	.10

Machine screws are called out in the same way as bolts, for example:

.25-20 x 1.5 SLOTTED PAN HEAD MACHINE SCREW, STEEL, ZINC PLATED

6-32 × 1.50 SLOTTED FLAT COUNTERSUNK HEAD MACHINE SCREW

For metric:

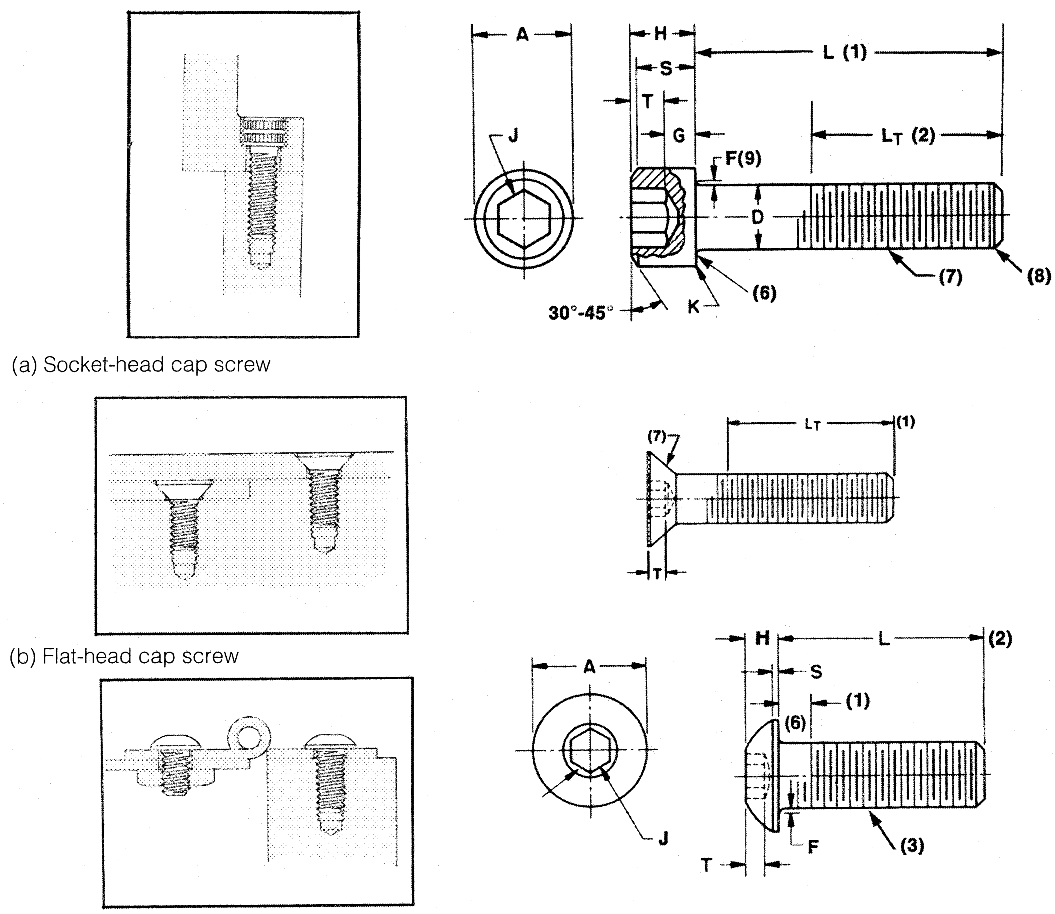
M8 × 1.25 × 30 SLOTTED PAN HEAD MACHINE SCREW, CLASS 4.8 STEEL, ZINC PLATED

M4 × 0.7 × 40 RECESSED PAN HEAD MACHINE SCREW, BRASS

17.13.6 Cap Screws

Cap screws are similar to machine screws except that there are fewer head styles available. Cap screws have their heads cold-formed from smaller-diameter stock. Cap screws are for applications that require closer tolerances and greater holding power per diameter. Figure 17.47 shows three examples of cap screws. Cap screws are finished and are more expensive than similar-size bolts and machines screws. Cap screws come in course, fine, and special threads. Cap screws 1 in. in diameter and under have a Class 3A thread; those greater than 1 in. in diameter have a Class 2A thread.

Cap screws are available in steel, brass, bronze, aluminum, and titanium. Steel hex-head cap screws (Fig. 17.48) are available in diameters from $\frac{1}{4}$ to 3 in. and have their



(a) Socket-head cap screw

(b) Flat-head cap screw

(c) Round-head (button-head) cap screw

FIGURE 17.47 Cap Screw Applications

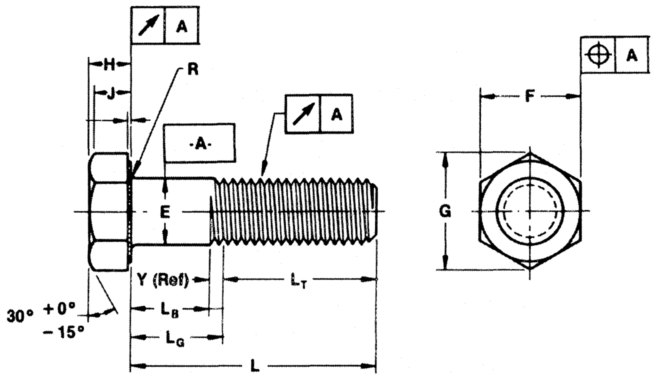


FIGURE 17.48 Hex Cap Screws

Size	E	F	G	H	J	LT	L
.500	.500	.750	.86	.32	.21	1.25	6.00 or less
.75	.750	1.125	1.29	.48	.32	1.75	6.00 or less

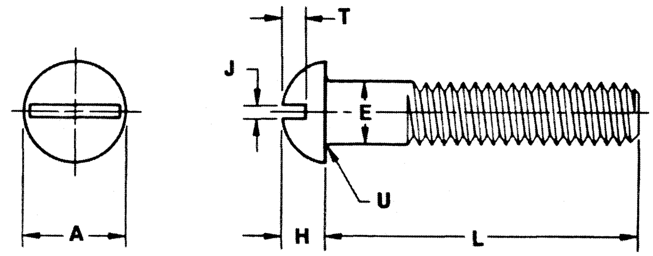


FIGURE 17.50 Slotted Fillister-Head Cap Screws

Nominal Size	A	E	H	J	O	T
.312	.437	.312	.20	.08	.25	.11
.562	.812	.562	.37	.11	.46	.21

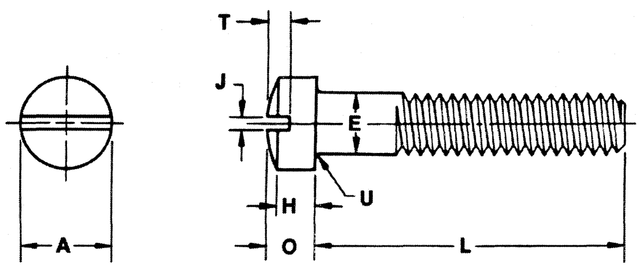


FIGURE 17.49 Slotted Round-Head Cap Screws

Nominal Size	A	E	H	J	T
.250	.437	.250	.19	.07	.11
.500	.812	.500	.35	.10	.21

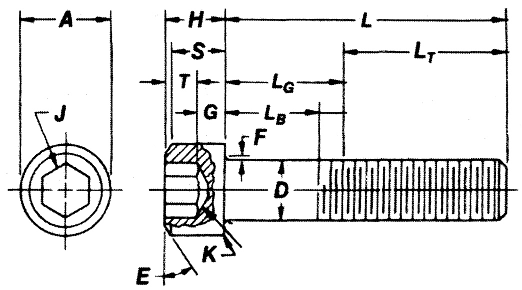


FIGURE 17.51 Socket-Head Cap Screws

Nominal Size	A	D	H	J	LT
.375	.56	.375	.372	.312	1.25
1.000	1.50	1.000	1.000	.750	2.50

strength indicated on their hex head by a geometric symbol. Slotted-head cap screws come in round (Fig. 17.49), fillister (Fig. 17.50), and flat heads.

Socket-head cap screws (Fig. 17.51) are used throughout industry for precision and high-strength fastening and where the head of the screw must be flush or below the part's surface. A clearance hole for the head is counterbored into the part (Fig. 17.47). Socket-head cap screws are also made with socket button heads and socket flat heads.

The metric format for designating fasteners can be abbreviated. For example, SOCKET HEAD SHOULDER SCREW becomes SHSS. American standard fasteners can also have abbreviated designations. For example, HEXAGON HEAD CAP SCREW can be abbreviated HEX HD CAP SCR.

When designating cap screws on your drawing, use the following format:

.138-32 × 1.00 HEXAGON SOCKET HEAD CAP SCREW, ALLOY STEEL, CADMIUM PLATED

$\frac{1}{4}$ - 28 × 1.75 HEXAGON SOCKET FLAT COUNTERSUNK HEAD CAP SCREW, ALLOY STEEL

For metric:

B18.3.1M-M6 × 1 × 20 HEXAGON SOCKET HEAD CAP SCREW

IFI-535 - 6 × 1 × 8 SOCKET COUNTERSUNK HEAD CAP SCREW, ZINC PLATED

Socket-head shoulder screws are used for location and fastening by combining the features of dowels and screws, and for applications requiring a pivot. This type of screw has an enlarged, toleranced, unthreaded portion of the screw body called a *shoulder* (Fig. 17.52). The length of a shoulder screw is measured from under its head to the end of its shoulder. The threaded portion is not included in the length specification.

When designating a shoulder screw on a drawing, give the nominal size or basic shoulder diameter in fractions or decimal equivalent, a shoulder length, the product name, the material, and the finish, as in the following examples:

$\frac{1}{4}$ × 1.250 HEX SOCKET HEAD SHOULDER SCREW, ALLOY STEEL

1.25 × 4.25 HEX SOCKET HEAD SHOULDER SCREW, ALLOY STEEL, PHOSPHATE COATED

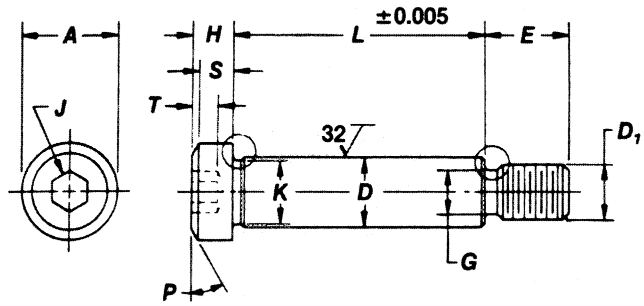


FIGURE 17.52 Hexagon Socket-Head Cap Shoulder Screw

Nominal Size	A	D	D1	E	G	H	J	K
.500	.75	.500	.375	.625	.30	.31	.25	.47
1.000	1.31	.998	.750	1.000	.63	.625	.50	.97

For metric:

B18.3.3M-8 × 25 SOCKET HEAD SHOULDER SCREW

B18.3.3M-10 × 50 SHSS, ZINC PLATED

17.13.7 Set Screws

There are three types of **set screws:** slotted, socket, and square head. In a set screw, there are three types of holding power: torsional (resistance to rotation), axial (resistance to lateral movement), and vibrational. Set screws serve in a variety of applications, such as securing components to shafts (Fig. 17.53).

Set screws are available in number sizes from 0 to 12 and in fractional sizes from $\frac{1}{4}$ to 2 in. Metric set screws come in nominal diameters of 1.6, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, and 24 millimeters.

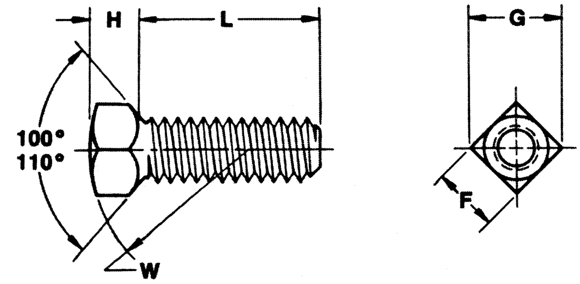


FIGURE 17.54 Square-Head Set Screws

Nominal Size	F	G	H	W
.250	.250	.35	.19	.62
.500	.500	.70	.38	1.25

The size of a set screw is an important factor in holding power. A rough rule of thumb is that the set screw diameter be 25% of the shaft diameter. When more than one set screw is used, the second should be placed near and in line with the first one. If the second set screw must be in the same location as the first, it should be staggered at an angle of 60°.

Square-head set screws protrude above the surface of the part (Fig. 17.54). Headless types disappear below the work surface when tightened. **Socket set screws** have spline or hex sockets (Fig. 17.55). Slotted set screws are tightened with screw drivers (Fig. 17.56). Figure 17.56 also shows examples of six standard point forms available for both socket and slotted set screws. The *cone point* is used where two parts must be joined in a permanent position relative to each other. The *cup point* is for applications that require rapid assembly. The *oval point* serves in applications similar to the cup point. The *flat point* is valued where fine adjustments are needed. Since the half-dog and full-dog points penetrate a mating hole drilled in the shaft, they have the greatest holding power.

A set screw is designated on a drawing by giving the nominal size, threads per inch, length, product name, point style, material, and protective coating (if needed), as in the

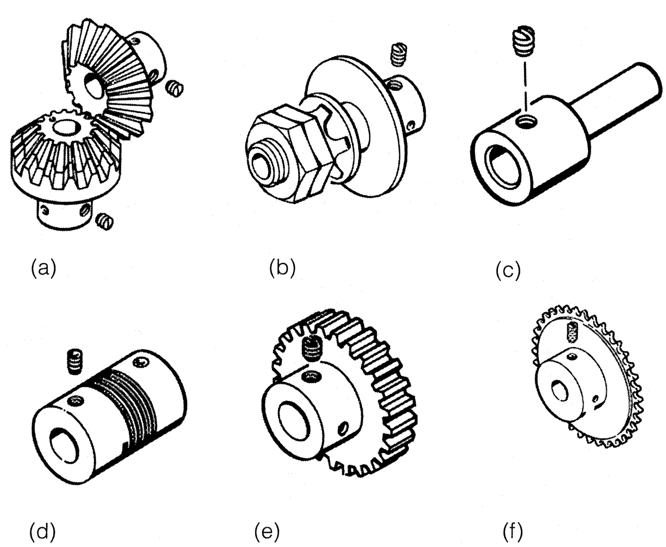


FIGURE 17.53 Set Screws in Use

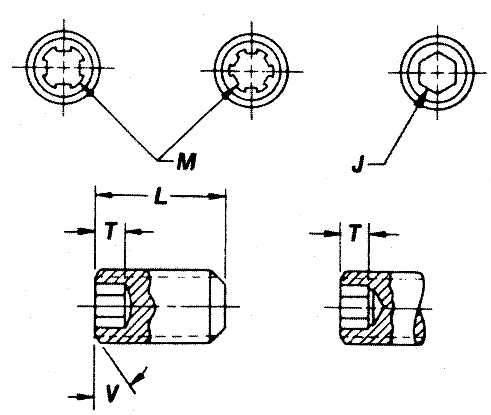
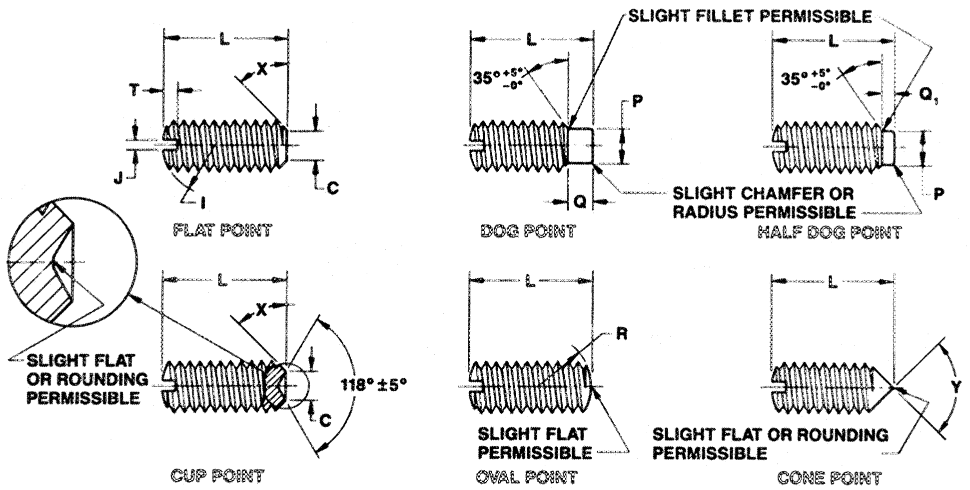


FIGURE 17.55 Socket-Head Set Screws

Nominal Size	J	M	T
.250	.125	.14	.13
.375	.188	.21	.18



ːIGURE 17.56 Slotted Headless Set Screws

Jominal Size	J	P	Q	Q1	T
.250	.04	.15	.13	.06	.06
.375	.06	.25	.19	.09	.09

ollowing examples:

$\frac{1}{4}$-20 × .375 HEXAGON SOCKET SET SCREW, CUP POINT, ALLOY STEEL

.250-20 × 50 SLOTTED HEADLESS SET SCREW, HALF DOG POINT, STEEL

'or metric:

B18.3 6M-10 × 1.5 CUP POINT SOCKET SET SCREW, ZINC PLATED

17.14 NUTS

1any types of nuts are available to satisfy specific design and ınctional requirements. Lock nuts, swivel nuts, hex uts,flange nuts, coupling nuts, square nuts, slotted nuts, nd jam nuts are just a few of the types used in industry. 1ost nuts are either hex-head or square-head varieties. Nuts re identified by the size of bolt they fit, not by their outside imensions.

Flange nuts incorporate a washer into the nut that ıcreases the bearing area of the nut. **Hexagon nuts** are vailable as unfinished, plain, slotted, regular, heavy, and ım types. Semifinished hex nuts are available in plain, otted, jam, thick plain, thick slotted, and castle varieties. emifinished nuts have one side machined on the bearing de of the nut. Heavy nuts are .125 inches wider across the ats on the hexagon. **Slotted nuts** (Fig. 17.57) have slots for se with cotter pins, which prevent the nut from coming off r untightening. Regular hex nuts (Fig. 17.58) are thinner ıan their size designations. A $\frac{1}{2}$ in. regular hex nut is ctually $\frac{7}{16}$ in. thick, and a $\frac{1}{2}$ in. heavy hex nut is $\frac{31}{64}$ in. thick. Metric nuts are also thinner than their designated size. An M6 × 1 metric hex nut, Style 2, is 5.70 mm thick. There are two types of metric nuts, Style 1 and Style 2.

The nominal size, threads per inch, product name, material, and protective finish are given to designate a hex nut on a drawing, as in the following examples:

$\frac{1}{2}$ - 13 HEX NUT, STEEL, ZINC PLATED

750-20 HEX NUT, SAE J995 GRADE 5, CORROSION RESISTANT STEEL

For metric:

HEX NUT, STYLE 2, M20 × 2.5, ASTM A563, CLASS 9, ZINC PLATED

HEAVY HEX NUT, M30 × 3.5, ASTM A563M, CLASS 105, HOT DIP GALVANIZED

Jam nuts are thin hex nuts and are used where height is restricted, or as a means of locking the working nut, if assembled as in Figure 17.59.

Jam nuts are designated in the same way as hex nuts, for example:

.500-16 HEX JAM NUT, STEEL, ZINC PLATED

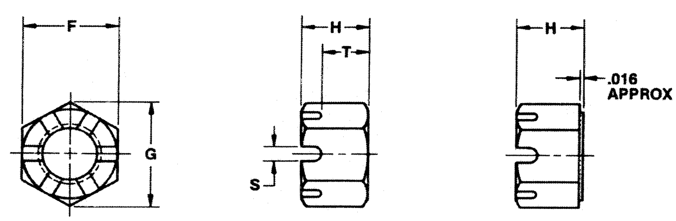


FIGURE 17.57 Hex Slotted Nuts

Nominal Size	F	G	H	S
.500	.75	.86	.56	.18
1.000	1.50	1.72	1.018	.30

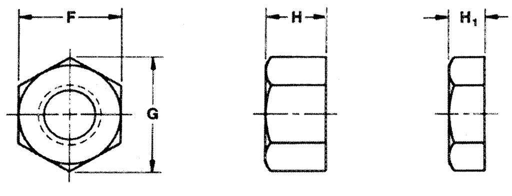


FIGURE 17.58 Hex Flat and Jam Nuts

Nominal Size	F	G	H	H1
.500	.75	.86	.43	.31
.750	1.12	1.29	.66	.44

For metric:

HEX JAM NUT, M10 × 1.5, ASTM A563M CLASS 04 ZINC PLATED

Square nuts, because they must be installed with an open-ended wrench and not a socket wrench, are less common. Square nuts are designated on drawings in the same way as hex nuts, for instance:

1.000-8 SQUARE NUT, STEEL

17.15 STANDARD BOLT, NUT, AND SCREW REPRESENTATION

Bolts, screws, and nuts should be drawn with the aid of a template. When a template is not available, use the fastener's dimensions for drawing the part. A simplified method is also acceptable (Fig. 17.60). These dimensions are acceptable when constructing bolts and screws. The most important dimensions on fasteners are their diameter and length, which must be constructed accurately because they affect clearances.

Figure 17.60 shows some approximate dimensions that can be used to draw fasteners. Although they do not correspond exactly to the fastener's actual dimensions, it is standard practice to simplify the constructions. In this figure, *the basic sizes of each part of a fastener are given relative to the diameter dimension.* Each dimension is a fraction of the diameter. Chamfered endpoints are normally drawn at 45°. When rendering the end view of a slotted fastener, the slots are drawn at 45°, not at 90° or 180°. The head of hex-head bolts and nuts is drawn so that three surfaces are visible from an elevation view. The depth of the hex on a hex socket-head cap screw is not drawn. Figure 17.61 shows three steps in the drawing of a hex-head bolt and nut. Figure 17.62 shows the dimensions for drawing a square-head bolt.

17.16 WASHERS

Washers are used in conjunction with threaded fasteners. The three basic types of washers are *plain, spring lock,* and *tooth lock.* Plain washers spread the bearing area of the fastener head or nut and are normally used with soft metals. Spring washers maintain tension on the nut or bolt head, and tooth-lock washers have teeth that dig into the fastener and the part to prevent the fastener from loosening. **Plain washers** are flat and ring shaped (Fig. 17.63).

Washers are designated on drawings by providing the product name and type, size (ID), material, and finish, as in the following:

TYPE A PLAIN WASHER, $1\frac{1}{2}$ STEEL, CADMIUM PLATED

TYPE B PLAIN WASHER, NO. 12, STEEL

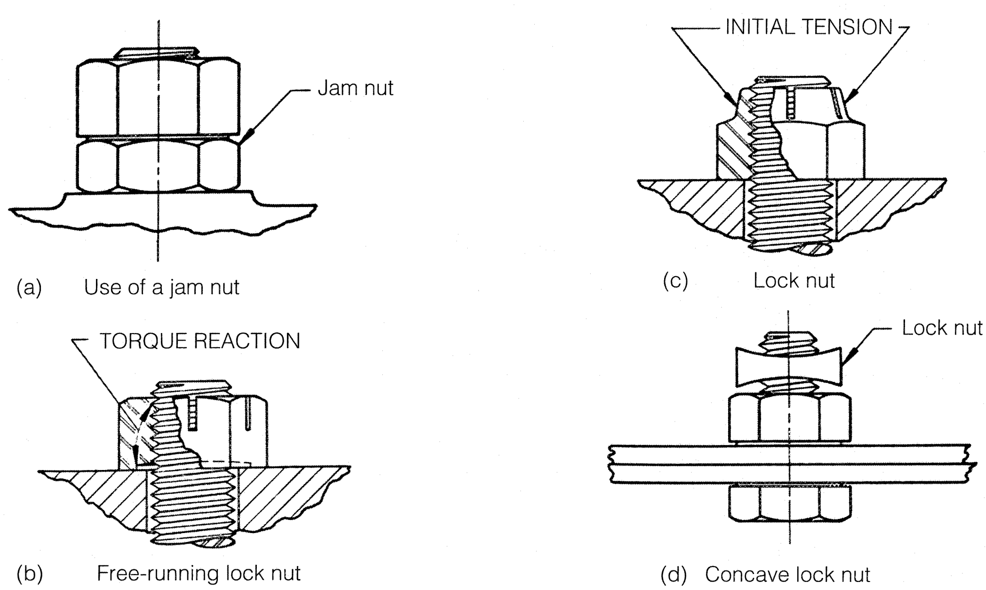
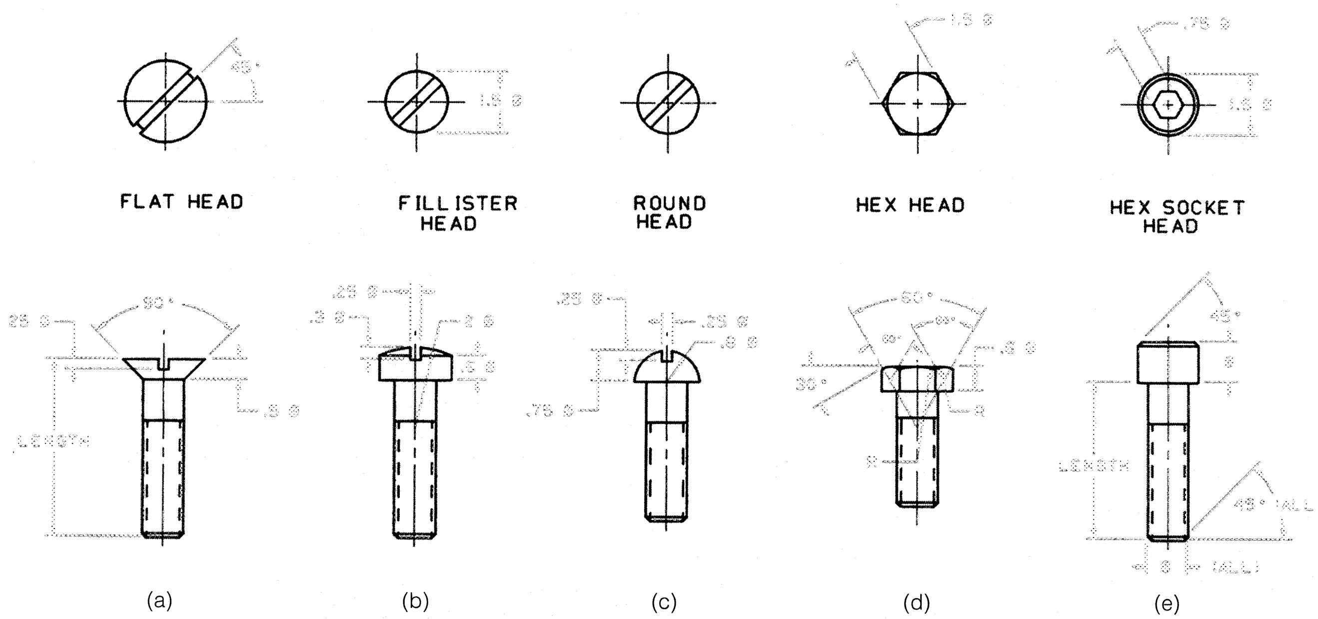


FIGURE 17.59 Lock and Jam Nut Applications

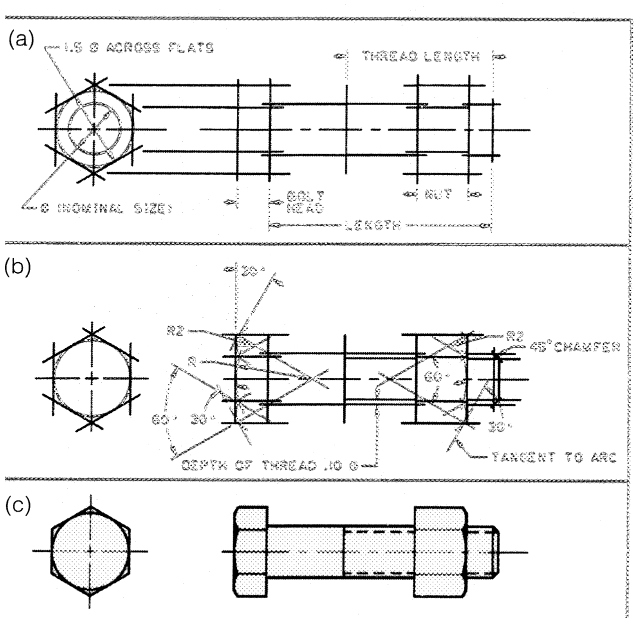


IGURE 17.60 Approximate Sizes for Drawing Screws

or metric:

PLAIN WASHER, 6MM, NARROW, SOFT, STEEL, ZINC PLATED

Spring-lock washers are split on one side and are helical ı shape. They have the dual function of acting as a spring ıke-up, to compensate for developed looseness and a loss of :nsion between component parts of an assembly, and as a ardened thrust bearing, to aid in assembly and disassembly f bolted fastenings. Lock washer (Fig. 17.64) sizes are selected by the nominal bolt or screw sizes. Figure 17.65 shows two common types of **tooth-lock washers:** Type A and Type B. Both are internal–external types.



GURE 17.61 Drawing a Hex Bolt and Nut Without a mplate

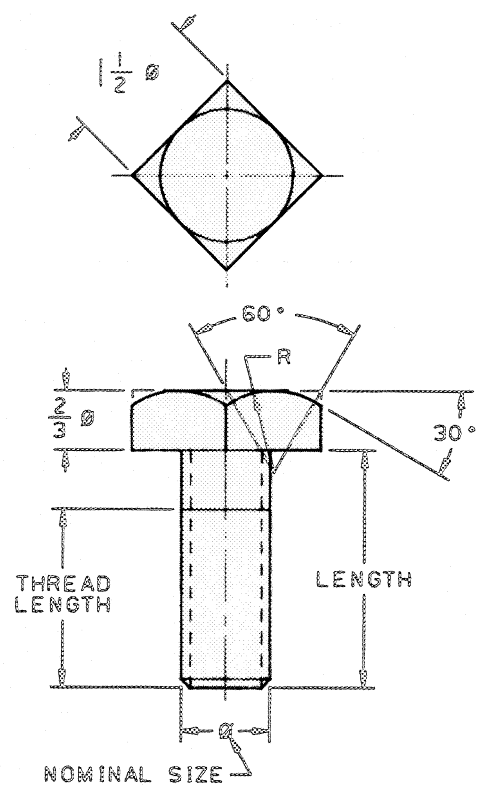


FIGURE 17.62 Drawing a Square-Head Bolt Without a Template

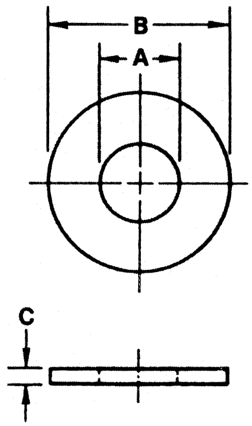


FIGURE 17.63 Plain Washers

Nominal Size	A	B	C
.500	.531	1.06	.09
1.000	1.062	2.50	.16

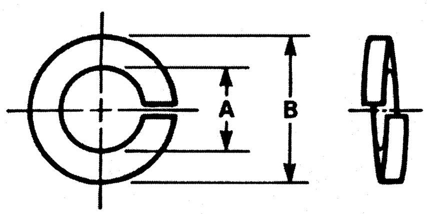


FIGURE 17.64 Spring-Lock Washers

Nominal Size	A	B	Width
.500	.518	.87	.125
.625	.65	1.07	.156

Designate lock washers on drawings as in the following examples:

HELICAL SPRING LOCK WASHER, .125 REGULAR, CORROSION RESISTANT STEEL, CADMIUM PLATED

HELICAL SPRING LOCK WASHER, $\frac{3}{8}$ EXTRA DUTY, STEEL, PHOSPHATE COATED

INTERNAL-EXTERNAL TOOTH LOCK WASHER, NO. 10 (.760 O.D.), TYPE A, STEEL, CADMIUM PLATED

EXTERNAL TOOTH LOCK WASHER, .625, TYPE B, STEEL, PHOSPHATE COATED

For metric:

4MM INTERNAL TOOTH, TYPE A

You May Complete Exercises 17.5 Through 17.8 at This Time

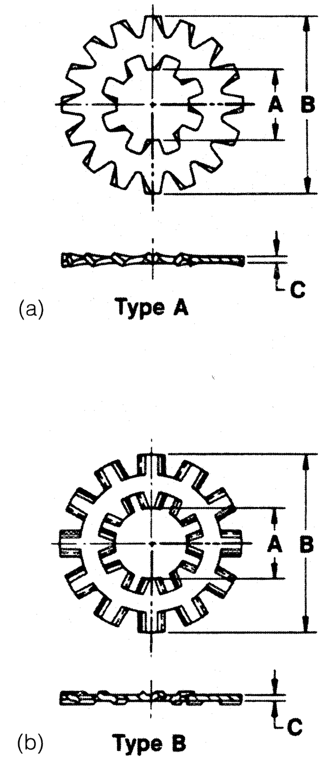


FIGURE 17.65 Tooth-Lock Washers

Nominal Size	A	B	C
#10 (.190)	.20	.76	.04
.500	.53	1.41	.06

17.17 MACHINE PINS

Standard machine pins are used throughout industry wherever there is a need for the assembly and alignment of mating parts, and for attaching gears, cams, collars, pulleys, sprockets, and other mechanical parts to shafts. Three types of pins are shown securing a gear to a shaft in Figure 17.66: (a) a straight pin, (b) a taper pin, and (c) a spring pin. Most of the pin types have metric-sized standard equivalents.

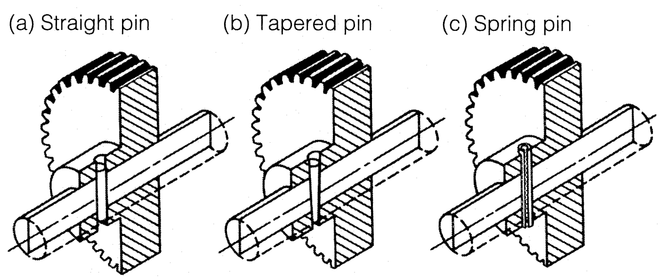


FIGURE 17.66 Pinning Applications

Applying Parametric Design . . .

STANDARD PART FAMILIES AND COSMETIC FASTENER THREADS

In parametric design, **threads** are a cosmetic feature representing the diameter of a thread and having the capability of imbedding information into the feature (see Fig. A). It is displayed in a unique color (magenta), and can be displayed, blanked, or suppressed as required when plotting. Threads are created with the default tolerance setting of limits. The socket-head cap shoulder screw shown in Figure A has a threaded end

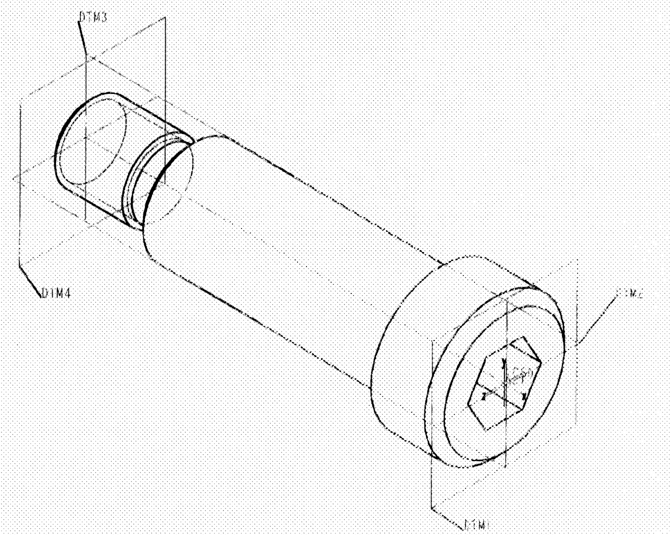


FIGURE C Datum, Planes, Datum Axes, Coordinate System, and Cosmetic Threads Displayed

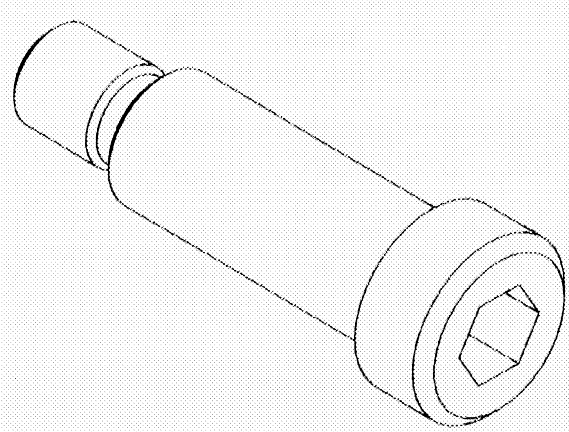


FIGURE A Socket-Head Cap Shoulder Screw

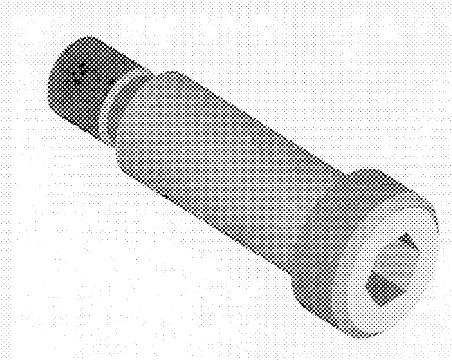


FIGURE D Shaded Image of Shoulder Screw

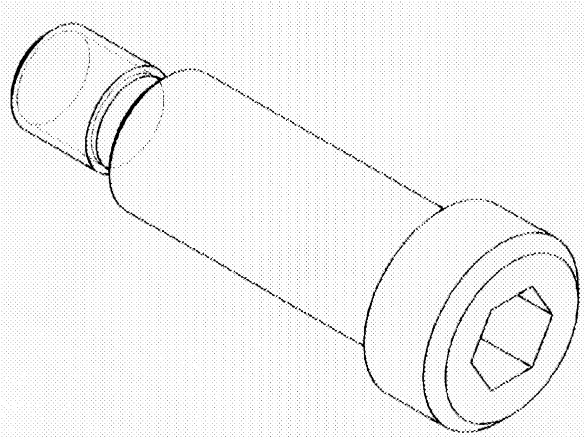


FIGURE B Cosmetic Threads Displayed on Model

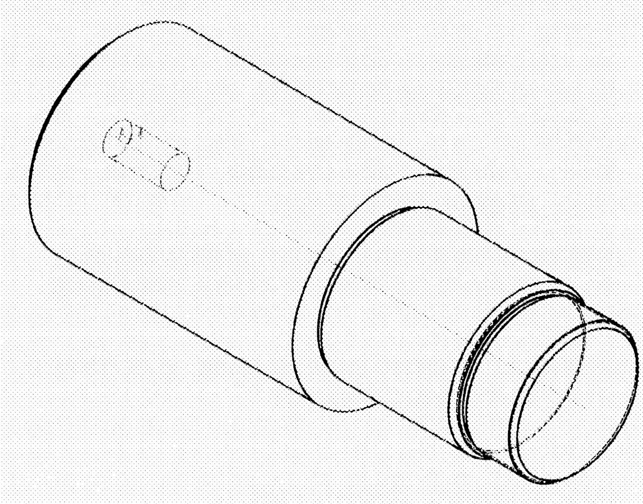


FIGURE E Shaft with External and Internal Cosmetic Threads in Figure B. The cosmetic threads are displayed with dashed lines representing the threads' external thread root diameter. In Figure C, the datum planes, datum lines, coordinate system, and cosmetic threads are displayed (the hidden lines are now shown). A shaded image of the screw (Fig. D) completes the sequence.

Cosmetic threads can be external or internal, blind or through. In the shaft example, one end has external blind threads and the opposite end has internal blind threads (Fig. E). The shaft was modeled by creating a revolved protrusion (Fig. F). The geometry of the revolved feature is shown in section and pictorially (Fig. G). After the protrusion (base feature) was created, the hole, chamfers, and slot (relief) were modeled.

The cosmetic threads for the external shaft end (Figs. H and I) and the internal hole threads (Fig. J) were added last. They are created by specifying the minor or major diameter (for external and internal threads, respectively), starting plane (here a datum plane was used—DTM4), and thread length or ending edge. A half-section-removed view shows the blind hole and the cosmetic threads. Note that the cosmetic feature is not cut (Fig. K).

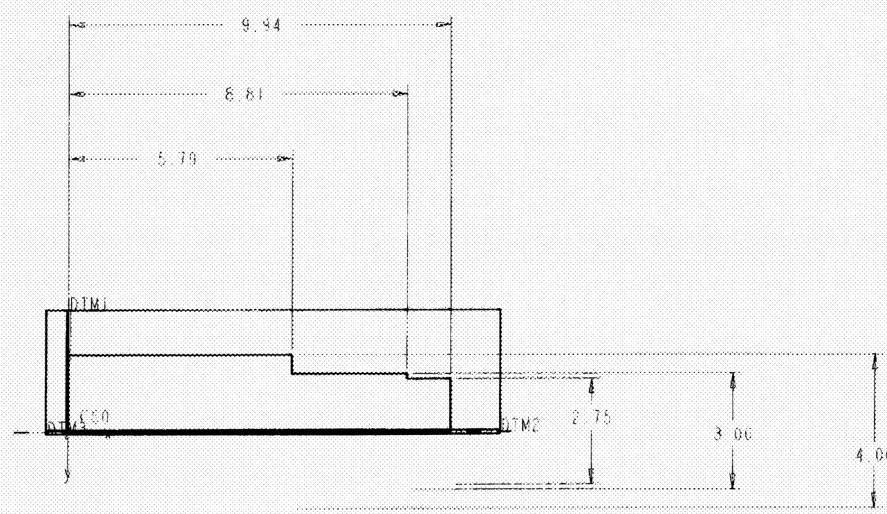


FIGURE F Sketch for Revolved Protrusion

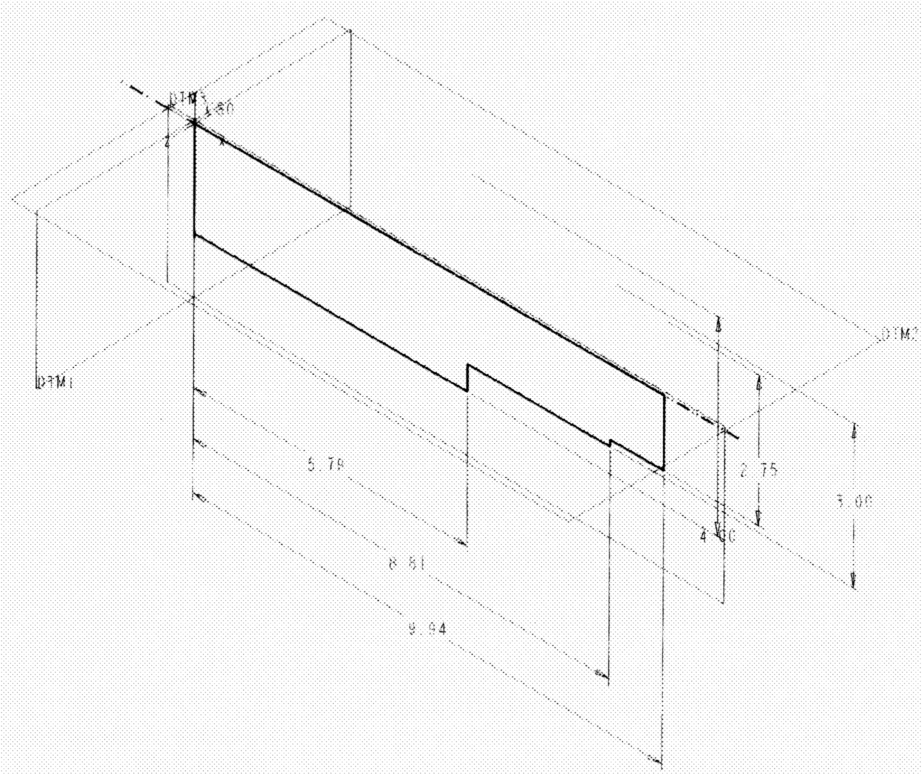


FIGURE G Pictorial View of Sketch

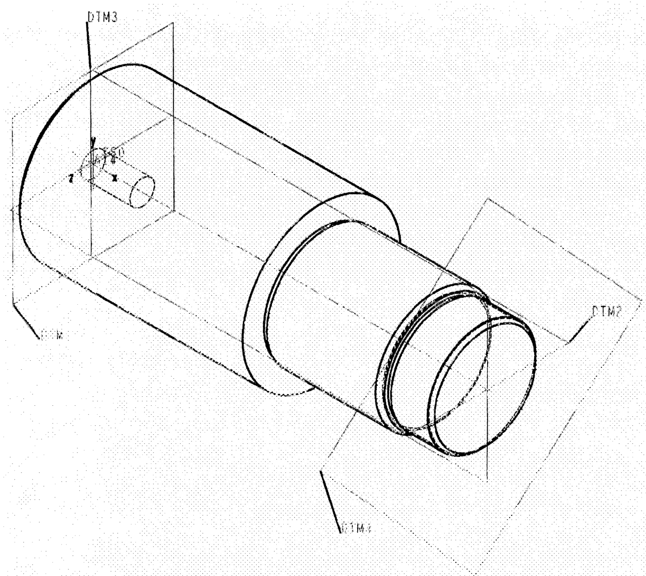


FIGURE H Datum Planes Displayed on Shaft

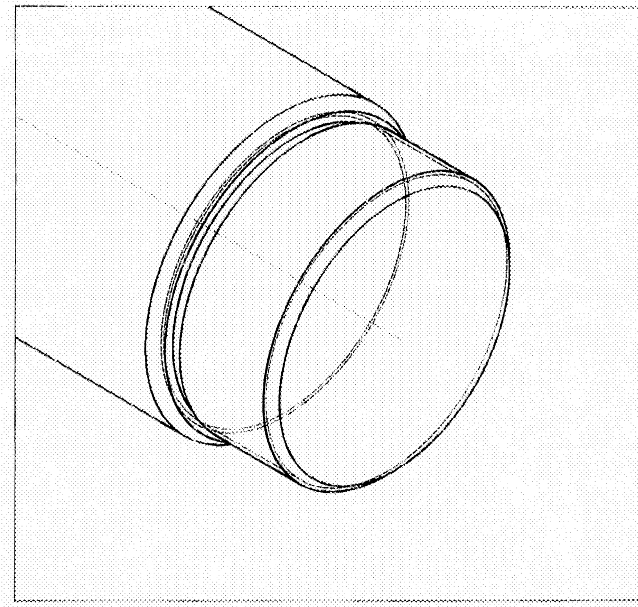


FIGURE I Close-Up View of External Threads

A thread has a set of supported parameters that can be defined either at its creation or later, when the thread is added. The following parameters can be defined for a thread:

Parameter Description	Parameter Name	Parameter Value
Thread major diameter	MAJOR_DIAMETER	Number
Threads per inch (pitch)	THREADS_PER_INCH	Number
Thread form	THREAD_FORM	String
Thread class	CLASS	Number
Thread placement (A—external, B—internal)	PLACEMENT	Character
Thread is metric	METRIC	TRUE/FALSE

Commands for Creating a Thread Feature

1. Choose **Create, Cosmetic, Thread.**
2. Specify whether the thread will be external or internal by selecting from the THREADS menu.
3. Specify the type of the thread: **blind** or **thru.**
4. Select from the FEAT PARAM menu:
   - **Mod Params** Modify thread parameters in Pro/TABLE environment.
   - **Show** Display a set of thread parameters in Info Window.
5. When finished, choose **Done/Return** to continue creating the thread.
6. For a blind thread, enter the thread length.
7. Enter the thread major/minor diameter.
8. Select a thread surface.
9. Select a thread starting plane.
10. From the MODIF PREV menu, select one of the options:
    - **Prev Prompt** Reselect references for the previous prompt. When finished, choose **Done**.
    - **Done** Accept previous specifications and conclude thread creation.

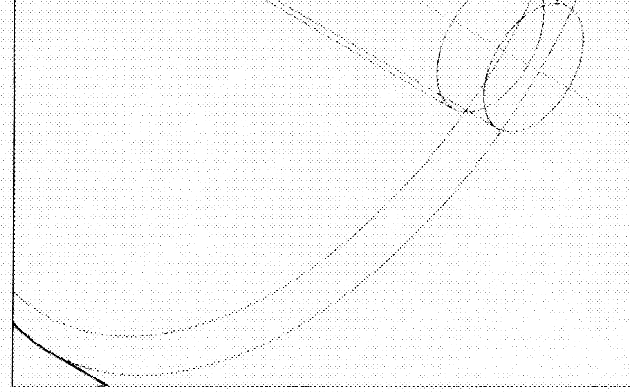


FIGURE J Close-Up View of Internal Threads and Blind Hole

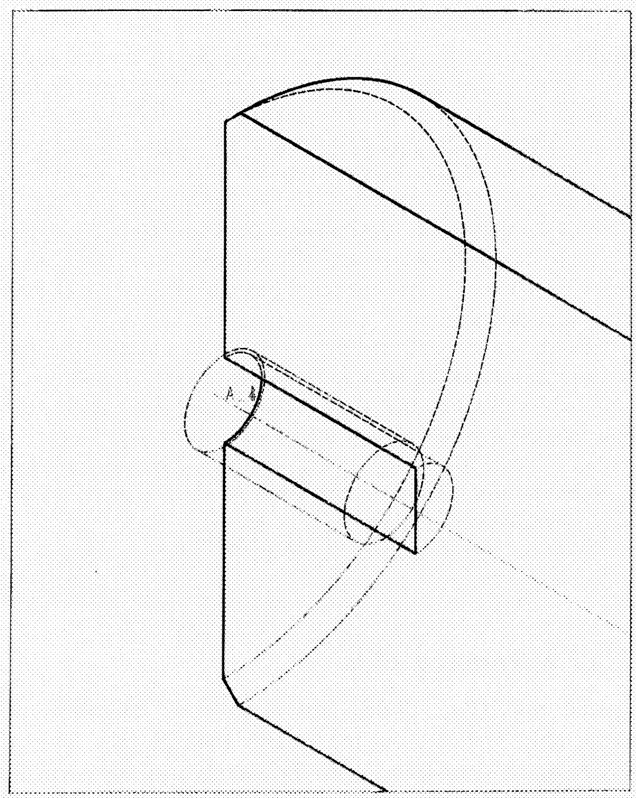


FIGURE K **Cutaway of Blind Hole and Cosmetic Threads**

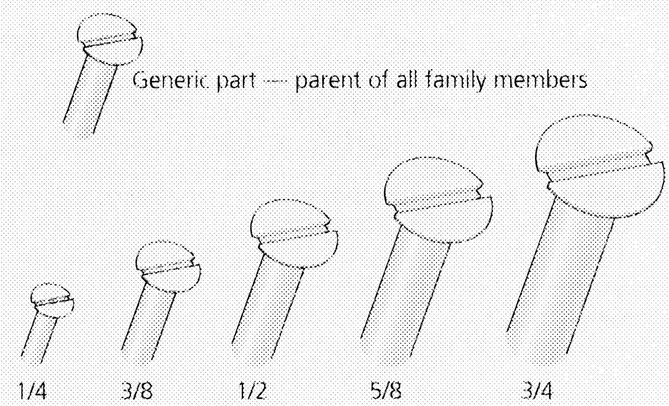


FIGURE L **Family of Screws.**

Thread parameters can be manipulated as are other user-defined parameters. They can be added, modified, deleted, or displayed via options in the MODEL PARAMS menu. The following information was extracted with the **Info** command:

Part—Feature—Info—Feature Info— (select the external thread)

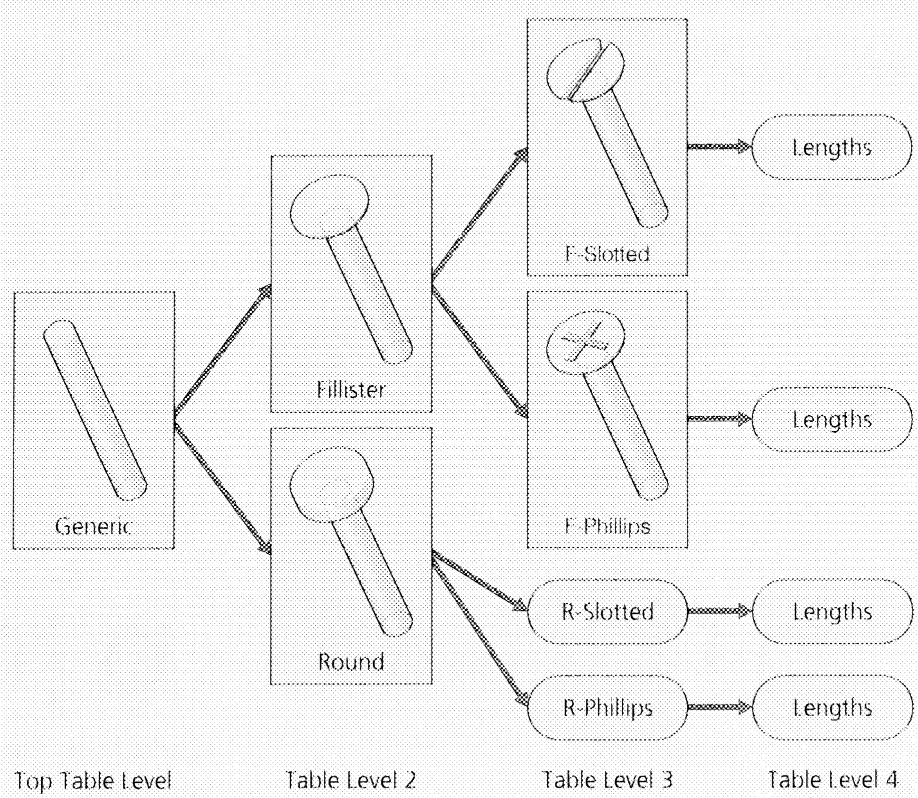


FIGURE M **Generic Screw and Family Tree**

(Continues)

Information appears in a window:

PART NAME = ROD
FEATURE NUMBER 13
INTERNAL FEATURE ID 246
PARENTS = 9(#5) 224(#12)
TYPE = THREAD
FORM = 360 DEG. REVOLVED
SECTION NAME = S2D0003
OPEN SECTION
FEATURES DIMENSIONS:
d28(d11) = 1.25
d29(d12) = .63 Dia.

MAJOR_DIAMETER	.625
THREADS_PER_INCH	11
FORM	UNC
CLASS	2A

Like the standardized parts you purchase from a catalog, **families of parts** (also called "table-driven parts") are collections of similar parts that are available in different sizes or have slightly different detailing features. For example, screws come in all different sizes, but they all perform the same function and look somewhat alike. Thus, it is convenient to think of them as a family of parts (Fig. L). Likewise, we can create a family of assemblies and features. These all have the same attributes, where a "generic" object is created and all members of the family look somewhat like the generic but are of different sizes or use slightly different components.

Table-driven families provide a very simple and compact way of creating and storing large numbers of objects. In additional, family tables promote the use of standardized components and allow you to represent your actual part inventory. Moreover, families facilitate interchangeability of parts and subassemblies in an assembly; instances from the same family are automatically interchangeable with each other (Fig. M).

Eight common types of pins are found in industry and are recognized as American National standards:

- Straight
- Tapered
- Spring
- Grooved
- Dowel
- Cotter
- Clevis
- Push–pull

Pins can be either quick-release or semipermanent. Quick-release pins include the cotter, clevis, push–pull, and positive locking varieties. Dowel, tapered, straight, grooved, and spring pins are semipermanent types because they all require some form of pressure to insert.

17.17.1 Straight Pins

Straight pins (Fig. 17.67) are somewhat difficult to align during assembly and must be a precise fit to make them secure.

To designate a pin on a drawing, the product name, nominal size, length, material, and finish (if required) are given:

PIN, CHAMFERED STRAIGHT, $\frac{5}{16}$ × 2, STEEL

17.17.2 Tapered Pins

Tapered pins (Fig. 17.68) add to ease of assembly and disassembly. They fall out more easily than dowels. Tapered pins come in sizes from $\frac{1}{16}$ to $1\frac{1}{2}$ inches and are normally steel. Tapered pins are called out by a number, from 0 (small diameter) to 14 (large diameter), and by their length requirement. The large end of a tapered pin is constant for a particular-size pin, but the small end changes according to the length. Tapered pins have a taper of $\frac{1}{4}$ in. per foot.

Step drilling or tapered reaming is required for tapered holes. The information contained Figure 17.69 should be provided on all taper details. Tapered pins are designated as in the following example:

PIN, TAPER (COMMERCIAL CLASS) NO. 2 × $1\frac{1}{4}$, STEEL

17.17.3 Spring Pins

Since the spring force retains the pin in the hole, a **spring pin** (rolled pin) reduces the possibility of falling out during operation. The hole for a spring pin is drilled slightly smaller

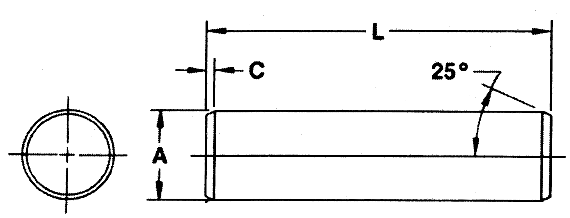


FIGURE 17.67 Straight Pins

Nominal Size	A	C
.250	.2500	.025
.375	.3750	.040

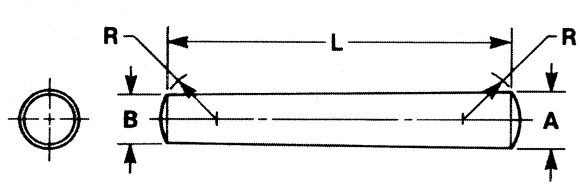


FIGURE 17.68 Tapered Pins

Nominal Size	A	R
#4 (.2500)	.2500	.26
#8 (.4920)	.4920	.50

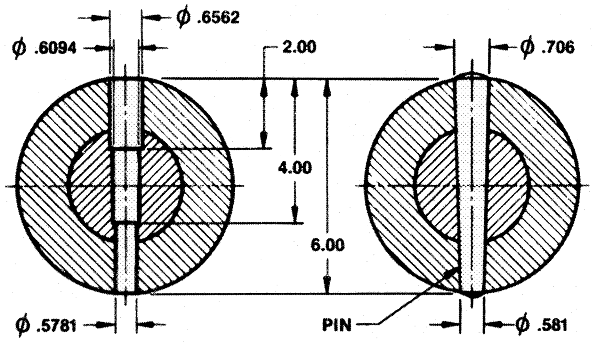


FIGURE 17.69 Dimensioning Tapered Pins

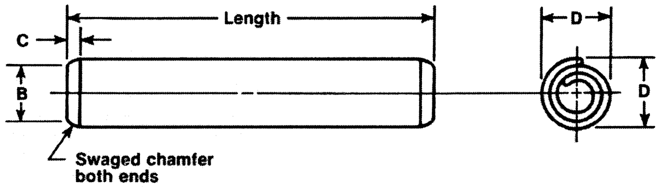


FIGURE 17.71 Metric Coiled Spring Pins

Nominal Size	B	C	D
10	9.75	2.5	10.80
20	19.6	4.5	21.10

than the pin. Spring pins are reusable and can be removed repeatedly without distortion or without losing their locking efficiency

Spring pins come in two basic styles. One type has a slot throughout its length (Fig. 17.70), and the other is shaped in the form of a coil (Fig. 17.71). Spring pins are designated on drawings as in the following examples:

PIN, COILED SPRING, $\frac{1}{2}$ × 2$\frac{1}{4}$, STANDARD DUTY, STEEL, ZINC PLATED

PIN, SLOTTED SPRING, .250 × .75, AISI 420 CORROSION RESISTANT STEEL

For metric:

PIN, COILED SPRING, 10 × 40, HEAVY DUTY, STAINLESS STEEL, PHOSPHATE COATED

PIN, SLOTTED SPRING, 20 × 60, STANDARD DUTY, CHROME-NICKEL AUSTENITIC STAINLESS STEEL, CADMIUM PLATED

17.17.4 Grooved Pins

Grooved pins (Fig. 17.72) are tapered or straight, with longitudinal grooves pressed into the body The pin will deform when pressed into the part. Because they hold securely even after repeated removal and reassembly, grooved pins are employed in situations where repeated disassembly is required. Grooved pins are designated as in the following example:

PIN, TYPE B GROOVED, $\frac{5}{16}$ × 2, CORROSION RESISTANT STEEL

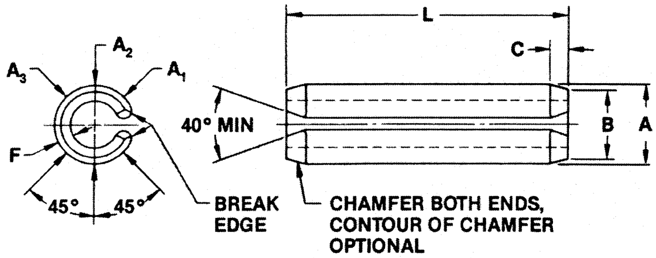


FIGURE 17.70 Slotted Spring Pins

Nominal Size	A	B	C
.375	.39	.36	.09
.500	.521	.48	.11

17.17.5 Dowel Pins

Dowel pins (Fig. 17.73) are heat-treated, precision-ground pins. Dowels align mating parts precisely or retain parts in a fixed position; they are not used as fasteners. Since the dowels are press-fit, holes for dowels are reamed and not drilled. The dowel is slightly larger than the hole and the dowel pin is forced ("press-fit") into the hole to ensure accurate alignment between mating parts. Dowels provide alignment and the screws serve to fasten. A general rule is to use dowels that are close to the same diameter as the screws. The dowel length should be 1$\frac{1}{2}$ to 2 times its diameter in each plate or part to be doweled. Dowel pins are designated as in the following examples:

PIN, HARDENED GROUND PRODUCTION DOWEL, .500 × 1.75, STEEL, PHOSPHATE COATED

PIN, UNHARDENED GROUND DOWEL, $\frac{3}{4}$ × 1$\frac{1}{2}$ STEEL

For metric:

PIN DOWEL, 16 × 70, STAINLESS STEEL

17.17.6 Clevis Pins and Cotter Pins

Clevis pins (Fig. 17.74) are used with cotter pins to retain parts on a shaft or to lock a nut and bolt. **Cotter pins** (Fig. 17.75) are used with clevis pins to retain parts on a shaft or to lock a slotted nut and bolt. Cotter pins are good where quick-and-easy assembly and disassembly are required. Clevis pins and cotter pins are designated as in the following examples:

PIN, CLEVIS, .438 × 1.19, STEEL, CADMIUM PLATED

PIN, CLEVIS, $\frac{1}{4}$ × 0.77, STEEL

PIN, COTTER, $\frac{1}{8}$ × 1$\frac{1}{2}$, EXTENDED PRONG TYPE, STEEL, ZINC PLATED

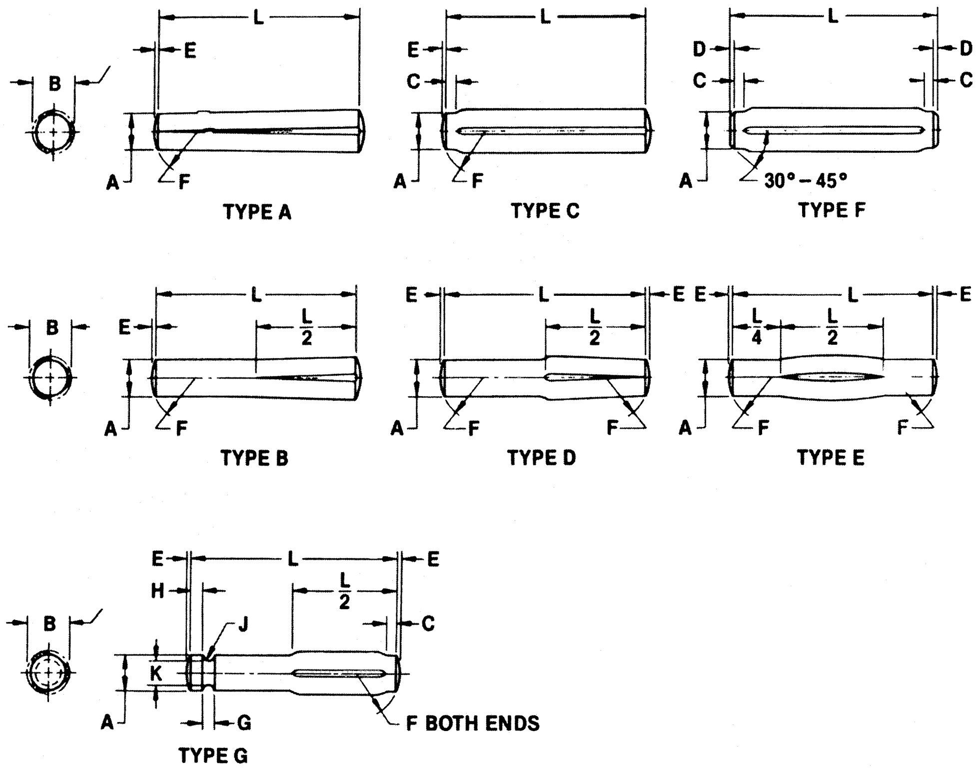


FIGURE 17.72 Grooved Pins

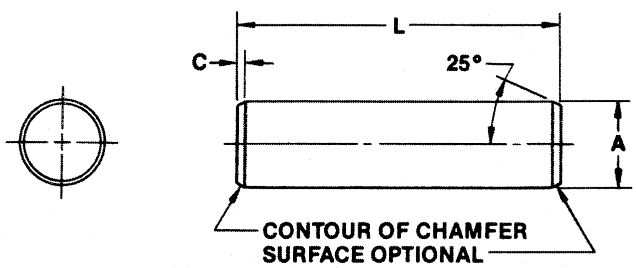


FIGURE 17.73 Dowel Pins

Nominal Size	A	C
.375	.371	.04
.500	.496	.04

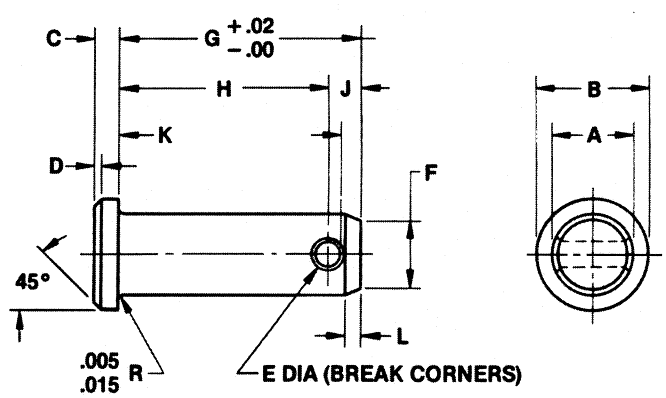


FIGURE 17.74 Clevis Pins

Nominal Size	A	B	C	D	F	G	H	J	L	Pin Size
.375	.37	.51	.13	.03	.33	1.06	.95	.12	.07	.093
.500	.49	.63	.16	.04	.44	1.36	1.22	.15	.08	1.250

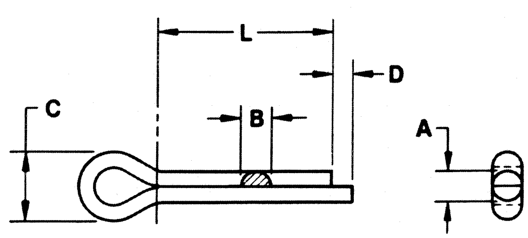


FIGURE 17.75 Cotter Pins

Nominal Size	A	B	C	D
.135	.12	.12	.25	.06
.188	.17	.17	.38	.09

17.18 RIVETS

Figure 17.76 shows four typical types of riveted joints: single-riveted lap, double-riveted lap, single-riveted butt, and double-riveted butt. The most common rivets are solid, tubular, split, and blind rivets. Solid rivets are good for assembling parts not to be taken apart.

Solid rivets are shown on drawings as in Figure 17.77. If plans, elevations, or sections show the conventional signs for the head of the shop rivets or field rivets, the corresponding lengthwise view of the rivet fastenings is normally omitted.

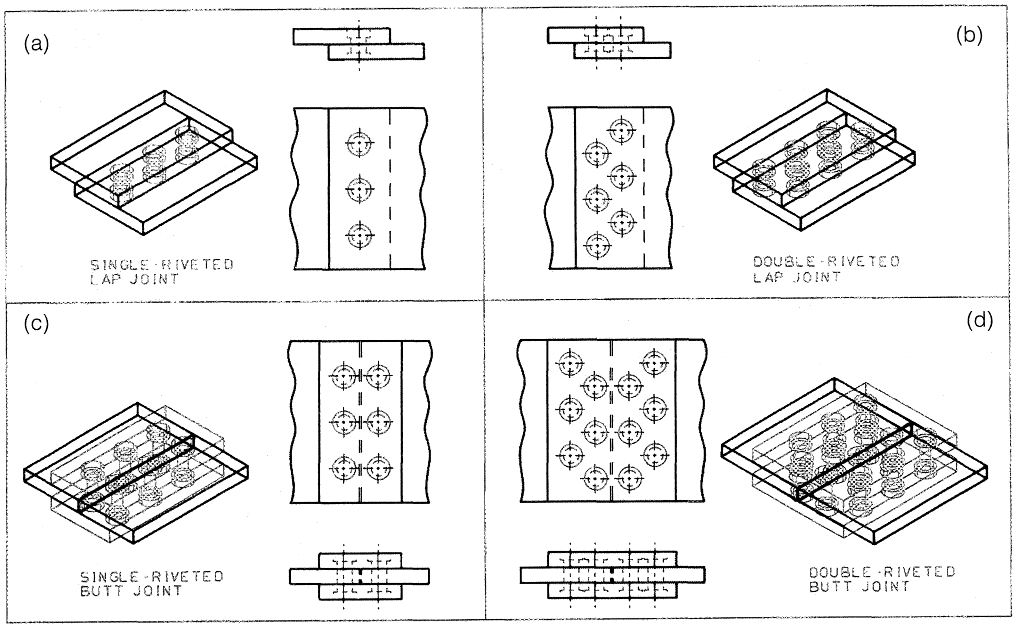


FIGURE 17.76
Riveted Joints

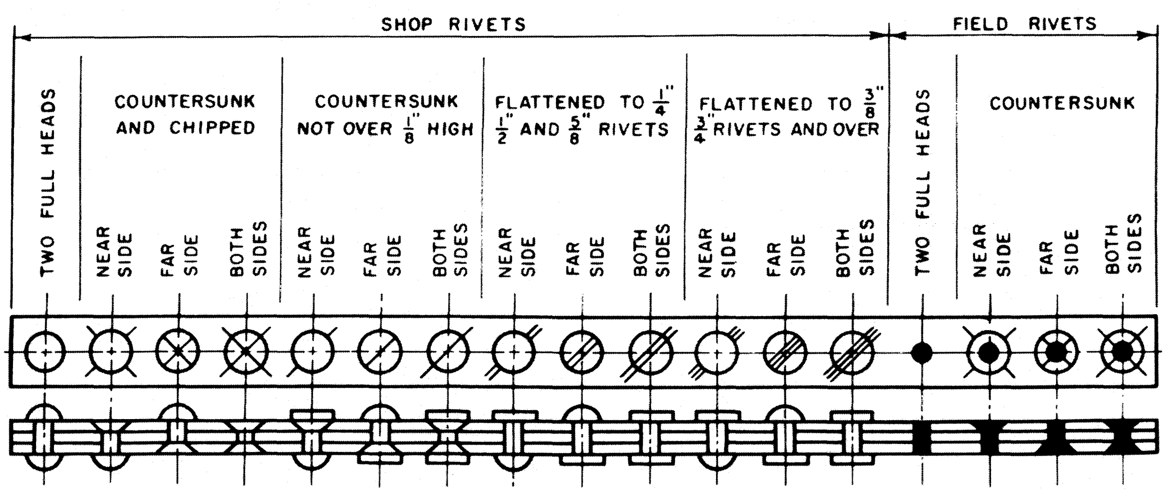


FIGURE 17.77 Drawing Conventions for Solid Rivets

Rivets are available in a variety of endpoints. The choice of head and endpoint is determined by the application. The hole size and type will be determined by the rivet choice. Figures 17.78 through 17.81 show four standard types of rivets.

Designate rivets on drawings as in the following examples:

.146 × .500 SEMI-TUBULAR, OVAL HEAD, STEEL, CADMIUM PLATED

$\frac{1}{4} \times 1\frac{1}{4}$ FLAT HEAD SMALL SOLID RIVET, STEEL, ZINC PLATED

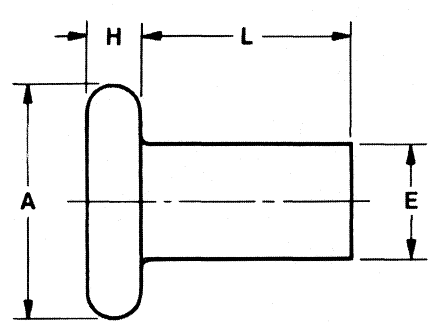


FIGURE 17.78 Flat-Head Rivets

Nominal Size	A	E	H
.125	.125	.25	.04
.250	.250	.50	.09

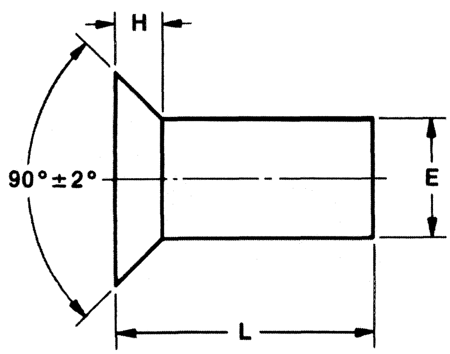


FIGURE 17.79 Flat-Countersunk-Head Rivets

Nominal Size	Head Dia.	E	H
.156	.29	.15	.06
.312	.58	.31	.13

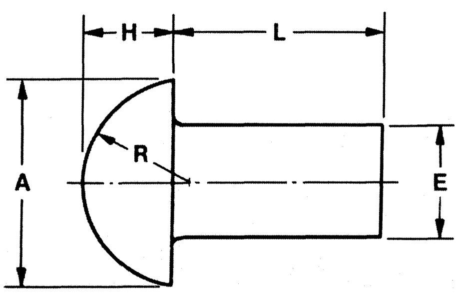


FIGURE 17.80 Button-Head Rivets

Nominal Size	A	E	H	R
.094	.18	.094	.07	.08
.281	.51	.281		

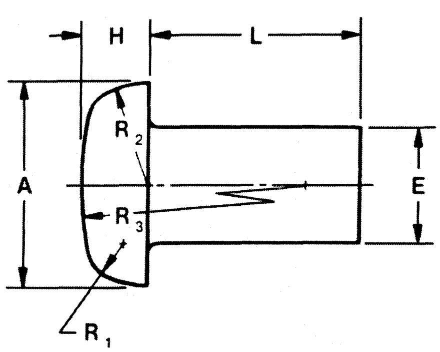


FIGURE 17.81 Pan-Head Rivets

Nominal Size	A	E	H	R1	R2	R3
.188	.33	.187	.11	.05	.15	.64
.312	.55	.312	.18	.09	.26	1.07

17.19 RETAINING RINGS

Retaining rings are semipermanent fasteners found on many assemblies. They are used as shoulders that can be located along a shaft (or pin) or in a recessed hole to keep the components of an assembly properly positioned, as shown in Figure 17.82. Many different styles of retaining rings are available (Fig. 17.83).

Retaining rings can easily be installed in machined grooves, internally in housings or externally on shafts or pins. Some styles of retaining rings require no grooves but have a self-locking spring-type action. The two types of retaining rings are internal and external.

Radially assembled rings are designed to be snapped directly onto a shaft. Axially assembled rings require special tools to expand the ring (for external rings) or to contract the ring (for internal rings) to slide over a shaft (external) or slip into a grooved housing (internal) while installing.

17.20 COLLARS

A **collar** (Fig. 17.84) is a ring installed over a shaft and positioned adjacent to a machine element such as a pulley, a gear, or a sprocket. A collar is held in position in most cases by a set screw. The advantage of a collar is that axial location can be established virtually anywhere along the shaft to allow adjustment of the position at the time of assembly.

Typical Collar Applications

- Spacer on a machine shaft
- Thrust collar on pillow block
- Hub or plate on a sprocket
- Adjustment for torsion spring
- Clutch part
- Locating a gear or cam on a shaft.

17.21 KEYS AND KEYSEATS

A key is a machine component used to assemble a shaft and the hub of a power-transmitting element (gear, sprocket, pulley) to transmit torque. Keys are removable to facilitate assembly and disassembly of the shaft and components. A key is installed in an axial groove machined into the shaft, called a **keyseat** (Fig. 17.85). A similar groove in the hub of the power-transmitting element is usually called a keyway but is more properly called a keyseat.

Square keys (the width and the height are equal) are preferred on shaft sizes up to 6.50 inches in diameter. Square keys (Fig. 17.86) are sunk halfway into the shaft and extend halfway into the hub of the assembly. Above 6.50 inches in diameter, rectangular keys are recommended. The **rectangular key** (flat key) is recommended for larger shafts

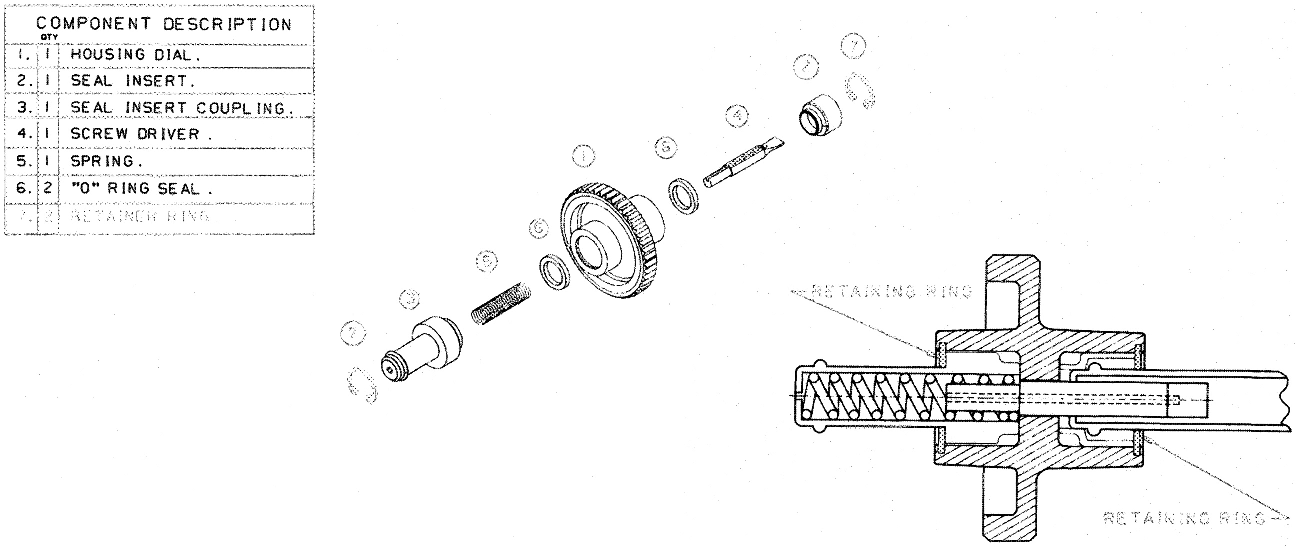


FIGURE 17.82 Internal Retaining Rings Used on an Assembly

and is used for smaller shafts where the shorter height is acceptable for the design requirements.

The **taper key** (Fig. 17.86) permits the key to be inserted from the end of the shaft after the hub is in position. If the opposite end of the key is not accessible to be driven out, the gib-head key provides the means for extracting the key

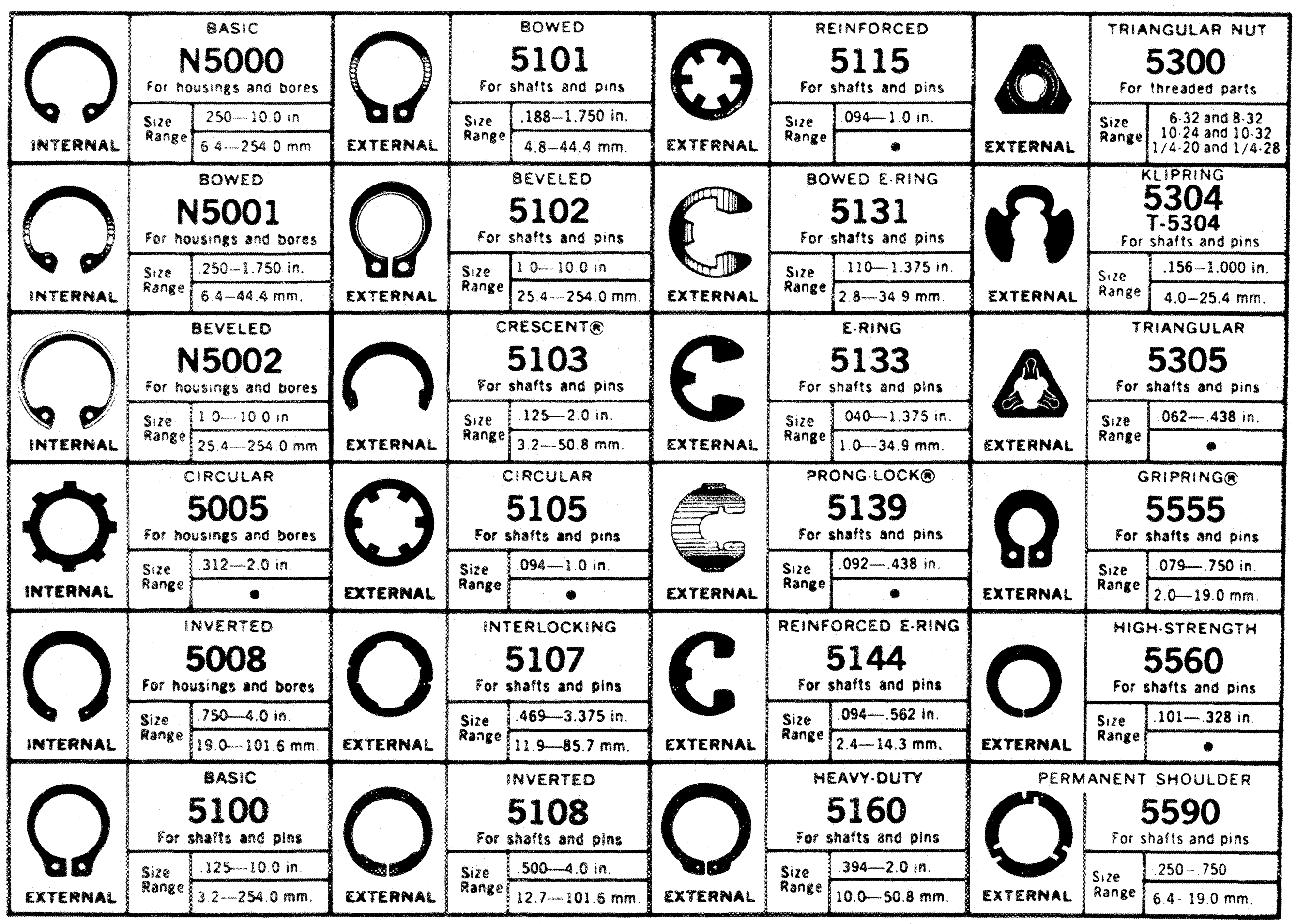


FIGURE 17.83 Retaining Ring Styles

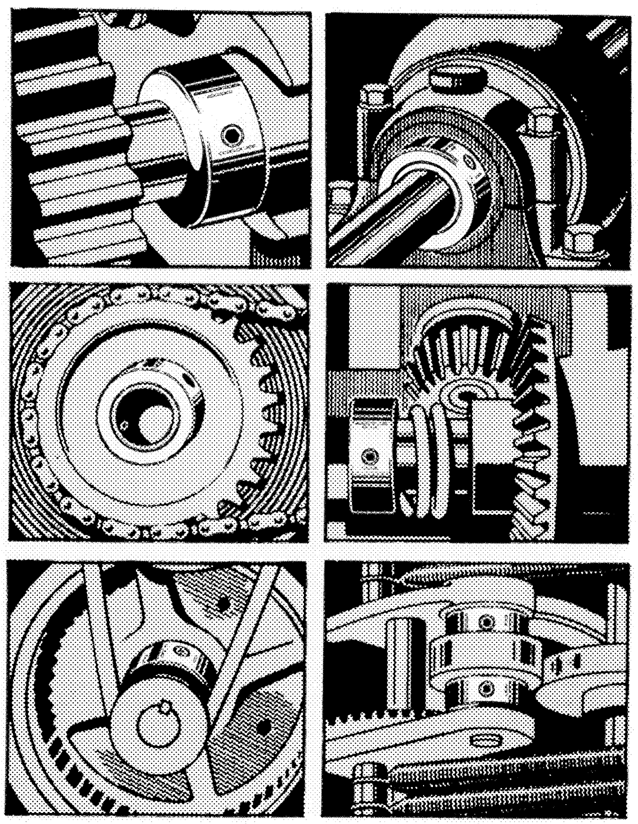


FIGURE 17.84 Coupling Applications

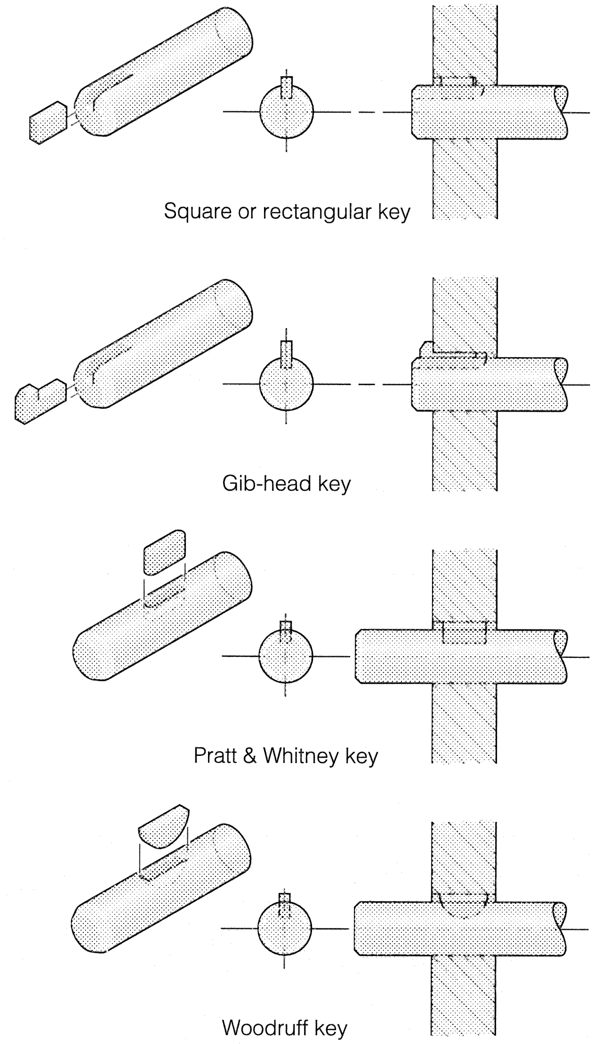


FIGURE 17.85 Types of Keys

On both the plain-taper and the gib-head key, the taper is 8 in. per foot. The cross-sectional dimensions of the key, *W* and *H*, are the same as for parallel keys, with the height *H* measured at the position specified in Figure 17.86.

17.21.1 Key Size Versus Shaft Diameter

For a stepped shaft (one that has multiple diameters), the size of a key is determined by the diameter of the shaft at the

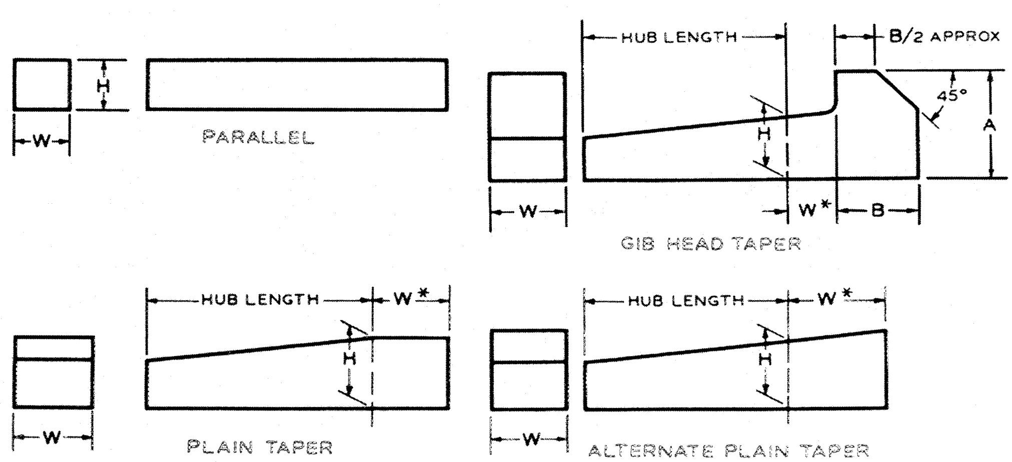


FIGURE 17.86 Keys

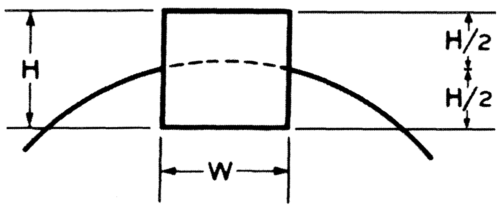


FIGURE 17.87 Key Sizes for Square Keys

Nominal Shaft Dia.	H	W
.875.1.25	.25	.25
1.750.2.25	.50	.50

point of location of the key, regardless of the number of different diameters on the shaft. Sizes and dimensions for keys are found in tables in the *Machinery's Handbook* and in ANSI B17.1. Figure 17.87 shows the preferred dimensions for parallel keys as a function of the shaft diameter. The width is normally one-fourth of the diameter of the shaft.

17.21.2 Woodruff Keys

Woodruff keys, which are almost in the shape of a half circle, are used where relatively light loads are transmitted. One advantage of Woodruff keys is that they cannot change their axial location on a shaft, because they are retained in a pocket. Woodruff keys can be either the full-radius type (Figs. 17.88 and 17.89) or the flat-bottom type.

17.21.3 Design of Keys and Keyseats

The key and keyseat are designed after the shaft diameter is determined. Then, with the shaft diameter as a guide, the size of the key is selected from ANSI B17.1 or ANSI B17.2. The only remaining variables are the length of the key and its material. One of these can be specified, and the requirements for the other can then be computed. Typically, the length of a key is specified to be the hub length of the element in which it is installed, to provide for good alignment and stable operation. Figure 17.90 shows keyseat dimensions for Woodruff keys. Keys are designed to fail *before* the shaft or hub fails, to lower the cost for replacement.

For rectangular and square keys, keyseats in the shaft and the hub are designed so that exactly one-half of the height of the key is in the shaft keyseat and the other half is in the hub keyseat. Figure 17.91 shows the resulting geometry. The distance *Y* is the radial distance from the theoretical top of the shaft, before the keyseat is machined, to the top edge of the finished keyseat, to produce a keyseat depth of exactly *H*/2. To assist in machining and inspecting the shaft or the hub, the dimensions *S* and *T* can be computed and shown on the part drawings. The equations are given in Figure 17.91. Tabulated values of *Y, S,* and *T* (Fig. 17.92) are available in the standard and in the *Machinery's Handbook.* Standard key sizes are also listed in Appendix C.9.

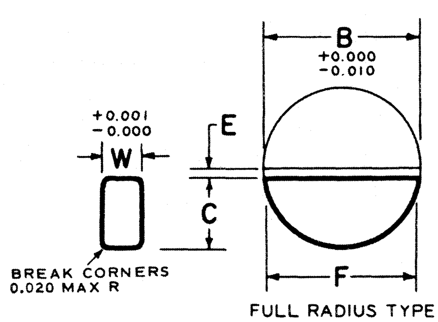


FIGURE 17.88 Full-Radius Woodruff Keys

Key #	W × B	C	D	E	F
403	.125 × .375	.17	.17	1/64	.37
806	.250 × .7501	.31	.30	1/16	.74

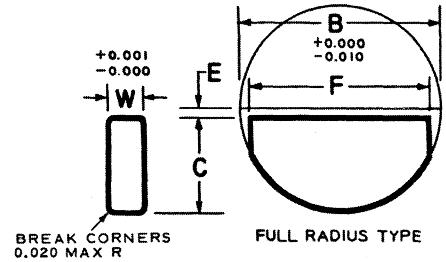


FIGURE 17.89 Woodruff Keys

Key #	W × B	C	D	E	F
817.1	.250 × 2.125	.40	.39	21/32	1.38
1217.1	.375 × 2.125	.40	.29	21/32	1.38

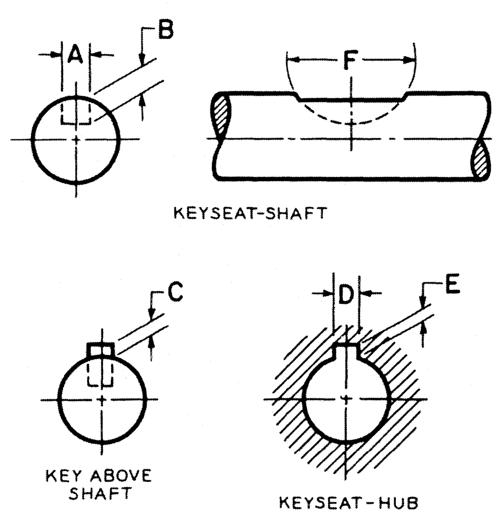


FIGURE 17.90 Keyseat Dimensions

Key #	Nominal Size	A	B	C	D	E	F
403	.125 × .375	.12	.10	.06	.12	.06	.375
806	.250 × .750	.24	.18	.12	.25	.13	.750

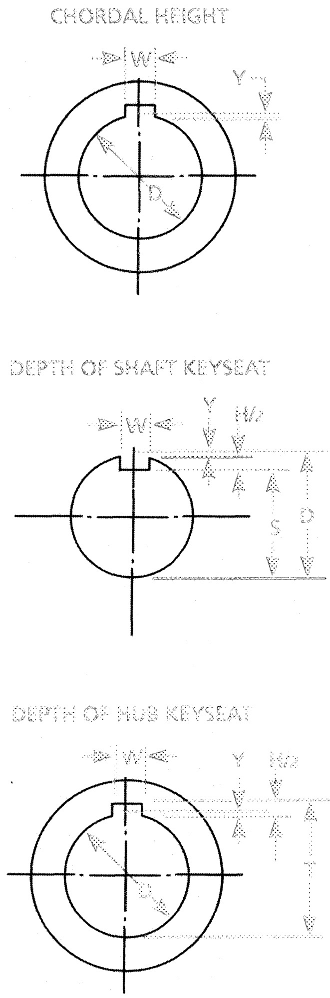


FIGURE 17.91 Calculating Keyseats

The chordal height *Y* is determined from the following formula:

$$Y = \frac{D - \sqrt{D^2 - W^2}}{2}$$

The distance from the bottom of the shaft keyseat to the opposite side of the shaft is specified by dimension *S*. The following formula may be used for calculating this dimension:

$$S = D - Y - \frac{H}{2} = \frac{D - H + \sqrt{D^2 - W^2}}{2}$$

The distance from the bottom of the hub keyseat to the opposite side of the hub bore is specified by dimension *T*. For taper keyseats, *T* is measured at the deeper end. The following formula may be used for calculating this dimension:

$$T = D - Y + \frac{H}{2} + C = \frac{D + H + \sqrt{D^2 - W^2}}{2} + C$$

Symbols

C = Allowance

+ 0.005 inch clearance for parallel keys

– 0.020 inch interference for taper keys

D = Nominal shaft or bore diameter, inches

H = Nominal key height, inches

W = Nominal key width, inches

Y = Chordal height, inches

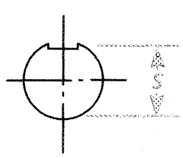
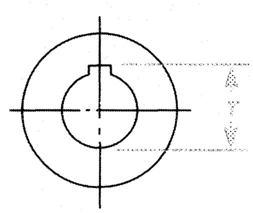
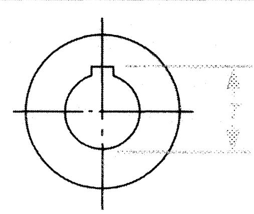
NOMINAL SHAFT DIAMETER	 PARALLEL AND TAPER		 PARALLEL		 TAPER	
	SQUARE	RECTANGULAR	SQUARE	RECTANGULAR	SQUARE	RECTANGULAR
	S	*S*	*T*	*T*	*T*	*T*
1/2	0.430	0.445	0.560	0.544	0.535	0.519
9/16	0.493	0.509	0.623	0.607	0.598	0.582
5/8	0.517	0.548	0.709	0.678	0.684	0.653
11/16	0.581	0.612	0.773	0.742	0.748	0.717
3/4	0.644	0.676	0.837	0.806	0.812	0.781
13/16	0.708	0.739	0.900	0.869	0.875	0.844
7/8	0.771	0.802	0.964	0.932	0.939	0.907
15/16	0.796	0.827	1.051	1.019	1.026	0.994
1	0.859	0.890	1.114	1.083	1.089	1.058
1-1/16	0.923	0.954	1.178	1.146	1.153	1.121

FIGURE 17.92 Shaft Diameter and Keyseat Dimensions

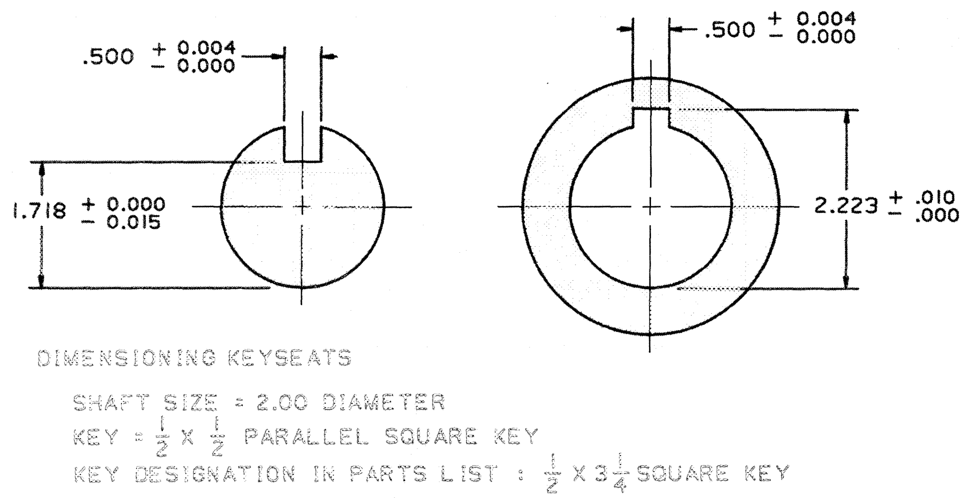


FIGURE 17.93 Dimensioning Keyseats

17.21.4 Dimensioning Keyseats

Keyseats (Fig. 17.93) are dimensioned by giving the width, depth, location, and, if required, length. For shafts, the width of the keyseat, the distance from the bottom of the shaft to the bottom of the keyseat, and the length are given. For the hub, the width of the keyseat and the distance from the bottom of the shaft hole to the top of the keyseat are given.

When designating keys on drawings, the key number or size, length, and product name are given, as in the following:

$\frac{1}{2}$ × 3 SQUARE KEY

NO. 403 WOODRUFF KEY

$\frac{1}{4}$ × $1\frac{1}{2}$ SQUARE GIB HEAD KEY

$1\frac{1}{4}$ × 4 SQUARE PLAIN TAPER KEY

NO. 8 PRATT & WHITNEY KEY

$\frac{1}{8}$ × $\frac{3}{32}$ × $\frac{3}{4}$ RECTANGULAR KEY

You May Complete Exercises 17.9 Through 17.12 at This Time

17.22 USING A CAD SYSTEM TO DRAW THREADS

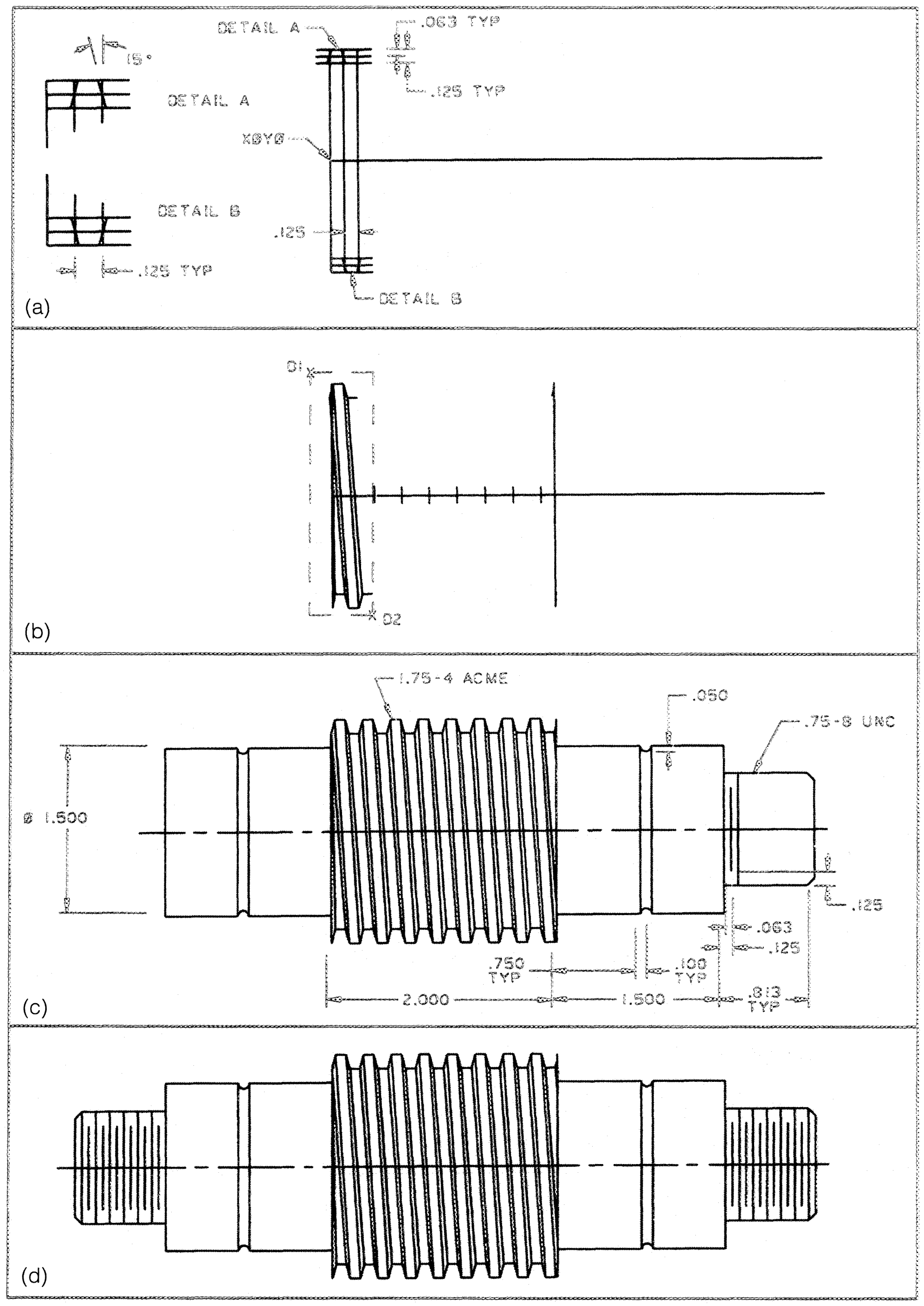
Drawing threads with a 2D CAD system is similar to the processes already described for detailed and Acme threads (see Sections 17.6.3 and 17.6.4). However, the thread profile of only one thread is constructed; the other threads are constructed simply through CAD commands such as **COPY** and **ARRAY**. Figures 17.94 and 17.95 show projects that were completed on a CAD system. AutoCAD was used to create the threads in Figure 17.94. The **ARRAY** command created the additional threads.

```
Command: ARRAY
Select Objects: W (D1 and D2 are used to window
the entities)
Rectangular or polar array (R/P): R
Number of rows (---) <1>: Return/Enter
Number of columns (:::) <1>:7
Unit cell or distance between rows (---):
Return/Enter
Distance between columns (:::): .125
```

The socket-head cap screw in Figure 17.95 was drawn with Computervision's Personal Designer software. The command that generated the threads is different (**MOVE COPY**), but the results are the same for both examples.

With a CAD system, a standard library of parts is normally available for rapid and accurate insertion of standard fasteners as a 3D model or a 2D part (Fig. 17.96). Many standard parts are now available with 2D and 3D parts libraries for CAD systems. A library of standard parts eliminates the need to redraw each part. The part can be recalled and inserted as required anywhere on the design, in as many places as required. Library parts are a CAD system's version of a manual drafter's template.

FIGURE 17.94 Using a CAD System to Draw Detailed Acme Threads



The fasteners shown in Figures 17.97 and 17.98 are additional examples of fasteners created on CAD systems. Both the model of the fastener and its orthographic projection are available to the designer.

The bolt shown in Figure 17.99 was created on Pro/ENGINEER's parametric design modeling system and has threads modeled on the bolt. In most cases, cosmetic or simplified threads are used for 3D models. The threads on this fastener were cut on the bolt shank. This method requires a huge amount of processing power and a very large file size. The shaded-image-plot file for this illustration took 24 Mbytes, and the part file took over 3 Mbytes! The access, process, regeneration, and repaint time (let alone the storage space on disk) make this type of modeling unrealistic for most situations, for example, a simple assembly with six pieces and twenty-four bolts.

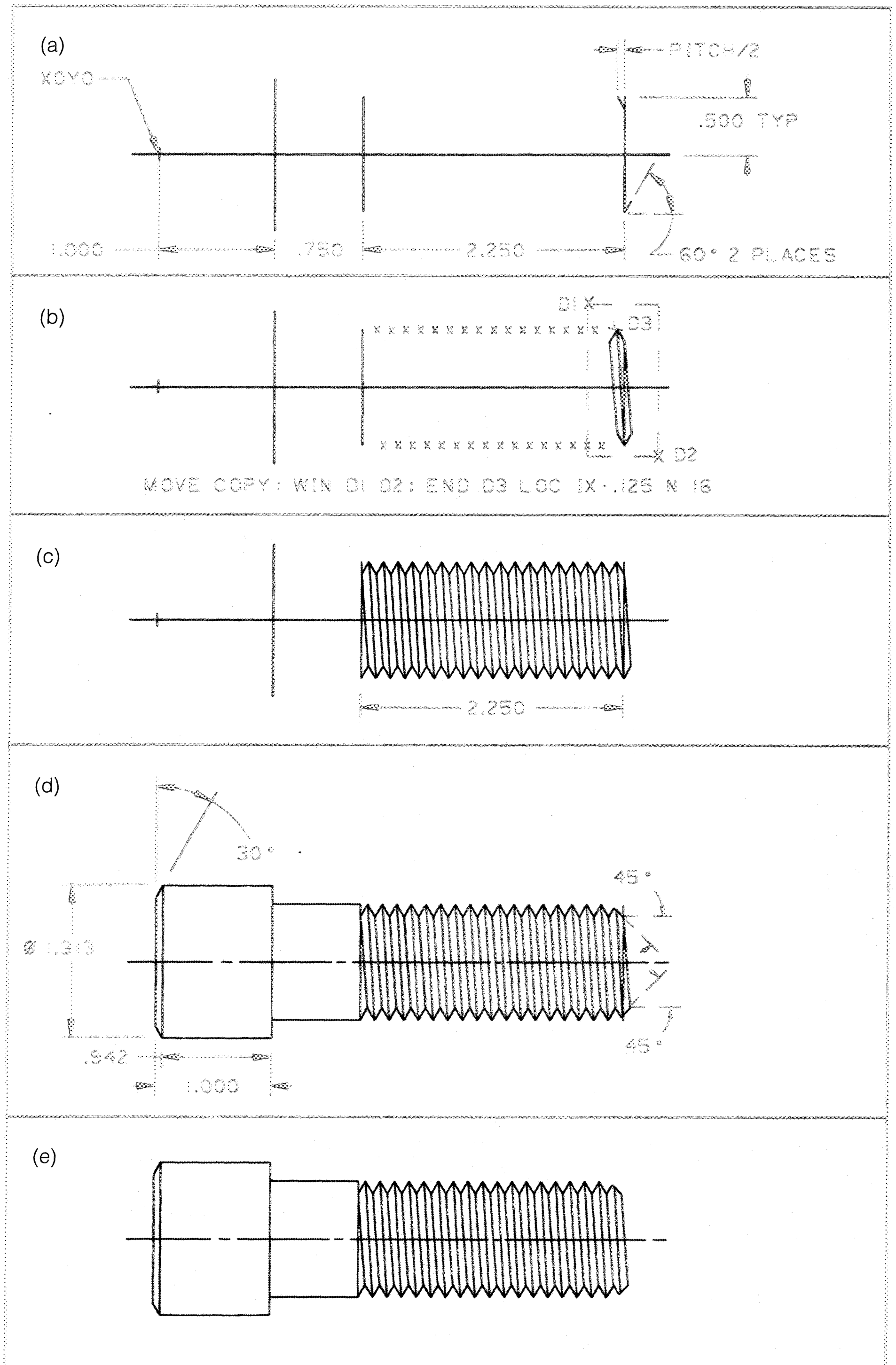


FIGURE 17.95 Using a CAD System to Draw Detailed Threads

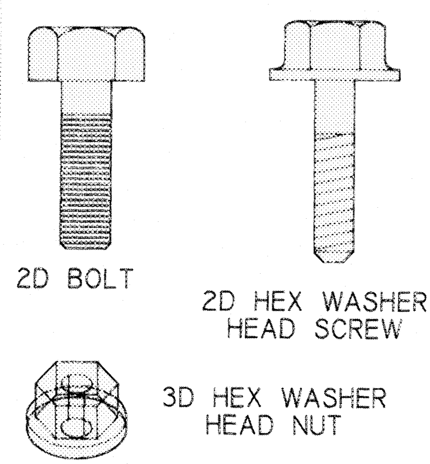


FIGURE 17.96 2D and 3D CAD Library Parts

This chapter has presented only a few of the millions of standard fasteners available on the market. Understanding the basic sizes, threads (where appropriate), and design uses of the fasteners is more important than knowing every style. When designing, remember to consult a variety of trade magazines, part catalogs, and design manuals before creating any new nonstandard fastener for your design project.

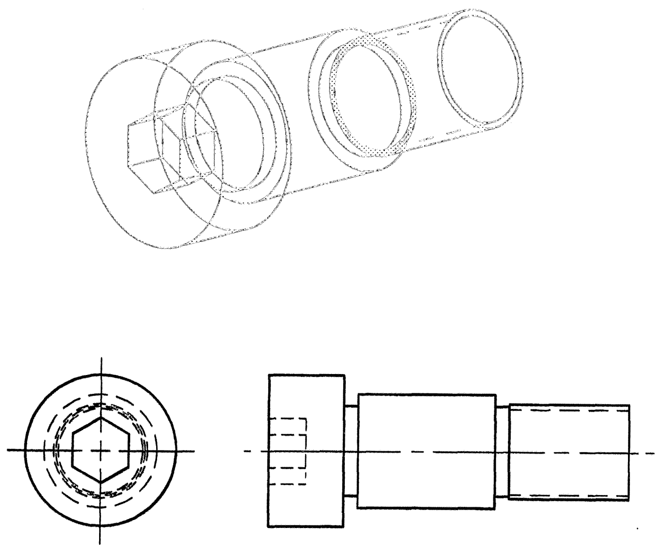


FIGURE 17.97 A Fastener Design That Was Created on a CAD System

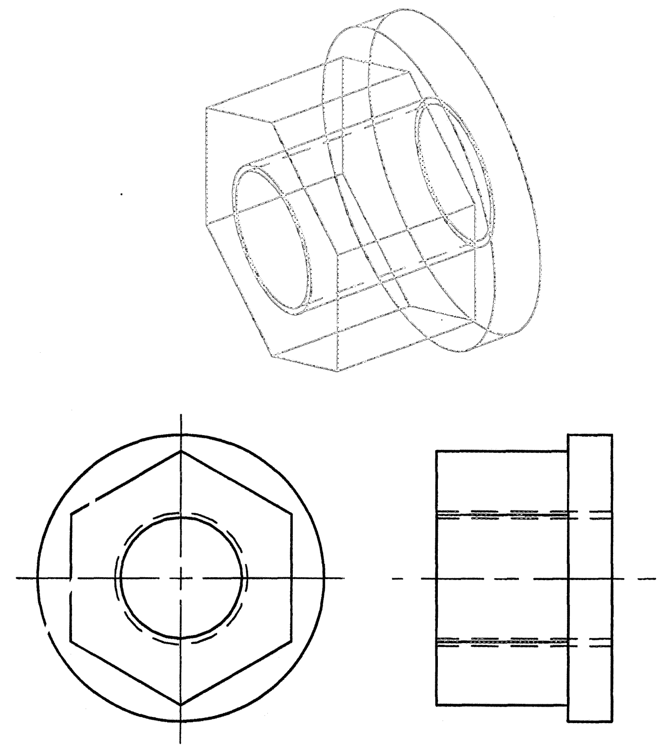


FIGURE 17.98 A Solid Model and an Orthographic Projection of a Fastener

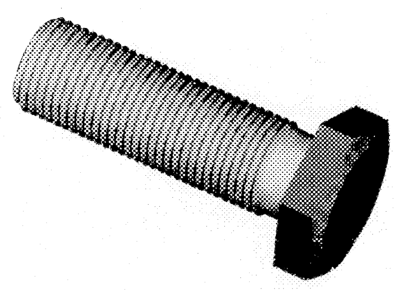


FIGURE 17.99 Parametric Model of a Bolt with Modeled Threads

QUIZ

True or False

1. M5 × 1.50-6g is a designation for an American National thread.
2. UNC means United National thread form.
3. The B symbol for threads indicates that the thread is external.
4. Dowel pins are used to align and locate parts.
5. Studs are fasteners that secure two left-handed parts together.
6. Carriage bolts have a square body under the head.
7. The 13 in ".500-13 UNC-2B" means the number of threads per foot.
8. Tapered pins are tapered $\frac{1}{8}$ in. per foot.

Fill in the Blanks

9. __________ , __________ , and __________ are types of keys.
10. __________ , __________ , and __________ are primarily for power transmission.
11. __________ pins are used to retain parts such as slotted nuts and __________ pins.
12. __________ threads are used in place of the old __________ threads.
13. __________ __________ rings are installed on __________ machined grooves in housings.
14. A __________ key is shaped similar to a half circle.
15. Basic industrial fasteners include __________ and __________ bolts, __________ , carriage bolts, studs, __________ , and __________ .
16. __________ are fasteners with no head but with threads at both ends of the shank.

Answer the Following

17. Describe how an axially assembled external retaining ring might be used in a design.
18. What is a set screw? Describe some of its possible design functions.
19. Name and describe three types of locating pins.
20. What are the meanings of UN, UNF, and UNC?
21. What is the difference between Class 1, 2, and 5 threads?
22. List four considerations in the selection of a fastener.
23. Describe two types of studs.
24. What is the difference between a right-hand and a left-hand thread?

EXERCISES

Exercises may be assigned as sketching or instrument 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 instructional material. Dimensions for fasteners used in exercises can be located in figures throughout the chapter and in Appendix C.

After Reading the Chapter Through Section 17.12.1, You May Complete the Following Four Exercises

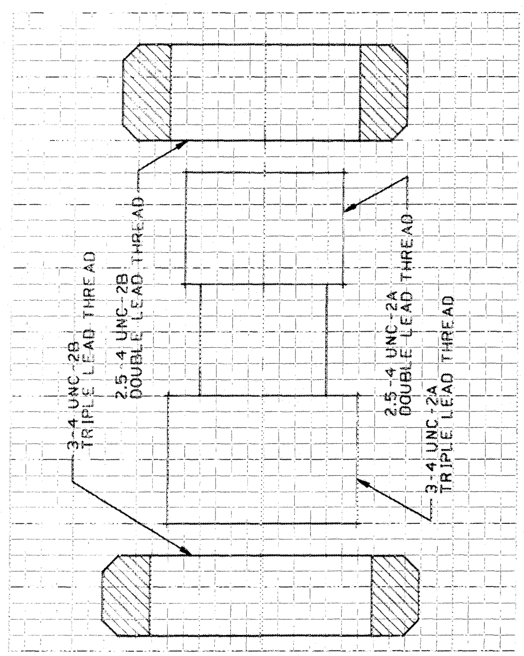
Exercise 17.1 Complete the three parts using the appropriate threads. Use detailed thread representation.

Exercise 17.2 Draw the detailed representation of the Acme threads.

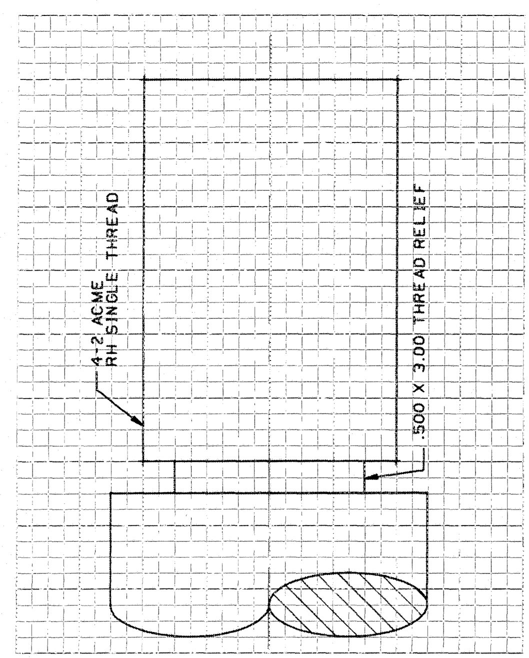
Exercise 17.3(A) Calculate the normal engagement, effective thread, and pipe end. Draw the flange and pipe as shown. The NPT pipe thread has a taper of $\frac{3}{4}$ in. per foot. The pipe has a 3 in. nominal size.

Exercise 17.3(B) Complete the pipe plug and flange. The plug has a standard NPT $\frac{3}{4}$ in. nominal pipe thread with a taper of $\frac{3}{4}$ in. per foot. Calculate and draw the effective thread, normal thread engagement, and length. Use simplified thread representation. Complete the end views showing only details that are visible and the threads.

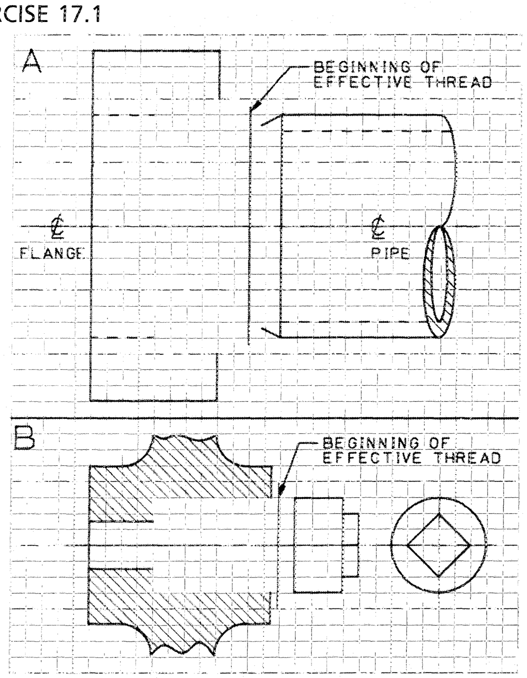
Exercise 17.4 Draw the threaded shaft as shown. Include all chamfers, reliefs, and threads. Use schematic thread representation.



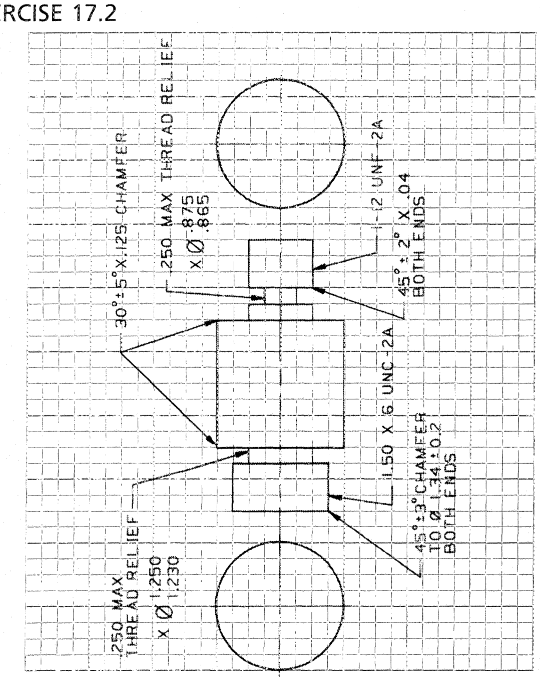
EXERCISE 17.1



EXERCISE 17.2



EXERCISE 17.3



EXERCISE 17.4

After Reading the Chapter Through Section 17.16, You May Complete Exercises 17.5 Through 17.8

Exercise 17.5(A) Using detailed representation, draw a 1.50-6 UNC-2A × 4 square-head bolt. Draw only the axial (side) view in the given space.

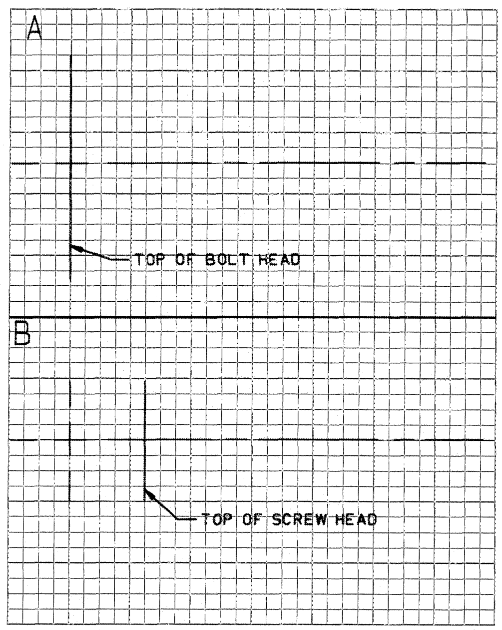
Exercise 17.5(B) Draw a detailed representation of the 1-8 UNC-2A × 3 hex socket-head cap screw. Show the side and end views in the given space, and label the drawing correctly.

Exercise 17.6(A) Fasten the rest block to the plate with four $\frac{3}{8}$ in. diameter hex socket-head cap screws (S) and two $\frac{3}{8}$ in. diameter steel dowel pins (D). Calculate the screw and dowel lengths. The plate will have threaded through-holes. The rest block will have clearance through-holes for the screws to pass through. Calculate the screw's length of engagement, and counterbore the block so that the screw's head will be flush with the top surface. Calculate the counterbore diameter and depth. The dowel will be press-fit (interference-fit) into the block and the plate. Calculate the ream hole diameter for the dowels.

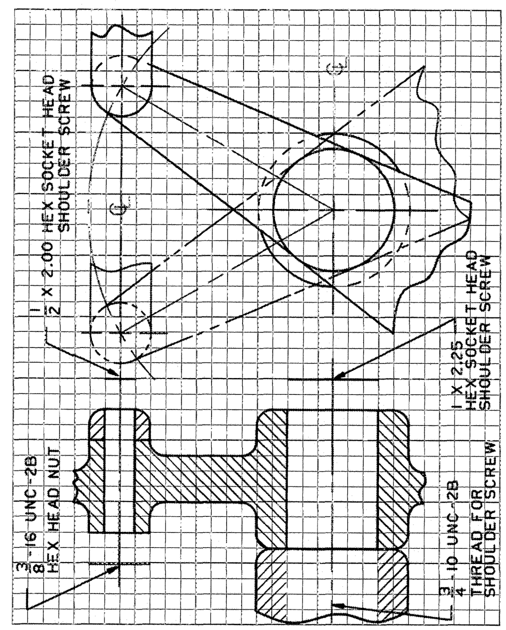
Exercise 17.6(B) Dimension the hole pattern for the screws and the dowels. Call out the proper clearance hole size for the drilled clearance holes, the screws, and the reamed holes for the dowels.

Exercise 17.7 Draw the moving shaft pivot as shown. Use two hex socket-head shoulder screws. Show the screws in both views. The screws have different diameters and lengths.

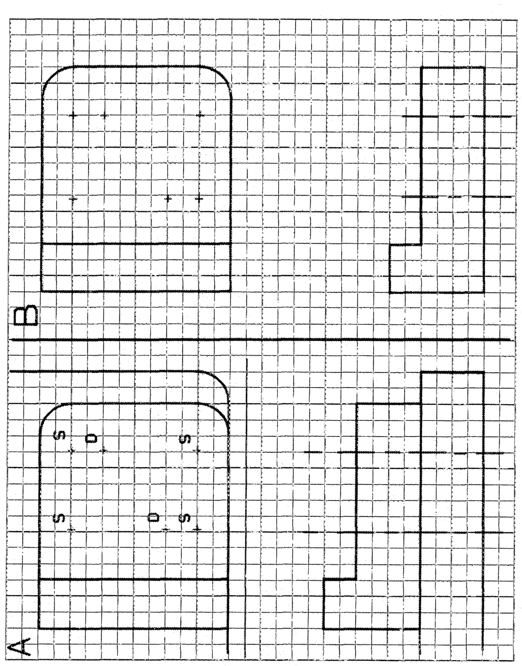
Exercise 17.8 Read Section 17.13.7 on set screws, and complete the exercise as described. Determine the proper diameter and length of the set screws as per shaft diameter. There are two hex socket set screws required for each shaft. They are installed at 90° to one another. Use a cup point for the small set screws and a dog point for the two larger set screws.



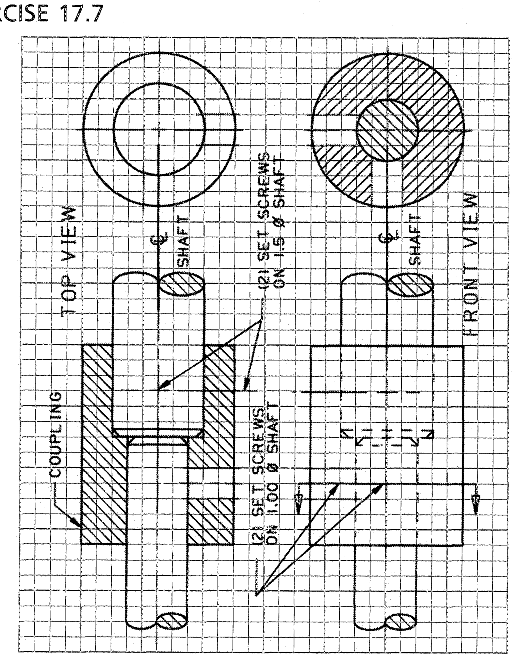
EXERCISE 17.5



EXERCISE 17.7



EXERCISE 17.6



EXERCISE 17.8

After Reading the Chapter Through Section 17.21.4, You May Complete the Following Exercises

Exercise 17.9(A) Attach the collar to the shaft using one of the two following types of spring pins:

Pin, Coiled Spring, 10 × 100, Metric, Steel
Pin, Slotted Spring, .500 × 4.00, ANSI 302

Exercise 17.9(B) Attach the collar to the shaft with a tapered pin. Call out the hole size and dimensions for tapered holes, and use the following pin: Pin, Tapered, No. 8 × 2.50, Steel.

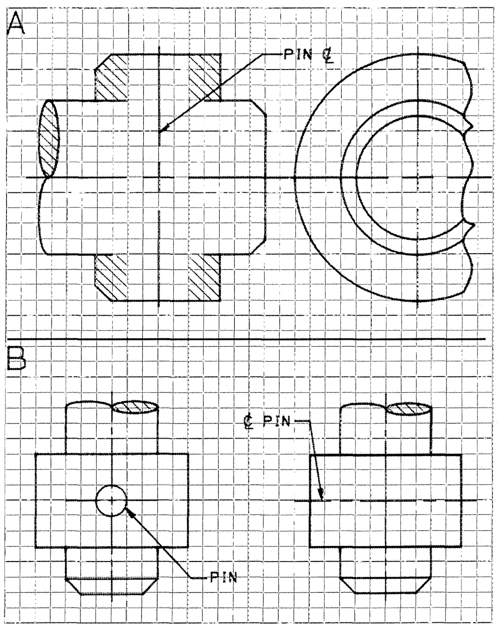
Exercise 17.10 Fasten the hitch at C with a .500 in. clevis pin. Use two .500 in. plain washers above and below the hitch and plate. Show a .175 in. diameter cotter pin to secure the clevis pin. Fasten the plates at B with three .625 in. diameter hex bolts. Use lock washers on both sides and hex flat nuts on the bottom. Show fasteners in both views. You will need to determine the length of the bolts and the clevis pin based on the fastening requirements. Call out the clevis pin, cotter pin, washers, nuts, and bolts on a separate parts list, and attach it to the drawing.

Exercise 17.11(A) Calculate the size and length of a Woodruff key or a square key (ask your instructor). Draw the key in the view provided. The shaft has a 2.00 in. diameter.

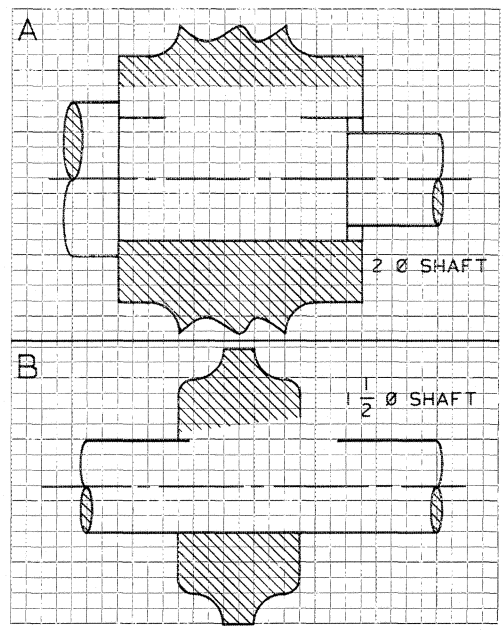
Exercise 17.11(B) Secure the shaft to the sprocket using a tapered gib key or a tapered key. Determine the size and length of a key for the 1.50 in. diameter shaft.

Exercise 17.12(A) Draw and dimension the shaft and a basic 5100 external retaining ring. See Appendix C.6 or manufacturing catalogs for the ring dimensions.

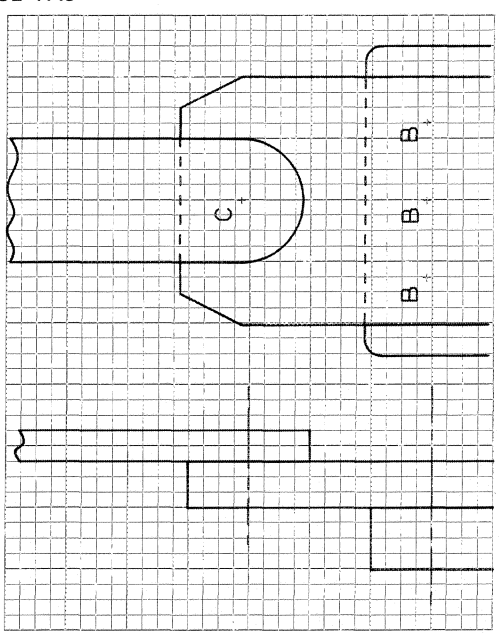
Exercise 17.12(B) Repeat Exercise 17.12(A), except use an N5000 basic 3 in. internal retaining ring for the housing. Draw and dimension completely.



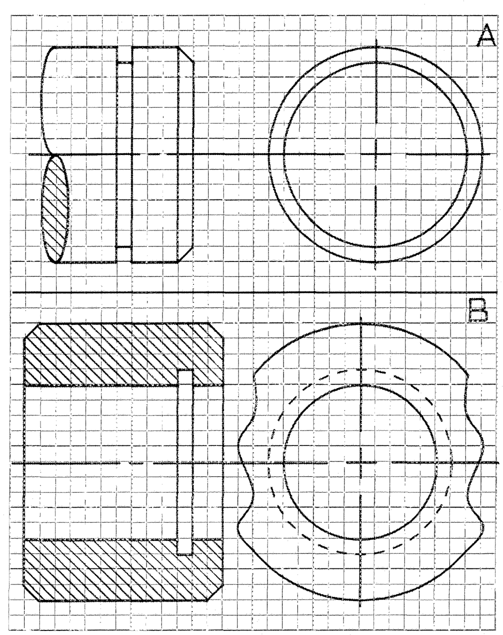
EXERCISE 17.9



EXERCISE 17.11



EXERCISE 17.10



EXERCISE 17.12

PROBLEMS

Problem 17.1 Draw a 1.00 in. pitch thread (2× size) of the following thread types: Acme, square, and UNC.

Problem 17.2 Draw 3–2 Acme thread with a length of 5.00 in. using detailed thread representation.

Problem 17.3 Draw a 1.25 × 4.50 hex socket-head shoulder screw full size. Show the length view and the end view of the head. Use schematic method to display the threads.

Problem 17.4 Fasten a 1.25 in. plate to an aluminum casting (3.00 in. thick) using a .500-13 UNC socket-head cap screw. Calculate and show the screw in two views. Dimension and call out the tap drill, clearance hole, and tap size.

Problem 17.5 Connect a 1.50 in. and a 1.375 in. plate with a 1.00 in. socket-head shoulder screw and appropriate nut. Show in views, and call out all hole sizes.

Problem 17.6 Bolt together two 1.50 in. thick steel plates with two 1.25-12 UNF hex-head bolts. Use lock washers on both ends and the appropriate nut. Show in section. Construct a small parts list for the hardware.

Problem 17.7 Fasten a 4.0 × 4.0 × 4.0 × 2.00 in. thick steel angle plate to a steel part using four .375-16 UNC socket-head caps screws and two .375 in. diameter dowels. Design the bolt pattern, and calculate all fastener sizes. Dimension and call out all fasteners. Counterbore the plate so that the screw heads will be below the surface.

Problem 17.8 Draw a 50 mm diameter shaft and a 74 mm wide collar (O.D. 100 mm/I.D. 51 mm). Fasten the collar to the shaft with appropriately sized socket set screws with a dog point. Show in two views.

Problem 17.9 Draw a 2.50 in. diameter shaft and a 4.00 in. wide (O.D. 5.00 in./I.D. 2.51 in.). Connect the two parts with a square key 2.00 in. long. Calculate the key size, and show in two views. Dimension the views as required.

Problem 17.10 Repeat Problem 17.9, but use a Woodruff key and keyseat. Dimension the views as required.

Problem 17.11 Connect two sheets of .125 in. thick aluminum with a .125 in. diameter button-head rivet. Show in two views at 2× size.

Problem 17.12 Using a butt joint, connect two .500 in. thick sheets of steel (6.00 in. wide) with twelve 1.125 in. diameter rivets. Use double rivets on each side of the joint. Show in two views, and dimension completely.