threshold value of the third variable can be estimated to provide a specified reliability. The actual value present in the design or part can then be compared to the threshold value to see if the part meets the desired reliability criteria and is then adequate for the specifications provided.

1.4 COMMUNICATION OF ENGINEERING INFORMATION

The output of an engineering department consists of specifications for a product or a process. Much of the output is in the form of drawings that convey instructions for the manufacturing of components, the assembly of components into machines, machine installations, and maintenance. Additional information is provided by parts lists and written specifications for assembly and testing of the product.

1.4.1 Drawing Identification

Drawings and machine components are normally identified by number and name, for example, Part no. 123456, Link. Each organization has its own system of numbering drawings. One system assigns numbers in sequence as drawings are prepared. In this system, the digits in the number have no significance; for example, no. 123456 would be followed by numbers 123457, 123458, etc., without regard to the nature of the drawing.

A different system of numbering detail drawings consists of digits that define the shape and nominal dimensions. This eases the task of locating an existing part drawing that may serve the purpose and thus reduces the likelihood of multiple drawings of nearly identical parts.

The generally preferred method of naming parts assigns a name that describes the nature of the part, such as piston, shaft, fender, or wheel assembly. Some organizations add descriptive words following the noun that describes the nature of its part; for example:

Bearing, roller, or bearing, ball

Piston, brake, or piston, engine

Shaft, axle, or shaft, governor

Fender, LH, or fender, RH

Wheel assembly, idler, or wheel assembly, drive

A long name that describes the first usage of a part or that ties the part to a particular model can be inappropriate if other uses are found for that part. A specific ball or roller bearing, for example, might be used for different applications and models.

1.4.2 Standard Components

Components that can be obtained according to commonly accepted standards for dimensions and strength or load capacity are known as *standard parts.* Such components can be used in many different applications, and many organizations assign part numbers from a separate series of numbers to the components. This tends to eliminate multiple part numbers for the same component and reduces the parts inventory. Standard components include such things as antifriction bearings, bolts, nuts, machine screws, cotter pins, rivets, and Woodruff keys.

1.4.3 Mechanical Drawings

Pictorial methods, such as perspective, isometric, and oblique projections, can be useful for visualizing shapes of objects. These methods, however, are very rarely used for working drawings in mechanical engineering. Orthographic projection, in which a view is formed on a plane by projecting perpendicularly from the object to the plane, is used almost exclusively.

In the United States, mechanical drawings are made in what is known as the *third-angle projection.* An example is provided in Fig. 1.4, in which the triangular shape can be considered to be the front view or front elevation. The top view, or plan, appears above the front view and the side view; the side elevation, or end view, appears alongside the front view. In this example, the view of the right-hand side is shown; the left-hand side would be shown to the left of the front view if it were needed.

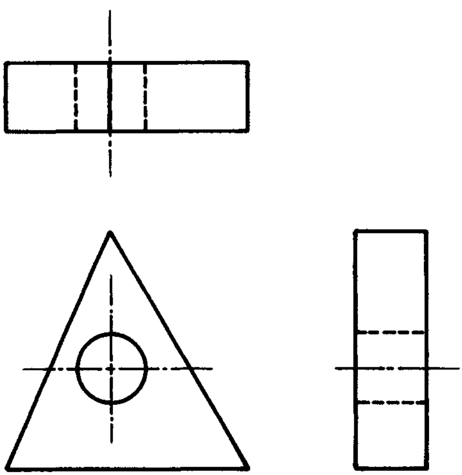


FIGURE 1.4 Arrangement of views of an object in third-angle orthographic projection.

The first-angle projection is used in many other countries. In that arrangement, the top view appears below the front view, and the view of the left side appears to the right of the front view. Some organizations follow the practice of redoing drawings that are to be sent to different countries in order to eliminate the confusion that results from an unfamiliar drawing arrangement.

Drawings, with the exception of schematics, are made to a convenient scale. The choice of scale depends on the size and complexity of the object and fitting it on a standard size of drawing paper. The recommended inch sizes of drawings are 8.5 × 11, 11 × 17, 17 × 22, 22 × 34, and 34 × 44. Then, sizes are multiples of the size of the commercial letterhead in general use, and folded prints will fit in letter-sized envelopes and files.

Drawings should be made to one of the standard scales in common usage. These are full, one-half, one-quarter, and one-eighth size. If a still smaller scale must be used, the mechanical engineer's or architect's rule is appropriate. These rules provide additional scales ranging from 1 in equals 1 ft to 3/32 in equals 1 ft. The civil engineer's scale with decimal divisions of 20, 30, 40, 50, and 60 parts to the inch is not appropriate for mechanical drawings.

Very small parts or enlarged details of drawings are sometimes drawn larger than full size. Scales such as 2, 4, 5, 10, or 20 times normal size may be appropriate, depending on the particular situation.

Several different types of drawings are made, but in numbers produced, the detail drawing (Fig. 1.5) exceeds all other types. A *detail drawing* provides all the instructions for producing a component with a unique set of specifications. The drawing specifies the material, finished dimensions, shape, surface finish, and special processing (such as heat treatment or plating) required. Usually, each component that has a unique set of specifications is given a separate drawing. There are numbering systems, however, in which similar components are specified on the same drawing and a table specifies the dimensions that change from item to item. Sometimes the material specification consists of another part to which operations are added. For example, another hole or a plating operation might be added to an existing part. Detail drawings are discussed in considerable detail in the next portion of this section.

An *assembly drawing* specifies the components that are to be joined in a permanent assembly and the procedures required to make the assembly. An example is given in Fig. 1.6. A weldment, for example, will specify the components that are to be welded, the weld locations, and the size of weld beads. The drawing may also specify operations that are to be performed after assembly, such as machining some areas.

Another type of assembly drawing consists of an interference fit followed by subsequent machining. A bushing, for example, may be pressed into the machine bore of the upper end of an engine connecting rod, and the bushing bore may then be machined to a specified dimension.

A *group drawing* (Fig. 1.7) may resemble a layout in that it shows a number of components, in their proper relationship to one another, that are assembled to form a unit. This unit may then be assembled with other units to make a complete machine. The drawing will normally include a parts list that identifies part numbers, part names, and the required number of pieces. A group drawing might be a section through a unit that must be assembled with other equipment to make a complete machine.

A *machine outline drawing* is provided to other engineering departments or to customers who purchase that machine for installation. An example is given in Fig. 1.8. An outline may show the general shape, the location and size of holes for mounting bolts, the shaft diameter, keyseat dimensions, location of the shaft with respect to the mounting holes, and some major dimensions.

Schematic drawings, such as for electrical controls, hydraulic systems, and piping systems, show the major components in symbolic form. An example is given in Fig. 1.9. They also show the manner in which the components are connected together to route the flow of electricity or fluids. Schematic diagrams are sometimes provided for shop use, but more frequently they are used in instruction books or maintenance manuals where the functioning of the system is described.

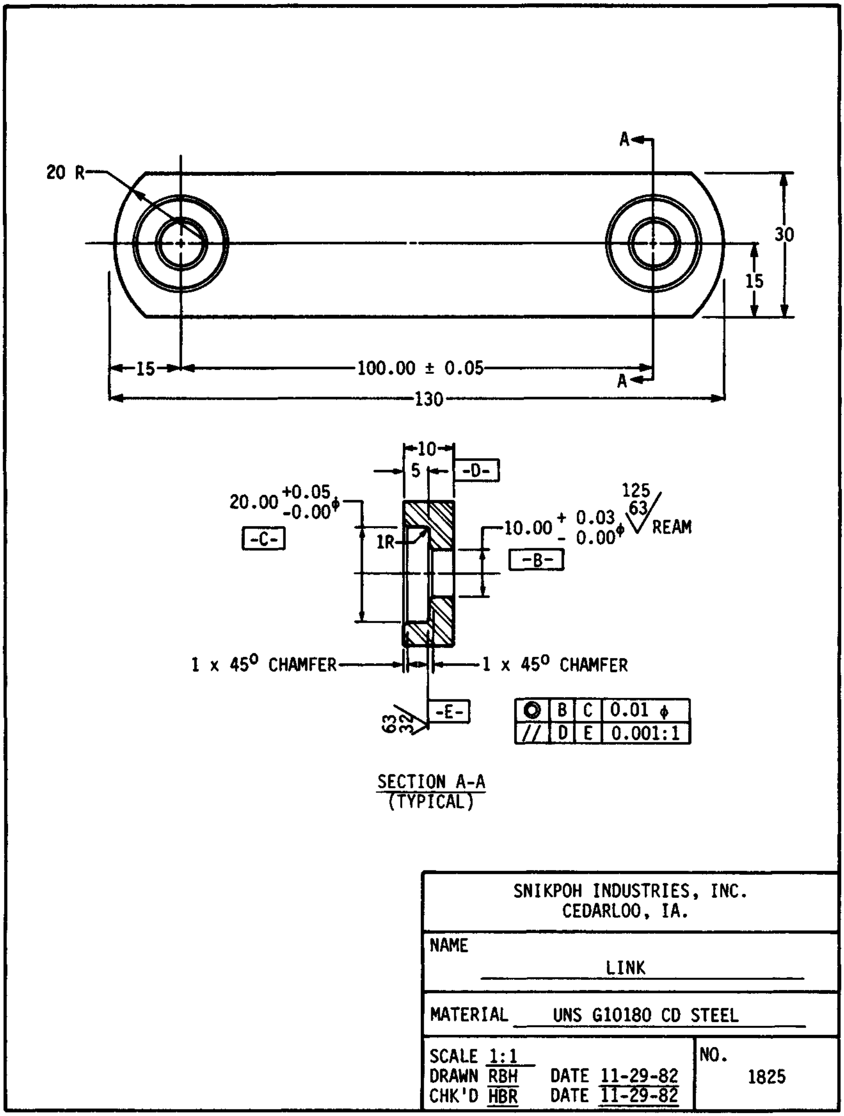


FIGURE 1.5 An example of a detail drawing.

1.4.4 Detail Drawings

A complete description of the shape of a part is provided by the views, sections, and specifications on a detail drawing. A simple part, such as a right-circular cylinder, may require only one view. A complex part, such as an engine cylinder block, may require several views and many sections for an adequate description of the geometry. The link in Fig. 1.5 is a basically simple shape with added complexity due to machining. The cut surfaces of sections are indicated by section lining (crosshatching). Standard symbols (Fig. 1.10)† are available that indicate the type of material sectioned. The use of proper section lining helps the user to understand the drawing with reduced clutter.

† See Sec. 1.6 for a discussion of standards and standards organizations.

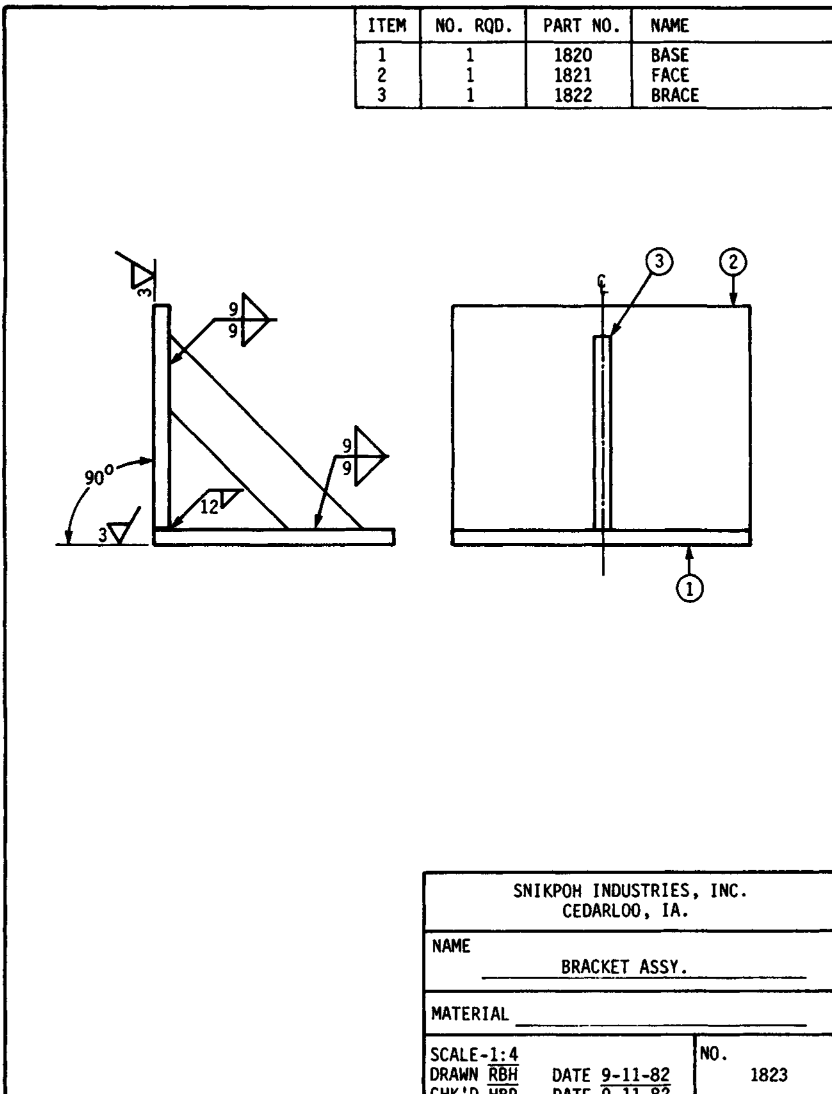
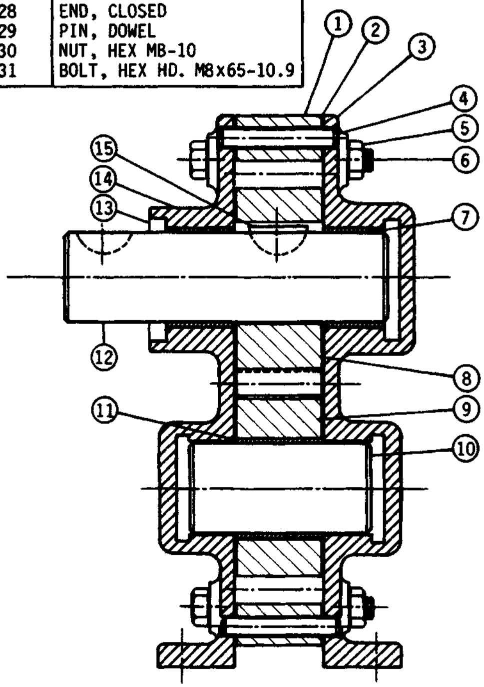


FIGURE 1.6 An example of an assembly drawing.

Dimensions. There are two reasons for providing dimensions: (1) to specify size and (2) to specify location. Dimensioning for sizes, in many cases, is based on the common geometric solids—cone, cylinder, prism, pyramid, and sphere. The number of dimensions required to specify these shapes varies from 1 for the sphere to 3 for the prism and frustum of a cone. Location dimensions are used to specify the positions of geometric shapes with respect to axes, surfaces, other shapes, or other refer-

ITEM	RQD	PART NO.	NAME
1	1	1826	BODY
2	2	1827	GASKET
3	1	1828	END, CLOSED
4	2	1829	PIN, DOWEL
5	8	1830	NUT, HEX MB-10
6	8	1831	BOLT, HEX HD. M8x65-10.9



ITEM	RQD	PART NO.	NAME
7	2	1832	BUSHING
8	1	1833	GEAR, DRIVER
9	1	1834	GEAR, DRIVEN
10	1	1835	SHAFT, IDLER
11	1	1836	BUSHING
12	1	1837	SHAFT, INPUT
13	1	1838	SEAL, SHAFT
14	1	1839	END, OPEN
15	1	1840	KEY, WOODRUFF ¼x1

SNIKPOH INDUSTRIES, INC.
CEDARLOO, IA.

NAME MODEL LXII PUMP

MATERIAL

SCALE 1:2
DRAWN RBH DATE 12-1-82
CHK'D HBR DATE 12-1-82
NO. 1841

FIGURE 1.7 An example of a group drawing.

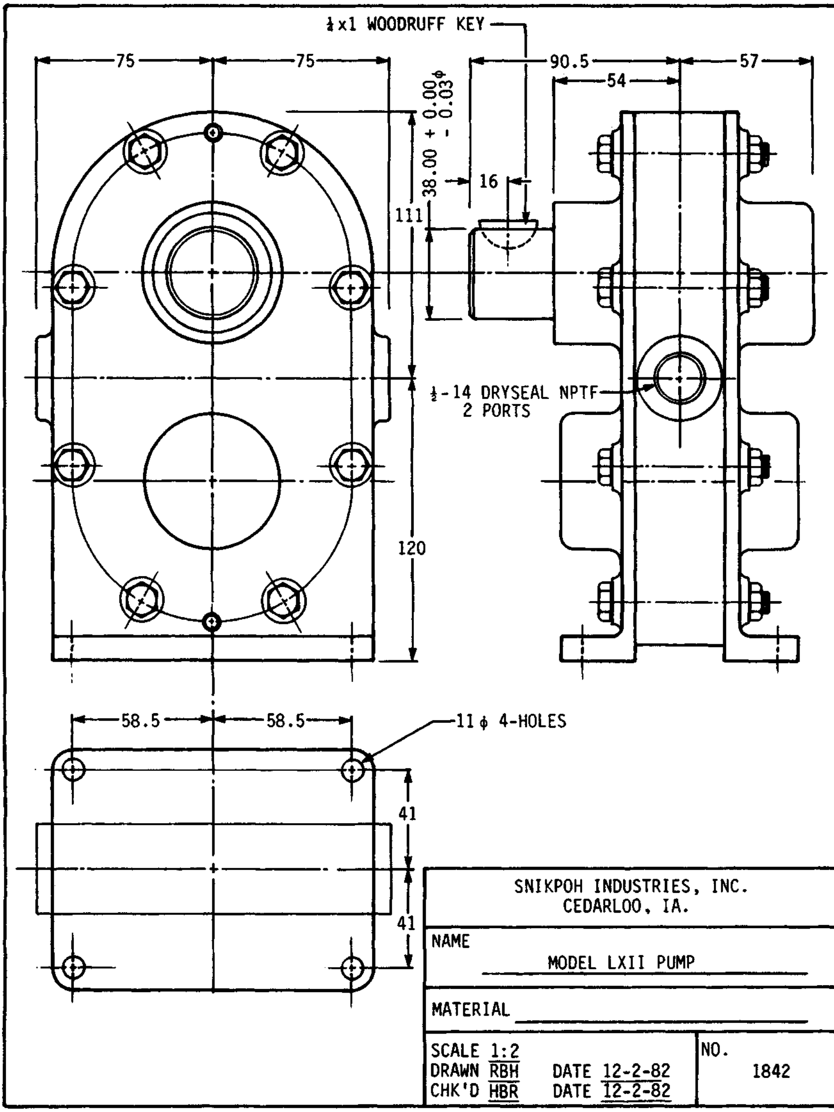


FIGURE 1.8 An example of an installation drawing.

ences. A sphere, for example, is located by its center. A cylinder is located by its axis and bases.

For many years, dimensions were stated in terms of inches and common fractions as small as 1/64 in. The common fractions are cumbersome when adding or subtracting dimensions, and decimal fractions are now used extensively. The decimal fractions are usually rounded to two digits following the decimal point unless a close toler-

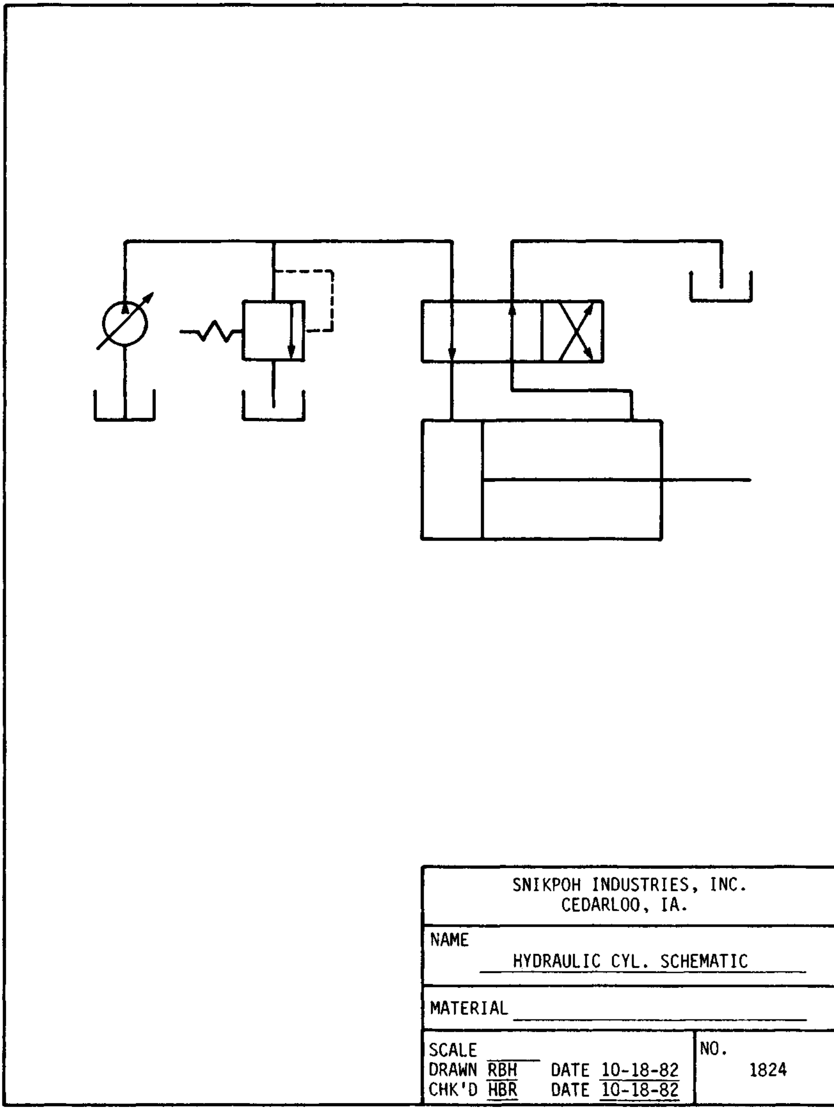


FIGURE 1.9 A hydraulic schematic diagram.

ance is to be stated. Thus ⅜ in, which is precisely equal to 0.375 in, is normally specified by dimension as 0.38 in.

The advent of the International System of Units (SI) has led to detail drawings on which dimensions are specified in metric units, usually millimeters (mm). Thus ½ mm (very nearly equal to 0.020 in) is the smallest dimension ordinarily specified without stating a tolerance. Because machine tools and measuring devices are still graduated

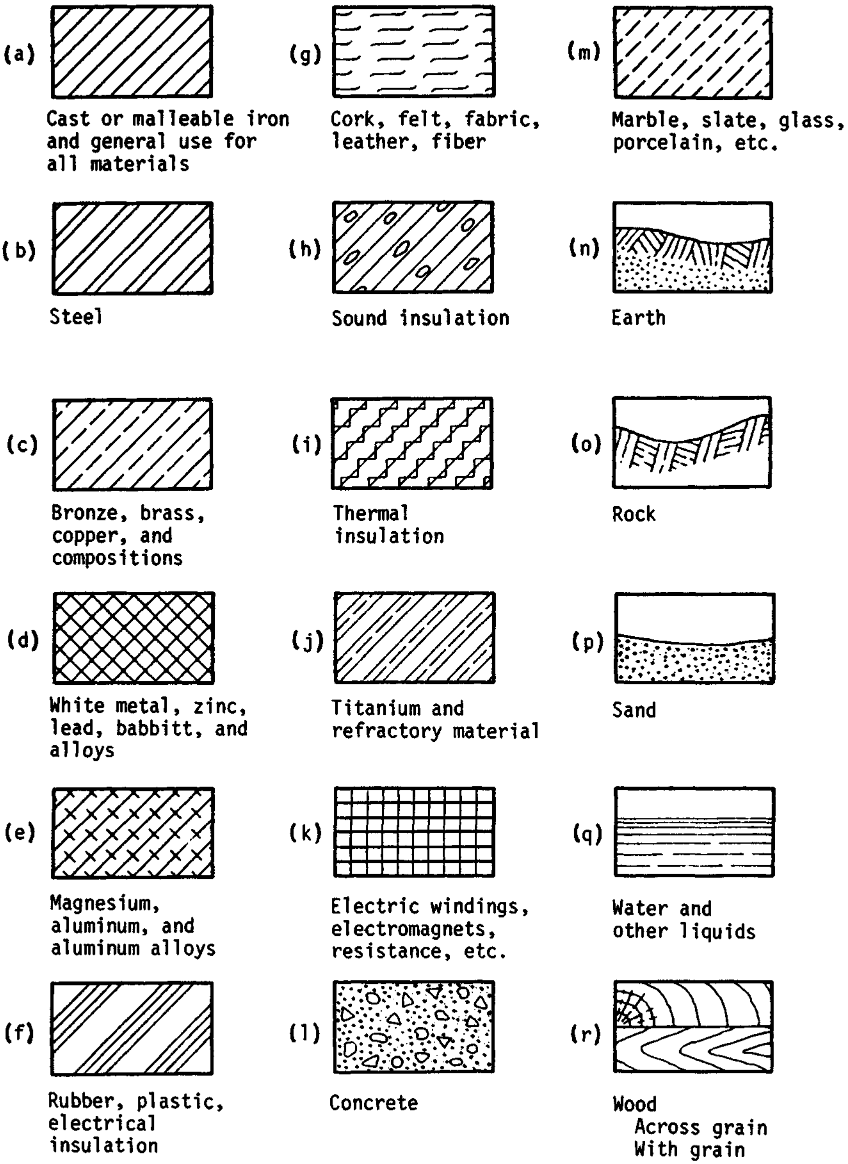


FIGURE 1.10 Symbols for section lining. (*ANSI standard Y14.2M-1979.*)

in inches, some organizations follow the practice of dual dimensioning. In this system, the dimensions in one system of units are followed by the dimensions in the other in parentheses. Thus a ½-in dimension might be stated as 0.50 (12.7), meaning 0.50 in or 12.7 mm.

It is poor practice to specify a shape or location more than once on a drawing. Not only can the dimensions conflict as originally stated, but the drawing may undergo subsequent changes. In making changes, the duplicate dimensions can be overlooked, and the user has the problem of determining the correct dimension.

Every dimension has either a stated or an implied tolerance associated with it. To avoid costly scrap, follow this rule: In a given direction, a surface should be located by one and only one dimension. To avoid a buildup of tolerances, it is better to locate points from a common datum than to locate each point in turn from the previous point. Standard procedures for specifying dimensions and tolerances are provided in ANSI standard Y14.5-1973.

Tolerances. Most organizations have general tolerances that apply to dimensions where an explicit tolerance is not specified on the drawing. In machined dimensions, a general tolerance might be ±0.02 in or 0.5 mm. Thus a dimension specified as 12 mm may range between 11.5 and 12.5 mm. Other general tolerances may apply to angles, drilled holes, punched holes, linear dimensions on formed metal, castings, forgings, and weld beads and fillets.

Control of dimensions is necessary for interchangeability of close-fitting parts. Consequently, tolerances are specified on critical dimensions that affect small clearances and interference fits. One method of specifying tolerances on a drawing is to state the nominal dimension followed by a permissible variation. Thus a dimension might be specified employing bilateral tolerance as 50.800 ± 0.003 mm. The limit-dimension method is to specify the maximum and minimum dimensions; for example, 50.803/50.797 mm. In this procedure, the first dimension corresponds to minimum removal of material. For a shaft, the display might be 50.803/50.797 mm and for a hole, 50.797/50.803 mm. This method of specifying dimensions and tolerances eliminates the need for each user of the drawing to perform additions and subtractions to obtain the limiting dimensions. Unilateral tolerancing has one tolerance zero, for example, $50.979\,^{+0.006}_{-0.000}$ mm.

Some organizations specify center-to-center distance on a gear set unilaterally with the positive tolerance nonzero. This is done because an increase in center-to-center distance increases backlash, whereas a decrease reduces backlash. The zero backlash, or tight-meshed, condition cannot be tolerated in the operation of gears unless special precautions are taken.

Standard symbols are available (Fig. 1.11) for use in specifying tolerances on geometric forms, locations, and runout on detail drawings. Information is provided in ANSI standard Y14.5M-1982 on the proper use of these symbols.

Surface Texture. The surface characteristics depend on processing methods used to produce the surface. Surface irregularities can vary over a wide range. Sand casting and hot working of metals, for example, tend to produce highly irregular surfaces. However, the metal-removal processes of grinding, polishing, honing, and lapping can produce surfaces which are very smooth in comparison. The deviations from the nominal surface can be defined in terms of roughness, waviness, lay, and flaws. The finer irregularities of surface which result from the inherent action of the production process are called *roughness*. Roughness may be superimposed on more widely spaced variations from the nominal surface, known as *waviness*. The direction of the pattern of surface irregularities is usually established by the method of material removal and is known as *lay*. *Flaws* are unintentional variations in surface texture, such as cracks, scratches, inclusions, and blow holes. These are usually not involved in the measurement of surface texture.

Surface roughness values that can be obtained by common production methods are provided in SAE standard J449a, "Surface Texture Control." The roughness that can be tolerated depends on the function served by the surface. The roughness of a clearance hole is usually not critical, whereas a surface that moves against another, such as a piston or journal, usually needs to be smooth.

A relationship exists between permissible surface-texture variations and dimensional tolerances. Precise control of dimensions requires precise control of surface texture. Consequently, when a high degree of precision is required in a dimension, it is necessary that the variation in surface roughness and waviness also be small.

Surface texture is specified on drawings through a set of symbols (Fig. 1.12) established by ANSI standard Y14.36-1978. The basic symbol is derived from a 60° letter V which was formerly used to indicate a machined surface. Use of the symbols on a drawing is demonstrated in Fig. 1.13. It is common practice to specify a range for the surface roughness rather than a single value. In such a case, the maximum roughness is placed above the minimum value. The waviness height and width can be

SYMBOL FOR:	ANSI Y14.5	ISO
STRAIGHTNESS	—	—
FLATNESS	⏥	⏥
CIRCULARITY	○	○
CYLINDRICITY	⌭	⌭
PROFILE OF A LINE	⌒	⌒
PROFILE OF A SURFACE	⌓	⌓
ALL-AROUND PROFILE	—○—	NONE
ANGULARITY	∠	∠
PERPENDICULARITY	⊥	⊥
PARALLELISM	//	//
POSITION	⌖	⌖
CONCENTRICITY/COAXIALITY	◎	◎
SYMMETRY	NONE	⌯
CIRCULAR RUNOUT	*↗	↗
TOTAL RUNOUT	*⌰	⌰
AT MAXIMUM MATERIAL CONDITION	Ⓜ	Ⓜ
AT LEAST MATERIAL CONDITION	Ⓛ	NONE
REGARDLESS OF FEATURE SIZE	Ⓢ	NONE
PROJECTED TOLERANCE ZONE	Ⓟ	Ⓟ
DIAMETER	Ø	Ø
BASIC DIMENSION	[50]	[50]
REFERENCE DIMENSION	(50)	(50)
DATUM FEATURE	[-A-]	* OR * [A]
DATUM TARGET	Φ6/A1	Φ6/A1
TARGET POINT	X	X

* MAY BE FILLED IN

FIGURE 1.11 Symbols for geometric characteristics and tolerances on detail drawings. (*ANSI standard Y14.5M-1982.*)

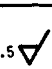
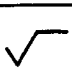
specified above the horizontal line, the distance over which the roughness is measured below the horizontal line, and the direction of lay above the surface.

The use of symbols for material-removal allowance on a weldment is illustrated in Fig. 1.6, and the specifications for a range of surface finishes are given in Fig. 1.5.

Machining Information. Some parts, such as noncircular cams, gears, and involute splines, may require a table of information that is needed for machining and checking the parts. The drawing of a standard spur gear, for example, requires a list of the number of teeth, diametral pitch or module, pressure angle, pitch diameter, tooth form, circular tooth thickness, and dimensions for checking the teeth. These data are required for obtaining the proper tools, setting up for the machining, and checking the finished parts.

Joining Information. Permanent assembly of components requires instructions for joining and specification of the material for making the connection. These processes include bonding, brazing, riveting, soldering, and welding. The use of symbols to specify welds is illustrated in Fig. 1.6. Chapter 14 covers bonding, brazing, and welding, and riveting is discussed in Chap. 23.

The amount of interference in press fits and shrink fits is normally specified through the dimensions and tolerances on the mating parts. Heating or cooling of parts for ease of assembly may be specified on an assembly drawing or in assembly specifications.

Symbol	Meaning
(a) 	Basic Surface Texture Symbol. Surface may be produced by any method except when the bar or circle (Figure b or d) is specified.
(b) 	Material Removal By Machining Is Required. The horizontal bar indicates that material removal by machining is required to produce the surface and that material must be provided for that purpose.
(c) 3.5 	Material Removal Allowance. The number indicates the amount of stock to be removed by machining in millimeters (or inches). Tolerances may be added to the basic value shown or in a general note.
(d) 	Material Removal Prohibited. The circle in the vee indicates that the surface must be produced by processes such as casting, forging, hot finishing, cold finishing, die casting, powder metallurgy or injection molding without subsequent removal of material.
(e) 	Surface Texture Symbol. To be used when any surface characteristics are specified above the horizontal line or the right of the symbol. Surface may be produced by any method except when the bar or circle (Figure b and d) is specified.

(f)

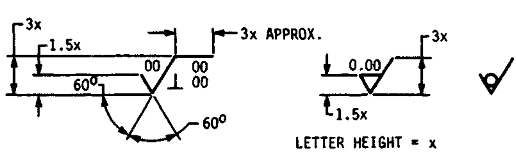


FIGURE 1.12 Surface-texture symbols and construction. (*ANSI standard Y14.36-1978.*)

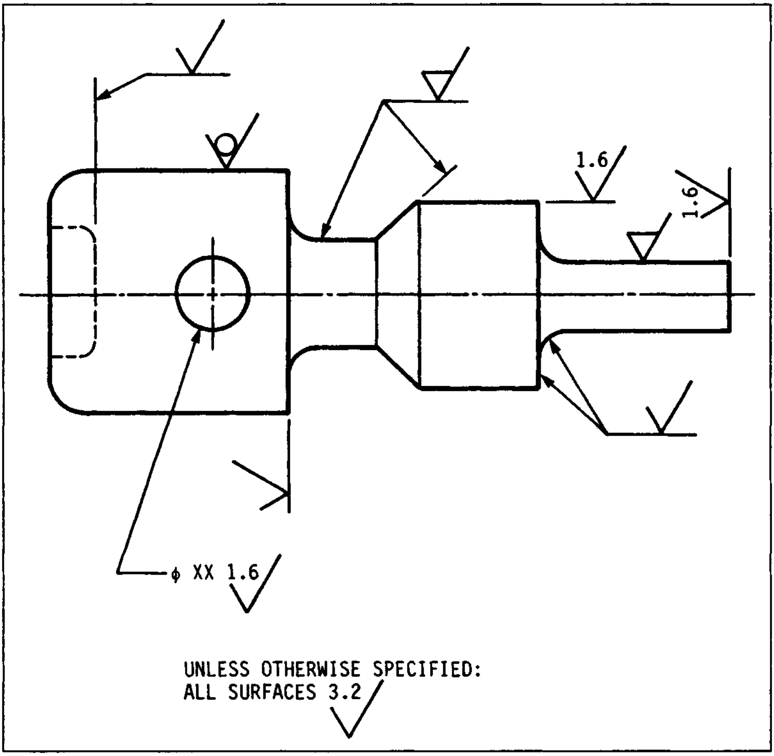


FIGURE 1.13 Application of surface-texture symbols. (*ANSI standard Y14.36-1978.*)

Material Specifications. Designation of the material for a part is essential. Such ambiguous specifications as cast iron, gray iron, or mild steel should not be used. Although there may be a common understanding of the meaning of such terms within the organization, misunderstandings can arise if the drawings are sent outside the firm. The use of the term *cast iron,* for example, might be interpreted as gray iron, white iron, malleable iron, or nodular iron.

Each type of cast iron includes several grades, and so castings should be specified by both type and grade of iron. Gray iron castings can be specified according to ASTM standard A48 or SAE standard J431 AUG79, and there are similar standards for malleable iron and nodular iron. When the type and grade of cast iron have been specified, the approximate strength of the metal is known.

The composition of wrought steel bars can be specified through use of the SAE/ANSI numbering system or the newer UNS standard. Steel plate, sheet, and structural shapes are more commonly specified according to ASTM specifications. The surface condition on bars, plate, and sheet can also be specified, such as hot-rolled, cold-finished, or pickled and oiled. The use of the standard material specification and surface finish, in effect, specifies the minimum material strength and the surface condition.

Some of the larger manufacturers have their own systems of material specifications which may be very similar to the standard systems. Materials are then ordered according to the company's own specification. Such a system prevents surprises due to changes in the standard and also provides a convenient method for specifying special compositions when needed.

Heat Treatment. Processes such as annealing or normalizing may be required prior to machining and are specified on the drawings. Other treatments such as carburizing, induction hardening, or through hardening can be performed after some or all of the machining has been done and must be specified. The results desired (for example, the case depth and surface hardness after carburizing) are a better specification than processing temperatures, times, and quenching media. Especially in the case of induction hardening, it may be necessary to specify both a surface hardness and a hardness at some particular depth below the surface in order to prevent subsurface failures.

Special Processes. The use of special processes or handling, such as methods of cleaning castings, impregnation of castings to prevent leakage of fluids, degreasing of finished parts, or protection of surfaces, is frequently specified on the drawing. If the painting of internal surfaces or dipping of castings to prevent rusting is to be done, the paint color, paint type, and method of application are usually specified. Drawings of parts that are to be plated specify the plating metal and thickness of plating that is to be applied.

Weight limits may also be specified on drawings. Pistons for internal combustion engines, for example, may have provisions for metal removal to obtain the desired weight. The location of material that can be removed and the weight limits are then specified on the drawing. Engine connecting rods may have pads for weight control on each end. The maximum amount of metal that can be removed is then shown, and the weight limits at the center of each bearing journal are also specified.

Drawings of rotating parts or assemblies may have specifications for limits on static or dynamic balance. Instructions as to the location and method of metal removal or addition in order to obtain balance are then shown on the drawing.

Qualifying Tests. Drawings of parts of assemblies in which fluid leakage may be detrimental to performance may have a specification for a pressure test to evaluate leakage. A pressure vessel may have a specification for a proof test or a rotating body may have a specification for a spin test to determine that the object will meet performance requirements.

1.4.5 Release of Drawings and Specifications

A formal method of notifying other departments in the organization that drawings and specifications have been prepared is commonly used. This may be accomplished by a decision that lists parts, assemblies, and other necessary specifications for manufacture and assembly. Some organizations use a drawing release form for the same purpose. Regardless of the name by which it is known, the procedure initiates the processes in other departments to obtain tooling, purchase materials, and provide for manufacturing and assembly facilities.

Many drawings undergo changes for such purposes as to correct design or drafting errors, improve the design, or facilitate manufacturing or assembly. If the revised part is interchangeable with the previous version, the same drawing number is retained. If the part is not interchangeable, a new drawing number is assigned. Usually, the changes and the reasons for the changes are given on the decision or drawing change notice.

1.4.6 Deviations

Inevitably, situations arise in which parts do not conform to drawings. In periods of materials shortages, it may become necessary to make a materials substitution. Moreover, manufacturing errors can occur or manufacturing processes may need to be altered quickly for improvement of the part. Such temporary changes can be processed much more quickly through a deviation letter than through the decision process. A *deviation letter* specifies the part number and name, the products affected, the nature of the departure from specifications, the corrective action to be taken, and the records to be kept of the usage of deviant parts.

1.5 LEGAL CONSIDERATIONS IN DESIGN

Legal considerations have always been included in design to some extent, but they came to prominence in 1963 when the concept of strict liability was first enunciated in a court decision [*Greenman* v. *Yuba Power Products, Inc.*, 377 P. 2d 897 (1963)] and then was formally established in the Restatement of Torts (2d), Sec. 402A (1965).

In 1970, the National Commission on Product Safety issued a report which included statistics showing that the incidence of product-related injuries was very high. The report concluded that although the user, the environment, and the product were all involved, the best place to reduce the potential for injury was in the design of the products involved. This report, along with a heightened awareness of product-related problems, also contributed to the increase in product liability litigation and further delineation of the legal responsibilities of the designer and manufacturer.

The law addressing the responsibilities and duties of designers and manufacturers changes rapidly; thus details will not be presented here. Instead, the emphasis of the laws as they affect designers, manufacturers, and sellers of products will be discussed.

The law, through the various theories under which lawsuits are filed, addresses contractural representations (express warranty); implied representations of performance and operation (implied warranty); conduct of designers, manufacturers, sellers, and users (negligence); and the characteristics of the product exclusive of the conduct of all involved with the product (strict liability). Litigation affecting machines and their designers is most often filed under negligence or strict liability theories, both of which may allege the presence of a defect. Thus a major concern of designers would be to eliminate or reduce the effect of defects present in products.

A *product defect* is a characteristic of a product that makes it substandard. These characteristics, in a legal sense, lead to conditions under which a product is unreasonably dangerous or hazardous when used in certain expected or foreseeable ways.

The standards applied and the determination of whether a product (as a result of the defined characteristic) is unreasonably dangerous or hazardous is done by either a jury or a judge in court rather than by the action of the designer's peers.

The types of defects encountered may be categorized as manufacturing defects, warning defects, and design defects. *Manufacturing defects* occur when a product is not made to the designer's or manufacturer's own standards, i.e., blueprints, layouts, or specifications. Examples are holes drilled the wrong size or in the wrong place, a different material used than was specified, or welds that do not meet the designer's or manufacturer's specifications.

Warning defects occur when proper warnings are not present at hazardous locations, thus creating a defect. The warnings may be absent, insufficient in extent, unreadable, unclear, or inadequate.

Design defects occur when a product is manufactured to the designer's drawings and specifications and functions as intended by the designer and the manufacturer but is alleged to be unreasonably hazardous when used in an expected or foreseeable manner.

Since the concept of a defective design was originated in the courts, the definitions and associated tests were legal in nature rather than rooted in engineering. In an attempt to clarify the concept of a design defect, the California Supreme Court, in the case of *Barker* v. *Lull Engineering Co.,* 573 P. 2d. 443 (1978), established two tests to be applied to a product to determine if a design defect existed. If a product does not perform as safely as an ordinary user or consumer would expect when it is used in a reasonably foreseeable manner or if the benefits of a design are not greater than the risks of danger inherent in the use of the product with all things considered, then the product may be found defective.

The *consumer-expectation test* used is based on the idea that consumers expect products to operate reliably and predictably and that if the products fail, the failure will not cause harm. The risk-benefit or risk-utility analysis assumes that all factors involved in designing the product were included and evaluated in arriving at the final design chosen; thus there are no better ways of designing and manufacturing the product to accomplish its intended purposes. When the product design and manufacturing are completed, the hazards that remain have to be evaluated both on the basis of the probability that harm will occur and on all the consequences of that harm, including its seriousness and costs to all involved. Then this evaluation is balanced against the utility or benefits of the product when it is used in a foreseeable manner.

Close examination of consumer expectations and risk-benefit (or utility) considerations show that in many cases conformity to good design practices and procedures, with a heavy emphasis on safety considerations that were well known and utilized prior to the development of product liability litigation, would significantly reduce the occurrence of design defects and the resulting legal actions.

In many states, the final fault is evaluated by the jury or the judge on a comparative basis. Thus if a judgment is rendered against a manufacturer, the percentage of the fault is also established by the jury or the judge. The injured party then recovers only the same percentage of the judgment as the percentage of fault not assigned to the injured party.

The law varies from state to state on how long the injured party has after the harm is done to file the suit. This period of time is called the *statute of limitations.* If a lawsuit is not filed within the time specified by the statute of limitations, it cannot be filed at all.

Another period of time, called the *statute of repose,* is in effect in some states. This period of time starts when the product is put in service. When a product is older than the statute of repose specifies, only under certain conditions may a lawsuit be filed.

No specific lengths of time are given in this section because of the variance among states and changes occurring in the various laws involved. For such specific information as the time involved or other laws involved, either a lawyer should be consulted or an updated legal publication such as *Products Liability,* by L. R. Frumer and M. I. Friedman (Matthew Bender, N.Y.) or *American Law of Products Liability,* by R. D. Hursh and H. J. Bailey (2d ed., Lawyers Cooperative Publishing Company, Rochester, N.Y. 1976), should be consulted.

This discussion of legal considerations in design is necessarily brief and general because of the volatility of the law and the overall field. More complete discussions in the law, engineering, and all aspects of the area can be found in other publications such as Weinstein et al. [1.22], Thorpe and Middendorf [1.23], Colangelo and Thornton [1.24], Philo [1.25], Goodman [1.26], and Dieter [1.15].

1.6 STANDARDS, CODES, AND GOVERNMENTAL REGULATIONS IN DESIGN

1.6.1 Definitions and Descriptions

Design constraints, in addition to those provided by the engineer's management and sales organizations and the marketplace, now include standards, codes, and governmental regulations, both domestic and foreign.

A *standard* is defined as a criterion, rule, principle, or description considered by an authority, or by general consent or usage and acceptance, as a basis for comparison or judgment or as an approved model. The terms *standards* and *specifications* are sometimes used interchangeably; however, *standards* refer to generalized situations, whereas *specifications* refer to specialized situations. For example, a standard might refer to mechanical power transmission equipment; a specification might refer to a particular gear drive.

A *code* is a systematic collection of existing laws of a country or of rules and regulations relating to a given subject. Federal, state, or local governments may adopt engineering, design, or safety codes as part of their own laws.

Governmental regulations are the regulations developed as a result of legislation to control some area of activity. Examples are the regulations developed by the Occupational Safety and Health Administration (OSHA). These regulations, in addition to setting up various methods of operation of the areas controlled, refer to standards and codes which are then given the status and weight of laws.

Standards may be classified as mandatory or voluntary, although standards established as voluntary may be made mandatory if they become a part of a code or by themselves are referenced in governmental regulations having the effect of law.

1.6.2 Categorization by Source

Standards may be categorized by source of development as follows:

1. Governmental regulations
2. Governmental standards
3. Consensus standards
4. Technical society, trade association, and industry standards
5. Company standards
6. Standards of good engineering practice
7. Standards of consumer expectations

Governmental Regulations. Governmental regulations function as standards and also create specific standards. Examples are OSHA regulations, CPSC regulations and standards, and the National Highway Traffic Safety Administration Motor Vehicle Safety Standards.

In addition to the regulations and standards developed by these and other governmental agencies, the regulations and standards include, by reference, other standards, such as those of the American National Standards Institute (ANSI), the Society of Automotive Engineers (SAE), and the American Society for Testing and Materials (ASTM), thus giving the referenced standards the same weight as the governmental regulations and standards. Regulations and standards developed or referenced by the government are considered as mandatory standards and have the weight of laws.

Governmental Standards. Another category of governmental standards consists of those which cover items purchased by the U.S. government and its branches. In order for an item to be considered for purchase by the U.S. government, the item must meet Air Force–Navy Aeronautical (AN or AND) standards, military standards (MS), or governmental specifications (GSA), which are standards covering all items not covered in the AN, AND, and MS standards.

Consensus Standards. Consensus standards are standards developed by a group representing all who are interested in the standard. The group is composed of representatives of the manufacturers, sellers, users, and the general or affected public. All items in the standard have to be unanimously agreed to (i.e., a consensus must be reached) before the standard is published. Since a consensus has to be reached for the standard to be accepted, many compromises have to be made. Thus consensus standards—and, for that matter, all standards developed with input from several involved parties—represent a minimum level of acceptance and are regarded generally as minimum standards. ANSI and ASTM standards generally fall into the consensus category.

Technical Societies and Trade Associations. Technical societies and trade associations develop standards which are applicable to their constituents. These standards are also known as industrial standards and are not true consensus standards unless the public or users of the products are involved in the standards formulation.

One example occurs in the agricultural equipment industry. The Farm and Industrial Equipment Institute (FIEI) is the trade association to which most of the manufacturers belong. The FIEI proposes and assists in developing standards which are published by the American Society of Agricultural Engineers or the Society of Automotive Engineers, or both. These standards include characteristics of farm crops (useful in harvesting, storing, and transporting), specifications for farm-implement mounting and operation so that farm equipment made by one manufacturer can be used with that made by another manufacturer, and safety and design specifications for items such as grain dryers, augers, and farm-implement controls.

Company Standards. Company standards are those developed by or within an individual company and include such things as specific fasteners, sizes of steel plates or shapes to be purchased, and drafting practices or design practices. Rarely are these standards used outside of a given company. These standards usually refer to or use outside standards wherever applicable.

Standards of Good Engineering Practice. The standards of good engineering practice are not as clearly defined as those previously discussed. Hammer [1.20] states that the mark of a good engineer, and inferentially, good engineering practice, is the design of a product or system to preclude failures, accidents, injuries, and damage. This increases safety and reliability when specific technical requirements do not exist or when conditions are other than ideal. Good engineering practice includes designing at least to minimum standards and generally beyond what the standards require in an effort to minimize failures and their effects, such as machine downtime, lost time, injuries, and damage. Some of the considerations in designing to good engineering practice standards are ease of operation, ease of manufacturability, accessibility for adjustments and service, ease of maintenance, ease of repair, safety, reliability, and overall economic feasibility.

Standards of Consumer and User Expectations. Consumer and user expectations are another source of standards that are not clearly defined. In many cases, these expectation standards have been established in the marketplace and in the courts through product liability litigation.

When a consumer or user purchases or uses a product, certain expectations of performance, safety, reliability, and predictability of operation are present. For example, a person purchasing an automobile expects it to deliver the performance advertised by the manufacturer and the dealer: start reliably, stop predictably and reliably, and when in motion, speed up, slow down, and steer in a predictably reliable manner. If a brake locks when applied or the steering does not respond, the automobile has not met what would be standard consumer expectations. The failure to meet these expectations provides impetus for product liability actions, depending on the effects of not meeting the expectations. This is particularly true if personal injury, death, or property damage results. A court decision, *Barker* v. *Lull Engineering Co., Inc.,* discussed in Sec. 1.5 and accepted in many jurisdictions, established a legal criterion or standard to use in evaluating designs for meeting consumer and user expectations.

1.6.3 Categorization by Function

Functionally, all the standards discussed previously can be classified as follows:

1. Interchangeability standards
2. Performance standards
3. Construction standards
4. Safety standards
5. Test-procedure or test-method standards

There is much overlap in the functional categories. Although the standard may be listed as a safety standard, the safety may be specified in terms of machine construction or performance. For example, ANSI/ASME standard B15.1-1992 is entitled "Safety Standard for Mechanical Power Transmission Apparatus." It specifies performance requirements for the types of guarding which apply to mechanical power transmission apparatuses and shows some construction information.

Examples of interchangeability standards are SAE standard J403h, May, 1992, "Chemical Composition of SAE Carbon Steels," SAE standard J246, June 1993, "Spherical and Flanged Sleeve (Compression) Tube Fittings," and the ANSI standards in the C78 series which standardize incandescent light bulbs and screw bases. Because of these interchangeability standards, an SAE 1020 steel is the same in any part of the country, a hydraulic machine using compression fittings that were manufactured in one part of the country can be serviced or replaced with hydraulic compression tube fittings locally available in other parts of the country, and in the last case, when a bulb is blown in a lighting fixture, the fixture does not have to be taken to the store to be certain that the correct bulb is purchased.

Examples of test-procedure or test-method standards are SAE standard J406, "Methods of Determining Hardenability of Steels," ASTM standard E84-91a, "Standard Test Method for Surface Burning Characteristics of Building Materials," and ASTM standard E108-93 (reapproved 1970), "Standard Test Methods for Fire Tests of Roof Coverings." Actually, the testing standards are written to assist in achieving interchangeable or repeatable test results; thus these two categories also overlap.

1.6.4 Sources of General Information

A further discussion of the history of standards and standards-making organizations can be found in Peters [1.27]. Further information about standards in general can be found in Talbot and Stephens [1.28] and in Refs. [1.29] to [1.32], taken from Klaas [1.33].

1.6.5 Use of Standards, Codes, and Governmental Regulations in Design

In design, the development of a product or a system requires the solution of a great many repetitive problems, such as the specification of a sheet metal thickness, the selection of fasteners, the construction of welded joints, the specification of materials in noncritical areas, and other recurring problems.

Standards provide the organized solution to recurring problems. For example, an engineer does not have to design a new cap screw each time a fastener is required. All that is needed is either a company standard or an SAE standard which details the screws already designed; the engineer can quickly select one and pursue other design problems. In fact, the presence of standards allows the designer more time to create or innovate, since solutions to recurring problems of the type discussed above are provided.

Standards can also provide economy by minimizing the number of items to be carried in inventory and the number of different manufacturing operations for a given product. Henderson [1.34] cites the example of a five-sided box formed from sheet metal which had 320 different holes of nine different diameters, of which 243 were tapped. The remaining nontapped holes were for machine screws with nuts and lock washers. Sixteen different screws and rivets were required, and the labor costs required to make certain the correct fasteners were present were high.

In a design review, it was found that 304 of the 320 holes could be made the same size and that 4 different fasteners could be used rather than the original 16. Specifying a single-diameter hole for 95 percent of the cases increased production while lowering costs significantly.

Standards allow the use of technicians or drafters to do the detail work and free the designer, since company standards will generally provide analyses and sizes and finishes of raw materials either available in stock or commercially available. Other standard manuals provide tap drill sizes, bushings, standard bores and shaft sizes for bearings, and other information in this regard.

Engineers and management may perceive standards as stifling originality or creativity and being an onerous burden. In many cases, what may be meant is that the standards do not allow or recommend design practices that are detrimental in terms of pollution, safety, or some other effect on the user, consumer, or society and will require the manufacturer to spend time and money to make the proposed product meet the standards. This argument usually arises when the engineer and/or management had very little input into creation of the standard and the provisions of the standard require redesign or elimination of the product in question.

Some of these products should not have been marketed in the first place. Some standards have required conditions of performance that were beyond the state of the art of measure when insufficient or arbitrary input was used to establish the standard. However, when standards are published, there is always inertia and resistance to change or a required modification because of a standard. The other extreme of resistance is use of the standard as a design specification with very little effort made to exceed the requirements of the standard.

In general, standards are minimum requirements, particularly when proposed as consensus standards, since much compromise is required to make a standard under these conditions. The competent designer, while not always unquestioningly accepting all the standards affecting the product, uses them as a guide and as a source of information to assist in the design and to identify areas of concern.

In the case of governmental regulations and standards, the use of these and other referenced standards is required by law. The use of other consensus or industry standards as a minimum usually indicates use of the standards of good engineering practice. However, if the standard is inadequate, meeting the standard does not guarantee that the design is satisfactory. In some cases, standards-making organizations have been found liable for an inadequate standard.

The engineer should be aware that designs and applications of standards in the design process may be evaluated not by peers, but by the courts. The final evaluations will be made by nontechnical people: users, consumers, and ultimately society in general.

A standards search should be initiated in the design process either at the stage where all available information is researched or at the stage where problem-solving and solution constraints are determined. Sources for locating standards are listed at the end of this chapter. In many cases, engineering departments will be involved in developing standards that affect their product and will have a file of applicable standards.

Since standards for a specific product, such as bakery equipment, reference general standards (for example, conveyors, power transmission apparatus), the general standards should also be available in the file.

1.7 SOURCES OF STANDARDS, CODES, GOVERNMENTAL REGULATIONS, INDEXES, AND STANDARDIZATION ACTIVITIES

1.7.1 General

The information provided for sources, indexes, and activities is taken in large part from Klass [1.33] and Talbot and Stephens [1.28] and is categorized as domestic mandatory standards, domestic voluntary standards, codes and recommended practices, and foreign standards. A general source guide for regulations, codes, standards, and publications is Miller [1.35].

1.7.2 Domestic Mandatory Standards

The domestic mandatory standards are published by the U.S. government and include AN, AND, and MS series of standards. (For sources see Refs. [1.36] and [1.37].)

Reference [1.38] lists all unclassified specifications and standards adopted by the Department of Defense. This reference includes listings by title and by specification and standard numbers as well as availability, number, and date of the latest edition. A subject classification is also listed [1.39].

Reference [1.40] indexes General Services Administration (GSA) nonmilitary standards for common items used by government agencies. The listings are alphabetical by title; numerical by specification, commercial item, or standard numbers; and numerical by federal supply classification (FSC) numbers.

The executive departments and agencies of the federal government publish general and permanent rules in the *Code of Federal Regulation* (CFR) [1.41], which is published annually, and the *Federal Register* [1.42], which is published daily, providing current general and permanent rules between revisions of the CFR.

The Occupational Safety and Health Administration (OSHA), established in 1970, is responsible for producing mandatory standards for the workplace, which are available from Refs. [1.43] and [1.44] and are also published under Title 19 of the CFR [1.41].

The Consumer Product Safety Commission (CPSC), established in 1972, is responsible for producing mandatory standards for consumer products. These standards are also published in Title 16 of the CFR [1.41].

The Institute of Basic Standards of the National Institute of Standards and Technology (NIST), a part of the Department of Commerce, prepares basic standards, including those for measurement of electricity, temperature, mass, and length. These standards and other associated publications may be obtained from the Superintendent of Documents, Washington, D.C. Information on ordering these documents is in Title 15 of the CFR, parts 200–299 [1.41]. The NIST also has standards on information processing [1.45] and an *Index of State Specifications and Standards* [1.46].

1.7.3 Domestic Voluntary Standards, Codes, and Recommended Practices

Voluntary Standards. The official coordinating organization in the United States for voluntary standards is the American National Standards Institute (ANSI) [1.47]. Other general standards organizations are the American Society for Testing and Materials (ASTM) and Underwriters Laboratories, Inc. (UL). In addition, professional societies, trade associations, and other organizations formed of people and organizations having like interests develop and promulgate voluntary standards.

The *American Society for Testing and Materials* is an international and nonprofit organization formed in 1898 to develop standards on the characteristics and performance of materials, products, systems, and services while promoting related knowledge. In addition, ASTM has become a managing organization for developing consensus standards. ASTM publishes standards and allied publications and provides a catalog and index which are continually being updated. For the latest catalogs, ASTM should be contacted directly [1.48]. Many of the ASTM standards are designated as ANSI standards also.

Underwriters Laboratories, Inc. was established in 1894 to develop standards and testing capabilities for fire resistance and electric devices. The standards were to include performance specifications and testing. A certification and testing service has evolved along with the development of safety standards for other products as well as those initially included. Many of the UL standards are also designated as ANSI standards. A listing of UL standards and other relevant information can be found in Ref. [1.49], which is available from UL.

Professional societies, trade associations, and other groups promulgate standards in their own areas of interest. Chumas [1.50] and Ref. [1.51] list the groups that fall into these categories.

Aids to finding U.S. voluntary standards are Slattery [1.52], Chumas [1.53], Parker et al. [1.54], and Hilyard et al. [1.55]. Although Slattery [1.52] is relatively old, the data base from which the reference was printed has been kept up to date and a computer printout of the up-to-date list, which provides key word access to standards, can be obtained from the National Bureau of Standards.

Standards or standards' titles and description search systems available are listed in Refs. [1.56] to [1.58]. Philo [1.25], which ostensibly is a publication for lawyers, is of particular interest in that it covers U.S. voluntary standards in chaps. 17 and 18 and international safety standards and information sources in chap. 19.

Codes. A *code* is defined as a collection of rules or standards applying to one topic. In many cases codes become a part of federal, state, or local laws, thus becoming mandatory in application.

The National Fire Protection Association (NFPA) publishes an annual set of codes [1.59], which includes the National Electric Codes as well as NFPA standards and additional safety and design publications emphasizing fire prevention. Many of these codes and standards are also designated ANSI standards.

Other well-known codes are the *National Electrical Safety Code* [1.60], the *ASME Boiler and Pressure Vessel Code* [1.61], the *Safety Code for Elevators and Escalators* [1.62], and the *ASME Performance Test Codes* [1.63]. The *Structural Welding Code* [1.64], the *Uniform Plumbing Code* [1.65], and the *Uniform Mechanical Code* [1.66] are available and should be referred to by engineers, even though they do not appear to directly affect mechanical designers. In these and similar cases, the requirements of the codes dictate how products to be used in these areas should be designed. Another useful collection of codes was compiled by the International Labour Office and is available as *A Model Code of Safety Regulations for the Guidance of Governments and Industry* [1.67]. This discussion and listing of codes is not to be considered complete, but it does provide a listing of which mechanical designers should be aware for reference in designing products.

References for Good Engineering Practice. There are many references that provide other standards, standard data, recommended practices, and good reference information that should be accessible to engineering designers. These and similar publications are considered standards of good engineering practice. The listing of references is not to be construed as all-encompassing, and the order listed does not indicate relative importance. It does include well-known and widely accepted and used references and data. Reference [1.20] and Refs. [1.68] to [1.78] are handbooks and compilations of reference data.

Professional Societies, Trade Associations, and Miscellaneous. In addition to the other references presented, professional societies and trade associations publish standards in specific areas that are accepted and used by machine designers. A representative listing is found in Refs. [1.79] to [1.103].

1.7.4 Foreign Standards

Standardization activity has become worldwide in nature to facilitate international exchange of goods and services and to provide a common international framework for scientific, technologic, and economic activity. Designers of products to be sold outside the United States must include considerations of applicable international and foreign standards to effectively market their products.

The International Organization for Standardization (ISO) covers all fields except electrical and electronic engineering and is located in Geneva, Switzerland. The International Electrotechnical Commission (IEC) covers electrical and electronic engineering and is located at the same address in Geneva as the ISO. The American National Standards Institute (ANSI) is a member body of the ISO and the IEC and, as such, is the sole sales agent for foreign and international standards in the United States. Catalogs of ISO and IEC standards, as well as their standards, may be ordered from ANSI. In addition, 17 countries have standards organizations listed as correspondent members. In this case, the standards organizations are not yet the official national standards organizations for the countries in this category. The latest ISO catalog lists all the members and correspondent members.

The ISO catalog provides names, addresses, and telephone, telegraph, and telex addresses for each of the member body organizations and names and addresses for the correspondent member organizations.

There are regional standardization activities in addition to those in the countries listed in the ISO catalog. Examples are:

1. Central America Research Institute for Industry, Institute de Recherches et de Technologie, Industrielles pour d'Amerique centrale (ICAITI), Guatemala City, Guatemala. Its members are Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.
2. European Union, which publishes *Journal Officiel des Communautés Européennes,* Rue De la Loi 200, B-1049, Bruxelles, Belgium. This journal is published daily and is the equivalent to the *U.S. Federal Register,* publishing laws, regulations, and standards.

Indexes for standards of a given country may be obtained either through ANSI or by contacting the official standards organization of the country. The most up-to-date listing of addresses is found in the ISO catalog of standards referred to previously.

Chumas [1.104] is an index by key word in context and includes addresses of standards organizations of various countries in 1974, in addition to 2700 standards titles of the ISO, IEC, the International Commission on Rules for the approval of Electrical Equipment (CEE), the International Special Committee on Radio Interference (CISPR), and the International Organization of Legal Metrology (OIML).

The *World Standards Mutual Speedy Finder* [1.105] is a six-volume set having tables of equivalent standards for the United States, the United Kingdom, West Germany, France, Japan, and the ISO in the following areas: vol. 1, Chemicals; vol. 2, Electrical and Electronics; vol. 3, Machinery; vol. 4, Materials; vol. 5, Safety, Electrical and Electronics Products; and vol. 6, Steel. The NBS Standards Information Service, library, and bibliography search referred to previously also include standards from many of the foreign countries.

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