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DRAFTING PRACTICES

American National Standard Drafting Practices

Several American National Standards for use in preparing engineering drawings and related documents are referred to for use.

Sizes of Drawing Sheets.—Recommended trimmed sheet sizes, based on ANSI Y14.1-1980 (R1987), are shown in the following table.

Size, inches				Metric Size, mm			
A	8½ × 11	*D*	22 × 34	*A*0	841 × 1189	*A*3	297 × 420
B	11 × 17	*E*	34 × 44	*A*1	594 × 841	*A*4	210 × 297
C	17 × 22	*F*	28 × 40	*A*2	420 × 594		

The standard sizes shown by the left-hand section of the table are based on the dimensions of the commercial letter head, 8½ × 11 inches, in general use in the United States. The use of the basic sheet size 8½ × 11 inches and its multiples permits filing of small tracings and folded blueprints in commercial standard letter files with or without correspondence. These sheet sizes also cut without unnecessary waste from the present 36-inch rolls of paper and cloth.

For drawings made in the metric system of units or for foreign correspondence, it is recommended that the metric standard trimmed sheet sizes be used. (Right-hand section of table.) These sizes are based on the width-to-length ratio of 1 to $\sqrt{2}$.

Line Conventions and Drawings.—American National Standard Y14.2M-1979 (R1987) establishes line and lettering practices for engineering drawings. The line conventions and the symbols for section lining are as shown on pages 607 and 608.

Approximate width of THICK lines for metric drawings are 0.6 mm, and for inch drawings, 0.032 inch. Approximate width of THIN lines for metric drawings are 0.3 mm, and for inch drawings, 0.016 inch. These approximate line widths are intended to differentiate between THICK and THIN lines and are not values for control of acceptance or rejection of the drawings.

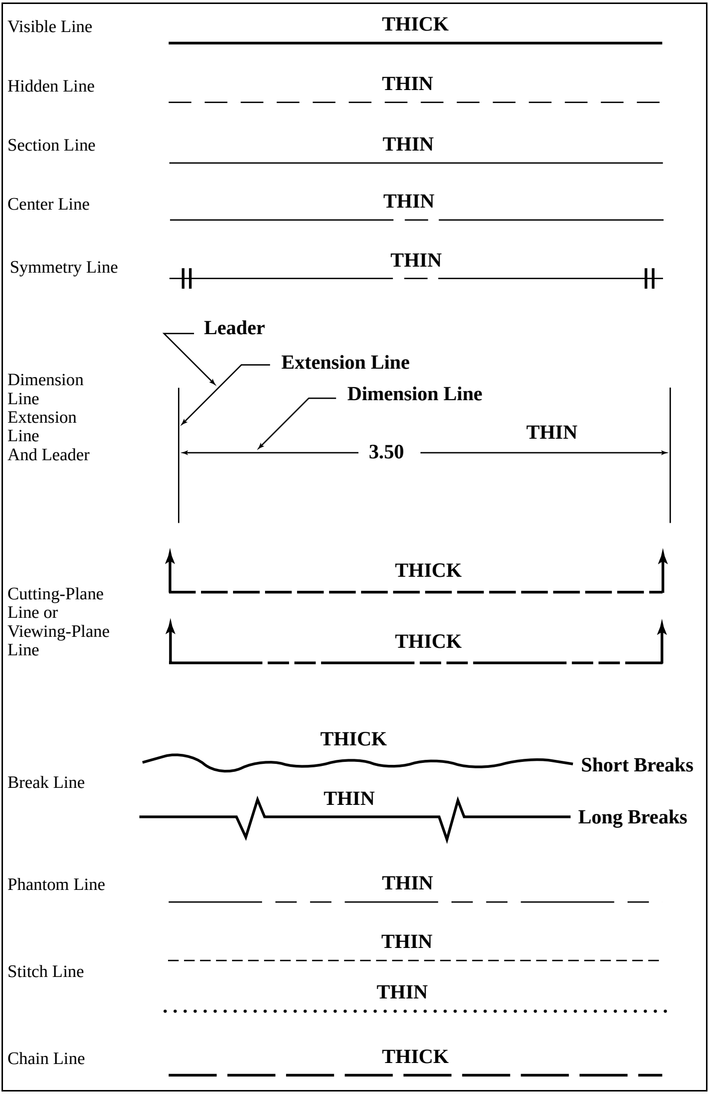
Surface-Texture Symbols.—A detailed explanation of the use of surface-texture symbols from American National Standard Y14.36M-1996 begins on page 705.

Geometric Dimensioning and Tolerancing.—ANSI/ASME Y14.5M-1994, “Dimensioning and Tolerancing,” covers dimensioning, tolerancing, and similar practices for engineering drawings and related documentation. The mathematical definitions of dimensioning and tolerancing principles are given in the standard ANSI/ASME Y14.5.1M-1994. ISO standards ISO 8015 and ISO 26921 contain a detailed explanation of ISO geometric dimensioning and tolerancing practices.

Geometric dimensioning and tolerancing provides a comprehensive system for symbolically defining the geometrical tolerance zone within which features must be contained. It provides an accurate transmission of design specifications among the three primary users of engineering drawings; design, manufacturing and quality assurance.

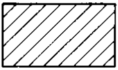
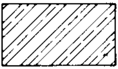
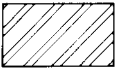
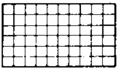
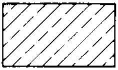
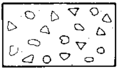
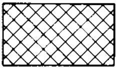
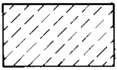
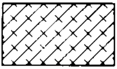
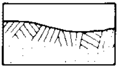
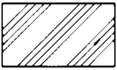
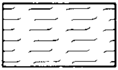
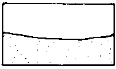
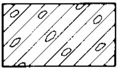
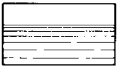
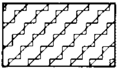
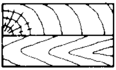
Some techniques introduced in ANSI/ASME Y14.5M-1994 have been accepted by ISO. These techniques include projected tolerance zone, three-plane datum concept, total runout tolerance, multiple datums, and datum targets. Although this Standard follows ISO practice closely, there are still differences between ISO and U.S. practice. (A comparison of the symbols used in ISO standards and Y14.5M is given on page 609.)

American National Standard for Engineering Drawings
ANSI/ASME Y14.2M-1992



American National Standard Symbols for Section Lining

ANSI Y14.2M-1979 (R1987)

	Cast and Malleable iron (Also for general use of all materials)		Titanium and refractory material
	Steel		Electric windings, electro magnets, resistance, etc.
	Bronze, brass, copper, and compositions		Concrete
	White metal, zinc, lead, babbitt, and alloys		Marble, slate, glass, porcelain, etc.
	Magnesium, aluminum, and aluminum alloys		Earth
	Rubber, plastic electrical insulation		Rock
	Cork, felt, fabric, leather, fiber		Sand
	Sound insulation		Water and other liquids
	Thermal insulation		Wood-across grain Wood-with grain

Comparison of ANSI and ISO Geometric Symbols *ASME Y14.5M-1994*

Symbol for	ANSI Y14.5	ISO	Symbol for	ANSI Y14.5	ISO	Symbol for	ANSI Y14.5	ISO
Straightness	⏤	⏤	Circular Runout[a]	↗	↗	Feature Control Frame	⌖ Ø 0.5 Ⓜ A B C	⌖ Ø 0.5 Ⓜ A B C
Flatness	⏥	⏥	Total Runout[a]	⌰	⌰	Datum Feature[a]	-A-	
Circularity	○	○	At Maximum Material Condition	Ⓜ	Ⓜ	All Around - Profile		 (proposed)
Cylindricity	⌭	⌭	At Least Material Condition	Ⓛ	Ⓛ	Conical Taper	⌲	⌲
Profile of a Line	⌒	⌒	Regardless of Feature Size	**NONE**	**NONE**	Slope	⌳	⌳
Profile of a Surface	⌓	⌓	Projected Tolerance Zone	Ⓟ	Ⓟ	Counterbore/Spotface	⌴	⌴ **(proposed)**
Angularity	∠	∠	Diameter	Ø	Ø	Countersink	⌵	⌵ **(proposed)**
Perpendicularity	⊥	⊥	Basic Dimension	$\boxed{50}$	$\boxed{50}$	Depth/Deep	↧	↧ **(proposed)**
Parallelism	//	//	Reference Dimension	**(50)**	**(50)**	Square (Shape)	□	□
Position	⌖	⌖	Datum Target			Dimension Not to Scale	$\underline{15}$	$\underline{15}$
Concentricity/Coaxiality	◎	◎	Target Point	✕	✕	Number of Times/Places	**8X**	**8X**
Symmetry	⌯	⌯	Dimension Origin			Arc Length	$\overset{\frown}{105}$	$\overset{\frown}{105}$
Radius	**R**	**R**	Spherical Radius	**SR**	**SR**	Sperical Diameter	**SØ**	**SØ**

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[a] Arrowheads may be filled in.

One major area of disagreement is the ISO “principle of independency” versus the “Taylor principle.” Y14.5M and standard U.S. practice both follow the Taylor principle, in which a geometric tolerancing zone may not extend beyond the boundary (or envelope) of perfect form at MMC (maximum material condition). This boundary is prescribed to control variations as well as the size of individual features. The U.S. definition of independency further defines features of size as being independent and not required to maintain a perfect relationship with other features. The envelope principle is optional in treatment of these principles. A summary of the application of ANSI/ASME geometric control symbols and their use with basic dimensions and modifiers is given in Table 1.

Table 1. Application of Geometric Control Symbols

Type	Geometric Characteristics		Pertains To	Basic Dimensions	Feature Modifier	Datum Modifier
Form	⏤	Straightness	ONLY individual feature		Modifier not applicable	NO datum
	○	Circularity				
	⏥	Flatness				
	⌭	Cylindricity				
Profile	⌒	Profile (Line)	Individual or related	Yes if related		RFS implied unless MMC or LMC is stated
	⌓	Profile (Surface)				
Orientation	∠	Angularity	ALWAYS related feature(s)	Yes	RFS implied unless MMC or LMC is stated	
	⊥	Perpendicularity				
	∥	Parallelism				
Location	⌖	Position		Yes		
	◎	Concentricity			Only RFS	Only RFS
	⌯	Symmetry				
Runout	↗	Circular Runout				
	⌰	Total Runout				

Five types of geometric control, when datums are indicated, when basic dimensions are required, and when MMC and LMC modifiers may be used.

ANSI/ASME Y14.5M features metric SI units (the International System of Units), but customary units may be used without violating any principles. On drawings where all dimensions are either in millimeters or in inches, individual identification of linear units is not required. However, the drawing should contain a note stating UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN MILLIMETERS (or IN INCHES, as applicable). According to this Standard, all dimensions are applicable at a temperature of 20 C (68 F) unless otherwise specified. Compensation may be made for measurements taken at other temperatures.

Angular units are expressed in degrees and decimals of a degree (35.4) or in degrees (°), minutes (′), and seconds (″), as in 35° 25′ 10″.A 90-degree angle is implied where center lines and depicting features are shown on a drawing at right angles and no angle is specified. A 90-degree BASIC angle applies where center lines of features in a pattern or surface shown at right angles on a drawing are located or defined by basic dimensions and no angle is specified.

Definitions.—The following terms are defined as their use applies to ANSI/ASME Y14.5M.

Datum Feature: The feature of a part that is used to establish a datum.

Datum Identifier: The graphic symbol on a drawing used to indicate the datum feature.

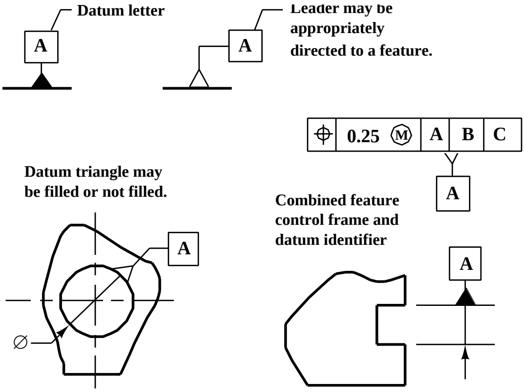


Fig. 1. Datum Feature Symbol

Datum Plane: The individual theoretical planes of the reference frame derived from a specified datum feature. A datum is the origin from which the location or other geometric characteristics of features of a part are established.

Datum Reference Frame: Sufficient features on a part are chosen to position the part in relationship to three planes. The three planes are mutually perpendicular and together called the datum reference frame. The planes follow an order of precedence and allow the part to be immobilized. This immobilization in turn creates measurable relationships among features.

Datum Simulator: Formed by the datum feature contacting a precision surface such as a surface plate, gage surface or by a mandrel contacting the datum. Thus, the plane formed by contact restricts motion and constitutes the specific reference surface from which measurements are taken and dimensions verified. The datum simulator is the practical embodiment of the datum feature during manufacturing and quality assurance.

Datum Target: A specified point, line, or area on a part, used to establish a datum.

Degrees of Freedom: The six directions of movement or translation are called degrees of freedom in a three-dimensional environment. They are up-down, left-right, fore-aft, roll, pitch and yaw.

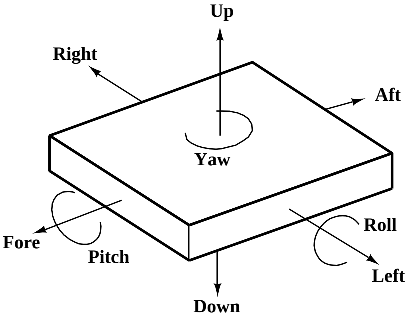


Fig. 2. Degrees of Freedom (Movement) That Must be Controlled, Depending on the Design Requirements.

Dimension, Basic: A numerical value used to describe the theoretically exact size, orientation, location, or optionally, profile, of a feature or datum or datum target. Basic dimensions are indicated by a rectangle around the dimension and are not toleranced directly or by default. The specific dimensional limits are determined by the permissible variations as established by the tolerance zone specified in the feature control frame. A dimension is only considered basic for the geometric control to which it is related.

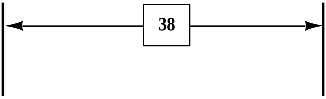


Fig. 3. Basic Dimensions

Dimension Origin: Symbol used to indicate the origin and direction of a dimension between two features. The dimension originates from the symbol with the dimension tolerance zone being applied at the other feature.

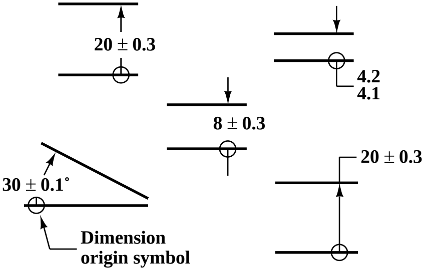


Fig. 4. Dimension Origin Symbol

Dimension, Reference: A dimension, usually without tolerance, used for information purposes only. Considered to be auxiliary information and not governing production or inspection operations. A reference dimension is a repeat of a dimension or is derived from a calculation or combination of other values shown on the drawing or on related drawings.

Feature Control Frame: Specification on a drawing that indicates the type of geometric control for the feature, the tolerance for the control, and the related datums, if applicable.

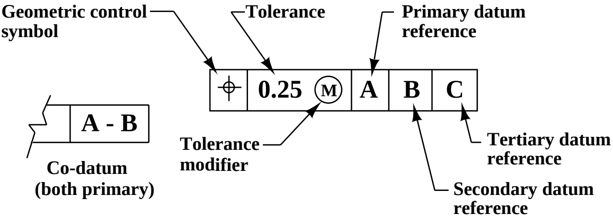


Fig. 5. Feature Control Frame and Datum Order of Precedence

Feature: The general term applied to a physical portion of a part, such as a surface, hole, pin, tab, or slot.

Least Material Condition (LMC): The condition in which a feature of size contains the least amount of material within the stated limits of size, for example, upper limit or maximum hole diameter and lower limit or minimum shaft diameter.

Limits, Upper and Lower (UL and LL): The arithmetic values representing the maximum and minimum size allowable for a dimension or tolerance. The upper limit represents the maximum size allowable. The lower limit represents the minimum size allowable.

Maximum Material Condition (MMC): The condition in which a feature of size contains the maximum amount of material within the stated limits of size. For example, the lower limit of a hole is the minimum hole diameter. The upper limit of a shaft is the maximum shaft diameter.

Position: Formerly called true position, position is the theoretically exact location of a feature established by basic dimensions.

Regardless of Feature Size (RFS): The term used to indicate that a geometric tolerance or datum reference applies at any increment of size of the feature within its tolerance limits. RFS is the default condition unless MMC or LMC is specified. The concept is now the default in ANSI/ASME Y14.5M-1994, unless specifically stated otherwise. Thus the symbol for RFS is no longer supported in ANSI/ASME Y14.5M-1994.

Size, Actual: The term indicating the size of a feature as produced.

Size, Feature of: A feature that can be described dimensionally. May include a cylindrical or spherical surface, or a set of two opposed parallel surfaces associated with a size dimension.

Tolerance Zone Symmetry: In geometric tolerancing, the tolerance value stated in the feature control frame is always a single value. Unless otherwise specified, it is assumed that the boundaries created by the stated tolerance are bilateral and equidistant about the perfect form control specified. However, if desired, the tolerance may be specified as unilateral or unequally bilateral. (See Figs. 6 through 8)

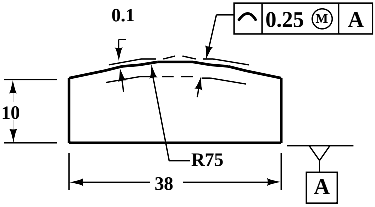
Tolerance, Bilateral: A tolerance where variation is permitted in both directions from the specified dimension. Bilateral tolerances may be equal or unequal.

Tolerance, Geometric: The general term applied to the category of tolerances used to control form, profile, orientation, location, and runout.

Tolerance, Unilateral: A tolerance where variation is permitted in only one direction from the specified dimension.

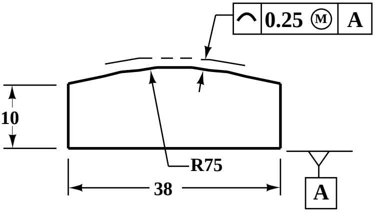
True Geometric Counterpart: The theoretically perfect plane of a specified datum feature.

Virtual Condition: A constant boundary generated by the collective effects of the feature size, its specified MMC or LMC material condition, and the geometric tolerance for that condition.



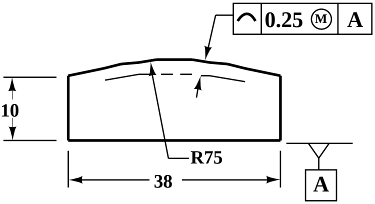
Bilateral zone with 0.1 of the 0.25 tolerance outside perfect form.

Fig. 6. Application of a bilateral geometric tolerance



Unilateral zone with all of the 0.25 tolerance outside perfect form.

Fig. 7. Application of a unilateral geometric tolerance zone outside perfect form



Unilateral zone with all of the 0.25 tolerance inside perfect form.

Fig. 8. Application of a unilateral geometric tolerance zone inside a perfect form

Datum Referencing.—A datum indicates the origin of a dimensional relationship between a toleranced feature and a designated feature or features on a part. The designated feature serves as a datum feature, whereas its true geometric counterpart establishes the datum plane. Because measurements cannot be made from a true geometric counterpart, which is theoretical, a datum is assumed to exist in, and be simulated by the associated processing equipment.

For example, machine tables and surface plates, although not true planes, are of such quality that they are used to simulate the datums from which measurements are taken and dimensions are verified. When magnified, flat surfaces of manufactured parts are seen to have irregularities, so that contact is made with a datum plane formed at a number of surface extremities or high points.

Sufficient datum features, those most important to the design of the part, are chosen to position the part in relation to a set of three mutually perpendicular planes, the datum reference frame. This reference frame exists only in theory and not on the part. Therefore, it is necessary to establish a method for simulating the theoretical reference frame from existing features of the part. This simulation is accomplished by positioning the part on appropriate datum features to adequately relate the part to the reference frame and to restrict the degrees of freedom of the part in relation to it.

These reference frame planes are simulated in a mutually perpendicular relationship to provide direction as well as the origin for related dimensions and measurements. Thus, when the part is positioned on the datum reference frame (by physical contact between each datum feature and its counterpart in the associated processing equipment), dimensions related to the datum reference frame by a feature control frame are thereby mutually perpendicular. This theoretical reference frame constitutes the three-plane dimensioning system used for datum referencing.

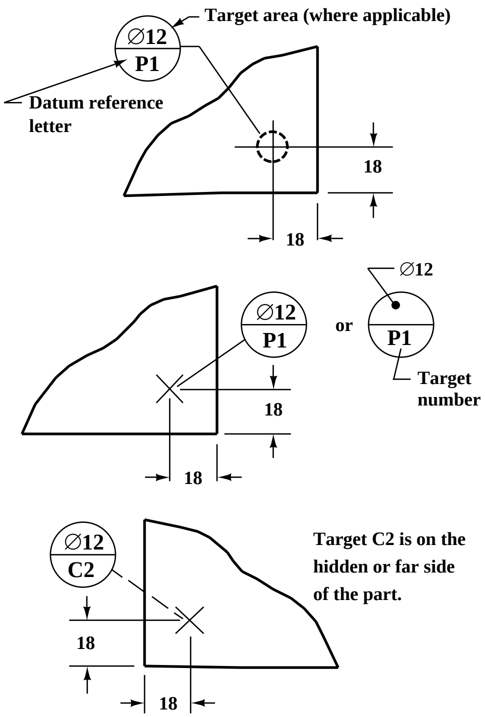


Fig. 9. Datum target symbols

Depending on the degrees of freedom that must be controlled, a simple reference frame may suffice. At other times, additional datum reference frames may be necessary where physical separation occurs or the functional relationship. Depending on the degrees of freedom that must be controlled, a single datum of features require that datum reference frames be applied at specific locations on the part. Each feature control frame must contain the datum feature references that are applicable.

Datum Targets: Datum targets are used to establish a datum plane. They may be points, lines or surface areas. Datum targets are used when the datum feature contains irregularities, the surface is blocked by other features or the entire surface cannot be used. Examples where datum targets may be indicated include uneven surfaces, forgings and castings, weldments, non-planar surfaces or surfaces subject to warping or distortion. The datum target symbol is located outside the part outline with a leader directed to the target point, area or line. The targets are dimensionally located on the part using basic or toleranced dimensions. If basic dimensions are used, established tooling or gaging tolerances apply. A solid leader line from the symbol to the target is used for visible or near side locations with a dashed leader line used for hidden or far side locations. The datum target symbol is divided horizontally into two halves. The top half contains the target point area if applicable; the bottom half contains a datum feature identifying letter and target number. Target numbers indicate the quantity required to define a primary, secondary, or tertiary datum. If indicating a target point or target line, the top half is left blank. Datum targets and datum features may be combined to form the datum reference frame, Fig. 9.

Datum Target points: A datum target point is indicated by the symbol “X,” which is dimensionally located on a direct view of the surface. Where there is no direct view, the point location is dimensioned on multiple views.

Datum Target Lines: A datum target line is dimensionally located on an edge view of the surface using a phantom line on the direct view. Where there is no direct view, the location is dimensioned on multiple views. Where the length of the datum target line must be controlled, its length and location are dimensioned.

Datum Target Areas: Where it is determined that an area or areas of flat contact are necessary to ensure establishment of the datum, and where spherical or pointed pins would be inadequate, a target area of the desired shape is specified. Examples include the need to span holes, finishing irregularities, or rough surface conditions. The datum target area may be indicated with the “X” symbol as with a datum point, but the area of contact is specified in the upper half of the datum target symbol. Datum target areas may additionally be specified by defining controlling dimensions and drawing the contact area on the feature with section lines inside a phantom outline of the desired shape.

Positional Tolerance.—A positional tolerance defines a zone within which the center, axis, or center plane of a feature of size is permitted to vary from true (theoretically exact) position. Basic dimensions establish the true position from specified datum features and between interrelated features. A positional tolerance is indicated by the position symbol, a tolerance, and appropriate datum references placed in a feature control frame.

Modifiers: In certain geometric tolerances, modifiers in the form of additional symbols may be used to further refine the level of control. The use of the MMC and LMC modifiers has been common practice for many years. However, several new modifiers were introduced with the 1994 U.S. national standard. Some of the new modifiers include free state, tangent plane and statistical tolerancing, Fig. 10.

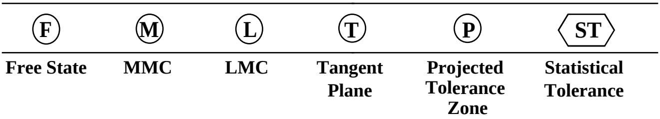


Fig. 10. Tolerance modifiers

Projected Tolerance Zone: Application of this concept is recommended where any variation in perpendicularity of the threaded or press-fit holes could cause fasteners such as screws, studs, or pins to interfere with mating parts. An interference with subsequent parts can occur even though the hole axes are inclined within allowable limits. This interference occurs because, without a projected tolerance zone, a positional tolerance is applied only to the depth of threaded or press-fit holes. Unlike the floating fastener application involving clearance holes only, the attitude of a fixed fastener is restrained by the inclination of the produced hole into which it assembles.

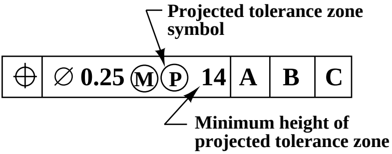


Fig. 11. Projected tolerance zone callout

With a projected tolerance zone equal to the thickness of the mating part, the inclinational error is accounted for in both parts. The minimum extent and direction of the projected tolerance zone is shown as a value in the feature control frame. The zone may be shown in a drawing view as a dimensioned value with a heavy chain line drawn closely adjacent to an extension of the center line of the hole.

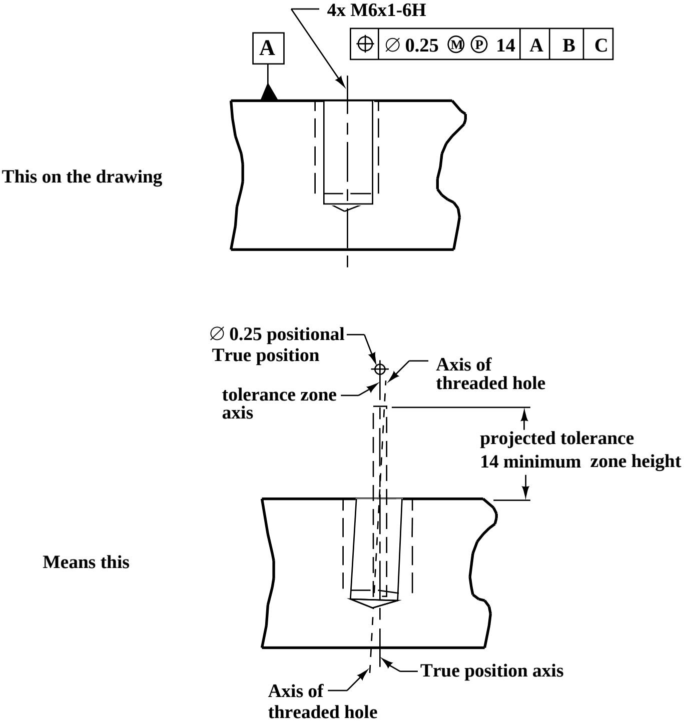


Fig. 12. Projected tolerance zone application

Statistical Tolerance: The statistical tolerancing symbol is a modifier that may be used to indicate that a tolerance is controlled statistically as opposed to being controlled arithmetically. With arithmetic control, assembly tolerances are typically divided arithmetically among the individual components of the assembly. This division results in the assumption that assemblies based on “worst case” conditions would be guaranteed to fit because the worst case set of parts fit — so that anything better would fit as well.

When this technique is restrictive, statistical tolerancing, via the symbol, may be specified in the feature control frame as a method of increasing tolerances for individual parts. This procedure may reduce manufacturing costs because its use changes the assumption that statistical process control may make a statistically significant quantity of parts fit, but not absolutely all. The technique should only be used when sound statistical methods are employed.

Tangent Plane: When it is desirable to control the surface of a feature by the contacting or high points of the surface, a tangent plane symbol is added as a modifier to the tolerance in the feature control frame, Fig. 13.

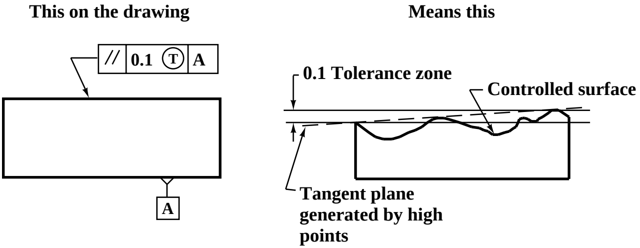


Fig. 13. Tangent plane modifier

Free State: The free state modifier symbol is used when the geometric tolerance applies to the feature in its "free state," or after removal of any forces used in the manufacturing process. With removal of forces the part may distort due to gravity, flexibility, spring back, or other release of internal stresses developed during fabrication. Typical applications include parts with extremely thin walls and non-rigid parts made of rubber or plastics. The modifier is placed in the tolerance portion of the feature control frame and follows any other modifier.

The above examples are just a few of the numerous concepts and related symbols covered by ANSI/ASME Y14.5M-1994. Refer to the standard for a complete discussion with further examples of the application of geometric dimensioning and tolerancing principles.

Checking Drawings.—In order that the drawings may have a high standard of excellence, a set of instructions, as given in the following, has been issued to the checkers, and also to the draftsmen and tracers in the engineering department of a well-known machine-building company.

Inspecting a New Design: When a new design is involved, first inspect the layouts carefully to see that the parts function correctly under all conditions, that they have the proper relative proportions, that the general design is correct in the matters of strength, rigidity, bearing areas, appearance, convenience of assembly, and direction of motion of the parts, and that there are no interferences. Consider the design as a whole to see if any improvements can be made. If the design appears to be unsatisfactory in any particular, or improvements appear to be possible, call the matter to the attention of the chief engineer.

Checking for Strength: Inspect the design of the part being checked for strength, rigidity, and appearance by comparing it with other parts for similar service whenever possible, giving preference to the later designs in such comparison, unless the later designs are known to be unsatisfactory. If there is any question regarding the matter, compute the stresses and deformations or find out whether the chief engineer has approved the stresses or deformations that will result from the forces applied to the part in service. In checking parts that are to go on a machine of increased size, be sure that standard parts used in similar machines and proposed for use on the larger machine, have ample strength and rigidity under the new and more severe service to which they will be put.

Materials Specified: Consider the kind of material required for the part and the various possibilities of molding, forging, welding, or otherwise forming the rough part from this material. Then consider the machining operations to see whether changes in form or design will reduce the number of operations or the cost of machining.

See that parts are designed with reference to the economical use of material, and whenever possible, utilize standard sizes of stock and material readily obtainable from local dealers. In the case of alloy steel, special bronze, and similar materials, be sure that the material can be obtained in the size required.

Method of Making Drawing: Inspect the drawing to see that the projections and sections are made in such a way as to show most clearly the form of the piece and the work to be done on it. Make sure that any worker looking at the drawing will understand what the shape of the piece is and how it is to be molded or machined. Make sure that the delineation is correct in every particular, and that the information conveyed by the drawing as to the form of the piece is complete.

Checking Dimensions: Check all dimensions to see that they are correct. Scale all dimensions and see that the drawing is to scale. See that the dimensions on the drawing agree with the dimensions scaled from the lay-out. Wherever any dimension is out of scale, see that the dimension is so marked. Investigate any case where the dimension, the scale of the drawing, and the scale of the lay-out do not agree. All dimensions not to scale must be underlined on the tracing. In checking dimensions, note particularly the following points:

See that all figures are correctly formed and that they will print clearly, so that the workers can easily read them correctly.

See that the overall dimensions are given.

See that all witness lines go to the correct part of the drawing.

See that all arrow points go to the correct witness lines.

See that proper allowance is made for all fits.

See that the tolerances are correctly given where necessary.

See that all dimensions given agree with the corresponding dimensions of adjacent parts.

Be sure that the dimensions given on a drawing are those that the machinist will use, and that the worker will not be obliged to do addition or subtraction to obtain the necessary measurements for machining or checking his work.

Avoid strings of dimensions where errors can accumulate. It is generally better to give a number of dimensions from the same reference surface or center line.

When holes are to be located by boring on a horizontal spindle boring machine or other similar machine, give dimensions to centers of bored holes in rectangular coordinates and from the center lines of the first hole to be bored, so that the operator will not be obliged to add measurements or transfer gages.

Checking Assembly: See that the part can readily be assembled with the adjacent parts. If necessary, provide tapped holes for eyebolts and cored holes for tongs, lugs, or other methods of handling.

Make sure that, in being assembled, the piece will not interfere with other pieces already in place and that the assembly can be taken apart without difficulty.

Check the sum of a number of tolerances; this sum must not be great enough to permit two pieces that should not be in contact to come together.

Checking Castings: In checking castings, study the form of the pattern, the methods of molding, the method of supporting and venting the cores, and the effect of draft and rough molding on clearances.

Avoid undue metal thickness, and especially avoid thick and thin sections in the same casting.

Indicate all metal thicknesses, so that the molder will know what chaplets to use for supporting the cores.

See that ample fillets are provided, and that they are properly dimensioned.

See that the cores can be assembled in the mold without crushing or interference.

See that swelling, shrinkage, or misalignment of cores will not make trouble in machining.

See that the amount of extra material allowed for finishing is indicated.

See that there is sufficient extra material for finishing on large castings to permit them to be “cleaned up,” even though they warp. In such castings, make sure that the metal thickness will be sufficient after finishing, even though the castings do warp.

Make sure that sufficient sections are shown so that the pattern makers and molders will not be compelled to make assumptions about the form of any part of the casting. These details are particularly important when a number of sections of the casting are similar in form, while others differ slightly.

Checking Machined Parts: Study the sequences of operations in machining and see that all finish marks are indicated.

See that the finish marks are placed on the lines to which dimensions are given.

See that methods of machining are indicated where necessary.

Give all drill, reamer, tap, and rose bit sizes.

See that jig and gage numbers are indicated at the proper places.

See that all necessary bosses, lugs, and openings are provided for lifting, handling, clamping, and machining the piece.

See that adequate wrench room is provided for all nuts and bolt heads.

Avoid special tools, such as taps, drills, reamers, etc., unless such tools are specifically authorized.

Where parts are right- and left-hand, be sure that the hand is correctly designated. When possible, mark parts as symmetrical, so as to avoid having them right- and left-hand, but do not sacrifice correct design or satisfactory operation on this account.

When heat-treatment is required, the heat-treatment should be specified.

Check the title, size of machine, the scale, and the drawing number on both the drawing and the drawing record card.

ALLOWANCES AND TOLERANCES FOR FITS

Limits and Fits.—Fits between cylindrical parts, i.e., cylindrical fits, govern the proper assembly and performance of many mechanisms. Clearance fits permit relative freedom of motion between a shaft and a hole—axially, radially, or both. Interference fits secure a certain amount of tightness between parts, whether these are meant to remain permanently assembled or to be taken apart from time to time. Or again, two parts may be required to fit together snugly—without apparent tightness or looseness. The designer's problem is to specify these different types of fits in such a way that the shop can produce them. Establishing the specifications requires the adoption of two manufacturing limits for the hole and two for the shaft, and, hence, the adoption of a manufacturing tolerance on each part.

In selecting and specifying limits and fits for various applications, it is essential in the interests of interchangeable manufacturing that 1) standard definitions of terms relating to limits and fits be used; 2) preferred basic sizes be selected wherever possible to reduce material and tooling costs; 3) limits be based upon a series of preferred tolerances and allowances; and 4) a uniform system of applying tolerances (preferably unilateral) be used. These principles have been incorporated in both the American and British standards for limits and fits. Information about these standards is given beginning on page 627.

Basic Dimensions.—The basic size of a screw thread or machine part is the theoretical or nominal standard size from which variations are made. For example, a shaft may have a *basic* diameter of 2 inches, but a maximum variation of minus 0.010 inch may be permitted. The minimum hole should be of basic size wherever the use of standard tools represents the greatest economy. The maximum shaft should be of basic size wherever the use of standard purchased material, without further machining, represents the greatest economy, even though special tools are required to machine the mating part.

Tolerances.—Tolerance is the amount of variation permitted on dimensions or surfaces of machine parts. The tolerance is equal to the difference between the maximum and minimum limits of any specified dimension. For example, if the maximum limit for the diameter of a shaft is 2.000 inches and its minimum limit 1.990 inches, the tolerance for this diameter is 0.010 inch. The extent of these tolerances is established by determining the maximum and minimum clearances required on operating surfaces. As applied to the fitting of machine parts, the word tolerance means the amount that duplicate parts are allowed to vary in size in connection with manufacturing operations, owing to unavoidable imperfections of workmanship. Tolerance may also be defined as the amount that duplicate parts are permitted to vary in size to secure sufficient accuracy without unnecessary refinement. The terms “tolerance” and “allowance” are often used interchangeably, but, according to common usage, *allowance* is a difference in dimensions prescribed to secure various classes of fits between different parts.

Unilateral and Bilateral Tolerances.—The term “unilateral tolerance” means that the total tolerance, as related to a basic dimension, is in *one* direction only. For example, if the basic dimension were 1 inch and the tolerance were expressed as 1.000 – 0.002, or as 1.000 + 0.002, these would be unilateral tolerances because the total tolerance in each is in one direction. On the contrary, if the tolerance were divided, so as to be partly plus and partly minus, it would be classed as “bilateral.”

Thus,

$$1.000\begin{array}{l}+0.001\\-0.001\end{array}$$

is an example of bilateral tolerance, because the total tolerance of 0.002 is given in two directions—plus and minus.

When unilateral tolerances are used, one of the three following methods should be used to express them:

1) Specify, limiting dimensions only as

Diameter of hole: 2.250, 2.252

Diameter of shaft: 2.249, 2.247

2) One limiting size may be specified with its tolerances as

Diameter of hole: $2.250 + 0.002, -0.000$

Diameter of shaft: $2.249 + 0.000, -0.002$

3) The nominal size may be specified for both parts, with a notation showing both allowance and tolerance, as

Diameter of hole: $2\frac{1}{4} + 0.002, -0.000$

Diameter of shaft: $2\frac{1}{4} - 0.001, -0.003$

Bilateral tolerances should be specified as such, usually with plus and minus tolerances of equal amount. An example of the expression of bilateral tolerances is

$$2 \pm 0.001 \quad \text{or} \quad 2\begin{array}{l}+0.001\\-0.001\end{array}$$

Application of Tolerances.—According to common practice, tolerances are applied in such a way as to show the permissible amount of dimensional variation in the direction that is less dangerous. When a variation in either direction is equally dangerous, a bilateral tolerance should be given. When a variation in one direction is more dangerous than a variation in another, a unilateral tolerance should be given in the less dangerous direction.

For nonmating surfaces, or atmospheric fits, the tolerances may be bilateral, or unilateral, depending entirely upon the nature of the variations that develop in manufacture. On mating surfaces, with few exceptions, the tolerances should be unilateral.

Where tolerances are required on the distances between holes, usually they should be bilateral, as variation in either direction is normally equally dangerous. The variation in the distance between shafts carrying gears, however, should always be unilateral and plus; otherwise, the gears might run too tight. A slight increase in the backlash between gears is seldom of much importance.

One exception to the use of unilateral tolerances on mating surfaces occurs when tapers are involved; either bilateral or unilateral tolerances may then prove advisable, depending upon conditions. These tolerances should be determined in the same manner as the tolerances on the distances between holes. When a variation either in or out of the position of the mating taper surfaces is equally dangerous, the tolerances should be bilateral. When a variation in one direction is of less danger than a variation in the opposite direction, the tolerance should be unilateral and in the less dangerous direction.

Locating Tolerance Dimensions.—Only one dimension in the same straight line can be controlled within fixed limits. That dimension is the distance between the cutting surface of the tool and the locating or registering surface of the part being machined. Therefore, it is incorrect to locate any point or surface with tolerances from more than one point in the same straight line.

Every part of a mechanism must be located in each plane. Every operating part must be located with proper operating allowances. After such requirements of location are met, all other surfaces should have liberal clearances. Dimensions should be given between those points or surfaces that it is essential to hold in a specific relation to each other. This restriction applies particularly to those surfaces in each plane that control the location of other component parts. Many dimensions are relatively unimportant in this respect. It is good practice to establish a common locating point in each plane and give, as far as possible, all such dimensions from these common locating points. The locating points on the drawing, the locatingor registering points used for machining the surfaces and the locating points for measuring should all be identical.

The initial dimensions placed on component drawings should be the exact dimensions that would be used if it were possible to work without tolerances. Tolerances should be given in that direction in which variations will cause the least harm or danger. When a variation in either direction is equally dangerous, the tolerances should be of equal amount in both directions, or bilateral. The initial clearance, or allowance, between operating parts should be as small as the operation of the mechanism will permit. The maximum clearance should be as great as the proper functioning of the mechanism will permit.

Direction of Tolerances on Gages.—The extreme sizes for all plain limit gages shall not exceed the extreme limits of the part to be gaged. All variations in the gages, whatever their cause or purpose, shall bring these gages within these extreme limits.

The data for gage tolerances on page 656 cover gages to inspect workpieces held to tolerances in the American National Standard ANSI B4.4M-1981.

Allowance for Forced Fits.—The allowance per inch of diameter usually ranges from 0.001 inch to 0.0025 inch, 0.0015 being a fair average. Ordinarily the allowance per inch decreases as the diameter increases; thus the total allowance for a diameter of 2 inches might be 0.004 inch, whereas for a diameter of 8 inches the total allowance might not be over 0.009 or 0.010 inch. The parts to be assembled by forced fits are usually made cylindrical, although sometimes they are slightly tapered. The advantages of the taper form are that the possibility of abrasion of the fitted surfaces is reduced; that less pressure is required in assembling; and that the parts are more readily separated when renewal is required. On the other hand, the taper fit is less reliable, because if it loosens, the entire fit is free with but little axial movement. Some lubricant, such as white lead and lard oil mixed to the consistency of paint, should be applied to the pin and bore before assembling, to reduce the tendency toward abrasion.

Pressure for Forced Fits.—The pressure required for assembling cylindrical parts depends not only upon the allowance for the fit, but also upon the area of the fitted surfaces, the pressure increasing in proportion to the distance that the inner member is forced in. The approximate ultimate pressure in tons can be determined by the use of the following formula in conjunction with the accompanying table of "Pressure Factors." Assuming that A = area of surface in contact in "fit"; a = total allowance in inches; P = ultimate pressure required, in tons; F = pressure factor based upon assumption that the diameter of the hub is twice the diameter of the bore, that the shaft is of machine steel, and that the hub is of cast iron:

$$P = \frac{A \times a \times F}{2}$$

Pressure Factors

Diameter, Inches	Pressure Factor	Diameter, Inches	Pressure Factor	Diameter, Inches	Pressure Factor	Diameter, Inches	Pressure Factor	Diameter, Inches	Pressure Factor
1	500	3½	132	6	75	9	48.7	14	30.5
1¼	395	3¾	123	6¼	72	9½	46.0	14½	29.4
1½	325	4	115	6½	69	10	43.5	15	28.3
1¾	276	4¼	108	6¾	66	10½	41.3	15½	27.4
2	240	4½	101	7	64	11	39.3	16	26.5
2¼	212	4¾	96	7¼	61	11½	37.5	16½	25.6
2½	189	5	91	7½	59	12	35.9	17	24.8
2¾	171	5¼	86	7¾	57	12½	34.4	17½	24.1
3	156	5½	82	8	55	13	33.0	18	23.4
3¼	143	5¾	78	8½	52	13½	31.7	…	…

Allowance for Given Pressure.—By transposing the preceding formula, the approximate allowance for a required ultimate tonnage can be determined. Thus, $a = \frac{2P}{AF}$. The average ultimate pressure in tons commonly used ranges from 7 to 10 times the diameter in inches.

Expansion Fits.—In assembling certain classes of work requiring a very tight fit, the inner member is contracted by sub-zero cooling to permit insertion into the outer member and a tight fit is obtained as the temperature rises and the inner part expands. To obtain the sub-zero temperature, solid carbon dioxide or "dry ice" has been used but its temperature of about 109 degrees F. below zero will not contract some parts sufficiently to permit insertion in holes or recesses. Greater contraction may be obtained by using high purity liquid nitrogen which has a temperature of about 320 degrees F. below zero. During a temperature reduction from 75 degrees F. to −321 degrees F., the shrinkage per inch of diameter varies from about 0.002 to 0.003 inch for steel; 0.0042 inch for aluminum alloys; 0.0046 inch for magnesium alloys; 0.0033 inch for copper alloys; 0.0023 inch for monel metal; and 0.0017 inch for cast iron (not alloyed). The cooling equipment may vary from an insulated bucket to a special automatic unit, depending upon the kind and quantity of work. One type of unit is so arranged that parts are precooled by vapors from the liquid nitrogen before immersion. With another type, cooling is entirely by the vapor method.

Shrinkage Fits.—General practice seems to favor a smaller allowance for shrinkage fits than for forced fits, although in many shops the allowances are practically the same for each, and for some classes of work, shrinkage allowances exceed those for forced fits. The shrinkage allowance also varies to a great extent with the form and construction of the part that has to be shrunk into place. The thickness or amount of metal around the hole is the most important factor. The way in which the metal is distributed also has an influence on the results. Shrinkage allowances for locomotive driving wheel tires adopted by the American Railway Master Mechanics Association are as follows:

Center diameter, inches	38	44	50	56	62	66
Allowances, inches	0.040	0.047	0.053	0.060	0.066	0.070

Whether parts are to be assembled by forced or shrinkage fits depends upon conditions. For example, to press a tire over its wheel center, without heating, would ordinarily be a rather awkward and difficult job. On the other hand, pins, etc., are easily and quickly forced into place with a hydraulic press and there is the additional advantage of knowing the exact pressure required in assembling, whereas there is more or less uncertainty connected with a shrinkage fit, unless the stresses are calculated. Tests to determine the difference in the quality of shrinkage and forced fits showed that the resistance of a shrinkage fit to slippage for an axial pull was 3.66 times greater than that of a forced fit, and in rotation or torsion, 3.2 times greater. In each comparative test, the dimensions and allowances were the same.

Allowances for Shrinkage Fits.—The most important point to consider when calculating shrinkage fits is the stress in the hub at the bore, which depends chiefly upon the shrinkage allowance. If the allowance is excessive, the elastic limit of the material will be exceeded and permanent set will occur, or, in extreme conditions, the ultimate strength of the metal will be exceeded and the hub will burst. The intensity of the grip of the fit and the resistance to slippage depends mainly upon the thickness of the hub; the greater the thickness, the stronger the grip, and *vice versa.* Assuming the modulus of elasticity for steel to be 30,000,000, and for cast iron, 15,000,000, the shrinkage allowance per inch of nominal diameter can be determined by the following formula, in which A = allowance per inch of diameter; T = true tangential tensile stress at inner surface of outer member; C = factor taken from one of the accompanying tables, *Factors for Calculating Shrinkage Fit Allowances*.

For a cast-iron hub and steel shaft:

$$A = \frac{T(2 + C)}{30{,}000{,}000} \qquad (1)$$

When both hub and shaft are of steel:

$$A = \frac{T(1 + C)}{30{,}000{,}000} \qquad (2)$$

If the shaft is solid, the factor C is taken from Table 1; if it is hollow and the hub is of steel, factor C is taken from Table 2; if it is hollow and the hub is of cast iron, the factor is taken from Table 3.

Table 1. Factors for Calculating Shrinkage Fit Allowances

Ratio of Diameters $\frac{D_2}{D_1}$	Steel Hub	Cast-iron Hub	Ratio of Diameters $\frac{D_2}{D_1}$	Steel Hub	Cast-iron Hub
1.5	0.227	0.234	2.8	0.410	0.432
1.6	0.255	0.263	3.0	0.421	0.444
1.8	0.299	0.311	3.2	0.430	0.455
2.0	0.333	0.348	3.4	0.438	0.463
2.2	0.359	0.377	3.6	0.444	0.471
2.4	0.380	0.399	3.8	0.450	0.477
2.6	0.397	0.417	4.0	0.455	0.482

Values of factor C for solid steel shafts of nominal diameter D_1, and hubs of steel or cast iron of nominal external and internal diameters D_2 and D_1, respectively.

Example 1: A steel crank web 15 inches outside diameter is to be shrunk on a 10-inch solid steel shaft. Required the allowance per inch of shaft diameter to produce a maximum tensile stress in the crank of 25,000 pounds per square inch, assuming the stresses in the crank to be equivalent to those in a ring of the diameter given.

The ratio of the external to the internal diameters equals 15 ÷ 10 = 1.5; $T = 25{,}000$ pounds; from Table 1, $C = 0.227$. Substituting in Formula (2):

$$A = \frac{25{,}000 \times (1 + 0.227)}{30{,}000{,}000} = 0.001 \text{ inch}$$

Example 2: Find the allowance per inch of diameter for a 10-inch shaft having a 5-inch axial through hole, other conditions being the same as in Example 1.

The ratio of external to internal diameters of the hub equals 15 ÷ 10 = 1.5, as before, and the ratio of external to internal diameters of the shaft equals 10 ÷ 5 = 2. From Table 2, we find that factor $C = 0.455$; $T = 25{,}000$ pounds. Substituting these values in Formula (2):

$$A = \frac{25{,}000(1 + 0.455)}{30{,}000{,}000} = 0.0012 \text{ inch}$$

The allowance is increased, as compared with Example 1, because the hollow shaft is more compressible.

Table 2. Factors for Calculating Shrinkage Fit Allowances

$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C	$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C	$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C
1.5	2.0	0.468	2.4	2.0	0.798	3.4	2.0	0.926
	2.5	0.368		2.5	0.628		2.5	0.728
	3.0	0.322		3.0	0.549		3.0	0.637
	3.5	0.296		3.5	0.506		3.5	0.587
1.6	2.0	0.527	2.6	2.0	0.834	3.6	2.0	0.941
	2.5	0.414		2.5	0.656		2.5	0.740
	3.0	0.362		3.0	0.574		3.0	0.647
	3.5	0.333		3.5	0.528		3.5	0.596
1.8	2.0	0.621	2.8	2.0	0.864	3.8	2.0	0.953
	2.5	0.488		2.5	0.679		2.5	0.749
	3.0	0.427		3.0	0.594		3.0	0.656
	3.5	0.393		3.5	0.547		3.5	0.603
2.0	2.0	0.696	3.0	2.0	0.888	4.0	2.0	0.964
	2.5	0.547		2.5	0.698		2.5	0.758
	3.0	0.479		3.0	0.611		3.0	0.663
	3.5	0.441		3.5	0.562		3.5	0.610
2.2	2.0	0.753	3.2	2.0	0.909	…	…	…
	2.5	0.592		2.5	0.715		…	…
	3.0	0.518		3.0	0.625		…	…
	3.5	0.477		3.5	0.576		…	…

Values of factor C for hollow steel shafts and cast-iron hubs.
Notation as in Table 1.

Table 3. Factors for Calculating Shrinkage Fit Allowances

$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C	$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C	$\frac{D_2}{D_1}$	$\frac{D_1}{D_0}$	C
1.5	2.0	0.455	2.4	2.0	0.760	3.4	2.0	0.876
	2.5	0.357		2.5	0.597		2.5	0.689
	3.0	0.313		3.0	0.523		3.0	0.602
	3.5	0.288		3.5	0.481		3.5	0.555
1.6	2.0	0.509	2.6	2.0	0.793	3.6	2.0	0.888
	2.5	0.400		2.5	0.624		2.5	0.698
	3.0	0.350		3.0	0.546		3.0	0.611
	3.5	0.322		3.5	0.502		3.5	0.562
1.8	2.0	0.599	2.8	2.0	0.820	3.8	2.0	0.900
	2.5	0.471		2.5	0.645		2.5	0.707
	3.0	0.412		3.0	0.564		3.0	0.619
	3.5	0.379		3.5	0.519		3.5	0.570
2.0	2.0	0.667	3.0	2.0	0.842	4.0	2.0	0.909
	2.5	0.524		2.5	0.662		2.5	0.715
	3.0	0.459		3.0	0.580		3.0	0.625
	3.5	0.422		3.5	0.533		3.5	0.576
2.2	2.0	0.718	3.2	2.0	0.860	…	…	…
	2.5	0.565		2.5	0.676		…	…
	3.0	0.494		3.0	0.591		…	…
	3.5	0.455		3.5	0.544		…	…

Values of factor C for hollow steel shafts of external and internal diameters D_1 and D_0, respectively, and steel hubs of nominal external diameter D_2.

Example 3: If the crank web in Example 1 is of cast iron and 4000 pounds per square inch is the maximum tensile stress in the hub, what is the allowance per inch of diameter?

$$\frac{D_2}{D_1} = 1.5 \qquad T = 4000$$

In Table 1, we find that $C = 0.234$. Substituting in Formula (1), for cast-iron hubs, $A = 0.0003$ inch, which, owing to the lower tensile strength of cast iron, is endout one-third the shrinkage allowance in Example 1, although the stress is two-thirds of the elastic limit.

Temperatures for Shrinkage Fits.—The temperature to which the outer member in a shrinkage fit should be heated for clearance in assembling the parts depends on the total expansion required and on the coefficient α of linear expansion of the metal (i.e., the increase in length of any section of the metal in any direction for an increase in temperature of 1 degree F). The total expansion in diameter that is required consists of the total allowance for shrinkage and an added amount for clearance. The value of the coefficient α is, for nickel-steel, 0.000007; for steel in general, 0.0000065; for cast iron, 0.0000062. As an example, take an outer member of steel to be expanded 0.005 inch per inch of internal diameter, 0.001 being the shrinkage allowance and the remainder for clearance. Then

$$\alpha \times t^{\circ} = 0.005$$

$$t = \frac{0.005}{0.0000065} = 769 \text{ degrees F}$$

The value t is the number of degrees F that the temperature of the member must be raised above that of the room temperature.

ANSI Standard Limits and Fits (ANSI B4.1-1967 (R1994)).—This American National Standard for Preferred Limits and Fits for Cylindrical Parts presents definitions of terms applying to fits between plain (non threaded) cylindrical parts and makes recommendations on preferred sizes, allowances, tolerances, and fits for use wherever they are applicable. This standard is in accord with the recommendations of American-British-Canadian (ABC) conferences up to a diameter of 20 inches. Experimental work is being carried on with the objective of reaching agreement in the range above 20 inches. The recommendations in the standard are presented for guidance and for use where they might serve to improve and simplify products, practices, and facilities. They should have application for a wide range of products.

As revised in 1967, and reaffirmed in 1979, the definitions in ANSI B4.1 have been expanded and some of the limits in certain classes have been changed.

Factors Affecting Selection of Fits.—Many factors, such as length of engagement, bearing load, speed, lubrication, temperature, humidity, and materials must be taken into consideration in the selection of fits for a particular application, and modifications in the ANSI recommendations may be required to satisfy extreme conditions. Subsequent adjustments may also be found desirable as a result of experience in a particular application to suit critical functional requirements or to permit optimum manufacturing economy.

Definitions.—The following terms are defined in this standard:

Nominal Size: The nominal size is the designation used for the purpose of general identification.

Dimension: A dimension is a geometrical characteristic such as diameter, length, angle, or center distance.

Size: Size is a designation of magnitude. When a value is assigned to a dimension, it is referred to as the size of that dimension. (It is recognized that the words “dimension” and “size” are both used at times to convey the meaning of magnitude.)

Allowance: An allowance is a prescribed difference between the maximum material limits of mating parts. (See definition of *Fit*). It is a minimum clearance (positive allowance) or maximum interference (negative allowance) between such parts.

Tolerance: A tolerance is the total permissible variation of a size. The tolerance is the difference between the limits of size.

Basic Size: The basic size is that size from which the limits of size are derived by the application of allowances and tolerances.

Design Size: The design size is the basic size with allowance applied, from which the limits of size are derived by the application of tolerances. Where there is no allowance, the design size is the same as the basic size.

Actual Size: An actual size is a measured size.

Limits of Size: The limits of size are the applicable maximum and minimum sizes.

Maximum Material Limit: A maximum material limit is that limit of size that provides the maximum amount of material for the part. Normally it is the maximum limit of size of an external dimension or the minimum limit of size of an internal dimension.*

Minimum Material Limit: A minimum material limit is that limit of size that provides the minimum amount of material for the part. Normally it is the minimum limit of size of an external dimension or the maximum limit of size of an internal dimension.*

Tolerance Limit: A tolerance limit is the variation, positive or negative, by which a size is permitted to depart from the design size.

Unilateral Tolerance: A unilateral tolerance is a tolerance in which variation is permitted in only one direction from the design size.

Bilateral Tolerance: A bilateral tolerance is a tolerance in which variation is permitted in both directions from the design size.

Unilateral Tolerance System: A design plan that uses only unilateral tolerances is known as a Unilateral Tolerance System.

Bilateral Tolerance System: A design plan that uses only bilateral tolerances is known as a Bilateral Tolerance System.

Fit: Fit is the general term used to signify the range of tightness that may result from the application of a specific combination of allowances and tolerances in the design of mating parts.

Actual Fit: The actual fit between two mating parts is the relation existing between them with respect to the amount of clearance or interference that is present when they are assembled. (Fits are of three general types: clearance, transition, and interference.)

Clearance Fit: A clearance fit is one having limits of size so specified that a clearance always results when mating parts are assembled.

Interference Fit: An interference fit is one having limits of size so specified that an interference always results when mating parts are assembled.

Transition Fit: A transition fit is one having limits of size so specified that either a clearance or an interference may result when mating parts are assembled.

Basic Hole System: A basic hole system is a system of fits in which the design size of the hole is the basic size and the allowance, if any, is applied to the shaft.

Basic Shaft System: A basic shaft system is a system of fits in which the design size of the shaft is the basic size and the allowance, if any, is applied to the hole.

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* An example of exceptions: an exterior corner radius where the maximum radius is the minimum material limit and the minimum radius is the maximum material limit.

Preferred Basic Sizes.—In specifying fits, the basic size of mating parts may be chosen from the decimal series or the fractional series in the following table.

Table 1. Preferred Basic Sizes

Decimal			Fractional					
0.010	2.00	8.50	$\frac{1}{64}$	0.015625	$2\frac{1}{4}$	2.2500	$9\frac{1}{2}$	9.5000
0.012	2.20	9.00	$\frac{1}{32}$	0.03125	$2\frac{1}{2}$	2.5000	10	10.0000
0.016	2.40	9.50	$\frac{1}{16}$	0.0625	$2\frac{3}{4}$	2.7500	$10\frac{1}{2}$	10.5000
0.020	2.60	10.00	$\frac{3}{32}$	0.09375	3	3.0000	11	11.0000
0.025	2.80	10.50	$\frac{1}{8}$	0.1250	$3\frac{1}{4}$	3.2500	$11\frac{1}{2}$	11.5000
0.032	3.00	11.00	$\frac{5}{32}$	0.15625	$3\frac{1}{2}$	3.5000	12	12.0000
0.040	3.20	11.50	$\frac{3}{16}$	0.1875	$3\frac{3}{4}$	3.7500	$12\frac{1}{2}$	12.5000
0.05	3.40	12.00	$\frac{1}{4}$	0.2500	4	4.0000	13	13.0000
0.06	3.60	12.50	$\frac{5}{16}$	0.3125	$4\frac{1}{4}$	4.2500	$13\frac{1}{2}$	13.5000
0.08	3.80	13.00	$\frac{3}{8}$	0.3750	$4\frac{1}{2}$	4.5000	14	14.0000
0.10	4.00	13.50	$\frac{7}{16}$	0.4375	$4\frac{3}{4}$	4.7500	$14\frac{1}{2}$	14.5000
0.12	4.20	14.00	$\frac{1}{2}$	0.5000	5	5.0000	15	15.0000
0.16	4.40	14.50	$\frac{9}{16}$	0.5625	$5\frac{1}{4}$	5.2500	$15\frac{1}{2}$	15.5000
0.20	4.60	15.00	$\frac{5}{8}$	0.6250	$5\frac{1}{2}$	5.5000	16	16.0000
0.24	4.80	15.50	$\frac{11}{16}$	0.6875	$5\frac{3}{4}$	5.7500	$16\frac{1}{2}$	16.5000
0.30	5.00	16.00	$\frac{3}{4}$	0.7500	6	6.0000	17	17.0000
0.40	5.20	16.50	$\frac{7}{8}$	0.8750	$6\frac{1}{2}$	6.5000	$17\frac{1}{2}$	17.5000
0.50	5.40	17.00	1	1.0000	7	7.0000	18	18.0000
0.60	5.60	17.50	$1\frac{1}{4}$	1.2500	$7\frac{1}{2}$	7.5000	$18\frac{1}{2}$	18.5000
0.80	5.80	18.00	$1\frac{1}{2}$	1.5000	8	8.0000	19	19.0000
1.00	6.00	18.50	$1\frac{3}{4}$	1.7500	$8\frac{1}{2}$	8.5000	$19\frac{1}{2}$	19.5000
1.20	6.50	19.00	2	2.0000	9	9.0000	20	20.0000
1.40	7.00	19.50	…	…	…	…	…	…
1.60	7.50	20.00	…	…	…	…	…	…
1.80	8.00	…	…	…	…	…	…	…

All dimensions are in inches.

Preferred Series of Tolerances and Allowances (In thousandths of an inch)

0.1	1	10	100	0.3	3	30	…
…	1.2	12	125	…	3.5	35	…
0.15	1.4	14	…	0.4	4	40	…
…	1.6	16	160	…	4.5	45	…
…	1.8	18	…	0.5	5	50	…
0.2	2	20	200	0.6	6	60	…
…	2.2	22	…	0.7	7	70	…
0.25	2.5	25	250	0.8	8	80	…
…	2.8	28	…	0.9	9	…	…

Standard Tolerances.—The series of standard tolerances shown in Table 1 are so arranged that for any one grade they represent approximately similar production difficulties throughout the range of sizes. This table provides a suitable range from which appropriate tolerances for holes and shafts can be selected and enables standard gages to be used. The tolerances shown in Table 1 have been used in the succeeding tables for different classes of fits.

Table 1. ANSI Standard Tolerances *ANSI B4.1-1967 (R1987)*

Nominal Size, Inches		Grade									
		4	5	6	7	8	9	10	11	12	13
Over	To	Tolerances in thousandths of an inch[a]									
0	0.12	0.12	0.15	0.25	0.4	0.6	1.0	1.6	2.5	4	6
0.12	0.24	0.15	0.20	0.3	0.5	0.7	1.2	1.8	3.0	5	7
0.24	0.40	0.15	0.25	0.4	0.6	0.9	1.4	2.2	3.5	6	9
0.40	0.71	0.2	0.3	0.4	0.7	1.0	1.6	2.8	4.0	7	10
0.71	1.19	0.25	0.4	0.5	0.8	1.2	2.0	3.5	5.0	8	12
1.19	1.97	0.3	0.4	0.6	1.0	1.6	2.5	4.0	6	10	16
1.97	3.15	0.3	0.5	0.7	1.2	1.8	3.0	4.5	7	12	18
3.15	4.73	0.4	0.6	0.9	1.4	2.2	3.5	5	9	14	22
4.73	7.09	0.5	0.7	1.0	1.6	2.5	4.0	6	10	16	25
7.09	9.85	0.6	0.8	1.2	1.8	2.8	4.5	7	12	18	28
9.85	12.41	0.6	0.9	1.2	2.0	3.0	5.0	8	12	20	30
12.41	15.75	0.7	1.0	1.4	2.2	3.5	6	9	14	22	35
15.75	19.69	0.8	1.0	1.6	2.5	4	6	10	16	25	40
19.69	30.09	0.9	1.2	2.0	3	5	8	12	20	30	50
30.09	41.49	1.0	1.6	2.5	4	6	10	16	25	40	60
41.49	56.19	1.2	2.0	3	5	8	12	20	30	50	80
56.19	76.39	1.6	2.5	4	6	10	16	25	40	60	100
76.39	100.9	2.0	3	5	8	12	20	30	50	80	125
100.9	131.9	2.5	4	6	10	16	25	40	60	100	160
131.9	171.9	3	5	8	12	20	30	50	80	125	200
171.9	200	4	6	10	16	25	40	60	100	160	250

[a] All tolerances above heavy line are in accordance with American-British-Canadian (ABC) agreements.

Table 2. Relation of Machining Processes to Tolerance Grades

This chart may be used as a general guide to determine the machining processes that will under normal conditions, produce work withen the tolerance grades indicated.

(See also *Relation of Surface Roughness to Tolerances* starting on page 702.)

MACHINING OPERATION	TOLERANCE GRADES									
	4	5	6	7	8	9	10	11	12	13
Lapping & Honing	■	■								
Cylindrical Grinding		■	■	■						
Surface Grinding		■	■	■	■					
Diamond Turning		■	■	■						
Diamond Boring		■	■	■						
Broaching		■	■	■	■					
Reaming			■	■	■	■	■			
Turning				■	■	■	■	■	■	■
Boring					■	■	■	■	■	■
Milling							■	■	■	■
Planing & Shaping							■	■	■	■
Drilling							■	■	■	■

ANSI Standard Fits.—Tables 3 through 9 inclusive show a series of standard types and classes of fits on a unilateral hole basis, such that the fit produced by mating parts in any one class will produce approximately similar performance throughout the range of sizes. These tables prescribe the fit for any given size, or type of fit; they also prescribe the standard limits for the mating parts that will produce the fit. The fits listed in these tables contain all those that appear in the approved American-British-Canadian proposal.

Selection of Fits: In selecting limits of size for any application, the type of fit is determined first, based on the use or service required from the equipment being designed; then the limits of size of the mating parts are established, to insure that the desired fit will be produced.

Theoretically, an infinite number of fits could be chosen, but the number of standard fits shown in the accompanying tables should cover most applications.

Designation of Standard Fits: Standard fits are designated by means of the following symbols which, facilitate reference to classes of fit for educational purposes. The symbols are not intended to be shown on manufacturing drawings; instead, sizes should be specified on drawings.

The letter symbols used are as follows:

RC = Running or Sliding Clearance Fit
LC = Locational Clearance Fit
LT = Transition Clearance or Interference Fit
LN = Locational Interference Fit
FN = Force or Shrink Fit

These letter symbols are used in conjunction with numbers representing the class of fit; thus FN 4 represents a Class 4, force fit.

Each of these symbols (two letters and a number) represents a complete fit for which the minimum and maximum clearance or interference and the limits of size for the mating parts are given directly in the tables.

Description of Fits.—The classes of fits are arranged in three general groups: running and sliding fits, locational fits, and force fits.

Running and Sliding Fits (RC): Running and sliding fits, for which limits of clearance are given in Table 2, are intended to provide a similar running performance, with suitable lubrication allowance, throughout the range of sizes. The clearances for the first two classes, used chiefly as slide fits, increase more slowly with the diameter than for the other classes, so that accurate location is maintained even at the expense of free relative motion.

These fits may be described as follows:

RC 1 *Close sliding fits* are intended for the accurate location of parts that must assemble without perceptible play.

RC 2 *Sliding fits* are intended for accurate location, but with greater maximum clearance than class RC 1. Parts made to this fit move and turn easily but are not intended to run freely, and in the larger sizes may seize with small temperature changes.

RC 3 *Precision running fits* are about the closest fits that can be expected to run freely, and are intended for precision work at slow speeds and light journal pressures, but are not suitable where appreciable temperature differences are likely to be encountered.

RC 4 *Close running fits* are intended chiefly for running fits on accurate machinery with moderate surface speeds and journal pressures, where accurate location and minimum play are desired.

RC 5 and RC 6 *Medium running fits* are intended for higher running speeds, or heavy journal pressures, or both.

RC 7 *Free running fits* are intended for use where accuracy is not essential, or where large temperature variations are likely to be encountered, or under both these conditions.

RC 8 and RC 9 *Loose running fits* are intended for use where wide commercial tolerances may be necessary, together with an allowance, on the external member.

Locational Fits (LC, LT, and LN): Locational fits are fits intended to determine only the location of the mating parts; they may provide rigid or accurate location, as with interference fits, or provide some freedom of location, as with clearance fits. Accordingly, they are divided into three groups: clearance fits (LC), transition fits (LT), and interference fits (LN).

These are described as follows:

LC *Locational clearance fits* are intended for parts which are normally stationary, but that can be freely assembled or disassembled. They range from snug fits for parts requiring accuracy of location, through the medium clearance fits for parts such as spigots, to the looser fastener fits where freedom of assembly is of prime importance.

LT *Locational transition fits* are a compromise between clearance and interference fits, for applications where accuracy of location is important, but either a small amount of clearance or interference is permissible.

LN *Locational interference fits* are used where accuracy of location is of prime importance, and for parts requiring rigidity and alignment with no special requirements for bore pressure. Such fits are not intended for parts designed to transmit frictional loads from one part to another by virtue of the tightness of fit. These conditions are covered by force fits.

Force Fits: (FN): Force or shrink fits constitute a special type of interference fit, normally characterized by maintenance of constant bore pressures throughout the range of sizes. The interference therefore varies almost directly with diameter, and the difference between its minimum and maximum value is small, to maintain the resulting pressures within reasonable limits.

These fits are described as follows:

FN 1 *Light drive fits* are those requiring light assembly pressures, and produce more or less permanent assemblies. They are suitable for thin sections or long fits, or in cast-iron external members.

FN 2 *Medium drive fits* are suitable for ordinary steel parts, or for shrink fits on light sections. They are about the tightest fits that can be used with high-grade cast-iron external members.

FN 3 *Heavy drive fits* are suitable for heavier steel parts or for shrink fits in medium sections.

FN 4 and FN 5 *Force fits* are suitable for parts that can be highly stressed, or for shrink fits where the heavy pressing forces required are impractical.

Graphical Representation of Limits and Fits.—A visual comparison of the hole and shaft tolerances and the clearances or interferences provided by the various types and classes of fits can be obtained from the diagrams on page 633. These diagrams have been drawn to scale for a nominal diameter of 1 inch.

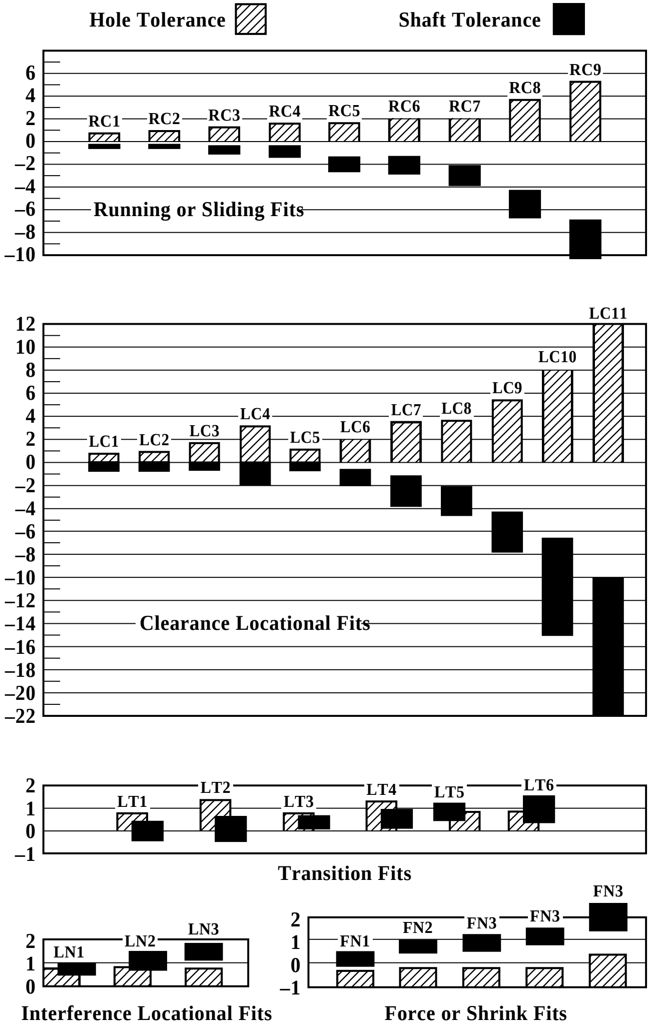
Use of Standard Fit Tables.—*Example 1:* A Class RC 1 fit is to be used in assembling a mating hole and shaft of 2-inch nominal diameter. This class of fit was selected because the application required accurate location of the parts with no perceptible play (see *Description of Fits*, RC 1 close sliding fits). From the data in Table 2, establish the limits of size and clearance of the hole and shaft.

Maximum hole = 2 + 0.0005 = 2.0005; minimum hole = 2 inches

Maximum shaft = 2 – 0.0004 = 1.9996; minimum shaft = 2 – 0.0007 = 1.9993 inches

Minimum clearance = 0.0004; maximum clearance = 0.0012 inch

Graphical Representation of ANSI Standard Limits and Fits



Diagrams show disposition of hole and shaft tolerances (in thousandths of an inch) with respect to basic size (0) for a diameter of 1 inch.

Table 3. American National Standard Running and Sliding Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class RC 1			Class RC 2			Class RC 3			Class RC 4		
		Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits		Clearance[a]	Standard Tolerance Limits	
			Hole H5	Shaft g4		Hole H6	Shaft g5		Hole H7	Shaft f6		Hole H8	Shaft f7
Over	To	Values shown below are in thousandths of an inch											
0	0.12	0.1	+0.2	−0.1	0.1	+0.25	−0.1	0.3	+0.4	−0.3	0.3	+0.6	−0.3
		0.45	0	−0.25	0.55	0	−0.3	0.95	0	−0.55	1.3	0	−0.7
0.12	0.24	0.15	+0.2	−0.15	0.15	+0.3	−0.15	0.4	+0.5	−0.4	0.4	+0.7	−0.4
		0.5	0	−0.3	0.65	0	−0.35	1.12	0	−0.7	1.6	0	−0.9
0.24	0.40	0.2	+0.25	−0.2	0.2	+0.4	−0.2	0.5	+0.6	−0.5	0.5	+0.9	−0.5
		0.6	0	−0.35	0.85	0	−0.45	1.5	0	−0.9	2.0	0	−1.1
0.40	0.71	0.25	+0.3	−0.25	0.25	+0.4	−0.25	0.6	+0.7	−0.6	0.6	+1.0	−0.6
		0.75	0	−0.45	0.95	0	−0.55	1.7	0	−1.0	2.3	0	−1.3
0.71	1.19	0.3	+0.4	−0.3	0.3	+0.5	−0.3	0.8	+0.8	−0.8	0.8	+1.2	−0.8
		0.95	0	−0.55	1.2	0	−0.7	2.1	0	−1.3	2.8	0	−1.6
1.19	1.97	0.4	+0.4	−0.4	0.4	+0.6	−0.4	1.0	+1.0	−1.0	1.0	+1.6	−1.0
		1.1	0	−0.7	1.4	0	−0.8	2.6	0	−1.6	3.6	0	−2.0
1.97	3.15	0.4	+0.5	−0.4	0.4	+0.7	−0.4	1.2	+1.2	−1.2	1.2	+1.8	−1.2
		1.2	0	−0.7	1.6	0	−0.9	3.1	0	−1.9	4.2	0	−2.4
3.15	4.73	0.5	+0.6	−0.5	0.5	+0.9	−0.5	1.4	+1.4	−1.4	1.4	+2.2	−1.4
		1.5	0	−0.9	2.0	0	−1.1	3.7	0	−2.3	5.0	0	−2.8
4.73	7.09	0.6	+0.7	−0.6	0.6	+1.0	−0.6	1.6	+1.6	−1.6	1.6	+2.5	−1.6
		1.8	0	−1.1	2.3	0	−1.3	4.2	0	−2.6	5.7	0	−3.2
7.09	9.85	0.6	+0.8	−0.6	0.6	+1.2	−0.6	2.0	+1.8	−2.0	2.0	+2.8	−2.0
		2.0	0	−1.2	2.6	0	−1.4	5.0	0	−3.2	6.6	0	−3.8
9.85	12.41	0.8	+0.9	−0.8	0.8	+1.2	−0.8	2.5	+2.0	−2.5	2.5	+3.0	−2.5
		2.3	0	−1.4	2.9	0	−1.7	5.7	0	−3.7	7.5	0	−4.5
12.41	15.75	1.0	+1.0	−1.0	1.0	+1.4	−1.0	3.0	+2.2	−3.0	3.0	+3.5	−3.0
		2.7	0	−1.7	3.4	0	−2.0	6.6	0	−4.4	8.7	0	−5.2
15.75	19.69	1.2	+1.0	−1.2	1.2	+1.6	−1.2	4.0	+2.5	−4.0	4.0	+4.0	−4.0
		3.0	0	−2.0	3.8	0	−2.2	8.1	0	−5.6	10.5	0	−6.5

[a] Pairs of values shown represent minimum and maximum amounts of clearance resulting from application of standard tolerance limits.

Table 4. American National Standard Running and Sliding Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class RC 5			Class RC 6			Class RC 7			Class RC 8			Class RC 9		
			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
		Clearance[a]	Hole H8	Shaft e7	Clearance[a]	Hole H9	Shaft e8	Clearance[a]	Hole H9	Shaft d8	Clearance[a]	Hole H10	Shaft c9	Clearance[a]	Hole H11	Shaft
Over	To	Values shown below are in thousandths of an inch														
0 –	0.12	0.6 1.6	+0.6 0	– 0.6 – 1.0	0.6 2.2	+1.0 0	– 0.6 – 1.2	1.0 2.6	+1.0 0	– 1.0 – 1.6	2.5 5.1	+1.6 0	– 2.5 – 3.5	4.0 8.1	+2.5 0	– 4.0 – 5.6
0.12 –	0.24	0.8 2.0	+0.7 0	– 0.8 – 1.3	0.8 2.7	+1.2 0	– 0.8 – 1.5	1.2 3.1	+1.2 0	– 1.2 – 1.9	2.8 5.8	+1.8 0	– 2.8 – 4.0	4.5 9.0	+3.0 0	– 4.5 – 6.0
0.24 –	0.40	1.0 2.5	+0.9 0	– 1.0 – 1.6	1.0 3.3	+1.4 0	– 1.0 – 1.9	1.6 3.9	+1.4 0	– 1.6 – 2.5	3.0 6.6	+2.2 0	– 3.0 – 4.4	5.0 10.7	+3.5 0	– 5.0 – 7.2
0.40 –	0.71	1.2 2.9	+1.0 0	– 1.2 – 1.9	1.2 3.8	+1.6 0	– 1.2 – 2.2	2.0 4.6	+1.6 0	– 2.0 – 3.0	3.5 7.9	+2.8 0	– 3.5 – 5.1	6.0 12.8	+4.0 0	– 6.0 – 8.8
0.71 –	1.19	1.6 3.6	+1.2 0	– 1.6 – 2.4	1.6 4.8	+2.0 0	– 1.6 – 2.8	2.5 5.7	+2.0 0	– 2.5 – 3.7	4.5 10.0	+3.5 0	– 4.5 – 6.5	7.0 15.5	+5.0 0	– 7.0 –10.5
1.19 –	1.97	2.0 4.6	+1.6 0	– 2.0 – 3.0	2.0 6.1	+2.5 0	– 2.0 – 3.6	3.0 7.1	+2.5 0	– 3.0 – 4.6	5.0 11.5	+4.0 0	– 5.0 – 7.5	8.0 18.0	+6.0 0	– 8.0 –12.0
1.97 –	3.15	2.5 5.5	+1.8 0	– 2.5 – 3.7	2.5 7.3	+3.0 0	– 2.5 – 4.3	4.0 8.8	+3.0 0	– 4.0 – 5.8	6.0 13.5	+4.5 0	– 6.0 – 9.0	9.0 20.5	+7.0 0	– 9.0 –13.5
3.15 –	4.73	3.0 6.6	+2.2 0	– 3.0 – 4.4	3.0 8.7	+3.5 0	– 3.0 – 5.2	5.0 10.7	+3.5 0	– 5.0 – 7.2	7.0 15.5	+5.0 0	– 7.0 –10.5	10.0 24.0	+9.0 0	–10.0 –15.0
4.73 –	7.09	3.5 7.6	+2.5 0	– 3.5 – 5.1	3.5 10.0	+4.0 0	– 3.5 – 6.0	6.0 12.5	+4.0 0	– 6.0 – 8.5	8.0 18.0	+6.0 0	– 8.0 –12.0	12.0 28.0	+10.0 0	–12.0 –18.0
7.09 –	9.85	4.0 8.6	+2.8 0	– 4.0 – 5.8	4.0 11.3	+4.5 0	– 4.0 – 6.8	7.0 14.3	+4.5 0	– 7.0 – 9.8	10.0 21.5	+7.0 0	–10.0 –14.5	15.0 34.0	+12.0 0	–15.0 –22.0
9.85 –	12.41	5.0 10.0	+3.0 0	– 5.0 – 7.0	5.0 13.0	+5.0 0	– 5.0 – 8.0	8.0 16.0	+5.0 0	– 8.0 –11.0	12.0 25.0	+8.0 0	–12.0 –17.0	18.0 38.0	+12.0 0	–18.0 –26.0
12.41 –	15.75	6.0 11.7	+3.5 0	– 6.0 – 8.2	6.0 15.5	+6.0 0	– 6.0 – 9.5	10.0 19.5	+6.0 0	–10.0 –13.5	14.0 29.0	+9.0 0	–14.0 –20.0	22.0 45.0	+14.0 0	–22.0 –31.0
15.75 –	19.69	8.0 14.5	+4.0 0	– 8.0 –10.5	8.0 18.0	+6.0 0	– 8.0 –12.0	12.0 22.0	+6.0 0	–12.0 –16.0	16.0 32.0	+10.0 0	–16.0 –22.0	25.0 51.0	+16.0 0	–25.0 –35.0

Tolerance limits given in body of table are added to or subtracted from basic size (as indicated by + or – sign) to obtain maximum and minimum sizes of mating parts.

All data above heavy lines are in accord with ABC agreements. Symbols H5, g4, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are also given in the ANSI Standard.

Table 5. American National Standard Clearance Locational Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches	Class LC 1			Class LC 2			Class LC 3			Class LC 4			Class LC 5		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Clearance[a]	Hole H6	Shaft h5	Clearance[a]	Hole H7	Shaft h6	Clearance[a]	Hole H8	Shaft h7	Clearance[a]	Hole H10	Shaft h9	Clearance[a]	Hole H7	Shaft g6
Over To	Values shown below are in thousandths of an inch														
0– 0.12	0 0.45	+0.25 0	0 −0.2	0 0.65	+0.4 0	0 −0.25	0 1	+0.6 0	0 −0.4	0 2.6	+1.6 0	0 −1.0	0.1 0.75	+0.4 0	−0.1 −0.35
0.12– 0.24	0 0.5	+0.3 0	0 −0.2	0 0.8	+0.5 0	0 −0.3	0 1.2	+0.7 0	0 −0.5	0 3.0	+1.8 0	0 −1.2	0.15 0.95	+0.5 0	−0.15 −0.45
0.24– 0.40	0 0.65	+0.4 0	0 −0.25	0 1.0	+0.6 0	0 −0.4	0 1.5	+0.9 0	0 −0.6	0 3.6	+2.2 0	0 −1.4	0.2 1.2	+0.6 0	−0.2 −0.6
0.40– 0.71	0 0.7	+0.4 0	0 −0.3	0 1.1	+0.7 0	0 −0.4	0 1.7	+1.0 0	0 −0.7	0 4.4	+2.8 0	0 −1.6	0.25 1.35	+0.7 0	−0.25 −0.65
0.71– 1.19	0 0.9	+0.5 0	0 −0.4	0 1.3	+0.8 0	0 −0.5	0 2	+1.2 0	0 −0.8	0 5.5	+3.5 0	0 −2.0	0.3 1.6	+0.8 0	−0.3 −0.8
1.19– 1.97	0 1.0	+0.6 0	0 −0.4	0 1.6	+1.0 0	0 −0.6	0 2.6	+1.6 0	0 −1	0 6.5	+4.0 0	0 −2.5	0.4 2.0	+1.0 0	−0.4 −1.0
1.97– 3.15	0 1.2	+0.7 0	0 −0.5	0 1.9	+1.2 0	0 −0.7	0 3	+1.8 0	0 −1.2	0 7.5	+4.5 0	0 −3	0.4 2.3	+1.2 0	−0.4 −1.1
3.15– 4.73	0 1.5	+0.9 0	0 −0.6	0 2.3	+1.4 0	0 −0.9	0 3.6	+2.2 0	0 −1.4	0 8.5	+5.0 0	0 −3.5	0.5 2.8	+1.4 0	−0.5 −1.4
4.73– 7.09	0 1.7	+1.0 0	0 −0.7	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 10.0	+6.0 0	0 −4	0.6 3.2	+1.6 0	−0.6 −1.6
7.09– 9.85	0 2.0	+1.2 0	0 −0.8	0 3.0	+1.8 0	0 −1.2	0 4.6	+2.8 0	0 −1.8	0 11.5	+7.0 0	0 −4.5	0.6 3.6	+1.8 0	−0.6 −1.8
9.85– 12.41	0 2.1	+1.2 0	0 −0.9	0 3.2	+2.0 0	0 −1.2	0 5	+3.0 0	0 −2.0	0 13.0	+8.0 0	0 −5	0.7 3.9	+2.0 0	−0.7 −1.9
12.41– 15.75	0 2.4	+1.4 0	0 −1.0	0 3.6	+2.2 0	0 −1.4	0 5.7	+3.5 0	0 −2.2	0 15.0	+9.0 0	0 −6	0.7 4.3	+2.2 0	−0.7 −2.1
15.75– 19.69	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 6.5	+4 0	0 −2.5	0 16.0	+10.0 0	0 −6	0.8 4.9	+2.5 0	−0.8 −2.4

[a] Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Table 6. American National Standard Clearance Locational Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class LC 6			Class LC 7			Class LC 8			Class LC 9			Class LC 10			Class LC 11		
			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits	
		Clearance[a]	Hole H9	Shaft f8	Clearance[a]	Hole H10	Shaft e9	Clearance[a]	Hole H10	Shaft d9	Clearance[a]	Hole H11	Shaft c10	Clearance[a]	Hole H12	Shaft	Clearance[a]	Hole H13	Shaft
Over	To	Values shown below are in thousandths of an inch																	
0 –	0.12	0.3 1.9	+1.0 0	–0.3 –0.9	0.6 3.2	+1.6 0	– 0.6 – 1.6	1.0 2.0	+1.6 0	– 1.0 – 2.0	2.5 6.6	+2.5 0	– 2.5 – 4.1	4 12	+4 0	– 4 – 8	5 17	+6 0	– 5 – 11
0.12 –	0.24	0.4 2.3	+1.2 0	–0.4 –1.1	0.8 3.8	+1.8 0	– 0.8 – 2.0	1.2 4.2	+1.8 0	– 1.2 – 2.4	2.8 7.6	+3.0 0	– 2.8 – 4.6	4.5 14.5	+5 0	– 4.5 – 9.5	6 20	+7 0	– 6 –13
0.24 –	0.40	0.5 2.8	+1.4 0	–0.5 –1.4	1.0 4.6	+2.2 0	– 1.0 – 2.4	1.6 5.2	+2.2 0	– 1.6 – 3.0	3.0 8.7	+3.5 0	– 3.0 – 5.2	5 17	+6 0	– 5 –11	7 25	+9 0	– 7 –16
0.40 –	0.71	0.6 3.2	+1.6 0	–0.6 –1.6	1.2 5.6	+2.8 0	– 1.2 – 2.8	2.0 6.4	+2.8 0	– 2.0 – 3.6	3.5 10.3	+4.0 0	– 3.5 – 6.3	6 20	+7 0	– 6 –13	8 28	+10 0	– 8 –18
0.71 –	1.19	0.8 4.0	+2.0 0	–0.8 –2.0	1.6 7.1	+3.5 0	– 1.6 – 3.6	2.5 8.0	+3.5 0	– 2.5 – 4.5	4.5 13.0	+5.0 0	– 4.5 – 8.0	7 23	+8 0	– 7 –15	10 34	+12 0	–10 –22
1.19 –	1.97	1.0 5.1	+2.5 0	–1.0 –2.6	2.0 8.5	+4.0 0	– 2.0 – 4.5	3.6 9.5	+4.0 0	– 3.0 – 5.5	5.0 15.0	+6 0	– 5.0 – 9.0	8 28	+10 0	– 8 –18	12 44	+16 0	–12 –28
1.97 –	3.15	1.2 6.0	+3.0 0	–1.0 –3.0	2.5 10.0	+4.5 0	– 2.5 – 5.5	4.0 11.5	+4.5 0	– 4.0 – 7.0	6.0 17.5	+7 0	– 6.0 –10.5	10 34	+12 0	–10 –22	14 50	+18 0	–14 –32
3.15 –	4.73	1.4 7.1	+3.5 0	–1.4 –3.6	3.0 11.5	+5.0 0	– 3.0 – 6.5	5.0 13.5	+5.0 0	– 5.0 – 8.5	7 21	+9 0	– 7 –12	11 39	+14 0	–11 –25	16 60	+22 0	–16 –38
4.73 –	7.09	1.6 8.1	+4.0 0	–1.6 –4.1	3.5 13.5	+6.0 0	– 3.5 – 7.5	6 16	+6 0	– 6 –10	8 24	+10 0	– 8 –14	12 44	+16 0	–12 –28	18 68	+25 0	–18 –43
7.09 –	9.85	2.0 9.3	+4.5 0	–2.0 –4.8	4.0 15.5	+7.0 0	– 4.0 – 8.5	7 18.5	+7 0	– 7 –11.5	10 29	+12 0	–10 –17	16 52	+18 0	–16 –34	22 78	+28 0	–22 –50
9.85 –	12.41	2.2 10.2	+5.0 0	–2.2 –5.2	4.5 17.5	+8.0 0	– 4.5 – 9.5	7 20	+8 0	– 7 –12	12 32	+12 0	–12 –20	20 60	+20 0	–20 –40	28 88	+30 0	–28 –58
12.41 –	15.75	2.5 12.0	+6.0 0	–2.5 –6.0	5.0 20.0	+9.0 0	– 5 –11	8 23	+9 0	– 8 –14	14 37	+14 0	–14 –23	22 66	+22 0	–22 –44	30 100	+35 0	–30 –65
15.75 –	19.69	2.8 12.8	+6.0 0	–2.8 –6.8	5.0 21.0	+10.0 0	– 5 –11	9 25	+10 0	– 9 –15	16 42	+16 0	–16 –26	25 75	+25 0	–25 –50	35 115	+40 0	–35 –75

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or – sign) to obtain maximum and minimum sizes of mating parts.

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

Table 7. ANSI Standard Transition Locational Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class LT 1			Class LT 2			Class LT 3			Class LT 4			Class LT 5			Class LT 6		
		Fit[a]	Std. Tolerance Limits		Fit[a]	Std. Tolerance Limits		Fit[a]	Std. Tolerance Limits		Fit[a]	Std. Tolerance Limits		Fit[a]	Std. Tolerance Limits		Fit[a]	Std. Tolerance Limits	
			Hole H7	Shaft js6		Hole H8	Shaft js7		Hole H7	Shaft k6		Hole H8	Shaft k7		Hole H7	Shaft n6		Hole H7	Shaft n7
Over	To	Values shown below are in thousandths of an inch																	
0 –	0.12	−0.12 +0.52	+0.4 0	+0.12 −0.12	−0.2 +0.8	+0.6 0	+0.2 −0.2							−0.5 +0.15	+0.4 0	+0.5 +0.25	−0.65 +0.15	+0.4 0	+0.65 +0.25
0.12 –	0.24	−0.15 +0.65	+0.5 0	+0.15 −0.15	−0.25 +0.95	+0.7 0	+0.25 −0.25							−0.6 +0.2	+0.5 0	+0.6 +0.3	−0.8 +0.2	+0.5 0	+0.8 +0.3
0.24 –	0.40	−0.2 +0.8	+0.6 0	+0.2 −0.2	−0.3 +1.2	+0.9 0	+0.3 −0.3	−0.5 +0.5	+0.6 0	+0.5 +0.1	−0.7 +0.8	+0.9 0	+0.7 +0.1	−0.8 +0.2	+0.6 0	+0.8 +0.4	−1.0 +0.2	+0.6 0	+1.0 +0.4
0.40 –	0.71	−0.2 +0.9	+0.7 0	+0.2 −0.2	−0.35 +1.35	+1.0 0	+0.35 −0.35	−0.5 +0.6	+0.7 0	+0.5 +0.1	−0.8 +0.9	+1.0 0	+0.8 +0.1	−0.9 +0.2	+0.7 0	+0.9 +0.5	−1.2 +0.2	+0.7 0	+1.2 +0.5
0.71 –	1.19	−0.25 +1.05	+0.8 0	+0.25 −0.25	−0.4 +1.6	+1.2 0	+0.4 −0.4	−0.6 +0.7	+0.8 0	+0.6 +0.1	−0.9 +1.1	+1.2 0	+0.9 +0.1	−1.1 +0.2	+0.8 0	+1.1 +0.6	−1.4 +0.2	+0.8 0	+1.4 +0.6
1.19 –	1.97	−0.3 +1.3	+1.0 0	+0.3 −0.3	−0.5 +2.1	+1.6 0	+0.5 −0.5	−0.7 +0.9	+1.0 0	+0.7 +0.1	−1.1 +1.5	+1.6 0	+1.1 +0.1	−1.3 +0.3	+1.0 0	+1.3 +0.7	−1.7 +0.3	+1.0 0	+1.7 +0.7
1.97 –	3.15	−0.3 +1.5	+1.2 0	+0.3 −0.3	−0.6 +2.4	+1.8 0	+0.6 −0.6	−0.8 +1.1	+1.2 0	+0.8 +0.1	−1.3 +1.7	+1.8 0	+1.3 +0.1	−1.5 +0.4	+1.2 0	+1.5 +0.8	−2.0 +0.4	+1.2 0	+2.0 +0.8
3.15 –	4.73	−0.4 +1.8	+1.4 0	+0.4 −0.4	−0.7 +2.9	+2.2 0	+0.7 −0.7	−1.0 +1.3	+1.4 0	+1.0 +0.1	−1.5 +2.1	+2.2 0	+1.5 +0.1	−1.9 +0.4	+1.4 0	+1.9 +1.0	−2.4 +0.4	+1.4 0	+2.4 +1.0
4.73 –	7.09	−0.5 +2.1	+1.6 0	+0.5 −0.5	−0.8 +3.3	+2.5 0	+0.8 −0.8	−1.1 +1.5	+1.6 0	+1.1 +0.1	−1.7 +2.4	+2.5 0	+1.7 +0.1	−2.2 +0.4	+1.6 0	+2.2 +1.2	−2.8 +0.4	+1.6 0	+2.8 +1.2
7.09 –	9.85	−0.6 +2.4	+1.8 0	+0.6 −0.6	−0.9 +3.7	+2.8 0	+0.9 −0.9	−1.4 +1.6	+1.8 0	+1.4 +0.2	−2.0 +2.6	+2.8 0	+2.0 +0.2	−2.6 +0.4	+1.8 0	+2.6 +1.4	−3.2 +0.4	+1.8 0	+3.2 +1.4
9.85 –	12.41	−0.6 +2.6	+2.0 0	+0.6 −6.6	−1.0 +4.0	+3.0 0	+1.0 −1.0	−1.4 +1.8	+2.0 0	+1.4 +0.2	−2.2 +2.8	+3.0 0	+2.2 +0.2	−2.6 +0.6	+2.0 0	+2.6 +1.4	−3.4 +0.6	+2.0 0	+3.4 +1.4
12.41 –	15.75	−0.7 +2.9	+2.2 0	+0.7 −0.7	−1.0 +4.5	+3.5 0	+1.0 −1.0	−1.6 +2.0	+2.2 0	+1.6 +0.2	−2.4 +3.3	+3.5 0	+2.4 +0.2	−3.0 +0.6	+2.2 0	+3.0 +1.6	−3.8 +0.6	+2.2 0	+3.8 +1.6
15.75 –	19.69	−0.8 +3.3	+2.5 0	+0.8 −0.8	−1.2 +5.2	+4.0 0	+1.2 −1.2	−1.8 +2.3	+2.5 0	+1.8 +0.2	−2.7 +3.8	+4.0 0	+2.7 +0.2	−3.4 +0.7	+2.5 0	+3.4 +1.8	−4.3 +0.7	+2.5 0	+4.3 +1.8

[a] Pairs of values shown represent maximum amount of interference (–) and maximum amount of clearance (+) resulting from application of standard tolerance limits.

All data above heavy lines are in accord with ABC agreements. Symbols H7, js6, etc., are hole and shaft designations in the ABC system.

Table 8. ANSI Standard Interference Location Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches	Class LN 1			Class LN 2			Class LN 3		
	Limits of Interference	Standard Limits		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits	
		Hole H6	Shaft n5		Hole H7	Shaft p6		Hole H7	Shaft r6
Over To	Values shown below are given in thousandths of an inch								
0– 0.12	0 0.45	+0.25 0	+0.45 +0.25	0 0.65	+0.4 0	+0.65 +0.4	0.1 0.75	+0.4 0	+0.75 +0.5
0.12– 0.24	0 0.5	+0.3 0	+0.5 +0.3	0 0.8	+0.5 0	+0.8 +0.5	0.1 0.9	+0.5 0	+0.9 +0.6
0.24– 0.40	0 0.65	+0.4 0	+0.65 +0.4	0 1.0	+0.6 0	+1.0 +0.6	0.2 1.2	+0.6 0	+1.2 +0.8
0.40– 0.71	0 0.8	+0.4 0	+0.8 +0.4	0 1.1	+0.7 0	+1.1 +0.7	0.3 1.4	+0.7 0	+1.4 +1.0
0.71– 1.19	0 1.0	+0.5 0	+1.0 +0.5	0 1.3	+0.8 0	+1.3 +0.8	0.4 1.7	+0.8 0	+1.7 +1.2
1.19– 1.97	0 1.1	+0.6 0	+1.1 +0.6	0 1.6	+1.0 0	+1.6 +1.0	0.4 2.0	+1.0 0	+2.0 +1.4
1.97– 3.15	0.1 1.3	+0.7 0	+1.3 +0.8	0.2 2.1	+1.2 0	+2.1 +1.4	0.4 2.3	+1.2 0	+2.3 +1.6
3.15– 4.73	0.1 1.6	+0.9 0	+1.6 +1.0	0.2 2.5	+1.4 0	+2.5 +1.6	0.6 2.9	+1.4 0	+2.9 +2.0
4.73– 7.09	0.2 1.9	+1.0 0	+1.9 +1.2	0.2 2.8	+1.6 0	+2.8 +1.8	0.9 3.5	+1.6 0	+3.5 +2.5
7.09– 9.85	0.2 2.2	+1.2 0	+2.2 +1.4	0.2 3.2	+1.8 0	+3.2 +2.0	1.2 4.2	+1.8 0	+4.2 +3.0
9.85– 12.41	0.2 2.3	+1.2 0	+2.3 +1.4	0.2 3.4	+2.0 0	+3.4 +2.2	1.5 4.7	+2.0 0	+4.7 +3.5
12.41– 15.75	0.2 2.6	+1.4 0	+2.6 +1.6	0.3 3.9	+2.2 0	+3.9 +2.5	2.3 5.9	+2.2 0	+5.9 +4.5
15.75– 19.69	0.2 2.8	+1.6 0	+2.8 +1.8	0.3 4.4	+2.5 0	+4.4 +2.8	2.5 6.6	+2.5 0	+6.6 +5.0

All data in this table are in accordance with American-British-Canadian (ABC) agreements.

Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

Symbols H7, p6, etc., are hole and shaft designations in the ABC system.

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or – sign) to obtain maximum and minimum sizes of mating parts.

Table 9. ANSI Standard Force and Shrink Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
		Interference[a]	Standard Tolerance Limits		Interference[a]	Standard Tolerance Limits		Interference[a]	Standard Tolerance Limits		Interference[a]	Standard Tolerance Limits		Interference[a]	Standard Tolerance Limits	
			Hole H6	Shaft		Hole H7	Shaft s6		Hole H7	Shaft t6		Hole H7	Shaft u6		Hole H8	Shaft x7
Over	To	Values shown below are in thousandths of an inch														
0	0.12	0.05	+0.25	+0.5	0.2	+0.4	+0.85				0.3	+0.4	+0.95	0.3	+0.6	+1.3
		0.5	0	+0.3	0.85	0	+0.6				0.95	0	+0.7	1.3	0	+0.9
0.12	0.24	0.1	+0.3	+0.6	0.2	+0.5	+1.0				0.4	+0.5	+1.2	0.5	+0.7	+1.7
		0.6	0	+0.4	1.0	0	+0.7				1.2	0	+0.9	1.7	0	+1.2
0.24	0.40	0.1	+0.4	+0.75	0.4	+0.6	+1.4				0.6	+0.6	+1.6	0.5	+0.9	+2.0
		0.75	0	+0.5	1.4	0	+1.0				1.6	0	+1.2	2.0	0	+1.4
0.40	0.56	0.1	+0.4	+0.8	0.5	+0.7	+1.6				0.7	+0.7	+1.8	0.6	+1.0	+2.3
		0.8	0	+0.5	1.6	0	+1.2				1.8	0	+1.4	2.3	0	+1.6
0.56	0.71	0.2	+0.4	+0.9	0.5	+0.7	+1.6				0.7	+0.7	+1.8	0.8	+1.0	+2.5
		0.9	0	+0.6	1.6	0	+1.2				1.8	0	+1.4	2.5	0	+1.8
0.71	0.95	0.2	+0.5	+1.1	0.6	+0.8	+1.9				0.8	+0.8	+2.1	1.0	+1.2	+3.0
		1.1	0	+0.7	1.9	0	+1.4				2.1	0	+1.6	3.0	0	+2.2
0.95	1.19	0.3	+0.5	+1.2	0.6	+0.8	+1.9	0.8	+0.8	+2.1	+1.0	+0.8	+2.3	1.3	+1.2	+3.3
		1.2	0	+0.8	1.9	0	+1.4	2.1	0	+1.6	2.3	0	+1.8	3.3	0	+2.5
1.19	1.58	0.3	+0.6	+1.3	0.8	+1.0	+2.4	1.0	+1.0	+2.6	1.5	+1.0	+3.1	1.4	+1.6	+4.0
		1.3	0	+0.9	2.4	0	+1.8	2.6	0	+2.0	3.1	0	+2.5	4.0	0	+3.0
1.58	1.97	0.4	+0.6	+1.4	0.8	+1.0	+2.4	1.2	+1.0	+2.8	1.8	+1.0	+3.4	2.4	+1.6	+5.0
		1.4	0	+1.0	2.4	0	+1.8	2.8	0	+2.2	3.4	0	+2.8	5.0	0	+4.0
1.97	2.56	0.6	+0.7	+1.8	0.8	+1.2	+2.7	1.3	+1.2	+3.2	2.3	+1.2	+4.2	3.2	+1.8	+6.2
		1.8	0	+1.3	2.7	0	+2.0	3.2	0	+2.5	4.2	0	+3.5	6.2	0	+5.0
2.56	3.15	0.7	+0.7	+1.9	1.0	+1.2	+2.9	1.8	+1.2	+3.7	2.8	+1.2	+4.7	4.2	+1.8	+7.2
		1.9	0	+1.4	2.9	0	+2.2	3.7	0	+3.0	4.7	0	+4.0	7.2	0	+6.0
3.15	3.94	0.9	+0.9	+2.4	1.4	+1.4	+3.7	2.1	+1.4	+4.4	3.6	+1.4	+5.9	4.8	+2.2	+8.4
		2.4	0	+1.8	3.7	0	+2.8	4.4	0	+3.5	5.9	0	+5.0	8.4	0	+7.0
3.94	4.73	1.1	+0.9	+2.6	1.6	+1.4	+3.9	2.6	+1.4	+4.9	4.6	+1.4	+6.9	5.8	+2.2	+9.4
		2.6	0	+2.0	3.9	0	+3.0	4.9	0	+4.0	6.9	0	+6.0	9.4	0	+8.0

Table 9. *(Continued)* ANSI Standard Force and Shrink Fits *ANSI B4.1-1967 (R1987)*

Nominal Size Range, Inches		Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
Over	To	Interference[a]	Hole H6	Shaft	Interference[a]	Hole H7	Shaft s6	Interference[a]	Hole H7	Shaft t6	Interference[a]	Hole H7	Shaft u6	Interference[a]	Hole H8	Shaft x7
		Values shown below are in thousandths of an inch														
4.73–	5.52	1.2	+1.0	+2.9	1.9	+1.6	+4.5	3.4	+1.6	+6.0	5.4	+1.6	+8.0	7.5	+2.5	+11.6
		2.9	0	+2.2	4.5	0	+3.5	6.0	0	+5.0	8.0	0	+7.0	11.6	0	+10.0
5.52–	6.30	1.5	+1.0	+3.2	2.4	+1.6	+5.0	3.4	+1.6	+6.0	5.4	+1.6	+8.0	9.5	+2.5	+13.6
		3.2	0	+2.5	5.0	0	+4.0	6.0	0	+5.0	8.0	0	+7.0	13.6	0	+12.0
6.30–	7.09	1.8	+1.0	+3.5	2.9	+1.6	+5.5	4.4	+1.6	+7.0	6.4	+1.6	+9.0	9.5	+2.5	+13.6
		3.5	0	+2.8	5.5	0	+4.5	7.0	0	+6.0	9.0	0	+8.0	13.6	0	+12.0
7.09–	7.88	1.8	+1.2	+3.8	3.2	+1.8	+6.2	5.2	+1.8	+8.2	7.2	+1.8	+10.2	11.2	+2.8	+15.8
		3.8	0	+3.0	6.2	0	+5.0	8.2	0	+7.0	10.2	0	+9.0	15.8	0	+14.0
7.88–	8.86	2.3	+1.2	+4.3	3.2	+1.8	+6.2	5.2	+1.8	+8.2	8.2	+1.8	+11.2	13.2	+2.8	+17.8
		4.3	0	+3.5	6.2	0	+5.0	8.2	0	+7.0	11.2	0	+10.0	17.8	0	+16.0
8.86–	9.85	2.3	+1.2	+4.3	4.2	+1.8	+7.2	6.2	+1.8	+9.2	10.2	+1.8	+13.2	13.2	+2.8	+17.8
		4.3	0	+3.5	7.2	0	+6.0	9.2	0	+8.0	13.2	0	+12.0	17.8	0	+16.0
9.85–	11.03	2.8	+1.2	+4.9	4.0	+2.0	+7.2	7.0	+2.0	+10.2	10.0	+2.0	+13.2	15.0	+3.0	+20.0
		4.9	0	+4.0	7.2	0	+6.0	10.2	0	+9.0	13.2	0	+12.0	20.0	0	+18.0
11.03–	12.41	2.8	+1.2	+4.9	5.0	+2.0	+8.2	7.0	+2.0	+10.2	12.0	+2.0	+15.2	17.0	+3.0	+22.0
		4.9	0	+4.0	8.2	0	+7.0	10.2	0	+9.0	15.2	0	+14.0	22.0	0	+20.0
12.41–	13.98	3.1	+1.4	+5.5	5.8	+2.2	+9.4	7.8	+2.2	+11.4	13.8	+2.2	+17.4	18.5	+3.5	+24.2
		5.5	0	+4.5	9.4	0	+8.0	11.4	0	+10.0	17.4	0	+16.0	24.2	0	+22.0
13.98–	15.75	3.6	+1.4	+6.1	5.8	+2.2	+9.4	9.8	+2.2	+13.4	15.8	+2.2	+19.4	21.5	+3.5	+27.2
		6.1	0	+5.0	9.4	0	+8.0	13.4	0	+12.0	19.4	0	+18.0	27.2	0	+25.0
15.75–	17.72	4.4	+1.6	+7.0	6.5	+2.5	+10.6	+9.5	+2.5	+13.6	17.5	+2.5	+21.6	24.0	+4.0	+30.5
		7.0	0	+6.0	10.6	0	+9.0	13.6	0	+12.0	21.6	0	+20.0	30.5	0	+28.0
17.72–	19.69	4.4	+1.6	+7.0	7.5	+2.5	+11.6	11.5	+2.5	+15.6	19.5	+2.5	+23.6	26.0	+4.0	+32.5
		7.0	0	+6.0	11.6	0	+10.0	15.6	0	+14.0	23.6	0	+22.0	32.5	0	+30.0

[a] Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc., are hole and shaft designations in the ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI standard.

Modified Standard Fits.—Fits having the same limits of clearance or interference as those shown in Tables 3 to 7 may sometimes have to be produced by using holes or shafts having limits of size other than those shown in these tables. These modifications may be accomplished by using either a *Bilateral Hole* (*System B*) or a *Basic Shaft System* (*Symbol S*). Both methods will result in nonstandard holes and shafts.

Bilateral Hole Fits: (*Symbol B*): The common situation is where holes are produced with fixed tools such as drills or reamers; to provide a longer wear life for such tools, a bilateral tolerance is desired.

The symbols used for these fits are identical with those used for standard fits except that they are followed by the letter B. Thus, LC 4B is a clearance locational fit, Class 4, except that it is produced with a bilateral hole.

The limits of clearance or interference are identical with those shown in Tables 3 to 7 for the corresponding fits.

The hole tolerance, however, is changed so that the plus limit is that for one grade finer than the value shown in the tables and the minus limit equals the amount by which the plus limit was lowered. The shaft limits are both lowered by the same amount as the lower limit of size of the hole. The finer grade of tolerance required to make these modifications may be obtained from Table 1. For example, an LC 4B fit for a 6-inch diameter hole would have tolerance limits of + 4.0, – 2.0 (+ 0.0040 inch, – 0.0020 inch); the shaft would have tolerance limits of – 2.0, – 6.0 (– 0.0020 inch, – 0.0060 inch).

Basic Shaft Fits: (*Symbol S*): For these fits, the maximum size of the shaft is basic. The limits of clearance or interference are identical with those shown in Tables 3 to 7 for the corresponding fits and the symbols used for these fits are identical with those used for standard fits except that they are followed by the letter S. Thus, LC 4S is a clearance locational fit, Class 4, except that it is produced on a basic shaft basis.

The limits for hole and shaft as given in Tables 3 to 7 are increased for clearance fits (*decreased* for transition or interference fits) by the value of the upper shaft limit; that is, by the amount required to change the maximum shaft to the basic size.

American National Standard Preferred Metric Limits and Fits.—This standard ANSI B4.2-1978 (R1994) describes the ISO system of metric limits and fits for mating parts as approved for general engineering usage in the United States.

It establishes: 1) the designation symbols used to define dimensional limits on drawings, material stock, related tools, gages, etc.; 2) the preferred basic sizes (first and second choices); 3) the preferred tolerance zones (first, second, and third choices); 4) the preferred limits and fits for sizes (first choice only) up to and including 500 millimeters; and

5) the definitions of related terms.

The general terms "hole" and "shaft" can also be taken to refer to the space containing or contained by two parallel faces of any part, such as the width of a slot, or the thickness of a key.

Definitions.—The most important terms relating to limits and fits are shown in Fig. 1 and are defined as follows:

Basic Size: The size to which limits of deviation are assigned. The basic size is the same for both members of a fit. For example, it is designated by the numbers 40 in 40H7.

Deviation: The algebraic difference between a size and the corresponding basic size.

Upper Deviation: The algebraic difference between the maximum limit of size and the corresponding basic size.

Lower Deviation: The algebraic difference between the minimum limit of size and the corresponding basic size.

Fundamental Deviation: That one of the two deviations closest to the basic size. For example, it is designated by the letter H in 40H7.

Tolerance: The difference between the maximum and minimum size limits on a part.

Tolerance Zone: A zone representing the tolerance and its position in relation to the basic size.

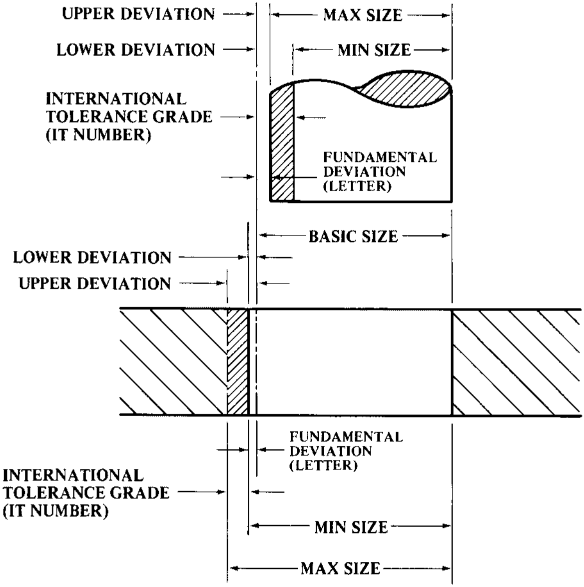


Fig. 1. Illustration of Definitions

International Tolerance Grade: (*IT*): A group of tolerances that vary depending on the basic size, but that provide the same relative level of accuracy within a given grade. For example, it is designated by the number 7 in 40H7 or as IT7.

Hole Basis: The system of fits where the minimum hole size is basic. The fundamental deviation for a hole basis system is H.

Shaft Basis: The system of fits where the maximum shaft size is basic. The fundamental deviation for a shaft basis system is h.

Clearance Fit: The relationship between assembled parts when clearance occurs under all tolerance conditions.

Interference Fit: The relationship between assembled parts when interference occurs under all tolerance conditions.

Transition Fit: The relationship between assembled parts when either a clearance or an interference fit can result, depending on the tolerance conditions of the mating parts.

Tolerances Designation.—An “International Tolerance grade” establishes the magnitude of the tolerance zone or the amount of part size variation allowed for external and internal dimensions alike (see Fig. 1). Tolerances are expressed in grade numbers that are consistent with International Tolerance grades identified by the prefix IT, such as IT6, IT11, etc. A smaller grade number provides a smaller tolerance zone.

A fundamental deviation establishes the position of the tolerance zone with respect to the basic size (see Fig. 1). Fundamental deviations are expressed by tolerance position letters.

Capital letters are used for internal dimensions and lowercase or small letters for external dimensions.

Symbols.—By combining the IT grade number and the tolerance position letter, the tolerance symbol is established that identifies the actual maximum and minimum limits of the part. The toleranced size is thus defined by the basic size of the part followed by a symbol composed of a letter and a number, such as 40H7, 40f7, etc.

A fit is indicated by the basic size common to both components, followed by a symbol corresponding to each component, the internal part symbol preceding the external part symbol, such as 40H8/f7.

Some methods of designating tolerances on drawings are:

A) 40H8

B) 40H8 $\left(\begin{matrix}40.039\\40.000\end{matrix}\right)$

C) $\left(\begin{matrix}40.039\\40.000\end{matrix}\right)$ 40H8

The values in parentheses indicate reference only.

Table 10. American National Standard Preferred Metric Sizes
ANSI B4.2-1978 (R1994)

Basic Size, mm		Basic Size, mm		Basic Size, mm		Basic Size, mm	
1st Choice	2nd Choice	1st Choice	2nd Choice	1st Choice	2nd Choice	1st Choice	2nd Choice
1	…	6	…	40	…	250	…
…	1.1	…	7	…	45	…	280
1.2	…	8	…	50	…	300	…
…	1.4	…	9	…	55	…	350
1.6	…	10	…	60	…	400	…
…	1.8	…	11	…	70	…	450
2	…	12	…	80	…	500	…
…	2.2	…	14	…	90	…	550
2.5	…	16	…	100	…	600	…
…	2.8	…	18	…	110	…	700
3	…	20	…	120	…	800	…
…	3.5	…	22	…	140	…	900
4	…	25	…	160	…	1000	…
…	4.5	…	28	…	180	…	…
5	…	30	…	200	…	…	…
…	5.5	…	35	…	220	…	…

Preferred Metric Sizes.—American National Standard ANSI B32.4M-1980 (R1994), presents series of preferred metric sizes for round, square, rectangular, and hexagonal metal products. Table 10 gives preferred metric diameters from 1 to 320 millimeters for round metal products. Wherever possible, sizes should be selected from the Preferred Series shown in the table. A Second Preference series is also shown. A Third Preference Series not shown in the table is: 1.3, 2.1, 2.4, 2.6, 3.2, 3.8, 4.2, 4.8, 7.5, 8.5, 9.5, 36, 85, and 95.

Most of the Preferred Series of sizes are derived from the American National Standard "10 series" of preferred numbers (see *American National Standard for Preferred Numbers* on page 19). Most of the Second Preference Series are derived from the "20 series" of preferred numbers. Third Preference sizes are generally from the "40 series" of preferred numbers.

For preferred metric diameters less than 1 millimeter, preferred across flat metric sizes of square and hexagon metal products, preferred across flat metric sizes of rectangular metal products, and preferred metric lengths of metal products, reference should be made to the Standard.

Preferred Fits.—First-choice tolerance zones are used to establish preferred fits in the Standard for Preferred Metric Limits and Fits, ANSI B4.2, as shown in Figs. 2 and 3. A complete listing of first-, second-, and third- choice tolerance zones is given in the Standard.

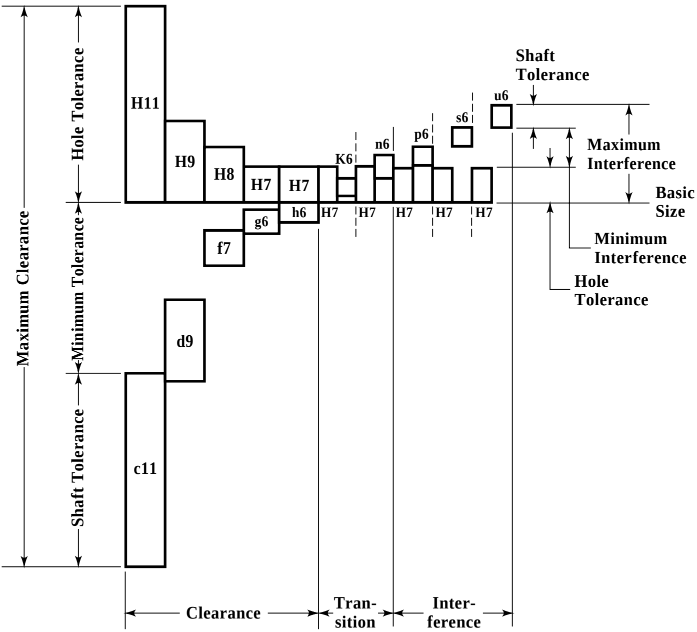


Fig. 2. Preferred Hole Basis Fits

Hole basis fits have a fundamental deviation of H on the hole, and shaft basis fits have a fundamental deviation of h on the shaft and are shown in Fig. 2 for hole basis and Fig. 3 for shaft basis fits. A description of both types of fits, that have the same relative fit condition, is given in Table 11. Normally, the hole basis system is preferred; however, when a common shaft mates with several holes, the shaft basis system should be used.

The hole basis and shaft basis fits shown in Table 11 are combined with the first-choice sizes shown in Table 10 to form Tables 12, 13, 14, and 15, where specific limits as well as the resultant fits are tabulated.

If the required size is not tabulated in Tables 12 through 15 then the preferred fit can be calculated from numerical values given in an appendix of ANSI B4.2-1978 (R1984). It is anticipated that other fit conditions may be necessary to meet special requirements, and a preferred fit can be loosened or tightened simply by selecting a standard tolerance zone as given in the Standard. Information on how to calculate limit dimensions, clearances, and interferences, for nonpreferred fits and sizes can also be found in an appendix of this Standard.

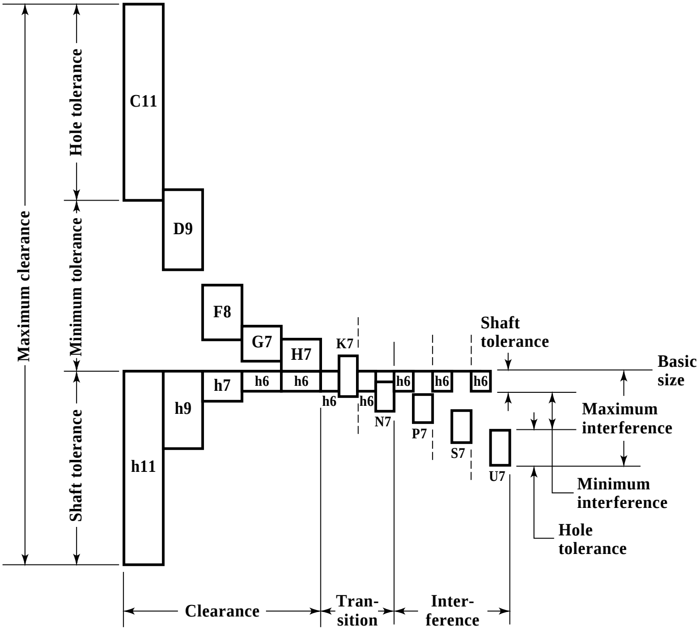


Fig. 3. Preferred Shaft Basis Fits

Table 11. Description of Preferred Fits

	ISO SYMBOL		DESCRIPTION	
	Hole Basis	Shaft Basis		
Clearance Fits	H11/c11	C11/h11	*Loose running* fit for wide commercial tolerances or allowances on external members.	
	H9/d9	D9/h9	*Free running* fit not for use where accuracy is essential, but good for large temperature variations, high running speeds, or heavy journal pressures.	
	H8/f7	F8/h7	*Close Running* fit for running on accurate machines and for accurate moderate speeds and journal pressures.	↑ More Clearance
	H7/g6	G7/h6	*Sliding fit* not intended to run freely, but to move and turn freely and locate accurately.	
	H7/h6	H7/h6	*Locational clearance* fit provides snug fit for locating stationary parts; but can be freely assembled and disassembled.	
Transition Fits	H7/k6	K7/h6	*Locational transition* fit for accurate location, a compromise between clearance and interferance.	
	H7/n6	N7/h6	*Locational transition* fit for more accurate location where greater interferance is permissible.	
Interference Fits	H7/p6[a]	P7/h6	*Locational interference* fit for parts requiring rigidity and alignment with prime accuracy of location but without special bore pressure requirements.	More Interferance ↓
	H7/s6	S7/h6	*Medium drive* fit for ordinary steel parts or shrink fits on light sections, the tightest fit usable with cast iron.	
	H7/u6	U7/h6	*Force* fit suitable for parts which can be highly stressed or for shrink fits where the heavy pressing forces required are impractical.	

[a] Transition fit for basic sizes in range from 0 through 3 mm.

Table 12. American National Standard Preferred Hole Basis Metric Clearance Fits *ANSI B4.2-1978 (R1994)*

		Loose Running			Free Running			Close Running			Sliding			Locational Clearance		
Basic Size[a]		Hole H11	Shaft C11	Fit[b]	Hole H9	Shaft d9	Fit[b]	Hole H8	Shaft f7	Fit[b]	Hole H7	Shaft g6	Fit[b]	Hole H7	Shaft h6	Fit[b]
1	Max	1.060	0.940	0.180	1.025	0.980	0.070	1.014	0.994	0.030	1.010	0.998	0.018	1.010	1.000	0.016
	Min	1.000	0.880	0.060	1.000	0.995	0.020	1.000	0.984	0.006	1.000	0.992	0.002	1.000	0.994	0.000
1.2	Max	1.260	1.140	0.180	1.225	1.180	0.070	1.214	1.194	0.030	1.210	1.198	0.018	1.210	1.200	0.016
	Min	1.200	1.080	0.060	1.200	1.155	0.020	1.200	1.184	0.006	1.200	1.192	0.002	1.200	1.194	0.000
1.6	Max	1.660	1.540	0.180	1.625	1.580	0.070	1.614	1.594	0.030	1.610	1.598	0.018	1.610	1.600	0.016
	Min	1.600	1.480	0.060	1.600	1.555	0.020	1.600	1.584	0.006	1.600	1.592	0.002	1.600	1.594	0.000
2	Max	2.060	1.940	0.180	2.025	1.980	0.070	2.014	1.994	0.030	2.010	1.998	0.018	2.010	2.000	0.016
	Min	2.000	1.880	0.060	2.000	1.955	0.020	2.000	1.984	0.006	2.000	1.992	0.002	2.000	1.994	0.000
2.5	Max	2.560	2.440	0.180	2.525	2.480	0.070	2.514	2.494	0.030	2.510	2.498	0.018	2.510	2.500	0.016
	Min	2.500	2.380	0.060	2.500	2.455	0.020	2.500	2.484	0.006	2.500	2.492	0.002	2.500	2.494	0.000
3	Max	3.060	2.940	0.180	3.025	2.980	0.070	3.014	2.994	0.030	3.010	2.998	0.018	3.010	3.000	0.016
	Min	3.000	2.880	0.060	3.000	2.955	0.020	3.000	2.984	0.006	3.000	2.992	0.002	3.000	2.994	0.000
4	Max	4.075	3.930	0.220	4.030	3.970	0.090	4.018	3.990	0.040	4.012	3.996	0.024	4.012	4.000	0.020
	Min	4.000	3.855	0.070	4.000	3.940	0.030	4.000	3.978	0.010	4.000	3.988	0.004	4.000	3.992	0.000
5	Max	5.075	4.930	0.220	5.030	4.970	0.090	5.018	4.990	0.040	5.012	4.996	0.024	5.012	5.000	0.020
	Min	5.000	4.855	0.070	5.000	4.940	0.030	5.000	4.978	0.010	5.000	4.988	0.004	5.000	4.992	0.000
6	Max	6.075	5.930	0.220	6.030	5.970	0.090	6.018	5.990	0.040	6.012	5.996	0.024	6.012	6.000	0.020
	Min	6.000	5.855	0.070	6.000	5.940	0.030	6.000	5.978	0.010	6.000	5.988	0.004	6.000	5.992	0.000
8	Max	8.090	7.920	0.260	8.036	7.960	0.112	8.022	7.987	0.050	8.015	7.995	0.029	8.015	8.000	0.024
	Min	8.000	7.830	0.080	8.000	7.924	0.040	8.000	7.972	0.013	8.000	7.986	0.005	8.000	7.991	0.000
10	Max	10.090	9.920	0.260	10.036	9.960	0.112	10.022	9.987	0.050	10.015	9.995	0.029	10.015	10.000	0.024
	Min	10.000	9.830	0.080	10.000	9.924	0.040	10.000	9.972	0.013	10.000	9.986	0.005	10.000	9.991	0.000
12	Max	12.110	11.905	0.315	12.043	11.956	0.136	12.027	11.984	0.061	12.018	11.994	0.035	12.018	12.000	0.029
	Min	12.000	11.795	0.095	12.000	11.907	0.050	12.000	11.966	0.016	12.000	11.983	0.006	12.000	11.989	0.000
16	Max	16.110	15.905	0.315	16.043	15.950	0.136	16.027	15.984	0.061	16.018	15.994	0.035	16.018	16.000	0.029
	Min	16.000	15.795	0.095	16.000	15.907	0.050	16.000	15.966	0.016	16.000	15.983	0.006	16.000	15.989	0.000
20	Max	20.130	19.890	0.370	20.052	19.935	0.169	20.033	19.980	0.074	20.021	19.993	0.041	20.021	20.000	0.034
	Min	20.000	19.760	0.110	20.000	19.883	0.065	20.000	19.959	0.020	20.000	19.980	0.007	20.000	19.987	0.000
25	Max	25.130	24.890	0.370	25.052	24.935	0.169	25.033	24.980	0.074	25.021	24.993	0.041	25.021	25.000	0.034
	Min	25.000	24.760	0.110	25.000	24.883	0.065	25.000	24.959	0.020	25.000	24.980	0.007	25.000	24.987	0.000

Table 12. *(Continued)* **American National Standard Preferred Hole Basis Metric Clearance Fits** *ANSI B4.2-1978 (R1994)*

Basic Size[a]		Loose Running			Free Running			Close Running			Sliding			Locational Clearance		
		Hole H11	Shaft C11	Fit[b]	Hole H9	Shaft d9	Fit[b]	Hole H8	Shaft f7	Fit[b]	Hole H7	Shaft g6	Fit[b]	Hole H7	Shaft h6	Fit[b]
30	Max	30.130	29.890	0.370	30.052	29.935	0.169	30.033	29.980	0.074	30.021	29.993	0.041	30.021	30.000	0.034
	Min	30.000	29.760	0.110	30.000	29.883	0.065	30.000	29.959	0.020	30.000	29.980	0.007	30.000	29.987	0.000
40	Max	40.160	39.880	0.440	40.062	39.920	0.204	40.039	39.975	0.089	40.025	39.991	0.050	40.025	40.000	0.041
	Min	40.000	39.720	0.120	40.000	39.858	0.080	40.000	39.950	0.025	40.000	39.975	0.009	40.000	39.984	0.000
50	Max	50.160	49.870	0.450	50.062	49.920	0.204	50.039	49.975	0.089	50.025	49.991	0.050	50.025	50.000	0.041
	Min	50.000	49.710	0.130	50.000	49.858	0.080	50.000	49.950	0.025	50.000	49.975	0.009	50.000	49.984	0.000
60	Max	60.190	59.860	0.520	60.074	59.900	0.248	60.046	59.970	0.106	60.030	59.990	0.059	60.030	60.000	0.049
	Min	60.000	59.670	0.140	60.000	59.826	0.100	60.000	59.940	0.030	60.000	59.971	0.010	60.000	59.981	0.000
80	Max	80.190	79.850	0.530	80.074	79.900	0.248	80.046	79.970	0.106	80.030	79.990	0.059	80.030	80.000	0.049
	Min	80.000	79.660	0.150	80.000	79.826	0.100	80.000	79.940	0.030	80.000	79.971	0.010	80.000	79.981	0.000
100	Max	100.220	99.830	0.610	100.087	99.880	0.294	100.054	99.964	0.125	100.035	99.988	0.069	100.035	100.000	0.057
	Min	100.000	99.610	0.170	100.000	99.793	0.120	100.000	99.929	0.036	100.000	99.966	0.012	100.000	99.978	0.000
120	Max	120.220	119.820	0.620	120.087	119.880	0.294	120.054	119.964	0.125	120.035	119.988	0.069	120.035	120.000	0.057
	Min	120.000	119.600	0.180	120.000	119.793	0.120	120.000	119.929	0.036	120.000	119.966	0.012	120.000	119.978	0.000
160	Max	160.250	159.790	0.710	160.100	159.855	0.345	160.063	159.957	0.146	160.040	159.986	0.079	160.040	160.000	0.065
	Min	160.000	159.540	0.210	160.000	159.755	0.145	160.000	159.917	0.043	160.000	159.961	0.014	160.000	159.975	0.000
200	Max	200.290	199.760	0.820	200.115	199.830	0.400	200.072	199.950	0.168	200.046	199.985	0.090	200.046	200.000	0.075
	Min	200.000	199.470	0.240	200.000	199.715	0.170	200.000	199.904	0.050	200.000	199.956	0.015	200.000	199.971	0.000
250	Max	250.290	249.720	0.860	250.115	249.830	0.400	250.072	249.950	0.168	250.046	249.985	0.090	250.046	250.000	0.075
	Min	250.000	249.430	0.280	250.000	249.715	0.170	250.000	249.904	0.050	250.000	249.956	0.015	250.000	249.971	0.000
300	Max	300.320	299.670	0.970	300.130	299.810	0.450	300.081	299.944	0.189	300.052	299.983	0.101	300.052	300.000	0.084
	Min	300.000	299.350	0.330	300.000	299.680	0.190	300.000	299.892	0.056	300.000	299.951	0.017	300.000	299.968	0.000
400	Max	400.360	399.600	1.120	400.140	399.790	0.490	400.089	399.938	0.208	400.057	399.982	0.111	400.057	400.000	0.093
	Min	400.000	399.240	0.400	400.000	399.650	0.210	400.000	399.881	0.062	400.000	399.946	0.018	400.000	399.964	0.000
500	Max	500.400	499.520	1.280	500.155	499.770	0.540	500.097	499.932	0.228	500.063	499.980	0.123	500.063	500.000	0.103
	Min	500.000	499.120	0.480	500.000	499.615	0.230	500.000	499.869	0.068	500.000	499.940	0.020	500.000	499.960	0.000

[a] The sizes shown are first-choice basic sizes (see Table 10). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978 (R1984).

[b] All fits shown in this table have clearance.

All dimensions are in millimeters.

Table 13. American National Standard Preferred Hole Basis Metric Transition and Interference Fits *ANSI B4.2-1978 (R1994)*

		Locational Transition			Locational Transition			Locational Interference			Medium Drive			Force		
Basic Size[a]		Hole H7	Shaft k6	Fit[b]	Hole H7	Shaft n6	Fit[b]	Hole H7	Shaft p6	Fit[b]	Hole H7	Shaft s6	Fit[b]	Hole H7	Shaft u6	Fit[b]
1	Max	1.010	1.006	+0.010	1.010	1.010	+0.006	1.010	1.012	+0.004	1.010	1.020	–0.004	1.010	1.024	–0.008
	Min	1.000	1.000	–0.006	1.000	1.004	–0.010	1.000	1.006	–0.012	1.000	1.014	–0.020	1.000	1.018	–0.024
1.2	Max	1.210	1.206	+0.010	1.210	1.210	+0.006	1.210	1.212	+0.004	1.210	1.220	–0.004	1.210	1.224	–0.008
	Min	1.200	1.200	–0.006	1.200	1.204	–0.010	1.200	1.206	–0.012	1.200	1.214	–0.020	1.200	1.218	–0.024
1.6	Max	1.610	1.606	+0.010	1.610	1.610	+0.006	1.610	1.612	+0.004	1.610	1.620	–0.004	1.610	1.624	–0.008
	Min	1.600	1.600	–0.006	1.600	1.604	–0.010	1.600	1.606	–0.012	1.600	1.614	–0.020	1.600	1.618	–0.024
2	Max	2.010	2.006	+0.010	2.010	2.010	+0.006	2.010	2.012	+0.004	2.010	2.020	–0.004	2.010	2.024	–0.008
	Min	2.000	2.000	–0.006	2.000	2.004	–0.010	2.000	2.006	–0.012	2.000	2.014	–0.020	2.000	2.018	–0.024
2.5	Max	2.510	2.506	+0.010	2.510	2.510	+0.006	2.510	2.512	+0.004	2.510	2.520	–0.004	2.510	2.524	–0.008
	Min	2.500	2.500	–0.006	2.500	2.504	–0.010	2.500	2.506	–0.012	2.500	2.514	–0.020	2.500	2.518	–0.024
3	Max	3.010	3.006	+0.010	3.010	3.010	+0.006	3.010	3.012	+0.004	3.010	3.020	–0.004	3.010	3.024	–0.008
	Min	3.000	3.000	–0.006	3.000	3.004	–0.010	3.000	3.006	–0.012	3.000	3.014	–0.020	3.000	3.018	–0.024
4	Max	4.012	4.009	+0.011	4.012	4.016	+0.004	4.012	4.020	0.000	4.012	4.027	–0.007	4.012	4.031	–0.011
	Min	4.000	4.001	–0.009	4.000	4.008	–0.016	4.000	4.012	–0.020	4.000	4.019	–0.027	4.000	4.023	–0.031
5	Max	5.012	5.009	+0.011	5.012	5.016	+0.004	5.012	5.020	0.000	5.012	5.027	–0.007	5.012	5.031	–0.011
	Min	5.000	5.001	–0.009	5.000	5.008	–0.016	5.000	5.012	–0.020	5.000	5.019	–0.027	5.000	5.023	–0.031
6	Max	6.012	6.009	+0.011	6.012	6.016	+0.004	6.012	6.020	0.000	6.012	6.027	–0.007	6.012	6.031	–0.011
	Min	6.000	6.001	–0.009	6.000	6.008	–0.016	6.000	6.012	–0.020	6.000	6.019	–0.027	6.000	6.023	–0.031
8	Max	8.015	8.010	+0.014	8.015	8.019	+0.005	8.015	8.024	0.000	8.015	8.032	–0.008	8.015	8.037	–0.013
	Min	8.000	8.001	–0.010	8.000	8.010	–0.019	8.000	8.015	–0.024	8.000	8.023	–0.032	8.000	8.028	–0.037
10	Max	10.015	10.010	+0.014	10.015	10.019	+0.005	10.015	10.024	0.000	10.015	10.032	–0.008	10.015	10.034	–0.013
	Min	10.000	10.001	–0.010	10.000	10.010	–0.019	10.000	10.015	–0.024	10.000	10.023	–0.032	10.000	10.028	–0.037
12	Max	12.018	12.012	+0.017	12.018	12.023	+0.006	12.018	12.029	0.000	12.018	12.039	–0.010	12.018	12.044	–0.015
	Min	12.000	12.001	–0.012	12.000	12.012	–0.023	12.000	12.018	–0.029	12.000	12.028	–0.039	12.000	12.033	–0.044
16	Max	16.018	16.012	+0.017	16.018	16.023	+0.006	16.018	16.029	0.000	16.018	16.039	–0.010	16.018	16.044	–0.015
	Min	16.000	16.001	–0.012	16.000	16.012	–0.023	16.000	16.018	–0.029	16.000	16.028	–0.039	16.000	16.033	–0.044
20	Max	20.021	20.015	+0.019	20.021	20.028	+0.006	20.021	20.035	–0.001	20.021	20.048	–0.014	20.021	20.054	–0.020
	Min	20.000	20.002	–0.015	20.000	20.015	–0.028	20.000	20.022	–0.035	20.000	20.035	–0.048	20.000	20.041	–0.054
25	Max	25.021	25.015	+0.019	25.021	25.028	+0.006	25.021	25.035	–0.001	25.021	25.048	–0.014	25.021	25.061	–0.027
	Min	25.000	25.002	–0.015	25.000	25.015	–0.028	25.000	25.022	–0.035	25.000	25.035	–0.048	25.000	25.048	–0.061

Table 13. *(Continued)* American National Standard Preferred Hole Basis Metric Transition and Interference Fits *ANSI B4.2-1978 (R1994)*

Basic Size[a]		Locational Transition			Locational Transition			Locational Interference			Medium Drive			Force		
		Hole H7	Shaft k6	Fit[b]	Hole H7	Shaft n6	Fit[b]	Hole H7	Shaft p6	Fit[b]	Hole H7	Shaft s6	Fit[b]	Hole H7	Shaft u6	Fit[b]
30	Max	30.021	30.015	+0.019	30.021	30.028	+0.006	30.021	30.035	−0.001	30.021	30.048	−0.014	30.021	30.061	−0.027
	Min	30.000	30.002	−0.015	30.000	30.015	−0.028	30.000	30.022	−0.035	30.000	30.035	−0.048	30.000	30.048	−0.061
40	Max	40.025	40.018	+0.023	40.025	40.033	+0.008	40.025	40.042	−0.001	40.025	40.059	−0.018	40.025	40.076	−0.035
	Min	40.000	40.002	−0.018	40.000	40.017	−0.033	40.000	40.026	−0.042	40.000	40.043	−0.059	40.000	40.060	−0.076
50	Max	50.025	50.018	+0.023	50.025	50.033	+0.008	50.025	50.042	−0.001	50.025	50.059	−0.018	50.025	50.086	−0.045
	Min	50.000	50.002	−0.018	50.000	50.017	−0.033	50.000	50.026	−0.042	50.000	50.043	−0.059	50.000	50.070	−0.086
60	Max	60.030	60.021	+0.028	60.030	60.039	+0.010	60.030	60.051	−0.002	60.030	60.072	−0.023	60.030	60.106	−0.057
	Min	60.000	60.002	−0.021	60.000	60.020	−0.039	60.000	60.032	−0.051	60.000	60.053	−0.072	60.000	60.087	−0.106
80	Max	80.030	80.021	+0.028	80.030	80.039	+0.010	80.030	80.051	−0.002	80.030	80.078	−0.029	80.030	80.121	−0.072
	Min	80.000	80.002	−0.021	80.000	80.020	−0.039	80.000	80.032	−0.051	80.000	80.059	−0.078	80.000	80.102	−0.121
100	Max	100.035	100.025	+0.032	100.035	100.045	+0.012	100.035	100.059	−0.002	100.035	100.093	−0.036	100.035	100.146	−0.089
	Min	100.000	100.003	−0.025	100.000	100.023	−0.045	100.000	100.037	−0.059	100.000	100.071	−0.093	100.000	100.124	−0.146
120	Max	120.035	120.025	+0.032	120.035	120.045	+0.012	120.035	120.059	−0.002	120.035	120.101	−0.044	120.035	120.166	−0.109
	Min	120.000	120.003	−0.025	120.000	120.023	−0.045	120.000	120.037	−0.059	120.000	120.079	−0.101	120.000	120.144	−0.166
160	Max	160.040	160.028	+0.037	160.040	160.052	+0.013	160.040	160.068	−0.003	160.040	160.125	−0.060	160.040	160.215	−0.150
	Min	160.000	160.003	−0.028	160.000	160.027	−0.052	160.000	160.043	−0.068	160.000	160.100	−0.125	160.000	160.190	−0.215
200	Max	200.046	200.033	+0.042	200.046	200.060	+0.015	200.046	200.079	−0.004	200.046	200.151	−0.076	200.046	200.265	−0.190
	Min	200.000	200.004	−0.033	200.000	200.031	−0.060	200.000	200.050	−0.079	200.000	200.122	−0.151	200.000	200.236	−0.265
250	Max	250.046	250.033	+0.042	250.046	250.060	+0.015	250.046	250.079	−0.004	250.046	250.169	−0.094	250.046	250.313	−0.238
	Min	250.000	250.004	−0.033	250.000	250.031	−0.060	250.000	250.050	−0.079	250.000	250.140	−0.169	250.000	250.284	−0.313
300	Max	300.052	300.036	+0.048	300.052	300.066	+0.018	300.052	300.088	−0.004	300.052	300.202	−0.118	300.052	300.382	−0.298
	Min	300.000	300.004	−0.036	300.000	300.034	−0.066	300.000	300.056	−0.088	300.000	300.170	−0.202	300.000	300.350	−0.382
400	Max	400.057	400.040	+0.053	400.057	400.073	+0.020	400.057	400.098	−0.005	400.057	400.244	−0.151	400.057	400.471	−0.378
	Min	400.000	400.004	−0.040	400.000	400.037	−0.073	400.000	400.062	−0.098	400.000	400.208	−0.244	400.000	400.435	−0.471
500	Max	500.063	500.045	+0.058	500.063	500.080	+0.023	500.063	500.108	−0.005	500.063	500.292	−0.189	500.063	500.580	−0.477
	Min	500.000	500.005	−0.045	500.000	500.040	−0.080	500.000	500.068	−0.108	500.000	500.252	−0.292	500.000	500.540	−0.580

[a] The sizes shown are first-choice basic sizes (see Table 10). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978 (R1984).

[b] A plus sign indicates clearance; a minus sign indicates interference.

All dimensions are in millimeters.

Table 14. American National Standard Preferred Shaft Basis Metric Clearance Fits *ANSI B4.2-1978 (R1994)*

		Loose Running			Free Running			Close Running			Sliding			Locational Clearance		
Basic Size[a]		Hole C11	Shaft h11	Fit[b]	Hole D9	Shaft h9	Fit[b]	Hole F8	Shaft h7	Fit[b]	Hole G7	Shaft h6	Fit[b]	Hole H7	Shaft h6	Fit[b]
1	Max	1.120	1.000	0.180	1.045	1.000	0.070	1.020	1.000	0.030	1.012	1.000	0.018	1.010	1.000	0.016
	Min	1.060	0.940	0.060	1.020	0.975	0.020	1.006	0.990	0.006	1.002	0.994	0.002	1.000	0.994	0.000
1.2	Max	1.320	1.200	0.180	1.245	1.200	0.070	1.220	1.200	0.030	1.212	1.200	0.018	1.210	1.200	0.016
	Min	1.260	1.140	0.060	1.220	1.175	0.020	1.206	1.190	0.006	1.202	1.194	0.002	1.200	1.194	0.000
1.6	Max	1.720	1.600	0.180	1.645	1.600	0.070	1.620	1.600	0.030	1.612	1.600	0.018	1.610	1.600	0.016
	Min	1.660	1.540	0.060	1.620	1.575	0.020	1.606	1.590	0.006	1.602	1.594	0.002	1.600	1.594	0.000
2	Max	2.120	2.000	0.180	2.045	2.000	0.070	2.020	2.000	0.030	2.012	2.000	0.018	2.010	2.000	0.016
	Min	2.060	1.940	0.060	2.020	1.975	0.020	2.006	1.990	0.006	2.002	1.994	0.002	2.000	1.994	0.000
2.5	Max	2.620	2.500	0.180	2.545	2.500	0.070	2.520	2.500	0.030	2.512	2.500	0.018	2.510	2.500	0.016
	Min	2.560	2.440	0.060	2.520	2.475	0.020	2.506	2.490	0.006	2.502	2.494	0.002	2.500	2.494	0.000
3	Max	3.120	3.000	0.180	3.045	3.000	0.070	3.020	3.000	0.030	3.012	3.000	0.018	3.010	3.000	0.016
	Min	3.060	2.940	0.060	3.020	2.975	0.020	3.006	2.990	0.006	3.002	2.994	0.002	3.000	2.994	0.000
4	Max	4.145	4.000	0.220	4.060	4.000	0.090	4.028	4.000	0.040	4.016	4.000	0.024	4.012	4.000	0.020
	Min	4.070	3.925	0.070	4.030	3.970	0.030	4.010	3.988	0.010	4.004	3.992	0.004	4.000	3.992	0.000
5	Max	5.145	5.000	0.220	5.060	5.000	0.090	5.028	5.000	0.040	5.016	5.000	0.024	5.012	5.000	0.020
	Min	5.070	4.925	0.070	5.030	4.970	0.030	5.010	4.988	0.010	5.004	4.992	0.004	5.000	4.992	0.000
6	Max	6.145	6.000	0.220	6.060	6.000	0.090	6.028	6.000	0.040	6.016	6.000	0.024	6.012	6.000	0.020
	Min	6.070	5.925	0.070	6.030	5.970	0.030	6.010	5.988	0.010	6.004	5.992	0.004	6.000	5.992	0.000
8	Max	8.170	8.000	0.260	8.076	8.000	0.112	8.035	8.000	0.050	8.020	8.000	0.029	8.015	8.000	0.024
	Min	8.080	7.910	0.080	8.040	7.964	0.040	8.013	7.985	0.013	8.005	7.991	0.005	8.000	7.991	0.000
10	Max	10.170	10.000	0.260	10.076	10.000	0.112	10.035	10.000	0.050	10.020	10.000	0.029	10.015	10.000	0.024
	Min	10.080	9.910	0.080	10.040	9.964	0.040	10.013	9.985	0.013	10.005	9.991	0.005	10.000	9.991	0.000
12	Max	12.205	12.000	0.315	12.093	12.000	0.136	12.043	12.000	0.061	12.024	12.000	0.035	12.018	12.000	0.029
	Min	12.095	11.890	0.095	12.050	11.957	0.050	12.016	11.982	0.016	12.006	11.989	0.006	12.000	11.989	0.000
16	Max	16.205	16.000	0.315	16.093	16.000	0.136	16.043	16.000	0.061	16.024	16.000	0.035	16.018	16.000	0.029
	Min	16.095	15.890	0.095	16.050	15.957	0.050	16.016	15.982	0.016	16.006	15.989	0.006	16.000	15.989	0.000
20	Max	20.240	20.000	0.370	20.117	20.000	0.169	20.053	20.000	0.074	20.028	20.000	0.041	20.021	20.000	0.034
	Min	20.110	19.870	0.110	20.065	19.948	0.065	20.020	19.979	0.020	20.007	19.987	0.007	20.000	19.987	0.000
25	Max	25.240	25.000	0.370	25.117	25.000	0.169	25.053	25.000	0.074	25.028	25.000	0.041	25.021	25.000	0.034
	Min	25.110	24.870	0.110	25.065	24.948	0.065	25.020	24.979	0.020	25.007	24.987	0.007	25.000	24.987	0.000

Table 14. *(Continued)* American National Standard Preferred Shaft Basis Metric Clearance Fits *ANSI B4.2-1978 (R1994)*

Basic Size[a]		Loose Running			Free Running			Close Running			Sliding			Locational Clearance		
		Hole C11	Shaft h11	Fit[b]	Hole D9	Shaft h9	Fit[b]	Hole F8	Shaft h7	Fit[b]	Hole G7	Shaft h6	Fit[b]	Hole H7	Shaft h6	Fit[b]
30	Max	30.240	30.000	0.370	30.117	30.000	0.169	30.053	30.000	0.074	30.028	30.000	0.041	30.021	30.000	0.034
	Min	30.110	29.870	0.110	30.065	29.948	0.065	30.020	29.979	0.020	30.007	29.987	0.007	30.000	29.987	0.000
40	Max	40.280	40.000	0.440	40.142	40.000	0.204	40.064	40.000	0.089	40.034	40.000	0.050	40.025	40.000	0.041
	Min	40.120	39.840	0.120	40.080	39.938	0.080	40.025	39.975	0.025	40.009	39.984	0.009	40.000	39.984	0.000
50	Max	50.290	50.000	0.450	50.142	50.000	0.204	50.064	50.000	0.089	50.034	50.000	0.050	50.025	50.000	0.041
	Min	50.130	49.840	0.130	50.080	49.938	0.080	50.025	49.975	0.025	50.009	49.984	0.009	50.000	49.984	0.000
60	Max	60.330	60.000	0.520	60.174	60.000	0.248	60.076	60.000	0.106	60.040	60.000	0.059	60.030	60.000	0.049
	Min	60.140	59.810	0.140	60.100	59.926	0.100	60.030	59.970	0.030	60.010	59.981	0.010	60.000	59.981	0.000
80	Max	80.340	80.000	0.530	80.174	80.000	0.248	80.076	80.000	0.106	80.040	80.000	0.059	80.030	80.000	0.049
	Min	80.150	79.810	0.150	80.100	79.926	0.100	80.030	79.970	0.030	80.010	79.981	0.010	80.000	79.981	0.000
100	Max	100.390	100.000	0.610	100.207	100.000	0.294	100.090	100.000	0.125	100.047	100.000	0.069	100.035	100.000	0.057
	Min	100.170	99.780	0.170	100.120	99.913	0.120	100.036	99.965	0.036	100.012	99.978	0.012	100.000	99.978	0.000
120	Max	120.400	120.000	0.620	120.207	120.000	0.294	120.090	120.000	0.125	120.047	120.000	0.069	120.035	120.000	0.057
	Min	120.180	119.780	0.180	120.120	119.913	0.120	120.036	119.965	0.036	120.012	119.978	0.012	120.000	119.978	0.000
160	Max	160.460	160.000	0.710	160.245	160.000	0.345	160.106	160.000	0.146	160.054	160.000	0.079	160.040	160.000	0.065
	Min	160.210	159.750	0.210	160.145	159.900	0.145	160.043	159.960	0.043	160.014	159.975	0.014	160.000	159.975	0.000
200	Max	200.530	200.000	0.820	200.285	200.000	0.400	200.122	200.000	0.168	200.061	200.000	0.090	200.046	200.000	0.075
	Min	200.240	199.710	0.240	200.170	199.885	0.170	200.050	199.954	0.050	200.015	199.971	0.015	200.000	199.971	0.000
250	Max	250.570	250.000	0.860	250.285	250.000	0.400	250.122	250.000	0.168	250.061	250.000	0.090	250.046	250.000	0.075
	Min	250.280	249.710	0.280	250.170	249.885	0.170	250.050	249.954	0.050	250.015	249.971	0.015	250.000	249.971	0.000
300	Max	300.650	300.000	0.970	300.320	300.000	0.450	300.137	300.000	0.189	300.069	300.000	0.101	300.052	300.000	0.084
	Min	300.330	299.680	0.330	300.190	299.870	0.190	300.056	299.948	0.056	300.017	299.968	0.017	300.000	299.968	0.000
400	Max	400.760	400.000	1.120	400.350	400.000	0.490	400.151	400.000	0.208	400.075	400.000	0.111	400.057	400.000	0.093
	Min	400.400	399.640	0.400	400.210	399.860	0.210	400.062	399.943	0.062	400.018	399.964	0.018	400.000	399.964	0.000
500	Max	500.880	500.000	1.280	500.385	500.000	0.540	500.165	500.000	0.228	500.083	500.000	0.123	500.063	500.000	0.103
	Min	500.480	499.600	0.480	500.230	499.845	0.230	500.068	499.937	0.068	500.020	499.960	0.020	500.000	499.960	0.000

[a] The sizes shown are first-choice basic sizes (see Table 10). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978 (R1984).

[b] All fits shown in this table have clearance.

All dimensions are in millimeters.

Table 15. American National Standard Preferred Shaft Basis Metric Transition and Interference Fits *ANSI B4.2-1978 (R1994)*

Basic Size[a]		Locational Transition			Locational Transition			Locational Interference			Medium Drive			Force		
		Hole K7	Shaft h6	Fit[b]	Hole N7	Shaft h6	Fit[b]	Hole P7	Shaft h6	Fit[b]	Hole S7	Shaft h6	Fit[b]	Hole U7	Shaft h6	Fit[b]
1	Max	1.000	1.000	+0.006	0.996	1.000	+0.002	0.994	1.000	0.000	0.986	1.000	–0.008	0.982	1.000	–0.012
	Min	0.990	0.994	–0.010	0.986	0.994	–0.014	0.984	0.994	–0.016	0.976	0.994	–0.024	0.972	0.994	–0.028
1.2	Max	1.200	1.200	+0.006	1.196	1.200	+0.002	1.194	1.200	0.000	1.186	1.200	–0.008	1.182	1.200	–0.012
	Min	1.190	1.194	–0.010	1.186	1.194	–0.014	1.184	1.194	–0.016	1.176	1.194	–0.024	1.172	1.194	–0.028
1.6	Max	1.600	1.600	+0.006	1.596	1.600	+0.002	1.594	1.600	0.000	1.586	1.600	–0.008	1.582	1.600	–0.012
	Min	1.590	1.594	–0.010	1.586	1.594	–0.014	1.584	1.594	–0.016	1.576	1.594	–0.024	1.572	1.594	–0.028
2	Max	2.000	2.000	+0.006	1.996	2.000	+0.002	1.994	2.000	0.000	1.986	2.000	–0.008	1.982	2.000	–0.012
	Min	1.990	1.994	–0.010	1.986	1.994	–0.014	1.984	1.994	–0.016	1.976	1.994	–0.024	1.972	1.994	–0.028
2.5	Max	2.500	2.500	+0.006	2.496	2.500	+0.002	2.494	2.500	0.000	2.486	2.500	–0.008	2.482	2.500	–0.012
	Min	2.490	2.494	–0.010	2.486	2.494	–0.014	2.484	2.494	–0.016	2.476	2.494	–0.024	2.472	2.494	–0.028
3	Max	3.000	3.000	+0.006	2.996	3.000	+0.002	2.994	3.000	0.000	2.986	3.000	–0.008	2.982	3.000	–0.012
	Min	2.990	2.994	–0.010	2.986	2.994	–0.014	2.984	2.994	–0.016	2.976	2.994	–0.024	2.972	2.994	–0.028
4	Max	4.003	4.000	+0.011	3.996	4.000	+0.004	3.992	4.000	0.000	3.985	4.000	–0.007	3.981	4.000	–0.011
	Min	3.991	3.992	–0.009	3.984	3.992	–0.016	3.980	3.992	–0.020	3.973	3.992	–0.027	3.969	3.992	–0.031
5	Max	5.003	5.000	+0.011	4.996	5.000	+0.004	4.992	5.000	0.000	4.985	5.000	–0.007	4.981	5.000	–0.011
	Min	4.991	4.992	–0.009	4.984	4.992	–0.016	4.980	4.992	–0.020	4.973	4.992	–0.027	4.969	4.992	–0.031
6	Max	6.003	6.000	+0.011	5.996	6.000	+0.004	5.992	6.000	0.000	5.985	6.000	–0.007	5.981	6.000	–0.011
	Min	5.991	5.992	–0.009	5.984	5.992	–0.016	5.980	5.992	–0.020	5.973	5.992	–0.027	5.969	5.992	–0.031
8	Max	8.005	8.000	+0.014	7.996	8.000	+0.005	7.991	8.000	0.000	7.983	8.000	–0.008	7.978	8.000	–0.013
	Min	7.990	7.991	–0.010	7.981	7.991	–0.019	7.976	7.991	–0.024	7.968	7.991	–0.032	7.963	7.991	–0.037
10	Max	10.005	10.000	+0.014	9.996	10.000	+0.005	9.991	10.000	0.000	9.983	10.000	–0.008	9.978	10.000	–0.013
	Min	9.990	9.991	–0.010	9.981	9.991	–0.019	9.976	9.991	–0.024	9.968	9.991	–0.032	9.963	9.991	–0.037
12	Max	12.006	12.000	+0.017	11.995	12.000	+0.006	11.989	12.000	0.000	11.979	12.000	–0.010	11.974	12.000	–0.015
	Min	11.988	11.989	–0.012	11.977	11.989	–0.023	11.971	11.989	–0.029	11.961	11.989	–0.039	11.956	11.989	–0.044
16	Max	16.006	16.000	+0.017	15.995	16.000	+0.006	15.989	16.000	0.000	15.979	16.000	–0.010	15.974	16.000	–0.015
	Min	15.988	15.989	–0.012	15.977	15.989	–0.023	15.971	15.989	–0.029	15.961	15.989	–0.039	15.956	15.989	–0.044
20	Max	20.006	20.000	+0.019	19.993	20.000	+0.006	19.986	20.000	–0.001	19.973	20.000	–0.014	19.967	20.000	–0.020
	Min	19.985	19.987	–0.015	19.972	19.987	–0.028	19.965	19.987	–0.035	19.952	19.987	–0.048	19.946	19.987	–0.054
25	Max	25.006	25.000	+0.019	24.993	25.000	+0.006	24.986	25.000	–0.001	24.973	25.000	–0.014	24.960	25.000	–0.027
	Min	24.985	24.987	–0.015	24.972	24.987	–0.028	24.965	24.987	–0.035	24.952	24.987	–0.048	24.939	24.987	–0.061

Table 15. *(Continued)* **American National Standard Preferred Shaft Basis Metric Transition and Interference Fits** *ANSI B4.2-1978 (R1994)*

		Locational Transition			Locational Transition			Locational Interference			Medium Drive			Force		
Basic Size[a]		Hole K7	Shaft h6	Fit[b]	Hole N7	Shaft h6	Fit[b]	Hole P7	Shaft h6	Fit[b]	Hole S7	Shaft h6	Fit[b]	Hole U7	Shaft h6	Fit[b]
30	Max	30.006	30.000	+0.019	29.993	30.000	+0.006	29.986	30.000	–0.001	29.973	30.000	–0.014	29.960	30.000	–0.027
	Min	29.985	29.987	–0.015	29.972	29.987	–0.028	29.965	29.987	–0.035	29.952	29.987	–0.048	29.939	29.987	–0.061
40	Max	40.007	40.000	+0.023	39.992	40.000	+0.008	39.983	40.000	–0.001	39.966	40.000	–0.018	39.949	40.000	–0.035
	Min	39.982	39.984	–0.018	39.967	39.984	–0.033	39.958	39.984	–0.042	39.941	39.984	–0.059	39.924	39.984	–0.076
50	Max	50.007	50.000	+0.023	49.992	50.000	+0.008	49.983	50.000	–0.001	49.966	50.000	–0.018	49.939	50.000	–0.045
	Min	49.982	49.984	–0.018	49.967	49.984	–0.033	49.958	49.984	–0.042	49.941	49.984	–0.059	49.914	49.984	–0.086
60	Max	60.009	60.000	+0.028	59.991	60.000	+0.010	59.979	60.000	–0.002	59.958	60.000	–0.023	59.924	60.000	–0.087
	Min	59.979	59.981	–0.021	59.961	59.981	–0.039	59.949	59.981	–0.051	59.928	59.981	–0.072	59.894	59.981	–0.106
80	Max	80.009	80.000	+0.028	79.991	80.000	+0.010	79.979	80.000	–0.002	79.952	80.000	–0.029	79.909	80.000	–0.072
	Min	79.979	79.981	–0.021	79.961	79.981	–0.039	79.949	79.981	–0.051	79.922	79.981	–0.078	79.879	79.981	–0.121
100	Max	100.010	100.000	+0.032	99.990	100.000	+0.012	99.976	100.000	–0.002	99.942	100.000	–0.036	99.889	100.000	–0.089
	Min	99.975	99.978	–0.025	99.955	99.978	–0.045	99.941	99.978	–0.059	99.907	99.978	–0.093	99.854	99.978	–0.146
120	Max	120.010	120.000	+0.032	119.990	120.000	+0.012	119.976	120.000	–0.002	119.934	120.000	–0.044	119.869	120.000	–0.109
	Min	119.975	119.978	–0.025	119.955	119.978	–0.045	119.941	119.978	–0.059	119.899	119.978	–0.101	119.834	119.978	–0.166
160	Max	160.012	160.000	+0.037	159.988	160.000	+0.013	159.972	160.000	–0.003	159.915	160.000	–0.060	159.825	160.000	–0.150
	Min	159.972	159.975	–0.028	159.948	159.975	–0.052	159.932	159.975	–0.068	159.875	159.975	–0.125	159.785	159.975	–0.215
200	Max	200.013	200.00	+0.042	199.986	200.000	+0.015	199.967	200.000	–0.004	199.895	200.000	–0.076	199.781	200.000	–0.190
	Min	199.967	199.971	–0.033	199.940	199.971	–0.060	199.921	199.971	–0.079	199.849	199.971	–0.151	199.735	199.971	–0.265
250	Max	250.013	250.000	+0.042	249.986	250.000	+0.015	249.967	250.000	–0.004	249.877	250.000	–0.094	249.733	250.000	–0.238
	Min	249.967	249.971	–0.033	249.940	249.971	–0.060	249.921	249.971	–0.079	249.831	249.971	–0.169	249.687	249.971	–0.313
300	Max	300.016	300.000	+0.048	299.986	300.000	+0.018	299.964	300.000	–0.004	299.850	300.000	–0.118	299.670	300.000	–0.298
	Min	299.964	299.968	–0.036	299.934	299.968	–0.066	299.912	299.968	–0.088	299.798	299.968	–0.202	299.618	299.968	–0.382
400	Max	400.017	400.000	+0.053	399.984	400.000	+0.020	399.959	400.000	–0.005	399.813	400.000	–0.151	399.586	400.000	–0.378
	Min	399.960	399.964	–0.040	399.927	399.964	–0.073	399.902	399.964	–0.098	399.756	399.964	–0.244	399.529	399.964	–0.471
500	Max	500.018	500.000	+0.058	499.983	500.000	+0.023	499.955	500.000	–0.005	499.771	500.000	–0.189	499.483	500.000	–0.477
	Min	499.955	499.960	–0.045	499.920	499.960	–0.080	499.892	499.960	–0.108	499.708	499.960	–0.292	499.420	499.960	–0.580

[a] The sizes shown are first-choice basic sizes (see Table 10). Preferred fits for other sizes can be calculated from data given in ANSI B4.2-1978 (R1984).

[b] A plus sign indicates clearance; a minus sign indicates interference.

All dimensions are in millimeters.

Table 16. American National Standard Gagemakers Tolerances
ANSI B4.4M-1981 (R1987)

Gagemakers Tolerance			Workpiece Tolerance	
	Class	ISO Symbol[a]	IT Grade	Recommended Gage Usage
↑ Rejection of Good Parts Increase	ZM	0.05 IT11	IT11	Low-precision gages recommended to be used to inspect workpieces held to internal (hole) tolerances C11 and H11 and to external (shaft) tolerances c11 and h11.
	YM	0.05 IT9	IT9	Gages recommended to be used to inspect workpieces held to internal (hole) tolerances D9 and H9 and to external (shaft) tolerances d9 and h9.
	XM	0.05 IT8	IT8	Precision gages recommended to be used to inspect workpieces held to internal (hole) tolerances F8 and H8.
Gage Cost Increase ↓	XXM	0.05 IT7	IT7	Recommended to be used for gages to inspect workpieces held to internal (hole) tolerances G7, H7, K7, N7, P7, S7, and U7, and to external (shaft) tolerances f7 and h7.
	XXXM	0.05 IT6	IT6	High-precision gages recommended to be used to inspect workpieces held to external (shaft) tolerances g6, h6, k6, n6, p6, s6, and u6.

[a] Gagemakers tolerance is equal to 5 per cent of workpiece tolerance or 5 per cent of applicable IT grade value. See table *American National Standard Gagemakers Tolerances ANSI B4.4M-1981 (R1987)*.

For workpiece tolerance class values, see previous Tables 12 through 15, incl.

Table 17. American National Standard Gagemakers Tolerances
ANSI B4.4M-1981 (R1987)

Basic Size		Class ZM	Class YM	Class XM	Class XXM	Clas XXXM
Over	To	(0.05 IT11)	(0.05 IT9)	(0.05 IT8)	(0.05 IT7)	(0.05 IT6)
0	3	0.0030	0.0012	0.0007	0.0005	0.0003
3	6	0.0037	0.0015	0.0009	0.0006	0.0004
6	10	0.0045	0.0018	0.0011	0.0007	0.0005
10	18	0.0055	0.0021	0.0013	0.0009	0.0006
18	30	0.0065	0.0026	0.0016	0.0010	0.0007
30	50	0.0080	0.0031	0.0019	0.0012	0.0008
50	80	0.0095	0.0037	0.0023	0.0015	0.0010
80	120	0.0110	0.0043	0.0027	0.0017	0.0011
120	180	0.0125	0.0050	0.0031	0.0020	0.0013
180	250	0.0145	0.0057	0.0036	0.0023	0.0015
250	315	0.0160	0.0065	0.0040	0.0026	0.0016
315	400	0.0180	0.0070	0.0044	0.0028	0.0018
400	500	0.0200	0.0077	0.0048	0.0031	0.0020

All dimensions are in millimeters. For closer gagemakers tolerance classes than Class XXXM, specify 5 per cent of IT5, IT4, or IT3 and use the designation 0.05 IT5, 0.05 IT4, etc.

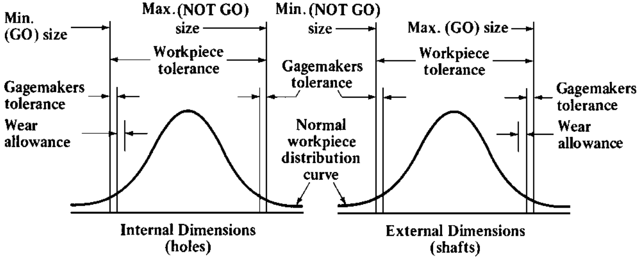


Fig. 4. Relationship between Gagemakers Tolerance, Wear Allowance and Workpiece Tolerance

Applications.—Many factors such as length of engagement, bearing load, speed, lubrication, operating temperatures, humidity, surface texture, and materials must be taken into account in fit selections for a particular application.

Choice of other than the preferred fits might be considered necessary to satisfy extreme conditions. Subsequent adjustments might also be desired as the result of experience in a particular application to suit critical functional requirements or to permit optimum manufacturing economy. Selection of a departure from these recommendations will depend upon consideration of the engineering and economic factors that might be involved; however, the benefits to be derived from the use of preferred fits should not be overlooked.

A general guide to machining processes that may normally be expected to produce work within the tolerances indicated by the IT grades given in ANSI B4.2-1978 (R1994) is shown in the chart in Table 18.

Table 18. Relation of Machining Processes to IT Tolerance Grades

	IT Grades							
	4	5	6	7	8	9	10	11
Lapping & Honing	■	■						
Cylindrical Grinding		■	■	■				
Surface Grinding		■	■	■	■			
Diamond Turning		■	■	■				
Diamond Boring		■	■	■				
Broaching		■	■	■	■			
Powder Metal sizes			■	■	■			
Reaming			■	■	■	■	■	
Turning				■	■	■	■	■
Powder Metal sintered				■	■	■	■	
Boring				■	■	■	■	■
Milling							■	■
Planing & Shaping							■	■
Drilling							■	■
Punching							■	■
Die Casting								■

British Standard for Metric ISO Limits and Fits.—Based on ISO Recommendation R286, this British Standard BS 4500:1969 is intended to provide a comprehensive range of metric limits and fits for engineering purposes, and meets the requirements of metrication in the United Kingdom. Sizes up to 3,150 mm are covered by the Standard, but the condensed information presented here embraces dimensions up to 500 mm only. The system is based on a series of tolerances graded to suit all classes of work from the finest to the most coarse, and the different types of fits that can be obtained range from coarse clearance to heavy interference. In the Standard, only cylindrical parts, designated holes and shafts are referred to explicitly, but it is emphasized that the recommendations apply equally well to other sections, and the general term *hole* or *shaft* can be taken to mean the space contained by or containing two parallel faces or tangent planes of any part, such as the width of a slot, or the thickness of a key. It is also strongly emphasized that the grades series of tolerances are intended for the most general application, and should be used wherever possible whether the features of the component involved are members of a fit or not.

Definitions.—The definitions given in the Standard include the following:

Limits of Size: The maximum and minimum sizes permitted for a feature.

Basic Size: The reference size to which the limits of size are fixed. The basic size is the same for both members of a fit.

Upper Deviation: The algebraical difference between the maximum limit of size and the corresponding basic size. It is designated as ES for a hole, and as es for a shaft, which stands for the French term *écart supérieur.*

Lower Deviation: The algebraical difference between the minimum limit of size and the corresponding basic size. It is designated as EI for a hole, and as ei for a shaft, which stands for the French term *écart inférieur.*

Zero Line: In a graphical representation of limits and fits, the straight line to which the deviations are referred. The zero line is the line of zero deviation and represents the basic size.

Tolerance: The difference between the maximum limit of size and the minimum limit of size. It is an absolute value without sign.

Tolerance Zone: In a graphical representation of tolerances, the zone comprised between the two lines representing the limits of tolerance and defined by its magnitude (tolerance) and by its position in relation to the zero line.

Fundamental Deviation: That one of the two deviations, being the one nearest to the zero line, which is conventionally chosen to define the position of the tolerance zone in relation to the zero line.

Shaft-Basis System of Fits: A system of fits in which the different clearances and interferences are obtained by associating various holes with a single shaft. In the ISO system, the basic shaft is the shaft the upper deviation of which is zero.

Hole-Basis System of Fits: A system of fits in which the different clearances and interferences are obtained by associating various shafts with a single hole. In the ISO system, the basic hole is the hole the lower deviation of which is zero.

Selected Limits of Tolerance, and Fits.—The number of fit combinations that can be built up with the ISO system is very large. However, experience shows that the majority of fits required for usual engineering products can be provided by a limited selection of tolerances. Limits of tolerance for selected holes are shown in Table 19, and for shafts, in Table 20. Selected fits, based on combinations of the selected hole and shaft tolerances, are given in Table 21.

Tolerances and Fundamental Deviations.—There are 18 tolerance grades intended to meet the requirements of different classes of work, and they are designated IT 01, IT 02, and IT 1 to IT 16. (IT stands for ISO series of tolerances.) Table 22 shows the standardized numerical values for the 18 tolerance grades, which are known as standard tolerances. The system provides 27 fundamental deviations for sizes up to and including 500 mm, and Tables 15 and 25 contain the values for shafts and holes, respectively. Uppercase (capital) letters designate hole deviations, and the same letters in lower case designate shaft deviations. The deviation j_s (J_s for holes) is provided to meet the need for symmetrical bilateral tolerances. In this instance, there is no fundamental deviation, and the tolerance zone, of whatever magnitude, is equally disposed about the zero line.

Calculated Limits of Tolerance.—The deviations and fundamental tolerances provided by the ISO system can be combined in any way that appears necessary to give a required fit. Thus, for example, the deviations H (basic hole) and f (clearance shaft) could be associated, and with each of these deviations any one of the tolerance grades IT 01 to IT 16 could be used. All the limits of tolerance that the system is capable of providing for sizes up to and including 500 mm can be calculated from the standard tolerances given in Table 22, and the fundamental deviations given in Tables 15 and 25. The range includes limits of tolerance for shafts and holes used in small high-precision work and horology.

The system provides for the use of either hole-basis or shaft-basis fits, and the Standard includes details of procedures for converting from one type of fit to the other.

The limits of tolerance for a shaft or hole are designated by the appropriate letter indicating the fundamental deviation, followed by a suffix number denoting the tolerance grade. This suffix number is the numerical part of the tolerance grade designation. Thus, a hole tolerance with deviation H and tolerance grade IT7 is designated H7. Likewise, a shaft with deviation p and tolerance grade IT 6 is designated p6. The limits of size of a component feature are defined by the basic size, say, 45 mm, followed by the appropriate tolerance designation, for example, 45 H7 or 45 p6. A fit is indicated by combining the basic size common to both features with the designation appropriate to each of them, for example, 45 H7-p6 or 45 H7/p6.

When calculating the limits of size for a shaft, the upper deviation es, or the lower deviation ei, is first obtained from Table 15, depending on the particular letter designation, and nominal dimension. If an upper deviation has been determined, the lower deviation ei = es − IT. The IT value is obtained from Table 22 for the particular tolerance grade being applied. If a lower deviation has been obtained from Table 15, the upper deviation es = ei + IT. When the upper deviation ES has been determined for a hole from Table 25, the lower deviation EI = ES − IT. If a lower deviation EI has been obtained from Table 25, then the upper deviation ES = EI + IT.

The upper deviations for holes K, M, and N with tolerance grades up to and including IT8, and for holes P to ZC with tolerance grades up to and including IT7 must be calculated by adding the delta (Δ) values given in Table 25 as indicated.

Example of Calculations: The limits of size for a part of 133 mm basic size with a tolerance designation g9 are derived as follows:

From Table 15, the upper deviation (es) is − 0.014 mm. From Table 22, the tolerance grade (ITg) is 0.100 mm. The lower deviation (ei) = es − IT = 0.114 mm, and the limits of size are thus 132.986 and 132.886 mm.

The limits of size for a part 20 mm in size, with tolerance designation D3, are derived as follows: From Table 25, the lower deviation (EI) is + 0.065 mm. From Table 22, the tolerance grade (IT9) is 0.004 mm. The upper deviation (ES) = EI + IT = 0.069 mm, and thus the limits of size for the part are 20.069 and 20.065 mm.

The limits of size for a part 32 mm in size, with tolerance designation M5, which involves a delta value, are obtained as follows: From Table 25, the upper deviation ES is − 0.009 mm + Δ = −0.005 mm. (The delta value given at the end of this table for this size and grade IT 5 is 0.004 mm.) From Table 22, the tolerance grade (IT5) is 0.011 mm. The lower deviation (EI) = ES − IT = − 0.016 mm, and thus the limits of size for the part are 31.995 and 31.984 mm.

Where the designations h and H or j_s and J_s are used, it is only necessary to refer to Table 22. For h and H, the fundamental deviation is always zero, and the disposition of the tolerance is always negative (−) for a shaft, and positive (+) for a hole. Thus, the limits for a part 40 mm in size, designated h8 are derived as follows:

From Table 22, the tolerance grade (IT 8) is 0.039 mm, and the limits are therefore 40.000 and 39.961 mm.

The limits for a part 60 mm in size, designated j_s7 or J_s7 are derived as follows:

From Table 1, the tolerance grade (IT 7) is 0.030 mm, and this value is divided equally about the basic size to give limits of 60.015 and 59.985 mm.

Table 19. British Standard Limits of Tolerance for Selected Holes (Upper and Lower Deviations) *BS 4500:1969*

Nominal Sizes, mm		H7		H8		H9		H11	
Over	Up to and Including	ES +	EI	ES +	EI	ES +	EI	ES +	EI
…	3	10	0	14	0	25	0	60	0
3	6	12	0	18	0	30	0	75	0
6	10	15	0	22	0	36	0	90	0
10	18	18	0	27	0	43	0	110	0
18	30	21	0	33	0	52	0	130	0
30	50	25	0	39	0	62	0	160	0
50	80	30	0	46	0	74	0	190	0
80	120	35	0	54	0	87	0	220	0
120	180	40	0	63	0	100	0	250	0
180	250	46	0	72	0	115	0	290	0
250	315	52	0	81	0	130	0	320	0
315	400	57	0	89	0	140	0	360	0
400	500	63	0	97	0	155	0	400	0

ES = Upper deviation.

EI = Lower deviation.

The dimensions are given in 0.001 mm, except for the nominal sizes, which are in millimeters.

Table 20. British Standard Limits of Tolerance for Selected Shafts (Upper and Lower Deviations) *BS 4500:1969*

Nominal Sizes, mm		c11		d10		e9		f7		g6		h6		k6		n6		p6		s6	
Over	Up to and Incl.	es −	ei −	es −	ei −	es −	ei −	es −	ei −	es −	ei −	es −	ei −	es +	ei +	es +	ei +	es +	ei +	es +	ei +
…	3	60	120	20	60	14	39	6	16	2	8	0	6	6	0	10	4	12	6	20	14
3	6	70	145	30	78	20	50	10	22	4	12	0	8	9	1	16	8	20	12	27	19
6	10	80	170	40	98	25	61	13	28	5	14	0	9	10	1	19	10	24	15	32	23
10	18	95	205	50	120	32	75	16	34	6	17	0	11	12	1	23	12	29	18	39	28
18	30	110	240	65	149	40	92	20	41	7	20	0	13	15	2	28	15	35	22	48	35
30	40	120	280	80	180	50	112	25	50	9	25	0	16	18	2	33	17	42	26	59	43
40	50	130	290	80	180	50	112	25	50	9	25	0	16	18	2	33	17	42	26	59	43
50	65	140	330	100	220	60	134	30	60	10	29	0	19	21	2	39	20	51	32	72	53
65	80	150	340	100	220	60	134	30	60	10	29	0	19	21	2	39	20	51	32	78	59
80	100	170	390	120	260	72	159	36	71	12	34	0	22	25	3	45	23	59	37	93	71
100	120	180	400	120	260	72	159	36	71	12	34	0	22	25	3	45	23	59	37	101	79
120	140	200	450	145	305	85	185	43	83	14	39	0	25	28	3	52	27	68	43	117	92
140	160	210	460	145	305	85	185	43	83	14	39	0	25	28	3	52	27	68	43	125	100
160	180	230	480	145	305	85	185	43	83	14	39	0	25	28	3	52	27	68	43	133	108
180	200	240	530	170	355	100	215	50	96	15	44	0	29	33	4	60	31	79	50	151	122
200	225	260	550	170	355	100	215	50	96	15	44	0	29	33	4	60	31	79	50	159	130
225	250	280	570	170	355	100	215	50	96	15	44	0	29	33	4	60	31	79	50	169	140
250	280	300	620	190	400	110	240	56	108	17	49	0	32	36	4	66	34	88	56	190	158
280	315	330	650	190	400	110	240	56	108	17	49	0	32	36	4	66	34	88	56	202	170
315	355	360	720	210	440	125	265	62	119	18	54	0	36	40	4	73	37	98	62	226	190
355	400	400	760	210	440	125	265	62	119	18	54	0	36	40	4	73	37	98	62	244	208
400	450	440	840	230	480	135	290	68	131	20	60	0	40	45	5	80	40	108	68	272	232
450	500	480	880	230	480	135	290	68	131	20	60	0	40	45	5	80	40	108	68	292	252

es = Upper deviation.

ei = Lower deviation.

The dimensions are given in 0.001 mm, except for the nominal sizes, which are in millimeters.

Table 21. British Standard Selected Fits. Minimum and Maximum Clearances *BS 4500:1969*

Nominal Sizes, mm		H11—c11		H9—d10		H9—e9		H8—f7		H7—g6		H7—h6		H7—k6		H7—n6		H7—p6		H7—s6	
Over	Up to and Incl.	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
…	3	60	180	20	85	14	64	6	30	2	18	0	16	−6	+10	−10	+6	−12	+4	−20	−4
3	6	70	220	30	108	20	80	10	40	4	24	0	20	−9	+11	−16	+4	−20	0	−27	−7
6	10	80	260	40	134	25	97	13	50	5	29	0	24	−10	+14	−19	+5	−24	0	−32	−8
10	18	95	315	50	163	32	118	16	61	6	35	0	29	−12	+17	−23	+6	−29	0	−39	−10
18	30	110	370	65	201	40	144	20	74	7	41	0	34	−15	+19	−28	+6	−35	−1	−48	−14
30	40	120	440	80	242	50	174	25	89	9	50	0	41	−18	+23	−33	+8	−42	−1	−59	−18
40	50	130	450	80	242	50	174	25	89	9	50	0	41	−18	+23	−33	+8	−42	−1	−59	−18
50	65	140	520	100	294	60	208	30	106	10	59	0	49	−21	+28	−39	+10	−51	−2	−72	−23
65	80	150	530	100	294	60	208	30	106	10	59	0	49	−21	+28	−39	+10	−51	−2	−78	−29
80	100	170	610	120	347	72	246	36	125	12	69	0	57	−25	+32	−45	+12	−59	−2	−93	−36
100	120	180	620	120	347	72	246	36	125	12	69	0	57	−25	+32	−45	+12	−59	−2	−101	−44
120	140	200	700	145	405	85	285	43	146	14	79	0	65	−28	+37	−52	+13	−68	−3	−117	−52
140	160	210	710	145	405	85	285	43	146	14	79	0	65	−28	+37	−52	+13	−68	−3	−125	−60
160	180	230	730	145	405	85	285	43	146	14	79	0	65	−28	+37	−52	+13	−68	−3	−133	−68
180	200	240	820	170	470	100	330	50	168	15	90	0	75	−33	+42	−60	+15	−79	−4	−151	−76
200	225	260	840	170	470	100	330	50	168	15	90	0	75	−33	+42	−60	+15	−79	−4	−159	−84
225	250	280	860	170	470	100	330	50	168	15	90	0	75	−33	+42	−60	+15	−79	−4	−169	−94
250	280	300	940	190	530	110	370	56	189	17	101	0	84	−36	+48	−66	+18	−88	−4	−190	−126
280	315	330	970	190	530	110	370	56	189	17	101	0	84	−36	+48	−66	+18	−88	−4	−202	−112
315	355	360	1080	210	580	125	405	62	208	18	111	0	93	−40	−53	−73	+20	−98	−5	−226	−133
355	400	400	1120	210	580	125	405	62	208	18	111	0	93	−40	−53	−73	+20	−98	−5	−244	−151
400	450	440	1240	230	635	135	445	68	228	20	123	0	103	−45	+58	−80	+23	−108	−5	−272	−169
450	500	480	1280	230	635	135	445	68	228	20	123	0	103	−45	+58	−80	+23	−108	−5	−292	−189

The dimensions are given in 0.001 mm, except for the nominal sizes, which are in millimeters.

Minus (–) sign indicates negative clearance, i.e., interference.

Table 22. British Standard Limits and Fits *BS 4500:1969*

Nominal Sizes, mm		Tolerance Grades																	
Over	To	IT 01	IT 0	IT 1	IT 2	IT 3	IT 4	IT 5	IT 6	IT 7	IT 8	IT 9	IT 10	IT 11	IT 12	IT 13	IT 14[a]	IT 15[a]	IT 16[a]
…	3	0.3	0.5	0.8	1.2	2	3	4	6	10	14	25	40	60	100	140	250	400	600
3	6	0.4	0.6	1	1.5	2.5	4	5	8	12	18	30	48	75	120	180	300	480	750
6	10	0.4	0.6	1	1.5	2.5	4	6	9	15	22	36	58	90	150	220	360	580	900
10	18	0.5	0.8	1.2	2	3	5	8	11	18	27	43	70	110	180	270	430	700	1100
18	30	0.6	1	1.5	2.5	4	6	9	13	21	33	52	84	130	210	330	520	840	1300
30	50	0.6	1	1.5	2.5	4	7	11	16	25	39	62	100	160	250	390	620	1000	1600
50	80	0.8	1.2	2	3	5	8	13	19	30	46	74	120	190	300	460	740	1200	1900
80	120	1	1.5	2.5	4	6	10	15	22	35	54	87	140	220	350	540	870	1400	2200
120	180	1.2	2	3.5	5	8	12	18	25	40	63	100	160	250	400	630	1000	1600	2500
180	250	2	3	4.5	7	10	14	20	29	46	72	115	185	290	460	720	1150	1850	2900
250	315	2.5	4	6	8	12	16	23	32	52	81	130	210	320	520	810	1300	2100	3200
315	400	3	5	7	9	13	18	25	36	57	89	140	230	360	570	890	1400	2300	3600
400	500	4	6	8	10	15	20	27	40	63	97	155	250	400	630	970	1550	2500	4000

[a] Not applicable to sizes below 1 mm.

The dimensions are given in 0.001 mm, except for the nominal sizes which are in millimeters.

Table 23. British Standard Fundamental Deviations for Shafts *BS 4500:1969*

Nominal Sizes, mm		Grade																
		01 to 16												5–6	7	8	4–7	≤3 >7
		Fundamental (Upper) Deviation es												Fundamental (Lower) Deviation ei				
Over	To	a[a]	b[a]	c	cd	d	e	ef	f	fg	g	h	js[b]	j			k	
…	3	−270	−140	−60	−34	−20	−14	−10	−6	−4	−2	0	±IT/2	−2	−4	−6	0	0
3	6	−270	−140	−70	−46	−30	−20	−14	−10	−6	−4	0		−2	−4	…	+1	0
6	10	−280	−150	−80	−56	−40	−25	−18	−13	−8	−5	0		−2	−5	…	+1	0
10	14	−290	−150	−95	…	−50	−32	…	−16	…	−6	0		−3	−6	…	+1	0
14	18	−290	−150	−95	…	−50	−32	…	−16	…	−6	0		−3	−6	…	+1	0
18	24	−300	−160	−110	…	−65	−40	…	−20	…	−7	0		−4	−8	…	+2	0
24	30	−300	−160	−110	…	−65	−40	…	−20	…	−7	0		−4	−8	…	+2	0
30	40	−310	−170	−120	…	−80	−50	…	−25	…	−9	0		−5	−10	…	+2	0
40	50	−320	−180	−130	…	−80	−50	…	−25	…	−9	0		−5	−10	…	+2	0
50	65	−340	−190	−140	…	−100	−60	…	−30	…	−10	0		−7	−12	…	+2	0
65	80	−360	−200	−150	…	−100	−60	…	−30	…	−10	0		−7	−12	…	+2	0
80	100	−380	−220	−170	…	−120	−72	…	−36	…	−12	0		−9	−15	…	+3	0
100	120	−410	−240	−180	…	−120	−72	…	−36	…	−12	0		−9	−15	…	+3	0
120	140	−460	−260	−200	…	−145	−85	…	−43	…	−14	0		−11	−18	…	+3	0
140	160	−520	−280	−210	…	−145	−85	…	−43	…	−14	0		−11	−18	…	+3	0
160	180	−580	−310	−230	…	−145	−85	…	−43	…	−14	0		−11	−18	…	+3	0
180	200	−660	−340	−240	…	−170	−100	…	−50	…	−15	0		−13	−21	…	+4	0
200	225	−740	−380	−260	…	−170	−100	…	−50	…	−15	0		−13	−21	…	+4	0
225	250	−820	−420	−280	…	−170	−100	…	−50	…	−15	0		−13	−21	…	+4	0
250	280	−920	−480	−300	…	−190	−110	…	−56	…	−17	0		−16	−26	…	+4	0
280	315	−1050	−540	−330	…	−190	−110	…	−56	…	−17	0		−16	−26	…	+4	0
315	355	−1200	−600	−360	…	−210	−125	…	−62	…	−18	0		−18	−28	…	+4	0
355	400	−1350	−680	−400	…	−210	−125	…	−62	…	−18	0		−18	−28	…	+4	0
400	450	−1500	−760	−440	…	−230	−135	…	−68	…	−20	0		−20	−32	…	+5	0
450	500	−1650	−840	−480	…	−230	−135	…	−68	…	−20	0		−20	−32	…	+5	0

[a] Not applicable to sizes up to 1 mm.

[b] In grades 7 to 11, the two symmetrical deviations ±IT/2 should be rounded if the IT value in micrometers is an odd value by replacing it with the even value immediately below. For example, if IT = 175, replace it by 174.

Table 24. British Standard Fundamental Deviations for Shafts *BS 4500:1969*

Nominal Sizes, mm		Grade													
		01 to 16													
		Fundamental (Lower) Deviation ei													
Over	To	m	n	p	r	s	t	u	v	x	y	z	za	zb	zc
…	3	+2	+4	+6	+10	+14	…	+18	…	+20	…	+26	+32	+40	+60
3	6	+4	+8	+12	+15	+19	…	+23	…	+28	…	+35	+42	+50	+80
6	10	+6	+10	+15	+19	+23	…	+28	…	+34	…	+42	+52	+67	+97
10	14	+7	+12	+18	+23	+28	…	+33	…	+40	…	+50	+64	+90	+130
14	18	+7	+12	+18	+23	+28	…	+33	+39	+45	…	+60	+77	+108	+150
18	24	+8	+15	+22	+28	+35	…	+41	+47	+54	+63	+73	+98	+136	+188
24	30	+8	+15	+22	+28	+35	+41	+48	+55	+64	+75	+88	+118	+160	+218
30	40	+9	+17	+26	+34	+43	+48	+60	+68	+80	+94	+112	+148	+200	+274
40	50	+9	+17	+26	+34	+43	+54	+70	+81	+97	+114	+136	+180	+242	+325
50	65	+11	+20	+32	+41	+53	+66	+87	+102	+122	+144	+172	+226	+300	+405
65	80	+11	+20	+32	+43	+59	+75	+102	+120	+146	+174	+210	+274	+360	+480
80	100	+13	+23	+37	+51	+71	+91	+124	+146	+178	+214	+258	+335	+445	+585
100	120	+13	+23	+37	+54	+79	+104	+144	+172	+210	+254	+310	+400	+525	+690
120	140	+15	+27	+43	+63	+92	+122	+170	+202	+248	+300	+365	+470	+620	+800
140	160	+15	+27	+43	+65	+100	+134	+190	+228	+280	+340	+415	+535	+700	+900
160	180	+15	+27	+43	+68	+108	+146	+210	+252	+310	+380	+465	+600	+780	+1000
180	200	+17	+31	+50	+77	+122	+166	+236	+284	+350	+425	+520	+670	+880	+1150
200	225	+17	+31	+50	+80	+130	+180	+258	+310	+385	+470	+575	+740	+960	+1250
225	250	+17	+31	+50	+84	+140	+196	+284	+340	+425	+520	+640	+820	+1050	+1350
250	280	+20	+34	+56	+94	+158	+218	+315	+385	+475	+580	+710	+920	+1200	+1550
280	315	+20	+34	+56	+98	+170	+240	+350	+425	+525	+650	+790	+1000	+1300	+1700
315	355	+21	+37	+62	+108	+190	+268	+390	+475	+590	+730	+900	+1150	+1500	+1900
355	400	+21	+37	+62	+114	+208	+294	+435	+530	+660	+820	+1000	+1300	+1650	+2100
400	450	+23	+40	+68	+126	+232	+330	+490	+595	+740	+920	+1100	+1450	+1850	+2400
450	500	+23	+40	+68	+132	+252	+360	+540	+660	+820	+1000	+1250	+1600	+2100	+2600

The dimensions are in 0.001 mm, except the nominal sizes, which are in millimeters.

Table 25. British Standard Fundamental Deviations for Holes *BS 4500:1969*

Nominal Sizes, mm		Grade																				
		01 to 16												6	7	8	≤8	>8	≤8[a]	>8	≤8	>8[b]
		Fundamental (Lower) Deviation EI												Fundamental (Upper) Deviation ES								
Over	To	A[b]	B[b]	C	CD	D	E	EF	F	FG	G	H	Js[c]	J			K[d]		M[d]		N[d]	
…	3	+270	+140	+60	+34	+20	+14	+10	+6	+4	+2	0	±IT/2	+2	+4	+6	0	0	−2	−2	−4	−4
3	6	+270	+140	+70	+46	+30	+20	+14	+10	+6	+4	0		+5	+6	+10	−1+Δ	…	−4+Δ	−4	−8+Δ	0
6	10	+280	+150	+80	+56	+40	+25	+18	+13	+8	+5	0		+5	+8	+12	−1+Δ	…	−6+Δ	−6	−10+Δ	0
10	14	+290	+150	+95	…	+50	+32	…	+16	…	+6	0		+6	+10	+15	−1+Δ	…	−7+Δ	−7	−12+Δ	0
14	18	+290	+150	+95	…	+50	+32	…	+16	…	+6	0		+6	+10	+15	−1+Δ	…	−7+Δ	−7	−12+Δ	0
18	24	+300	+160	+110	…	+65	+40	…	+20	…	+7	0		+8	+12	+20	−2+Δ	…	−8+Δ	−8	−15+Δ	0
24	30	+300	+160	+110	…	+65	+40	…	+20	…	+7	0		+8	+12	+20	−2+Δ	…	−8+Δ	−8	−15+Δ	0
30	40	+310	+170	+120	…	+80	+50	…	+25	…	+9	0		+10	+14	+24	−2+Δ	…	−9+Δ	−9	−17+Δ	0
40	50	+320	+180	+130	…	+80	+50	…	+25	…	+9	0		+10	+14	+24	−2+Δ	…	−9+Δ	−9	−17+Δ	0
50	65	+340	+190	+140	…	+100	+60	…	+30	…	+10	0		+13	+18	+28	−2+Δ	…	−11+Δ	−11	−20+Δ	0
65	80	+360	+200	+150	…	+100	+60	…	+30	…	+10	0		+13	+18	+28	−2+Δ	…	−11+Δ	−11	−20+Δ	0
80	100	+380	+220	+170	…	+120	+72	…	+36	…	+12	0		+16	+22	+34	−3+Δ	…	−13+Δ	−13	−23+Δ	0
100	120	+410	+240	+180	…	+120	+72	…	+36	…	+12	0		+16	+22	+34	−3+Δ	…	−13+Δ	−13	−23+Δ	0
120	140	+460	+260	+200	…	+145	+85	…	+43	…	+14	0		+18	+26	+41	−3+Δ	…	−15+Δ	−15	−27+Δ	0
140	160	+520	+280	+210	…	+145	+85	…	+43	…	+14	0		+18	+26	+41	−3+Δ	…	−15+Δ	−15	−27+Δ	0
160	180	+580	+310	+230	…	+145	+85	…	+43	…	+14	0		+18	+26	+41	−3+Δ	…	−15+Δ	−15	−27+Δ	0
180	200	+660	+340	+240	…	+170	+100	…	+50	…	+15	0		+22	+30	+47	−4+Δ	…	−17+Δ	−17	−31+Δ	0
200	225	+740	+380	+260	…	+170	+100	…	+50	…	+15	0		+22	+30	+47	−4+Δ	…	−17−Δ	−17	−31+Δ	0
225	250	+820	+420	+280	…	+170	+100	…	+50	…	+15	0		+22	+30	+47	−4+Δ	…	−17+Δ	−17	−31+Δ	0
250	280	+920	+480	+300	…	+190	+110	…	+56	…	+17	0		+25	+36	+55	−4+Δ	…	−20+Δ	−20	−34+Δ	0
280	315	+1050	+540	+330	…	+190	+110	…	+56	…	+17	0		+25	+36	+55	−4+Δ	…	−20+Δ	−20	−34+Δ	0
315	355	+1200	+600	+360	…	+210	+125	…	+62	…	+18	0		+29	+39	+60	−4+Δ	…	−21+Δ	−21	−37+Δ	0
355	400	+1350	+680	+400	…	+210	+125	…	+62	…	+18	0		+29	+39	+60	−4+Δ	…	−21+Δ	−21	−37+Δ	0
400	450	+1500	+760	+440	…	+230	+135	…	+68	…	+20	0		+33	+43	+66	−5+4	…	−23+Δ	−23	−40+Δ	0
450	500	+1650	+840	+480	…	+230	+135	…	+68	…	+20	0		+33	+43	+66	−5+4	…	−23+Δ	−23	−40+Δ	0

[a] Special case: for M6, ES = –9 for sizes from 250 to 315 mm, instead of –11.

[b] Not applicable to sizes up to 1 mm.

[c] In grades 7 to 11, the two symmetrical deviations ±IT/2 should be rounded if the IT value in micrometers is an odd value, by replacing it with the even value below. For example, if IT = 175, replace it by 174.

[d] When calculating deviations for holes K, M, and N with tolerance grades up to and including IT 8, and holes F to ZC with tolerance grades up to and including IT 7, the delta (Δ) values are added to the upper deviation ES. For example, for 25 P7, ES = –0.022 + 0.008 = –0.014 mm.

Table 26. British Standard Fundamental Deviations for Holes *BS 4500:1969*

Nominal Sizes, mm		Grade													Values for delta (Δ)[d]					
		≤7	>7																	
		Fundamental (Upper) Deviation ES													Grade					
Over	To	P to ZC	P	R	S	T	U	V	X	Y	Z	ZA	ZB	ZC	3	4	5	6	7	8
…	3	Same deviation as for grades above 7 increased by Δ	− 6	−10	−14	…	−18	…	−20	…	−26	−32	−40	−60	0	0	0	0	0	0
3	6		−12	−15	−19	…	−23	…	−28	…	−35	−42	−50	−80	1	1.5	1	3	4	6
6	10		−15	−19	−23	…	−28	…	−34	…	−42	−52	−67	−97	1	1.5	2	3	6	7
10	14		−18	−23	−28	…	−33	…	−40	…	−50	−64	−90	−130	1	2	3	3	7	9
14	18		−18	−23	−28	…	−33	−39	−45	…	−60	−77	−108	−150	1	2	3	3	7	9
18	24		−22	−28	−35	…	−41	−47	−54	−63	−73	−98	−136	−188	1.5	2	3	4	8	12
24	30		−22	−28	−35	−41	−48	−55	−64	−75	−88	−118	−160	−218	1.5	2	3	4	8	12
30	40		−26	−34	−43	−48	−60	−68	−80	−94	−112	−148	−200	−274	1.5	3	4	5	9	14
40	50		−26	−34	−43	−54	−70	−81	−97	−114	−136	−180	−242	−325	1.5	3	4	5	9	14
50	65		−32	−41	−53	−66	−87	−102	−122	−144	−172	−226	−300	−405	2	3	5	6	11	16
65	80		−32	−43	−59	−75	−102	−120	−146	−174	−210	−274	−360	−480	2	3	5	6	11	16
80	100		−37	−51	−71	−91	−124	−146	−178	−214	−258	−335	−445	−585	2	4	5	7	13	19
100	120		−37	−54	−79	−104	−144	−172	−210	−254	−310	−400	−525	−690	2	4	5	7	13	19
120	140		−43	−63	−92	−122	−170	−202	−248	−300	−365	−470	−620	−800	3	4	6	7	15	23
140	160		−43	−65	−100	−134	−190	−228	−280	−340	−415	−535	−700	−900	3	4	6	7	15	23
160	180		−43	−68	−108	−146	−210	−252	−310	−380	−465	−600	−780	−1000	3	4	6	7	15	23
180	200		−50	−77	−122	−166	−226	−284	−350	−425	−520	−670	−880	−1150	3	4	6	9	17	26
200	225		−50	−80	−130	−180	−258	−310	−385	−470	−575	−740	−960	−1250	3	4	6	9	17	26
225	250		−50	−84	−140	−196	−284	−340	−425	−520	−640	−820	−1050	−1350	3	4	6	9	17	26
250	280		−56	−94	−158	−218	−315	−385	−475	−580	−710	−920	−1200	−1550	4	4	7	9	20	29
280	315		−56	−98	−170	−240	−350	−425	−525	−650	−790	−1000	−1300	−1700	4	4	7	9	20	29
315	355		−62	−108	−190	−268	−390	−475	−590	−730	−900	−1150	−1500	−1800	4	5	7	11	21	32
355	400		−62	−114	−208	−294	−435	−530	−660	−820	−1000	−1300	−1650	−2100	4	5	7	11	21	32
400	450		−68	−126	−232	−330	−490	−595	−740	−920	−1100	−1450	−1850	−2400	5	5	7	13	23	34
450	500		−68	−132	−252	−360	−540	−660	−820	−1000	−1250	−1600	−2100	−2600	5	5	7	13	23	34

The dimensions are given in 0.001 mm, except the nominal sizes, which are in millimeters.

British Standard Preferred Numbers and Preferred Sizes.—This British Standard, PD 6481:1977 1983, gives recommendations for the use of preferred numbers and preferred sizes for functional characteristics and dimensions of various products.

The preferred number system is internationally standardized in ISO 3. It is also referred to as the Renard, or R, series (see *American National Standard for Preferred Numbers*, on page 19).

The series in the preferred number system are geometric series, that is, there is a constant ratio between each figure and the succeeding one, within a decimal framework. Thus, the R5 series has five steps between 1 and 10, the R10 series has 10 steps between 1 and 10, the R20 series, 20 steps, and the R40 series, 40 steps, giving increases between steps of approximately 60, 25, 12, and 6 per cent, respectively.

The preferred size series have been developed from the preferred number series by rounding off the inconvenient numbers in the basic series and adjusting for linear measurement in millimeters. These series are shown in the following table.

After taking all normal considerations into account, it is recommended that (a) for ranges of values of the primary *functional* characteristics (outputs and capacities) of a series of products, the preferred number series R5 to R40 (see page 19) should be used, and (b) whenever linear sizes are concerned, the preferred sizes as given in the following table should be used. The presentation of preferred sizes gives designers and users a logical selection and the benefits of rational variety reduction.

The second-choice size given should only be used when it is not possible to use the first choice, and the third choice should be applied only if a size from the second choice cannot be selected. With this procedure, common usage will tend to be concentrated on a limited range of sizes, and a contribution is thus made to variety reduction. However, the decision to use a particular size cannot be taken on the basis that one is first choice and the other not. Account must be taken of the effect on the design, the availability of tools, and other relevant factors.

British Standard Preferred Sizes, *PD 6481: 1977 (1983)*

Choice			Choice			Choice			Choice			Choice			Choice		
1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
1					5.2			23	65					122			188
	1.1			5.5				24			66		125		190		
1.2					5.8	25				68				128			192
		1.3	6					26	70			130				195	
	1.4				6.2		28			72				132			198
		1.5		6.5		30					74		135		200		
1.6					6.8		32		75					138			205
		1.7		7				34			76	140				210	
	1.8				7.5	35				78				142			215
		1.9	8					36	80				145		220		
2					8.5		38				82			148			225
		2.1		9		40				85		150				230	
	2.2				9.5		42				88			152			235
		2.4	10					44	90				155		240		
2.5				11		45					92			158			245
		2.6	12					46		95		160				250	
2.8					13		48				98			162			255
3				14		50			100				165		260		
		3.2			15		52				102			168			265
	3.5		16					54	105			170				270	
		3.8			17	55					108			172			275
4				18				56	110				175		280		
		4.2			19		58				112			178			285
	4.5		20			60				115		180				290	
		4.8			21		62				118			182			295
5				22				64	120				185		300		

For dimensions above 300, each series continues in a similar manner, i.e., the intervals between each series number are the same as between 200 and 300.

Length Differences Due to Temperature Changes.—The following table gives changes in length for variations from the standard reference temperature of 68 deg. F (20 deg. C) for materials of known coefficients of expansion. Coefficients of expansion are given in tables on pages 367 and 368.

In the table below, for coefficients between those listed, add appropriate listed values. For example, a length change for a coefficient of 7 is the sum of values in the 5 and 2 columns. Fractional interpolation also is possible. Thus, in a steel bar with a coefficient of thermal expansion of 6.3 × 10^{-6} [= 0.0000063 in./in. (µin./in.) of length/deg. F], the increase in length at 73 deg. F is 25 + 5 + 1.5 = 31.5 µin./in. of length. For a steel with the same coefficient of expansion, the change in length, measured in deg. C, is expressed in microns (micrometers)/meter (µm/m) of length.

Table Showing Differences in Length in Inches/Inch (Microns/Meter) for Changes from the Standard Temperature of 68 Deg. F (20 Deg. C)

Temperature Deg.		Coefficient of Thermal Expansion of Material per Degree F (C) × 10^4									
		1	2	3	4	5	10	15	20	25	30
		Total Change in Length from Standard for F Deg. Microinches/Inch (µin./in.) and for C deg. (K) microns/meter (µm/m) of length									
F	C										
48	0	–20	–40	–60	–80	–100	–200	–300	–400	–500	–600
49	1	–19	–38	–57	–76	–95	–190	–285	–380	–475	–570
50	2	–18	–36	–54	–72	–90	–180	–270	–360	–450	–540
51	3	–17	–34	–51	–68	–85	–170	–255	–340	–425	–510
52	4	–16	–32	–48	–64	–80	–160	–240	–320	–400	–480
53	5	–15	–30	–45	–60	–75	–150	–225	–300	–375	–450
54	6	–14	–28	–42	–56	–70	–140	–210	–280	–350	–420
55	7	–13	–26	–39	–52	–65	–130	–195	–260	–325	–390
56	8	–12	–24	–36	–48	–60	–120	–180	–240	–300	–360
57	9	–11	–22	–33	–44	–55	–110	–165	–220	–275	–330
58	10	–10	–20	–30	–40	–50	–100	–150	–200	–250	–300
59	11	–9	–18	–27	–36	–45	–90	–135	–180	–225	–270
60	12	–8	–16	–24	–32	–40	–80	–120	–160	–200	–240
61	13	–7	–14	–21	–28	–35	–70	–105	–140	–175	–210
62	14	–6	–12	–18	–24	–30	–60	–90	–120	–150	–180
63	15	–5	–10	–15	–20	–25	–50	–75	–100	–125	–150
64	16	–4	–8	–12	–16	–20	–40	–60	–80	–100	–120
65	17	–3	–6	–9	–12	–15	–30	–45	–60	–75	–90
66	18	–2	–4	–6	–8	–10	–20	–30	–40	–50	–60
67	19	–1	–2	–3	–4	–5	–10	–15	–20	–25	–30
68	20	0	0	0	0	0	0	0	0	0	0
69	21	1	2	3	4	5	10	15	20	25	30
70	22	2	4	6	8	10	20	30	40	50	60
71	23	3	6	9	12	15	30	45	60	75	90
72	24	4	8	12	16	20	40	60	80	100	120
73	25	5	10	15	20	25	50	75	100	125	150
74	26	6	12	18	24	30	60	90	120	150	180
75	27	7	14	21	28	35	70	105	140	175	210
76	28	8	16	24	32	40	80	120	160	200	240
77	29	9	18	27	36	45	90	135	180	225	270
78	30	10	20	30	40	50	100	150	200	250	300
79	31	11	22	33	44	55	110	165	220	275	330
80	32	12	24	36	48	60	120	180	240	300	360
81	33	13	26	39	52	65	130	195	260	325	390
82	34	14	28	42	56	70	140	210	280	350	420
83	35	15	30	45	60	75	150	225	300	375	450
84	36	16	32	48	64	80	160	240	320	400	480
85	37	17	34	51	68	85	170	255	340	425	510
86	38	18	36	54	72	90	180	270	360	450	540
87	39	19	38	57	76	95	190	285	380	475	570
88	40	20	40	60	80	100	200	300	400	500	600

MEASURING INSTRUMENTS AND INSPECTION METHODS

Verniers and Micrometers

Reading a Vernier.— A general rule for taking readings with a vernier scale is as follows: Note the number of inches and sub-divisions of an inch that the zero mark of the vernier scale has moved along the true scale, and then add to this reading as many thousandths, or hundredths, or whatever fractional part of an inch the vernier reads to, as there are spaces between the vernier zero and that line on the vernier which coincides with one on the true scale. For example, if the zero line of a vernier which reads to thousandths is slightly beyond the 0.5 inch division on the main or true scale, as shown in Fig. 1, and graduation line 10 on the vernier exactly coincides with one on the true scale, the reading is 0.5 + 0.010 or 0.510 inch. In order to determine the reading or fractional part of an inch that can be obtained by a vernier, multiply the denominator of the finest sub-division given on the true scale by the total number of divisions on the vernier. For example, if one inch on the true scale is divided into 40 parts or fortieths (as in Fig. 1), and the vernier into twenty-five parts, the vernier will read to thousandths of an inch, as 25 × 40 = 1000. Similarly, if there are sixteen divisions to the inch on the true scale and a total of eight on the vernier, the latter will enable readings to be taken within one-hundred-twenty-eighths of an inch, as 8 × 16 = 128.

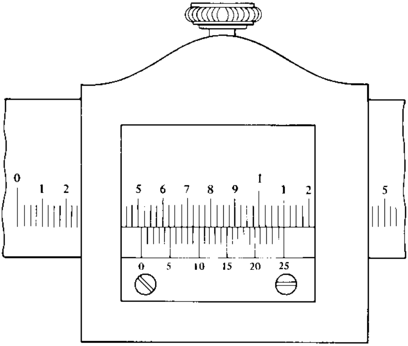


Fig. 1.

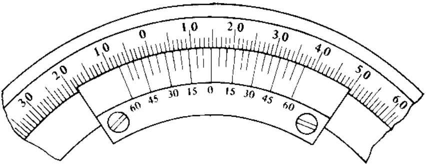


Fig. 2.

If the vernier is on a protractor, note the whole number of degrees passed by the vernier zero mark and then count the spaces between the vernier zero and that line which coincides with a graduation on the protractor scale. If the vernier indicates angles within five minutes or one-twelfth degree (as in Fig. 2), the number of spaces multiplied by 5 will, of course, give the number of minutes to be added to the whole number of degrees. The reading of the protractor set as illustrated would be 14 whole degrees (the number passed by the zero mark on the vernier) plus 30 minutes, as the graduation 30 on the vernier is the only one to the right of the vernier zero which exactly coincides with a line on the protractor scale. It will be noted that there are duplicate scales on the vernier, one being to the right and the other to the left of zero. The left-hand scale is used when the vernier zero is moved to the left of the zero of the protractor scale, whereas the right-hand graduations are used when the movement is to the right.

Reading a Metric Vernier.—The smallest graduation on the bar (true or main scale) of the metric vernier gage shown in Fig. 1, is 0.5 millimeter. The scale is numbered at each twentieth division, and thus increments of 10, 20, 30, 40 millimeters, etc., are indicated. There are 25 divisions on the vernier scale, occupying the same length as 24 divisions on the bar, which is 12 millimeters. Therefore, one division on the vernier scale equals one twenty-fifth of 12 millimeters $= 0.04 \times 12 = 0.48$ millimeter. Thus, the difference between one bar division (0.50 mm) and one vernier division (2.48 mm) is $0.50 - 0.48 = 0.02$ millimeter, which is the minimum measuring increment that the gage provides. To permit direct readings, the vernier scale has graduations to represent tenths of a millimeter (0.1 mm) and fiftieths of a millimeter (0.02 mm).

To read a vernier gage, first note how many millimeters the zero line on the vernier is from the zero line on the bar. Next, find the graduation on the vernier scale which exactly coincides with a graduation line on the bar, and note the value of the vernier scale graduation. This value is added to the value obtained from the bar, and the result is the total reading.

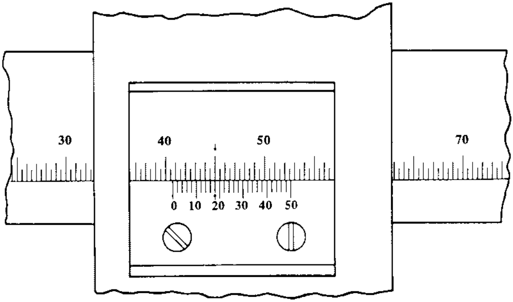


Fig. 1.

In the example shown in Fig. 1, the vernier zero is just past the 40.5 millimeters graduation on the bar. The 0.18 millimeter line on the vernier coincides with a line on the bar, and the total reading is therefore $40.5 + 0.18 = 40.68$ mm.

Dual Metric-Inch Vernier.—The vernier gage shown in Fig. 2 has separate metric and inch 50-division vernier scales to permit measurements in either system.

A 50-division vernier has more widely spaced graduations than the 25-division vernier shown on the previous pages, and is thus easier to read. On the bar, the smallest metric graduation is 1 millimeter, and the 50 divisions of the vernier occupy the same length as 49 divisions on the bar, which is 49 mm. Therefore, one division on the vernier scale equals one-fiftieth of 49 millimeters $= 0.02 \times 49 = 0.98$ mm. Thus, the difference between one bar division (1.0 mm) and one vernier division (0.98 mm) is 0.02 mm, which is the minimum measuring increment the gage provides.

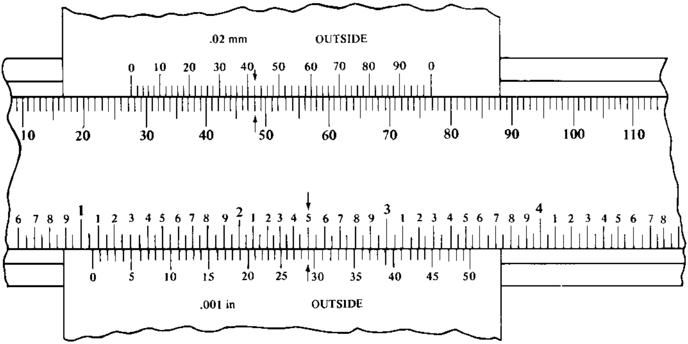


Fig. 2.

The vernier scale is graduated for direct reading to 0.02 mm. In the figure, the vernier zero is just past the 27 mm graduation on the bar, and the 0.42 mm graduation on the vernier coincides with a line on the bar. The total reading is therefore 27.42 mm.

The smallest inch graduation on the bar is 0.05 inch, and the 50 vernier divisions occupy the same length as 49 bar divisions, which is 2.45 inches. Therefore, one vernier division equals one-fiftieth of 2.45 inches = 0.02 × 2.45 = 0.049 inch. Thus, the difference between the length of a bar division and a vernier division is 0.050-0.049 = 0.001 inch. The vernier scale is graduated for direct reading to 0.001 inch. In the example, the vernier zero is past the 1.05 graduation on the bar, and the 0.029 graduation on the vernier coincides with a line on the bar. Thus, the total reading is 1.079 inches.

Reading a Micrometer.—The spindle of an inch-system micrometer has 40 threads per inch, so that one turn moves the spindle axially 0.025 inch (1 ÷ 40 = 0.025), equal to the distance between two graduations on the frame. The 25 graduations on the thimble allow the 0.025 inch to be further divided, so that turning the thimble through one division moves the spindle axially 0.001 inch (0.025 ÷ 25 = 0.001). To read a micrometer, count the number of whole divisions that are visible on the scale of the frame, multiply this number by 25 (the number of thousandths of an inch that each division represents) and add to the product the number of that division on the thimble which coincides with the axial zero line on the frame. The result will be the diameter expressed in thousandths of an inch. As the numbers 1, 2, 3, etc., opposite every fourth sub-division on the frame, indicate hundreds of thousandths, the reading can easily be taken mentally. Suppose the thimble were screwed out so that graduation 2, and three additional sub-divisions, were visible (as shown in Fig. 3), and that graduation 10 on the thimble coincided with the axial line on the frame. The reading then would be 0.200 + 0.075 + 0.010, or 0.285 inch.

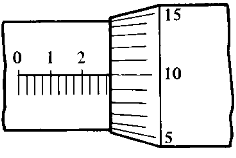


Fig. 3. Inch Micrometer

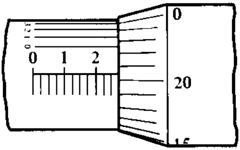


Fig. 4. Inch Micrometer with Vernier

Some micrometers have a vernier scale on the frame in addition to the regular graduations, so that measurements within 0.0001 part of an inch can be taken. Micrometers of this type are read as follows: First determine the number of thousandths, as with an ordinary micrometer, and then find a line on the vernier scale that exactly coincides with one on the thimble; the number of this line represents the number of ten-thousandths to be added to the number of thousandths obtained by the regular graduations. The reading shown in the illustration, Fig. 4, is 0.270 + 0.0003 = 0.2703 inch.

Micrometers graduated according to the English system of measurement ordinarily have a table of decimal equivalents stamped on the sides of the frame, so that fractions such as sixty-fourths, thirty-seconds, etc., can readily be converted into decimals.

Reading a Metric Micrometer.—The spindle of an ordinary metric micrometer has 2 threads per millimeter, and thus one complete revolution moves the spindle through a distance of 0.5 millimeter. The longitudinal line on the frame is graduated with 1 millimeter divisions and 0.5 millimeter sub-divisions. The thimble has 50 graduations, each being 0.01 millimeter (one-hundredth of a millimeter).

To read a metric micrometer, note the number of millimeter divisions visible on the scale of the sleeve, and add the total to the particular division on the thimble which coincides with the axial line on the sleeve. Suppose that the thimble were screwed out so that graduation 5, and one additional 0.5 sub-division were visible (as shown in Fig. 5), and that graduation 28 on the thimble coincided with the axial line on the sleeve. The reading then would be 5.00 + 0.5 + 0.28 = 5.78 mm.

Some micrometers are provided with a vernier scale on the sleeve in addition to the regular graduations to permit measurements within 0.002 millimeter to be made. Micrometers of this type are read as follows: First determine the number of whole millimeters (if any) and the number of hundredths of a millimeter, as with an ordinary micrometer, and then find a line on the sleeve vernier scale which exactly coincides with one on the thimble. The number of this coinciding vernier line represents the number of two-thousandths of a millimeter to be added to the reading already obtained. Thus, for example, a measurement of 2.958 millimeters would be obtained by reading 2.5 millimeters on the sleeve, adding 0.45 millimeter read from the thimble, and then adding 0.008 millimeter as determined by the vernier.

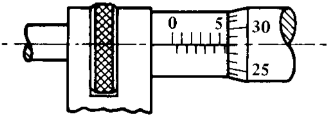


Fig. 5. Metric Micrometer

Note: 0.01 millimeter = 0.000393 inch, and 0.002 millimeter = 0.000078 inch (78 millionths). Therefore, metric micrometers provide smaller measuring increments than comparable inch unit micrometers—the smallest graduation of an ordinary inch reading micrometer is 0.001 inch; the vernier type has graduations down to 0.0001 inch. When using either a metric or inch micrometer, without a vernier, smaller readings than those graduated may of course be obtained by visual interpolation between graduations.

Sine-bar

The sine-bar is used either for very accurate angular measurements or for locating work at a given angle as, for example, in surface grinding templets, gages, etc. The sine-bar is especially useful in measuring or checking angles when the limit of accuracy is 5 minutes or less. Some bevel protractors are equipped with verniers which read to 5 minutes but the setting depends upon the alignment of graduations whereas a sine-bar usually is located by positive contact with precision gage-blocks selected for whatever dimension is required for obtaining a given angle.

Types of Sine-bars.—A sine-bar consists of a hardened, ground and lapped steel bar with very accurate cylindrical plugs of equal diameter attached to or near each end. The form illustrated by Fig. 3 has notched ends for receiving the cylindrical plugs so that they are held firmly against both faces of the notch. The standard center-to-center distance C between the plugs is either 5 or 10 inches. The upper and lower sides of sine-bars are parallel to the center line of the plugs within very close limits. The body of the sine-bar ordinarily has several through holes to reduce the weight. In the making of the sine-bar shown in Fig. 4, if too much material is removed from one locating notch, regrinding the shoulder at the opposite end would make it possible to obtain the correct center distance. That is the reason for this change in form. The type of sine-bar illustrated by Fig. 5 has the cylindrical disks or plugs attached to one side. These differences in form or arrangement do not, of course, affect the principle governing the use of the sine-bar. An accurate surface plate or master flat is always used in conjunction with a sine-bar in order to form the base from which the vertical measurements are made

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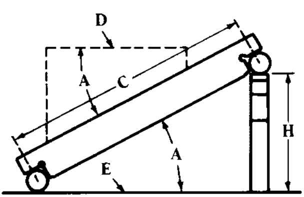


Fig. 1.

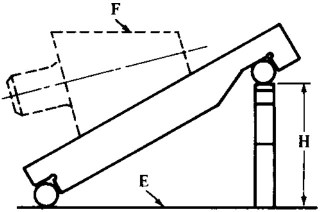


Fig. 2.

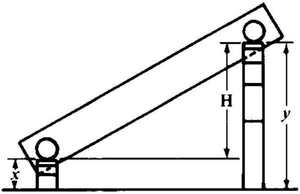


Fig. 3.

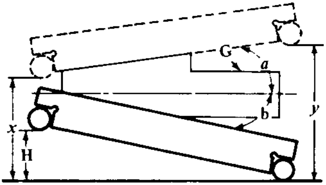


Fig. 4.

Setting a Sine Bar to a Given Angle.—To find the vertical distance *H*, for setting a sine bar to the required angle, convert the angle to decimal form on a pocket calculator, take the sine of that angle, and multiply by the distance between the cylinders. For example, if an angle of 31 degrees, 30 minutes is required, the equivalent angle is 31 degrees plus $^{30}\!/_{60}$ = 31 + 0.5, or 31.5 degrees. (For conversions from minutes and seconds to decimals of degrees and vice versa, see page 90). The sine of 31.5 degrees is 0.5225 and multiplying this value by the sine bar length gives 2.613 in. for the height *H*, Fig. 1 and 3, of the gage blocks.

Finding Angle when Height *H* of Sine Bar is Known.—To find the angle equivalent to a given height *H*, reverse the above procedure. Thus, if the height *H* is 1.4061 in., dividing by 5 gives a sine of 0.28122, which corresponds to an angle of 16.333 degrees, or 16 degrees 20 minutes.

Checking Angle of Templet or Gage by Using Sine Bar.—Place templet or gage on sine bar as indicated by dotted lines, Fig. 1. Clamps may be used to hold work in place. Place upper end of sine bar on gage blocks having total height *H* corresponding to the required angle. If upper edge *D* of work is parallel with surface plate *E*, then angle *A* of work equals angle *A* to which sine bar is set. Parallelism between edge *D* and surface plate may be tested by checking the height at each end with a dial gage or some type of indicating comparator.

Measuring Angle of Templet or Gage with Sine Bar.—To measure such an angle, adjust height of gage blocks and sine bar until edge *D*, Fig. 1, is parallel with surface plate *E*; then find angle corresponding to height *H*, of gage blocks. For example, if height *H* is 2.5939 inches when *D* and *E* are parallel, the calculator will show that the angle *A* of the work is 31 degrees, 15 minutes.

Checking Taper per Foot with Sine Bar.—As an example, assume that the plug gage in Fig. 2 is supposed to have a taper of 6⅛ inches per foot and taper is to be checked by using a 5-inch sine bar. The table of *Tapers per Foot and Corresponding Angles* on page 684 shows that the included angle for a taper of 6 ⅛ inches per foot is 28 degrees 38 minutes 1 second, or 28.6336 degrees from the calculator. For a 5-inch sine bar, the calculator gives a value of 2.396 in. for the height *H* of the gage blocks. Using this height, if the upper surface *F* of the plug gage is parallel to the surface plate the angle corresponds to a taper of 6 ⅛ inches per foot.

Setting Sine Bar having Plugs Attached to Side.—If the lower plug does not rest directly on the surface plate, as in Fig. 3, the height *H* for the sine bar is the difference between heights *x* and *y*, or the difference between the heights of the plugs; otherwise, the procedure in setting the sine bar and checking angles is the same as previously described.

Checking Templets Having Two Angles.—Assume that angle *a* of templet, Fig. 4, is 9 degrees, angle *b* 12 degrees, and that edge *G* is parallel to the surface plate. For an angle *b* of 12 degrees, the calculator shows that the height *H* is 1.03956 inches. For an angle *a* of 9 degrees, the difference between measurements *x* and *y* when the sine bar is in contact with the upper edge of the templet is 0.78217 inch.

Setting 10-inch Sine Bar to Given Angle.—A 10-inch sine bar may sometimes be preferred because of its longer working surface or because the longer center distance is conducive to greater precision. To obtain the vertical distances *H* for setting a 10-inch sine bar, multiply the sine of the angle by 10, by shifting the decimal point one place to the right.

For example, the sine of 39 degrees is 0.62932, hence the vertical height *H* for setting a 10-inch sine bar is 6.2932 inches.

Constants for Setting a 5-inch Sine-Bar for 1° to 7°

Min.	0°	1°	2°	3°	4°	5°	6°	7°
0	0.00000	0.08726	0.17450	0.26168	0.34878	0.43578	0.52264	0.60935
1	0.00145	0.08872	0.17595	0.26313	0.35023	0.43723	0.52409	0.61079
2	0.00291	0.09017	0.17740	0.26458	0.35168	0.43868	0.52554	0.61223
3	0.00436	0.09162	0.17886	0.26604	0.35313	0.44013	0.52698	0.61368
4	0.00582	0.09308	0.18031	0.26749	0.35459	0.44157	0.52843	0.61512
5	0.00727	0.09453	0.18177	0.26894	0.35604	0.44302	0.52987	0.61656
6	0.00873	0.09599	0.18322	0.27039	0.35749	0.44447	0.53132	0.61801
7	0.01018	0.09744	0.18467	0.27185	0.35894	0.44592	0.53277	0.61945
8	0.01164	0.09890	0.18613	0.27330	0.36039	0.44737	0.53421	0.62089
9	0.01309	0.10035	0.18758	0.27475	0.36184	0.44882	0.53566	0.62234
10	0.01454	0.10180	0.18903	0.27620	0.36329	0.45027	0.53710	0.62378
11	0.01600	0.10326	0.19049	0.27766	0.36474	0.45171	0.53855	0.62522
12	0.01745	0.10471	0.19194	0.27911	0.36619	0.45316	0.54000	0.62667
13	0.01891	0.10617	0.19339	0.28056	0.36764	0.45461	0.54144	0.62811
14	0.02036	0.10762	0.19485	0.28201	0.36909	0.45606	0.54289	0.62955
15	0.02182	0.10907	0.19630	0.28346	0.37054	0.45751	0.54433	0.63099
16	0.02327	0.11053	0.19775	0.28492	0.37199	0.45896	0.54578	0.63244
17	0.02473	0.11198	0.19921	0.28637	0.37344	0.46040	0.54723	0.63388
18	0.02618	0.11344	0.20066	0.28782	0.37489	0.46185	0.54867	0.63532
19	0.02763	0.11489	0.20211	0.28927	0.37634	0.46330	0.55012	0.63677
20	0.02909	0.11634	0.20357	0.29072	0.37779	0.46475	0.55156	0.63821
21	0.03054	0.11780	0.20502	0.29218	0.37924	0.46620	0.55301	0.63965
22	0.03200	0.11925	0.20647	0.29363	0.38069	0.46765	0.55445	0.64109
23	0.03345	0.12071	0.20793	0.29508	0.38214	0.46909	0.55590	0.64254
24	0.03491	0.12216	0.20938	0.29653	0.38360	0.47054	0.55734	0.64398
25	0.03636	0.12361	0.21083	0.29798	0.38505	0.47199	0.55879	0.64542
26	0.03782	0.12507	0.21228	0.29944	0.38650	0.47344	0.56024	0.64686
27	0.03927	0.12652	0.21374	0.30089	0.38795	0.47489	0.56168	0.64830
28	0.04072	0.12798	0.21519	0.30234	0.38940	0.47633	0.56313	0.64975
29	0.04218	0.12943	0.21664	0.30379	0.39085	0.47778	0.56457	0.65119
30	0.04363	0.13088	0.21810	0.30524	0.39230	0.47923	0.56602	0.65263
31	0.04509	0.13234	0.21955	0.30669	0.39375	0.48068	0.56746	0.65407
32	0.04654	0.13379	0.22100	0.30815	0.39520	0.48212	0.56891	0.65551
33	0.04800	0.13525	0.22246	0.30960	0.39665	0.48357	0.57035	0.65696
34	0.04945	0.13670	0.22391	0.31105	0.39810	0.48502	0.57180	0.65840
35	0.05090	0.13815	0.22536	0.31250	0.39954	0.48647	0.57324	0.65984
36	0.05236	0.13961	0.22681	0.31395	0.40099	0.48791	0.57469	0.66128
37	0.05381	0.14106	0.22827	0.31540	0.40244	0.48936	0.57613	0.66272
38	0.05527	0.14252	0.22972	0.31686	0.40389	0.49081	0.57758	0.66417
39	0.05672	0.14397	0.23117	0.31831	0.40534	0.49226	0.57902	0.66561
40	0.05818	0.14542	0.23263	0.31976	0.40679	0.49370	0.58046	0.66705
41	0.05963	0.14688	0.23408	0.32121	0.40824	0.49515	0.58191	0.66849
42	0.06109	0.14833	0.23553	0.32266	0.40969	0.49660	0.58335	0.66993
43	0.06254	0.14979	0.23699	0.32411	0.41114	0.49805	0.58480	0.67137
44	0.06399	0.15124	0.23844	0.32556	0.41259	0.49949	0.58624	0.67281
45	0.06545	0.15269	0.23989	0.32702	0.41404	0.50094	0.58769	0.67425
46	0.06690	0.15415	0.24134	0.32847	0.41549	0.50239	0.58913	0.67570
47	0.06836	0.15560	0.24280	0.32992	0.41694	0.50383	0.59058	0.67714
48	0.06981	0.15705	0.24425	0.33137	0.41839	0.50528	0.59202	0.67858
49	0.07127	0.15851	0.24570	0.33282	0.41984	0.50673	0.59346	0.68002
50	0.07272	0.15996	0.24715	0.33427	0.42129	0.50818	0.59491	0.68146
51	0.07417	0.16141	0.24861	0.33572	0.42274	0.50962	0.59635	0.68290
52	0.07563	0.16287	0.25006	0.33717	0.42419	0.51107	0.59780	0.68434
53	0.07708	0.16432	0.25151	0.33863	0.42564	0.51252	0.59924	0.68578
54	0.07854	0.16578	0.25296	0.34008	0.42708	0.51396	0.60068	0.68722
55	0.07999	0.16723	0.25442	0.34153	0.42853	0.51541	0.60213	0.68866
56	0.08145	0.16868	0.25587	0.34298	0.42998	0.51686	0.60357	0.69010
57	0.08290	0.17014	0.25732	0.34443	0.43143	0.51830	0.60502	0.69154
58	0.08435	0.17159	0.25877	0.34588	0.43288	0.51975	0.60646	0.69298
59	0.08581	0.17304	0.26023	0.34733	0.43433	0.52120	0.60790	0.69443
60	0.08726	0.17450	0.26168	0.34878	0.43578	0.52264	0.60935	0.69587

Constants for Setting a 5-inch Sine-Bar for 8° to 15°

Min.	8°	9°	10°	11°	12°	13°	14°	15°
0	0.69587	0.78217	0.86824	0.95404	1.03956	1.12476	1.20961	1.29410
1	0.69731	0.78361	0.86967	0.95547	1.04098	1.12617	1.21102	1.29550
2	0.69875	0.78505	0.87111	0.95690	1.04240	1.12759	1.21243	1.29690
3	0.70019	0.78648	0.87254	0.95833	1.04383	1.12901	1.21384	1.29831
4	0.70163	0.78792	0.87397	0.95976	1.04525	1.13042	1.21525	1.29971
5	0.70307	0.78935	0.87540	0.96118	1.04667	1.13184	1.21666	1.30112
6	0.70451	0.79079	0.87683	0.96261	1.04809	1.13326	1.21808	1.30252
7	0.70595	0.79223	0.87827	0.96404	1.04951	1.13467	1.21949	1.30393
8	0.70739	0.79366	0.87970	0.96546	1.05094	1.13609	1.22090	1.30533
9	0.70883	0.79510	0.88113	0.96689	1.05236	1.13751	1.22231	1.30673
10	0.71027	0.79653	0.88256	0.96832	1.05378	1.13892	1.22372	1.30814
11	0.71171	0.79797	0.88399	0.96974	1.05520	1.14034	1.22513	1.30954
12	0.71314	0.79941	0.88542	0.97117	1.05662	1.14175	1.22654	1.31095
13	0.71458	0.80084	0.88686	0.97260	1.05805	1.14317	1.22795	1.31235
14	0.71602	0.80228	0.88829	0.97403	1.05947	1.14459	1.22936	1.31375
15	0.71746	0.80371	0.88972	0.97545	1.06089	1.14600	1.23077	1.31516
16	0.71890	0.80515	0.89115	0.97688	1.06231	1.14742	1.23218	1.31656
17	0.72034	0.80658	0.89258	0.97830	1.06373	1.14883	1.23359	1.31796
18	0.72178	0.80802	0.89401	0.97973	1.06515	1.15025	1.23500	1.31937
19	0.72322	0.80945	0.89544	0.98116	1.06657	1.15166	1.23640	1.32077
20	0.72466	0.81089	0.89687	0.98258	1.06799	1.15308	1.23781	1.32217
21	0.72610	0.81232	0.89830	0.98401	1.06941	1.15449	1.23922	1.32357
22	0.72754	0.81376	0.89973	0.98544	1.07084	1.15591	1.24063	1.32498
23	0.72898	0.81519	0.90117	0.98686	1.07226	1.15732	1.24204	1.32638
24	0.73042	0.81663	0.90260	0.98829	1.07368	1.15874	1.24345	1.32778
25	0.73185	0.81806	0.90403	0.98971	1.07510	1.16015	1.24486	1.32918
26	0.73329	0.81950	0.90546	0.99114	1.07652	1.16157	1.24627	1.33058
27	0.73473	0.82093	0.90689	0.99256	1.07794	1.16298	1.24768	1.33199
28	0.73617	0.82237	0.90832	0.99399	1.07936	1.16440	1.24908	1.33339
29	0.73761	0.82380	0.90975	0.99541	1.08078	1.16581	1.25049	1.33479
30	0.73905	0.82524	0.91118	0.99684	1.08220	1.16723	1.25190	1.33619
31	0.74049	0.82667	0.91261	0.99826	1.08362	1.16864	1.25331	1.33759
32	0.74192	0.82811	0.91404	0.99969	1.08504	1.17006	1.25472	1.33899
33	0.74336	0.82954	0.91547	1.00112	1.08646	1.17147	1.25612	1.34040
34	0.74480	0.83098	0.91690	1.00254	1.08788	1.17288	1.25753	1.34180
35	0.74624	0.83241	0.91833	1.00396	1.08930	1.17430	1.25894	1.34320
36	0.74768	0.83384	0.91976	1.00539	1.09072	1.17571	1.26035	1.34460
37	0.74911	0.83528	0.92119	1.00681	1.09214	1.17712	1.26175	1.34600
38	0.75055	0.83671	0.92262	1.00824	1.09355	1.17854	1.26316	1.34740
39	0.75199	0.83815	0.92405	1.00966	1.09497	1.17995	1.26457	1.34880
40	0.75343	0.83958	0.92547	1.01109	1.09639	1.18136	1.26598	1.35020
41	0.75487	0.84101	0.92690	1.01251	1.09781	1.18278	1.26738	1.35160
42	0.75630	0.84245	0.92833	1.01394	1.09923	1.18419	1.26879	1.35300
43	0.75774	0.84388	0.92976	1.01536	1.10065	1.18560	1.27020	1.35440
44	0.75918	0.84531	0.93119	1.01678	1.10207	1.18702	1.27160	1.35580
45	0.76062	0.84675	0.93262	1.01821	1.10349	1.18843	1.27301	1.35720
46	0.76205	0.84818	0.93405	1.01963	1.10491	1.18984	1.27442	1.35860
47	0.76349	0.84961	0.93548	1.02106	1.10632	1.19125	1.27582	1.36000
48	0.76493	0.85105	0.93691	1.02248	1.10774	1.19267	1.27723	1.36140
49	0.76637	0.85248	0.93834	1.02390	1.10916	1.19408	1.27863	1.36280
50	0.76780	0.85391	0.93976	1.02533	1.11058	1.19549	1.28004	1.36420
51	0.76924	0.85535	0.94119	1.02675	1.11200	1.19690	1.28145	1.36560
52	0.77068	0.85678	0.94262	1.02817	1.11342	1.19832	1.28285	1.36700
53	0.77211	0.85821	0.94405	1.02960	1.11483	1.19973	1.28426	1.36840
54	0.77355	0.85965	0.94548	1.03102	1.11625	1.20114	1.28566	1.36980
55	0.77499	0.86108	0.94691	1.03244	1.11767	1.20255	1.28707	1.37119
56	0.77643	0.86251	0.94833	1.03387	1.11909	1.20396	1.28847	1.37259
57	0.77786	0.86394	0.94976	1.03529	1.12050	1.20538	1.28988	1.37399
58	0.77930	0.86538	0.95119	1.03671	1.12192	1.20679	1.29129	1.37539
59	0.78074	0.86681	0.95262	1.03814	1.12334	1.20820	1.29269	1.37679
60	0.78217	0.86824	0.95404	1.03956	1.12476	1.20961	1.29410	1.37819

Constants for Setting a 5-inch Sine-Bar for 16° to 23°

Min.	16°	17°	18°	19°	20°	21°	22°	23°
0	1.37819	1.46186	1.54509	1.62784	1.71010	1.79184	1.87303	1.95366
1	1.37958	1.46325	1.54647	1.62922	1.71147	1.79320	1.87438	1.95499
2	1.38098	1.46464	1.54785	1.63059	1.71283	1.79456	1.87573	1.95633
3	1.38238	1.46603	1.54923	1.63197	1.71420	1.79591	1.87708	1.95767
4	1.38378	1.46742	1.55062	1.63334	1.71557	1.79727	1.87843	1.95901
5	1.38518	1.46881	1.55200	1.63472	1.71693	1.79863	1.87977	1.96035
6	1.38657	1.47020	1.55338	1.63609	1.71830	1.79998	1.88112	1.96169
7	1.38797	1.47159	1.55476	1.63746	1.71966	1.80134	1.88247	1.96302
8	1.38937	1.47298	1.55615	1.63884	1.72103	1.80270	1.88382	1.96436
9	1.39076	1.47437	1.55753	1.64021	1.72240	1.80405	1.88516	1.96570
10	1.39216	1.47576	1.55891	1.64159	1.72376	1.80541	1.88651	1.96704
11	1.39356	1.47715	1.56029	1.64296	1.72513	1.80677	1.88786	1.96837
12	1.39496	1.47854	1.56167	1.64433	1.72649	1.80812	1.88920	1.96971
13	1.39635	1.47993	1.56306	1.64571	1.72786	1.80948	1.89055	1.97105
14	1.39775	1.48132	1.56444	1.64708	1.72922	1.81083	1.89190	1.97238
15	1.39915	1.48271	1.56582	1.64845	1.73059	1.81219	1.89324	1.97372
16	1.40054	1.48410	1.56720	1.64983	1.73195	1.81355	1.89459	1.97506
17	1.40194	1.48549	1.56858	1.65120	1.73331	1.81490	1.89594	1.97639
18	1.40333	1.48687	1.56996	1.65257	1.73468	1.81626	1.89728	1.97773
19	1.40473	1.48826	1.57134	1.65394	1.73604	1.81761	1.89863	1.97906
20	1.40613	1.48965	1.57272	1.65532	1.73741	1.81897	1.89997	1.98040
21	1.40752	1.49104	1.57410	1.65669	1.73877	1.82032	1.90132	1.98173
22	1.40892	1.49243	1.57548	1.65806	1.74013	1.82168	1.90266	1.98307
23	1.41031	1.49382	1.57687	1.65943	1.74150	1.82303	1.90401	1.98440
24	1.41171	1.49520	1.57825	1.66081	1.74286	1.82438	1.90535	1.98574
25	1.41310	1.49659	1.57963	1.66218	1.74422	1.82574	1.90670	1.98707
26	1.41450	1.49798	1.58101	1.66355	1.74559	1.82709	1.90804	1.98841
27	1.41589	1.49937	1.58238	1.66492	1.74695	1.82845	1.90939	1.98974
28	1.41729	1.50075	1.58376	1.66629	1.74831	1.82980	1.91073	1.99108
29	1.41868	1.50214	1.58514	1.66766	1.74967	1.83115	1.91207	1.99241
30	1.42008	1.50353	1.58652	1.66903	1.75104	1.83251	1.91342	1.99375
31	1.42147	1.50492	1.58790	1.67041	1.75240	1.83386	1.91476	1.99508
32	1.42287	1.50630	1.58928	1.67178	1.75376	1.83521	1.91610	1.99641
33	1.42426	1.50769	1.59066	1.67315	1.75512	1.83657	1.91745	1.99775
34	1.42565	1.50908	1.59204	1.67452	1.75649	1.83792	1.91879	1.99908
35	1.42705	1.51046	1.59342	1.67589	1.75785	1.83927	1.92013	2.00041
36	1.42844	1.51185	1.59480	1.67726	1.75921	1.84062	1.92148	2.00175
37	1.42984	1.51324	1.59617	1.67863	1.76057	1.84198	1.92282	2.00308
38	1.43123	1.51462	1.59755	1.68000	1.76193	1.84333	1.92416	2.00441
39	1.43262	1.51601	1.59893	1.68137	1.76329	1.84468	1.92550	2.00574
40	1.43402	1.51739	1.60031	1.68274	1.76465	1.84603	1.92685	2.00708
41	1.43541	1.51878	1.60169	1.68411	1.76601	1.84738	1.92819	2.00841
42	1.43680	1.52017	1.60307	1.68548	1.76737	1.84873	1.92953	2.00974
43	1.43820	1.52155	1.60444	1.68685	1.76873	1.85009	1.93087	2.01107
44	1.43959	1.52294	1.60582	1.68821	1.77010	1.85144	1.93221	2.01240
45	1.44098	1.52432	1.60720	1.68958	1.77146	1.85279	1.93355	2.01373
46	1.44237	1.52571	1.60857	1.69095	1.77282	1.85414	1.93490	2.01506
47	1.44377	1.52709	1.60995	1.69232	1.77418	1.85549	1.93624	2.01640
48	1.44516	1.52848	1.61133	1.69369	1.77553	1.85684	1.93758	2.01773
49	1.44655	1.52986	1.61271	1.69506	1.77689	1.85819	1.93892	2.01906
50	1.44794	1.53125	1.61408	1.69643	1.77825	1.85954	1.94026	2.02039
51	1.44934	1.53263	1.61546	1.69779	1.77961	1.86089	1.94160	2.02172
52	1.45073	1.53401	1.61683	1.69916	1.78097	1.86224	1.94294	2.02305
53	1.45212	1.53540	1.61821	1.70053	1.78233	1.86359	1.94428	2.02438
54	1.45351	1.53678	1.61959	1.70190	1.78369	1.86494	1.94562	2.02571
55	1.45490	1.53817	1.62096	1.70327	1.78505	1.86629	1.94696	2.02704
56	1.45629	1.53955	1.62234	1.70463	1.78641	1.86764	1.94830	2.02837
57	1.45769	1.54093	1.62371	1.70600	1.78777	1.86899	1.94964	2.02970
58	1.45908	1.54232	1.62509	1.70737	1.78912	1.87034	1.95098	2.03103
59	1.46047	1.54370	1.62647	1.70873	1.79048	1.87168	1.95232	2.03235
60	1.46186	1.54509	1.62784	1.71010	1.79184	1.87303	1.95366	2.03368

Constants for Setting a 5-inch Sine-Bar for 24° to 31°

Min.	24°	25°	26°	27°	28°	29°	30°	31°
0	2.03368	2.11309	2.19186	2.26995	2.34736	2.42405	2.50000	2.57519
1	2.03501	2.11441	2.19316	2.27125	2.34864	2.42532	2.50126	2.57644
2	2.03634	2.11573	2.19447	2.27254	2.34993	2.42659	2.50252	2.57768
3	2.03767	2.11704	2.19578	2.27384	2.35121	2.42786	2.50378	2.57893
4	2.03900	2.11836	2.19708	2.27513	2.35249	2.42913	2.50504	2.58018
5	2.04032	2.11968	2.19839	2.27643	2.35378	2.43041	2.50630	2.58142
6	2.04165	2.12100	2.19970	2.27772	2.35506	2.43168	2.50755	2.58267
7	2.04298	2.12231	2.20100	2.27902	2.35634	2.43295	2.50881	2.58391
8	2.04431	2.12363	2.20231	2.28031	2.35763	2.43422	2.51007	2.58516
9	2.04563	2.12495	2.20361	2.28161	2.35891	2.43549	2.51133	2.58640
10	2.04696	2.12626	2.20492	2.28290	2.36019	2.43676	2.51259	2.58765
11	2.04829	2.12758	2.20622	2.28420	2.36147	2.43803	2.51384	2.58889
12	2.04962	2.12890	2.20753	2.28549	2.36275	2.43930	2.51510	2.59014
13	2.05094	2.13021	2.20883	2.28678	2.36404	2.44057	2.51636	2.59138
14	2.05227	2.13153	2.21014	2.28808	2.36532	2.44184	2.51761	2.59262
15	2.05359	2.13284	2.21144	2.28937	2.36660	2.44311	2.51887	2.59387
16	2.05492	2.13416	2.21275	2.29066	2.36788	2.44438	2.52013	2.59511
17	2.05625	2.13547	2.21405	2.29196	2.36916	2.44564	2.52138	2.59635
18	2.05757	2.13679	2.21536	2.29325	2.37044	2.44691	2.52264	2.59760
19	2.05890	2.13810	2.21666	2.29454	2.37172	2.44818	2.52389	2.59884
20	2.06022	2.13942	2.21796	2.29583	2.37300	2.44945	2.52515	2.60008
21	2.06155	2.14073	2.21927	2.29712	2.37428	2.45072	2.52640	2.60132
22	2.06287	2.14205	2.22057	2.29842	2.37556	2.45198	2.52766	2.60256
23	2.06420	2.14336	2.22187	2.29971	2.37684	2.45325	2.52891	2.60381
24	2.06552	2.14468	2.22318	2.30100	2.37812	2.45452	2.53017	2.60505
25	2.06685	2.14599	2.22448	2.30229	2.37940	2.45579	2.53142	2.60629
26	2.06817	2.14730	2.22578	2.30358	2.38068	2.45705	2.53268	2.60753
27	2.06950	2.14862	2.22708	2.30487	2.38196	2.45832	2.53393	2.60877
28	2.07082	2.14993	2.22839	2.30616	2.38324	2.45959	2.53519	2.61001
29	2.07214	2.15124	2.22969	2.30745	2.38452	2.46085	2.53644	2.61125
30	2.07347	2.15256	2.23099	2.30874	2.38579	2.46212	2.53769	2.61249
31	2.07479	2.15387	2.23229	2.31003	2.38707	2.46338	2.53894	2.61373
32	2.07611	2.15518	2.23359	2.31132	2.38835	2.46465	2.54020	2.61497
33	2.07744	2.15649	2.23489	2.31261	2.38963	2.46591	2.54145	2.61621
34	2.07876	2.15781	2.23619	2.31390	2.39091	2.46718	2.54270	2.61745
35	2.08008	2.15912	2.23749	2.31519	2.39218	2.46844	2.54396	2.61869
36	2.08140	2.16043	2.23880	2.31648	2.39346	2.46971	2.54521	2.61993
37	2.08273	2.16174	2.24010	2.31777	2.39474	2.47097	2.54646	2.62117
38	2.08405	2.16305	2.24140	2.31906	2.39601	2.47224	2.54771	2.62241
39	2.08537	2.16436	2.24270	2.32035	2.39729	2.47350	2.54896	2.62364
40	2.08669	2.16567	2.24400	2.32163	2.39857	2.47477	2.55021	2.62488
41	2.08801	2.16698	2.24530	2.32292	2.39984	2.47603	2.55146	2.62612
42	2.08934	2.16830	2.24660	2.32421	2.40112	2.47729	2.55271	2.62736
43	2.09066	2.16961	2.24789	2.32550	2.40239	2.47856	2.55397	2.62860
44	2.09198	2.17092	2.24919	2.32679	2.40367	2.47982	2.55522	2.62983
45	2.09330	2.17223	2.25049	2.32807	2.40494	2.48108	2.55647	2.63107
46	2.09462	2.17354	2.25179	2.32936	2.40622	2.48235	2.55772	2.63231
47	2.09594	2.17485	2.25309	2.33065	2.40749	2.48361	2.55896	2.63354
48	2.09726	2.17616	2.25439	2.33193	2.40877	2.48487	2.56021	2.63478
49	2.09858	2.17746	2.25569	2.33322	2.41004	2.48613	2.56146	2.63602
50	2.09990	2.17877	2.25698	2.33451	2.41132	2.48739	2.56271	2.63725
51	2.10122	2.18008	2.25828	2.33579	2.41259	2.48866	2.56396	2.63849
52	2.10254	2.18139	2.25958	2.33708	2.41386	2.48992	2.56521	2.63972
53	2.10386	2.18270	2.26088	2.33836	2.41514	2.49118	2.56646	2.64096
54	2.10518	2.18401	2.26217	2.33965	2.41641	2.49244	2.56771	2.64219
55	2.10650	2.18532	2.26347	2.34093	2.41769	2.49370	2.56895	2.64343
56	2.10782	2.18663	2.26477	2.34222	2.41896	2.49496	2.57020	2.64466
57	2.10914	2.18793	2.26606	2.34350	2.42023	2.49622	2.57145	2.64590
58	2.11045	2.18924	2.26736	2.34479	2.42150	2.49748	2.57270	2.64713
59	2.11177	2.19055	2.26866	2.34607	2.42278	2.49874	2.57394	2.64836
60	2.11309	2.19186	2.26995	2.34736	2.42405	2.50000	2.57519	2.64960

Constants for Setting a 5-inch Sine-Bar for 32° to 39°

Min.	32°	33°	34°	35°	36°	37°	38°	39°
0	2.64960	2.72320	2.79596	2.86788	2.93893	3.00908	3.07831	3.14660
1	2.65083	2.72441	2.79717	2.86907	2.94010	3.01024	3.07945	3.14773
2	2.65206	2.72563	2.79838	2.87026	2.94128	3.01140	3.08060	3.14886
3	2.65330	2.72685	2.79958	2.87146	2.94246	3.01256	3.08174	3.14999
4	2.65453	2.72807	2.80079	2.87265	2.94363	3.01372	3.08289	3.15112
5	2.65576	2.72929	2.80199	2.87384	2.94481	3.01488	3.08403	3.15225
6	2.65699	2.73051	2.80319	2.87503	2.94598	3.01604	3.08518	3.15338
7	2.65822	2.73173	2.80440	2.87622	2.94716	3.01720	3.08632	3.15451
8	2.65946	2.73295	2.80560	2.87741	2.94833	3.01836	3.08747	3.15564
9	2.66069	2.73416	2.80681	2.87860	2.94951	3.01952	3.08861	3.15676
10	2.66192	2.73538	2.80801	2.87978	2.95068	3.02068	3.08976	3.15789
11	2.66315	2.73660	2.80921	2.88097	2.95185	3.02184	3.09090	3.15902
12	2.66438	2.73782	2.81042	2.88216	2.95303	3.02300	3.09204	3.16015
13	2.66561	2.73903	2.81162	2.88335	2.95420	3.02415	3.09318	3.16127
14	2.66684	2.74025	2.81282	2.88454	2.95538	3.02531	3.09433	3.16240
15	2.66807	2.74147	2.81402	2.88573	2.95655	3.02647	3.09547	3.16353
16	2.66930	2.74268	2.81523	2.88691	2.95772	3.02763	3.09661	3.16465
17	2.67053	2.74390	2.81643	2.88810	2.95889	3.02878	3.09775	3.16578
18	2.67176	2.74511	2.81763	2.88929	2.96007	3.02994	3.09890	3.16690
19	2.67299	2.74633	2.81883	2.89048	2.96124	3.03110	3.10004	3.16803
20	2.67422	2.74754	2.82003	2.89166	2.96241	3.03226	3.10118	3.16915
21	2.67545	2.74876	2.82123	2.89285	2.96358	3.03341	3.10232	3.17028
22	2.67668	2.74997	2.82243	2.89403	2.96475	3.03457	3.10346	3.17140
23	2.67791	2.75119	2.82364	2.89522	2.96592	3.03572	3.10460	3.17253
24	2.67913	2.75240	2.82484	2.89641	2.96709	3.03688	3.10574	3.17365
25	2.68036	2.75362	2.82604	2.89759	2.96827	3.03803	3.10688	3.17478
26	2.68159	2.75483	2.82723	2.89878	2.96944	3.03919	3.10802	3.17590
27	2.68282	2.75605	2.82843	2.89996	2.97061	3.04034	3.10916	3.17702
28	2.68404	2.75726	2.82963	2.90115	2.97178	3.04150	3.11030	3.17815
29	2.68527	2.75847	2.83083	2.90233	2.97294	3.04265	3.11143	3.17927
30	2.68650	2.75969	2.83203	2.90351	2.97411	3.04381	3.11257	3.18039
31	2.68772	2.76090	2.83323	2.90470	2.97528	3.04496	3.11371	3.18151
32	2.68895	2.76211	2.83443	2.90588	2.97645	3.04611	3.11485	3.18264
33	2.69018	2.76332	2.83563	2.90707	2.97762	3.04727	3.11599	3.18376
34	2.69140	2.76453	2.83682	2.90825	2.97879	3.04842	3.11712	3.18488
35	2.69263	2.76575	2.83802	2.90943	2.97996	3.04957	3.11826	3.18600
36	2.69385	2.76696	2.83922	2.91061	2.98112	3.05073	3.11940	3.18712
37	2.69508	2.76817	2.84042	2.91180	2.98229	3.05188	3.12053	3.18824
38	2.69630	2.76938	2.84161	2.91298	2.98346	3.05303	3.12167	3.18936
39	2.69753	2.77059	2.84281	2.91416	2.98463	3.05418	3.12281	3.19048
40	2.69875	2.77180	2.84401	2.91534	2.98579	3.05533	3.12394	3.19160
41	2.69998	2.77301	2.84520	2.91652	2.98696	3.05648	3.12508	3.19272
42	2.70120	2.77422	2.84640	2.91771	2.98813	3.05764	3.12621	3.19384
43	2.70243	2.77543	2.84759	2.91889	2.98929	3.05879	3.12735	3.19496
44	2.70365	2.77664	2.84879	2.92007	2.99046	3.05994	3.12848	3.19608
45	2.70487	2.77785	2.84998	2.92125	2.99162	3.06109	3.12962	3.19720
46	2.70610	2.77906	2.85118	2.92243	2.99279	3.06224	3.13075	3.19831
47	2.70732	2.78027	2.85237	2.92361	2.99395	3.06339	3.13189	3.19943
48	2.70854	2.78148	2.85357	2.92479	2.99512	3.06454	3.13302	3.20055
49	2.70976	2.78269	2.85476	2.92597	2.99628	3.06568	3.13415	3.20167
50	2.71099	2.78389	2.85596	2.92715	2.99745	3.06683	3.13529	3.20278
51	2.71221	2.78510	2.85715	2.92833	2.99861	3.06798	3.13642	3.20390
52	2.71343	2.78631	2.85834	2.92950	2.99977	3.06913	3.13755	3.20502
53	2.71465	2.78752	2.85954	2.93068	3.00094	3.07028	3.13868	3.20613
54	2.71587	2.78873	2.86073	2.93186	3.00210	3.07143	3.13982	3.20725
55	2.71709	2.78993	2.86192	2.93304	3.00326	3.07257	3.14095	3.20836
56	2.71831	2.79114	2.86311	2.93422	3.00443	3.07372	3.14208	3.20948
57	2.71953	2.79235	2.86431	2.93540	3.00559	3.07487	3.14321	3.21059
58	2.72076	2.79355	2.86550	2.93657	3.00675	3.07601	3.14434	3.21171
59	2.72198	2.79476	2.86669	2.93775	3.00791	3.07716	3.14547	3.21282
60	2.72320	2.79596	2.86788	2.93893	3.00908	3.07831	3.14660	3.21394

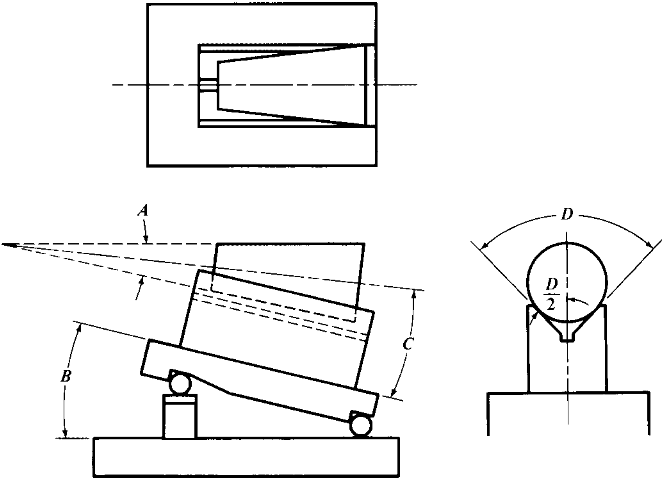
Constants for Setting a 5-inch Sine-Bar for 40° to 47°

Min.	40°	41°	42°	43°	44°	45°	46°	47°
0	3.21394	3.28030	3.34565	3.40999	3.47329	3.53553	3.59670	3.65677
1	3.21505	3.28139	3.34673	3.41106	3.47434	3.53656	3.59771	3.65776
2	3.21617	3.28249	3.34781	3.41212	3.47538	3.53759	3.59872	3.65875
3	3.21728	3.28359	3.34889	3.41318	3.47643	3.53862	3.59973	3.65974
4	3.21839	3.28468	3.34997	3.41424	3.47747	3.53965	3.60074	3.66073
5	3.21951	3.28578	3.35105	3.41531	3.47852	3.54067	3.60175	3.66172
6	3.22062	3.28688	3.35213	3.41637	3.47956	3.54170	3.60276	3.66271
7	3.22173	3.28797	3.35321	3.41743	3.48061	3.54273	3.60376	3.66370
8	3.22284	3.28907	3.35429	3.41849	3.48165	3.54375	3.60477	3.66469
9	3.22395	3.29016	3.35537	3.41955	3.48270	3.54478	3.60578	3.66568
10	3.22507	3.29126	3.35645	3.42061	3.48374	3.54580	3.60679	3.66667
11	3.22618	3.29235	3.35753	3.42168	3.48478	3.54683	3.60779	3.66766
12	3.22729	3.29345	3.35860	3.42274	3.48583	3.54785	3.60880	3.66865
13	3.22840	3.29454	3.35968	3.42380	3.48687	3.54888	3.60981	3.66964
14	3.22951	3.29564	3.36076	3.42486	3.48791	3.54990	3.61081	3.67063
15	3.23062	3.29673	3.36183	3.42592	3.48895	3.55093	3.61182	3.67161
16	3.23173	3.29782	3.36291	3.42697	3.48999	3.55195	3.61283	3.67260
17	3.23284	3.29892	3.36399	3.42803	3.49104	3.55297	3.61383	3.67359
18	3.23395	3.30001	3.36506	3.42909	3.49208	3.55400	3.61484	3.67457
19	3.23506	3.30110	3.36614	3.43015	3.49312	3.55502	3.61584	3.67556
20	3.23617	3.30219	3.36721	3.43121	3.49416	3.55604	3.61684	3.67655
21	3.23728	3.30329	3.36829	3.43227	3.49520	3.55707	3.61785	3.67753
22	3.23838	3.30438	3.36936	3.43332	3.49624	3.55809	3.61885	3.67852
23	3.23949	3.30547	3.37044	3.43438	3.49728	3.55911	3.61986	3.67950
24	3.24060	3.30656	3.37151	3.43544	3.49832	3.56013	3.62086	3.68049
25	3.24171	3.30765	3.37259	3.43649	3.49936	3.56115	3.62186	3.68147
26	3.24281	3.30874	3.37366	3.43755	3.50039	3.56217	3.62286	3.68245
27	3.24392	3.30983	3.37473	3.43861	3.50143	3.56319	3.62387	3.68344
28	3.24503	3.31092	3.37581	3.43966	3.50247	3.56421	3.62487	3.68442
29	3.24613	3.31201	3.37688	3.44072	3.50351	3.56523	3.62587	3.68540
30	3.24724	3.31310	3.37795	3.44177	3.50455	3.56625	3.62687	3.68639
31	3.24835	3.31419	3.37902	3.44283	3.50558	3.56727	3.62787	3.68737
32	3.24945	3.31528	3.38010	3.44388	3.50662	3.56829	3.62887	3.68835
33	3.25056	3.31637	3.38117	3.44494	3.50766	3.56931	3.62987	3.68933
34	3.25166	3.31746	3.38224	3.44599	3.50869	3.57033	3.63087	3.69031
35	3.25277	3.31854	3.38331	3.44704	3.50973	3.57135	3.63187	3.69130
36	3.25387	3.31963	3.38438	3.44810	3.51077	3.57236	3.63287	3.69228
37	3.25498	3.32072	3.38545	3.44915	3.51180	3.57338	3.63387	3.69326
38	3.25608	3.32181	3.38652	3.45020	3.51284	3.57440	3.63487	3.69424
39	3.25718	3.32289	3.38759	3.45126	3.51387	3.57542	3.63587	3.69522
40	3.25829	3.32398	3.38866	3.45231	3.51491	3.57643	3.63687	3.69620
41	3.25939	3.32507	3.38973	3.45336	3.51594	3.57745	3.63787	3.69718
42	3.26049	3.32615	3.39080	3.45441	3.51697	3.57846	3.63886	3.69816
43	3.26159	3.32724	3.39187	3.45546	3.51801	3.57948	3.63986	3.69913
44	3.26270	3.32832	3.39294	3.45651	3.51904	3.58049	3.64086	3.70011
45	3.26380	3.32941	3.39400	3.45757	3.52007	3.58151	3.64186	3.70109
46	3.26490	3.33049	3.39507	3.45862	3.52111	3.58252	3.64285	3.70207
47	3.26600	3.33158	3.39614	3.45967	3.52214	3.58354	3.64385	3.70305
48	3.26710	3.33266	3.39721	3.46072	3.52317	3.58455	3.64484	3.70402
49	3.26820	3.33375	3.39827	3.46177	3.52420	3.58557	3.64584	3.70500
50	3.26930	3.33483	3.39934	3.46281	3.52523	3.58658	3.64683	3.70598
51	3.27040	3.33591	3.40041	3.46386	3.52627	3.58759	3.64783	3.70695
52	3.27150	3.33700	3.40147	3.46491	3.52730	3.58861	3.64882	3.70793
53	3.27260	3.33808	3.40254	3.46596	3.52833	3.58962	3.64982	3.70890
54	3.27370	3.33916	3.40360	3.46701	3.52936	3.59063	3.65081	3.70988
55	3.27480	3.34025	3.40467	3.46806	3.53039	3.59164	3.65181	3.71085
56	3.27590	3.34133	3.40573	3.46910	3.53142	3.59266	3.65280	3.71183
57	3.27700	3.34241	3.40680	3.47015	3.53245	3.59367	3.65379	3.71280
58	3.27810	3.34349	3.40786	3.47120	3.53348	3.59468	3.65478	3.71378
59	3.27920	3.34457	3.40893	3.47225	3.53451	3.59569	3.65578	3.71475
60	3.28030	3.34565	3.40999	3.47329	3.53553	3.59670	3.65677	3.71572

Constants for Setting a 5-inch Sine-Bar for 48° to 55°

Min.	48°	49°	50°	51°	52°	53°	54°	55°
0	3.71572	3.77355	3.83022	3.88573	3.94005	3.99318	4.04508	4.09576
1	3.71670	3.77450	3.83116	3.88665	3.94095	3.99405	4.04594	4.09659
2	3.71767	3.77546	3.83209	3.88756	3.94184	3.99493	4.04679	4.09743
3	3.71864	3.77641	3.83303	3.88847	3.94274	3.99580	4.04765	4.09826
4	3.71961	3.77736	3.83396	3.88939	3.94363	3.99668	4.04850	4.09909
5	3.72059	3.77831	3.83489	3.89030	3.94453	3.99755	4.04936	4.09993
6	3.72156	3.77927	3.83583	3.89122	3.94542	3.99842	4.05021	4.10076
7	3.72253	3.78022	3.83676	3.89213	3.94631	3.99930	4.05106	4.10159
8	3.72350	3.78117	3.83769	3.89304	3.94721	4.00017	4.05191	4.10242
9	3.72447	3.78212	3.83862	3.89395	3.94810	4.00104	4.05277	4.10325
10	3.72544	3.78307	3.83956	3.89487	3.94899	4.00191	4.05362	4.10409
11	3.72641	3.78402	3.84049	3.89578	3.94988	4.00279	4.05447	4.10492
12	3.72738	3.78498	3.84142	3.89669	3.95078	4.00366	4.05532	4.10575
13	3.72835	3.78593	3.84235	3.89760	3.95167	4.00453	4.05617	4.10658
14	3.72932	3.78688	3.84328	3.89851	3.95256	4.00540	4.05702	4.10741
15	3.73029	3.78783	3.84421	3.89942	3.95345	4.00627	4.05787	4.10823
16	3.73126	3.78877	3.84514	3.90033	3.95434	4.00714	4.05872	4.10906
17	3.73222	3.78972	3.84607	3.90124	3.95523	4.00801	4.05957	4.10989
18	3.73319	3.79067	3.84700	3.90215	3.95612	4.00888	4.06042	4.11072
19	3.73416	3.79162	3.84793	3.90306	3.95701	4.00975	4.06127	4.11155
20	3.73513	3.79257	3.84886	3.90397	3.95790	4.01062	4.06211	4.11238
21	3.73609	3.79352	3.84978	3.90488	3.95878	4.01148	4.06296	4.11320
22	3.73706	3.79446	3.85071	3.90579	3.95967	4.01235	4.06381	4.11403
23	3.73802	3.79541	3.85164	3.90669	3.96056	4.01322	4.06466	4.11486
24	3.73899	3.79636	3.85257	3.90760	3.96145	4.01409	4.06550	4.11568
25	3.73996	3.79730	3.85349	3.90851	3.96234	4.01495	4.06635	4.11651
26	3.74092	3.79825	3.85442	3.90942	3.96322	4.01582	4.06720	4.11733
27	3.74189	3.79919	3.85535	3.91032	3.96411	4.01669	4.06804	4.11816
28	3.74285	3.80014	3.85627	3.91123	3.96500	4.01755	4.06889	4.11898
29	3.74381	3.80109	3.85720	3.91214	3.96588	4.01842	4.06973	4.11981
30	3.74478	3.80203	3.85812	3.91304	3.96677	4.01928	4.07058	4.12063
31	3.74574	3.80297	3.85905	3.91395	3.96765	4.02015	4.07142	4.12145
32	3.74671	3.80392	3.85997	3.91485	3.96854	4.02101	4.07227	4.12228
33	3.74767	3.80486	3.86090	3.91576	3.96942	4.02188	4.07311	4.12310
34	3.74863	3.80581	3.86182	3.91666	3.97031	4.02274	4.07395	4.12392
35	3.74959	3.80675	3.86274	3.91756	3.97119	4.02361	4.07480	4.12475
36	3.75056	3.80769	3.86367	3.91847	3.97207	4.02447	4.07564	4.12557
37	3.75152	3.80863	3.86459	3.91937	3.97296	4.02533	4.07648	4.12639
38	3.75248	3.80958	3.86551	3.92027	3.97384	4.02619	4.07732	4.12721
39	3.75344	3.81052	3.86644	3.92118	3.97472	4.02706	4.07817	4.12803
40	3.75440	3.81146	3.86736	3.92208	3.97560	4.02792	4.07901	4.12885
41	3.75536	3.81240	3.86828	3.92298	3.97649	4.02878	4.07985	4.12967
42	3.75632	3.81334	3.86920	3.92388	3.97737	4.02964	4.08069	4.13049
43	3.75728	3.81428	3.87012	3.92478	3.97825	4.03050	4.08153	4.13131
44	3.75824	3.81522	3.87104	3.92568	3.97913	4.03136	4.08237	4.13213
45	3.75920	3.81616	3.87196	3.92658	3.98001	4.03222	4.08321	4.13295
46	3.76016	3.81710	3.87288	3.92748	3.98089	4.03308	4.08405	4.13377
47	3.76112	3.81804	3.87380	3.92839	3.98177	4.03394	4.08489	4.13459
48	3.76207	3.81898	3.87472	3.92928	3.98265	4.03480	4.08572	4.13540
49	3.76303	3.81992	3.87564	3.93018	3.98353	4.03566	4.08656	4.13622
50	3.76399	3.82086	3.87656	3.93108	3.98441	4.03652	4.08740	4.13704
51	3.76495	3.82179	3.87748	3.93198	3.98529	4.03738	4.08824	4.13785
52	3.76590	3.82273	3.87840	3.93288	3.98616	4.03823	4.08908	4.13867
53	3.76686	3.82367	3.87931	3.93378	3.98704	4.03909	4.08991	4.13949
54	3.76782	3.82461	3.88023	3.93468	3.98792	4.03995	4.09075	4.14030
55	3.76877	3.82554	3.88115	3.93557	3.98880	4.04081	4.09158	4.14112
56	3.76973	3.82648	3.88207	3.93647	3.98967	4.04166	4.09242	4.14193
57	3.77068	3.82742	3.88298	3.93737	3.99055	4.04252	4.09326	4.14275
58	3.77164	3.82835	3.88390	3.93826	3.99143	4.04337	4.09409	4.14356
59	3.77259	3.82929	3.88481	3.93916	3.99230	4.04423	4.09493	4.14437
60	3.77355	3.83022	3.88573	3.94005	3.99318	4.04508	4.09576	4.14519

Measuring Tapers with Vee-Block and Sine-Bar.—The taper on a conical part may be checked or found by placing the part in a vee-block which rests on the surface of a sine-plate or sine-bar as shown in the accompanying diagram. The advantage of this method is that the axis of the vee-block may be aligned with the sides of the sine-bar. Thus when the tapered part is placed in the vee-block it will be aligned perpendicular to the transverse axis of the sine-bar.



The sine-bar is set to angle $B = (C + A/2)$ where $A/2$ is one-half the included angle of the tapered part. If D is the included angle of the precision vee-block, the angle C is calculated from the formula:

$$\sin C = \frac{\sin(A/2}{\sin(D/2}$$

If dial indicator readings show no change across all points along the top of the taper surface, then this checks that the angle A of the taper is correct.

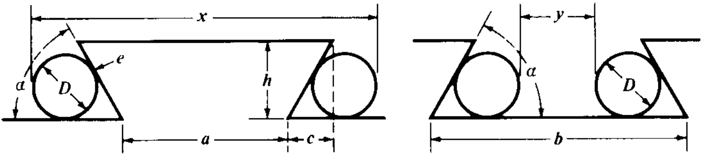
If the indicator readings vary, proceed as follows to find the actual angle of taper:

1) Adjust the angle of the sine-bar until the indicator reading is constant. Then find the new angleB' as explained in the paragraph *Measuring Angle of Templet or Gage with Sine Bar* on page 674; and 2) Using the angle B' calculate the actual half-angle $A'/2$ of the taper from the formula:.

$$\tan\frac{A'}{2} = \frac{\sin B'}{\csc\frac{D}{2} + \cos B'}$$

The taper per foot corresponding to certain half-angles of taper may be found in the table on page 684.

Measuring Dovetail Slides.—Dovetail slides that must be machined accurately to a given width are commonly gaged by using pieces of cylindrical rod or wire and measuring as indicated by the dimensions x and y of the accompanying illustrations.



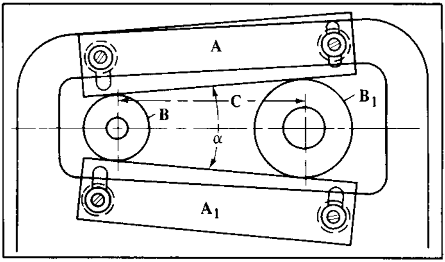
To obtain dimension *x* for measuring male dovetails, add I to the cotangent of one-half the dovetail angle α, multiply by diameter *D* of the rods used, and add the product to dimension α. To obtain dimension *y* for measuring a female dovetail, add 1 to the cotangent of one-half the dovetail angle α, multiply by diameter *D* of the rod used, and subtract the result from dimension *b*. Expressing these rules as formulas:

$$x = D(1 + \cot \tfrac{1}{2}\alpha) + a$$
$$y = b - D(1 + \cot \tfrac{1}{2}\alpha)$$
$$c = h \times \cot\alpha$$

The rod or wire used should be small enough so that the point of contact e is somewhat below the corner or edge of the dovetail.

Accurate Measurement of Angles and Tapers

When great accuracy is required in the measurement of angles, or when originating tapers, disks are commonly used. The principle of the disk method of taper measurement is that if two disks of unequal diameters are placed either in contact or a certain distance apart, lines tangent to their peripheries will represent an angle or taper, the degree of which depends upon the diameters of the two disks and the distance between them.



The gage shown in the accompanying illustration, which is a form commonly used for originating tapers or measuring angles accurately, is set by means of disks. This gage consists of two adjustable straight edges *A* and A_1, which are in contact with disks *B* and B_1. The angle α or the taper between the straight edges depends, of course, upon the diameters of the disks and the center distance *C*, and as these three dimensions can be measured accurately, it is possible to set the gage to a given angle within very close limits. Moreover, if a record of the three dimensions is kept, the exact setting of the gage can be reproduced quickly at any time. The following rules may be used for adjusting a gage of this type, and cover all problems likely to arise in practice. Disks are also occasionally used for the setting of parts in angular positions when they are to be machined accurately to a given angle: the rules are applicable to these conditions also.

Tapers per Foot and Corresponding Angles

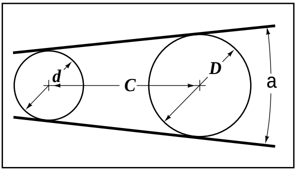
Taper per Foot	Included Angle	Angle with Center Line	Taper per Foot	Included Angle	Angle with Center Line
1/64	0° 4′ 29″	0° 2′ 14″	1 7/8	8° 56′ 4″	4° 28′ 2″
1/32	0 8 57	0 4 29	1 15/16	9 13 51	4 36 56
1/16	0 17 54	0 8 57	2	9 31 38	4 45 49
3/32	0 26 51	0 13 26	2 1/8	10 7 11	5 3 36
1/8	0 35 49	0 17 54	2 1/4	10 42 42	5 21 21
5/32	0 44 46	0 22 23	2 3/8	11 18 11	5 39 5
3/16	0 53 43	0 26 51	2 1/2	11 53 37	5 56 49
7/32	1 2 40	0 31 20	2 5/8	12 29 2	6 14 31
1/4	1 11 37	0 35 49	2 3/4	13 4 24	6 32 12
9/32	1 20 34	0 40 17	2 7/8	13 39 43	6 49 52
5/16	1 29 31	0 44 46	3	14 15 0	7 7 30
11/32	1 38 28	0 49 14	3 1/8	14 50 14	7 25 7
3/8	1 47 25	0 53 43	3 1/4	15 25 26	7 42 43
13/32	1 56 22	0 58 11	3 3/8	16 0 34	8 0 17
7/16	2 5 19	1 2 40	3 1/2	16 35 39	8 17 50
15/32	2 14 16	1 7 8	3 5/8	17 10 42	8 35 21
1/2	2 23 13	1 11 37	3 3/4	17 45 41	8 52 50
17/32	2 32 10	1 16 5	3 7/8	18 20 36	9 10 18
9/16	2 41 7	1 20 33	4	18 55 29	9 27 44
19/32	2 50 4	1 25 2	4 1/8	19 30 17	9 45 9
5/8	2 59 1	1 29 30	4 1/4	20 5 3	10 2 31
21/32	3 7 57	1 33 59	4 3/8	20 39 44	10 19 52
11/16	3 16 54	1 38 27	4 1/2	21 14 22	10 37 11
23/32	3 25 51	1 42 55	4 5/8	21 48 55	10 54 28
3/4	3 34 47	1 47 24	4 3/4	22 23 25	11 11 42
25/32	3 43 44	1 51 52	4 7/8	22 57 50	11 28 55
13/16	3 52 41	1 56 20	5	23 32 12	11 46 6
27/32	4 1 37	2 0 49	5 1/8	24 6 29	12 3 14
7/8	4 10 33	2 5 17	5 1/4	24 40 41	12 20 21
29/32	4 19 30	2 9 45	5 3/8	25 14 50	12 37 25
15/16	4 28 26	2 14 13	5 1/2	25 48 53	12 54 27
31/32	4 37 23	2 18 41	5 5/8	26 22 52	13 11 26
1	4 46 19	2 23 9	5 3/4	26 56 47	13 28 23
1 1/16	5 4 11	2 32 6	5 7/8	27 30 36	13 45 18
1 1/8	5 22 3	2 41 2	6	28 4 21	14 2 10
1 3/16	5 39 55	2 49 57	6 1/8	28 38 1	14 19 0
1 1/4	5 57 47	2 58 53	6 1/4	29 11 35	14 35 48
1 5/16	6 15 38	3 7 49	6 3/8	29 45 5	14 52 32
1 3/8	6 33 29	3 16 44	6 1/2	30 18 29	15 9 15
1 7/16	6 51 19	3 25 40	6 5/8	30 51 48	15 25 54
1 1/2	7 9 10	3 34 35	6 3/4	31 25 2	15 42 31
1 9/16	7 27 0	3 43 30	6 7/8	31 58 11	15 59 5
1 5/8	7 44 49	3 52 25	7	32 31 13	16 15 37
1 11/16	8 2 38	4 1 19	7 1/8	33 4 11	16 32 5
1 3/4	8 20 27	4 10 14	7 1/4	33 37 3	16 48 31
1 13/16	8 38 16	4 19 8	7 3/8	34 9 49	17 4 54

For conversions into decimal degrees and radians see *Conversion Tables of Angular Measure* on page 90.

Rules for Figuring Tapers

Given	To Find	Rule
The taper per foot.	The taper per inch.	Divide the taper per foot by 12.
The taper per inch.	The taper per foot.	Multiply the taper per inch by 12.
End diameters and length of taper in inches.	The taper per foot.	Subtract small diameter from large; divide by length of taper; and multiply quotient by 12.
Large diameter and length of taper in inches, and taper per foot.	Diameter at small end in inches	Divide taper per foot by 12; multiply by length of taper; and subtract result from large diameter.
Small diameter and length of taper in inches, and taper per foot.	Diameter at large end in inches.	Divide taper per foot by 12; multiply by length of taper; and add result to small diameter.
The taper per foot and two diameters in inches.	Distance between two given diameters in inches.	Subtract small diameter from large; divide remainder by taper per foot; and multiply quotient by 12.
The taper per foot.	Amount of taper in a certain length in inches.	Divide taper per foot by 12; multiply by given length of tapered part.

To find angle α for given taper T in inches per foot.—



$$\alpha = 2\arctan(T/24).$$

Example: What angle α is equivalent to a taper of 1.5 inches per foot?

$$\alpha = 2 \times \arctan(1.5/24) = 7.153°$$

To find taper per foot T given angle α in degrees.—

$$T = 24 \tan(\alpha/2) \text{ inches per foot}$$

Example: What taper T is equivalent to an angle of 7.153°?

$$T = 24\tan(7.153/2) = 1.5 \text{ inches per foot}$$

To find angle α given dimensions D, d, and C.— Let K be the difference in the disk diameters divided by twice the center distance. $K = (D - d)/(2C)$, then $\alpha = 2\arcsin K$

Example: If the disk diameters d and D are 1 and 1.5 inches, respectively, and the center distance C is 5 inches, find the included angle α.

$$K = (1.5 - 1)/(2 \times 5) = 0.05 \qquad \alpha = 2 \times \arcsin 0.05 = 5.732°$$

To find taper T measured at right angles to a line through the disk centers given dimensions D, d, and distance C.— Find K using the formula in the previous example, then $T = 24K/\sqrt{1 - K^2}$ inches per foot

Example: If disk diameters d and D are 1 and 1.5 inches, respectively, and the center distance C is 5 inches, find the taper per foot.

$$K = (1.5 - 1)/(2 \times 5) = 0.05 \qquad T = \frac{24 \times 0.05}{\sqrt{1 - (0.05)^2}} = 1.2015 \text{ inches per foot}$$

To find center distance *C* for a given taper *T* in inches per foot.—

$$C = \frac{D-d}{2} \times \frac{\sqrt{1+(T/24)^2}}{T/24} \text{ inches}$$

Example: Gage is to be set to ¾ inch per foot, and disk diameters are 1.25 and 1.5 inches, respectively. Find the required center distance for the disks.

$$C = \frac{1.5-1.25}{2} \times \frac{\sqrt{1+(0.75/24)^2}}{0.75/24} = 4.002 \text{ inches}$$

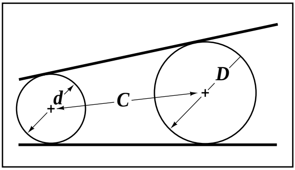
To find center distance *C* for a given angle α and dimensions *D* and *d*.—

$$C = (D-d)/2\sin(\alpha/2) \text{ inches}$$

Example: If an angle α of 20° is required, and the disks are 1 and 3 inches in diameter, respectively, find the required center distance *C*.

$$C = (3-1)/(2 \times \sin 10°) = 5.759 \text{ inches}$$

To find taper *T* measured at right angles to one side .— When one side is taken as a base line and the taper is measured at right angles to that side, calculate *K* as explained above and use the following formula for determining the taper *T*:



$$T = 24K\frac{\sqrt{1-K^2}}{1-2K^2} \text{ inches per foot}$$

Example: If the disk diameters are 2 and 3 inches, respectively, and the center I distance is 5 inches, what is the taper per foot measured at right angles to one side?

$$K = \frac{3-2}{2 \times 5} = 0.1 \qquad T = 24 \times 0.1 \times \frac{\sqrt{1-(0.1)^2}}{1-[2 \times (0.1)^2]} = 2.4367 \text{ in. per ft.}$$

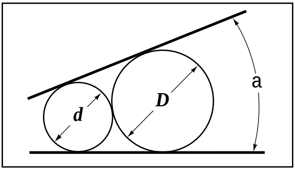
To find center distance *C* when taper *T* is measured from one side.—

$$C = \frac{D-d}{\sqrt{2-2/\sqrt{1+(T/12)^2}}} \text{ inches}$$

Example: If the taper measured at right angles to one side is 6.9 inches per foot, and the disks are 2 and 5 inches in diameter, respectively, what is center distance *C*?

$$C = \frac{5-2}{\sqrt{2-2/\sqrt{1+(6.9/12)^2}}} = 5.815 \text{ inches.}$$

To find diameter *D* of a large disk in contact with a small disk of diameter *d* given angle α.—



$$D = d \times \frac{1+\sin(\alpha/2)}{1-\sin(\alpha/2)} \text{ inches}$$

Example: The required angle α is 15°. Find diameter *D* of a large disk that is in contact with a standard 1-inch reference disk.

$$D = 1 \times \frac{1 + \sin 7.5^\circ}{1 - \sin 7.5^\circ} = 1.3002 \text{ inches}$$

Measurement over Pins.—When the distance across a bolt circle is too large to measure using ordinary measuring tools, then the required distance may be found from the distance across adacent or alternate holes using one of the methods that follow:

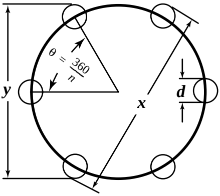


Fig. 1a.

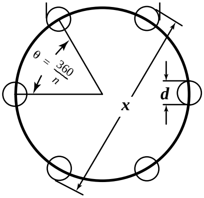


Fig. 1b.

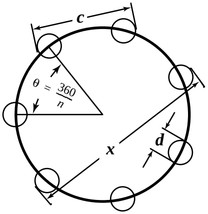


Fig. 1c.

Even Number of Holes in Circle: To measure the unknown distance *x* over opposite plugs in a bolt circle of *n* holes (*n* is even and greater than 4), as shown in Fig. 1a, where *y* is the distance over alternate plugs, *d* is the diameter of the holes, and θ = 360°/*n* is the angle between adjacent holes, use the following general equation for obtaining *x*:

$$x = \frac{y - d}{\sin\theta} + d$$

Example: In a die that has six 3/4-inch diameter holes equally spaced on a circle, where the distance *y* over alternate holes is 4½ inches, and the angle θ between adjacent holes is 60°, then

$$x = \frac{4.500 - 0.7500}{\sin 60^\circ} + 0.7500 = 5.0801$$

In a similar problem, the distance *c* over adjacent plugs is given, as shown in Fig. 1b. If the number of holes is even and greater than 4, the distance *x* over opposite plugs is given in the following formula:

$$x = 2(c - d)\left(\frac{\sin\left(\frac{180 - \theta}{2}\right)}{\sin\theta}\right) + d$$

where *d* and θ are as defined above.

Odd Number of Holes in Circle: In a circle as shown in Fig. 1c, where the number of holes *n* is odd and greater than 3, and the distance *c* over adjacent holes is given, then θ equals 360/*n* and the distance *x* across the most widely spaced holes is given by:

$$x = \frac{\frac{c - d}{2}}{\sin\frac{\theta}{4}} + d$$

Compound Angles

Three types of compound angles are illustrated by Figs. 1 through 6. The first type is shown in Figs. 1, 2, and 3; the second in Fig. 4; and the third in Figs. 5 and 6.

In Fig. 1 is shown what might be considered as a thread-cutting tool without front clearance. *A* is a known angle in plane *y–y* of the top surface. *C* is the corresponding angle in plane *x–x* that is at some given angle *B* with plane *y–y*. Thus, angles *A* and *B* are components of the compound angle *C*.

Example Problem Referring to Fig. 1: Angle 2*A* in plane *y–y* is known, as is also angle *B* between planes *x–x* and *y–y*. It is required to find compound angle 2*C* in plane *x–x*.

Solution:

$$\text{Let } 2A = 60 \text{ and } B = 15$$

Then

$$\tan C = \tan A \cos B$$

$$\tan C = \tan 30 \cos 15$$

$$\tan C = 0.57735 ¥ 0.96592$$

$$\tan C = 0.55767$$

$$C = 29\ 8.8' \qquad 2C = 58\ 17.6'$$

Fig. 2 shows a thread-cutting tool with front clearance angle *B*. Angle *A* equals one-half the angle between the cutting edges in plane *y–y* of the top surface and compound angle *C* is one-half the angle between the cutting edges in a plane *x–x* at right angles to the inclined front edge of the tool. The angle between planes *y–y* and *x–x* is, therefore, equal to clearance angle *B*.

Example Problem Referring to Fig. 2: Find the angle 2*C* between the front faces of a thread-cutting tool having a known clearance angle *B*, which will permit the grinding of these faces so that their top edges will form the desired angle 2*A* for cutting the thread.

Solution:

$$\text{Let } 2A = 60 \text{ and } B = 15$$

Then

$$\tan C = \frac{\tan A}{\cos B} = \frac{\tan 30^\circ}{\cos 15^\circ} = \frac{0.57735}{0.96592}$$

$$\tan C = 0.59772$$

$$C = 30\ 52' \qquad 2C = 61\ 44'$$

In Fig. 3 is shown a form-cutting tool in which the angle *A* is one-half the angle between the cutting edges in plane *y–y* of the top surface; *B* is the front clearance angle; and *C* is one-half the angle between the cutting edges in plane *x–x* at right angles to the front edges of the tool. The formula for finding angle *C* when angles *A* and *B* are known is the same as that for Fig. 2.

Example Problem Referring to Fig. 3: Find the angle 2*C* between the front faces of a form-cutting tool having a known clearance angle *B* that will permit the grinding of these faces so that their top edges will form the desired angle 2*A* for form cutting.

Solution:

$$\text{Let } 2A = 46 \text{ and } B = 12$$

Then

$$\tan C = \frac{\tan A}{\cos B} = \frac{\tan 23^\circ}{\cos 12^\circ} = \frac{0.42447}{0.97815}$$

$$\tan C = 0.43395$$

$$C = 23\ 27.5' \qquad 2C = 46\ 55'$$

In Fig. 4 is shown a wedge-shaped block, the top surface of which is inclined at compound angle *C* with the base in a plane at right angles with the base and at angle *R* with the front edge. Angle *A* in the vertical plane of the front of the plate and angle *B* in the vertical plane of one side that is at right angles to the front are components of angle *C*.

Formulas for Compound Angles

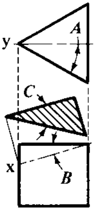


Fig. 1.

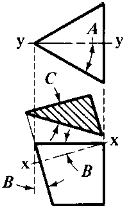


Fig. 2.

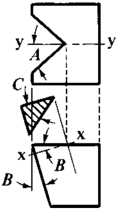


Fig. 3.

For given angles *A* and *B*, find the resultant angle *C* in plane *x*–*x*. Angle *B* is measured in vertical plane *y*–*y* of midsection.

(Fig. 1) $\tan C = \tan A \times \cos B$

(Fig. 2) $\tan C = \dfrac{\tan A}{\cos B}$

(Fig. 3) (Same formula as for Fig. 2)

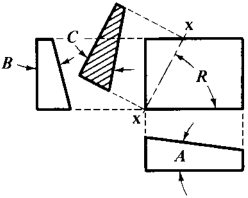


Fig. 4.

Fig. 4. In machining plate to angles *A* and *B*, it is held at angle *C* in plane *x*–*x*. Angle of rotation *R* in plane parallel to base (or complement of *R*) is for locating plate so that plane *x*–*x* is perpendicular to axis of pivot on angle-plate or work-holding vise.

$$\tan R = \frac{\tan B}{\tan A}; \quad \tan C = \frac{\tan A}{\cos R}$$

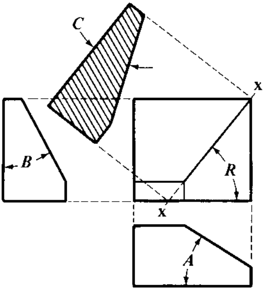


Fig. 5. Angle *R* in horizontal plane parallel to base is angle from plane *x*–*x* to side having angle *A*.

$$\tan R = \frac{\tan A}{\tan B}$$

$\tan C = \tan A \cos R = \tan B \sin R$
Compound angle *C* is angle in plane *x*–*x* from base to corner formed by intersection of planes inclined to angles *A* and *B*. This formula for *C* may be used to find cot of complement of C_1, Fig. 6.

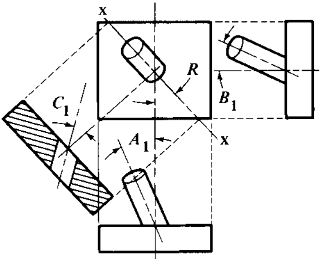


Fig. 6. Angles A_1 and B_1 are measured in vertical planes of front and side elevations. Plane *x*–*x* is located by angle *R* from center-line or from plane of angle B_1.

$$\tan R = \frac{\tan A_1}{\tan B_1}$$

$$\tan C_1 = \frac{\tan A_1}{\sin R} = \frac{\tan B_1}{\cos R}$$

The resultant angle C_1 would be required in drilling hole for pin.

C = compound angle in plane *x*–*x* and is the resultant of angles *A* and *B*

Problem Referring to Fig. 4: Find the compound angle *C* of a wedge-shaped block having known component angles *A* and *B* in sides at right angles to each other.

Solution:

Let $A = 47\ 14'$ and $B = 38\ 10'$

$$\tan R = \frac{\tan B}{\tan A} = \frac{\tan 38°10'}{\tan 47°14'} \qquad \tan C = \frac{\tan A}{\cos R} = \frac{\tan 47°14'}{\cos 36°0.9'}$$

$$\tan R = \frac{0.78598}{1.0812} = 0.72695 \qquad \tan C = \frac{1.0812}{0.80887} = 1.3367$$

$$R = 36°09' \qquad C = 53°12'$$

In Fig. 5 is shown a four-sided block, two sides of which are at right angles to each other and to the base of the block. The other two sides are inclined at an oblique angle with the base. Angle *C* is a compound angle formed by the intersection of these two inclined sides and the intersection of a vertical plane passing through *x*–*x*, and the base of the block. The components of angle *C* are angles *A* and *B* and angle *R* is the angle in the base plane of the block between the plane of angle *C* and the plane of angle *A*.

Problem Referring to Fig. 5**:** Find the angles *C* and *R* in the block shown in Fig. 5 when angles *A* and *B* are known.

Solution:

Let angle $A = 27°$ and $B = 36°$

$$\tan R = \frac{\cot B}{\cot A} = \frac{\cot 36°}{\cot 27°} = \frac{1.3764}{1.9626} \qquad \cot C = \sqrt{\cot^2 A + \cot^2 B}$$

$$\tan R = 0.70131 \qquad R = 35°2.5' \qquad = \sqrt{1.9626^2 + 1.3764^2}$$

$$= \sqrt{5.74627572} = 2.3971$$

$$C = 22°38.6'$$

Problem Referring to Fig. 6**:** A rod or pipe is inserted into a rectangular block at an angle. Angle C_1 is the compound angle of inclination (measured from the vertical) in a plane passing through the center line of the rod or pipe and at right angles to the top surface of the block. Angles A_1 and B_1 are the angles of inclination of the rod or pipe when viewed respectively in the front and side planes of the block. Angle *R* is the angle between the plane of angle C_1 and the plane of angle B_1. Find angles C_1 and *R* when a rod or pipe is inclined at known angles A_1 and B_1.

Solution:

Let $A_1 = 39$ and $B_1 = 34$

Then

$$\tan C_1 = \sqrt{\tan^2 A_1 + \tan^2 B_1} = \sqrt{0.80978^2 + 0.67451^2}$$

$$\tan C_1 = \sqrt{1.1107074} = 1.0539$$

$C_1 = 46\ 30.2'$

$$\tan R = \frac{\tan A_1}{\tan B_1} = \frac{0.80978}{0.67451}$$

$\tan R = 1.2005$ $\qquad R = 50\ 12.4'$

Measurement over Pins and Rolls

Checking a V-shaped Groove by Measurement Over Pins.—In checking a groove of the shape shown in Fig. 7, it is necessary to measure the dimension *X* over the pins of radius

R. If values for the radius *R*, dimension *Z*, and the angles α and β are known, the problem is to determine the distance *Y*, to arrive at the required overall dimension for *X*. If a line *AC* is drawn from the bottom of the V to the center of the pin at the left in Fig. 7, and a line *CB* from the center of this pin to its point of tangency with the side of the V, a right-angled triangle is formed in which one side, *CB*, is known and one angle *CAB*, can be determined. A line drawn from the center of a circle to the point of intersection of two tangents to the circle bisects the angle made by the tangent lines, and angle *CAB* therefore equals $\frac{1}{2}(\alpha + \beta)$. The length *AC* and the angle *DAC* can now be found, and with *AC* known in the right-angled triangle *ADC*, *AD*, which is equal to *Y*. can be found.

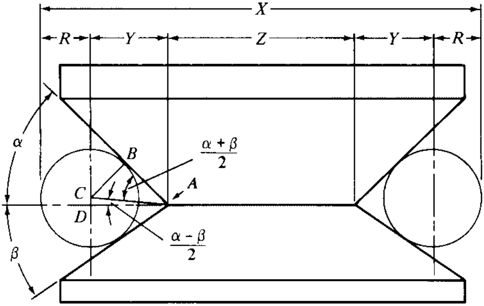


Fig. 7.

The value for *X* can be obtained from the formula

$$X = Z + 2R\left(\csc\frac{\alpha+\beta}{2}\cos\frac{\alpha-\beta}{2} + 1\right)$$

For example, if $R = 0.500$, $Z = 1.824$, $\alpha = 45$ degrees, and $\beta = 35$ degrees,

$$X = 1.824 + (2 \times 0.5)\left(\csc\frac{45° + 35°}{2}\cos\frac{45° - 35°}{2} + 1\right)$$

$$X = 1.824 + \csc 40° \cos 5° + 1$$

$$X = 1.824 + 1.5557 \times 0.99619 + 1$$

$$X = 1.824 + 1.550 + 1 = 4.374$$

Checking Radius of Arc by Measurement Over Rolls.—The radius *R* of large-radius concave and convex gages of the type shown in Figs. 8a, 8b and 8c can be checked by measurement *L* over two rolls with the gage resting on the rolls as shown. If the diameter of the rolls *D*, the length *L*, and the height *H* of the top of the arc above the surface plate (for the concave gage, Fig. 8a) are known or can be measured, the radius *R* of the workpiece to be checked can be calculated trigonometrically, as follows.

Referring to Fig. 8a for the concave gage, if *L* and *D* are known, *cb* can be found, and if *H* and *D* are known, *ce* can be found. With *cb* and *ce* known, *ab* can be found by means of a diagram as shown in Fig. 8c.

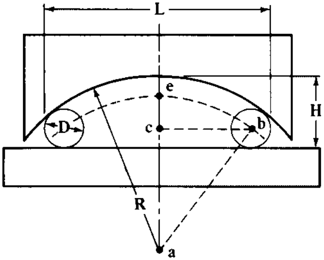


Fig. 8a.

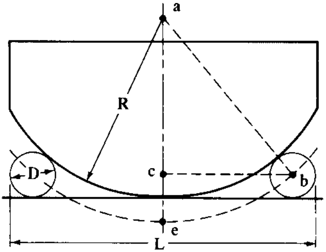


Fig. 8b.

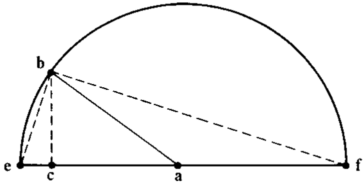


Fig. 8c.

In diagram Fig. 8c, *cb* and *ce* are shown at right angles as in Fig. 8a. A line is drawn connecting points *b* and *e* and line *ce* is extended to the right. A line is now drawn from point *b* perpendicular to *be* and intersecting the extension of *ce* at point *f*. A semicircle can now be drawn through points *b, e,* and *f* with point *a* as the center. Triangles *bce* and *bcf* are similar and have a common side. Thus *ce*:*bc*::*bc*:*cf*. With *ce* and *bc* known, *cf* can be found from this proportion and hence *ef* which is the diameter of the semicircle and radius *ab*. Then $R = ab + D/2$.

The procedure for the convex gage is similar. The distances *cb* and *ce* are readily found and from these two distances *ab* is computed on the basis of similar triangles as before. Radius *R* is then readily found.

The derived formulas for concave and convex gages are as follows:

Formulas:

$$R = \frac{(L-D)^2}{8(H-D)} + \frac{H}{2} \qquad \text{(Concave gage Fig. 8a)}$$

$$R = \frac{(L-D)^2}{8D} \qquad \text{(Convex gage Fig. 8b)}$$

For example: For Fig. 8a, let $L = 17.8$, $D = 3.20$, and $H = 5.72$, then

$$R = \frac{(17.8-3.20)^2}{8(5.72-3.20)} + \frac{5.72}{2} = \frac{(14.60)^2}{8 \times 2.52} + 2.86$$

$$R = \frac{213.16}{20.16} + 2.86 = 13.43$$

For Fig. 8b, let $L = 22.28$ and $D = 3.40$, then

$$R = \frac{(22.28 - 3.40)^2}{8 \times 3.40} = \frac{356.45}{27.20} = 13.1$$

Checking Shaft Conditions

Checking for Various Shaft Conditions.—An indicating height gage, together with V-blocks can be used to check shafts for ovality, taper, straightness (bending or curving), and concentricity of features (as shown exaggerated in Fig. 9). If a shaft on which work has been completed shows lack of concentricity. it may be due to the shaft having become bent or bowed because of mishandling or oval or tapered due to poor machine conditions. In checking for concentricity, the first step is to check for ovality, or out-of-roundness, as in Fig. 9a. The shaft is supported in a suitable V-block on a surface table and the dial indicator plunger is placed over the workpiece, which is then rotated beneath the plunger to obtain readings of the amount of eccentricity.

This procedure (sometimes called clocking, owing to the resemblance of the dial indicator to a clock face) is repeated for other shaft diameters as necessary, and, in addition to making a written record of the measurements, the positions of extreme conditions should be marked on the workpiece for later reference.

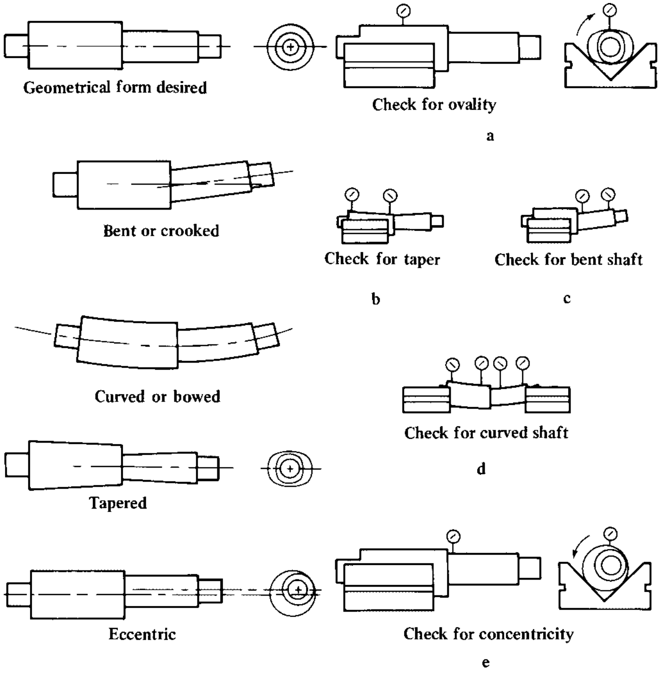


Fig. 9.

To check for taper, the shaft is supported in the V-block and the dial indicator is used to measure the maximum height over the shaft at various positions along its length, as shown in Fig. 9b, without turning the workpiece. Again, the shaft should be marked with the reading positions and values, also the direction of the taper, and a written record should be made of the amount and direction of any taper discovered.

Checking for a bent shaft requires that the shaft be clocked at the shoulder and at the farther end, as shown in Fig. 9c. For a second check the shaft is rotated only 90° or a quarter turn. When the recorded readings are compared with those from the ovality and taper checks, the three conditions can be distinguished.

To detect a curved or bowed condition, the shaft should be suspended in two V-blocks with only about ⅛ inch of each end in each vee. Alternatively, the shaft can be placed between centers. The shaft is then clocked at several points, as shown in Fig. 9d, but preferably not at those locations used for the ovality, taper, or crookedness checks. If the single element due to curvature is to be distinguished from the effects of ovality, taper, and crookedness, and its value assessed, great care must be taken to differentiate between the conditions detected by the measurements.

Finally, the amount of eccentricity between one shaft diameter and another may be tested by the setup shown in Fig. 9e. With the indicator plunger in contact with the smaller diameter, close to the shoulder, the shaft is rotated in the V-block and the indicator needle position is monitored to find the maximum and minimum readings.

Curvature, ovality, or crookedness conditions may tend to cancel each other, as shown in Fig. 10, and one or more of these degrees of defectiveness may add themselves to the true eccentricity readings, depending on their angular positions. Fig. 10a shows, for instance, how crookedness and ovality tend to cancel each other, and also shows their effect in falsifying the reading for eccentricity. As the same shaft is turned in the V-block to the position shown in Fig. 10b, the maximum curvature reading could tend to cancel or reduce the maximum eccentricity reading. Where maximum readings for ovality, curvature, or crookedness occur at the same angular position, their values should be subtracted from the eccentricity reading to arrive at a true picture of the shaft condition. Confirmation of eccentricity readings may be obtained by reversing the shaft in the V-block, as shown in Fig. 10c, and clocking the larger diameter of the shaft.

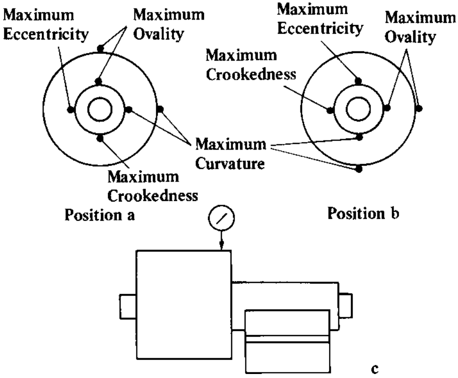


Fig. 10.

Out-of-Roundness—Lobing.—With the imposition of finer tolerances and the development of improved measurement methods, it has become apparent that no hole,' cylinder, or sphere can be produced with a perfectly symmetrical round shape. Some of the conditions are diagrammed in Fig. 11, where Fig. 11a shows simple ovality and Fig. 11b shows ovality occurring in two directions. From the observation of such conditions have come the terms lobe and lobing. Fig. 11c shows the three-lobed shape common with centerless-ground components, and Fig. 11d is typical of multi-lobed shapes. In Fig. 11e are shown surface waviness, surface roughness, and out-of-roundness, which often are combined with lobing.

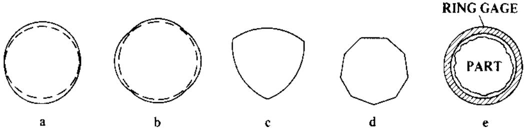


Fig. 11.

In Figs. 11a through 11d the cylinder (or hole) diameters are shown at full size but the lobes are magnified some 10,000 times to make them visible. In precision parts, the deviation from the round condition is usually only in the range of millionths of an inch, although it occasionally can be 0.0001 inch, 0.0002 inch, or more. For instance, a 3-inch-diameter part may have a lobing condition amounting to an inaccuracy of only 30 millionths (0.000030 inch). Even if the distortion (ovality, waviness, roughness) is small, it may cause hum, vibration, heat buildup, and wear, possibly leading to eventual failure of the component or assembly.

Plain elliptical out-of-roundness (two lobes), or any even number of lobes, can be detected by rotating the part on a surface plate under a dial indicator of adequate resolution, or by using an indicating caliper or snap gage. However, supporting such a part in a V-block during measurement will tend to conceal roundness errors. Ovality in a hole can be detected by a dial-type bore gage or internal measuring machine. Parts with odd numbers of lobes require an instrument that can measure the envelope or complete circumference. Plug and ring gages will tell whether a shaft can be assembled into a bearing, but not whether there will be a good fit, as illustrated in Fig. 11e.

A standard, 90-degree included-angle V-block can be used to detect and count the number of lobes, but to measure the exact amount of lobing indicated by *R-r* in Fig. 12 requires a V-block with an angle α, which is related to the number of lobes. This angle α can be calculated from the formula $2\alpha = 180° - 360°/N$, where N is the number of lobes. Thus, for a three-lobe form, α becomes 30 degrees, and the V-block used should have a 60-degree included angle. The distance M, which is obtained by rotating the part under the comparator plunger, is converted to a value for the radial variation in cylinder contour by the formula $M = (R-r)(1 + \csc\alpha)$.

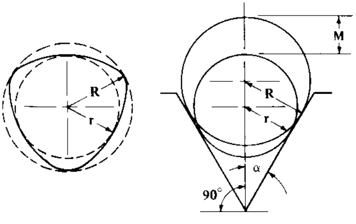


Fig. 12.

Using a V-block (even of appropriate angle) for parts with odd numbers of lobes will give exaggerated readings when the distance $R - r$ (Fig. 12) is used as the measure of the amount of out-of-roundness. The accompanying table shows the appropriate V-block angles for various odd numbers of lobes, and the factors (1 + csc α) by which the readings are increased over the actual out-of-roundness values.

Table of Lobes, V-block Angles and Exaggeration Factors in Measuring Out-of-round Conditions in Shafts

Number of Lobes	Included Angle of V-block (deg)	Exaggeration Factor (1 + csc α)
3	60	3.00
5	108	2.24
7	128.57	2.11
9	140	2.06

Measurement of a complete circumference requires special equipment, often incorporating a precision spindle running true within two millionths (0.000002) inch. A stylus attached to the spindle is caused to traverse the internal or external cylinder being inspected, and its divergences are processed electronically to produce a polar chart similar to the wavy outline in Fig. 11e. The electronic circuits provide for the variations due to surface effects to be separated from those of lobing and other departures from the "true" cylinder traced out by the spindle.

Measurements Using Light

Measuring by Light-wave Interference Bands.—Surface variations as small as two millionths (0.000002:) inch can be detected by light-wave interference methods, using an optical flat. An optical flat is a transparent block, usually of plate glass, clear fused quartz, or borosilicate glass, the faces of which are finished to extremely fine limits (of the order of 1 to 8 millionths [0.000001 to 0.000008] inch, depending on the application) for flatness. When an optical flat is placed on a "flat" surface, as shown in Fig. 13, any small departure from flatness will result in formation of a wedge-shaped layer of air between the work surface and the underside of the flat.

Light rays reflected from the work surface and the underside of the flat either interfere with or reinforce each other. Interference of two reflections results when the air gap measures exactly half the wavelength of the light used, and produces a dark band across the work surface when viewed perpendicularly, under monochromatic helium light. A light band is produced halfway between the dark bands when the rays reinforce each other. With the 0.0000232-inch-wavelength helium light used, the dark bands occur where the optical flat and the work surface are separated by 11.6 millionths (0.0000116) inch, or multiples thereof.

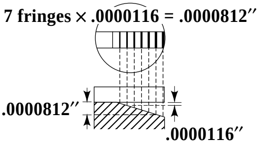


Fig. 13.

For instance, at a distance of seven dark bands from the point of contact, as shown in Fig. 13, the underface of the optical flat is separated from the work surface by a distance of 7 × 0.0000116 inch or 0.0000812 inch. The bands are separated more widely and the indications become increasingly distorted as the viewing angle departs from the perpendicular. If the bands appear straight, equally spaced and parallel with each other, the work surface is flat. Convex or concave surfaces cause the bands to curve correspondingly, and a cylindrical tendency in the work surface will produce unevenly spaced, straight bands.

SURFACE TEXTURE

American National Standard Surface Texture (Surface Roughness, Waviness, and Lay).—American National Standard ANSI/ASME B46.1-1995 is concerned with the geometric irregularities of surfaces of solid materials, physical specimens for gaging roughness, and the characteristics of stylus instrumentation for measuring roughness. The standard defines surface texture and its constituents: roughness, waviness, lay, and flaws. A set of symbols for drawings, specifications, and reports is established. To ensure a uniform basis for measurements the standard also provides specifications for Precision Reference Specimens, and Roughness Comparison Specimens, and establishes requirements for stylus-type instruments. The standard is not concerned with luster, appearance, color, corrosion resistance, wear resistance, hardness, subsurface microstructure, surface integrity, and many other characteristics that may be governing considerations in specific applications.

The standard is expressed in SI metric units but U.S. customary units may be used without prejudice. The standard does not define the degrees of surface roughness and waviness or type of lay suitable for specific purposes, nor does it specify the means by which any degree of such irregularities may be obtained or produced. However, criteria for selection of surface qualities and information on instrument techniques and methods of producing, controlling and inspecting surfaces are included in Appendixes attached to the standard. The Appendix sections are not considered a part of the standard: they are included for clarification or information purposes only.

Surfaces, in general, are very complex in character. The standard deals only with the height, width, and direction of surface irregularities because these characteristics are of practical importance in specific applications. Surface texture designations as delineated in this standard may not be a sufficient index to performance. Other part characteristics such as dimensional and geometrical relationships, material, metallurgy, and stress must also be controlled.

Definitions of Terms Relating to the Surfaces of Solid Materials.—The terms and ratings in the standard relate to surfaces produced by such means as abrading, casting, coating, cutting, etching, plastic deformation, sintering, wear, and erosion.

Error of form is considered to be that deviation from the nominal surface caused by errors in machine tool ways, guides, insecure clamping or incorrect alignment of the workpiece or wear, all of which are not included in surface texture. Out-of-roundness and out-of-flatness are examples of errors of form. See ANSI/ASME B46.3.1-1988 for measurement of out-of-roundness.

Flaws are unintentional, unexpected, and unwanted interruptions in the topography typical of a part surface and are defined as such only when agreed upon by buyer and seller. If flaws are defined, the surface should be inspected specifically to determine whether flaws are present, and rejected or accepted prior to performing final surface roughness measurements. If defined flaws are not present, or if flaws are not defined, then interruptions in the part surface may be included in roughness measurements.

Lay is the direction of the predominant surface pattern, ordinarily determined by the production method used.

Roughness consists of the finer irregularities of the surface texture, usually including those irregularities that result from the inherent action of the production process. These irregularities are considered to include traverse feed marks and other irregularities within the limits of the roughness sampling length.

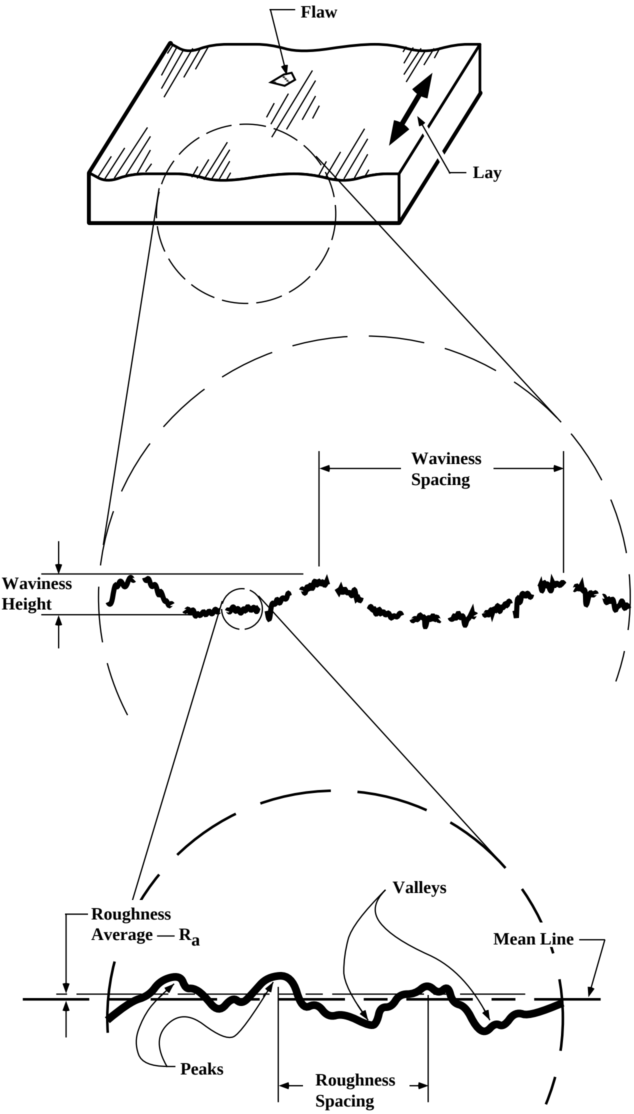


Fig. 1. Pictorial Display of Surface Characteristics

Surface is the boundary of an object that separates that object from another object, substance or space.

Surface, measured is the real surface obtained by instrumental or other means.

Surface, nominal is the intended surface contour (exclusive of any intended surface roughness), the shape and extent of which is usually shown and dimensioned on a drawing or descriptive specification.

Surface, real is the actual boundary of the object. Manufacturing processes determine its deviation from the nominal surface.

Surface texture is repetitive or random deviations from the real surface that forms the three-dimensional topography of the surface. Surface texture includes roughness, waviness, lay and flaws. Fig. 1 is an example of a unidirectional lay surface. Roughness and waviness parallel to the lay are not represented in the expanded views.

Waviness is the more widely spaced component of surface texture. Unless otherwise noted, waviness includes all irregularities whose spacing is greater than the roughness sampling length and less than the waviness sampling length. Waviness may result from such factors as machine or work deflections, vibration, chatter, heat-treatment or warping strains. Roughness may be considered as being superposed on a ‘wavy’ surface.

Definitions of Terms Relating to the Measurement of Surface Texture.—Terms regarding surface texture pertain to the geometric irregularities of surfaces and include roughness, waviness and lay.

Profile is the contour of the surface in a plane measured normal, or perpendicular, to the surface, unless another other angle is specified.

Graphical centerline. See Mean Line.

Height (z) is considered to be those measurements of the profile in a direction normal, or perpendicular, to the nominal profile. For digital instruments, the profile Z(x) is approximated by a set of digitized values. Height parameters are expressed in micrometers (µm).

Height range (z) is the maximum peak-to-valley surface height that can be detected accurately with the instrument. It is measurement normal, or perpendicular, to the nominal profile and is another key specification.

Mean line (M) is the line about which deviations are measured and is a line parallel to the general direction of the profile within the limits of the sampling length. See Fig. 2. The mean line may be determined in one of two ways. The filtered mean line is the centerline established by the selected cutoff and its associated circuitry in an electronic roughness average measuring instrument. The least squares mean line is formed by the nominal profile but by dividing into selected lengths the sum of the squares of the deviations minimizes the deviation from the nominal form. The form of the nominal profile could be a curve or a straight line.

Peak is the point of maximum height on that portion of a profile that lies above the mean line and between two intersections of the profile with the mean line.

Profile measured is a representation of the real profile obtained by instrumental or other means. When the measured profile is a graphical representation, it will usually be distorted through the use of different vertical and horizontal magnifications but shall otherwise be as faithful to the profile as technically possible.

Profile, modified is the measured profile where filter mechanisms (including the instrument datum) are used to minimize certain surface texture characteristics and emphasize others. Instrument users apply profile modifications typically to differentiate surface roughness from surface waviness.

Profile, nominal is the profile of the nominal surface; it is the intended profile (exclusive of any intended roughness profile). Profile is usually drawn in an x-z coordinate system. See Fig. 2.

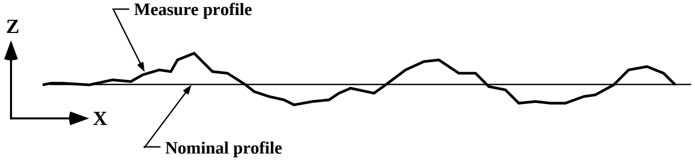


Fig. 2. Nominal and Measured Profiles

Profile, real is the profile of the real surface.

Profile, total is the measured profile where the heights and spacing may be amplified differently but otherwise no filtering takes place.

Roughness profile is obtained by filtering out the longer wavelengths characteristic of waviness.

Roughness spacing is the average spacing between adjacent peaks of the measured profile within the roughness sampling length.

Roughness topography is the modified topography obtained by filtering out the longer wavelengths of waviness and form error.

Sampling length is the nominal spacing within which a surface characteristic is determined. The range of sampling lengths is a key specification of a measuring instrument.

Spacing is the distance between specified points on the profile measured parallel to the nominal profile.

Spatial (x) resolution is the smallest wavelength which can be resolved to 50% of the actual amplitude. This also is a key specification of a measuring instrument.

System height resolution is the minimum height that can be distinguished from background noise of the measurement instrument. Background noise values can be determined by measuring approximate rms roughness of a sample surface where actual roughness is significantly less than the background noise of the measuring instrument. It is a key instrumentation specification.

Topography is the three-dimensional representation of geometric surface irregularities.

Topography, measured is the three-dimensional representation of geometric surface irregularities obtained by measurement.

Topography, modified is the three-dimensional representation of geometric surface irregularities obtained by measurement but filtered to minimize certain surface characteristics and accentuate others.

Valley is the point of maximum depth on that portion of a profile that lies below the mean line and between two intersections of the profile with the mean line.

Waviness, evaluation length (L), is the length within which waviness parameters are determined.

Waviness, long-wavelength cutoff (lcw) the spatial wavelength above which the undulations of waviness profile are removed to identify form parameters. A digital Gaussian filter can be used to separate form error from waviness but its use must be specified.

Waviness profile is obtained by filtering out the shorter roughness wavelengths characteristic of roughness and the longer wavelengths associated with the part form parameters.

Waviness sampling length is a concept no longer used. See waviness long-wavelength cutoff and waviness evaluation length.

Waviness short-wavelength cutoff (lsw) is the spatial wavelength below which roughness parameters are removed by electrical or digital filters.

Waviness topography is the modified topography obtained by filtering out the shorter wavelengths of roughness and the longer wavelengths associated with form error.

Waviness spacing is the average spacing between adjacent peaks of the measured profile within the waviness sampling length.

Sampling Lengths.—Sampling length is the normal interval for a single value of a surface parameter. Generally it is the longest spatial wavelength to be included in the profile measurement. Range of sampling lengths is an important specification for a measuring instrument.

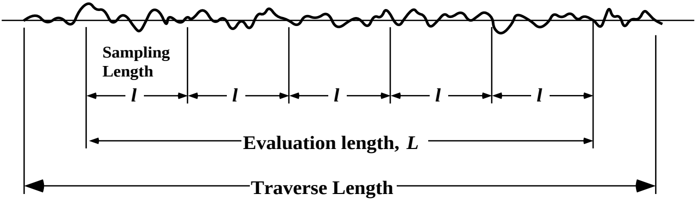


Fig. 3. Traverse Length

Roughness sampling length (l) is the sampling length within which the roughness average is determined. This length is chosen to separate the profile irregularities which are designated as roughness from those irregularities designated as waviness. It is different from evaluation length (L) and the traversing length. See Fig. 3.

Evaluation length (L) is the length the surface characteristics are evaluated. The evaluation length is a key specification of a measuring instrument.

Traversing length is profile length traversed to establish a representative evaluation length. It is always longer than the evaluation length. See Section 4.4.4 of ANSI/ASME B46.1-1995 for values which should be used for different type measurements.

Cutoff is the electrical response characteristic of the measuring instrument which is selected to limit the spacing of the surface irregularities to be included in the assessment of surface texture. Cutoff is rated in millimeters. In most electrical averaging instruments, the cutoff can be user selected and is a characteristic of the instrument rather than of the surface being measured. In specifying the cutoff, care must be taken to choose a value which will include all the surface irregularities to be assessed.

Waviness sampling length (l) is a concept no longer used. See waviness long-wavelength cutoff and waviness evaluation length.

Roughness Parameters.—Roughness is the fine irregularities of the surface texture resulting from the production process or material condition.

Roughness average (Ra), also known as arithmetic average (AA) is the arithmetic average of the absolute values of the measured profile height deviations divided by the evaluation length, L. This is shown as the shaded area of Fig. 4 and generally includes sampling lengths or cutoffs. For graphical determinations of roughness average, the height deviations are measured normal, or perpendicular, to the chart center line.

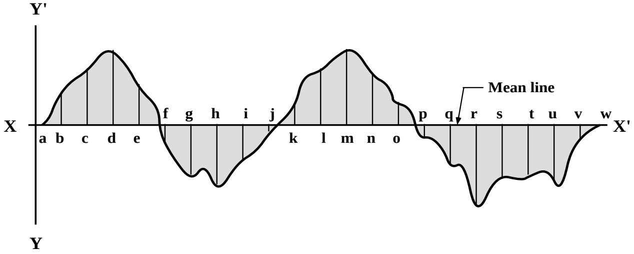


Fig. 4.

Roughness average is expressed in micrometers (μm). A micrometer is one millionth of a meter (0.000001 meter). A microinch (μin) is one millionth of an inch (0.000001 inch). One microinch equals 0.0254 micrometer (1 μin. = 0.0254 μm).

Roughness Average Value (Ra) From Continuously Averaging Meter Reading. So that uniform interpretation may be made of readings from stylus-type instruments of the continuously averaging type, it should be understood that the reading that is considered significant is the mean reading around which the needle tends to dwell or fluctuate with a small amplitude.

Roughness is also indicated by the root-mean-square (rms) average, which is the square root of the average value squared, within the evaluation length and measured from the mean line shown in Fig. 4, expressed in micrometers. A roughness-measuring instrument calibrated for rms average usually reads about 11 per cent higher than an instrument calibrated for arithmetical average. Such instruments usually can be recalibrated to read arithmetical average. Some manufacturers consider the difference between rms and AA to be small enough that rms on a drawing may be read as AA for many purposes.

Roughness evaluation length (L), for statistical purposes should, whenever possible, consist of five sampling lengths (l). Use of other than five sampling lengths must be clearly indicated.

Waviness Parameters.—Waviness is the more widely spaced component of surface texture. Roughness may be thought of as superimposed on waviness.

Waviness height (Wt) is the peak-to-valley height of the modified profile with roughness and part form errors removed by filtering, smoothing or other means. This value is typically three or more times the roughness average. The measurement is taken normal, or perpendicular, to the nominal profile within the limits of the waviness sampling length.

Waviness evaluation length (Lw) is the evaluation length required to determine waviness parameters. For waviness, the sampling length concept is no longer used. Rather, only waviness evaluation length (*Lw*) and waviness long-wavelength cutoff (*lew*) are defined. For better statistics, the waviness evaluation length should be several times the waviness long-wavelength cutoff.

Relation of Surface Roughness to Tolerances.—Because the measurement of surface roughness involves the determination of the average linear deviation of the measured surface from the nominal surface, there is a direct relationship between the dimensional tolerance on a part and the permissible surface roughness. It is evident that a requirement for the accurate measurement of a dimension is that the variations introduced by surface roughness should not exceed the dimensional tolerances. If this is not the case, the measurement of the dimension will be subject to an uncertainty greater than the required tolerance, as illustrated in Fig. 5.

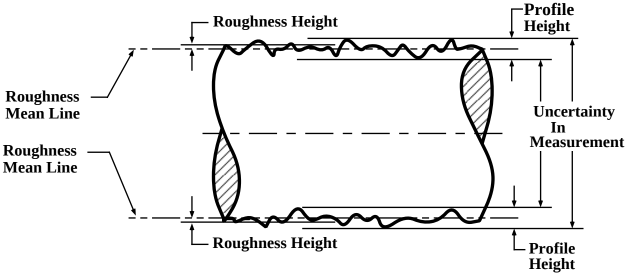


Fig. 5.

The standard method of measuring surface roughness involves the determination of the average deviation from the mean surface. On most surfaces the total profile height of the surface roughness (peak-to-valley height) will be approximately four times (4×) the measured average surface roughness. This factor will vary somewhat with the character of the surface under consideration, but the value of four may be used to establish approximate profile heights.

From these considerations it follows that if the arithmetical average value of surface roughness specified on a part exceeds one eighth of the dimensional tolerance, the whole tolerance will be taken up by the roughness height. In most cases, a smaller roughness specification than this will be found; but on parts where very small dimensional tolerances are given, it is necessary to specify a suitably small surface roughness so useful dimensional measurements can be made. The tables on pages pages 630 and 657 show the relations between machining processes and working tolerances.

Values for surface roughness produced by common processing methods are shown in Table 1. The ability of a processing operation to produce a specific surface roughness depends on many factors. For example, in surface grinding, the final surface depends on the peripheral speed of the wheel, the speed of the traverse, the rate of feed, the grit size, bonding material and state of dress of the wheel, the amount and type of lubrication at the point of cutting, and the mechanical properties of the piece being ground. A small change in any of the above factors can have a marked effect on the surface produced.

Table 1. Surface Roughness Produced by Common Production Methods

	Roughness Average, R_a – Micrometers μm (Microinches μin.)											
Process	50–25 (2000–1000)	25–12.5 (1000–500)	12.5–6.3 (500–250)	6.3–3.2 (250–125)	3.2–1.6 (125–63)	1.6–0.80 (63–32)	0.80–0.40 (32–16)	0.40–0.20 (16–8)	0.20–0.10 (8–4)	0.10–0.05 (4–2)	0.05–0.025 (2–1)	0.025–0.012 (1–0.5)
Flame Cutting	▨	■	▨									
Snagging	▨	■	■	▨								
Sawing	▨	■	■	■	■	▨						
Planing, Shaping		▨	■	■	■	▨	▨					
Drilling			▨	■	■	▨						
Chemical Milling			▨	■	■	▨						
Elect. Discharge Mach.			▨	▨■	■	▨						
Milling		▨	▨	■	■	■	▨	▨	▨			
Broaching				▨	■	■	▨					
Reaming				▨	■	■	▨					
Electron Beam				■	■	■	▨	▨				
Laser				■	■	■	▨	▨				
Electro-Chemical			▨	▨	■	■	■	■	▨	▨		
Boring, Turning		▨	▨	■	■	■	■	▨	▨	▨	▨	
Barrel Finishing					▨	▨	■	■	▨	▨		
Electrolytic Grinding							▨■	■	▨			
Roller Burnishing							▨	■	▨			
Grinding				▨	▨	■	■	■	■	▨	▨	
Honing						▨	■	■	■	▨	▨	
Electro-Polish						▨	■	■	■	▨	▨	▨
Polishing							▨	■	■	▨	▨	▨
Lapping							▨	■	■	■	▨	▨
Superfinishing							▨	▨	■	■	■	▨
Sand Casting	▨	■	▨									
Hot Rolling	▨	■	▨									
Forging		▨	■	■	▨							
Perm. Mold Casting				▨	■	▨						
Investment Casting				▨	■	▨	▨					
Extruding			▨	▨	■	■	▨					
Cold Rolling, Drawing				▨	■	■	▨	▨				
Die Casting					▨	■	▨					

The ranges shown above are typical of the processes listed

Higher or lower values may be obtained under special conditions

KEY ■ Average Application

▨ Less Frequent Application

Instrumentation for Surface Texture Measurement.—Instrumentation used for measurement of surface texture, including roughness and waviness generally falls into six types. These include:

Type I, Profiling Contact Skidless Instruments: Used for very smooth to very rough surfaces. Used for roughness and may measure waviness. Can generate filtered or unfiltered profiles and may have a selection of filters and parameters for data analysis. Examples include: 1) skidless stylus-type with LVDT (linear variable differential transformer) vertical transducers; 2) skidless-type using an interferometric transducer; 3)skidless stylus-type using capacitance transducer.

Type II, Profiling Non-contact Instruments: Capable of full profiling or topographical analysis. Non-contact operation may be advantageous for softness but may vary with sample type and reflectivity. Can generate filtered or unfiltered profiles but may have difficulty with steeply inclined surfaces. Examples include: 1) interferometric microscope; 2) optical focus sending; 3) Nomarski differential profiling; 4) laser triangulation; 5) scanning electron microscope (SEM) stereoscopy; 6) confocal optical microscope.

Type III, Scanned Probe Microscope: Feature high spatial resolution (at or near the atomic scale) but area of measurement may be limited. Examples include: 1) scanning tunneling microscope (STM) and 2) atomic force microscope (AFM).

Type IV, Profiling Contact Skidded Instruments: Uses a skid as a datum to eliminate longer wavelengths; thus cannot be used for waviness or errors of form. May have a selection of filters and parameters and generates an output recording of filtered and skid-modified profiles. Examples include: 1) skidded, stylus-type with LVDT vertical measuring transducer and 2) fringe-field capacitance (FFC) transducer.

Type V, Skidded Instruments with Parameters Only: Uses a skid as a datum to eliminate longer wavelengths; thus cannot be used for waviness or errors of form. Does not generate a profile. Filters are typically 2RC type and generate Ra but other parameters may be available. Examples include: 1) skidded, stylus-type with piezoelectric measuring transducer and 2) skidded, stylus-type with moving coil measuring transducer.

Type VI, Area Averaging Methods: Used to measure averaged parameters over defined areas but do not generate profiles. Examples include: 1) parallel plate capacitance (PPC) method; 2) total integrated scatter (TIS); 3) angle resolved scatter (ARS)/bi-directional reflectance distribution function (BRDF).

Selecting Cutoff for Roughness Measurements.—In general, surfaces will contain irregularities with a large range of widths. Surface texture instruments are designed to respond only to irregularity spacings less than a given value, called cutoff. In some cases, such as surfaces in which actual contact area with a mating surface is important, the largest convenient cutoff will be used. In other cases, such as surfaces subject to fatigue failure only the irregularities of small width will be important, and more significant values will be obtained when a short cutoff is used. In still other cases, such as identifying chatter marks on machined surfaces, information is needed on only the widely space irregularities. For such measurements, a large cutoff value and a larger radius stylus should be used.

The effect of variation in cutoff can be understood better by reference to Fig. 7. The profile at the top is the true movement of a stylus on a surface having a roughness spacing of about 1 mm and the profiles below are interpretations of the same surface with cutoff value settings of 0.8 mm, 0.25 mm and 0.08 mm, respectively. It can be seen that the trace based on 0.8 mm cutoff includes most of the coarse irregularities and all of the fine irregularities of the surface. The trace based on 0.25 mm excludes the coarser irregularities but includes the fine and medium fine. The trace based on 0.08 mm cutoff includes only the very fine irregularities. In this example the effect of reducing the cutoff has been to reduce the roughness average indication. However, had the surface been made up only of irregularities as fine as those of the bottom trace, the roughness average values would have been the same for all three cutoff settings.

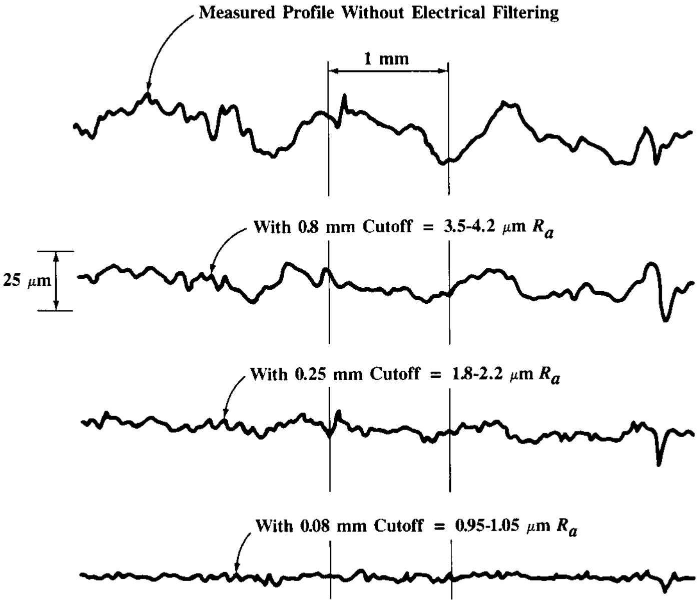


Fig. 6. Effects of Various Cutoff Values

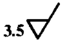
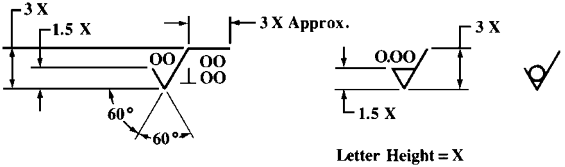
In other words, all irregularities having a spacing less than the value of the cutoff used are included in a measurement. Obviously, if the cutoff value is too small to include coarser irregularities of a surface, the measurements will not agree with those taken with a larger cutoff. For this reason, care must be taken to choose a cutoff value which will include all of the surface irregularities it is desired to assess.

To become proficient in the use of continuously averaging stylus-type instruments the inspector or machine operator must realize that for uniform interpretation, the reading which is considered significant is the mean reading around which the needle tends to dwell or fluctuate under small amplitude.

Drawing Practices for Surface Texture Symbols.—American National Standard ANSI/ASME Y14.36M-1996 establishes the method to designate symbolic controls for surface texture of solid materials. It includes methods for controlling roughness, waviness, and lay, and provides a set of symbols for use on drawings, specifications, or other documents. The standard is expressed in SI metric units but U.S. customary units may be used without prejudice. Units used (metric or non-metric) should be consistent with the other units used on the drawing or documents. Approximate non-metric equivalents are shown for reference.

Surface Texture Symbol.—The symbol used to designate control of surface irregularities is shown in Fig. 7b and Fig. 7d. Where surface texture values other than roughness average are specified, the symbol must be drawn with the horizontal extension as shown in Fig. 7f.

Surface Texture Symbols and Construction

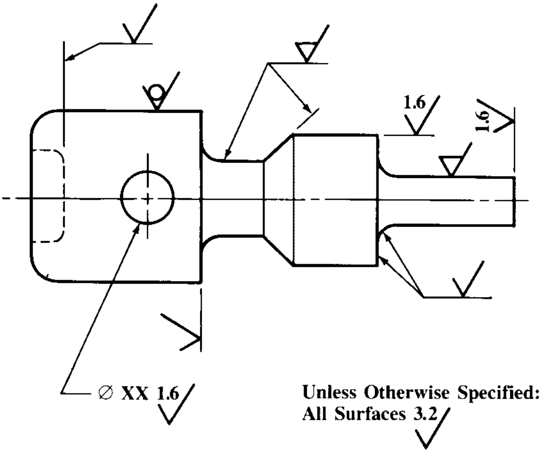
Symbol	Meaning
 Fig. 7a.	Basic Surface Texture Symbol. Surface may be produced by any method except when the bar or circle (Fig. 7b or 7d) is specified.
 Fig. 7b.	Material Removal By Machining Is Required. The horizontal bar indicates that material removal by machining is required to produce the surface and that material must be provided for that purpose.
 Fig. 7c.	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 general note.
 Fig. 7d.	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.
 Fig. 7e.	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 (Fig. 7b and 7d) is specified.
 Fig. 7f.	

Use of Surface Texture Symbols: When required from a functional standpoint, the desired surface characteristics should be specified. Where no surface texture control is specified, the surface produced by normal manufacturing methods is satisfactory provided it is within the limits of size (and form) specified in accordance with ANSI/ASME Y14.5M-1994, Dimensioning and Tolerancing. It is considered good practice to always specify some maximum value, either specifically or by default (for example, in the manner of the note shown in Fig. 2).

Material Removal Required or Prohibited: The surface texture symbol is modified when necessary to require or prohibit removal of material. When it is necessary to indicate that a surface must be produced by removal of material by machining, specify the symbol shown in Fig. 7b. When required, the amount of material to be removed is specified as shown in Fig. 7c, in millimeters for metric drawings and in inches for non-metric drawings. Tolerance for material removal may be added to the basic value shown or specified in a general note. When it is necessary to indicate that a surface must be produced without material removal, specify the machining prohibited symbol as shown in Fig. 7d.

Proportions of Surface Texture Symbols: The recommended proportions for drawing the surface texture symbol are shown in Fig. 7f. The letter height and line width should be the same as that for dimensions and dimension lines.

Applying Surface Texture Symbols.—The point of the symbol should be on a line representing the surface, an extension line of the surface, or a leader line directed to the surface, or to an extension line. The symbol may be specified following a diameter dimension. Although ANSI/ASME Y14.5M-1994, “Dimensioning and Tolerancing” specifies that normally all textual dimensions and notes should be read from the bottom of the drawing, the surface texture symbol itself with its textual values may be rotated as required. Regardless, the long leg (and extension) must be to the right as the symbol is read. For parts requiring extensive and uniform surface roughness control, a general note may be added to the drawing which applies to each surface texture symbol specified without values as shown in Fig. 8.



Unless Otherwise Specified:
All Surfaces 3.2

Fig. 8. Application of Surface Texture Symbols

When the symbol is used with a dimension, it affects the entire surface defined by the dimension. Areas of transition, such as chamfers and fillets, shall conform with the roughest adjacent finished area unless otherwise indicated.

Surface texture values, unless otherwise specified, apply to the complete surface. Drawings or specifications for plated or coated parts shall indicate whether the surface texture values apply before plating, after plating, or both before and after plating.

Only those values required to specify and verify the required texture characteristics should be included in the symbol. Values should be in metric units for metric drawing and non-metric units for non-metric drawings. Minority units on dual dimensioned drawings are enclosed in brackets.

Roughness and waviness measurements, unless otherwise specified, apply in a direction which gives the maximum reading; generally across the lay.

Cutoff or Roughness Sampling Length, (l): Standard values are listed in Table 2. When no value is specified, the value 0.8 mm (0.030 in.) applies.

Table 2. Standard Roughness Sampling Length (Cutoff) Values

mm	in.	mm	in.
0.08	0.003	2.5	0.1
0.25	0.010	8.0	0.3
0.80	0.030	25.0	1.0

Roughness Average (Ra): The preferred series of specified roughness average values is given in Table 3.

Table 3. Preferred Series Roughness Average Values (R_a)

μm	μin	μm	μin
0.012	0.5	1.25	50
0.025[a]	1[a]	1.60[a]	63[a]
0.050[a]	2[a]	2.0	80
0.075[a]	3	2.5	100
0.10[a]	4[a]	3.2[a]	125[a]
0.125	5	4.0	160
0.15	6	5.0	200
0.20[a]	8[a]	6.3[a]	250[a]
0.25	10	8.0	320
0.32	13	10.0	400
0.40[a]	16[a]	12.5[a]	500[a]
0.50	20	15	600
0.63	25	20	800
0.80[a]	32[a]	25[a]	1000[a]
1.00	40	…	…

[a] Recommended

Waviness Height (Wt): The preferred series of maximum waviness height values is listed in Table 3. Waviness height is not currently shown in U.S. or ISO Standards. It is included here to follow present industry practice in the United States.

Table 4. Preferred Series Maximum Waviness Height Values

mm	in.	mm	in.	mm	in.
0.0005	0.00002	0.008	0.0003	0.12	0.005
0.0008	0.00003	0.012	0.0005	0.20	0.008
0.0012	0.00005	0.020	0.0008	0.25	0.010
0.0020	0.00008	0.025	0.001	0.38	0.015
0.0025	0.0001	0.05	0.002	0.50	0.020
0.005	0.0002	0.08	0.003	0.80	0.030

Lay: Symbols for designating the direction of lay are shown and interpreted in Table 5.

Example Designations.—Table 6 illustrates examples of designations of roughness, waviness, and lay by insertion of values in appropriate positions relative to the symbol.

Where surface roughness control of several operations is required within a given area, or on a given surface, surface qualities may be designated, as in Fig. 9a. If a surface must be produced by one particular process or a series of processes, they should be specified as shown in Fig. 9b. Where special requirements are needed on a designated surface, a note should be added at the symbol giving the requirements and the area involved. An example is illustrated in Fig. 9c.

Surface Texture of Castings.—Surface characteristics should not be controlled on a drawing or specification unless such control is essential to functional performance or appearance of the product. Imposition of such restrictions when unnecessary may increase production costs and in any event will serve to lessen the emphasis on the control specified for important surfaces. Surface characteristics of castings should never be considered on

Table 5. Lay Symbols

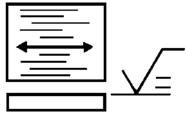
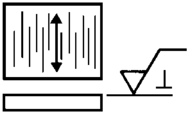
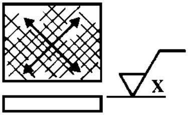
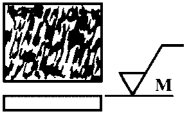
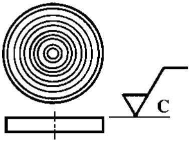
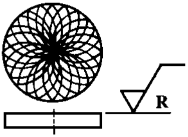
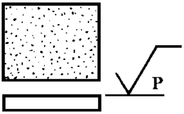
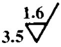
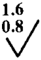
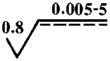
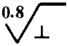
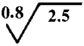
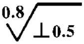
Lay Symbol	Meaning	Example Showing Direction of Tool Marks
=	Lay approximately parallel to the line representing the surface to which the symbol is applied.	
⊥	Lay approximately perpendicular to the line representing the surface to which the symbol is applied.	
X	Lay angular in both directions to line representing the surface to which the symbol is applied.	
M	Lay multidirectional	
C	Lay approximately circular relative to the center of the surface to which the symbol is applied.	
R	Lay approximately radial relative to the center of the surface to which the symbol is applied.	
P	Lay particulate, non-directional, or protuberant	

Table 6. Application of Surface Texture Values to Symbol

	Roughness average rating is placed at the left of the long leg. The specification of only one rating shall indicate the maximum value and any lesser value shall be acceptable. Specify in micrometers (microinch).		Material removal by machining is required to produce the surface. The basic amount of stock provided forf material removal is specified at the left of the short leg of the symbol. Specify in millimeters (inch).
	The specification of maximum and minimum roughness average values indicates permissible range of roughness. Specify in micrometers (microinch).		Removal of material is prohibited.
	Maximum waviness height rating is the first rating place above the horizontal extension. Any lesser rating shall be acceptable. Specify in millimeters (inch).		Lay designation is indicated by the lay symbol placed at the right of the long leg.
	Maximum waviness spacing rating is the second rating placed above the horizontal extension and to the right of the waviness height rating. Any lesser rating shall be acceptable. Specify in millimeters (inch).		Roughness sampling length or cutoff rating is placed below the horizontal extension. When no value is shown, 0.80 mm (0.030 inch) applies. Specify in millimeters (inch).
			Where required maximum roughness spacing shall be placed at the right of the lay symbol. Any lesser rating shall be acceptable. Specify in millimeters (inch).

the same basis as machined surfaces. Castings are characterized by random distribution of non-directional deviations from the nominal surface.

Surfaces of castings rarely need control beyond that provided by the production method necessary to meet dimensional requirements. Comparison specimens are frequently used for evaluating surfaces having specific functional requirements. Surface texture control should not be specified unless required for appearance or function of the surface. Specification of such requirements may increase cost to the user.

Engineers should recognize that different areas of the same castings may have different surface textures. It is recommended that specifications of the surface be limited to defined areas of the casting. Practicality of and methods of determining that a casting's surface texture meets the specification shall be coordinated with the producer. The Society of Automotive Engineers standard J435 "Automotive Steel Castings" describes methods of evaluating steel casting surface texture used in the automotive and related industries.

Metric Dimensions on Drawings.—The length units of the metric system that are most generally used in connection with any work relating to mechanical engineering are the meter (39.37 inches) and the millimeter (0.03937 inch). One meter equals 1000 millimeters. On mechanical drawings, all dimensions are generally given in millimeters, no matter how large the dimensions may be. In fact, dimensions of such machines as locomotives and large electrical apparatus are given exclusively in millimeters. This practice is adopted to avoid mistakes due to misplacing decimal points, or misreading dimensions as when other units are used as well. When dimensions are given in millimeters, many of them can

Table 7. Examples of Special Designations

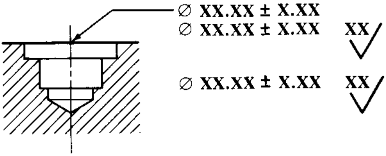


Fig. 9a.

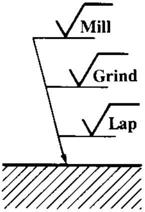


Fig. 9b.

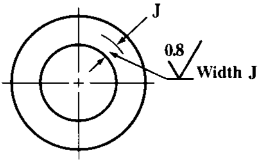


Fig. 9c.

be given without resorting to decimal points, as a millimeter is only a little more than $\frac{1}{32}$ inch. Only dimensions of precision need be given in decimals of a millimeter; such dimensions are generally given in hundredths of a millimeter—for example, 0.02 millimeter, which is equal to 0.0008 inch. As 0.01 millimeter is equal to 0.0004 inch, dimensions are seldom given with greater accuracy than to hundredths of a millimeter.

Scales of Metric Drawings: Drawings made to the metric system are not made to scales of $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc., as with drawings made to the English system. If the object cannot be drawn full size, it may be drawn $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{50}$, $\frac{1}{100}$, $\frac{1}{200}$, $\frac{1}{500}$, or $\frac{1}{1000}$ size. If the object is too small and has to be drawn larger, it is drawn 2, 5, or 10 times its actual size.

ISO Surface Finish

Differences Between ISO and ANSI Surface Finish Symbology.—ISO surface finish standards are comprised of numerous individual standards that taken as a whole form a set of standards roughly comparable in scope to American National Standard ANSI/ASME Y14.36M.

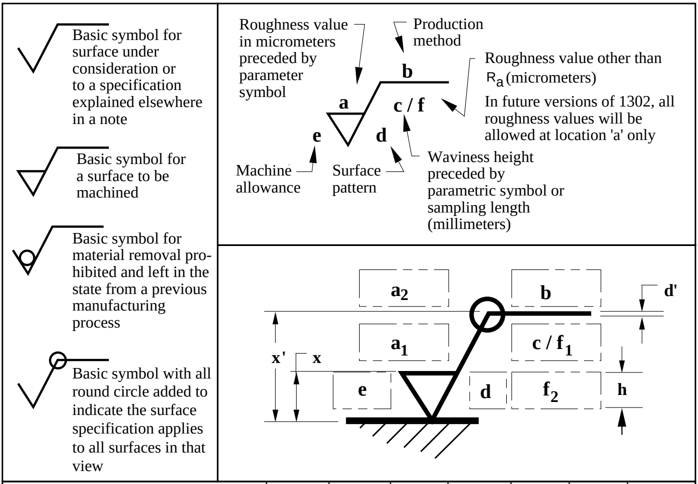
The primary standard dealing with surface finish, ISO 1302:1992, is concerned with the methods of specifying surface texture symbology and additional indications on engineering drawings. The parameters in ISO surface finish standards relate to surfaces produced by abrading, casting, coating, cutting, etching, plastic deformation, sintering, wear, erosion, and some other methods.

ISO 1302 defines how surface texture and its constituents, roughness, waviness, and lay, are specified on the symbology. Surface defects are specifically excluded from consideration during inspection of surface texture, but definitions of flaws and imperfections are discussed in ISO 8785.

As with American National Standard ASME Y14.36, ISO 1302 is not concerned with luster, appearance, color, corrosion resistance, wear resistance, hardness, sub-surface microstructure, surface integrity, and many other characteristics that may govern considerations in specific applications. Visually, the ISO surface finish symbol is similar to the ANSI symbol, but the proportions of the symbol in relationship to text height differs from

ANSI, as do some of the parameters as described in Fig. 1. Examples of the application of the ISO surface finish symbol are illustrated in Table 1.

The ISO 1302 standard does not define the degrees of surface roughness and waviness or type of lay for specific purposes, nor does it specify the means by which any degree of such irregularities may be obtained or produced. Also, errors of form such as out-of-roundness and out-of-flatness are not addressed in the ISO surface finish standards.



Text height **h** (ISO 3098-1)	2.5	3.5	5	7	10	14	20
Line width for symbols **d** and **d'**	0.25	0.35	0.5	0.7	1	1.2	2
Height for segment **x**	3.5	5	7	10	14	20	28
Height for symbol segment **x '**	8	11	15	21	30	42	60

Fig. 1. ISO Surface Finish Symbol

Other Iso Standards Related To Surface Finish

ISO 468:1982	"Surface roughness — parameters. Their values and general rules for specifying requirements."
ISO 4287:1997	"Surface texture: Profile method — Terms, definitions and surface texture parameters."
ISO 4288:1996	"Surface texture: Profile method — Rules and procedures for the assessment of surface texture." Includes specifications for precision reference specimens, and roughness comparison specimens, and establishes requirements for stylus-type instruments."
ISO 8785:1998	"Surface imperfections — Terms, definitions and parameters."
ISO 10135-1:CD	"Representation of parts produced by shaping processes — Part 1: Molded parts."

Table 1. Examples of ISO Applications of Surface Texture Symbology

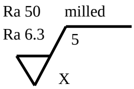
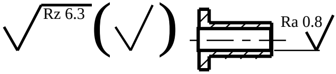
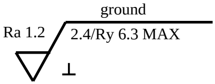
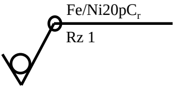
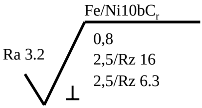
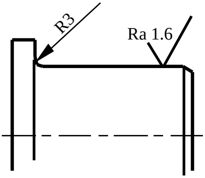
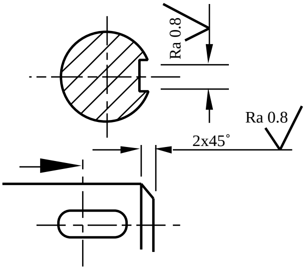
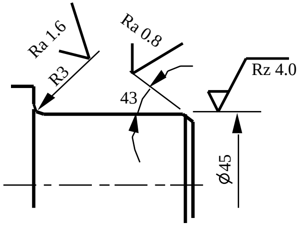
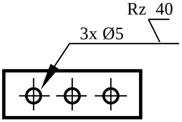
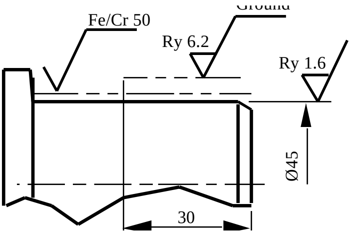
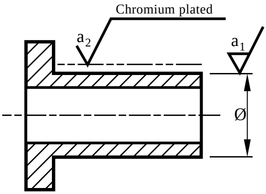
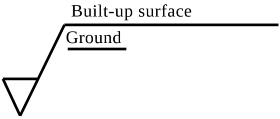
Interpretation	Example
Surface roughness is produced by milling and between upper limit of *Ra* = 50 µm and *Ra* = 6.3 µm; direction of lay is crossed in oblique directions relative to plane of projection; sampling length is 5 mm.	
Surface roughness of *Rz* = 6.3 µm is the default for all surfaces as indicated by the *Rz* = 6.3 specification, plus basic symbol within parentheses. Any deviating specification is called out with local notes such as the *Ra* = 0.8 µm specification.	
Surface roughness is produced by grinding to *Ra* = 1.2 µm and limited to Ry = 6.3 µm max; direction of lay is perpendicular relative to the plane of projection; sampling length is 2.4 mm.	
Surface treatment without any machining; nickel-chrome plated to *Rz* = 1 µm on all surfaces.	
Surface is nickel-chrome plated to roughness of *Ra* = 3.2 µm with a sampling length of 0.8 mm; limited to *Rz* = 16 µm to *Rz* = 6.3 µm with a sampling length of 2.5 mm.	
Surface roughness of *Rz* = 6.3 µm is the default for all surfaces except the inside diameter which is *Ra* = 0.8 mm.	
Surface texture symbology may be combined with dimension leaders and witness (extension) lines.	

Table 1. *(Continued)* **Examples of ISO Applications of Surface Texture Symbology**

Interpretation	Example
Surface texture symbology may be applied to extended extension lines or on extended projection lines.	
Surface roughness is produced by milling and between upper limit of *Ra* = 50 μm and *Ra* = 6.3 μm; direction of lay is crossed in oblique directions relative to plane of projection; sampling length is 5 mm.	
Surface treatment without any machining; nickel-chrome plated to *Rz* = 1 μm on all surfaces.	
Surface texture characteristics may be specified both before and after surface treatment.	
The symbol may be expanded with additional lines for textual information where there is insufficient room on the drawing.	

ISO Surface Parameter Symbols

Rp = max height profile
Rv = max profile valley depth
Rz^* = max height of the profile
Rc = mean height of profile
Rt = total height of the profile
Ra = arithmetic mean deviation of the profile
Rq = root mean square deviation of the profile
Rsk = skewness of the profile
Rku = kurtosis of the profile
RSm = mean width of the profile
$R\Delta q$ = root mean square slope of the profile
Rmr = material ration of the profile
$R\delta c$ = profile section height difference
Ip = sampling length – primary profile
lw = sampling length – waviness profile
lr = sampling length – roughness profile
ln = evaluation length
$Z(x)$ = ordinate value
dZ/dX = local slope
Zp = profile peak height
Zv = profile valley depth
Zt = profile element height
Xs = profile element width
Ml = material length of profile

Rules for Comparing Measured Values to Specified Limits

Max rule: When a maximum requirement is specified for a surface finish parameter on a drawing (e.g. *Rz*1.5max), none of the inspected values may extend beyond the upper limit over the entire surface. MAX must be added to the parametric symbol in the surface finish symbology on the drawing.

16% rule: When upper and lower limits are specified, no more than 16% of all measured values of the selected parameter within the evaluation length may exceed the upper limit. No more than 16% of all measured values of the selected parameter within the evaluation length may be less than the lower limit.

Exceptions to the 16% rule: Where the measured values of roughness profiles being inspected follow a normal distribution, the 16% rule may be overridden. This is allowed when greater than 16% of the measured values exceed the upper limit, but the total roughness profile conforms with the sum of the arithmetic mean and standard deviation $(\mu + \sigma)$. Effectively this means that the greater the value of σ, the further μ must be from the upper limit (see Fig. 2).

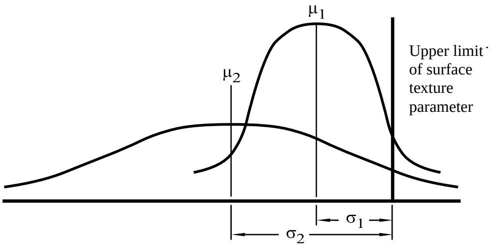


Fig. 2.

Basic rules for determining cut-off wavelength: When the sampling length is specified on the drawing or in documentation, the cut-off wavelength λc is equal to the sample length. When no sampling length is specified, the cut-off wavelength is estimated using Table .

Curves for Non-periodic Profiles such as Ground Surfaces		Curves for Periodic and Non-periodic Profiles	Sampling length, lr (mm)	Eevaluation length, ln (mm)
For Ra, Rq, Rsk, Rku, $R\Delta q$	For Rz, Rv, Rp, Rc, Rt	For R-parameters and RSm		
Ra, µm	Rz, $Rz1_{max}$, µm	RSm, µm		
$(0.006) < Ra \le 0.02$	$(0.025) < Rz, Rz1_{max} \le 0.1$	$0.013 < RSm \le 0.04$	0.08	0.4
$0.02 < Ra \le 0.1$	$0.1 < Rz, Rz1_{max} \le 0.5$	$0.04 < RSm \le 0.13$	0.25	1.25
$0.1 < Ra \le 2$	$0.5 < Rz, Rz1_{max} \le 10$	$0.13 < RSm \le 0.4$	0.8	4
$2 < Ra \le 10$	$10 < Rz, Rz1_{max} \le 50$	$0.4 < RSm \le 1.3$	2.5	12.5
$10 < Ra \le 80$	$50 < Rz, Rz1_{max} \le 200$	$1.3 < RSm \le 4$	8	40

Basic rules for measurement of roughness parameters: For non-periodic roughness the parameter Ra, Rz, $Rz1_{\max}$ or RSm are first estimated using visual inspection, comparison to specimens, graphic analysis, etc. The sampling length is then selected from Table , based on the use of Ra, Rz, $Rz1_{\max}$ or RSm. Then with instrumentation, a representative sample is taken using the sampling length chosen above.

The measured values are then compared to the ranges of values in Table for the particular parameter. If the value is outside the range of values for the estimated sampling length, the measuring instrument is adjusted for the next higher or lower sampling length and the measurement repeated. If the final setting corresponds to Table , then both the sampling length setting and Ra, Rz, $Rz1_{\max}$ or RSm values are correct and a representative measurement of the parameter can be taken.

For periodic roughness, the parameter RSm is estimated graphically and the recommended cut-off values selected using Table . If the value is outside the range of values for the estimated sampling length, the measuring instrument is adjusted for the next higher or lower sampling length and the measurement repeated. If the final setting corresponds to Table , then both the sampling length setting and RSm values are correct and a representative measurement of the parameter can be taken.

Table 2. Preferred Roughness Values and Roughness Grades

Roughness values, Ra		Previous Grade Number from ISO 1302	Roughness values, Ra		Previous Grade Number from ISO 1302
µm	µin		µm	µin	
50	2000	N12	0.8	32	N6
25	1000	N11	0.4	16	N5
12.5	500	N10	0.2	8	N4
6.3	250	N9	0.1	4	N3
3.2	125	N8	0.05	2	N2
1.6	63	N7	0.025	1	N1

Gage Blocks

Precision Gage Blocks.—Precision gage blocks are usually purchased in sets comprising a specific number of blocks of different sizes. The nominal gage lengths of individual blocks in a set are determined mathematically so that particular desired lengths can be obtained by combining selected blocks. They are made to several different tolerance grades which categorize them as master blocks, calibration blocks, inspection blocks, and workshop blocks. *Master blocks* are employed as basic reference standards; *calibration blocks* are used for high precision gaging work and calibrating inspection blocks; *inspection blocks* are used as toolroom standards and for checking and setting limit and comparator gages, for example. The *workshop blocks* are working gages used as shop standards for a variety of direct precision measurements and gaging applications, including sine bar settings.

Federal Specification GGG-G-15C, Gage Blocks (see below), lists typical sets, and gives details of materials, design, and manufacturing requirements, and tolerance grades. When there is in a set no single block of the exact size that is wanted, two or more blocks are combined by “wringing” them together. Wringing is achieved by first placing one block crosswise on the other and applying some pressure. Then a swiveling motion is used to twist the blocks to a parallel position, causing them to adhere firmly to one another.

When combining blocks for a given dimension, the object is to use as few blocks as possible to obtain the dimension. The procedure for selecting blocks is based on successively eliminating the right-hand figure of the desired dimension.

Example: Referring to gage block set number 1 in Table 1, determine the blocks required to obtain 3.6742 inches. *Step 1:* Eliminate 0.0002 by selecting a 0.1002 block. Subtract 0.1002 from 3.6743 = 3.5740. *Step 2:* Eliminate 0.004 by selecting a 0.124 block. Subtract 0.124 from 3.5740 = 3.450. *Step 3:* Eliminate 0.450 with a block this size. Subtract 0.450 from 3.450 = 3.000. *Step 4:* Select a 3.000 inch block. The combined blocks are 0.1002 + 0.124 + 0.450 + 3.000 = 3.6742 inches.

Federal Specification for Gage Blocks, Inch and Metric Sizes.—This Specification, GGG-G-15C, March 20, 1975, which supersedes GGG-G-15B, November 6, 1970, covers design, manufacturing, and purchasing details for precision gage blocks in inch and metric sizes up to and including 20 inches and 500 millimeters gage lengths. The shapes of blocks are designated Style 1, which is rectangular; Style 2, which is square with a center accessory hole, and Style 3, which defines other shapes as may be specified by the purchaser. Blocks may be made from steel, chromium-plated steel, chromium carbide, or tungsten carbide. There are four tolerance grades, which are designated Grade 0.5 (formerly Grade AAA in the GGG-G-15A issue of the Specification); Grade 1 (formerly Grade AA); Grade 2 (formerly Grade A +); and Grade 3 (a compromise between former Grades A and B). Grade 0.5 blocks are special reference gages used for extremely high precision gaging work, and are not recommended for general use. Grade 1 blocks are laboratory reference standards used for calibrating inspection gage blocks and high precision gaging work. Grade 2 blocks are used as inspection and toolroom standards, and Grade 3 blocks are used as shop standards.

Inch and metric sizes of blocks in specific sets are given in Tables 1 and 2, which is not a complete list of available sizes. It should be noted that some gage blocks must be ordered as specials, some may not be available in all materials, and some may not be available from all manufacturers. Gage block set number 4 (88 blocks), listed in the Specification, is not given in Table 1. It is the same as set number 1 (81 blocks) but contains seven additional blocks measuring 0.0625, 0.078125, 0.093750, 0.100025, 0.100050, 0.100075, and 0.109375 inch. In Table 2, gage block set number 3M (112 blocks) is not given. It is similar to set number 2M (88 blocks), and the chief difference is the inclusion of a larger number of blocks in the 0.5 millimeter increment series up to 24.5 mm. Set numbers 5M (88 blocks), 6M (112 blocks), and 7M (17 blocks) also are not listed.

Table 1. Gage Block Sets—Inch Sizes *Federal Specification GGG-G-15C*

Set Number 1 (81 Blocks)

First Series: 0.0001 Inch Increments (9 Blocks)

.1001	.1002	.1003	.1004	.1005	.1006	.1007	.1008	.1009

Second Series: 0.001 Inch Increments (49 Blocks)

.101	.102	.103	.104	.105	.106	.107	.108	.109	.110
.111	.112	.113	.114	.115	.116	.117	.118	.119	.120
.121	.122	.123	.124	.125	.126	.127	.128	.129	.130
.131	.132	.133	.134	.135	.136	.137	.138	.139	.140
.141	.142	.143	.144	.145	.146	.147	.148	.149	

Third Series: 0.050 Inch Increments (19 Blocks)

.050	.100	.150	.200	.250	.300	.350	.400	.450	.500
.550	.600	.650	.700	.750	.800	.850	.900	.950	

Fourth Series: 1.000 Inch Increments (4 Blocks)

1.000	2.000	3.000	4.000

Set Number 5 (21 Blocks)

First Series: 0.0001 Inch Increments (9 Blocks)

.0101	.0102	.0103	.0104	.0105	.0106	.0107	.0108	.0109

Second Series: 0.001 Inch Increments (11 Blocks)

.010	.011	.012	.013	.014	.015	.016	.017	.018	.019	.020

One Block 0.01005 Inch

Set Number 6 (28 Blocks)

First Series: 0.0001 Inch Increments (9 Blocks)

.0201	.0202	.0203	.0204	.0205	.0206	.0207	.0208	.0209

Second Series: 0.001 Inch Increments (9 Blocks)

.021	.022	.023	.024	.025	.026	.027	.028	.029

Third Series: 0.010 Inch Increments (9 Blocks)

.010	.020	.030	.040	.050	.060	.070	.080	.090

One Block 0.02005 Inch

Long Gage Block Set Number 7 (8 Blocks)

Whole Inch Series (8 Blocks)

5	6	7	8	10	12	16	20

Set Number 8 (36 Blocks)

First Series: 0.0001 Inch Increments (9 Blocks)

.1001	.1002	.1003	.1004	.1005	.1006	.1007	.1008	.1009

Second Series: 0.001 Inch Increments (11 Blocks)

.100	.101	.102	.103	.104	.105	.106	.107	.108	.109	.110

Third Series: 0.010 Inch Increments (8 Blocks)

.120	.130	.140	.150	.160	.170	.180	.190

Fourth Series: 0.100 Inch Increments (4 Blocks)

.200	.300	.400	.500

Whole Inch Series (3 Blocks)

1	2	4

One Block 0.050 Inch

Set Number 9 (20 Blocks)

First Series: 0.0001 Inch Increments (9 Blocks)

.0501	.0502	.0503	.0504	.0505	.0506	.0507	.0508	.0509

Second Series: 0.001 Inch Increments (10 Blocks)

.050	.051	.052	.053	.054	.055	.056	.057	.058	.059

One Block 0.05005 Inch

Set number 4 is not shown, and the Specification does not list a set 2 or 3.

Arranged here in incremental series for convenience of use.

Table 2. Gage Block Sets—Metric Sizes *Federal Specification GGG-G-15C*

Set Number 1M (45 Blocks)								
First Series: 0.001 Millimeter Increments (9 Blocks)								
1.001	1.002	1.003	1.004	1.005	1.006	1.007	1.008	1.009
Second Series: 0.01 Millimeter Increments (9 Blocks)								
1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09
Third Series: 0.10 Millimeter Increments (9 Blocks)								
1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
Fourth Series: 1.0 Millimeter Increments (9 Blocks)								
1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Fifth Series: 10 Millimeter Increments (9 Blocks)								
10	20	30	40	50	60	70	80	90
Set Number 2M (88 Blocks)								
First Series: 0.001 Millimeter Increments (9 Blocks)								
1.001	1.002	1.003	1.004	1.005	1.006	1.007	1.008	1.009

Second Series: 0.01 Millimeter Increments (49 Blocks)									
1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10
1.11	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.20
1.21	1.22	1.23	1.24	1.25	1.26	1.27	1.28	1.29	1.30
1.31	1.32	1.33	1.34	1.35	1.36	1.37	1.38	1.39	1.40
1.41	1.42	1.43	1.44	1.45	1.46	1.47	1.48	1.49	
Third Series: 0.50 Millimeter Increments (19 Blocks)									
0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	
Fourth Series: 10 Millimeter Increments (10 Blocks)									
10	20	30	40	50	60	70	80	90	100
One Block 1.0005 mm									

Set Number 4M (45 Blocks)								
First Series: 0.001 Millimeter Increments (9 Blocks)								
2.001	2.002	2.003	2.004	2.005	2.006	2.007	2.008	2.009
Second Series: 0.01 Millimeter Increments (9 Blocks)								
2.01	2.02	2.03	2.04	2.05	2.06	2.07	2.08	2.09
Third Series: 0.10 Millimeter Increments (9 Blocks)								
2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
Fourth Series: 1 Millimeter Increments (9 Blocks)								
1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
Fifth Series: 10 Millimeter Increments (9 Blocks)								
10	20	30	40	50	60	70	80	90

Long Gage Block Set Number 8M (8 Blocks)							
Whole Millimeter Series (8 Blocks)							
125	150	175	200	250	300	400	500

Set numbers 3M, 5M, 6M, and 7M are not listed.

Arranged here in incremental series for convenience of use.

Note: Gage blocks measuring 1.09 millimeters and under in set number 1M, blocks measuring 1.5 millimeters and under in set number 2M, and block measuring 1.0 millimeter in set number 4M are not available in tolerance grade 0.5.