SPLINES AND SERRATIONS

A splined shaft is one having a series of parallel keys formed integrally with the shaft and mating with corresponding grooves cut in a hub or fitting; this arrangement is in contrast to a shaft having a series of keys or feathers fitted into slots cut into the shaft. The latter construction weakens the shaft to a considerable degree because of the slots cut into it and consequently, reduces its torque-transmitting capacity.

Splined shafts are most generally used in three types of applications: 1) for coupling shafts when relatively heavy torques are to be transmitted without slippage; 2) for transmitting power to slidably-mounted or permanently-fixed gears, pulleys, and other rotating members; and 3) for attaching parts that may require removal for indexing or change in angular position.

Splines having straight-sided teeth have been used in many applications (see SAE Parallel Side Splines for Soft Broached Holes in Fittings); however, the use of splines with teeth of involute profile has steadily increased since 1) involute spline couplings have greater torque-transmitting capacity than any other type; 2) they can be produced by the same techniques and equipment as is used to cut gears; and 3) they have a self-centering action under load even when there is backlash between mating members.

Involute Splines

American National Standard Involute Splines[*]**.**—These splines or multiple keys are similar in form to internal and external involute gears. The general practice is to form the external splines either by hobbing, rolling, or on a gear shaper, and internal splines either by broaching or on a gear shaper. The internal spline is held to basic dimensions and the external spline is varied to control the fit. Involute splines have maximum strength at the base, can be accurately spaced and are self-centering, thus equalizing the bearing and stresses, and they can be measured and fitted accurately.

In American National Standard ANSI B92.1-1970 (R 1993), many features of the 1960 standard are retained; plus the addition of three tolerance classes, for a total of four. The term "involute serration," formerly applied to involute splines with 45-degree pressure angle, has been deleted and the standard now includes involute splines with 30-, 37.5-, and 45-degree pressure angles. Tables for these splines have been rearranged accordingly. The term "serration" will no longer apply to splines covered by this Standard.

The Standard has only one fit class for all side fit splines; the former Class 2 fit. Class 1 fit has been deleted because of its infrequent use. The major diameter of the flat root side fit spline has been changed and a tolerance applied to include the range of the 1950 and the 1960 standards. The interchangeability limitations with splines made to previous standards are given later in the section entitled "Interchangeability."

There have been no tolerance nor fit changes to the major diameter fit section.

The Standard recognizes the fact that proper assembly between mating splines is dependent only on the spline being within effective specifications from the tip of the tooth to the form diameter. Therefore, on side fit splines, the internal spline major diameter now is shown as a maximum dimension and the external spline minor diameter is shown as a minimum dimension. The minimum internal major diameter and the maximum external minor diameter must clear the specified form diameter and thus do not need any additional control.

The spline specification tables now include a greater number of tolerance level selections. These tolerance classes were added for greater selection to suit end product needs. The selections differ only in the tolerance as applied to space widthand tooth thickness.

---

[*] See American National Standard ANSI B92.2M-1980 (R1989), Metric Module Involute Splines; also see page 2148.

The tolerance class used in ASA B5.15-1960 is the basis and is now designated as tolerance Class 5. The new tolerance classes are based on the following formulas:

$$\text{Tolerance Class 4} = \text{Tolerance Class } 5 \times 0.71$$

$$\text{Tolerance Class 6} = \text{Tolerance Class } 5 \times 1.40$$

$$\text{Tolerance Class 7} = \text{Tolerance Class } 5 \times 2.00$$

All dimensions listed in this standard are for the finished part. Therefore, any compensation that must be made for operations that take place during processing, such as heat treatment, must be taken into account when selecting the tolerance level for manufacturing.

The standard has the same internal minimum effective space width and external maximum effective tooth thickness for all tolerance classes and has two types of fit. For tooth side fits, the minimum effective space width and the maximum effective tooth thickness are of equal value. This basic concept makes it possible to have interchangeable assembly between mating splines where they are made to this standard regardless of the tolerance class of the individual members. A tolerance class "mix" of mating members is thus allowed, which often is an advantage where one member is considerably less difficult to produce than its mate, and the "average" tolerance applied to the two units is such that it satisfies the design need. For instance, assigning a Class 5 tolerance to one member and Class 7 to its mate will provide an assembly tolerance in the Class 6 range. The maximum effective tooth thickness is less than the minimum effective space width for major diameter fits to allow for eccentricity variations.

In the event the fit as provided in this standard does not satisfy a particular design need and a specific amount of effective clearance or press fit is desired, the change should be made only to the external spline by a reduction or an increase in effective tooth thickness and a like change in actual tooth thickness. The minimum effective space width, in this standard, is always basic. The basic minimum effective space width should always be retained when special designs are derived from the concept of this standard.

Terms Applied to Involute Splines.—The following definitions of involute spline terms, here listed in alphabetical order, are given in the American National Standard. Some of these terms are illustrated in the diagram in Tables 6.

Active Spline Length (L_a) is the length of spline that contacts the mating spline. On sliding splines, it exceeds the length of engagement.

Actual Space Width (s) is the circular width on the pitch circle of any single space considering an infinitely thin increment of axial spline length.

Actual Tooth Thickness (t) is the circular thickness on the pitch circle of any single tooth considering an infinitely thin increment of axial spline length.

Alignment Variation is the variation of the effective spline axis with respect to the reference axis (see Fig. 1c).

Base Circle is the circle from which involute spline tooth profiles are constructed.

Base Diameter (D_b) is the diameter of the base circle.

Basic Space Width is the basic space width for 30-degree pressure angle splines; half the circular pitch. The basic space width for 37.5- and 45-degree pressure angle splines, however, is greater than half the circular pitch. The teeth are proportioned so that the external tooth, at its base, has about the same thickness as the internal tooth at the form diameter. This proportioning results in greater minor diameters than those of comparable involute splines of 30-degree pressure angle.

Circular Pitch (p) is the distance along the pitch circle between corresponding points of adjacent spline teeth.

Depth of Engagement is the radial distance from the minor circle of the internal spline to the major circle of the external spline, minus corner clearance and/or chamfer depth.

Diametral Pitch (*P*) is the number of spline teeth per inch of pitch diameter. The diametral pitch determines the circular pitch and the basic space width or tooth thickness. In conjunction with the number of teeth, it also determines the pitch diameter. (See also Pitch.)

Effective Clearance (c_v) is the effective space width of the internal spline minus the effective tooth thickness of the mating external spline.

Effective Space Width (S_v) of an internal spline is equal to the circular tooth thickness on the pitch circle of an imaginary perfect external spline that would fit the internal spline without looseness or interference considering engagement of the entire axial length of the spline. The minimum effective space width of the internal spline is always basic, as shown in Table 3. Fit variations may be obtained by adjusting the tooth thickness of the external spline.

Three types of involute spline variations

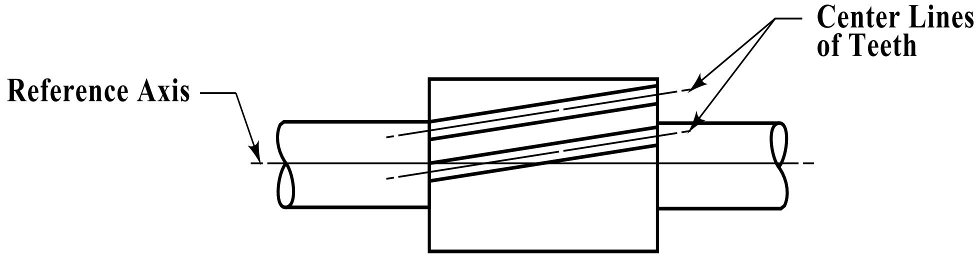


Fig. 1a. Lead Variation

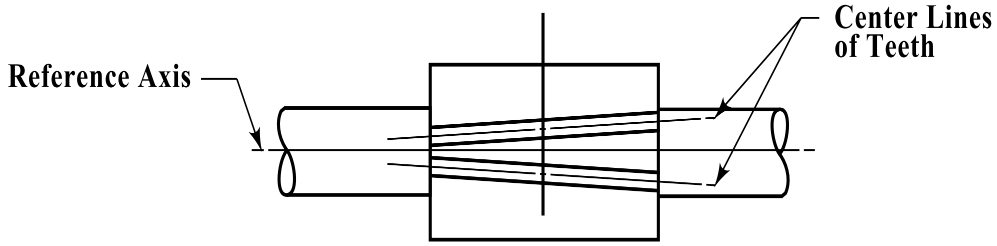


Fig. 1b. Parallelism Variation

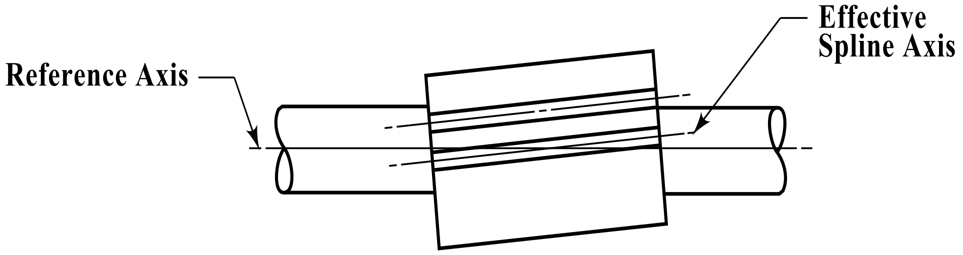


Fig. 1c. Alignment Variation

Effective Tooth Thickness (t_v) of an external spline is equal to the circular space width on the pitch circle of an imaginary perfect internal spline that would fit the external spline without looseness or interference, considering engagement of the entire axial length of the spline.

Effective Variation is the accumulated effect of the spline variations on the fit with the mating part.

External Spline is a spline formed on the outer surface of a cylinder.

Fillet is the concave portion of the tooth profile that joins the sides to the bottom of the space.

Fillet Root Splines are those in which a single fillet in the general form of an arc joins the sides of adjacent teeth.

Flat Root Splines are those in which fillets join the arcs of major or minor circles to the tooth sides.

Form Circle is the circle which defines the deepest points of involute form control of the tooth profile. This circle along with the tooth tip circle (or start of chamfer circle) determines the limits of tooth profile requiring control. It is located near the major circle on the internal spline and near the minor circle on the external spline.

Form Clearance (c_F) is the radial depth of involute profile beyond the depth of engagement with the mating part. It allows for looseness between mating splines and for eccentricities between the minor circle (internal), the major circle (external), and their respective pitch circles.

Form Diameter (D_{Fe}, D_{Fi}) the diameter of the form circle.

Internal Spline is a spline formed on the inner surface of a cylinder.

Involute Spline is one having teeth with involute profiles.

Lead Variation is the variation of the direction of the spline tooth from its intended direction parallel to the reference axis, also including parallelism and alignment variations (see Fig. 1a). *Note:* Straight (nonhelical) splines have an infinite lead.

Length of Engagement (L_q) is the axial length of contact between mating splines.

Machining Tolerance (m) is the permissible variation in actual space width or actual tooth thickness.

Major Circle is the circle formed by the outermost surface of the spline. It is the outside circle (tooth tip circle) of the external spline or the root circle of the internal spline.

Major Diameter (D_o, D_{ri}) is the diameter of the major circle.

Minor Circle is the circle formed by the innermost surface of the spline. It is the root circle of the external spline or the inside circle (tooth tip circle) of the internal spline.

Minor Diameter (D_{re}, D_i) is the diameter of the minor circle.

Nominal Clearance is the actual space width of an internal spline minus the actual tooth thickness of the mating external spline. It does not define the fit between mating members, because of the effect of variations.

Out of Roundness is the variation of the spline from a true circular configuration.

Parallelism Variation is the variation of parallelism of a single spline tooth with respect to any other single spline tooth (see Fig. 1b).

Pitch (P/P_s) is a combination number of a one-to-two ratio indicating the spline proportions; the upper or first number is the diametral pitch, the lower or second number is the stub pitch and denotes, as that fractional part of an inch, the basic radial length of engagement, both above and below the pitch circle.

Pitch Circle is the reference circle from which all transverse spline tooth dimensions are constructed.

Pitch Diameter (D) is the diameter of the pitch circle.

Pitch Point is the intersection of the spline tooth profile with the pitch circle.

Pressure Angle (ϕ) is the angle between a line tangent to an involute and a radial line through the point of tangency. Unless otherwise specified, it is the standard pressure angle.

Profile Variation is any variation from the specified tooth profile normal to the flank.

Spline is a machine element consisting of integral keys (spline teeth) or keyways (spaces) equally spaced around a circle or portion thereof.

Standard (Main) Pressure Angle (ϕ_D) is the pressure angle at the specified pitch diameter.

Stub Pitch (P_s) is a number used to denote the radial distance from the pitch circle to the major circle of the external spline and from the pitch circle to the minor circleof the internal spline. The stub pitch for splines in this standard is twice the diametral pitch.

Total Index Variation is the greatest difference in any two teeth (adjacent or otherwise) between the actual and the perfect spacing of the tooth profiles.

Total Tolerance ($m + \lambda$) is the machining tolerance plus the variation allowance.

Variation Allowance (λ) is the permissible effective variation.

Tooth Proportions.—There are 17 pitches: 2.5/5, 3/6, 4/8, 5/10, 6/12, 8/16, 10/20, 12/24, 16/32, 20/40, 24/48, 32/64, 40/80, 48/96, 64/128, 80/160, and 128/256. The numerator in this fractional designation is known as the diametral pitch and controls the pitch diameter; the denominator, which is always double the numerator, is known as the stub pitch and controls the tooth depth. For convenience in calculation, only the numerator is used in the formulas given and is designated as P. Diametral pitch, as in gears, means the number of teeth per inch of pitch diameter.

Table 1 shows the symbols and Table 2 the formulas for basic tooth dimensions of involute spline teeth of various pitches. Basic dimensions are given in Table 3.

Table 1. American National Standard Involute Spline Symbols
ANSI B92.1-1970, R1993

c_v	effective clearance	M_i	measurement between pins, internal spline
c_F	form clearance	N	number of teeth
D	pitch diameter	P	diametral pitch
D_b	base diameter	P_s	stub pitch
D_{ci}	pin contact diameter, internal spline	p	circular pitch
D_{ce}	pin contact diameter, external spline	r_f	fillet radius
D_{Fe}	form diameter, external spline	s	actual space width, circular
D_{Fi}	form diameter, internal spline	s_v	effective space width, circular
D_i	minor diameter, internal spline	s_c	allowable compressive stress, psi
D_o	major diameter, external spline	s_s	allowable shear stress, psi
D_{re}	minor diameter, external spline (root)	t	actual tooth thickness, circular
D_{ri}	major diameter, internal spline (root)	t_v	effective tooth thickness, circular
d_e	diameter of measuring pin for external spline	λ	variation allowance
d_i	diameter of measuring pin for internal spline	$\in$	involute roll angle
K_e	change factor for external spline	ϕ	pressure angle
K_i	change factor for internal spline	ϕ_D	standard pressure angle
L	spline length	ϕ_{ci}	pressure angle at pin contact diameter, internal spline
L_a	active spline length	ϕ_{ce}	pressure angle at pin contact diameter, external spline
L_g	length of engagement	ϕ_i	pressure angle at pin center, internal spline
m	machining tolerance	ϕ_e	pressure angle at pin center, external spline
M_e	measurement over pins, external spline	ϕ_F	pressure angle at form diameter

Table 2. Formulas for Basic Dimensions *ANSI B92.1-1970, R1993*

Term	Symbol	Formula				
		30 deg ϕ_D			37.5 deg ϕ_D	45 deg ϕ_D
		Flat Root Side Fit	Flat Root Major Dia Fit	Fillet Root Side Fit	Fillet Root Side Fit	Fillet Root Side Fit
		2.5/5–32/64 Pitch	3/6–16/32 Pitch	2.5/5–48/96 Pitch	2.5/5–48/96 Pitch	10/20–128/256 Pitch
Stub Pitch	P_s	$2P$	$2P$	$2P$	$2P$	$2P$
Pitch Diameter	D	$\frac{N}{P}$	$\frac{N}{P}$	$\frac{N}{P}$	$\frac{N}{P}$	$\frac{N}{P}$
Base Diameter	D_b	$D \cos \phi_D$	$D \cos \phi_D$	$D \cos \phi_D$	$D \cos \phi_D$	$D \cos \phi_D$
Circular Pitch	p	$\frac{\pi}{P}$	$\frac{\pi}{P}$	$\frac{\pi}{P}$	$\frac{\pi}{P}$	$\frac{\pi}{P}$
Minimum Effective Space Width	s_v	$\frac{\pi}{2P}$	$\frac{\pi}{2P}$	$\frac{\pi}{2P}$	$\frac{0.5\pi + 0.1}{P}$	$\frac{0.5\pi + 0.2}{P}$
Major Diameter, Internal	D_{ri}	$\frac{N + 1.35}{P}$	$\frac{N + 1}{P}$	$\frac{N + 1.8}{P}$	$\frac{N + 1.6}{P}$	$\frac{N + 1.4}{P}$
Major Diameter, External	D_o	$\frac{N + 1}{P}$	$\frac{N + 1}{P}$	$\frac{N + 1}{P}$	$\frac{N + 1}{P}$	$\frac{N + 1}{P}$
Minor Diameter, Internal	D_i	$\frac{N - 1}{P}$	$\frac{N - 1}{P}$	$\frac{N - 1}{P}$	$\frac{N - 0.8}{P}$	$\frac{N - 0.6}{P}$

Table 2. *(Continued)* **Formulas for Basic Dimensions** *ANSI B92.1-1970, R1993*

Term		Symbol	Formula				
			30 deg ϕ_D			37.5 deg ϕ_D	45 deg ϕ_D
			Flat Root Side Fit	Flat Root Major Dia Fit	Fillet Root Side Fit	Fillet Root Side Fit	Fillet Root Side Fit
			2.5/5–32/64 Pitch	3/6–16/32 Pitch	2.5/5–48/96 Pitch	2.5/5–48/96 Pitch	10/20–128/256 Pitch
Minor Dia. Ext.	2.5/5 thru 12/24 pitch	D_{re}	$\frac{N-1.35}{P}$		$\frac{N-1.8}{P}$	$\frac{N-1.3}{P}$	…
	16/32 pitch and finer				$\frac{N-2}{P}$		
	10/20 16/32 pitch and finer				…		$\frac{N-1}{P}$
Form Diameter, Internal		D_{Fi}	$\frac{N+1}{P}+2c_F$	$\frac{N+0.8}{P}-0.004+2c_F$	$\frac{N+1}{P}+2c_F$	$\frac{N+1}{P}+2c_F$	$\frac{N+1}{P}+2c_F$
Form Diameter, External		D_{Fe}	$\frac{N-1}{P}-2c_F$	$\frac{N-1}{P}-2c_F$	$\frac{N-1}{P}-2c_F$	$\frac{N-0.8}{P}-2c_F$	$\frac{N-0.6}{P}-2c_F$
Form Clearance (Radial)		c_F	0.001 D, with max of 0.010, min of 0.002				

$\pi = 3.1415927$

Note: All spline specification table dimensions in the standard are derived from these basic formulas by application of tolerances.

Table 3. Basic Dimensions for Involute Splines *ANSI B92.1-1970, R1993*

Pitch, P/P_s	Circular Pitch, p	Min Effective Space Width (BASIC), S_v min			Pitch, P/P_s	Circular Pitch, p	Min Effective Space Width (BASIC), S_v min		
		30 deg φ	37.5 deg φ	45 deg φ			30 deg φ	37.5 deg φ	45 deg φ
2.5/5	1.2566	0.6283	0.6683	…	20/40	0.1571	0.0785	0.0835	0.0885
3/6	1.0472	0.5236	0.5569	…	24/48	0.1309	0.0654	0.0696	0.0738
4/8	0.7854	0.3927	0.4177	…	32/64	0.0982	0.0491	0.0522	0.0553
5/10	0.6283	0.3142	0.3342	…	40/80	0.0785	0.0393	0.0418	0.0443
6/12	0.5236	0.2618	0.2785	…	48/96	0.0654	0.0327	0.0348	0.0369
8/16	0.3927	0.1963	0.2088	…	64/128	0.0491	…	…	0.0277
10/20	0.3142	0.1571	0.1671	0.1771	80/160	0.0393	…	…	0.0221
12/24	0.2618	0.1309	0.1392	0.1476	128/256	0.0246	…	…	0.0138
16/32	0.1963	0.0982	0.1044	0.1107	…	…	…	…	…

Tooth Numbers.—The American National Standard covers involute splines having tooth numbers ranging from 6 to 60 with a 30- or 37.5-degree pressure angle and from 6 to 100 with a 45-degree pressure angle. In selecting the number of teeth for a given spline application, it is well to keep in mind that there are no advantages to be gained by using odd numbers of teeth and that the diameters of splines with odd tooth numbers, particularly internal splines, are troublesome to measure with pins since no two tooth spaces are diametrically opposite each other.

Types and Classes of Involute Spline Fits.—Two types of fits are covered by the American National Standard for involute splines, the side fit, and the major diameter fit. Dimensional data for flat root side fit, flat root major diameter fit, and fillet root side fit splines are tabulated in this standard for 30-degree pressure angle splines; but for only the fillet root side fit for 37.5- and 45-degree pressure angle splines.

Side Fit: In the side fit, the mating members contact only on the sides of the teeth; major and minor diameters are clearance dimensions. The tooth sides act as drivers and centralize the mating splines.

Major Diameter Fit: Mating parts for this fit contact at the major diameter for centralizing. The sides of the teeth act as drivers. The minor diameters are clearance dimensions.

The major diameter fit provides a minimum effective clearance that will allow for contact and location at the major diameter with a minimum amount of location or centralizing effect by the sides of the teeth. The major diameter fit has only one space width and tooth thickness tolerance which is the same as side fit Class 5.

A fillet root may be specified for an external spline, even though it is otherwise designed to the flat root side fit or major diameter fit standard. An internal spline with a fillet root can be used only for the side fit.

Classes of Tolerances.—This standard includes four classes of tolerances on space width and tooth thickness. This has been done to provide a range of tolerances for selection to suit a design need. The classes are variations of the former single tolerance which is now Class 5 and are based on the formulas shown in the footnote of Table 4. All tolerance classes have the same minimum effective space width and maximum effective tooth thickness limits so that a mix of classes between mating parts is possible.

Table 4. Maximum Tolerances for Space Width and Tooth Thickness of Tolerance Class 5 Splines *ANSI B92.1-1970, R1993*

(Values shown in ten thousandths; 20 = 0.0020)

No. of Teeth	Pitch, P/P_s							
	2.5/5 and 3/6	4/8 and 5/10	6/12 and 8/16	10/20 and 12/24	16/32 and 20/40	24/48 thru 48/96	64/128 and 80/160	128/256
N	Machining Tolerance, m							
10	15.8	14.5	12.5	12.0	11.7	11.7	9.6	9.5
20	17.6	16.0	14.0	13.0	12.4	12.4	10.2	10.0
30	18.4	17.5	15.5	14.0	13.1	13.1	10.8	10.5
40	21.8	19.0	17.0	15.0	13.8	13.8	11.4	—
50	23.0	20.5	18.5	16.0	14.5	14.5	—	—
60	24.8	22.0	20.0	17.0	15.2	15.2	—	—
70	—	—	—	18.0	15.9	15.9	—	—
80	—	—	—	19.0	16.6	16.6	—	—
90	—	—	—	20.0	17.3	17.3	—	—
100	—	—	—	21.0	18.0	18.0	—	—
N	Variation Allowance, λ							
10	23.5	20.3	17.0	15.7	14.2	12.2	11.0	9.8
20	27.0	22.6	19.0	17.4	15.4	13.4	12.0	10.6
30	30.5	24.9	21.0	19.1	16.6	14.6	13.0	11.4
40	34.0	27.2	23.0	21.6	17.8	15.8	14.0	—
50	37.5	29.5	25.0	22.5	19.0	17.0	—	—
60	41.0	31.8	27.0	24.2	20.2	18.2	—	—
70	—	—	—	25.9	21.4	19.4	—	—
80	—	—	—	27.6	22.6	20.6	—	—
90	—	—	—	29.3	23.8	21.8	—	—
100	—	—	—	31.0	25.0	23.0	—	—
N	Total Index Variation							
10	20	17	15	15	14	12	11	10
20	24	20	18	17	15	13	12	11
30	28	22	20	19	16	15	14	13
40	32	25	22	20	18	16	15	—
50	36	27	25	22	19	17	—	—
60	40	30	27	24	20	18	—	—
70	—	—	—	26	21	20	—	—
80	—	—	—	28	22	21	—	—
90	—	—	—	29	24	23	—	—
100	—	—	—	31	25	24	—	—
N	Profile Variation							
All	+7 −10	+6 −8	+5 −7	+4 −6	+3 −5	+2 −4	+2 −4	+2 −4

Lead Variation												
L_g in.	0.3	0.5	1	2	3	4	5	6	7	8	9	10
Variation	2	3	4	5	6	7	8	9	10	11	12	13

For other tolerance classes: Class 4 = 0.71 × Tabulated value

Class 5 = As tabulated in table

Class 6 = 1.40 × Tabulated value

Class 7 = 2.00 × Tabulated value

Fillets and Chamfers.—Spline teeth may have either a flat root or a rounded fillet root.

Flat Root Splines: are suitable for most applications. The fillet that joins the sides to the bottom of the tooth space, if generated, has a varying radius of curvature. Specification of this fillet is usually not required. It is controlled by the form diameter, which is the diameter at the deepest point of the desired true involute form (sometimes designated as TIF).

When flat root splines are used for heavily loaded couplings that are not suitable for fillet root spline application, it may be desirable to minimize the stress concentration in the flat root type by specifying an approximate radius for the fillet.

Because internal splines are stronger than external splines due to their broad bases and high pressure angles at the major diameter, broaches for flat root internal splines are normally made with the involute profile extending to the major diameter.

Fillet Root Splines: are recommended for heavy loads because the larger fillets provided reduce the stress concentrations. The curvature along any generated fillet varies and cannot be specified by a radius of any given value.

External splines may be produced by generating with a pinion-type shaper cutter or with a hob, or by cutting with no generating motion using a tool formed to the contour of a tooth space. External splines are also made by cold forming and are usually of the fillet root design. Internal splines are usually produced by broaching, by form cutting, or by generating with a shaper cutter. Even when full-tip radius tools are used, each of these cutting methods produces a fillet contour with individual characteristics. Generated spline fillets are curves related to the prolate epicycloid for external splines and the prolate hypocycloid for internal splines. These fillets have a minimum radius of curvature at the point where the fillet is tangent to the external spline minor diameter circle or the internal spline major diameter circle and a rapidly increasing radius of curvature up to the point where the fillet comes tangent to the involute profile.

Chamfers and Corner Clearance: In major diameter fits, it is always necessary to provide corner clearance at the major diameter of the spline coupling. This clearance is usually effected by providing a chamfer on the top corners of the external member. This method may not be possible or feasible because of the following:

A) If the external member is roll formed by plastic deformation, a chamfer cannot be provided by the process.

B) A semitopping cutter may not be available.

C) When cutting external splines with small numbers of teeth, a semitopping cutter may reduce the width of the top land to a prohibitive point.

In such conditions, the corner clearance can be provided on the internal spline, as shown in Fig. 2.

When this option is used, the form diameter may fall in the protuberance area.

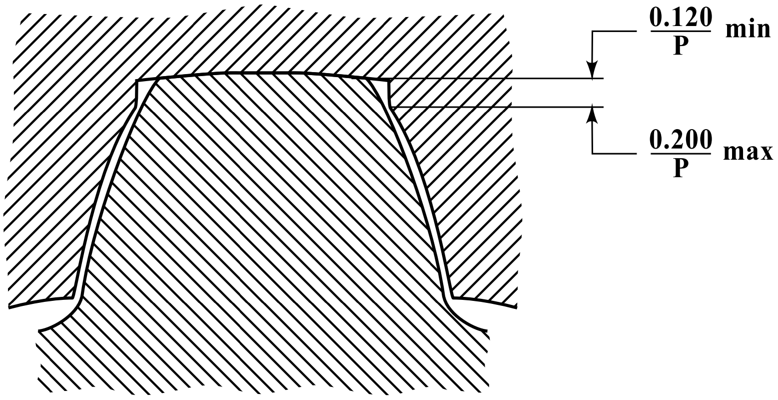


Fig. 2. Internal corner clearance.

Spline Variations.—The maximum allowable variations for involute splines are listed in Table 4.

Profile Variation: The reference profile, from which variations occur, passes through the point used to determine the actual space width or tooth thickness. This is either the pitch point or the contact point of the standard measuring pins.

Profile variation is positive in the direction of the space and negative in the direction of the tooth. Profile variations may occur at any point on the profile for establishing effective fits and are shown in Table 4.

Lead Variations: The lead tolerance for the total spline length applies also to any portion thereof unless otherwise specified.

Out of Roundness: This condition may appear merely as a result of index and profile variations given in Table 4 and requires no further allowance. However, heat treatment and deflection of thin sections may cause out of roundness, which increases index and profile variations. Tolerances for such conditions depend on many variables and are therefore not tabulated. Additional tooth and/or space width tolerance must allow for such conditions.

Eccentricity: Eccentricity of major and minor diameters in relation to the effective diameter of side fit splines should not cause contact beyond the form diameters of the mating splines, even under conditions of maximum effective clearance. This standard does not establish specific tolerances.

Eccentricity of major diameters in relation to the effective diameters of major diameter fit splines should be absorbed within the maximum material limits established by the tolerances on major diameter and effective space width or effective tooth thickness.

If the alignment of mating splines is affected by eccentricity of locating surfaces relative to each other and/or the splines, it may be necessary to decrease the effective and actual tooth thickness of the external splines in order to maintain the desired fit condition. This standard does not include allowances for eccentric location.

Effect of Spline Variations.—Spline variations can be classified as index variations, profile variations, or lead variations.

Index Variations: These variations cause the clearance to vary from one set of mating tooth sides to another. Because the fit depends on the areas with minimum clearance, index variations reduce the effective clearance.

Profile Variations: Positive profile variations affect the fit by reducing effective clearance. Negative profile variations do not affect the fit but reduce the contact area.

Lead Variations: These variations will cause clearance variations and therefore reduce the effective clearance.

Variation Allowance: The effect of individual spline variations on the fit (effective variation) is less than their total, because areas of more than minimum clearance can be altered without changing the fit. The variation allowance is 60 percent of the sum of twice the positive profile variation, the total index variation and the lead variation for the length of engagement. The variation allowances in Table 4 are based on a lead variation for an assumed length of engagement equal to one-half the pitch diameter. Adjustment may be required for a greater length of engagement.

Effective and Actual Dimensions.—Although each space of an internal spline may have the same width as each tooth of a perfect mating external spline, the two may not fit because of variations of index and profile in the internal spline. To allow the perfect external spline to fit in any position, all spaces of the internal spline must then be widened by the amount of interference. The resulting width of these tooth spaces is the *actual* space width of the internal spline. The *effective* space width is the tooth thickness of the perfect mating external spline. The same reasoning applied to an external spline that has variations of index and profile when mated with a perfect internal spline leads to the concept of effective tooth thickness, which exceeds the actual tooth thickness by the amount of the effective variation.

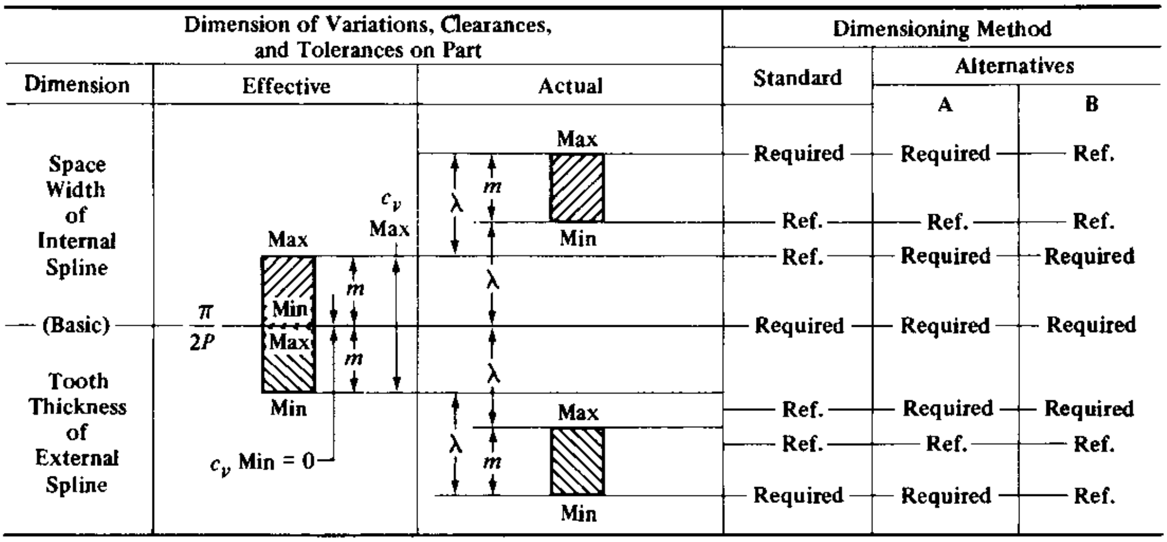
The effective space width of the internal spline minus the effective tooth thickness of the external spline is the effective clearance and defines the fit of the mating parts. (This statement is strictly true only if high points of mating parts come into contact.) Positive effective clearance represents looseness or backlash. Negative effective clearance represents tightness or interference.

Space Width and Tooth Thickness Limits.—The variation of actual space width and actual tooth thickness within the machining tolerance causes corresponding variations of effective dimensions, so that there are four limit dimensions for each component part.

These variations are shown diagrammatically in Table 5.

Table 5. Specification Guide for Space Width and Tooth Thickness

ANSI B92.1-1970, R1993



Dimensioning Method		
Standard	Alternatives A	Alternatives B
Required	Required	Ref.
Ref.	Ref.	Ref.
Ref.	Required	Required
Required	Required	Required
Ref.	Required	Required
Ref.	Ref.	Ref.
Required	Required	Ref.

The minimum effective space width is always basic. The maximum effective tooth thickness is the same as the minimum effective space width except for the major diameter fit. The major diameter fit maximum effective tooth thickness is less than the minimum effective space width by an amount that allows for eccentricity between the effective spline and the major diameter. The permissible variation of the effective clearance is divided between the internal and external splines to arrive at the maximum effective space width and the minimum effective tooth thickness. Limits for the actual space width and actual tooth thickness are constructed from suitable variation allowances.

Use of Effective and Actual Dimensions.—Each of the four dimensions for space width and tooth thickness shown in Table 5 has a definite function.

Minimum Effective Space Width and Maximum Effective Tooth Thickness: These dimensions control the minimum effective clearance, and must always be specified.

Minimum Actual Space Width and Maximum Actual Tooth Thickness: These dimensions cannot be used for acceptance or rejection of parts. If the actual space width is less than the minimum without causing the effective space width to be undersized, or if the actual tooth thickness is more than the maximum without causing the effective tooth thickness to be oversized, the effective variation is less than anticipated; such parts are desirable and not defective. The specification of these dimensions as processing reference dimensions is optional. They are also used to analyze undersize effective space width or oversize effective tooth thickness conditions to determine whether or not these conditions are caused by excessive effective variation.

Maximum Actual Space Width and Minimum Actual Tooth Thickness: These dimensions control machining tolerance and limit the effective variation. The spread between these dimensions, reduced by the effective variation of the internal and external spline, is the maximum effective clearance. Where the effective variation obtained in machining is appreciably less than the variation allowance, these dimensions must be adjusted in order to maintain the desired fit.

Maximum Effective Space Width and Minimum Effective Tooth Thickness: These dimensions define the maximum effective clearance but they do not limit the effective variation. They may be used, in addition to the maximum actual space width and minimum actual tooth thickness, to prevent the increase of maximum effective clearance due to reduction of effective variations. The notation "inspection optional" may be added where maximum effective clearance is an assembly requirement, but does not need absolute control. It will indicate, without necessarily adding inspection time and equipment, that the actual space width of the internal spline must be held below the maximum, or the actual tooth thickness of the external spline above the minimum, if machining methods result in less than the allowable variations. Where effective variation needs no control or is controlled by laboratory inspection, these limits may be substituted for maximum actual space width and minimum actual tooth thickness.

Combinations of Involute Spline Types.—Flat root side fit internal splines may be used with fillet root external splines where the larger radius is desired on the external spline for control of stress concentrations. This combination of fits may also be permitted as a design option by specifying for the minimum root diameter of the external, the value of the minimum root diameter of the fillet root external spline and noting this as "optional root."

A design option may also be permitted to provide either flat root internal or fillet root internal by specifying for the maximum major diameter, the value of the maximum major diameter of the fillet root internal spline and noting this as "optional root."

Interchangeability.—Splines made to this standard may interchange with splines made to older standards. Exceptions are listed below.

External Splines: These external splines will mate with older internal splines as follows:

Year	Major Dia. Fit	Flat Root Side Fit	Fillet Root Side Fit
1946	Yes	No (A)[a]	No (A)
1950[b]	Yes (B)	Yes (B)	Yes (C)
1950[c]	Yes (B)	No (A)	Yes (C)
1957 SAE	Yes	No (A)	Yes (C)
1960	Yes	No (A)	Yes (C)

[a] For exceptions A, B, C, see the paragraph on *Exceptions* that follows.

[b] Full dedendum.

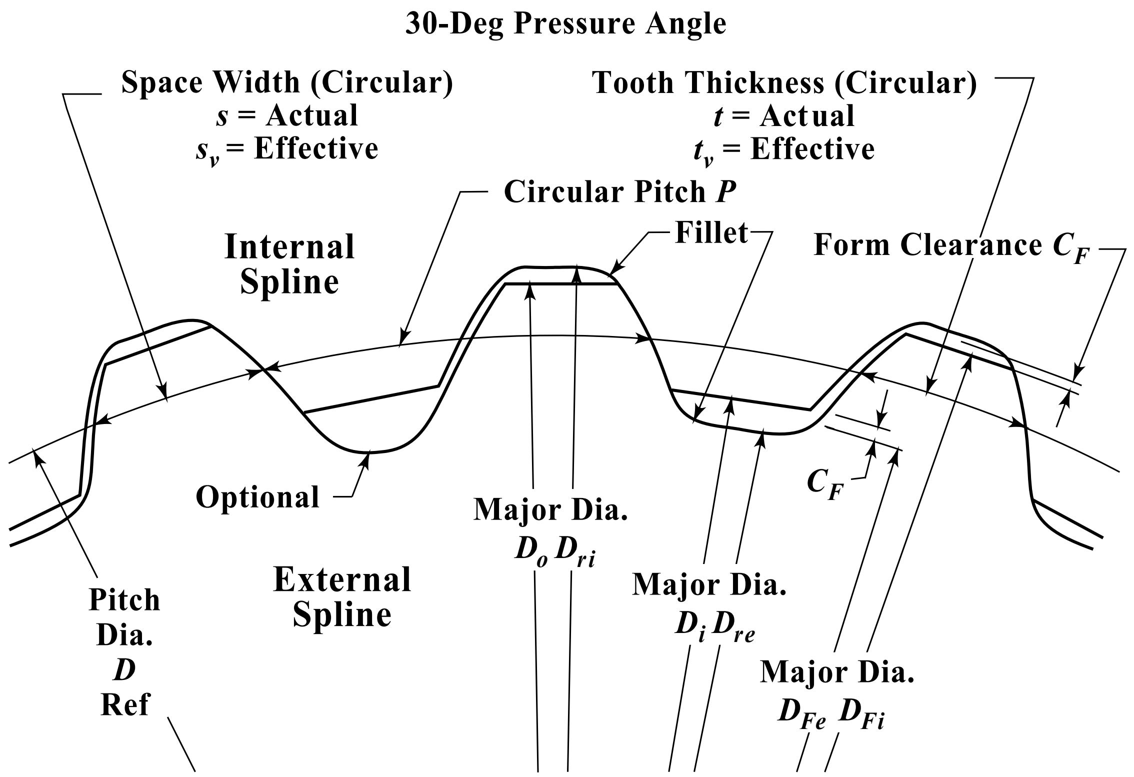
[c] Short dedendum.

Internal Splines: These will mate with older external splines as follows:

Year	Major Dia. Fit	Flat Root Side Fit	Fillet Root Side Fit
1946	No (D)[a]	No (E)	No (D)
1950	Yes (F)	Yes	Yes (C)
1957 SAE	Yes (G)	Yes	Yes
1960	Yes (G)	Yes	Yes

[a] For exceptions C, D, E, F, G, see the paragraph on *Exceptions* that follows.

Table 6. Spline Terms, Symbols, and Drawing Data, 30-Degree Pressure Angle, Flat Root Side Fit *ANSI B92.1-1970, R1993*



The fit shown is used in restricted areas (as with tubular parts with wall thickness too small to permit use of fillet roots, and to allow hobbing closer to shoulders, etc.) and for economy (when hobbing, shaping, etc., and using shorter broaches for the internal member).

Press fits are not tabulated because their design depends on the degree of tightness desired and must allow for such factors as the shape of the blank, wall thickness, materila, hardness, thermal expansion, etc. Close tolerances or selective size grouping may be required to limit fit variations.

Drawing Data			
Internal Involute Spline Data		External Involute Spline Data	
Flat Root Side Fit		Flat Root Side Fit	
Number of Teeth	xx	Number of Teeth	xx
Pitch	xx/xx	Pitch	xx/xx
Pressure Angle	30°	Pressure Angle	30°
Base Diameter	x.xxxxxx Ref	Base Diameter	x.xxxxxx Ref
Pitch Diameter	x.xxxxxx Ref	Pitch Diameter	x.xxxxxx Ref
Major Diameter	x.xxx max	Major Diameter	x.xxx/x.xxx
Form Diameter	x.xxx	Form Diameter	x.xxx
Minor Diameter	x.xxx/x.xxx	Minor Diameter	x.xxx min
Circular Space Width		Circular Tooth Thickness	
Max Actual	x.xxxx	Max Effective	x.xxxx
Min Effective	x.xxxx	Min Actual	x.xxxx
The following information may be added as required:		The following information may be added as required:	
Max Measurement Between Pins	x.xxx Ref	Min Measurement Over Pins	x.xxxx Ref
Pin Diameter	x.xxxx	Pin Diameter	x.xxxx

The above drawing data are required for the spline specifications. The standard system is shown; for alternate systems, see Table 5. Number of x's indicates number of decimal places normally used.

Exceptions:

A) The external major diameter, unless chamfered or reduced, may interfere with the internal form diameter on flat root side fit splines. Internal splines made to the 1957 and 1960 standards had the same dimensions as shown for the major diameter fit splines in this standard.

B) For 15 teeth or less, the minor diameter of the internal spline, unless chamfered, will interfere with the form diameter of the external spline.

C) For 9 teeth or less, the minor diameter of the internal spline, unless chamfered, will interfere with form diameter of the external spline.

D) The internal minor diameter, unless chamfered, will interfere with the external form diameter.

E) The internal minor diameter, unless chamfered, will interfere with the external form diameter.

F) For 10 teeth or less, the minimum chamfer on the major diameter of the external spline may not clear the internal form diameter.

G) Depending upon the pitch of the spline, the minimum chamfer on the major diameter may not clear the internal form diameter.

Drawing Data.—It is important that uniform specifications be used to show complete information on detail drawings of splines. Much misunderstanding will be avoided by following the suggested arrangement of dimensions and data as given in Table 6. The number of x's indicates the number of decimal places normally used. With this tabulated type of spline specifications, it is usually not necessary to show a graphic illustration of the spline teeth.

Spline Data and Reference Dimensions.—Spline data are used for engineering and manufacturing purposes. Pitch and pressure angle are not subject to individual inspection.

As used in this standard, *reference* is an added notation or modifier to a dimension, specification, or note when that dimension, specification, or note is:

1) Repeated for drawing clarification.

2) Needed to define a nonfeature datum or basis from which a form or feature is generated.

3) Needed to define a nonfeature dimension from which other specifications or dimensions are developed.

4) Needed to define a nonfeature dimension at which toleranced sizes of a feature are specified.

5) Needed to define a nonfeature dimension from which control tolerances or sizes are developed or added as useful information.

Any dimension, specification, or note that is noted "REF" should not be used as a criterion for part acceptance or rejection.

Estimating Key and Spline Sizes and Lengths.—Fig. 1 may be used to estimate the size of American Standard involute splines required to transmit a given torque. It also may be used to find the outside diameter of shafts used with single keys. After the size of the shaft is found, the proportions of the key can be determined from Table 1 on page 2342.

Curve A is for flexible splines with teeth hardened to Rockwell C 55–65. For these splines, lengths are generally made equal to or somewhat greater than the pitch diameter for diameters below $1\frac{1}{4}$ inches; on larger diameters, the length is generally one-third to two-thirds the pitch diameter. Curve A also applies for a single key used as a fixed coupling, the length of the key being one to one and one-quarter times the shaft diameter. The stress in the shaft, neglecting stress concentration at the keyway, is about 7500 pounds per square inch. See also *Effect of Keyways on Shaft Strength* starting on page 283.

Curve B represents high-capacity single keys used as fixed couplings for stresses of 9500 pounds per square inch, neglecting stress concentration. Key-length is one to one and one-quarter times shaft diameter and both shaft and key are of moderately hard heat-treated steel. This type of connection is commonly used to key commercial flexible couplings to motor or generator shafts.

Curve C is for multiple-key fixed splines with lengths of three-quarters to one and one-quarter times pitch diameter and shaft hardness of 200–300 BHN.

Curve D is for high-capacity splines with lengths one-half to one times the pitch diameter. Hardnesses up to Rockwell C 58 are common and in aircraft applications the shaft is generally hollow to reduce weight.

Curve E represents a solid shaft with 65,000 pounds per square inch shear stress. For hollow shafts with inside diameter equal to three-quarters of the outside diameter the shear stress would be 95,000 pounds per square inch.

Length of Splines: Fixed splines with lengths of one-third the pitch diameter will have the same shear strength as the shaft, assuming uniform loading of the teeth; however, errors in spacing of teeth result in only half the teeth being fully loaded. Therefore, for balanced strength of teeth and shaft the length should be two-thirds the pitch diameter. If weight is not important, however, this may be increased to equal the pitch diameter. In the case of flexible splines, long lengths do not contribute to load carrying capacity when there is misalignment to be accommodated. Maximum effective length for flexible splines may be approximated from Fig. 2.

Formulas for Torque Capacity of Involute Splines.—The formulas for torque capacity of 30-degree involute splines given in the following paragraphs are derived largely from an article "When Splines Need Stress Control" by D. W. Dudley, *Product Engineering*, Dec. 23, 1957.

In the formulas that follow the symbols used are as defined on page 2130 with the following additions: D_h = inside diameter of hollow shaft, inches; K_a = application factor from Table 1; K_m = load distribution factor from Table 2; K_f = fatigue life factor from Table 3; K_w = wear life factor from Table 4; L_e = maximum effective length from Fig. 2, to be used in stress formulas even though the actual length may be greater; T = transmitted torque, pound-inches. For fixed splines without helix modification, the effective length L_e should never exceed $5000\,D^{3.5} \div T$.

Table 1. Spline Application Factors, K_a

Power Source	Type of Load			
	Uniform (Generator-Fan)	Light Shock (Oscillating Pumps, etc.)	Intermittent Shock (Actuating Pumps, etc.)	Heavy Shock (Punches, Shears, etc.)
	Application Factor, K_a			
Uniform (Turbine, Motor)	1.0	1.2	1.5	1.8
Light Shock (Hydraulic Motor)	1.2	1.3	1.8	2.1
Medium Shock (Internal Combustion, Engine)	2.0	2.2	2.4	2.8

Table 2. Load Distribution Factors, K_m, for Misalignment of Flexible Splines

Misalignment, inches per inch	Load Distribution Factor, K_m[a]			
	½-in. Face Width	1-in. Face Width	2-in. Face Width	4-in. Face Width
0.001	1	1	1	1 ½
0.002	1	1	1 ½	2
0.004	1	1 ½	2	2 ½
0.008	1 ½	2	2 ½	3

[a] For fixed splines, K_m=1.

For fixed splines, K_m = 1.

Table 3. Fatigue-Life Factors, K_f, for Splines

No. of Torque Cycles[a]	Fatigue-Life Factor, K_f	
	Unidirectional	Fully-reversed
1,000	1.8	1.8
10,000	1.0	1.0
100,000	0.5	0.4
1,000,000	0.4	0.3
10,000,000	0.3	0.2

[a] A torque cycle consists of one start and one stop, not the number of revolutions.

Table 4. Wear Life Factors, K_w, for Flexible Splines

Number of Revolutions of Spline	Life Factor, K_w	Number of Revolutions of Spline	Life Factor, K_w
10,000	4.0	100,000,000	1.0
100,000	2.8	1,000,000,000	0.7
1,000,000	2.0	10,000,000,000	0.5
10,000,000	1.4	…	…

Wear life factors, unlike fatigue life factors given in Table 3, are based on the total number of revolutions of the spline, since each revolution of a flexible spline results in a complete cycle of rocking motion which contributes to spline wear.

Definitions: A *fixed* spline is one which is either shrink fitted or loosely fitted but piloted with rings at each end to prevent rocking of the spline which results in small axial movements that cause wear. A *flexible* spline permits some rocking motion such as occurs when the shafts are not perfectly aligned. This flexing or rocking motion causes axial movement and consequently wear of the teeth. Straight-toothed flexible splines can accommodate only small angular misalignments (less than 1 deg.) before wear becomes a serious problem. For greater amounts of misalignment (up to about 5 deg.), crowned splines are preferable to reduce wear and end-loading of the teeth.

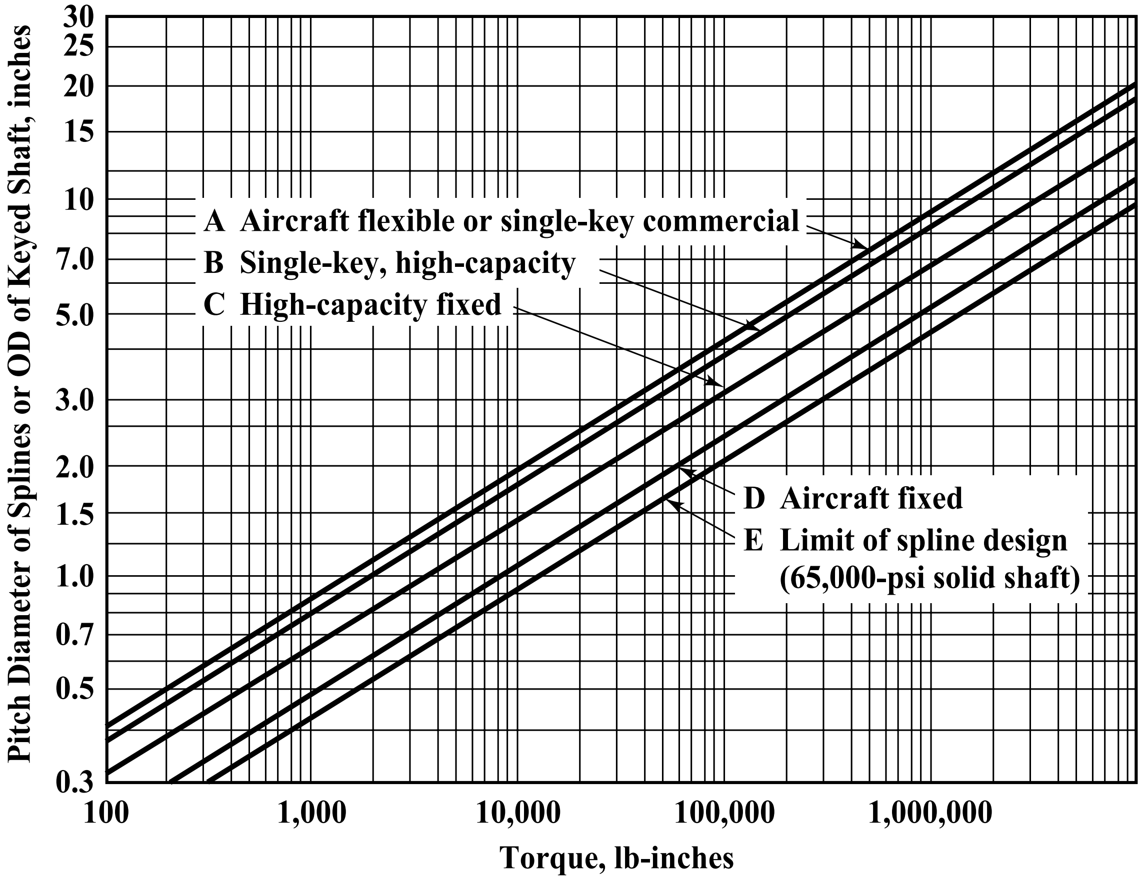


Fig. 1. Chart for Estimating Involute Spline Size Based on Diameter-Torque Relationships

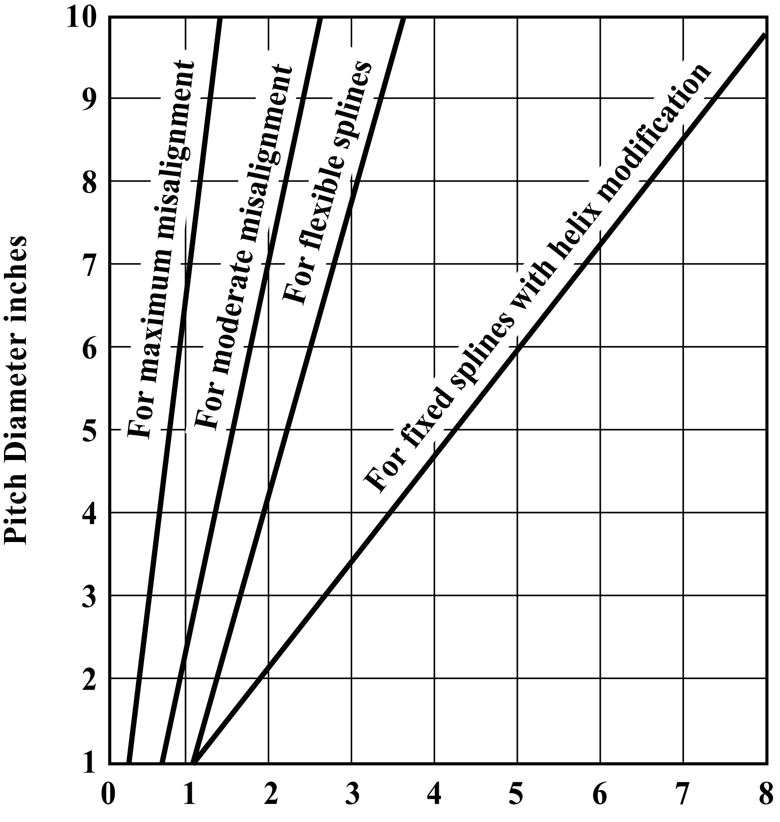


Fig. 2. Maximum Effective Length for Fixed and Flexible Splines

Shear Stress Under Roots of External Teeth: For a transmitted torque T, the torsional shear stress induced in the shaft under the root diameter of an external spline is:

$$S_s = \frac{16TK_a}{\pi D_{re}^3 K_f} \quad \text{for a solid shaft} \tag{1}$$

$$S_s = \frac{16TD_{re}K_a}{\pi(D_{re}^4 - D_h^4)K_f} \quad \text{for a hollow shaft} \tag{2}$$

The computed stress should not exceed the values in Table 5.

Table 5. Allowable Shear Stresses for Splines

Material	Hardness		Max. Allowable Shear Stress, psi
	Brinell	Rockwell C	
Steel	160–200	—	20,000
Steel	230–260	—	30,000
Steel	302–351	33–38	40,000
Surface-hardened Steel	—	48–53	40,000
Case-hardened Steel	—	58–63	50,000
Through-hardened Steel (Aircraft Quality)	—	42–46	45,000

Shear Stress at the Pitch Diameter of Teeth: The shear stress at the pitch line of the teeth for a transmitted torque T is:

$$S_s = \frac{4TK_aK_m}{DNL_etK_f} \tag{3}$$

The factor of 4 in (3) assumes that only half the teeth will carry the load because of spacing errors. For poor manufacturing accuracies, change the factor to 6.

The computed stress should not exceed the values in Table 5.

Compressive Stresses on Sides of Spline Teeth: Allowable compressive stresses on splines are very much lower than for gear teeth since non-uniform load distribution and misalignment result in unequal load sharing and end loading of the teeth.

$$\text{For flexible splines,} \quad S_c = \frac{2TK_mK_a}{DNL_ehK_w} \tag{4}$$

$$\text{For fixed splines,} \quad S_c = \frac{2TK_mK_a}{9DNL_ehK_f} \tag{5}$$

In these formulas, h is the depth of engagement of the teeth, which for flat root splines is $0.9/P$ and for fillet root splines is $1/P$, approximately.

The stresses computed from Formulas (4) and (5) should not exceed the values in Table 6.

Table 6. Allowable Compressive Stresses for Splines

Material	Hardness		Max. Allowable Compressive Stress, psi	
	Brinell	Rockwell C	Straight	Crowned
Steel	160–200	—	1,500	6,000
Steel	230–260	—	2,000	8,000
Steel	302–351	33–38	3,000	12,000
Surface-hardened Steel	—	48–53	4,000	16,000
Case-hardened Steel	—	58–63	5,000	20,000

Bursting Stresses on Splines: Internal splines may burst due to three kinds of tensile stress: 1) tensile stress due to the radial component of the transmitted load; 2) centrifugal tensile stress; and 3) tensile stress due to the tangential force at the pitch line causing bending of the teeth.

$$\text{Radial load tensile stress,} \quad S_1 = \frac{T \tan\phi}{\pi D t_w L} \qquad (6)$$

where t_w = wall thickness of internal spline = outside diameter of spline sleeve minus spline major diameter, all divided by 2. L = full length of spline.

$$\text{Centrifugal tensile stress,} \quad S_2 = \frac{1.656 \times (\text{rpm})^2 (D_{oi}^2 + 0.212 D_{ri}^2)}{1,000,000} \qquad (7)$$

where D_{oi} = outside diameter of spline sleeve.

$$\text{Beam loading tensile stress,} \quad S_3 = \frac{4T}{D^2 L_e Y} \qquad (8)$$

In this equation, Y is the Lewis form factor obtained from a tooth layout. For internal splines of 30-deg. pressure angle a value of Y = 1.5 is a satisfactory estimate. The factor 4 in (8) assumes that only half the teeth are carrying the load.

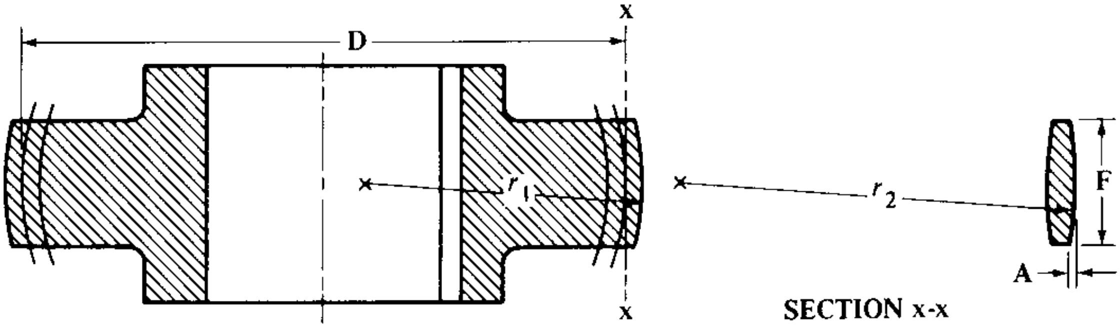
The total tensile stress tending to burst the rim of the external member is:
$S_t = [K_a K_m (S_1 + S_3) + S_2]/K_f$; and should be less than those in Table 7.

Table 7. Allowable Tensile Stresses for Splines

Material	Hardness		Max. Allowable Stress, psi
	Brinell	Rockwell C	
Steel	160–200	—	22,000
Steel	230–260	—	32,000
Steel	302–351	33–38	45,000
Surface-hardened Steel	—	48–53	45,000
Case-hardened Steel	—	58–63	55,000
Through-hardened Steel	—	42–46	50,000

Crowned Splines for Large Misalignments.—As mentioned on page 2142, crowned splines can accommodate misalignments of up to about 5 degrees. Crowned splines have considerably less capacity than straight splines of the same size if both are operating with precise alignment. However, when large misalignments exist, the crowned spline has greater capacity.

American Standard tooth forms may be used for crowned external members so that they may be mated with straight internal members of Standard form.



The accompanying diagram of a crowned spline shows the radius of the crown r_1; the radius of curvature of the crowned tooth, r_2; the pitch diameter of the spline, D; the face width, F; and the relief or crown height A at the ends of the teeth. The crown height A should always be made somewhat greater than one-half the face width multiplied by the tangent of the misalignment angle. For a crown height A, the approximate radius of curvature r_2 is $F^2 \div 8A$, and $r_1 = r_2 \tan \phi$, where ϕ is the pressure angle of the spline.

For a torque T, the compressive stress on the teeth is:

$$S_c = 2290\sqrt{2T \div DNhr_2};$$

and should be less than the value in Table 6.

Fretting Damage to Splines and Other Machine Elements.—Fretting is wear that occurs when cyclic loading, such as vibration, causes two surfaces in intimate contact to undergo small oscillatory motions with respect to each other. During fretting, high points or asperities of the mating surfaces adhere to each other and small particles are pulled out, leaving minute, shallow pits and a powdery debris. In steel parts exposed to air, the metallic debris oxidizes rapidly and forms a red, rustlike powder or sludge; hence, the coined designation "fretting corrosion."

Fretting is mechanical in origin and has been observed in most materials, including those that do not oxidize, such as gold, platinum, and nonmetallics; hence, the corrosion accompanying fretting of steel parts is a secondary factor.

Fretting can occur in the operation of machinery subject to motion or vibration or both. It can destroy close fits; the debris may clog moving parts; and fatigue failure may be accelerated because stress levels to initiate fatigue in fretted parts are much lower than for undamaged material. Sites for fretting damage include interference fits; splined, bolted, keyed, pinned, and riveted joints; between wires in wire rope; flexible shafts and tubes; between leaves in leaf springs; friction clamps; small amplitude-of-oscillation bearings; and electrical contacts.

Vibration or cyclic loadings are the main causes of fretting. If these factors cannot be eliminated, greater clamping force may reduce movement but, if not effective, may actually worsen the damage. Lubrication may delay the onset of damage; hard plating or surface hardening methods may be effective, not by reducing fretting, but by increasing the fatigue strength of the material. Plating soft materials having inherent lubricity onto contacting surfaces is effective until the plating wears through.

Involute Spline Inspection Methods.—Spline gages are used for routine inspection of production parts.

Analytical inspection, which is the measurement of individual dimensions and variations, may be required:

A) To supplement inspection by gages, for example, where NOT GO composite gages are used in place of NOT GO sector gages and variations must be controlled.

B) To evaluate parts rejected by gages.

C) For prototype parts or short runs where spline gages are not used.

D) To supplement inspection by gages where each individual variation must be restrained from assuming too great a portion of the tolerance between the minimum material actual and the maximum material effective dimensions.

Inspection with Gages.—A variety of gages is used in the inspection of involute splines.

Types of Gages: A composite spline gage has a full complement of teeth. A sector spline gage has two diametrically opposite groups of teeth. A sector plug gage with only two teeth per sector is also known as a "paddle gage." A sector ring gage with only two teeth per sector is also known as a "snap ring gage." A progressive gage is a gage consisting of two or more adjacent sections with different inspection functions. Progressive GO gages are physical combinations of GO gage members that check consecutively first one feature or one group of features, then their relationship to other features. GO and NOT GO gages may also be combined physically to form a progressive gage.

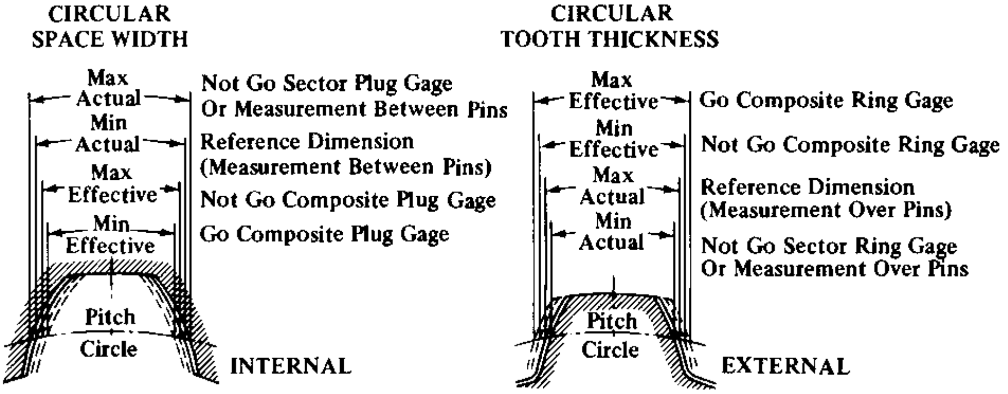


Fig. 3. Space width and tooth-thickness inspection.

GO and NOT GO Gages: GO gages are used to inspect maximum material conditions (maximum external, minimum internal dimensions). They may be used to inspect an individual dimension or the relationship between two or more functional dimensions. They control the minimum looseness or maximum interference.

NOT GO gages are used to inspect minimum material conditions (minimum external, maximum internal dimensions), thereby controlling the maximum looseness or minimum interference. Unless otherwise agreed upon, a product is acceptable only if the NOT GO gage does not enter or go on the part. A NOT GO gage can be used to inspect only one dimension. An attempt at simultaneous NOT GO inspection of more than one dimension could result in failure of such a gage to enter or go on (acceptance of part), even though all but one of the dimensions were outside product limits. In the event all dimensions are outside the limits, their relationship could be such as to allow acceptance.

Effective and Actual Dimensions: The effective space width and tooth thickness are inspected by means of an accurate mating member in the form of a composite spline gage.

The actual space width and tooth thickness are inspected with sector plug and ring gages, or by measurements with pins.

Measurements with Pins.—The actual space width of internal splines, and the actual tooth thickness of external splines, may be measured with pins. These measurements do not determine the fit between mating parts, but may be used as part of the analytic inspection of splines to evaluate the effective space width or effective tooth thickness by approximation.

Formulas for 2-Pin Measurement: For measurement *between* pins of internal splines using the symbols given on page 2130:

1) Find involute of pressure angle at pin center:

$$\mathrm{inv}\,\phi_i = s/D + \mathrm{inv}\,\phi_d - d_i/D_b$$

2) Find the value of ϕ_i, in degrees, in the involute function tables beginning on page 98. Find sec ϕ_i = 1/cosine ϕ_i in the trig tables, pages 94 through 96, using interpolation to obtain higher accuracy.

3) Compute measurement, M_i, between pins:

For even numbers of teeth: $M_i = D_b \sec\phi_i - d_i$

For odd numbers of teeth: $M_i = (D_b \cos 90°/N) \sec\phi_i - d_i$

where: $d_i = 1.7280/P$ for 30° and 37.5° standard pressure angle (ϕ_D) splines

$d_i = 1.9200/P$ for 45° pressure angle splines

For measurement *over* pins of external splines:

1) Find involute of pressure angle at pin center:

$$\mathrm{inv}\,\phi_e = t/D + \mathrm{inv}\,\phi_D + d_e/D_b - \pi/N$$

2) Find the value of ϕ_e and sec ϕ_e from the involute function tables beginning on page 98.

3) Compute measurement, M_e, over pins:

For even numbers of teeth: $M_e = D_b \sec\phi_e + d_e$

For odd numbers of teeth: $M_i = (D_b \cos 90°/N) \sec\phi_e - d_e$

where $d_e = 1.9200/P$ for all external splines

Example: Find the measurement between pins for *maximum* actual space width of an internal spline of 30° pressure angle, tolerance class 4, 3/6 diametral pitch, and 20 teeth.

The maximum actual space width to be substituted for *s* in Step 1 above is obtained as follows: In Table 5, page 2137, the maximum actual space width is the sum of the minimum effective space width (second column) and $\lambda + m$ (third column). The minimum effective space width s_v from Table 2, page 2131, is $\pi/2P = \pi/(2 \times 3)$. The values of λ and m from Table 4, page 2134, are, for a class 4 fit, 3/6 diametral pitch, 20-tooth spline: $\lambda = 0.0027 \times 0.71 = 0.00192$; and $m = 0.00176 \times 0.71 = 0.00125$, so that $s = 0.52360 + 0.00192 + 0.00125 = 0.52677$.

Other values required for Step 1 are:

$D = N/P = 20/3 = 6.66666$

$inv\phi_D = \mathrm{inv}\ 30° = 0.053751$ from a calculator

$d_i = 1.7280/3 = 0.57600$

$D_b = D\cos\phi_D = 6.66666 \times 0.86603 = 5.77353$

The computation is made as follows:

1) inv $\phi_i = 0.52677/6.66666 + 0.053751 - 0.57600/5.77353 = 0.03300$

2) From a calculator, $\phi_i = 25°46.18'$ and sec $\phi_i = 1.11044$

3) $M_i = 5.77353 \times 1.11044 - 0.57600 = 5.8352$ inches

American National Standard Metric Module Splines.—ANSI B92.2M-1980 (R1989) is the American National Standards Institute version of the International Standards Organization involute spline standard. It is not a "soft metric" conversion of any previous, inch-based, standard,* and splines made to this hard metric version are not intended for use with components made to the B92.1 or other, previous standards. The ISO 4156 Standard from

---

* A "soft" conversion is one in which dimensions in inches, when multiplied by 25.4 will, after being appropriately rounded off, provide equivalent dimensions in millimeters. In a "hard" system the tools of production, such as hobs, do not bear a usable relation to the tools in another system; i.e., a 10 diametral pitch hob calculates to be equal to a 2.54 module hob in the metric module system, a hob that does not exist in the metric standard.

which this one is derived is the result of a cooperative effort between the ANSI B92 committee and other members of the ISO/TC 14-2 involute spline committee.

Many of the features of the previous standard, ANSI B92.1-1970 (R1993), have been retained such as: 30-, 37.5-, and 45-degree pressure angles; flat root and fillet root side fits; the four tolerance classes 4, 5, 6, and 7; tables for a single class of fit; and the effective fit concept.

Among the major differences are: use of modules of from 0.25 through 10 mm in place of diametral pitch; dimensions in millimeters instead of inches; the "basic rack"; removal of the major diameter fit; and use of ISO symbols in place of those used previously. Also, provision is made for calculating three defined clearance fits.

The Standard recognizes that proper assembly between mating splines is dependent only on the spline being within effective specifications from the tip of the tooth to the form diameter. Therefore, the internal spline major diameter is shown as a maximum dimension and the external spline minor diameter is shown as a minimum dimension. The minimum internal major diameter and the maximum external minor diameter must clear the specified form diameter and thus require no additional control. All dimensions are for the finished part; any compensation that must be made for operations that take place during processing, such as heat treatment, must be considered when selecting the tolerance level for manufacturing.

The Standard provides the same internal minimum effective space width and external maximum effective tooth thickness for all tolerance classes. This basic concept makes possible interchangeable assembly between mating splines regardless of the tolerance class of the individual members, and permits a tolerance class "mix" of mating members. This arrangement is often an advantage when one member is considerably less difficult to produce than its mate, and the "average" tolerance applied to the two units is such that it satisfies the design need. For example, by specifying Class 5 tolerance for one member and Class 7 for its mate, an assembly tolerance in the Class 6 range is provided.

If a fit given in this Standard does not satisfy a particular design need, and a specific clearance or press fit is desired, the change shall be made only to the external spline by a reduction of, or an increase in, the effective tooth thickness and a like change in the actual tooth thickness. The minimum effective space width is always basic and this basic width should always be retained when special designs are derived from the concept of this Standard.

Spline Terms and Definitions: The spline terms and definitions given for American National Standard ANSI B92.1-1970 (R1993) described in the preceding section, may be used in regard to ANSI B92.2M-1980 (R1989). The 1980 Standard utilizes ISO symbols in place of those used in the 1970 Standard; these differences are shown in Table 1.

Table 1. Comparison of Symbols Used in *ANSI B92.2M-1980 (R1989)* and Those in *ANSI B92.1-1970, R1993*

Symbol		Meaning of Symbol	Symbol		Meaning of Symbol
B92.2M	B92.1		B92.2M	B92.1	
c	…	theoretical clearance	m	…	module
c_v	c_v	effective clearance	…	P	diametral pitch
c_F	c_F	form clearance	…	P_s	stub pitch = $2P$
D	D	pitch diameter	P_b	…	base pitch
DB	D_b	base diameter	p	p	circular pitch
d_{ce}	D_{ce}	pin contact diameter, external spline	π	π	3.141592654
d_{ci}	D_{ci}	pin contact diameter, internal spline	rfe	r_f	fillet rad., ext. spline
DEE	D_o	major diam., ext. spline	rfi	r_f	fillet rad., int. spline
DEI	D_{ri}	major diam., int. spline	E_{bsc}	s_v min	basic circular space width
DFE	D_{Fe}	form diam., ext. spline	E_{max}	s	max. actual circular space width
DFI	D_{Fi}	form diam., int. spline	E_{min}	s	min. actual circular space width
DIE	D_{re}	minor diam., ext. spline	EV	s_v	effective circular space width
DII	D_i	minor diam., int. spline	S_{bsc}	t_v max	basic circular tooth thickness
DRE	d_e	pin diam., ext. spline	S_{max}	t	max. actual circular tooth thick.
DRI	d_i	pin diam., int. spline	S_{min}	t	min. actual circular tooth thick.
h_s	…	see Figs. 1a, 1b, 1c, and 1d	SV	t_v	effective circular tooth thick.
λ	λ	effective variation	α	ϕ	pressure angle
INV α	…	involute $\alpha = \tan \alpha - \text{arc } \alpha$	α_D	ϕ_D	standard pressure angle
KE	K_e	change factor, ext. spline	α_{ci}	ϕ_{ci}	press. angle at pin contact diameter, internal spline
KI	K_i	change factor, int. spline	α_{ce}	ϕ_{ce}	press. angle at pin contact diameter, external spline
g	L	spline length	α_i	ϕ_i	press. angle at pin center, internal spline
g_w	…	active spline length	α_e	ϕ_e	press. angle at pin center, external spline
$g\gamma$	…	length of engagement	α_{Fe}	ϕ_F	press. angle at form diameter, external spline
T	m	machining tolerance	α_{Fi}	ϕ_F	press. angle at form diameter, internal spline
MRE	M_e	meas. over 2 pins, ext. spline	es	…	ext. spline cir. tooth thick.modification for required fit class=c_v min (Table 3)
MRI	M_i	meas. bet. 2 pins, int. spline	h, f, e, or d	…	tooth thick, size modifiers (called fundamental deviation in ISO R286), Table 3
Z	N	number of teeth	H	…	space width size modifier (called fundamental deviation in ISO R286), Table 3

Dimensions and Tolerances: Dimensions and tolerances of splines made to the 1980 Standard may be calculated using the formulas given in Table 2. These formulas are for metric module splines in the range of from 0.25 to 10 mm metric module of side-fit design and having pressure angles of 30-, 37.5-, and 45-degrees. The standard modules in the system are: 0.25; 0.5; 0.75; 1; 1.25; 1.5; 1.75; 2; 2.5; 3; 4; 5; 6; 8; and 10. The range of from 0.5 to 10 module applies to all splines except 45-degree fillet root splines; for these, the range of from 0.25 to 2.5 module applies.

Table 2. Formulas for Dimensions and Tolerances for All Fit Classes—Metric Module Involute Splines

Term	Symbol	Formula			
		30-Degree Flat Root	30-Degree Fillet Root	37.5-Degree Fillet Root	45-Degree Fillet Root
		0.5 to 10 module	0.5 to 10 module	0.5 to 10 module	0.25 to 2.5 module
Pitch Diameter	D	mZ			
Base Diameter	DB	$mZ \cos \alpha_D$			
Circular Pitch	p	πm			
Base Pitch	p_b	$\pi m \cos \alpha_D$			
Tooth Thick Mod	es	According to selected fit class, H/h, H/f, H/e, or H/d (see Table 3)			
Min Maj. Diam. Int	DEI min	$m(Z + 1.5)$	$m(Z + 1.8)$	$m(Z + 1.4)$	$m(Z + 1.2)$
Max Maj Diam. Int.	DEI max	DEI min + $(T + \lambda)/\tan \alpha_D$ (see Note 1)			
Form Diam, Int.	DFI	$m(Z + 1) + 2c_F$	$m(Z + 1) + 2c_F$	$m(Z + 0.9) + 2c_F$	$m(Z + 0.8) + 2c_F$
Min Minor Diam, Int	DII min	$DFE + 2c_F$ (see Note 2)			
Max Minor Diam, Int	DII max	DII min + $(0.2m^{0.667} - 0.01m^{-0.5})$[a]			
Cir Space Width,					
Basic	E_{bsc}	$0.5\pi m$			
Min Effective	EVmin	$0.5\pi m$			
Max Actual	E max	EVmin + $(T + \lambda)$ for classes 4, 5, 6, and 7 (see Table 4 for $T + \lambda$)			
Min Actual	E min	EVmin + λ (see text on page 2153 for λ)			
Max Effective	EVmax	E max − λ (see text on page 2153 for λ)			
Max Major Diam, Ext	DEE max	$m(Z + 1) - es/\tan \alpha_D$[b]	$m(Z + 1) - es/\tan \alpha_D$[b]	$m(Z + 0.9) - es/\tan \alpha_D$[b]	$m(Z + 0.8) - es/\tan \alpha_D$[b]
Min Major Diam. Ext	DEE min	DEE max − $(0.2m^{0.667} - 0.01m^{-0.5})$[a]			
Form Diam, External	DFE	$2 \times \sqrt{(0.5DB)^2 + \left[0.5D\sin\alpha_D - \frac{h_s + \left(\frac{0.5es}{\tan\alpha_D}\right)}{\sin\alpha_D}\right]^2}$			
Max Minor Diam, Ext	DIE max	$m(Z - 1.5) - es/\tan \alpha_D$[b]	$m(Z - 1.8) - es/\tan \alpha_D$[b]	$m(Z - 1.4) - es/\tan \alpha_D$[b]	$m(Z - 1.2) - es/\tan \alpha_D$[b]

Table 2. Formulas for Dimensions and Tolerances for All Fit Classes—Metric Module Involute Splines

Term	Symbol	Formula			
		30-Degree Flat Root	30-Degree Fillet Root	37.5-Degree Fillet Root	45-Degree Fillet Root
		0.5 to 10 module	0.5 to 10 module	0.5 to 10 module	0.25 to 2.5 module
Min Minor Diam, Ext	DIE min	DIE max − $(T + \lambda)/\tan \alpha_D$ (see Note 1)			
Cir Tooth Thick,					
Basic	S_{bsc}	$0.5\pi m$			
Max Effective	SVmax	$S_{bsc} - es$			
Min Actual	Smin	SVmax − $(T + \lambda)$ for classes 4, 5, 6, and 7 (see Table 4 for $T + \lambda$)			
Max Actual	Smax	SVmax − λ (see text on page 2153 for λ)			
Min Effective	SVmin	Smin + λ (see text on page 2153 for λ)			
Total Tolerance on Circular Space Width or Tooth Thickness	$(T + \lambda)$	See formulas in Table 4			
Machining Tolerance on Circular Space Width or Tooth Thickness	T	$T = (T + \lambda)$ from Table 4 − λ from text on page 2153.			
Effective Variation Allowed on Circular Space Width or Tooth Thickness	λ	See text on page 2153.			
Form Clearance	c_F	$0.1m$			
Rack Dimension	h_s	$0.6m$(see Fig. 1a)	$0.6m$(see Fig. 1b)	$0.55m$(see Fig. 1c)	$0.5m$(see Fig. 1d)

[a] Values of $(0.2m^{0.667} - 0.01m^{-0.5})$ are as follows: for 10 module, 0.93; for 8 module, 0.80; for 6 module, 0.66; for 5 module, 0.58; for 4 module, 0.50; for 3 module, 0.41; for 2.5 module, 0.36; for 2 module, 0.31; for 1.75 module, 0.28; for 1.5 module, 0.25; for 1.25 module, 0.22; for 1 module, 0.19; for 0.75 module, 0.15; for 0.5 module, 0.11; and for 0.25 module, 0.06.

[b] See Table 6 for values of $es/\tan \alpha_D$.

Note 1: Use $(T + \lambda)$ for class 7 from Table 4.

Note 2: For all types of fit, always use the DFE value corresponding to the H/h fit.

Fit Classes: Four classes of side fit splines are provided: spline fit class H/h having a minimum effective clearance, $c_v = es = 0$; classes H/f, H/e, and H/d having tooth thickness modifications, es, of f, e, and d, respectively, to provide progressively greater effective clearance c_v. The tooth thickness modifications h, f, e, and d in Table 3 are fundamental deviations selected from ISO R286, "ISO System of Limits and Fits." They are applied to the external spline by shifting the tooth thickness total tolerance below the basic tooth thickness by the amount of the tooth thickness modification to provide a prescribed minimum effective clearance c_v.

Table 3. Tooth Thickness Modification, *es*, for Selected Spline Fit Classes

Pitch Diameter in mm, *D*	External Splines[a]				Pitch Diameter in mm, *D*	External Splines[a]			
	Selected Fit Class					Selected Fit Class			
	d	e	f	h		d	e	f	h
	Tooth Thickness Modification (Reduction) Relative to Basic Tooth Thickness at Pitch Diameter, *es*, in mm					Tooth Thickness Modification (Reduction) Relative to Basic Tooth Thickness at Pitch Diameter, *es*, in mm			
≤ 3	0.020	0.014	0.006	0	> 120 to 180	0.145	0.085	0.043	0
> 3 to 6	0.030	0.020	0.010	0	> 180 to 250	0.170	0.100	0.050	0
> 6 to 10	**0.040**	0.025	0.013	0	> 250 to 315	0.190	0.110	0.056	0
> 10 to 18	0.050	0.032	0.016	0	> 315 to 400	0.210	**0.125**	**0.062**	0
> 18 to 30	0.065	0.040	0.020	0	> 400 to 500	0.230	0.135	**0.068**	0
> 30 to 50	0.080	0.050	0.025	0	> 500 to 630	0.260	0.145	**0.076**	0
> 50 to 80	0.100	0.060	0.030	0	> 630 to 800	0.290	0.160	**0.080**	0
> 80 to 120	0.120	**0.072**	0.036	0	> 800 to 1000	0.320	**0.170**	**0.086**	0

[a] Internal splines are fit class H and have space width modification from basic space width equal to zero; thus, an H/h fit class has effective clearance $c_v = 0$.

Note: The values listed in this table are taken from ISO R286 and have been computed on the basis of the geometrical mean of the size ranges shown. Values in **boldface** type do not comply with any documented rule for rounding but are those used by ISO R286; they are used in this table to comply with established international practice.

Basic Rack Profiles: The basic rack profile for the standard pressure angle splines are shown in see Fig. 1a, 1b, 1c, and 1d. The dimensions shown are for maximum material condition and for fit class H/h.

Spline Machining Tolerances and Variations.—The total tolerance $(T + \lambda)$, Table 4, is the sum of Effective Variation, λ, and a Machining Tolerance, T.

Table 4. Space Width and Tooth Thickness Total Tolerance, $(T + \lambda)$, in Millimeters

Spline Tolerance Class	Formula for Total Tolerance, $(T + \lambda)$	Spline Tolerance Class	Formula for Total Tolerance, $(T + \lambda)$	In these formulas, i* and i** are tolerance units based upon pitch diameter and tooth thickness, respectively:
4	10i* + 40i**	6	25i* + 100i**	$i^* = 0.001(0.45\sqrt[3]{D} + 0.001D)$ for D ≤ 500mm $= 0.001(0.004D + 2.1)$ for D > 500mm $i^{**} = 0.001(0.45\sqrt[3]{S_{bsc}} + 0.001S_{bsc})$
5	16i* + 64i**	7	40i* + 160i**	

Effective Variation: The effective variation, λ, is the combined effect that total index variation, positive profile variation, and tooth alignment variation has on the effective fit of mating involute splines. The effect of the individual variations is less than the sum of the allowable variations because areas of more than minimum clearance can have profile, tooth alignment, or index variations without changing the fit. It is also unlikely that these variations would occur in their maximum amounts simultaneously on the same spline. For this reason, total index variation, total profile variation, and tooth alignment variation are used to calculate the combined effect by the following formula:

$$\lambda = 0.6\sqrt{(F_p)^2 + (f_f)^2 + (F_\beta)^2} \text{ millimeters}$$

The above variation is based upon a length of engagement equal to one-half the pitch diameter of the spline; adjustment of λ may be required for a greater length of engagement. Formulas for values of F_p, f_f, and F_β used in the above formula are given in Table 5.

Table 5. Formulas for F_p, f_f, and F_β used to calculate λ

Spline Tolerance Class	Total Index Variation, in mm, F_p	Total Profile Variation, in mm, f_f	Total Lead Variation, in mm, F_β
4	$0.001(2.5\sqrt{mZ\pi/2} + 6.3)$	$0.001\ [1.6m(1 + 0.0125Z) + 10]$	$0.001(0.8\sqrt{g} + 4)$
5	$0.001(3.55\sqrt{mZ\pi/2} + 9)$	$0.001\ [2.5m(1 + 0.0125Z) + 16]$	$0.001(1.0\sqrt{g} + 5)$
6	$0.001(5\sqrt{mZ\pi/2} + 12.5)$	$0.001\ [4m(1 + 0.0125Z) + 25]$	$0.001(1.25\sqrt{g} + 6.3)$
7	$0.001(7.1\sqrt{mZ\pi/2} + 18)$	$0.001\ [6.3m(1 + 0.0125Z) + 40]$	$0.001(2\sqrt{g} + 10)$

g = length of spline in millimeters.

Table 6. Reduction, $es/\tan\alpha_D$, of External Spline Major and Minor Diameters Required for Selected Fit Classes

Pitch Diameter D in mm	Standard Pressure Angle, in Degrees									
	30	37.5	45	30	37.5	45	30	37.5	45	All
	Classes of Fit									
	d			e			f			h
	$es/\tan\alpha_D$ in millimeters									
≤3	0.035	0.026	0.020	0.024	0.018	0.014	0.010	0.008	0.006	0
>3 to 6	0.052	0.039	0.030	0.035	0.026	0.020	0.017	0.013	0.010	0
> 6 to 10	0.069	0.052	0.040	0.043	0.033	0.025	0.023	0.017	0.013	0
> 10 to 18	0.087	0.065	0.050	0.055	0.042	0.032	0.028	0.021	0.016	0
> 18 to 30	0.113	0.085	0.065	0.069	0.052	0.040	0.035	0.026	0.020	0
> 30 to 50	0.139	0.104	0.080	0.087	0.065	0.050	0.043	0.033	0.025	0
> 50 to 80	0.173	0.130	0.100	0.104	0.078	0.060	0.052	0.039	0.030	0
> 80 to 120	0.208	0.156	0.120	0.125	0.094	0.072	0.062	0.047	0.036	0
> 120 to 180	0.251	0.189	0.145	0.147	0.111	0.085	0.074	0.056	0.043	0
> 180 to 250	0.294	0.222	0.170	0.173	0.130	0.100	0.087	0.065	0.050	0
> 250 to 315	0.329	0.248	0.190	0.191	0.143	0.110	0.097	0.073	0.056	0
> 315 to 400	0.364	0.274	0.210	0.217	0.163	0.125	0.107	0.081	0.062	0
> 400 to 500	0.398	0.300	0.230	0.234	0.176	0.135	0.118	0.089	0.068	0
> 500 to 630	0.450	0.339	0.260	0.251	0.189	0.145	0.132	0.099	0.076	0
> 630 to 800	0.502	0.378	0.290	0.277	0.209	0.160	0.139	0.104	0.080	0
> 800 to 1000	0.554	0.417	0.320	0.294	0.222	0.170	0.149	0.112	0.086	0

These values are used with the applicable formulas in Table 2.

Machining Tolerance: A value for machining tolerance may be obtained by subtracting the effective variation, λ, from the total tolerance ($T + \lambda$). Design requirements or specific processes used in spline manufacture may require a different amount of machining tolerance in relation to the total tolerance.

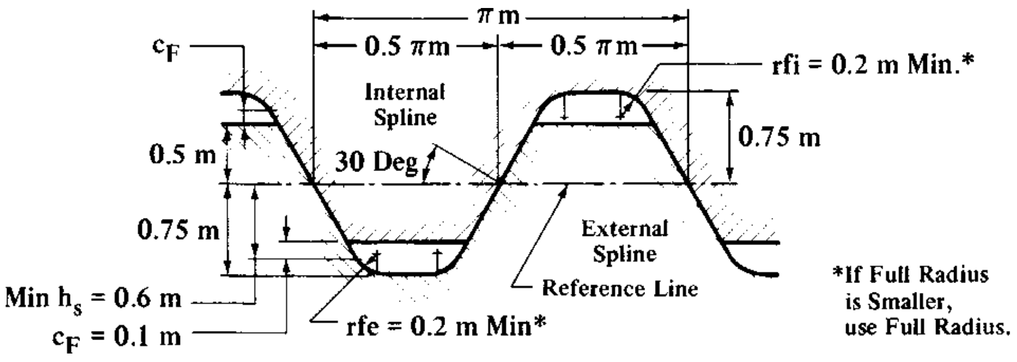


Fig. 1a. Profile of Basic Rack for 30° Flat Root Spline

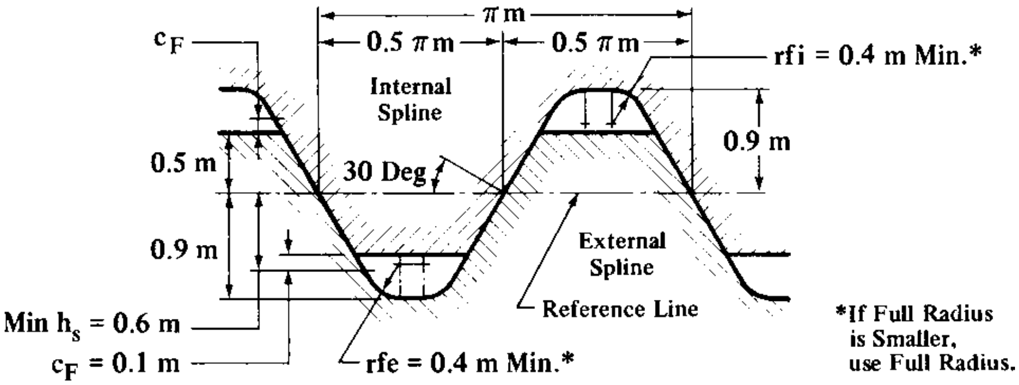


Fig. 1b. Profile of Basic Rack for 30° Fillet Root Spline

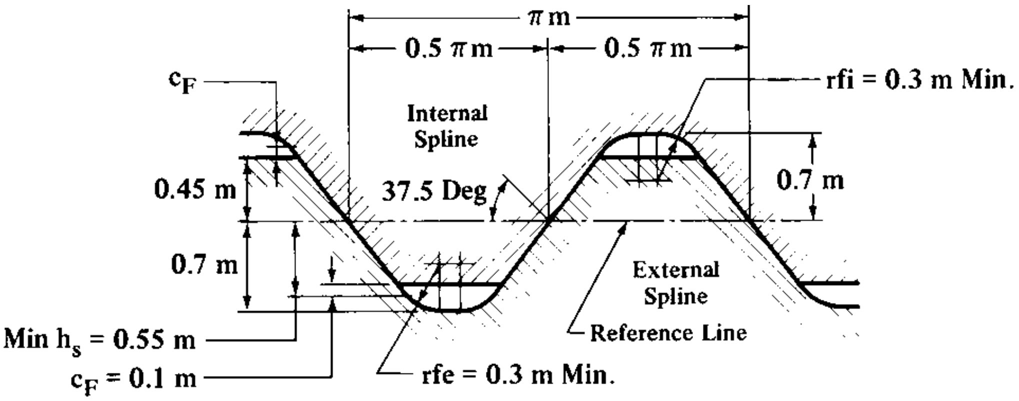


Fig. 1c. Profile of Basic Rack for 37.5° Fillet Root Spline

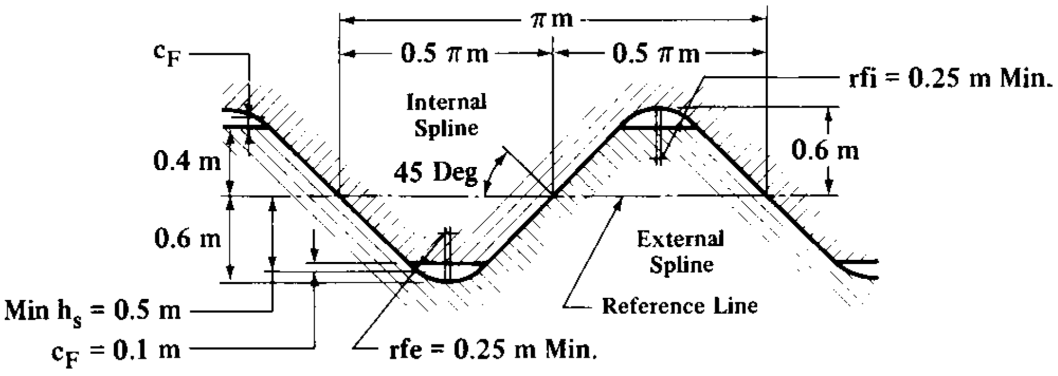


Fig. 1d. Profile of Basic Rack for 45° Fillet Root Spline

British Standard Striaght Splines.—British Standard BS 2059:1953, “Straight-sided Splines and Serrations”, was introduced because of the widespread development and use of splines and because of the increasing use of involute splines it was necessary to provide a separate standard for straight-sided splines. BS 2059 was prepared on the hole basis, the hole being the constant member, and provide for different fits to be obtained by varying the size of the splined or serrated shaft. Part 1 of the standard deals with 6 splines only, irrespective of the shaft diameter, with two depths termed shallow and deep. The splines are bottom fitting with top clearance.

The standard contains three different grades of fit, based on the principle of variations in the diameter of the shaft at the root of the splines, in conjunction with variations in the widths of the splines themselves. Fit 1 represents the condition of closest fit and is designed for minimum backlash. Fit 2 has a positive allowance and is designed for ease of assembly, and Fit 3 has a larger positive allowance for applications that can accept such clearances. all these splines allow for clearance on the sides of the splines (the widths), but in Fit 1, the minor diameters of the hole and the shaft may be of identical size.

Assembly of a splined shaft and hole requires consideration of the designed profile of each member, and this consideration should concentrate on the maximum diameter of the shafts and the widths of external splines, in association with the minimum diameter of the hole and the widths of the internal splineways. In other words, both internal and external splines are in the maximum metal condition. The accuracy of spacing of the splines will affect the quality of the resultant fit. If angular positioning is inaccurate, or the splines are not parallel with the axis, there will be interference between the hole and the shaft.

Part 2 of the Standard deals with straight-sided 90° serrations having nominal diameters from 0.25 to 6.0 inches. Provision is again made for three grades of fits, the basic constant being the serrated hole size. Variations in the fits of these serrations is obtained by varying the sizes of the serrations on the shaft, and the fits are related to flank bearing, the depth of engagement being constant for each size and allowing positive clearance at crest and root.

Fit 1 is an interference fit intended for permanent or semi-permanent ass emblies. Heating to expand the internally-serrated member is needed for assembly. Fit 2 is a transition fit intended for assemblies that require accurate location of the serrated members, but must allow disassembly. In maximum metal conditions, heating of the outside member may be needed for assembly. Fit. 3 is a clearance or sliding fit, intended for general applications.

Maximum and minimum dimensions for the various features are shown in the Standard for each class of fit. Maximum metal conditions presupposes that there are no errors of form such as spacing, alignment, or roundness of hole or shaft. Any compensation needed for such errors may require reduction of a shaft diameter or enlargement of a serrated bore, but the measured effective size must fall within the specified limits.

British Standard BS 3550:1963, “Involute Splines”, is complementary to BS 2059, and the basic dimensions of all the sizes of splines are the same as those in the ANSI/ASME B5.15-1960, for major diameter fit and side fit. The British Standard uses the same terms and symbols and provides data and guidance for design of straight involute splines of 30° pressure angle, with tables of limiting dimensions. The standard also deals with manufacturing errors and their effect on the fit between mating spline elements. The range of splines covered is:

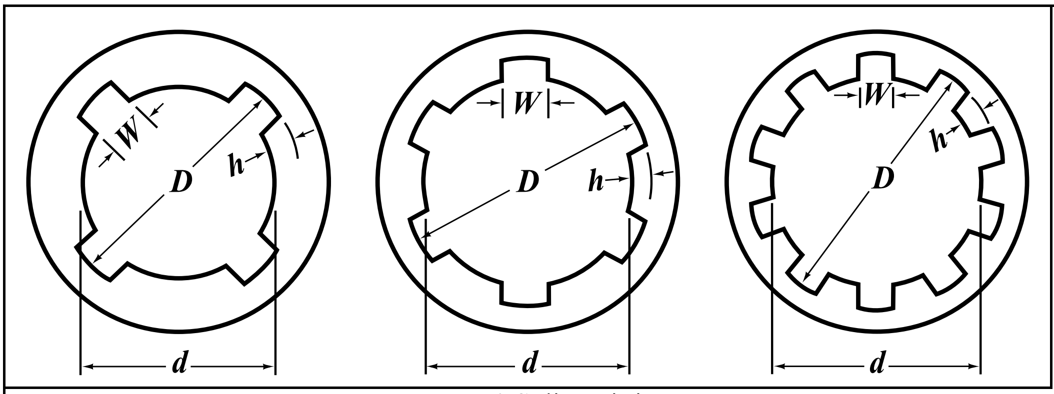
Side fit, flat root, 2.5/5.0 to 32/64 pitch, 6 to 60 splines.

Major diameter, flat root, 3.0/6.0 to 16/32 pitch, 6 to 60 splines.

Side fit, fillet root, 2.5/5.0 to 48/96 pitch, 6 to 60 splines.

British Standard BS 6186, Part 1:1981, “Involute Splines, Metric Module, Side Fit” is identical with sections 1 and 2 of ISO 4156 and with ANSI/ASME B92.2M-1980 (R1989) “Straight Cylindrical Involute Splines, Metric Module, Side Fit – Generalities, Dimensions and Inspection”.

Table 1. S.A.E. Standard Splined Fittings



4-Spline Fittings									
	For All Fits				4A—Permanent Fit				
Nom. Diam	*D*		*W*		*d*		*h*		*T*[a]
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
¾	0.749	0.750	0.179	0.181	0.636	0.637	0.055	0.056	78
⅞	0.874	0.875	0.209	0.211	0.743	0.744	0.065	0.066	107
1	0.999	1.000	0.239	0.241	0.849	0.850	0.074	0.075	139
1⅛	1.124	1.125	0.269	0.271	0.955	0.956	0.083	0.084	175
1¼	1.249	1.250	0.299	0.301	1.061	1.062	0.093	0.094	217
1⅜	1.374	1.375	0.329	0.331	1.168	1.169	0.102	0.103	262
1½	1.499	1.500	0.359	0.361	1.274	1.275	0.111	0.112	311
1⅝	1.624	1.625	0.389	0.391	1.380	1.381	0.121	0.122	367
1¾	1.749	1.750	0.420	0.422	1.486	1.487	0.130	0.131	424
2	1.998	2.000	0.479	0.482	1.698	1.700	0.148	0.150	555
2¼	2.248	2.250	0.539	0.542	1.910	1.912	0.167	0.169	703
2½	2.498	2.500	0.599	0.602	2.123	2.125	0.185	0.187	865
3	2.998	3.000	0.720	0.723	2.548	2.550	0.223	0.225	1249

4-Spline Fittings						6-Spline Fittings			
	4B—To Slide—No Load					For All Fits			
Nom. Diam.	*d*		*h*		*T*[a]	*D*		*W*	
	Min.	Max.	Min.	Max.		Min.	Max.	Min.	Max.
¾	0.561	0.562	0.093	0.094	123	0.749	0.750	0.186	0.188
⅞	0.655	0.656	0.108	0.109	167	0.874	0.875	0.217	0.219
1	0.749	0.750	0.124	0.125	219	0.999	1.000	0.248	0.250
1⅛	0.843	0.844	0.140	0.141	277	1.124	1.125	0.279	0.281
1¼	0.936	0.937	0.155	0.156	341	1.249	1.250	0.311	0.313
1⅜	1.030	1.031	0.171	0.172	414	1.374	1.375	0.342	0.344
1½	1.124	1.125	0.186	0.187	491	1.499	1.500	0.373	0.375
1⅝	1.218	1.219	0.202	0.203	577	1.624	1.625	0.404	0.406
1¾	1.311	1.312	0.218	0.219	670	1.749	1.750	0.436	0.438
2	1.498	1.500	0.248	0.250	875	1.998	2.000	0.497	0.500
2¼	1.685	1.687	0.279	0.281	1106	2.248	2.250	0.560	0.563
2½	1.873	1.875	0.310	0.312	1365	2.498	2.500	0.622	0.625
3	2.248	2.250	0.373	0.375	1969	2.998	3.000	0.747	0.750

[a] See note at end of Table 4.

Table 2. S.A.E. Standard Splined Fittings

6-Spline Fittings									
Nom. Diam.	6A—Permanent Fit			6B—To Slide—No Load			6C—To Slide Under Load		
	d		*T*[a]	*d*		*T*[a]	*d*		*T*[a]
	Min.	Max.		Min.	Max.		Min.	Max.	
¾	0.674	0.675	80	0.637	0.638	117	0.599	0.600	152
⅞	0.787	0.788	109	0.743	0.744	159	0.699	0.700	207
1	0.899	0.900	143	0.849	0.850	208	0.799	0.800	270
1⅛	1.012	1.013	180	0.955	0.956	263	0.899	0.900	342
1¼	1.124	1.125	223	1.062	1.063	325	0.999	1.000	421
1⅜	1.237	1.238	269	1.168	1.169	393	1.099	1.100	510
1½	1.349	1.350	321	1.274	1.275	468	1.199	1.200	608
1⅝	1.462	1.463	376	1.380	1.381	550	1.299	1.300	713
1¾	1.574	1.575	436	1.487	1.488	637	1.399	1.400	827
2	1.798	1.800	570	1.698	1.700	833	1.598	1.600	1080
2¼	2.023	2.025	721	1.911	1.913	1052	1.798	1.800	1367
2½	2.248	2.250	891	2.123	2.125	1300	1.998	2.000	1688
3	2.698	2.700	1283	2.548	2.550	1873	2.398	2.400	2430

[a] See note at end of Table 4.

10-Spline Fittings							
Nom. Diam.	For All Fits				10A—Permanent Fit		
	D		*W*		*d*		*T*[a]
	Min.	Max.	Min.	Max.	Min.	Max.	
¾	0.749	0.750	0.115	0.117	0.682	0.683	120
⅞	0.874	0.875	0.135	0.137	0.795	0.796	165
1	0.999	1.000	0.154	0.156	0.909	0.910	215
1⅛	1.124	1.125	0.174	0.176	1.023	1.024	271
1¼	1.249	1.250	0.193	0.195	1.137	1.138	336
1⅜	1.374	1.375	0.213	0.215	1.250	1.251	406
1½	1.499	1.500	0.232	0.234	1.364	1.365	483
1⅝	1.624	1.625	0.252	0.254	1.478	1.479	566
1¾	1.749	1.750	0.271	0.273	1.592	1.593	658
2	1.998	2.000	0.309	0.312	1.818	1.820	860
2¼	2.248	2.250	0.348	0.351	2.046	2.048	1088
2½	2.498	2.500	0.387	0.390	2.273	2.275	1343
3	2.998	3.000	0.465	0.468	2.728	2.730	1934
3½	3.497	3.500	0.543	0.546	3.182	3.185	2632
4	3.997	4.000	0.621	0.624	3.637	3.640	3438
4½	4.497	4.500	0.699	0.702	4.092	4.095	4351
5	4.997	5.000	0.777	0.780	4.547	4.550	5371
5½	5.497	5.500	0.855	0.858	5.002	5.005	6500
6	5.997	6.000	0.933	0.936	5.457	5.460	7735

Table 3. S.A.E. Standard Splined Fittings

10-Spline Fittings						
	10B—To Slide—No Load			10C—To Slide Under Load		
	d			*d*		
Nom. Diam.	Min.	Max.	T[a]	Min.	Max.	T[a]
¾	0.644	0.645	183	0.607	0.608	241
⅞	0.752	0.753	248	0.708	0.709	329
1	0.859	0.860	326	0.809	0.810	430
1⅛	0.967	0.968	412	0.910	0.911	545
1¼	1.074	1.075	508	1.012	1.013	672
1⅜	1.182	1.183	614	1.113	1.114	813
1½	1.289	1.290	732	1.214	1.215	967
1⅝	1.397	1.398	860	1.315	1.316	1135
1¾	1.504	1.505	997	1.417	1.418	1316
2	1.718	1.720	1302	1.618	1.620	1720
2¼	1.933	1.935	1647	1.821	1.823	2176
2½	2.148	2.150	2034	2.023	2.025	2688
3	2.578	2.580	2929	2.428	2.430	3869
3½	3.007	3.010	3987	2.832	2.835	5266
4	3.437	3.440	5208	3.237	3.240	6878
4½	3.867	3.870	6591	3.642	3.645	8705
5	4.297	4.300	8137	4.047	4.050	10746
5½	4.727	4.730	9846	4.452	4.455	13003
6	5.157	5.160	11718	4.857	4.860	15475

[a] See note at end of Table 4.

16-Spline Fittings							
	For All Fits				16A—Permanent Fit		
	D		*W*		*d*		
Nom. Diam.	Min.	Max.	Min.	Max.	Min.	Max.	T[a]
2	1.997	2.000	0.193	0.196	1.817	1.820	1375
2½	2.497	2.500	0.242	0.245	2.273	2.275	2149
3	2.997	3.000	0.291	0.294	2.727	2.730	3094
3½	3.497	3.500	0.340	0.343	3.182	3.185	4212
4	3.997	4.000	0.389	0.392	3.637	3.640	5501
4½	4.497	4.500	0.438	0.441	4.092	4.095	6962
5	4.997	5.000	0.487	0.490	4.547	4.550	8595
5½	5.497	5.500	0.536	0.539	5.002	5.005	10395
6	5.997	6.000	0.585	0.588	5.457	5.460	12377

Table 4. S.A.E. Standard Splined Fittings

Nom. Diam.	16-Spline Fittings					
	16B—To Slide—No Load			16C—To Slide Under Load		
	d			*d*		
	Min.	Max.	T[a]	Min.	Max.	T[a]
2	1.717	1.720	2083	1.617	1.620	2751
2½	2.147	2.150	3255	2.022	2.025	4299
3	2.577	2.580	4687	2.427	2.430	6190
3½	3.007	3.010	6378	2.832	2.835	8426
4	3.437	3.440	8333	3.237	3.240	11005
4½	3.867	3.870	10546	3.642	3.645	13928
5	4.297	4.300	13020	4.047	4.050	17195
5½	4.727	4.730	15754	4.452	4.455	20806
6	5.157	5.160	18749	4.857	4.860	24760

[a] *Torque Capacity of Spline Fittings:* The torque capacities of the different spline fittings are given in the columns headed "T." The torque capacity, per inch of bearing length at 1000 pounds pressure per square inch on the sides of the spline, may be determined by the following formula, in which T = torque capacity in inch-pounds per inch of length, N = number of splines, R = mean radius or radial distance from center of hole to center of spline, h = depth of spline: $T = 1000NRh$

Table 5. Formulas for Determining Dimensions of S.A.E. Standard Splines

No. of Splines	W For All Fits	A Permanent Fit		B To Slide Without Load		C To Slide Under Load	
		h	d	h	d	h	d
Four	$0.241D$[a]	$0.075D$	$0.850D$	$0.125D$	$0.750D$	…	…
Six	$0.250D$	$0.050D$	$0.900D$	$0.075D$	$0.850D$	$0.100D$	$0.800D$
Ten	$0.156D$	$0.045D$	$0.910D$	$0.070D$	$0.860D$	$0.095D$	$0.810D$
Sixteen	$0.098D$	$0.045D$	$0.910D$	$0.070D$	$0.860D$	$0.095D$	$0.810D$

[a] Four splines for fits A and B only.

The formulas in the table above give the maximum dimensions for W, h, and d, as listed in Tables 1 through 4 inclusive.

S.A.E. Standard Spline Fittings.—The S.A.E. spline fittings (Tables 1 through 4 inclusive) have become an established standard for many applications in the agricultural, automotive, machine tool, and other industries. The dimensions given, in inches, apply only to soft broached holes. The tolerances given may be readily maintained by usual broaching methods. The tolerances selected for the large and small diameters may depend upon whether the fit between the mating part, as finally made, is on the large or the small diameter. The other diameter, which is designed for clearance, may have a larger manufactured tolerance. If the final fit between the parts is on the sides of the spline only, larger tolerances are permissible for both the large and small diameters. The spline should not be more than 0.006 inch per foot out of parallel with respect to the shaft axis. No allowance is made for corner radii to obtain clearance. Radii at the corners of the spline should not exceed 0.015 inch.

Polygon-Type Shaft Connections.— Involute-form and straight-sided splines are used for both fixed and sliding connections between machine members such as shafts and gears. Polygon-type connections, so called because they resemble regular polygons but with curved sides, may be used similarly. German DIN Standards 32711 and 32712 include data for three- and four-sided metric polygon connections. Data for 11 of the sizes shown in those Standards, but converted to inch dimensions by Stoffel Polygon Systems, are given in the accompanying table.