International Standard 4156

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Straight cylindrical involute splines — Metric module, side fit — Generalities, dimensions and inspection

Cannelures cylindriques droites à flancs en développante — Module métrique, à centrage sur flancs — Généralités, dimensions et vérification

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ISO 4156-1981 (E)

Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

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It has been approved by the member bodies of the following countries :

Australia	India	Sweden
Austria	Italy	Turkey
Belgium	Japan	United Kingdom
Chile	Korea, Rep. of	USA
Finland	South Africa, Rep. of	Yugoslavia
France	Spain	

The member bodies of the following countries expressed disapproval of the document on technical grounds :

Czechoslovakia
Germany, F.R.

Contents

1) In preparation : will be the subject of an addendum.

Straight cylindrical involute splines — Metric module, side fit — Generalities, dimensions and inspection

Section one : Generalities

1 Scope and field of application

This International Standard provides data and guidance for the design, manufacture and inspection of straight (non-helical) cylindrical involute splines with side fit. It establishes a specification based on the module within the range 0,25 to 10 inclusive, relating to nominal pressure angles of 30°, 37,5° and 45°. (For electronic data processing purposes, the form of expression "37,5°" has been adopted instead of 37° 30'.)

Limiting dimensions, tolerances, manufacturing errors and their effects on the fit between connecting co-axial spline elements are defined and tabulated. Linear dimensions are expressed in millimetres and angular dimensions in degrees.

2 Terms and definitions relating to splines

2.1 spline joint : Connecting, co-axial elements that transmit torque through the simultaneous engagement of equally spaced teeth situated around the periphery of a cylindrical external member with similar spaced mating spaces situated around the inner surface of the related cylindrical internal member.

2.2 involute spline : One member of spline joint having teeth or spaces that have involute flank profiles.

2.3 internal spline : A spline formed on the inner surface of a cylinder.

2.4 external spline : A spline formed on the outer surface of a cylinder.

2.5 fillet : The concave surface of the tooth or space connecting the involute flank and the root circle. This curved surface as generated varies and cannot be properly specified by a radius of any given value.

2.6 fillet root spline : A spline having a tooth or space profile in which the opposing involute flanks are connected to the root circle (D_{ei} or D_{ie} diameter) by a single fillet.

2.7 flat root spline : A spline having a tooth or space profile in which each of the opposing involute flanks are connected to the root circle (D_{ei} or D_{ie} diameter) by a fillet.

2.8 module, m : The ratio of the circular pitch, expressed in millimetres, to the number π (or the ratio of the pitch diameter, expressed in millimetres, to the number of teeth).

2.9 pitch circle : The reference circle from which all normal spline dimensions are derived, and the circle on which the specified pressure angle has its nominal value.

2.10 pitch diameter, D : The diameter of the pitch circle, in millimetres, equal to the number of teeth multiplied by the module.

2.11 pitch point : The intersection of the spline tooth profile with the pitch circle.

2.12 circular pitch, p : A length of arc of the pitch circle between two consecutive pitch points of left- (or right-) hand flanks, which has a normal value of the number π multiplied by the module.

2.13 pressure angle, α : The acute angle between a radial line passing through any point on a tooth flank and the tangent plane to the flank at that point.

2.14 standard pressure angle, α_D : The pressure angle at the specified pitch point.

2.15 base circle : The circle from which involute spline tooth profiles are generated.

2.16 base diameter, D_b : The diameter of the base circle.

2.17 base pitch, p_b : The arc length of the base circle between two consecutive corresponding flanks.

2.18 major circle : 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.

2.19 major diameter, D_{ee}, D_{ei} : The diameter of the major circle.

2.20 minor circle : 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.

2.21 minor diameter, D_{ie}, D_{ii} : The diameter of the minor circle.

2.22 form circle : The circle which establishes 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 and below the major circle on the internal spline and near and above the minor circle on the external spline.

2.23 form diameter, D_{Fe}, D_{Fi} : The diameter of the form circle.

2.24 depth of engagement : 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.

2.25 basic (circular) space width or tooth thickness at the pitch diameter, E or S : For 30°, 37,5° and 45° pressure angle splines, half the circular pitch.

2.26 actual space width : The practically measured circular space width, on the pitch circle, of any single space width within the limit values $E_{max.}$ and $E_{min.}$.

2.27 effective space width, E_v : For an internal spline, equal to the circular tooth thickness on the pitch circle of an imaginary perfect external spline which would fit the internal spline without looseness or interference, considering engagement of the entire axial length of the splined assembly. The minimum effective space width ($E_{v\ min.}$, always equal to E) of the internal spline is always basic, as shown in table 1. Fit variations may be obtained by adjusting the tooth thickness of the external spline.

2.28 actual tooth thickness : The practically measured circular tooth thickness, on the pitch circle, of any single tooth within the limit values $S_{max.}$ and $S_{min.}$.

2.29 effective tooth thickness, S_v : For an external spline, equal to the circular space width on the pitch circle of an imaginary perfect internal spline which would fit the external spline without looseness or interference, considering engagement of the entire axial length of the splined assembly. Fit variations are obtained by adjusting this value S_v.

2.30 effective clearance, c_v (looseness or interference) : The effective space width of the internal spline minus the effective tooth thickness of the mating external spline.

2.31 theoretical clearance, c (looseness or interference) : 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.

2.32 form clearance, c_F : The radial depth of involute profile beyond the depth of engagement with the mating part. It allows eccentricity of the minor circle (internal), of the major circle (external) and of their respective pitch circles.

2.33 total index variation : Amount of absolute values of the two greatest actual (or practically measured) positive and negative variations from the theoretical spacing.

2.34 total profile variation : Amount of absolute values of the two greatest positive and negative variations, from the theoretical tooth profiles, measured normal to flanks.

2.35 total lead variation : Amount of absolute values of the two greatest opposite direction variations, from the theoretical direction (parallel to the datum axis), also including parallelism and alignment variations (see figure 1).

NOTE — Straight (non-helical) splines have an infinite lead.

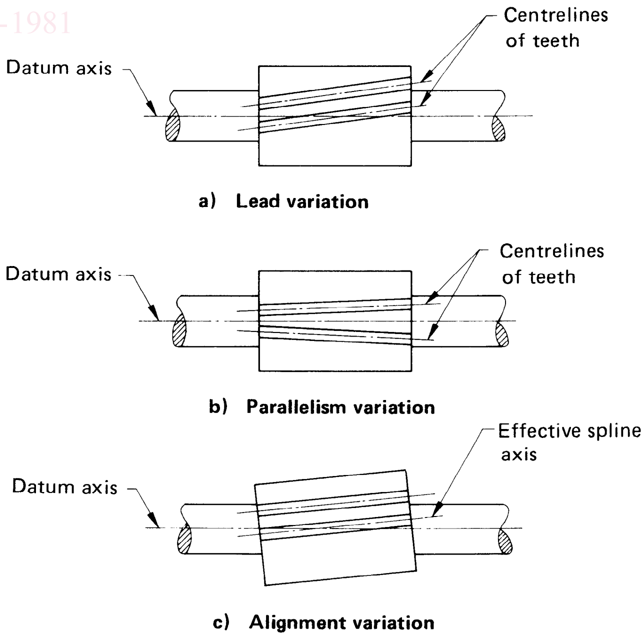


Figure 1 — Lead variations

2.36 parallelism variation : The variation of parallelism of a single spline tooth to any other single spline tooth (see figure 1).

2.37 alignment variation : The variation of the effective spline axis with respect to the reference axis (see figure 1).

2.38 out-of-roundness : The variation of the spline from a true circular configuration.

2.39 effective variation : The accumulated effect of the spline variations on the fit with the mating part.

2.40 variation allowance, λ : The permissible effective variation.

2.41 machining tolerance, T : The permissible variation in actual space width or actual tooth thickness.

2.42 total tolerance, $(T + \lambda)$: The machining tolerance plus the variation allowance. The total tolerance on an internal spline is the difference between the minimum effective space width and the maximum actual space width; on an external spline, it is the difference between the maximum effective tooth thickness and the minimum actual tooth thickness.

2.43 length of engagement, g_γ : The axial length of contact between mating splines.

2.44 active spline length, g_w : The maximum axial spline length in contact (when working) with the mating spline. On sliding splines, the active length exceeds the length of engagement.

2.45 basic dimension : A numerical value to describe the theoretically exact size, shape or location of a feature. It is the basis from which permissible variations are established by tolerances.

2.46 auxiliary dimension : A dimension, without tolerance, given for information purposes only, for the determination of the useful production and control dimensions.

3 Symbols

3.1 General symbols

The general symbols used to designate the various spline terms and dimensions are given below (see figures 10, 11, 12, 13, 14 and 15).

NOTE — In electronic data processing (EDP), it is not always possible to present symbols in their theoretically correct form because of limitations of connected printing equipment. For this reason, some alternative symbols for EDP usage are given in brackets below (for example, the symbol D_b for base diameter may be printed as DB).

c_v = effective clearance (looseness or interference)

c_F = form clearance

D = pitch diameter

D_b [DB] = base diameter

d_{ci} = pin contact diameter, internal spline

d_{ce} = pin contact diameter, external spline

D_{Fe} [DFE] = form diameter, external spline

D_{Fi} [DFI] = form diameter, internal spline

D_{ii} [DII] = minor diameter, internal spline

D_{ee} [DEE] = major diameter, external spline

D_{ie} [DIE] = minor diameter, external spline

D_{ei} [DEI] = major diameter, internal spline

D_{Re} [DRE] = diameter of measuring pin for external spline

D_{Ri} [DRI] = diameter of measuring pin for internal spline

λ = variation allowance

inv α = involute α (= tan $\alpha - \alpha$)

K_e [KE] = approximation factor for external spline

K_i [KI] = approximation factor for internal spline

g = spline length

g_w = active spline length

g_γ = length of engagement

T = machining tolerance

M_{Re} [MRE] = measurement over two pins, external spline

M_{Ri} [MRI] = measurement between two pins, internal spline

W = measurement over k teeth, external spline

Z = number of teeth

m = module

p_b = base pitch

p = circular pitch

ϱ_{Fe} = fillet radius of the basic rack, external spline

ϱ_{Fi} = fillet radius of the basic rack, internal spline

E = basic space width, circular

E_{max} = actual maximum space width, circular

E_{min} = actual minimum space width, circular

E_v [EV] = effective space width, circular

S = basic tooth thickness, circular

S_{max} = actual maximum tooth thickness, circular

S_{min} = actual minimum tooth thickness, circular

S_v [SV] = effective tooth thickness, circular

α = pressure angle

α_D = standard pressure angle

α_{ci} = pressure angle at pin contact diameter, internal spline

α_{ce} = pressure angle at pin contact diameter, external spline

α_i = pressure angle at pin centre, internal spline

α_e = pressure angle at pin centre, external spline

α_{Fe} = pressure angle at form diameter, external spline

α_{Fi} = pressure angle at form diameter, internal spline

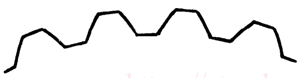
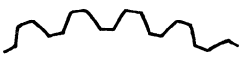
k — j_s — h — f — e and d = fundamental deviation on the external spline = $c_{v\ min}$

H = fundamental deviation on the internal spline

Tables 1 and 2 give the basic dimensions and fundamental formulae, a graphical presentation of which is given by figure 2.

Table 1 — Theoretical dimensions for splines

Dimensions in millimetres

Tooth α_D 30° *	Module m	Circular pitch p	Basic space width or tooth thickness at pitch diameter E or S			Base pitch p_b		
			α_D 30°	α_D 37,5°	α_D 45°	α_D 30°	α_D 37,5°	α_D 45°
	10	31,416	15,708	15,708	–	27,207 0	24,923 9	–
	8	25,133	12,566	12,566	–	21,765 6	19,939 2	–
	6	18,850	9,425	9,425	–	16,324 2	14,954 4	–
	5	15,708	7,854	7,854	–	13,603 5	12,462 0	–
	4	12,566	6,283	6,283	–	10,882 8	9,969 6	–
	3	9,425	4,712	4,712	–	8,162 1	7,477 2	–
	2,5	7,854	3,927	3,927	3,927	6,801 7	6,231 0	5,553 6
	2	6,283	3,142	3,142	3,142	5,441 4	4,984 8	4,442 9
	1,75	5,498	2,749	2,749	2,749	4,761 2	4,361 7	3,887 5
	1,5	4,712	2,356	2,356	2,356	4,081 0	3,738 6	3,332 2
	1,25	3,927	1,963	1,963	1,963	3,400 9	3,115 5	2,776 8
	1	3,142	1,571	1,571	1,571	2,720 7	2,492 4	2,221 4
	0,75	2,356	1,178	1,178	1,178	2,040 5	1,869 3	1,666 1
	0,5	1,571	0,785	0,785	0,785	1,360 4	1,246 2	1,110 7
	0,25	0,785	–	–	0,393	–	–	0,555 4

* For illustration purposes : relative tooth sizes for various spline modules for pressure angle $\alpha_D = 30°$.

Table 2 — Formulae for dimensions and tolerances for all fit classes

Term	Symbol	Formula
Pitch diameter	D	$m\,Z$
Base diameter	D_b	$m\,Z \cos \alpha_D$
Circular pitch	p	$\pi\,m$
Base pitch	p_b	$\pi\,m \cos \alpha_D$
Effective upper deviation, external	es_v	resulting from deviation allowance (fundamental) k – j_s – h – f – e and d
Minimum diameter, internal		
30°, flat root	$D_{ei\,min}$	$m(Z + 1{,}5)$
30°, fillet root	$D_{ei\,min}$	$m(Z + 1{,}8)$
37,5 °, fillet root	$D_{ei\,min}$	$m(Z + 1{,}4)$
45°, fillet root	$D_{ei\,min}$	$m(Z + 1{,}2)$
Maximum major diameter, internal	$D_{ei\,max}$	$D_{ei\,min} + (T + \lambda)/\tan \alpha_D$ (see note 1)
Minimum form diameter, internal		
30°, flat root and fillet root	$D_{Fi\,min}$	$m(Z + 1) + 2\,c_F$
37,5°, fillet root	$D_{Fi\,min}$	$m(Z + 0{,}9) + 2\,c_F$
45°, fillet root	$D_{Fi\,min}$	$m(Z + 0{,}8) + 2\,c_F$
Minimum diameter, internal	$D_{ii\,min}$	$D_{Fe\,max} + 2\,c_F$ (see note 2)
Maximum minor diameter, internal		
$m \leqslant 0{,}75$	$D_{ii\,max}$	$D_{ii\,min}$ + tol. H 10
$0{,}75 < m < 2$	$D_{ii\,max}$	$D_{ii\,min}$ + tol. H 11
$m \geqslant 2$	$D_{ii\,max}$	$D_{ii\,min}$ + tol. H 12
Basic space width and Minimum effective space width	E and $E_{v\,min}$	$0{,}5\,\pi\,m$
Maximum actual space width		
class 4	E_{max}	$E_{v\,min} + (T + \lambda)$ (see note 3)
class 5	E_{max}	$E_{v\,min} + (T + \lambda)$ (see note 3)
class 6	E_{max}	$E_{v\,min} + (T + \lambda)$ (see note 3)
class 7	E_{max}	$E_{v\,min} + (T + \lambda)$ (see note 3)
Minimum actual space width	E_{min}	$E_{v\,min} + \lambda$ (see 8.2)
Maximum effective space width	$E_{v\,max}$	$E_{max} - \lambda$ (see 8.2)
Maximum major diameter, external		
30°, flat root and fillet root	$D_{ee\,max}$	$m(Z + 1) + es_v/\tan \alpha_D$ (see note 4)
37,5°, fillet root	$D_{ee\,max}$	$m(Z + 0{,}9) + es_v/\tan \alpha_D$ (see note 4)
45°, fillet root	$D_{ee\,max}$	$m(Z + 0{,}8) + es_v/\tan \alpha_D$ (see note 4)
Minimum major diameter, external		
$m \leqslant 0{,}75$	$D_{ee\,min}$	$D_{ee\,max}$ – tol. h 10
$0{,}75 < m < 2$	$D_{ee\,min}$	$D_{ee\,max}$ – tol. h 11
$m \geqslant 2$	$D_{ee\,min}$	$D_{ee\,max}$ – tol. h 12
Maximum form diameter, external	$D_{Fe\,max}$	$2\sqrt{(0{,}5\,D_b)^2 + \left(0{,}5\,D \sin \alpha_D - \dfrac{h_s - \dfrac{0{,}5\,es_v}{\tan \alpha_D}}{\sin \alpha_D}\right)^2}$ (See note 6)
Maximum minor diameter, external		
30°, flat root	$D_{ie\,max}$	$m(Z - 1{,}5) + es_v/\tan \alpha_D$
30°, fillet root	$D_{ie\,max}$	$m(Z - 1{,}8) + es_v/\tan \alpha_D$
37,5°, fillet root	$D_{ie\,max}$	$m(Z - 1{,}4) + es_v/\tan \alpha_D$
45°, fillet root	$D_{ie\,max}$	$m(Z - 1{,}2) + es_v/\tan \alpha_D$

Table 2 — Formulae for dimensions and tolerances for all fit classes (*concluded*)

Term	Symbol	Formula
Minimum minor diameter, external	$D_{ie\ min}$	$D_{ie\ max} - (T + \lambda)/\tan \alpha_D$ (see note 1)
Basic tooth thickness	S	$0{,}5 \pi m$
Maximum effective tooth thickness	$S_{v\ max}$	$S + es_v$
Minimum actual tooth thickness		
class 4	S_{min}	$S_{v\ max} - (T + \lambda)$ (see note 3)
class 5	S_{min}	$S_{v\ max} - (T + \lambda)$ (see note 3)
class 6	S_{min}	$S_{v\ max} - (T + \lambda)$ (see note 3)
class 7	S_{min}	$S_{v\ max} - (T + \lambda)$ (see note 3)
Maximum actual tooth thickness	S_{max}	$S_{v\ max} - \lambda$
Minimum effective tooth thickness	$S_{v\ min}$	$S_{min} + \lambda$
Total tolerance, space width or tooth thickness	$(T + \lambda)$	(see clause 6)
Form clearance	c_F	$0{,}1\ m$
Pin diameter, internal spline	D_{Ri}	see note 5
Pin diameter, external spline	D_{Re}	see note 5
Measurement between pins	M_{Ri}	see note 5
Measurement over pins	M_{Re}	see note 5
Change factor, internal	K_i	see section three, "Inspection"
Change factor, external	K_e	see section three, "Inspection"

NOTES

1 $(T + \lambda)$ for class 7 — see clause 6.

2 For all classes of fit, always take the $D_{Fe\ max}$ value corresponding to the H/h fit.

3 See clause 6 and section two — tables of dimensions.

4 Take a null upper deviation value for j_s and k fundamental deviations.

5 See section two : "Dimensions", and section three : "Inspection", concerning choice of pins.

6 For h_s see figures 3, 4, 5 and 6.

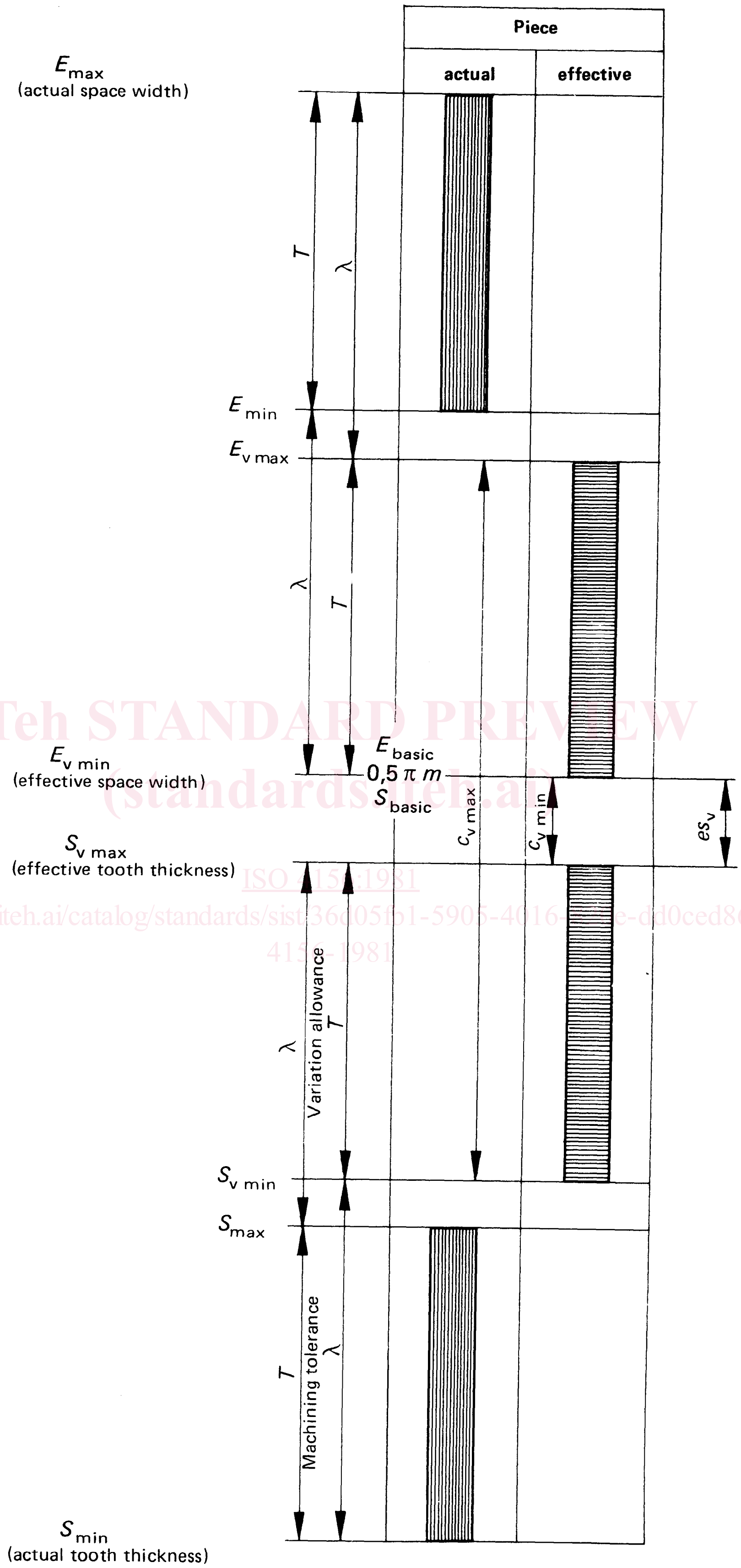


Figure 2 — Graphical representation of tables 1 and 2

3.2 Subscripts

The following subscripts (see also the note in 3.1) are used as part of the above general symbols to designate relative conditions or locations :

$_i$[I] = minor or internal (in this last case, in the last position)

$_e$[E] = major or external (in this last case, in the last position)

$_b$[B] = at base

$_c$ = at contact point

$_F$[F] = pertaining to form diameter

$_v$[V] = effective

$_w$ = active

$_R$[R] = pertaining to gauges

$_\gamma$ = of engagement

$_D$ = standard

4 Pressure angle (standard)

Standard pressure angles included in this International Standard for involute splines are 30°, 37,5° and 45°.

5 Type of fit

This International Standard deals with only one type of fit, the side fit, for 30°, 37,5° and 45° pressure angle splines. Formulae for the dimensions and tolerances for these splines are shown in table 2.

5.1 Side fit

In this fit, the mating members contact on the sides of the teeth only. Major and minor diameters are clearance dimensions. The tooth sides act as drivers and centralize mating splines.

5.2 Spline fit classes

This International Standard provides the side fit in six spline fit classes as follows :

Spline fit class	Effective interference
H/k	$c_{v\,max} = (T + \lambda)$
H/j$_s$	$c_{v\,max}$ = deviation allowance $j_s = \left(\frac{T + \lambda}{2}\right)$
	Effective looseness
H/h	$c_{v\,min}$ = deviation allowance h = zero
H/f	$c_{v\,min}$ = deviation allowance f
H/e	$c_{v\,min}$ = deviation allowance e
H/d	$c_{v\,min}$ = deviation allowance d

The deviation allowances (fundamental) k — j_s — h — f — e and d are the standard deviations selected from ISO/R 286 *ISO System of limits and fits — Part 1 : General, tolerances and deviations*, which are applied to the external spline. A prescribed maximum effective interference or minimum effective looseness is obtained, allowing the fitting by adjusting from the zero line the maximum effective and minimum actual limit values of tooth thickness by the amount of the deviation allowance (see 8.7.2). The spline dimensions in the spline tables of this International Standard are given for spline fit class H/h, $c_{v\,min}$ = zero.

6 Space width and tooth thickness, total tolerance $(T + \lambda)$

Tolerance classes

This International Standard includes four classes of total tolerance $(T + \lambda)$ on space width and tooth thickness selected from a combination of tolerance units (i) in ISO/R 286. The tolerance classes are indicated below, with corresponding combination of tolerance units (i). For the calculation of T and λ, see clause 8. The values of λ are given in tables 3 to 6 of clause 8.

Spline tolerance class	Tolerance unit (i)
4	= (10 i* + 40 i**)
5	= (16 i* + 64 i**)
6	= (25 i* + 100 i**)
7	= (40 i* + 160 i**)

* Tolerance based on pitch diameter

$i = 0{,}45\sqrt[3]{D} + 0{,}001\,D$ for $D \leqslant 500$ mm

$i = 0{,}004\,D + 2{,}1$ for $D > 500$ mm

** Tolerance based on space width or tooth thickness

$i = 0{,}45\sqrt[3]{E \text{ (or } S)} + 0{,}001\,E \text{ (or } S)$

where

D is the pitch diameter in millimetres;

E is the basic space width in millimetres;

S is the basic tooth thickness in millimetres.

the resultant $(T + \lambda)$ in micrometres. For $(T + \lambda)$ in millimetres, multiply the result by 0,001.

For the calculation of tolerance units (i), only the above indicated formulae (notes *, **) are to be taken into consideration.

It should to be noted that total values ($T + \lambda$) may **always** be subtracted from the limit values of space width and tooth thickness given in section 2 and are usable even if the chosen fit class is other than H/h.

NOTE — Below are listed the combinations of tolerance qualities IT corresponding to the combinations of tolerance units (i) indicated above. Those combinations of tolerance qualities IT are given only to indicate the conception principle of the tolerance system regarding its eventual extension, and **only to rediscover** the corresponding combinations of tolerance units (i).

Spline tolerance class	Tolerance quality (IT)
4	= (IT 6* + IT 9**)
5	= (IT 7* + IT 10**)
6	= (IT 8* + IT 11**)
7	= (IT 9* + IT 12**)

7 Basic rack profiles for spline

7.1 The basic rack is a section of the tooth surface of an involute spline of infinitely large diameter on a plane at right angles to the tooth surfaces, the profile of which is used as the basis for defining the standard tooth dimensions of a system of involute splines.

7.2 The reference line is a straight line crossing the profile of the basic rack, with reference to which the tooth dimensions are specified.

7.3 The profile of the basic rack for the standard pressure angle splines is represented in the following figures :

figure 3 : 30° flat root spline, for modules 0,5 to 10;

figure 4 : 30° fillet root spline, for modules 0,5 to 10;

figure 5 : 37,5° fillet root spline, for modules 0,5 to 10;

figure 6 : 45° fillet root spline, for modules 0,25 to 2,5.

* Tolerance based on pitch diameter.

** Tolerance based on space width and tooth thickness.

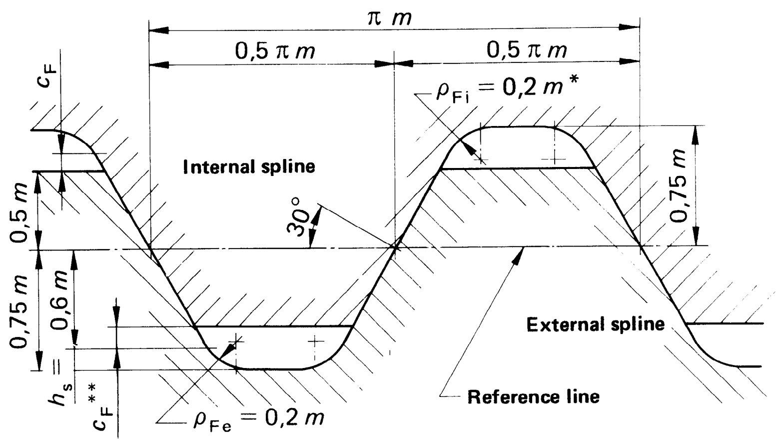


Figure 3 — Profile of the basic rack for 30° flat root spline

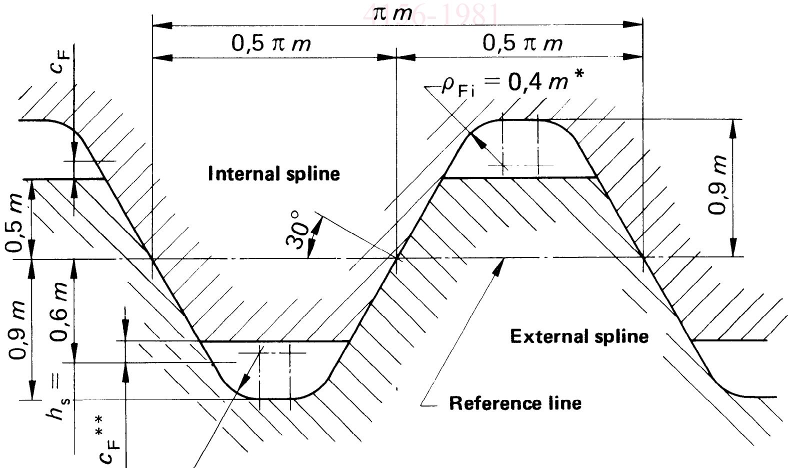


Figure 4 — Profile of the basic rack for 30° fillet root spline

* and ** See next page.

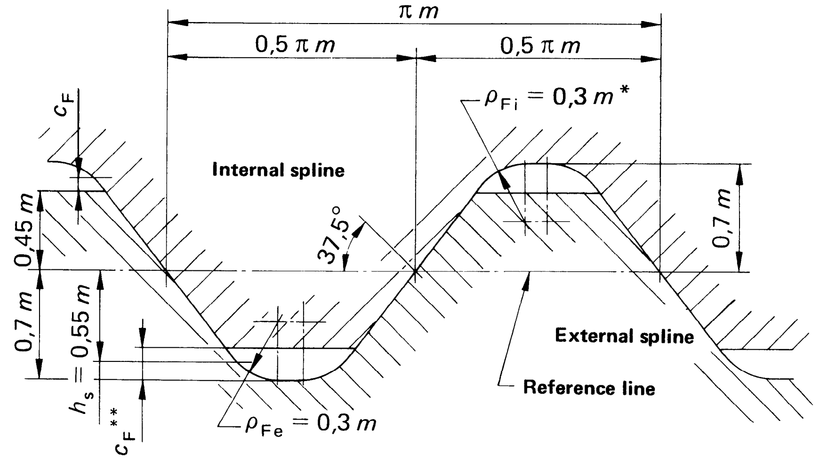


Figure 5 — Profile of the basic rack for 37,5° fillet root spline

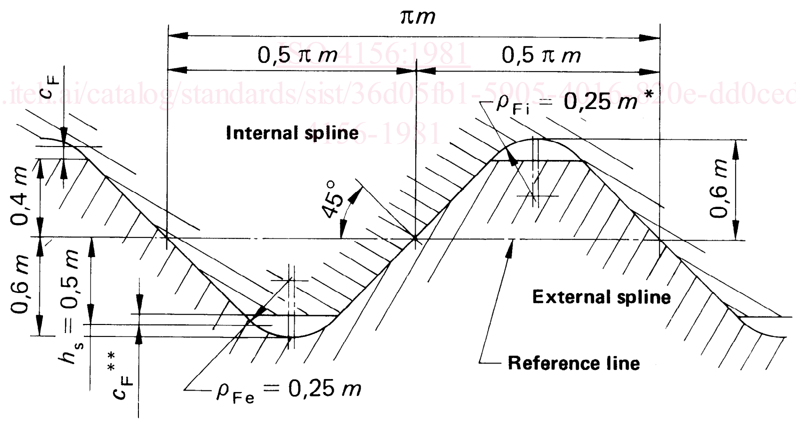


Figure 6 — Profile of the basic rack for 45° fillet root spline

NOTE concerning figures 3 to 6 :

* For internal splines (hub), the form diameter, obtained by generating from the basic rack, is always greater than the form diameter shown in the tables of dimensions (see section two), which corresponds in all fit cases to the major maximum diameter of the shaft (with upper deviation — es_V — zero) increased to diametral form clearance (2 c_F) equal to 0,2 module.

** For external splines (shafts), c_F is obtained by generation from the basic rack ($D_{Fe\ max}$) and for H/h fit (see note 2 under table 2).

The size c_F indicated is in fact a deviation permitting the form clearance c_F given in table 2 to be obtained and is equal to 0,1 m.