Autodesk Inventor Engineer s Handbook

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Joints / Movable Joints

Involute Splines Generator

Spline calculations in metric units

Transferred torque

$$T = \frac{30 \cdot 10^3 \cdot P}{\pi \cdot n} \qquad [Nm]$$

where:

Ptransferred power [Nm]

nspeed [min $^{-1}$]

Pressure on groove supporting surface

1. shaft inside diameter $d_h > 0$

a) $$d_{min} = 3\sqrt{\frac{16 \cdot T \cdot K_a \cdot S_v}{\pi \cdot \tau_A \cdot K_f}} \quad [mm]$$

b) if $d_{min} \leq d_h$ -> $d_{min} = 1.1\ d_h$ [mm]

c) if $d_{min} \leq 1.5\ d_h$ -> $d_{min} = 1.5\ d_h$ [mm]

2. shaft inside diameter $d_h = 0$

$$d_{min} = 3\sqrt{\frac{16 \cdot T \cdot K_a \cdot S_v}{\pi \cdot \tau_A \cdot K_f}} \quad [mm]$$

where:

d_{min}minimal shaft diameter [mm]

d_h shaft inside diameter [mm]

T torque [Nm]

K_a application factor

K_f fatigue-life factor

S_v desired safety

τ_{Al} Allowable Shear Stress

Minimum splines length to transfer the torque

1. Fixed connection: $$L_{min} = \frac{T \cdot 10^3 \cdot K_a \cdot S_v}{d_s \cdot p_{D\,min} \cdot \frac{h_{st}}{2} \cdot N \cdot K_m \cdot K_f} \quad [mm]$$

2. Flexible connection: $$L_{min} = \frac{T \cdot 10^3 \cdot K_a \cdot S_v}{d_s \cdot p_{D\,min} \cdot \frac{h_{st}}{2} \cdot N \cdot K_m \cdot K_w} \quad [mm]$$

where:

T	torque [Nm]
K_a	application factor
K_f	wear-life factor
K_w	application factor
K_m	load distribution factor
S_v	desired safety
d_s	middle diameter = (D + d) / 2 [mm]
D	outside diameter of groove section [mm]
d	inside diameter of groove section [mm]
N	number of grooves [-]
h	height of groove = (D - d) / 2 [mm]
s	chamfer [mm]
h_{st}	connection height h_{st} = h - 2 s [mm]

p_{Dmin}	allowable pressure on supporting surface of shaft or groove [MPa]

Allowable pressure

1. Fixed connection: $$p_{min} = \frac{T \cdot 10^3 \cdot K_a}{d_s \cdot l_f \cdot \frac{h_{st}}{2} \cdot N \cdot K_m \cdot K_f} \quad [MPa]$$

2. Flexible connection: $$p_{min} = \frac{T \cdot 10^3 \cdot K_a}{d_s \cdot l_f \cdot \frac{h_{st}}{2} \cdot N \cdot K_m \cdot K_w} \quad [MPa]$$

where:

T	torque [Nm]
K_a	application factor
K_f	wear-life factor
K_w	application factor
K_m	load distribution factor
S_v	desired safety
d_s	middle diameter = (D + d) / 2 [mm]
D	outside diameter of groove section [mm]
d	inside diameter of groove section [mm]
N	number of grooves [-]
h	height of groove = (D - d) / 2 [mm]
s	chamfer [mm]
h_{st}	connection height $h_{st} = h - 2s$ [mm]
l_f	active key length [mm]

Strength Check

$p_{min} \leq p_{ds}$

$p_{min} \leq p_{dh}$

where:

p_{min} minimal calculated h/2 pressure [MPa]

p_{ds} allowable pressure in shaft [MPa]

p_{dh} allowable pressure in hub [MPa]

Metric calculation according to CSN 01 4950

Bending stress

$$o = \frac{12 \cdot 1000 \cdot T \cdot h}{\varphi \cdot m \cdot L \cdot N^2 \cdot s_{sf}^2} = \frac{2548.3659 \cdot T \cdot h}{\varphi \cdot L \cdot N^2 \cdot m^3}$$

where:

s_{sf} shaft chordal tooth dedendum thickness	$s_{sf} = 2.17m$	
h shaft tooth height	h = 1.1m - 0.05	centering to tooth sides, flat groove bottom
	h = 1.28m - 0.05	centering to tooth sides, round groove bottom
	h = 1.2 m	outside centering

Pressure on groove supporting groove surface

$$p = \frac{2 \cdot 1000 \cdot T}{\varphi \cdot m \cdot h_n \cdot L \cdot N^2} \qquad [MPa]$$

where:

h_n load bearing spline height $h_n = 0.9\ m - 0.05$

Minimum splines length

$L_{min} = \max\ \{L_1, L_2\}$ [mm]

where:

$$L_1 = \frac{2548{,}3659 \cdot M_k \cdot h}{\varphi \cdot o_D \cdot z^2 \cdot m^3} \qquad L_2 = \frac{2 \cdot 1000 \cdot M_k}{\varphi \cdot m \cdot h_n \cdot L \cdot z^2} \qquad [mm]$$

Recommended values: L = (0.8 - 1.6) D

Splines check

$p \leq p_d$ and $\sigma \leq \sigma_d$

where:

P transferred power [kW]

n speed [min^{-1}]

z tooth number [-]

p_D allowable pressure on contact surfaces of teeth [MPa]

σ_D allowable bending stress [MPa]

L active spline length [mm]

D nominal spline diameter [mm]

φ factor of tooth side contact

Names, symbols, and relations for CSN standard

Name	*Symbol*	*Relation*
Module	m	-
Pressure angle		$\alpha = 30^{o}$
	α	
Diameter of pitch circle	d	d = m N
Shaft tooth height	h	$h_{min} = h_a + h_{fmin}$
Shaft tooth height when centering to tooth sides		$h_a = 0.45mm$
	h_a	
Shaft tooth height when centering outside		$h_a = 0.55m$
Shaft tooth height	h	$h_{min} = h_a + h_{fmin}$
Hub dedendum:		$H_{fmin} = 0.55m$
flat bottom of groove	H_f	$H_{fmin} = 0.65m$
round bottom of groove		$H_f = 0.77m$
Radius of tooth transition curve	ρ_r	$\rho_{rmin} = 0.15m$
Nominal groove width on pitch circle	e	$e = \pi / 2m + 2xm \text{ tg } \alpha$
Hub root diameter: flat bottom of groove		$D_f = D$
	D_f	
round bottom of groove		$D_{fmin} = D + 0.44m$
Displacement of basic profile	x_m	$x_m = 1/2 (D-m_N - 1.1m)$
Shaft root diameter: flat bottom of groove		$d_{fmax} = D - 2.2m$
	d_f	
round bottom of groove		$d_{fmax} = D - 2.76m$
Shaft outside diameter: centering to the tooth side		$d_a = D - 0.2m$
	d_a	
centering to the outside		$d_a = D$
Hub tooth chamfering or fillet diameter	K	K = 0.15m
Pitch	p	$p = \pi m$
Number of teeth	N	-
Basic diameter	d_b	$d_b = m_N \cos \alpha$
Hub tooth height	H	$H = H_a + H_f$
Addendum	H_a	$H_a = 0.45m$
Shaft addendum		$h_{fmin} = 0.55m$
for flat bottom of groove	h_f	$h_{fmin} = 0.65m$
for round bottom of groove		$h_f = 0.83m$

Shaft pitch width of tooth	s	$s = \pi / 2m + 2xm\ tg\ \alpha$
Nominal diameter of splining	D	$D = m_N + 2xm + 1.1m$
Hub outside diameter	D_a	$Da = D - 2m$
Radial clearance	c	$c_{min} = 0.1m$
Diameter of circle of limit points of hub tooth sides	D_1	$D_{1imin} = d_a + F_T$
Diameter of circle of limit points of shaft tooth sides	d_1	$d_{1imax} = D_a + F_T$
Splining diameter	D_d	-

Names, symbols and relations for ISO standard

Formulas for dimensions and tolerances for fit classes

Term	*Symbol*	*Formula*	*EDP representation*
Pitch diameter	D	m z	D
Base diameter	D_b	m z cos αD	DB
Circular pitch	p_b	m π cos αD	PB
Fundamental deviation, external	es_v	Resulting from external deviation k, js, h, f, e, d	ESV
Minimum major diameter, internal:	$D_{ei\ mim}$	m (z + 1.5)	DEIMIM
30 deg, flat root	$D_{ei\ mim}$	m (z + 1.8)	DEIMIM
30 deg, fillet root	$D_{ei\ mim}$	m (z + 1.4)	DEIMIM
37.5 deg, fillet root	$D_{ei\ mim}$	m (z + 1.2)	DEIMIM
45 deg, fillet root Maximum major diameter, external	$D_{ei\ max}$	$D_{ei\ max}$ + (T + λ)/tan α_D - *see Note 1*	DEIMAX
Minimum form diameter, internal:	$D_{Fi\ mim}$	m (z + 1) + 2 c_f	DFEIMIM
30 deg, flat root, and fillet root	$D_{Fi\ mim}$	m (z + 0.9) + 2 c_f	DFIMIM
37.5 deg, fillet root	$D_{Fei\ mim}$	m (z + 0.8) + 2 c_f	DFIMIM
45 deg, fillet root Minimum minor diameter, internal	$D_{ii\ min}$	$D_{Fe\ max}$ + 2 c_F - *see Note 2*	DEIMAX
Maximum minor diameter, internal:	$D_{ii\ max}$	$D_{ii\ max}$ + IT 10	DIIMAX
m ≤ 0.75	$D_{ii\ max}$	$_{ii\ max}$ + IT 11	DIIMAX
	$D_{ii\ max}$	$_{ii\ max}$ + IT 12	DIIMAX

0.75< m< 2			
m => 2			
Basic space width	E	$0.5 \pi m$	E
Minimum effective space width	$E_{v\ min}$	$0.5 \pi m$	EVMIN
Maximum actual space width	E_{max}	$E_{v\ min} + (T + \lambda)$	EMAX
class 4	E_{max}	$E_{v\ min} + (T + \lambda)$	EMAX
class 5	E_{max}	$E_{v\ min} + (T + \lambda)$	EMAX
class 6	E_{max}	$E_{v\ min} + (T + \lambda)$	EMAX
class 7			
Minimum actual space width	E_{min}	$E_{v\ min} + \lambda$	EMIN
Maximum effective space width	$E_{v\ max}$	$E_{v\ min} + T_v$	EVMAX
Maximum major diameter, external	$D_{ee\ max}$	$m\ (z + 1) + es_v / \tan \alpha_D$ - *see Note 3*	DEEMAX
30 deg, flat root, and fillet root	$D_{ee\ max}$	$m\ (z + 0.9) + es_v / \tan \alpha_D$ - *see Note 3*	DEEMAX
37.5 deg, fillet root	$D_{ee\ max}$	$m\ (z + 0.8) + es_v / \tan \alpha_D$ - *see Note 3*	DEEMAX
45 deg, fillet root			
Minimum minor diameter, external:	$D_{ee\ min}$	$D_{ee\ min}$ - IT 10	DEEMIN
$m \leq 0.75$	$D_{ee\ min}$	$_{ee\ min}$ - IT 11	DEEMIN
0.75< m< 2	$D_{ee\ min}$	$_{ee\ min}$ - IT 12	DEEMIN
m => 2			
Maximum form diameter	$D_{Fe\ max}$	$2 \cdot \sqrt{(0.5D_b)^2 + \left(0.5D \cdot \sin \alpha_D - \frac{h_s - \frac{0{,}5 \cdot es_v}{\tan \alpha_D}}{\sin \alpha_D}\right)^2}$	DFEMAX

Maximum minor diameter, external	$D_{\text{that is, max}}$		
		$m (z - 1.5) + es_v /\tan \alpha_D$	DIEEMAX
30 deg, flat root	$D_{\text{that is, max}}$	$m (z - 1.8) + es_v /\tan \alpha_D$	DIEMAX
30 deg, fillet root	$D_{\text{that is, max}}$	$m (z - 1.4) + es_v /\tan \alpha_D$	DIEMAX
37.5 deg, fillet root		$m (z - 1.2) + es_v /\tan \alpha_D$	DIEMAX
45 deg, fillet root	$D_{\text{that is, max}}$		
Minimum minor diameter, external	$D_{\text{that is, max}}$	$D_{\text{that is, max}} - (T + \lambda / \tan \alpha_D$	DIEMIN
Basic tooth thickness	S	$0.5 \pi m$	S
Maximum effective tooth thickness	$S_{v\,max}$	$S + es_V$	SVMAX
Minimum actual tooth thickness			
	S_{min}	$S_{v\,max} - (T + \lambda)$	SMIN
class 4	S_{min}	$S_{v\,max} - (T + \lambda)$	SMIN
class 5	S_{min}	$S_{v\,max} - (T + \lambda)$	SMIN
class 6	S_{min}	$S_{v\,max} - (T + \lambda)$	SMIN
class 7			
Maximum actual tooth thickness	S_{max}	$S_{v\,max} - \lambda$	SMAX
Minimum effective tooth thickness	S_{min}	$S_{v\,max} - \lambda$	SVMIN
Maximum effective clearance	$c_{v\,max}$	$E_{v\,max} - S_{v\,max}$	CVMAX
Minimum effective clearance	$c_{v\,min}$	$E_{v\,min} - S_{v\,mim}$	CVMIN
Note 1	$T + \lambda$ for class 7		
Note 2	For all classes of fit, always take the $D_{Fe\,max}$ value corresponding to the H/h fit.		
Note 3	Take $e_{sv} = 0$ for fundamental deviation js and k.		

Allowable compressive stresses

Material	*Hardness*		*Maximum 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 - 251	33 - 38	3 000	12 000
Surface-hardened Steel	---	48 - 53	4 000	16 000
Case-hardened Steel	---	58 - 63	5 000	20 000

Allowable shear stresses

Material	*Hardness* Brinell	Rockwell C	*Maximum Allowable Shear [psi]*
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

Allowable tensile stresses

Material	*Hardness* Brinell	Rockwell C	*Maximum Allowable Shear [psi]*
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 (Aircraft Quality)	---	42 - 46	50 000

Allowable pressure

Type of joining		*Operating condition*	*Non-hardened sides*	*Hardened sides*
			Allowable pressure p_a [MPa]	
Sliding	when loaded	adverse	-	3 to 10
		medium	-	5 - 15
		favorable	-	10 - 20
	without loading	adverse	15 to 20	20 - 35
		medium	20 - 30	30 - 60
		favorable	25 - 40	40 - 70
non-sliding		adverse	35 - 50	40 - 70
		medium	60 - 100	100 - 140
		favorable	80 - 120	120 - 200

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