Shaft Design

Materials	R_{sn} (MPa)	R_m (MPa)
S235	235	360
S275	275	430
S355	355	510
S450	440	550

Pre-sizing

$\sigma_{amm} = R_m/6 \qquad \tau_{amm} = R_m/15$

Just bending:

$$\sigma_{MAX} = \frac{32\, M_{f,max}}{\pi d^3} \leq \sigma_{amm} \Longrightarrow d \geq 2.17 \sqrt[3]{\frac{M_{f,max}}{\sigma_{amm}}}$$

Just torsion:

$$\tau_{max} = \frac{16\, M_{t,max}}{\pi d^3} \leq \tau_{amm} \Longrightarrow d \geq 1.72 \sqrt[3]{\frac{M_{t,max}}{\tau_{amm}}}$$

Bending and torsion

$$M_{f,eq} = \sqrt{M_{f,max}^2 + \alpha^2 M_{t,max}^2}$$

$\alpha^2 = 0.25$ (constant or pulsating)

$\alpha^2 = 0.75$ (alternating torsion)

$$\sigma_{eq} = \frac{32\, M_{f,eq}}{\pi d^3} \leq \sigma_{amm} \Longrightarrow d \geq 2.17 \sqrt[3]{\frac{M_{f,eq}}{\sigma_{amm}}}$$

Static Check

$$\sigma^*_{VM} = \sqrt{\sigma^2 + 3\tau^2} \longrightarrow \eta = \frac{\sigma_{lim}}{\sigma^*_{VM}}$$

$\hookrightarrow \times 1.6$ for ansynchronous motors

Fatigue Check

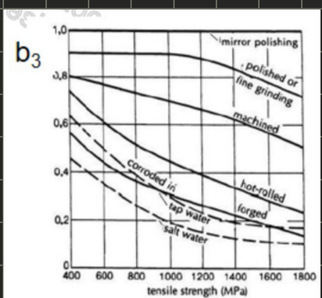
$$\sigma^*_{GP} = \sqrt{\sigma^2 + H^2\tau^2} \qquad H = \frac{\sigma_{lim}}{\tau_{lim}}$$

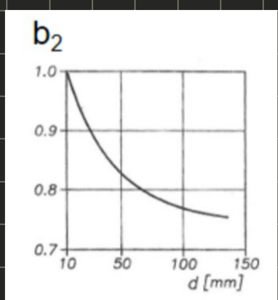
	Stress σ	Stress τ	σ_{lim}	τ_{lim}
σ and τ constant	$\sigma_{max} = \sigma_{nom}$ $\sigma_{max} = K_t\sigma_{nom}$	$\tau_{max} = \tau_{nom}$ $\tau_{max} = K_t\tau_{nom}$	σ_{sn}	τ_{sn}
σ variable τ constant	σ_a	$\tau_{max} = K_t\tau_{nom}$	σ'_F	τ_{sn}
σ constant τ variable	$\sigma_{max} = K_t\sigma_{nom}$	τ_a	σ_{sn}	τ'_F
σ and τ variable	σ_a	τ_a	σ'_F	τ'_F

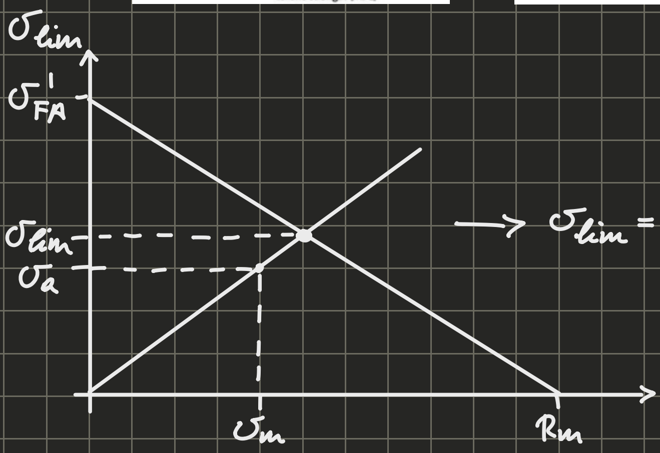
$$\sigma_{FAf} = 0.5\,R_m \qquad \sigma'_{FA} = \sigma_{FAf} \cdot \frac{b_2\, b_3}{k_{ff}}$$

$$k_{ff} = 1 + q\,(k_{tf} - 1) \qquad \tau_{FA} = \tau_{lim} = 0.29\,R_m$$

$$q = \frac{1}{1 + \sqrt{\rho'/r}} \qquad \rho' = \left(\frac{140}{R_m}\right)^2$$

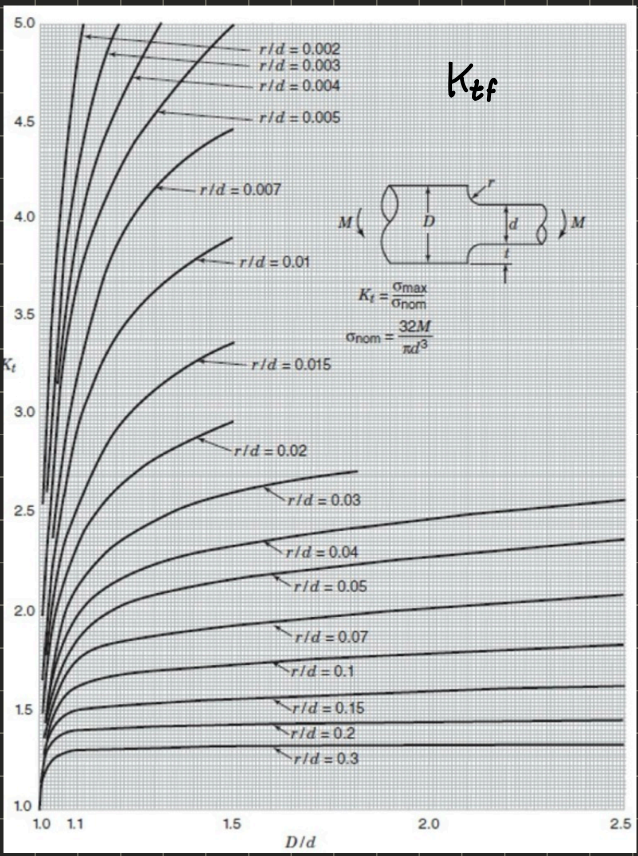


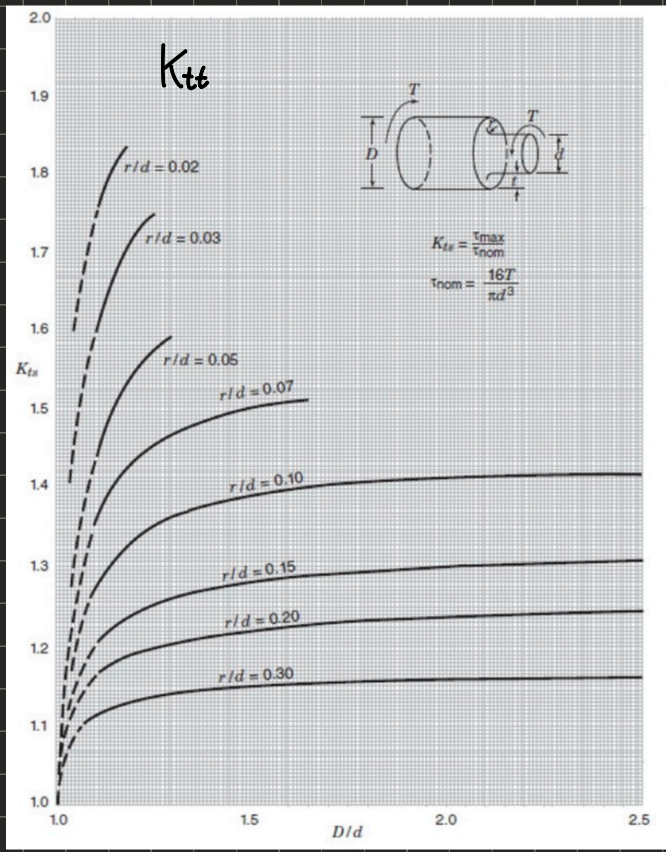




$$\longrightarrow \sigma_{lim} = R_m \left(\frac{\sigma_a \cdot \sigma'_{FA}}{\sigma_m \sigma'_{FA} + \sigma_a R_m} \right) \longrightarrow \eta = \frac{\sigma_{lim}}{\sigma^*_{GP}}$$

$$\tau_{lim} = \frac{R_{sn}}{\sqrt{3}}$$





Gear Theory

$$\tau = \frac{\omega_2}{\omega_1} = \frac{d_{p_2}}{d_{p_1}} = \frac{z_1}{z_2} = \frac{1}{u}$$

Spur Gears | **Helical Gears**

$$d_{p_1} = \frac{2a}{u+1} \rightarrow d_{p_2} = u\, d_{p_1}$$

$$F_t = \frac{2C_1}{d_{p_1}} = \frac{2C_2}{d_{p_2}}$$

$F_r = F_t \tan\alpha \rightarrow F_a = 0$ | $F_r = F_t \tan\alpha_t = F_t \dfrac{\tan\alpha_n}{\cos\beta} \rightarrow F_a = F_t \cdot \tan\beta$

$$b = \frac{1}{k^*} \cdot \frac{2C_1}{d_{p_1}^2} \cdot \frac{u+1}{u}$$

$m = \dfrac{F_t}{b \cdot U_L^*}$ | $m_n = \dfrac{F_t}{b\, U_L^*} \longrightarrow m_t = \dfrac{m_n}{\cos\beta}$

$$z = \frac{d_p}{m}$$

$$z = \frac{d_p}{m_t} \qquad z_{min} = \frac{2 \cdot \cos\beta}{\sin^2 \alpha_t}$$

Table 2-1 Standard Values of Module unit: mm

Series 1	Series 2	Series 3
0.1		
	0.15	
0.2		
	0.25	
0.3		
	0.35	
0.4		
	0.45	
0.5		
	0.55	
0.6		
		0.65
	0.7	
	0.75	
0.8		
	0.9	
1		
1.25		
1.5		
	1.75	
2		
	2.25	
2.5		
	2.75	
3		
		3.25

Series 1	Series 2	Series 3
	3.5	
		3.75
4		
	4.5	
5		
	5.5	
6		
		6.5
	7	
8		
	9	
10		
	11	
12		
	14	
16		
	18	
20		
	22	
25		
	28	
32		
	36	
40		
	45	
50		

Note: The preferred choices are in the series order beginning with 1.

Series 1: preferred
Series 2: admitted
Series 3: available, but, if possible, avoid

↳ use for m and m_n those are the ones which are standardized.

Limit values K* for K

Application		Materials 1	Materials 2	Surface finish 1	Surface finish 2	K* (MPa)	Speed	Service
Ordinary industrial gear boxes		C	C	sf/gr	sf/gr	5.6 – 10	low - average	nominal
		C	I	gr	cu	3.6 – 6.3		
		I	I	cu	cu	2.8 – 5		
Planetary reduction gears	Sun gear/pinion gears	C	C	sf/gr	sf/gr	4.5 – 8	low - average	nominal
	Pinion gears/ring gear	C	I	sf/gr	cu	2.8 – 5		
Parallel gears for high power transmission		C	C	gr	gr	2 – 6.3	high	nominal
Tooling machines for cutting and grinding of metals		C	C	gr	gr	4 – 7.1	low - average	average
Various machines		C	C	sf/gr	sf/gr	4.5 – 8	low - average	average
						3.2 – 5.6		heavy
		C	C	cu	cu	4.5 – 7.1		average
						2.8 – 5		heavy
		C	I	gr	cu	2.8 – 5		average
						2.3 – 6		heavy

C: case-hardened
I: induction-hardened

1: driving wheel
2: driven wheel

sf: superfinishing (before heat treatment of the surfaces of quenched and tempered plus case-hardened teeth)
gr: grinding
cu: standard machining

Use only if k^* not indicated

Bearings

$p = 3 \rightarrow$ ball bearing (eg. 6202, ...)

$p = 10/3 \rightarrow$ roller bearing (etc. NUP, NU, N classes)

for hinge

per carelli

$$L_{10} = \left(\frac{C}{P_0}\right)^p \longrightarrow L_{nm} = a_1 \, a_{SKF} \, L_{10} \longrightarrow L_{xh} = L_x \cdot \frac{10^6}{60 \cdot n}$$

10 or nm

[rpm]

Steps:

- Choose candidate bearing from shaft diameter
- Take P_u and D if lubricant added (creating L_{nm}) $\rightarrow d_m = \frac{d+D}{2}$
- C_0 and f_0 if F_a present $\longrightarrow e = f_0 \, F_a / C_0$
- Take f_m if F_r has both constant and rotating components

Purely Radial load

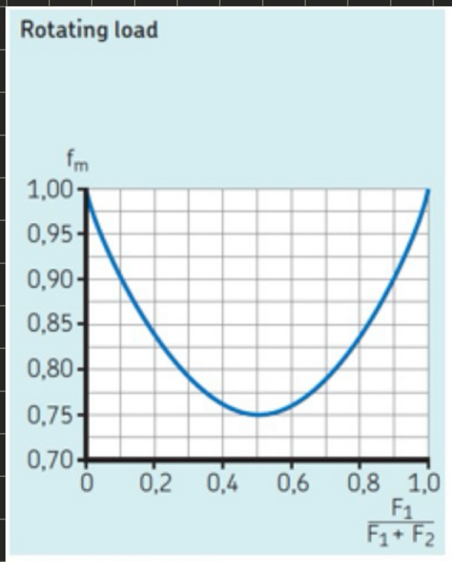
$P_0 = F_r$

Radial and Axial Loads

$$e = f_0 \frac{F_a}{C_0} \longrightarrow X_0, Y_0 \text{ from tables} \longrightarrow P_0 = X_0 F_r + Y_0 F_a$$

Mixed Radial load

Take f_m from graph:



$F_1 \to$ load constant in direction and orientation

$F_2 \to$ load rotating along with bearing

$$F_r = f_m \cdot (F_1 + F_2)$$

Just radial case: $P_0 = F_r$

Radial and axial case: $e = f_0 \frac{F_a}{C_0} \longrightarrow X_0, Y_0 \to P_0 = X_0 F_r + Y \cdot F_a$

$$K = \frac{v}{v_1}$$

v (operating temp, lube type)
↳ graph 1

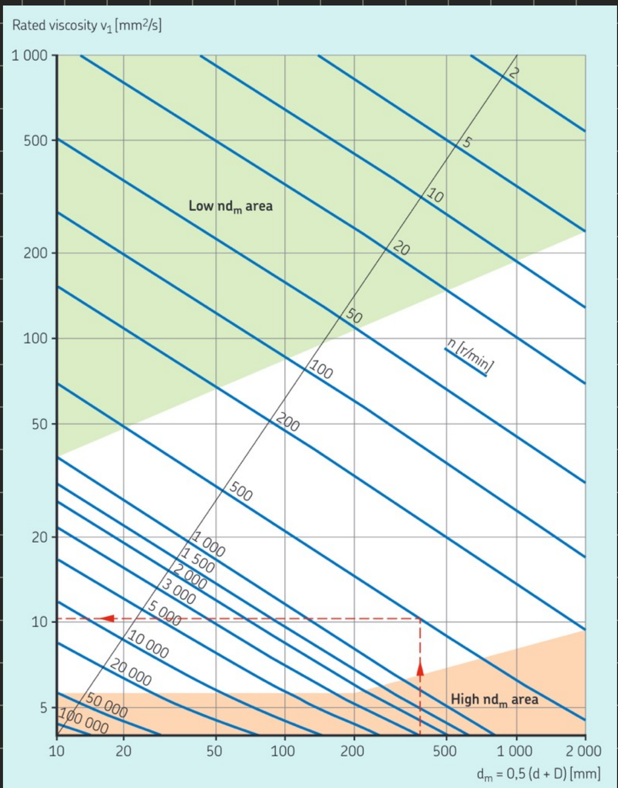
v_1 ($d_m = \frac{d+D}{2}$, $n \to$ rpms at which machine operates)
↳ graph 2

$a_{SKF}\left(K, \eta_c \frac{P_u}{P_0}\right)$
↳ Graph 3 for ball bearings
↳ Graph 4 for roller bearings

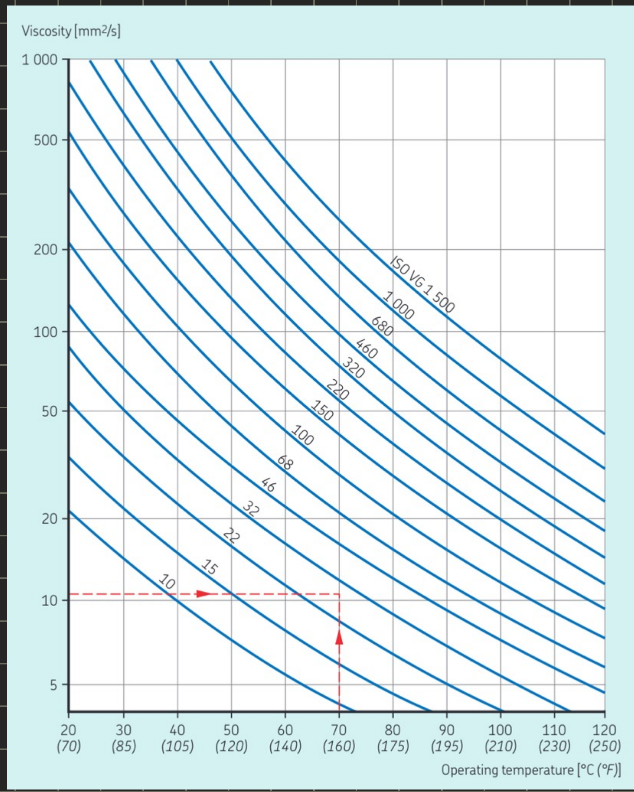
Chart for getting a_1 ⟶

Reliability [%]	a_1 [ ]
90	1.00
95	0.64
96	0.55
97	0.47
98	0.37
99	0.25

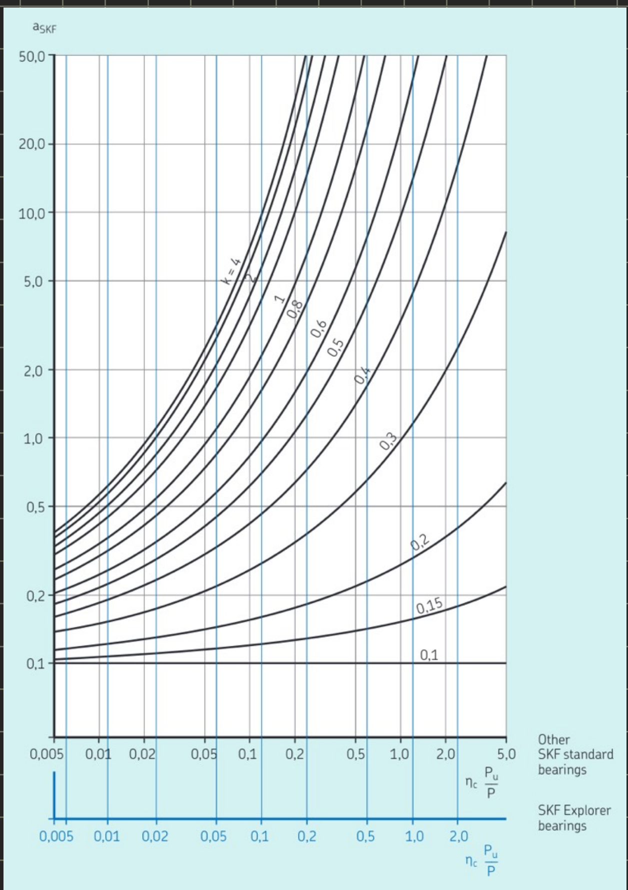
1)



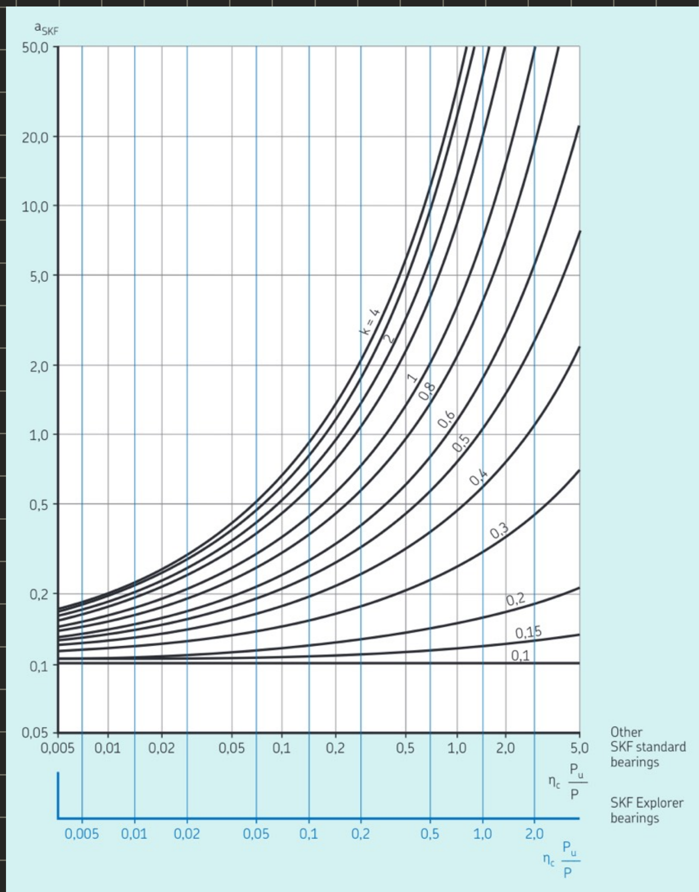
2)



3)



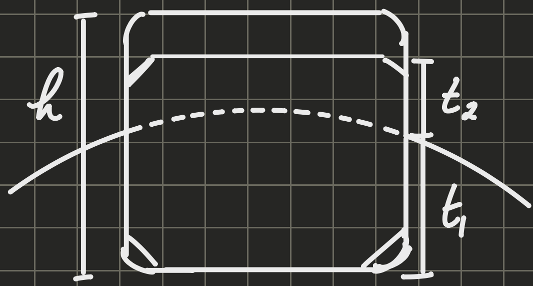
4)



- Now we calculate the C required for our use case and our required life. From here we check if the C of our candidate is over the required C or whether we need to do other checks.

Keys

$$p = \frac{M_t}{z \cdot d/2} \cdot \frac{1}{L(h - t_i)} \cdot k_{\varphi B}$$



$d \rightarrow$ shaft diameter

$L, h, t_i \rightarrow$ based on d.

All dimensions in millimetres

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shaft		Key (see Note)	Keyway											
nominal diameter (see Note) d		section $b \times h$ width × thickness	width b						depth				radius r	
				tolerance for class of fit					shaft t_1		hub t_2			
				free		normal		close and interference						
over	incl.		nom.	shaft (H9)	hub (D10)	shaft (N9)	hub (J_s9)[a]	shaft and hub (P9)	nom.	tol.	nom.	tol.	max.	min.
6	8	2 × 2	2	+0.025 / 0	+0.060 / +0.020	−0.004 / −0.029	+0.012 / −0.012	−0.006 / −0.031	1.2	+0.1 / 0	1	+0.1 / 0	0.16	0.08
8	10	3 × 3	3						1.8		1.4		0.16	0.08
10	12	4 × 4	4	+0.030 / 0	+0.078 / +0.030	0 / −0.030	+0.015 / −0.015	−0.012 / −0.042	2.5		1.8		0.16	0.08
12	17	5 × 5	5						3		2.3		0.25	0.16
17	22	6 × 6	6						3.5		2.8		0.25	0.16

NOTE The relations between shaft diameter and key section given above are for general applications. The use of smaller key sections is permitted if suitable for the torque transmitted. In cases such as stepped shafts when larger diameters are required, for example to resist bending, and when fans, gears and impellers are fitted with a smaller key than normal, an unequal disposition of key in shaft with relation to the hub results. Therefore, dimensions $d - t_1$ and $d + t_2$ should be recalculated to maintain the $h/2$ relationship. The use of larger key sections which are special to any particular application is outside the scope of this standard.

[a] The limits for tolerance J_s9 are quoted from BS 4500, "ISO limits and fits", to three significant figures.

Tables for h and t_i

Table 3 — Dimensions and tolerances of keyways for rectangular parallel keys

All dimensions in millimetres

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shaft		Key (see Note)	Keyway											
nominal diameter (see Note) d		section $b \times h$ width × thickness	width b						depth				radius r	
				tolerance for class of fit					shaft t_1		hub t_2			
				free		normal		close and interference						
over	incl.		nom.	shaft (H9)	hub (D10)	shaft (N9)	hub (J_s9)[a]	shaft and hub (P9)	nom.	tol.	nom.	tol.	max.	min.
22	30	8 × 7	8	+0.036 / 0	+0.098 / +0.040	0 / −0.036	+0.018 / −0.018	−0.015 / −0.051	4	+0.2 / 0	3.3	+0.2 / 0	0.25	0.16
30	38	10 × 8	10						5		3.3		0.40	0.25
38	44	12 × 8	12	+0.043 / 0	+0.120 / +0.050	0 / −0.043	+0.021 / −0.021	−0.018 / −0.061	5		3.3		0.40	0.25
44	50	14 × 9	14						5.5		3.8		0.40	0.25
50	58	16 × 10	16						6		4.3		0.40	0.25
58	65	18 × 11	18						7		4.4		0.40	0.25
65	75	20 × 12	20	+0.052 / 0	+0.149 / +0.065	0 / −0.052	+0.026 / −0.026	−0.022 / −0.074	7.5		4.9		0.60	0.40
75	85	22 × 14	22						9		5.4		0.60	0.40
85	95	25 × 14	25						9		5.4		0.60	0.40
95	110	28 × 16	28						10		6.4		0.60	0.40
110	130	32 × 18	32	+0.062 / 0	+0.180 / +0.080	0 / −0.062	+0.031 / −0.031	−0.026 / −0.088	11		7.4		0.60	0.40
130	150	36 × 20	36						12	+0.3 / 0	8.4	+0.3 / 0	1.00	0.70
150	170	40 × 22	40						13		9.4		1.00	0.70
170	200	45 × 25	45						15		10.4		1.00	0.70
200	230	50 × 28	50						17		11.4		1.00	0.70
230	260	56 × 32	56	+0.074 / 0	+0.220 / +0.100	0 / −0.074	+0.037 / −0.037	−0.032 / −0.106	20		12.4		1.60	1.20
260	290	63 × 32	63						20		12.4		1.60	1.20
290	330	70 × 36	70						22		14.4		1.60	1.20
330	380	80 × 40	80						25		15.4		2.50	2.00
380	440	90 × 45	90	+0.087 / 0	+0.260 / +0.120	0 / −0.087	+0.043 / −0.043	−0.037 / −0.124	28		17.4		2.50	2.00
440	500	100 × 50	100						31		19.5		2.50	2.00

NOTE The relations between shaft diameter and key section given above are for general applications. The use of smaller key sections is permitted if suitable for the torque transmitted. In cases such as stepped shafts when larger diameters are required, for example to resist bending, and when fans, gears and impellers are fitted with a smaller key than normal, an unequal disposition of key in shaft with relation to the hub results. Therefore, dimensions $d - t_1$ and $d + t_2$ should be recalculated to maintain the $h/2$ relationship. The use of larger key sections which are special to any particular application is outside the scope of this standard.

[a] The limits for tolerance J_s9 are quoted from BS 4500, "ISO limits and fits", to three significant figures.

All dimensions in millimetres

1	2	3	4	5	6	7	8
Width b		Thickness h		Chamfer s		Range of lengths l[a]	
nom.	tol. (h9)	nom.	tol. (h9)	min.	max.	from	incl.
2	0 / −0.025	2	0 / −0.025	0.16	0.25	6	20
3		3		0.16	0.25	6	36
4	0 / −0.030	4	0 / −0.030	0.16	0.25	8	45
5		5		0.25	0.40	10	56
6		6		0.25	0.40	14	70

[a] See Table 9 for preferred lengths of keys.

Tables to get L

Table 4 — Dimensions and tolerances of rectangular parallel keys

All dimensions in millimetres

1	2	3	4	5	6	7	8
Width b		Thickness h		Chamfer s		Range of lengths l[a]	
nom.	tol. (h9)	nom.	tol. (h11)	min.	max.	from	incl.
8	0 / −0.036	7	0 / −0.090	0.25	0.40	18	90
10		8		0.40	0.60	22	110
12	0 / −0.043	8		0.40	0.60	28	140
14		9		0.40	0.60	36	160
16		10		0.40	0.60	45	180
18		11	0 / −0.110	0.40	0.60	50	200
20	0 / −0.052	12		0.60	0.80	56	220
22		14		0.60	0.80	63	250
25		14		0.60	0.80	70	280
28		16		0.60	0.80	80	320
32	0 / −0.062	18		0.60	0.80	90	360
36		20	0 / −0.130	1.00	1.20	100	400
40		22		1.00	1.20	—	—
45		25		1.00	1.20	—	—
50		28		1.00	1.20	—	—
56	0 / −0.074	32	0 / −0.160	1.60	2.00	—	—
63		32		1.60	2.00	—	—
70		36		1.60	2.00	—	—
80		40		2.50	3.00	—	—
90	0 / −0.087	45		2.50	3.00	—	—
100		50		2.50	3.00	—	—

[a] See Table 9 for preferred lengths of keys.

Table to get $K_{\varphi B}$

(Take from first row [Teq])

Shape-based connection	Keys		Connection by (involute) splined shaft					
	Number		Tolerances DIN 5480					
	1	2	H5/IT4	H7/IT7	H8/IT8	H9/IT9	H11/IT11	Higher value
$k_{\varphi\beta}$ per T_{eq}	1	1,3	1,1	1,3	1,5	2	4	z/2
$k_{\varphi\beta}$ per T_{max}	1	1,1	1	1,1	1,3	1,7	3	

Depending on the cases, this is valid also for spline shafts and serrated shafts

Static Check:

$$p_{lim} = f_s R_{sn} \longrightarrow f_s:$$

Component	Material	f_s
Key	Carbon steel, quenched and tempered steel	1.0
Shaft	Carbon steel, quenched and tempered steel, case-hardened steel, cast iron GJS, cast iron GS	1.2
	Cast iron GJL	1.0
Hub	Carbon steel, quenched and tempered steel, case-hardened steel, cast iron GJS, cast iron GS	1.5
	Cast iron GJL	2.0

$$S_F = \frac{p}{p_{lim}} \geq S_{F,MIN}$$

$S_{F,MIN}$: 1-1.3 ductile; 1.3-2 brittle

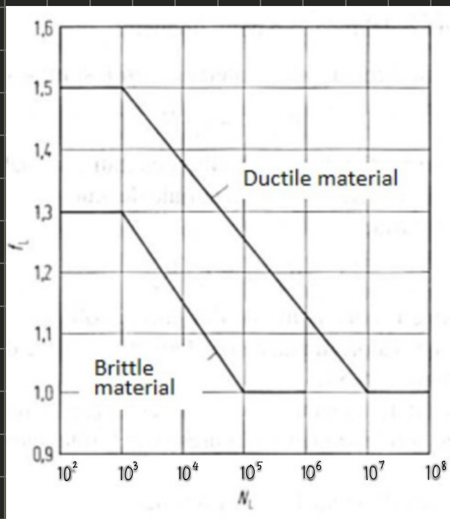
Repeat for shaft, hub, and key
For the key you pick the greater t_i value since it is the worst case-scenario.

Fatigue Check:

$p_{MAX} = 1.6\,p \rightarrow$ For shaft, key and hub.

$$p_{MAX,lim} = f_L(N) R_{sn} \longrightarrow$$

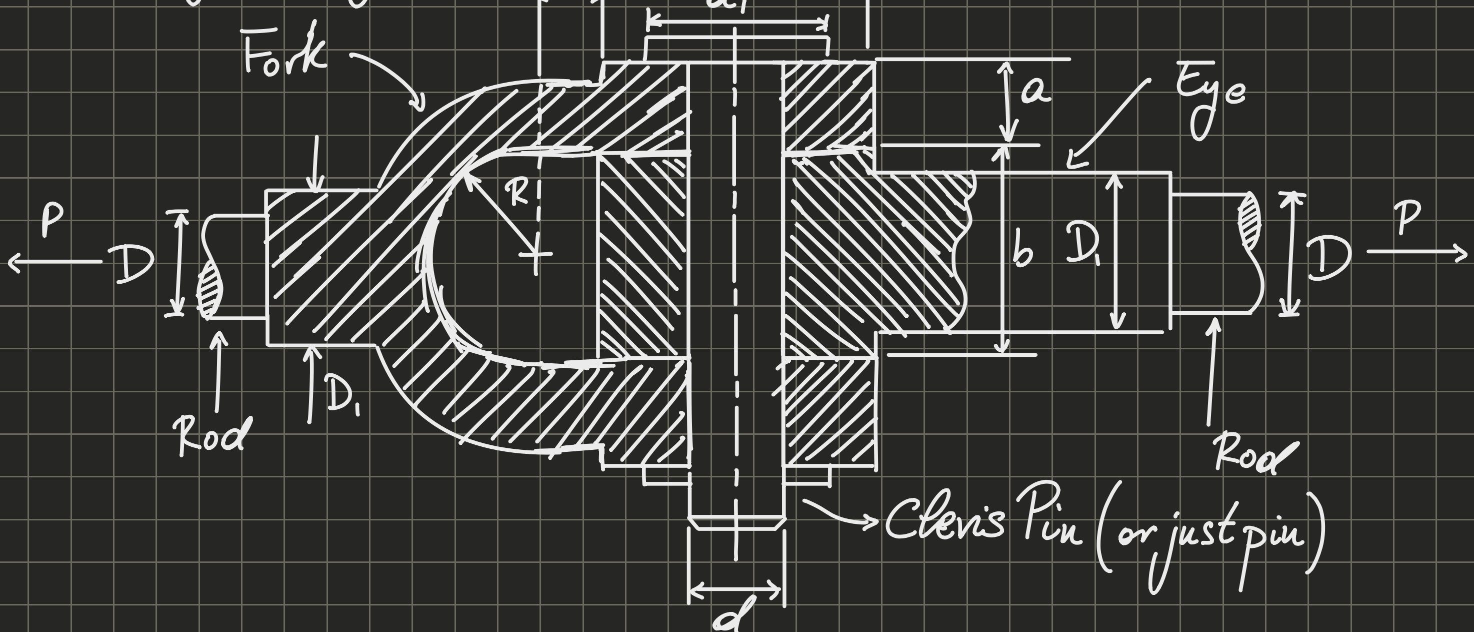
N: total cycles in useful life



$$S_F = \frac{p_{MAX,LIM}}{p_{MAX}} \geq S_{F,MIN} = 1-1.3$$

Key name: A $b \times h \times L$ UNI 6604-69

Sizing of Hinge



Sizing Rod:

$$D = \sqrt{\frac{4P\eta}{\pi R_{su}}} \longrightarrow \text{Round up} \longrightarrow D_1 = 1.1D \longrightarrow \text{Round}$$

Typically $\eta = 5$

Pre-sizing fork and eye

$a = D \qquad b = 2a$

Sizing of Clevis Pin

1) $$\tau_p = \frac{2P}{\pi d^2} \leq \tau_{SZUL}$$

$$\hookrightarrow d = \sqrt{\frac{2P}{\pi \tau_{SZUL}}}$$

2) $$M_{f,MAX} = \frac{P(a+b)}{4}$$

$$\hookrightarrow d = \sqrt[3]{\frac{32 M_{f,MAX}}{\pi \sigma_{SZUL}}}$$

	Material of the components					
	GJL	GS	S235	E295	E335	E360
$p_{zul,r}$ [1]	70	84	91	126	140	154
	Pin material with R_m =					
	400 p. es. 9520	490 E295	590 E335	690 E360		
$\sigma_{bzul,r}$ [1]	77	112	133	147		
$\tau_{szul,r}$ [1]	56	70	84	98		
	Precise connection for lubricated sliding systems (articulated joint), pin in steel. Material of the components					
	GJL	GS	Bronze	Steel		
p_{zul}	5	8	10	15		

1) For pins with static load and maximum value of a load spectrum: dynamic factor $C_D = 1$; variable load $C_D = 0.5$; for cyclic load from zero $C_D = 0.7$.
Reduction factors for pin without notches, bending and shear; surface pressure in notched pins: $C_k = 0.7$; $C_{kp} = 0.8$

Material and permissible stress (in N/mm²) for pin connections

Whichever d is greater is the one we use, since it imposes the most stringent condition.

Checks on eye

From d calculated in previous step $\longrightarrow d_0 = 2d$; $d_1 = 1.5d$

Tensile Action Check:

$$\sigma = \frac{P}{b(d_o - d)} \leq \frac{R_{sn}}{\eta}$$

Shear-out check:

$$\tau = \frac{P}{b(d_o - d)} \leq \frac{\tau_{sn}}{\eta} = \frac{R_{sn}}{\eta\sqrt{3}}$$

Checks on the fork:

Tensile Action Check:

$$\sigma = \frac{P}{2a(d_o - d)} \leq \frac{R_{sn}}{\eta}$$

Shear-out check:

$$\tau = \frac{P}{2a(d_o - d)} \leq \frac{\tau_{sn}}{\eta} = \frac{R_{sn}}{\eta\sqrt{3}}$$

Checks on Contact Pressure

$$p_{eye} = \frac{P}{db} < p_{SZUL} \qquad p_{fork} = \frac{P}{2ad} < p_{SZUL}$$

p_{SZUL} values (if either part is mobile) →

	Precise connection for lubricated sliding systems (articulated joint), pin in steel			
	Material of the components			
	GJL	GS	Bronze	Steel
p_{zul}	5	8	10	15

↳ otherwise p_{SZUL} values:

	Material of the components					
	GJL	GS	S235	E295	E335	E360
$p_{zul,r}$ [1]	70	84	91	126	140	154

Pressure-vessel Bolts and Loose Screws

Getting information on screws:

- R_{sn} and R_m (based on grade)

ISO grade (strength class)	3.6	4.6	4.8	5.6	5.8	6.8	8.8		10.9	12.9
							≤M16	>M16		
Minimum tensile strength R_m [N/mm²]	330	400	420	500	520	600	800	830	1040	1220
Minimum yield strength R_e [N/mm²]	190	240	320	300	400	480	–	–	–	–
Minimum conventional yield stress $R_{p0,2}$ [N/mm²]	–	–	–	–	–	–	640	660	940	1100

↳ Nut grade cannot be lower than screw grade.

- D, d_1, d_2, d_3, A_3 and Pitch:

$H = 0{,}866\,03\,P$

$H_1 = \frac{5}{8} H = 0{,}541\,27\,P$

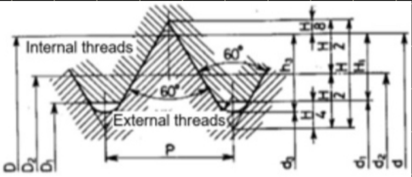
$h_3 = \frac{17}{24} H = 0{,}613\,43\,P$

$d_1 = D_1 = d - 2H_1 = d - 1{,}082\,53\,P$

$d_2 = D_2 = d - \frac{3}{4} H = d - 0{,}649\,52\,P$

$d_3 = d - 2h_3 = d - 1{,}226\,87\,P$

$r = \frac{H}{6} = 0{,}144\,34\,P$



Nominal thread diameter and major diameter d = D, Column 1	Column 2	Column 3	Pitch P	Pitch diameter $d_2 = D_2$	Minor diameter of the screw d_3	Diameter of the screw at the end of the fillet d_1	Minor diameter of the lead screw D_1	Depth of screw threads h_3	Depth of engagement H_1	Fillet radius of the screw r	Stress area mm^2	Minor area mm^2
1,6*			0,35*	1,373	1,171	1,221	1,221	0,215	0,189	0,051	1,27	1,08
	1,8*		0,35*	1,573	1,371	1,421	1,421	0,215	0,189	0,051	1,70	1,48
2			0,4	1,740	1,509	1,567	1,567	0,245	0,217	0,058	2,07	1,79
	2,2*		0,45*	1,908	1,648	1,713	1,713	0,276	0,244	0,065	2,48	2,13
2,5*			0,45*	2,208	1,948	2,013	2,013	0,276	0,244	0,065	3,39	2,98
3			0,5	2,675	2,387	2,459	2,459	0,307	0,271	0,072	5,03	4,47
	3,5		0,6	3,110	2,764	2,850	2,850	0,368	0,325	0,087	6,78	6,00
4			0,7	3,545	3,141	3,242	3,242	0,429	0,379	0,101	8,78	7,75
	4,5		0,75	4,013	3,580	3,688	3,688	0,460	0,406	0,108	11,3	10,1
5			0,8	4,480	4,019	4,134	4,134	0,491	0,433	0,115	14,2	12,7
6			1	5,350	4,773	4,917	4,917	0,613	0,541	0,144	20,1	17,9
		7	1	6,350	5,773	5,917	5,917	0,613	0,541	0,144	28,9	26,2
8			1,25	7,188	6,466	6,647	6,647	0,767	0,677	0,180	36,6	32,8
		9	1,25	8,188	7,466	7,647	7,647	0,767	0,677	0,180	48,1	43,8
10			1,5	9,026	8,160	8,376	8,376	0,920	0,812	0,217	58,0	52,3
		11	1,5	10,026	9,160	9,376	9,376	0,920	0,812	0,217	72,3	65,9
12			1,75	10,863	9,853	10,106	10,106	1,074	0,947	0,253	84,3	76,2
	14		2	12,701	11,546	11,835	11,835	1,227	1,083	0,289	115	105
16			2	14,701	13,546	13,835	13,835	1 227	1,083	0,289	157	144
	18		2,5	16,376	14,933	15,294	15,294	1,534	1,353	0,361	192	175
20			2,5	18,376	16,933	17,294	17,294	1,534	1,353	0,361	245	225
	22		2,5	20,376	18,933	19,294	19,294	1,534	1,353	0,361	303	282
24			3	22,051	20,319	20,752	20,752	1,840	1,624	0,433	353	324
	27		3	25,051	23,319	23,752	23,752	1,840	1,624	0,433	459	427
30			3,5	27,727	25,706	26,211	26,211	2,147	1,894	0,505	561	519
	33		3,5	30,727	28,706	29,211	29,211	2,147	1,894	0,505	694	647
36			4	33,402	31,093	31,670	31,670	2,454	2,165	0,577	817	759
	39		4	36,402	34,093	34,670	34,670	2,454	2,165	0,577	976	913
42			4,5	39,077	36,479	37,129	37,129	2,760	2,436	0,650	1120	1050
	45		4,5	42,077	39,479	40,129	40,129	2,760	2,436	0,650	1310	1220
48			5	44,752	41,866	42,587	42,587	3,067	2,706	0,722	1470	1380
	52		5	48,752	45,866	46,587	46,587	3,067	2,706	0,722	1760	1650
56			5,5	52,428	49,252	50,046	50,046	3,374	2,977	0,794	2030	1910
	60		5,5	56,428	53,252	54,046	54,046	3,374	2,977	0,794	2360	2230
64			6	60,103	56,639	57,505	57,505	3,681	3,248	0,866	2680	2520
	68		6	64,103	60,639	61,505	61,505	3,681	3,248	0,866	3060	2890

- σ'_{FA} (after initial sizing) $\longrightarrow$

Quenched and tempered screws

Fatigue limit $\sigma_{A,SV}$ [N/mm²]

	Diameter range M4–M8	M10–M16	M18–M30
12.9 / 10.9	70	60	50
8.8 / 6.9	60	50	40

Rolled screws

Fatigue limit $\sigma_{A,SG}$ [N/mm²]

Preload $\sigma_V = 0{,}2 - 0{,}8\ R_{p0,2}$

	Diameter range M4–M8	M10–M16	M18–M30
12.9 / 10.9	110	100	90
8.8 / 6.9	100	90	80

Immediately choose screw grade

Loose Screw Case:

Pre-sizing: $\sigma_{MAX} = \frac{4F_{MAX}}{\pi d_3^2} \leq \frac{R_{sn}}{\eta} \longrightarrow$ Minimum $d_3 \rightarrow$ Choose screw

Static Checks: $\sigma_{MAX} = \frac{F_{MAX}}{A_3} \longrightarrow \sigma_{MAX} \leq \frac{R_{sn}}{\eta}$

Fatigue Case: $\begin{cases} \sigma_a = \frac{F_{MAX} - F_{MIN}}{2A_3} \\ \sigma_m = \frac{F_{MAX} + F_{MIN}}{2A_3} \end{cases} \longrightarrow \sigma_a \leq \frac{\sigma_{lim}}{\eta}$

Where σ_{lim} is derived from σ'_{FA} and using Haigh diagram.

$\hookrightarrow$ A.K.A. $\sigma_{A,SV}/\sigma_{A,SG}$

Pre-load Case: (Pressure-vessel)

$$P = \frac{F_S \cdot n_B}{\pi\left[\frac{(D_r+2h)^2}{4} - \frac{D_r^2}{4}\right]} \longrightarrow F_S = \frac{\pi P}{n_B}\left[\frac{(D_r+2h)^2}{4} - \frac{D_r^2}{4}\right]$$

$\hookrightarrow$ Pre-load

$$F_{MAX} = \frac{1}{n_B}\pi\frac{(D_{rec}+h)^2}{4}p_{MAX} \qquad F_{MIN} = \frac{1}{n_B}\pi\frac{(D_{rec}+h)^2}{4}p_{MIN}$$

$$F_{b,MAX} = F_S + \frac{k_b}{k_b+k_g}F_{MAX} \qquad F_{b,MIN} = F_S + \frac{k_b}{k_b+k_g}F_{MIN}$$

(In case the problem isn't a pressure vessel for example an eye-bolt, and we are given F_S, F_{MAX} and F_{MIN}, the following procedures still hold true, just use $F_{b,MAX} = F_{MAX} + F_S$ and $F_{b,MIN} = F_S + F_{MIN}$, or if $F_{MAX} = F_{MIN} = 0$, consider $F_{b,MAX} = F_S$, and of course only the static case.)

Pre-sizing:

$$\sigma = \frac{4 \cdot F_{b,MAX}}{\pi d_3^2} \leq \frac{R_{sn}}{\eta} \longrightarrow \text{Minimum } d_3 \longrightarrow \text{Choose screw based on calculated } d_3\text{, which is not the left most number}$$

pitch

$$\varphi = \tan^{-1}\left(\frac{P}{\pi d_2}\right) \qquad \rho' = \tan^{-1}\left(f/\cos 30\right) \qquad d_m = 1.5\, d$$

Major diameter

$$T_A = T_K + T_{GA} = F_S\left[\mu_K \frac{d_m}{2} + \tan(\varphi+\rho')\cdot\frac{d_2}{2}\right]$$

$\hookrightarrow$ torque on screw due to pre-load

(e.g. d of M10 is 10)

Static Check:

$$\sigma = \frac{4 \cdot F_{b,MAX}}{\pi d_3^2} \qquad \tau = \frac{16\, T_{GA}}{\pi d_3^3} \qquad \sigma_{VM}^* = \sqrt{\sigma^2 + 3\tau^2} \qquad \eta = \frac{R_{sn}}{\sigma_{VM}^*}$$

Fatigue Check:

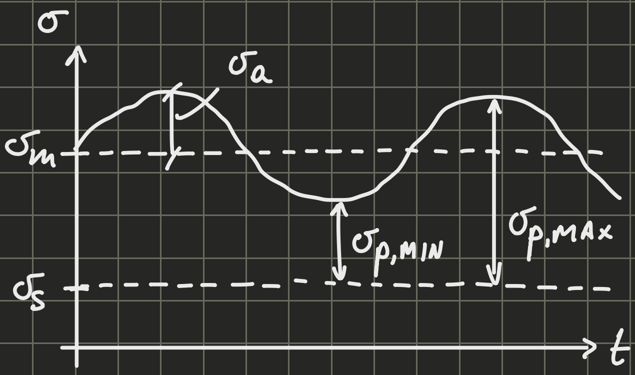
$$\sigma_s = \frac{F_s}{A_3}$$

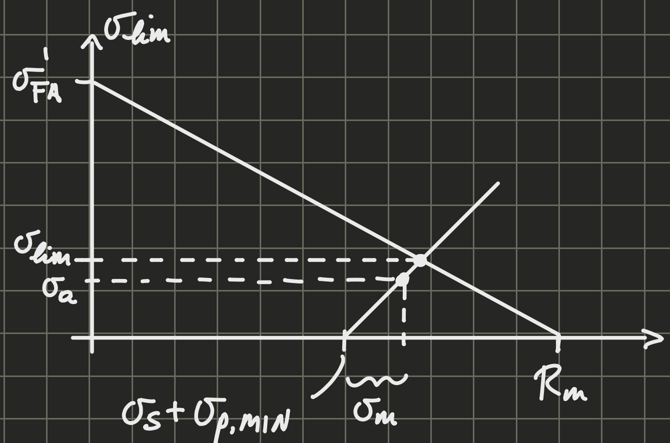
$$\sigma_{p,MIN} = \frac{\frac{k_b}{k_b+k_g} F_{MIN}}{A_3} = \frac{F_{b,MIN} - F_s}{A_3}$$

$$\sigma_{p,MAX} = \frac{\frac{k_b}{k_b+k_g} F_{MAX}}{A_3} = \frac{F_{b,MAX} - F_s}{A_3}$$

$$\sigma_a = \frac{\sigma_{p,MAX} - \sigma_{p,MIN}}{2}$$

$$\sigma_m = \sigma_s + \sigma_{p,MIN} + \sigma_a$$





σ'_{FA} taken from third table $(\sigma_{A,SV} / \sigma_{A,SG})$

$$\sigma_{lim} = \sigma'_{FA} \frac{R_m - (\sigma_s + \sigma_{p,MIN})}{R_m + \sigma'_{FA}}$$

Check: $\eta = \frac{\sigma_{lim}}{\sigma_a}$

Screw name: UNI 5735 M__ x pitch x length - grade

To remember:

- Check if being given in number of cycles or hours
- For the bolt pre-sizing you are finding d_3 not the nominal diameter, so choose based on that.
- READ
- Normal action go to hinges not rollers.
- 1.6 for asynchronous motors