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Axially grooved round profile shaft

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Crimp connection



Shafts:

Dimensioning according to fatigue limit

Akselit:

Jäykän akselin väsymisrajamitoitus



Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

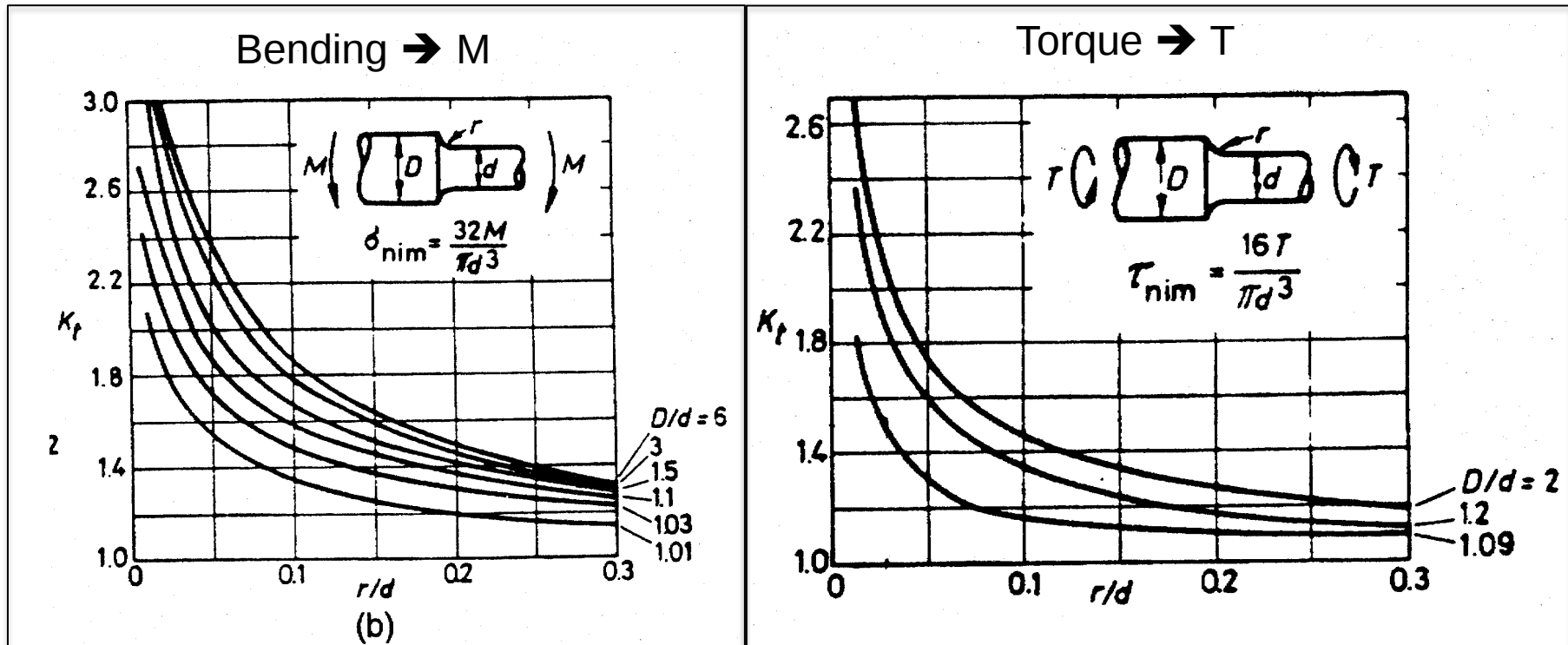
1. Taivutus- ja vääntömomentin määrittäminen	1. Define the bending moment and torque
2. Nimellisten taivutus- ja vääntöjännitysten laskenta σ_{nim} ja τ_{nim}	2. Calculate the nominal stresses σ_{nom} and τ_{nom}
3. Lovenvaikutusluvun K_f laskenta K_{ft} taivutukselle (M) K_{fv} väännölle (T) $K_f = 1 + q(K_t - 1)$ K_t on loven muotoluku q on materiaalin loviherkkyys $q = 0,9$: rakenneteräs S355 ja nuorrutus-teräkset	3. Calculate the fatigue stress concentration factors K_f K_{fb} for bending (M) K_{ft} for torque (T) $K_f = 1 + q(K_t - 1)$ K_t is stress factor of the notch or shoulder q is notch sensitivity of the material $q = 0.9$: structural steel S355 and tempered steels



Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

- K_t stress factors of the shoulder, loven muotolukuja



Bending →

$$K_{fb} = 1 + q(K_t - 1)$$

Torque →

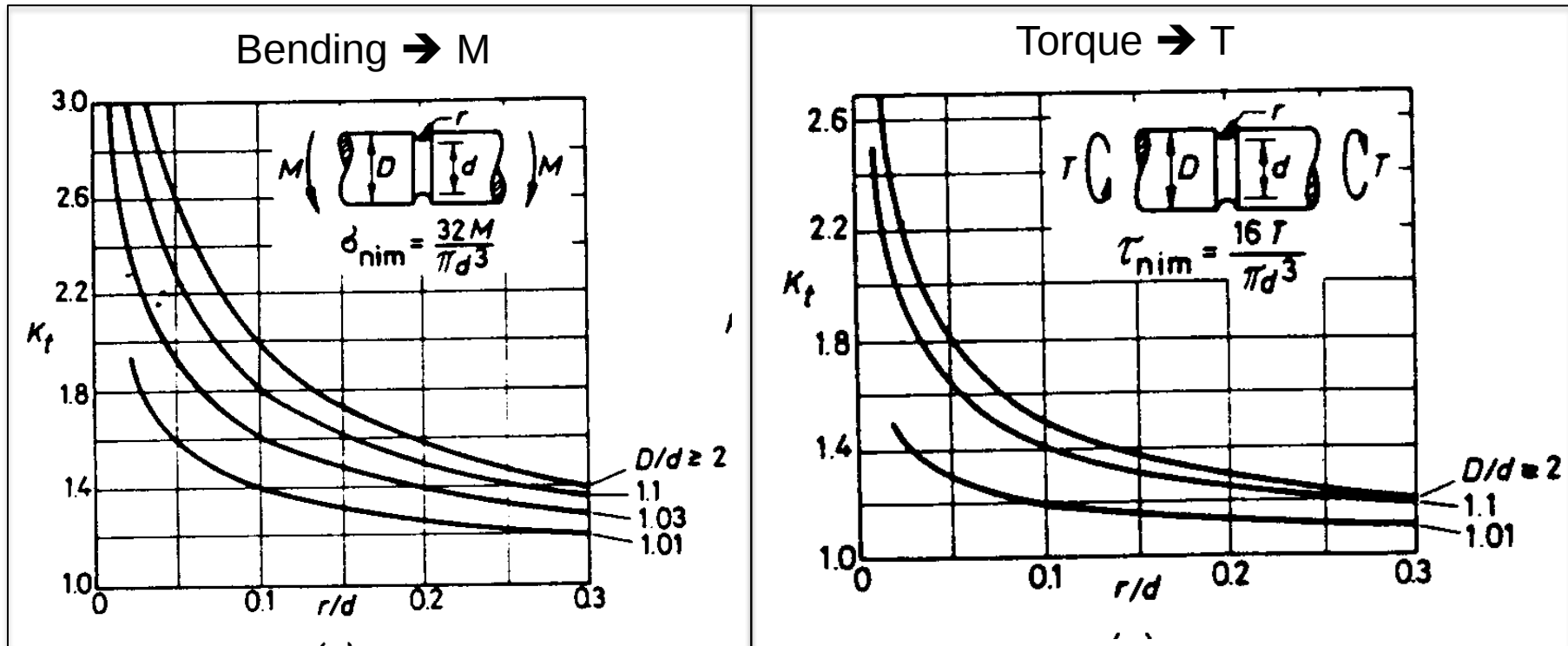
$$K_{ft} = 1 + q(K_t - 1)$$

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Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

- K_t stress factors of the notch, loven muotolukuja



Bending $\rightarrow$

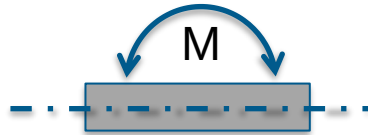
$$K_{fb} = 1 + q(K_t - 1)$$

Torque $\rightarrow$

$$K_{ft} = 1 + q(K_t - 1)$$

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Nimelliset jännitykset / nominal stresses



Max normal stress σ under bending load

$$\sigma_{\text{nom}} = M/W$$

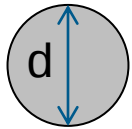
M is bending moment

W is section modulus

- round shaft

$$\sigma = 32M/\pi d^3$$

d is shaft diameter

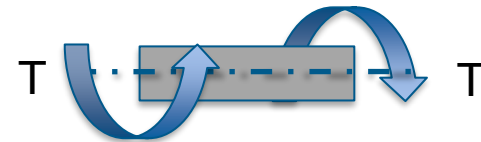
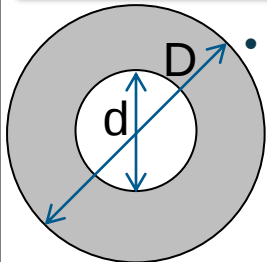


- hollow shaft

$$\sigma = 32MD/\pi(D^4 - d^4)$$

D is outside diameter of the shaft

d is inside diameter of the shaft



Max shear stress τ under torsion load

$$\tau_{\text{nom}} = T/W_v$$

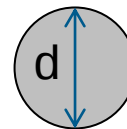
T is torque

W_v is section modulus in torsion

- round shaft

$$\tau = 16T/\pi d^3$$

d is diameter of the shaft

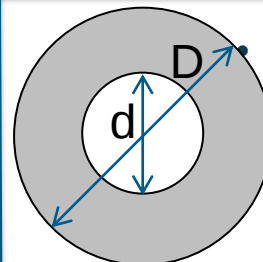


- hollow shaft

$$\tau = 16TD/\pi(D^4 - d^4)$$

D is outside diameter of the shaft

d is inside diameter of the shaft



Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

4. Jännityshuippujen laskenta

- taivutus: $\sigma_{\max} = K_{ft} * \sigma_{nim}$
- vääntö: $\tau_{\max} = K_{fv} * \tau_{nim}$

5. Jännitysamplitudien laskenta

- vaihtokuormitus:
 - $\sigma_a = \sigma_{\max}$ $\tau_a = \tau_{\max}$
- tykyttävä kuormitus:
 - $\sigma_a = \sigma_{\max}/2$ $\tau_a = \tau_{\max}/2$

6. Vertailujännityksen laskenta

$$\sigma_{aver} = \sqrt{\sigma_a^2 + 3\tau_a^2}$$

4. Calculate max stresses

- bending: $\sigma_{\max} = K_{fb} \sigma_{nom}$
- shear stress: $\tau_{\max} = K_{ft} \tau_{nom}$

5. Calculate the stress amplitudes

- reversed fatigue load:
 - $\sigma_a = \sigma_{\max}$ $\tau_a = \tau_{\max}$
- pulsating load:
 - $\sigma_a = \sigma_{\max}/2$ $\tau_a = \tau_{\max}/2$

6. Calculate the reference stress

$$\sigma_{aref} = \sqrt{\sigma_a^2 + 3\tau_a^2}$$



Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

$N > 10^7 \dots 10^8$

7. Materiaalin väsymislujuusarvon etsintä

- taivutusvaihtolujuus σ_{tw}
 - $N > 10^7 \dots 10^8 = \infty$ elinikä
 - materiaalitaulukko seuraavalla sivulla
 - Esim. S355: $\sigma_{tw} = 260 \text{ MPa}$
- tai likimääräisesti jos materiaalitaulukkoja ei ole käytettävissä
 - $\sigma_{tw} = k * R_m$
 - R_m on vetomurtolujuus
 - $k = 0,49$ rakenneteräksille
 - $k = 0,44$ nuorrutusteräksille
 - $k = 0,41$ hiiletysteräksille
 - $k = 0,37$ valuraudoille

7. Define the fatigue strength of the material

- fatigue strength of the material σ_{tw}
 - $N > 10^7 \dots 10^8 = \infty$ lifetime
 - material table next page
 - Example: S355: $\sigma_{tw} = 260 \text{ MPa}$
- or approximately if material tables are not available
 - $\sigma_{tw} = k * R_m$
 - R_m is ultimate tensile strength
 - $k = 0,49$ for structural steels
 - $k = 0,44$ for tempered steels
 - $k = 0,41$ for case hardened steels
 - $k = 0,37$ for cast irons



Shaft Materials

Akselimateriaalit

Steel type Teräksen tyyppi	Symbol, merkintä	Diameter, Halkaisija (mm)	R_m (MPa)	R_e (MPa)	σ_{tw} (MPa)
Structural steel Rakenneteräs	S355J2	...70 (70)...200	490 490	380 350	260
Tempered steel Nuorrutusteräs	25CrMo4	...16 (16)...40	900 800	700 600	430
	25CrMoS4	(40)...100 (100)...160	700 650	450 400	
	42CrMo4	...16 (16)...40	1100 1100	900 750	520
	42CrMoS4	(40)...100 (100)...160 (160)...250	900 800 750	650 550 500	
	34CrNiMo6	...16 (16)...40 (40)...100 (100)...160 (160)...250	1200 1100 1000 900 800	1000 900 800 700 600	540
	20NiCrMo2-2	...11 (11)...30 (30)...63	980 740 640	640 490 390	580
	20MnCr5	...11 (11)...30 (30)...63	1080 980 780	740 690 540	600
	18CrNiMo7-6	...11 (11)...30 (30)...63	1180 1080 980	830 780 690	650
Case hardening steel Hiiletysteräs					

Lujuusarvot suuntaa-antavia

R_m on min vetomurtolujuus

R_e min myötöraja

σ_{tw} on taivutusvaihtolujuus

The values are only suggestive

R_m is min ultimate tensile strength

R_e is min yield stress

σ_{tw} is fatigue resistance under pulsation

Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

$$N < 10^7$$

7. Materiaalin väsymislujuusarvon etsintä

- Taivutuskestolujuus, kun kuormituskertojen määrä
 - $N < 10^7$
- σ_{tw} korvataan σ_{tN} -arvolla

7. Define the fatigue strength of the material

- limited fatigue resistance under pulsation, when number of loads
 - $N < 10^7$
- σ_{tw} will be replaced by σ_{tN}

R_m on
vetomurtolujuus

N	σ_{tN}
1000	$0,85 * R_m$
10 000	$0,75 * R_m$
100 000	$0,60 * R_m$

R_m is ultimate
tensile strength

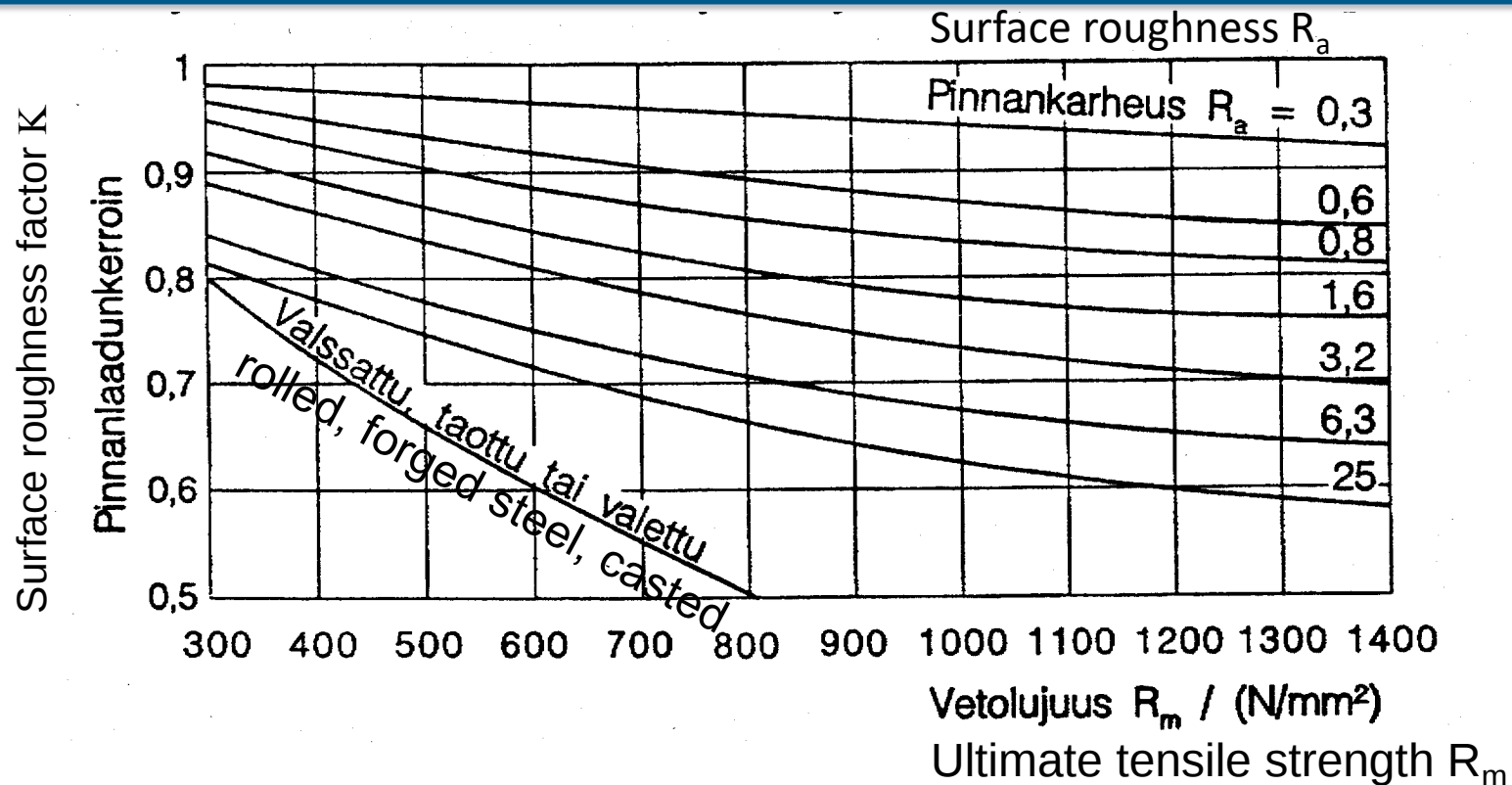


Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

8. Määrittele pinnanlaadun kerroin κ

8. Define the surface factor κ



Dimensioning according to fatigue limit

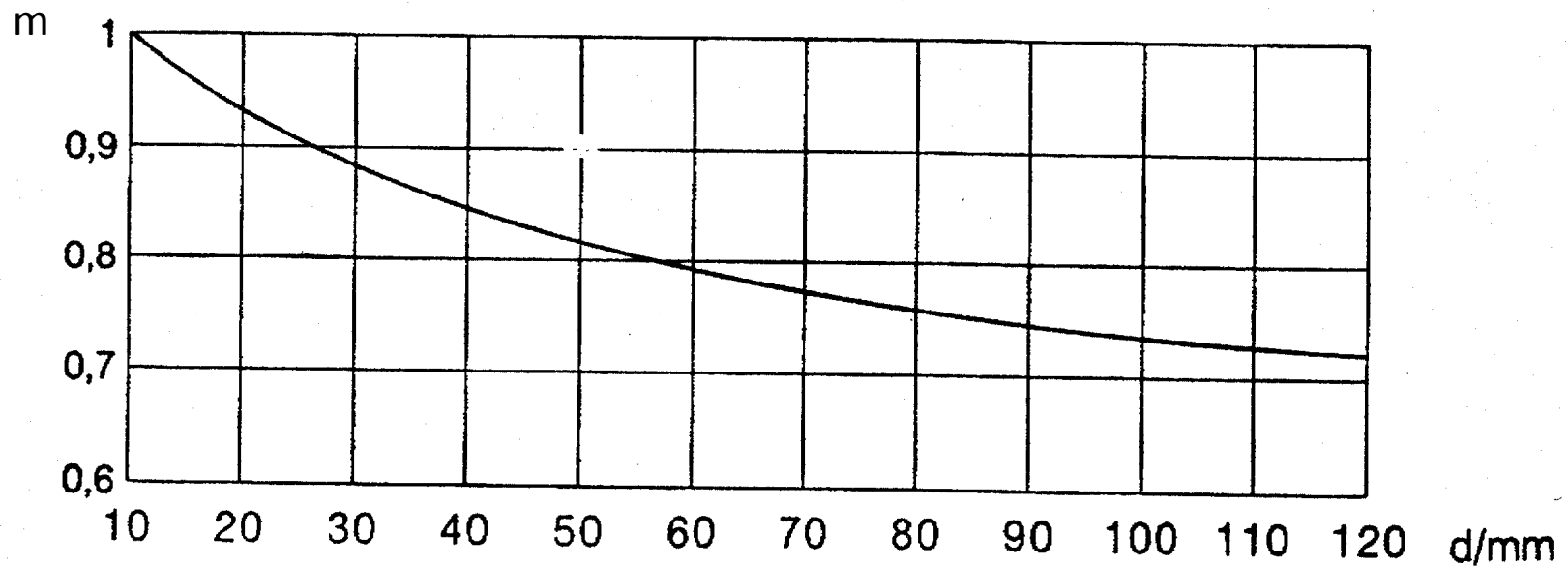
Jäykän akselin väsymisrajamitoitus

9. Määrittele kokokerroin m

d on akselin suurin halkaisija [mm]

9. Define the scale factor m

d is max diameter of the shaft [mm]



Dimensioning according to fatigue limit

Jäykän akselin väsymisrajamitoitus

10. Varmuusluvun laskenta

- sekä taivutus että vääntö

$$n = \frac{m \kappa \sigma_{tw}}{\sigma_{aver}}$$

- pelkkä taivutus

$$n = \frac{m \kappa \sigma_{tw}}{K_{fb} \sigma_{nim}}$$

- varmuuskerroin $n > (1,5...) 2...$

10. Calculate the safety factor

- both bending and torsion

$$n = \frac{m \kappa \sigma_{tw}}{\sigma_{aref}}$$

- only bending

$$n = \frac{m \kappa \sigma_{tw}}{K_{fb} \sigma_{nom}}$$

- safety factor $n > (1.5...) 2...$



Shaft connections with form

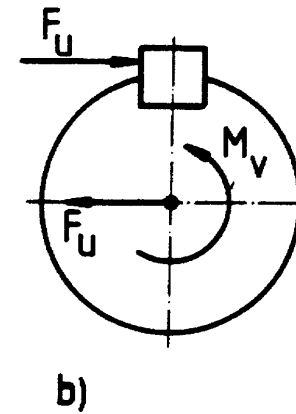
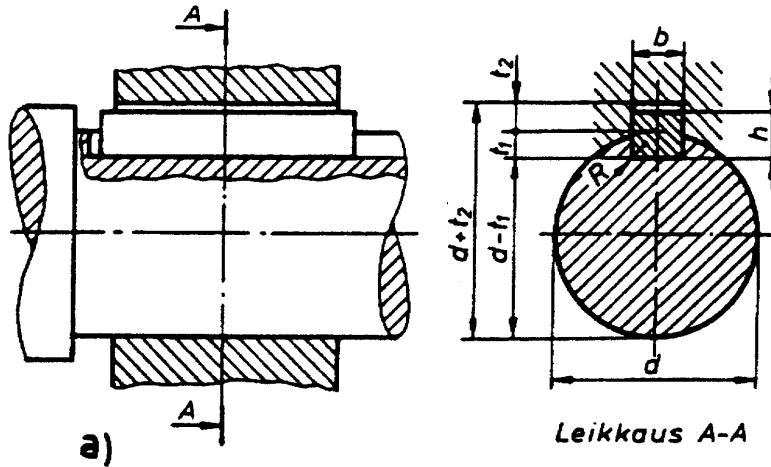
Muotosulkeiset akseliliitokset



Parallel key
Tasakiilaliitokset



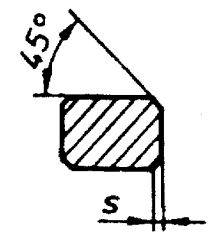
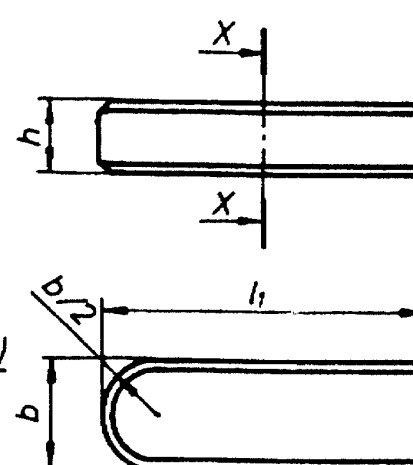
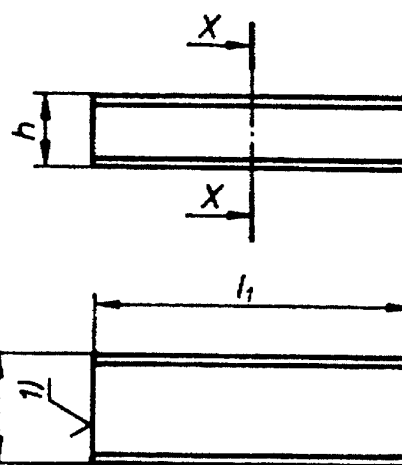
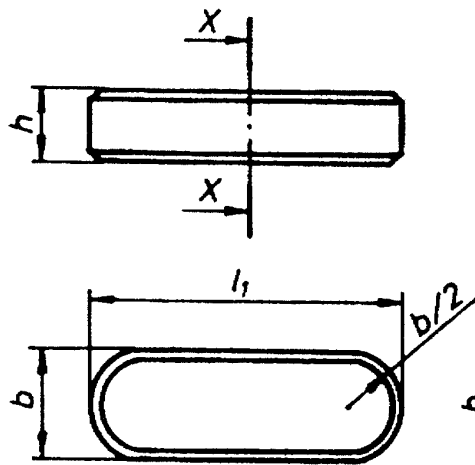
Parallel key, Tasakiila



A-type

B-type

C-type

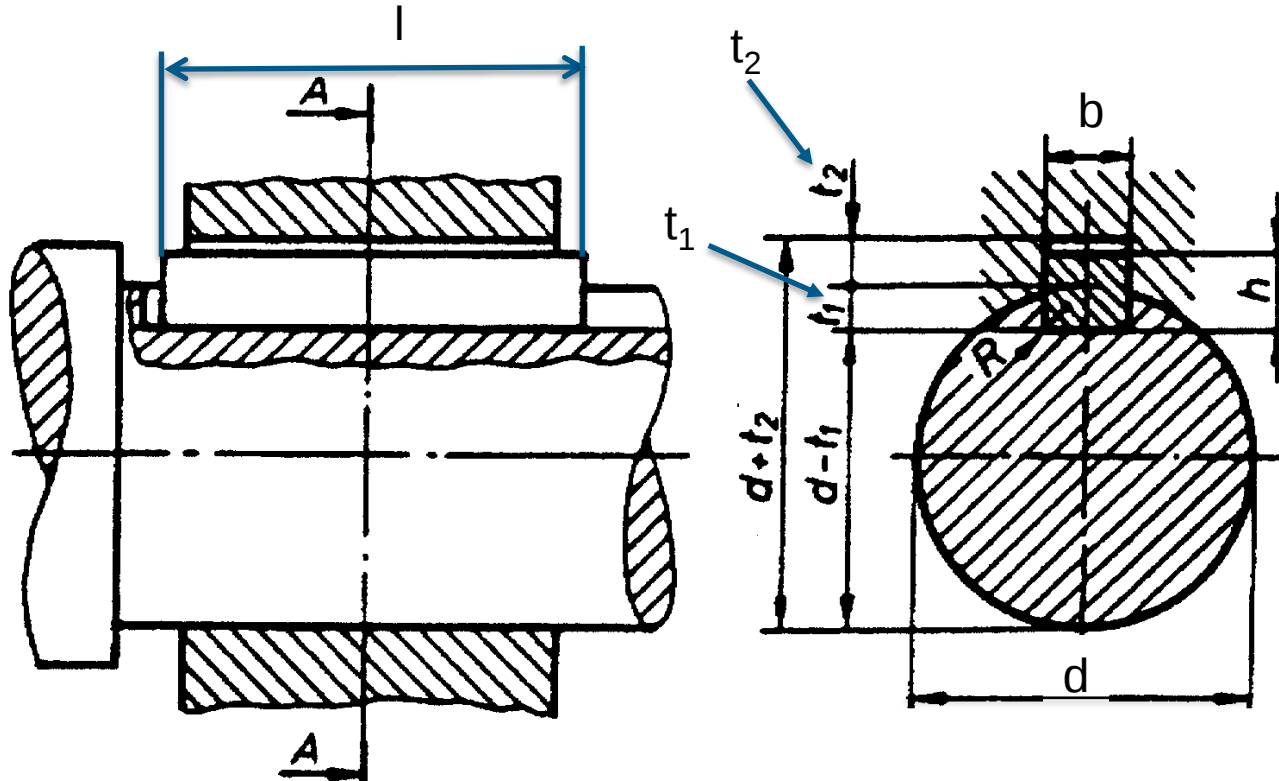


Leikkaus X-X



Parallel key, Tasakiila

B -18 x 11 x 44
↑ ↑ ↑ ↑
type b h l



t_1 = akselin kiilauran syvyys / is the depth of the key slot in the shaft
 t_2 = navan kiilauran syvyys / is the depth of the key groove in the hub
 l = kiilan pituus / is the length of the key
 b = kiilan leveys / is the width of the key

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Suostellut kiilan pituudet
Recommended lengths of parallel keys

Parallel keys SFS 2636 (dimensions in mm)															
Width		5	6	8	10	12	14	16	18	20	22	25	28	32	
Height		5	6	7	8	8	9	10	11	12	14	14	16	18	
Shaft diameter	>	12	17	22	30	38	44	50	58	65	75	85	95	110	
	≤	17	22	30	38	44	50	58	65	75	85	95	110	130	
Depth t ₁		3	3.5	4	5	5	5.5	6	7	7.5	9	9	10	11	
Depth t ₂		2.3	2.8	3.3	3.3	3.3	3.8	4.3	4.4	4.9	5.4	5.4	6.4	7.4	
Recommended lengths	Length l ₁	10	x												
		12	x												
		14	x	x											
		16	x	x											
		18	x	x	x										
		20	x	x	x										
		22	x	x	x	x									
		25	x	x	x	x									
		28	x	x	x	x	x								
		32	x	x	x	x	x								
		36	x	x	x	x	x	x							
		40	x	x	x	x	x	x							
		45	x	x	x	x	x	x	x						
		50	x	x	x	x	x	x	x	x					
		56	x	x	x	x	x	x	x	x	x				
		63		x	x	x	x	x	x	x	x	x			
		70		x	x	x	x	x	x	x	x	x	x		
		80			x	x	x	x	x	x	x	x	x	x	
		90			x	x	x	x	x	x	x	x	x	x	x
		100				x	x	x	x	x	x	x	x	x	x
		110				x	x	x	x	x	x	x	x	x	x
		125					x	x	x	x	x	x	x	x	x
		140					x	x	x	x	x	x	x	x	x
		160						x	x	x	x	x	x	x	x
		180							x	x	x	x	x	x	x
		200									x	x	x	x	x
		220										x	x	x	x
		250											x	x	x

Tasakiila / Parallel key

- vääntömomentin siirtokyky navalle
 - p_h on navan pintapaine, $p_h \leq p_{all}$
 - p_{all} taulukko 4.3-6
 - l on kiilan pituus,
 - ohjearvo $l = 1,5d$ ($0,7d < l < 2,5d$)
 - d on akselin halkaisija
 - t_2 on navan kiilauran syvyys
- Torque transmission capacity of the hub
 - p_h is the surface pressure of the hub, $p_h \leq p_{all}$
 - p_{all} table 4.3-6
 - l is the length of the key,
 - recommended value $l = 1.5d$ ($0.7d < l < 2.5d$)
 - d is the diameter of the shaft
 - t_2 is the depth of the key slot in the hub

$$T_{hub} = \frac{p_h * l * t_2 * (d + t_2)}{2}$$



Tasakiila / Parallel key

- vääntömomentin siirtokyky akselille

- p_s on akselin pintapaine,
- $p_s \leq p_{all}$
- p_{all} taulukko 4.3-6
- d on akselin halkaisija
- t_1 on akselin kiilauran syvyys

- Torque transmission capability of the shaft

- p_s is the surface pressure of the shaft,
- $p_s \leq p_{all}$
- p_{all} table 4.3-6
- d is the diameter of the shaft
- t_1 is the depth of the key slot in the shaft

$$T_{\text{shaft}} = \frac{p_s * l * t_1 * (d - t_1)}{2}$$



Taulukko / table 4.3-6

p_0

Basic surface pressure p_0 (MPa)				Alumiinivaluja / cast aluminium grades		
Steel Cast steel S355J2	Grey cast iron Harmaa-valurauta	Spheroidal iron Pallografiitti-valurauta	Bronze Brass Pronssi, messinki	AlCuMg	AlMg AlMn AlMnSi	G-AlSi G-AlSiMg
150 200 (hardened)	90	110	50	100	90	70

p_{all}

Allowable surface pressures p_{all} for parallel keys and axially grooved or toothed profile shafts		
One-way static load	$0.8p_0$	Yksisuuntainen kuormitus, lepokuormitus
One-way load with light impacts	$0.7p_0$	Yksisuuntainen kuormitus, kevyitä iskuja
One-way load with hard impacts	$0.6p_0$	Yksisuuntainen kuormitus, kovia iskuja
Two-way load with light impacts	$0.45p_0$	vaihtosuuntainen kuormitus, kevyitä iskuja
Two-way load with heavy impacts	$0.25p_0$	vaihtosuuntainen kuormitus, kovia iskuja

P_{all} depends on the load type,

P_{all} riippuu kuormitustyyppistä

ei suositeltu kiilaliitokselle / not recommended for parallel key

Parallel key

- Torque transmission capacity of the key (shear stress)

- τ is shear stress, $\tau \leq \tau_{\text{sall}}$ (table 4.3-7)
- A is cutting surface area of the parallel key

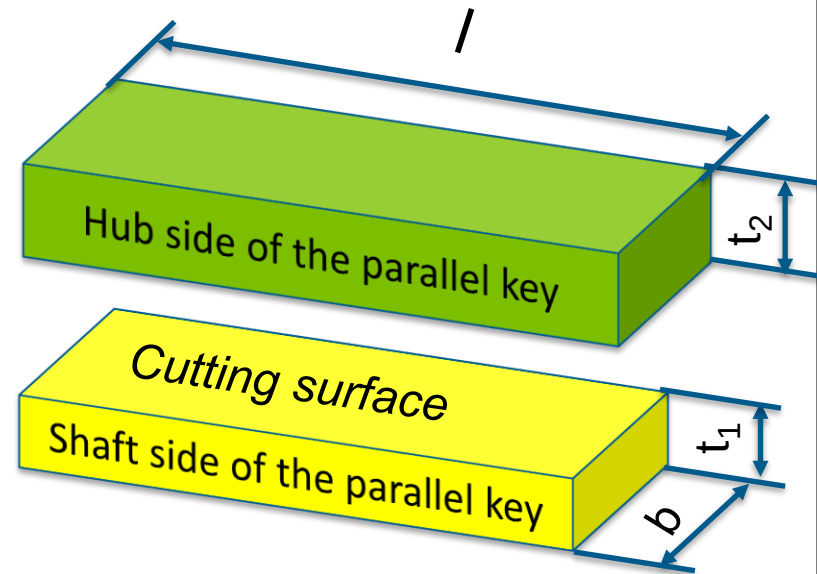
$$A = l * b$$

l is the length

b is the width of the parallel key

Typically surface pressure of the shaft and hub are the critical points, but it is always recommended to check shear stress capacity of the parallel key

$$T_{\text{key}} = \frac{\tau * A * d}{2}$$



valuteräs
harmaa valurauta
pronssi, messinki

materiaali	kuormitus- tyyppi	puristusylimitta			urallinen tai lovettu tapin kohta			Equal to parallel key Vastaa periaatteellisesti kiilaa		
Material of the parts round the steel pin	Load type	Press fit			Grooved or slot part of the pin			Loose, smooth pin		
		p MPa	σ MPa	τ MPa	p MPa	σ MPa	τ MPa	p MPa	σ MPa	τ MPa
S235 S355 Cast steel Grey cast iron Bronze, brass AlCuMg-alloys AlSi	Static load Staattinen	98 104 83 68 40 65 45	190	80	69 73 58 48 28 46 32	160	65	30 30 30 40 40 20 20	200	80
S235 S355 Cast steel Grey cast iron Bronze, brass AlCuMg-alloys AlSi	Pulsating load pulseeraava	72 76 62 52 29 47 33	145	60	52 55 43 36 21 35 24	120	50	24 24 24 32 32 16 16	140	60
S235 S355 Cast steel Grey cast iron Bronze, brass AlCuMg-alloys AlSi	Reversed fatigue load vaihtokuormitus	37 38 31 26 14 23 16	75	30	26 28 21 18 10 17 12	60	25	12 12 12 16 16 8 8	70	30

p = surface pressure σ = normal stress of bending

τ = shear stress

p = pintapaine

σ = taivutusjännitys

τ = leikkausjännitys 23

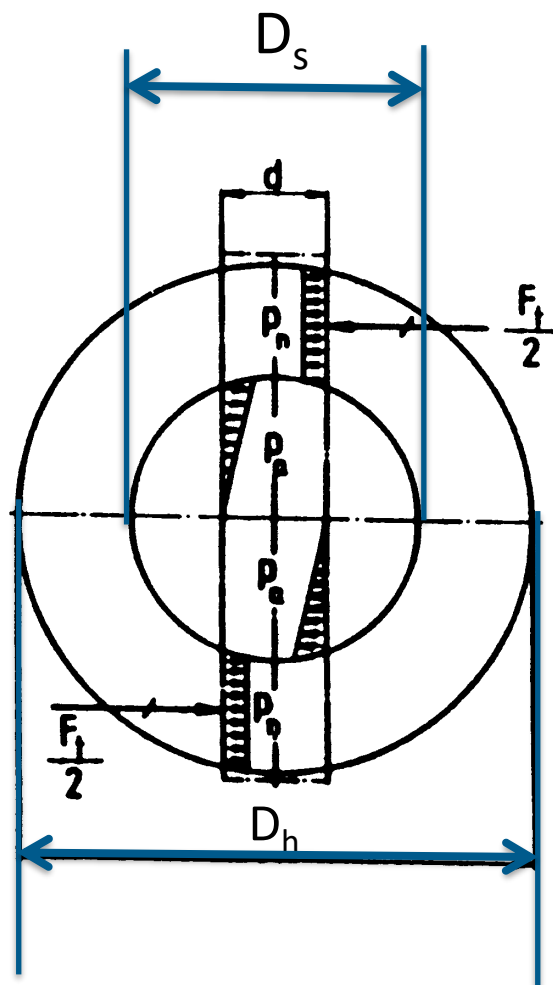
Transverse clevis pin

Poikittaislieriötappi akselin ja navan
välillä



Transverse clevis pin

Poikittaislieriötappi akselin ja navan välillä



D_h is the outside diameter of the hub
 D_s is the outside diameter of the shaft
 d is the diameter of the pin

D_h on navan ulkohalkaisija
 D_s on akselin ulkohalkaisija
 d on tapin halkaisija

Transverse clevis pin

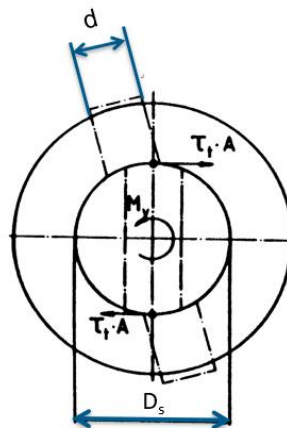
Poikittaislieriötappi akselin ja navan välillä

- navan siirtämä vääntömomentti
- torque transmission capacity of the hub

$$T_{\text{hub}} = \frac{p_h * (D_h^2 - D_s^2) * d}{4}$$

- D_h on navan ulkohalkaisija
- D_s on akselin ulkohalkaisija
- d on tapin halkaisija
- p_h on navan pintapaine
- $p_h \leq p_{\text{all}}$ (taul. 4.3-7)

- D_h is the outside diameter of the hub
- D_s is the outside diameter of the shaft
- d is the diameter of the pin
- p_h is the surface pressure of the hub,
- $p_h \leq p_{\text{all}}$ (table 4.3-7)



Transverse clevis pin

Poikittaislieriötappi akselin ja navan välillä

- akselin siirtämä vääntömomentti
- torque transmission capacity of the shaft

$$T_{\text{shaft}} = \frac{p_h * D_s^2 * d}{6}$$

- D_s on akselin ulkohalkaisija
- d on tapin halkaisija
- p_h on navan pintapaine
- $p_h \leq p_{\text{all}}$ (taul. 4.3-7)

- D_s is the outside diameter of the shaft
- d is the diameter of the pin
- p_h is the surface pressure of the hub,
- $p_h \leq p_{\text{all}}$ (table 4.3-7)



Transverse clevis pin

Poikittaislieriötappi akselin ja navan välillä

- tapin siirtämä vääntömomentti
- torque transmission capacity of the pin

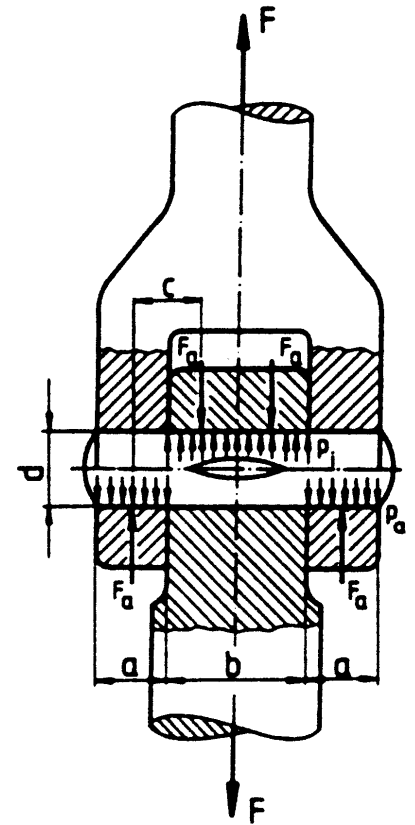
$$T_{\text{pin}} = \frac{\tau_p * \pi * d^2 * D_s}{4}$$

- τ_p on tapin leikkausjännitys ,
- $\tau_p \leq \tau_{\text{sall}}$ (taul. 4.3-7)
- d on tapin halkaisija
- D_s on akselin ulkohalkaisija
- τ_p is the shear stress of the pin,
- $\tau_p \leq \tau_{\text{all}}$ (table 4.3.-7)
- D_s is the outside diameter of the shaft
- d is the diameter of the pin



Transverse clevis pin
between a tension bar and
a forked bracket

Poikittaislieriötappi
vetotangon ja haarukan
liitoksessa



Poikittaislieriötappi vetotangon ja haarukan liitoksessa

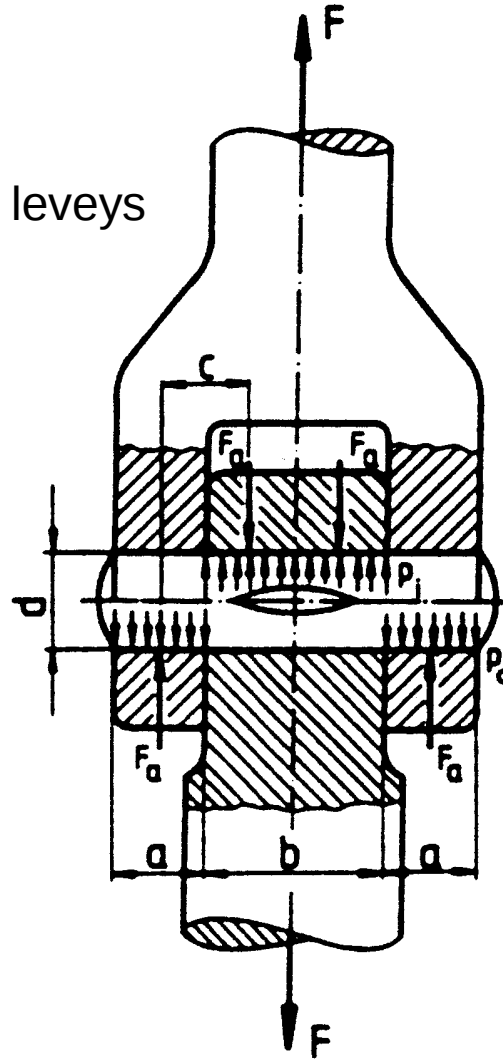
Transverse clevis pin between a tension bar and a forked bracket

Mitat

d = tapin halkaisija
 a = haarukan toisen puolen leveys
 b = vetotangon leveys

Dimensions

d = diameter of pin
 a = width of one half of the fork
 b = width of the bar



Poikittaislieriötappi vetotangon ja haarukan liitoksessa

Transverse clevis pin between a tension bar and a forked bracket

- tapin taivutusjännitys
- bending stress of the pin
- $W_t = 0,1 * d^3$
- W_t on tapin taivutusvastus
- W_t is the section modulus of the pin
- $\sigma_{p,all}$ taulukko 4.3-7
- $\sigma_{p,all}$ table 4.3-7

$$\sigma_p = \frac{M_v}{W_t} \leq \sigma_{p,all}$$

$$\sigma_p = \frac{F * (a + 0,5 * b)}{4 * W_t} = \frac{F * (a + 0,5 * b)}{4 * 0,1 * d^3} \leq \sigma_{p,all}$$

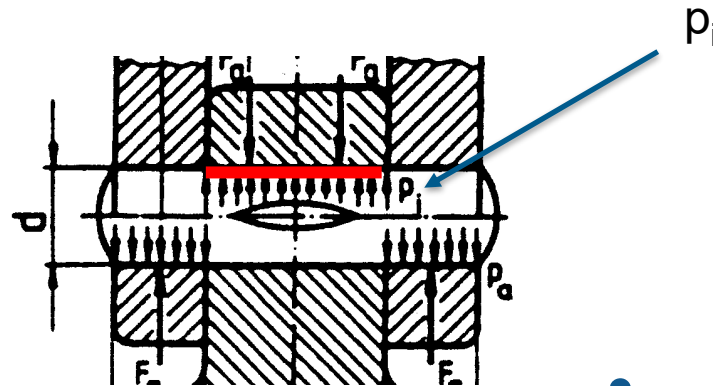


Poikittaislieriötappi vetotangon ja haarukan liitoksessa

Transverse clevis pin between a tension bar and a forked bracket

- tapin ja tangon välinen pintapaine
- surface pressure between the pin and the bar
- $p_{i,all}$ taulukko 4.3-7
- $p_{i,all}$ table 4.3-7

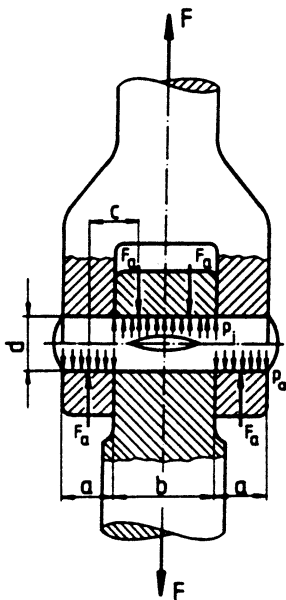
$$p_i = \frac{F}{b * d} \leq p_{i,all}$$



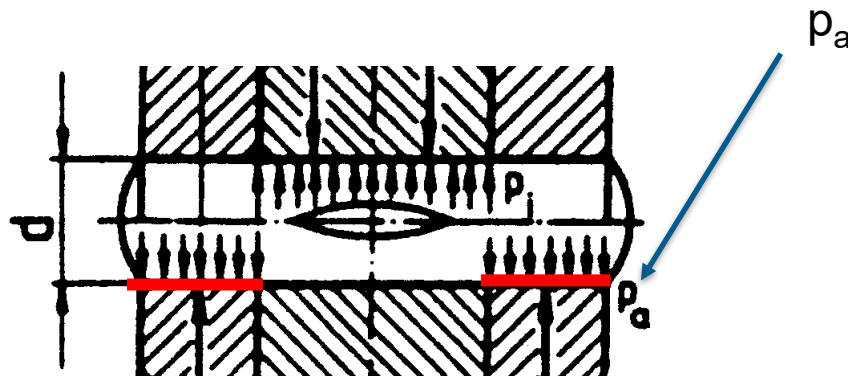
Poikittaislieriötappi vetotangon ja haarukan liitoksessa

Transverse clevis pin between a tension bar and a forked bracket

- tapin ja haarukan silmukoiden välinen pintapaine
- surface pressure between the pin and the fork
- $p_{a,all}$ taulukko 4.3-7
- $p_{a,all}$ table 4.3-7



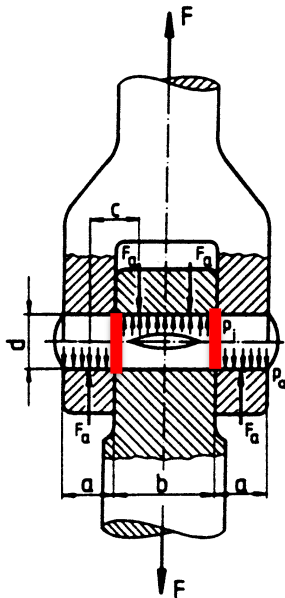
$$p_a = \frac{F}{2 * a * d} \leq p_{a,all}$$



Poikittaislieriötappi vetotangon ja haarukan liitoksessa

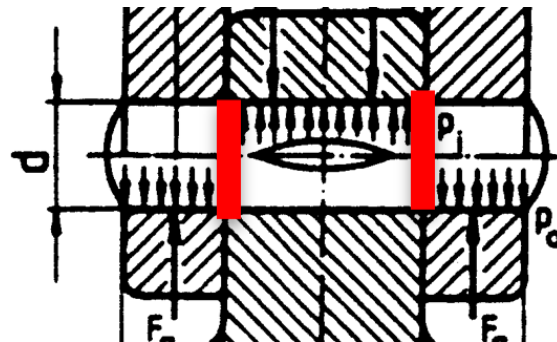
Transverse clevis pin between a tension bar and a forked bracket

- tapin leikkausjännitys
 - shear stress of the pin
-
- $\tau_{p,all}$ taulukko 4.3-7
 - $\tau_{p,all}$ table 4.3-7



$$\tau_a = \frac{F}{2 * A} = \frac{2 * F}{\pi * d^2} \leq \tau_{p,all}$$

$$A = \frac{\pi * d^2}{4}$$



Profile shafts

Axially grooved round profile shaft

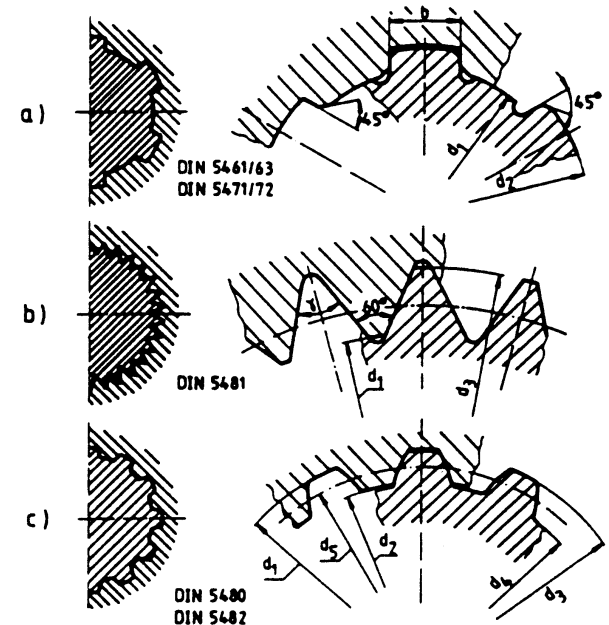
Profiiliakselit

Aksiaalisuunnassa uritettu pyöreä profiiliakseli

a) Tasopintaiset hampaat
Teeth profile: flat

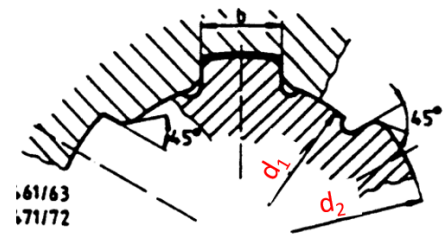
b) Sahaprofiilihampaat
Teeth profile: saw

c) Sahaprofiiliakseli elvoventtihampain
Teeth profile: involute



Aksiaalisuunnassa uritettu pyöreä profiiliakseli

Axially grooved round profile shaft



Vääntömomentin siirtokyky / torque transmission capacity

$$T = \frac{F_u * d_m}{2} = \frac{F_n * \cos \alpha * d_m}{2} = \frac{p * h * l * z * q * \cos \alpha * d_m}{2}$$

F_u on kehävoima / is the twisting force

F_n on normaalivoima / is the normal force

h on hampaan tehollinen korkeus, / is the effective height of the tooth

$$h = (d_2 - d_1) / 2$$

d_1 on tyvihalkaisija / the butt diameter,

d_2 on päähalkaisija / d_2 is the tip diameter

ura-akselille / for a spline shaft: $h = t'$

d_m on keskihalkaisija / the mean diameter

$$d_m = (d_1 + d_2) / 2$$

l on hampaan pituus aksiaalisuunnassa / the axial length of the tooth

α on ryntökulma

$\alpha = 0$ ura-akselille / for a spline shaft

$\alpha = 30^\circ$ evolventtihampaille / for an involute tooth

q on kantokerroin / the bearing factor,

$q = 0,75 \dots 0,80$ ura-akselille / for a spline shaft

$q = 0,80$ evolventtihampaille / for an involute tooth

z on hammasluku / the number of teeth

p on pintapaine / the surface pressure,

$$p \leq p_{all} \text{ (taulukko / table 4.3-6)}$$



Ura-akselin mittoja / Dimensions of spline shafts dimensions [mm]

Kevyt sarja (DIN 5462) Light series Nimellismitat / nominal dimensions					Keskisarja (DIN 5463) Medium series Nimellismitat / nominal dimensions				
z	d ₁	d ₂	b	t'	z	d ₁	d ₂	b	t'
6	23	26	6	0.9	6	11	14	3	0.9
6	28	32	7	1.4	6	16	20	4	1.4
					6	23	28	6	1.9
					6	28	34	7	2.2
8	32	36	6	1.2	8	32	38	6	2.2
8	46	50	9	1.2	8	46	54	9	3.0
8	62	68	12	2.0	8	62	72	12	4.0
10	72	78	12	2.0	10	72	82	12	4.0
10	112	120	18	3.0	10	112	125	18	5.5



Shaft connections with friction

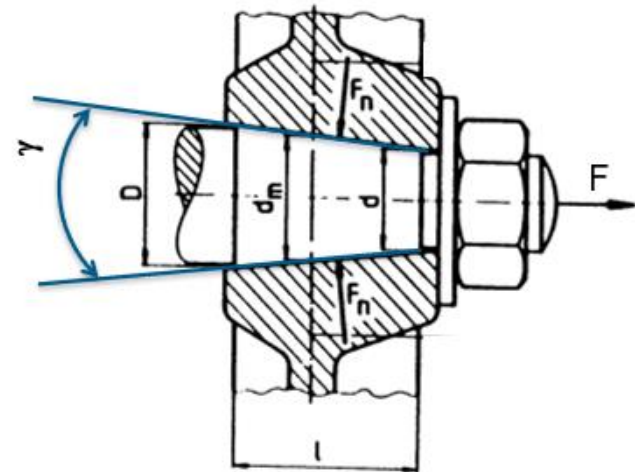
Kitkasulkeiset akseliliitokset



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Taper connection

Aksiaalinen kartiokiristysliitos

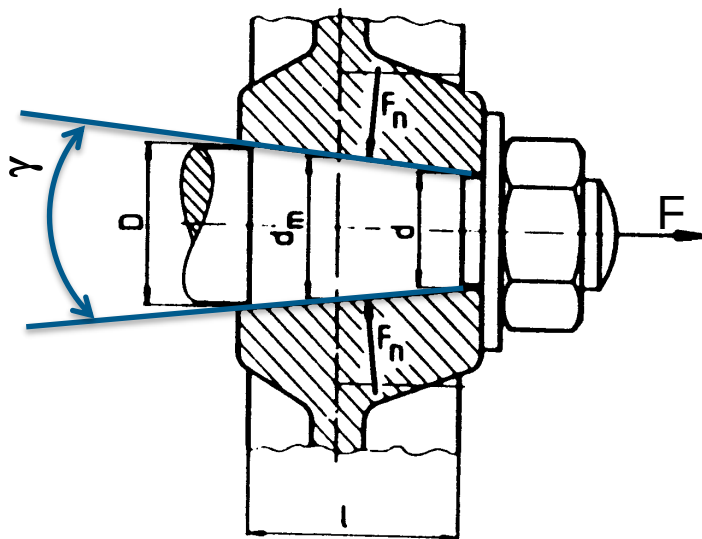


Aksiaalisesti kiristetty kartioliitos

Taper connection

vääntömomentin siirtokyky / torque transmission capacity

$$T = \frac{\mu * F_n * d_m}{2} = \frac{\mu * F * d_m}{2 * [\sin(0,5 * \gamma) + \mu * \cos(0,5 * \gamma)]}$$

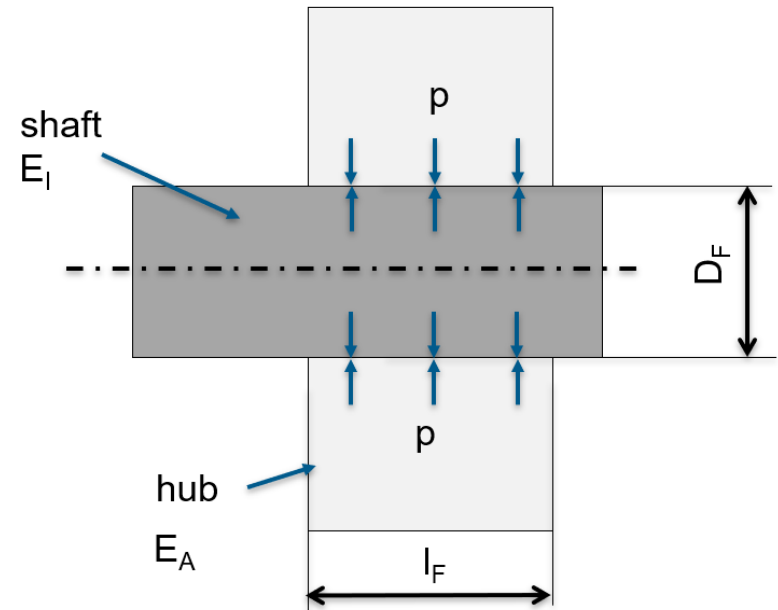


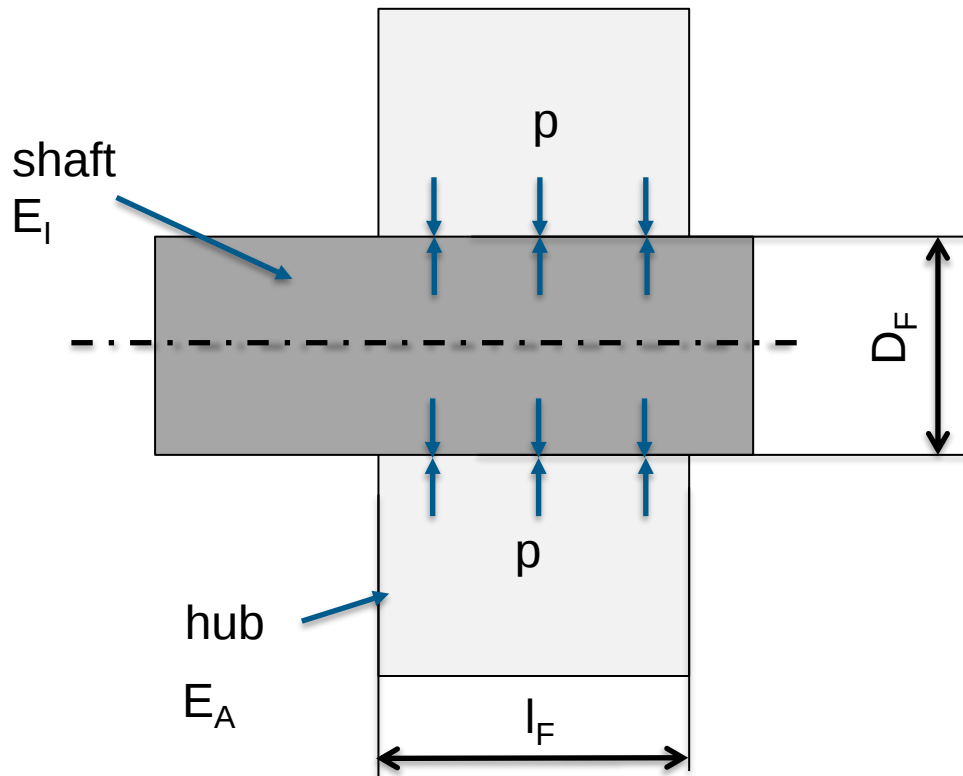
- F_n on normaalivoima / normal force
- F on aksiaalinen kiristysvoima / axial tensioning force
- γ on kartiokulma asteissa / taper angle
- μ on kitkakerroin / friction coefficient
 - $\mu = 0,25 \dots 0,30$ voitelemattomille pinnoille / non lubricated surfaces
- d_m on keskihalkaisija / mean diameter
 - $d_m = (D + d) / 2$
- D on akselin halkaisija (kartiotapin suurempi halkaisija) / shaft diameter (bigger diameter)
- d on kartiotapin pienempi halkaisija (ruuvien nimellishalkaisija) / the smaller diameter (nominal diameter of the screw)



Crimp connection

Puristusliitos





- D_F = liitospinnan nimellinen halkaisija / nominal diameter of the connection
- l_F = liitoksen pituus / axial length of the connection
- p kutistuspaine / surface pressure



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- vääntömomentin siirtokyky / torque transmission capacity

$$T = \frac{\pi * D_F^2 * l_F * v_{rl} * p}{2 * S_r} \quad (1)$$

- D_F on liitospinnan halkaisija (nimellismitta) / nominal diameter of the connection
- l_F on liitoksen pituus / axial length of the connection
- p on kutistusaine, pintapaine / shrink pressure (surface pressure)
- v_{rl} on tartuntakerroin tangentialsuunnassa liukumiseen nähden / is the grip coefficient factor against tangential sliding
 - arvot taulukossa 1. / values in table 1.
- S_r on varmuusluku liukumiseen nähden / is the safety factor towards the sliding:
 - $S_r = 1,5$ staattinen kuorma / static load
 - $S_r = 1,8$ tykyttävä kuorma / pulsating load
 - $S_r = 2,2$ vaihtokuormitus / reversed fatigue load



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- aksiaalivoiman siirtokyky / axial force transmission capacity

$$F_{ax} = \frac{\pi * D_F * l_F * v_{rl} * p}{S_r} \quad (2)$$

- D_F on liitospinnan halkaisija (nimellismitta) / nominal diameter of the connection
- l_F on liitoksen pituus / axial length of the connection
- p on kutistusaine, pintapaine / shrink pressure (surface pressure)
- v_{rl} on tartuntakerroin tangentialis suunnassa liukumiseen nähden / is the grip coefficient factor against tangential sliding
 - arvot taulukossa 1. / values in table 1.
- S_r on varmuusluku liukumiseen nähden / is the safety factor towards the sliding:
 - $S_r = 1,5$ staattinen kuorma / static load
 - $S_r = 1,8$ tykyttävä kuorma / pulsating load
 - $S_r = 2,2$ vaihtokuormitus / reversed fatigue load



Puristusliitos ja kutistusliitos

Crimp and shrink connection

Material of the hub	Grip coefficient	
	Dry	Lubricated
	ν_{rl}	ν_{rl}
Structural steel	0.08	0.07
Cast steel	0.08	0.07
Stainless steel	0.09	0.06
Grey cast iron	0.11	0.05
Spheroidal iron	0.09	0.05

Taulukko 1.
Table 1.

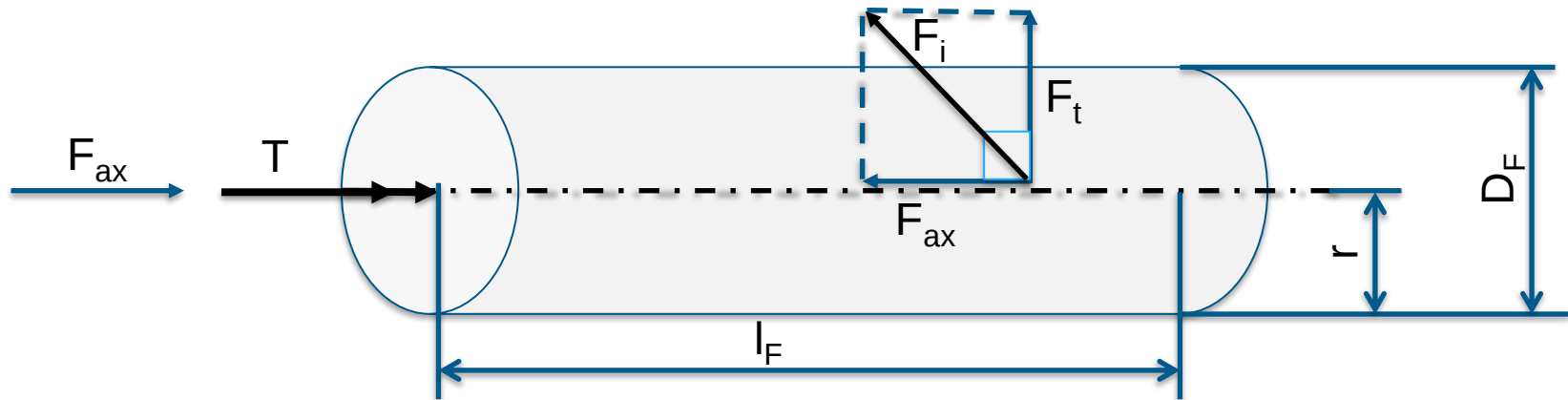
Grip coefficients factors against sliding
(for one-way load and steel shafts)



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- yhdistetty kuormitus: vääntömomentti T ja aksiaalivoima F_{ax}
- combined load: torque T and axial load F_{ax}



F_t = tangential force

F_{ax} = axial force

F_i = Resultant force

$$F_i = \sqrt{F_t^2 + F_{ax}^2}$$

Torque $T = F_t * r$

$$r = \frac{D_F}{2}$$

$$F_t = \frac{2 * T}{D_F}$$

Puristusliitos ja kutistusliitos

Crimp and shrink connection

- kun liitosta rasittaa yhtäaikaaisesti vääntömomentti M_v ja aksiaalivoima F_{ax}
- combined load: T and F_{ax}

Resultant $F_i = \sqrt{F_t^2 + F_{ax}^2}$

Tangential force $F_t = \frac{2 * T}{D_F}$

$$F_i = \sqrt{\left(2 * \frac{T}{D_F}\right)^2 + F_{ax}^2} \quad (3)$$

Dimensioning rule: $F_i < \pi * D_F * l_F * v_r * \frac{p}{S_r}$ (4)

- S_r on varmuusluku liukumiseen nähden / is the safety factor towards the sliding:
 - $S_r = 1,5$ staattinen kuorma / static load
 - $S_r = 1,8$ tykyttävä kuorma / pulsating load
 - $S_r = 2,2$ vaihtokuormitus / reversed fatigue load

Puristusliitos ja kutistusliitos

Crimp and shrink connection

- todellinen sovite / actual fit ("real life" connection)

$$|P_i| = D_{iA} - D_{al} \quad (5)$$

D_{aA} on navan ulkohalkaisija / the outside diameter of the hub

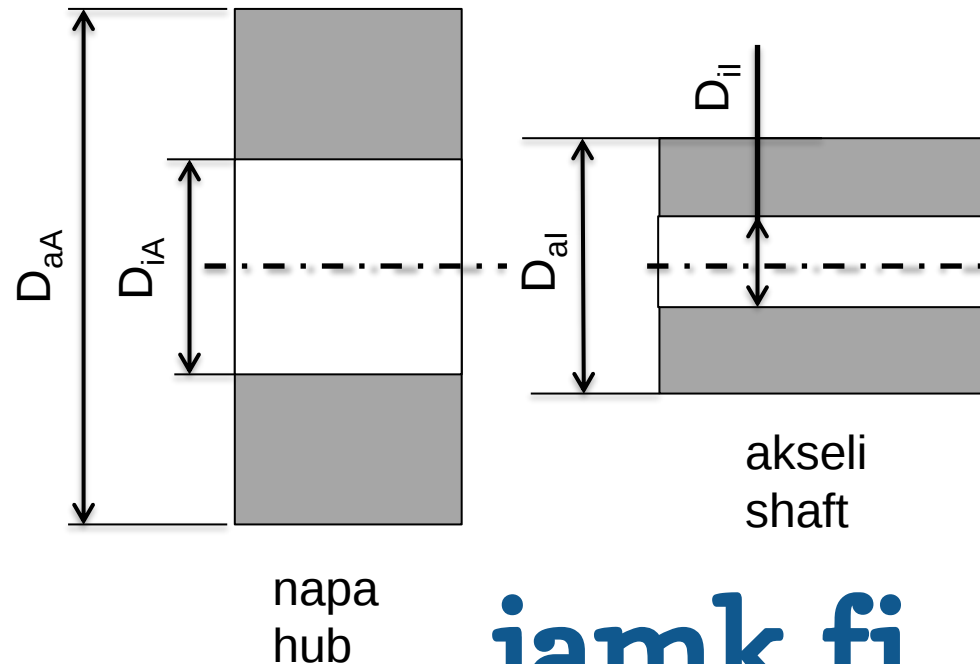
D_{iA} on navan sisähalkaisija / the inside diameter of the hub

D_{al} on akselin ulkohalkaisija / the outside diameter of the shaft

D_{il} on akselin sisähalkaisija / the inside diameter of the shaft

Actual fit can be defined by measuring "real life" parts:

- shaft
- hub



Puristusliitos ja kutistusliitos

Crimp and shrink connection

Itseisarvo $|X_x|$
absolute value $|X_x|$

- Toleransseihin perustuva sovite / fit based on tolerances of the parts
- minimiahdistus / minimum crimp

$$|P_o| = |A_{oA}| - |A_{ul}| \quad (6)$$

– Akseli halkaisijaltaan alarajalla & navan reikä ylärajalla / min shaft dia & max hub hole dia

- maksimiahdistus / maximum crimp

$$|P_u| = |A_{uA}| - |A_{ol}| \quad (7)$$

– Akseli halkaisijaltaan ylärajalla & napa alarajalla / max shaft dia & min hub hole dia

A_{oA} on navan sisähalkaisijan yläeromitta / the upper deviation of the inside diameter of the hub

A_{uA} on navan sisähalkaisijan alaeromitta / is the lower deviation of the inside diameter of the hub

A_{ol} on akselin ulkohalkaisijan yläeromitta / is the upper deviation of the outside diameter of the shaft

A_{ul} on akselin ulkohalkaisijan alaeromitta / is the lower deviation of the outside diameter of the shaft

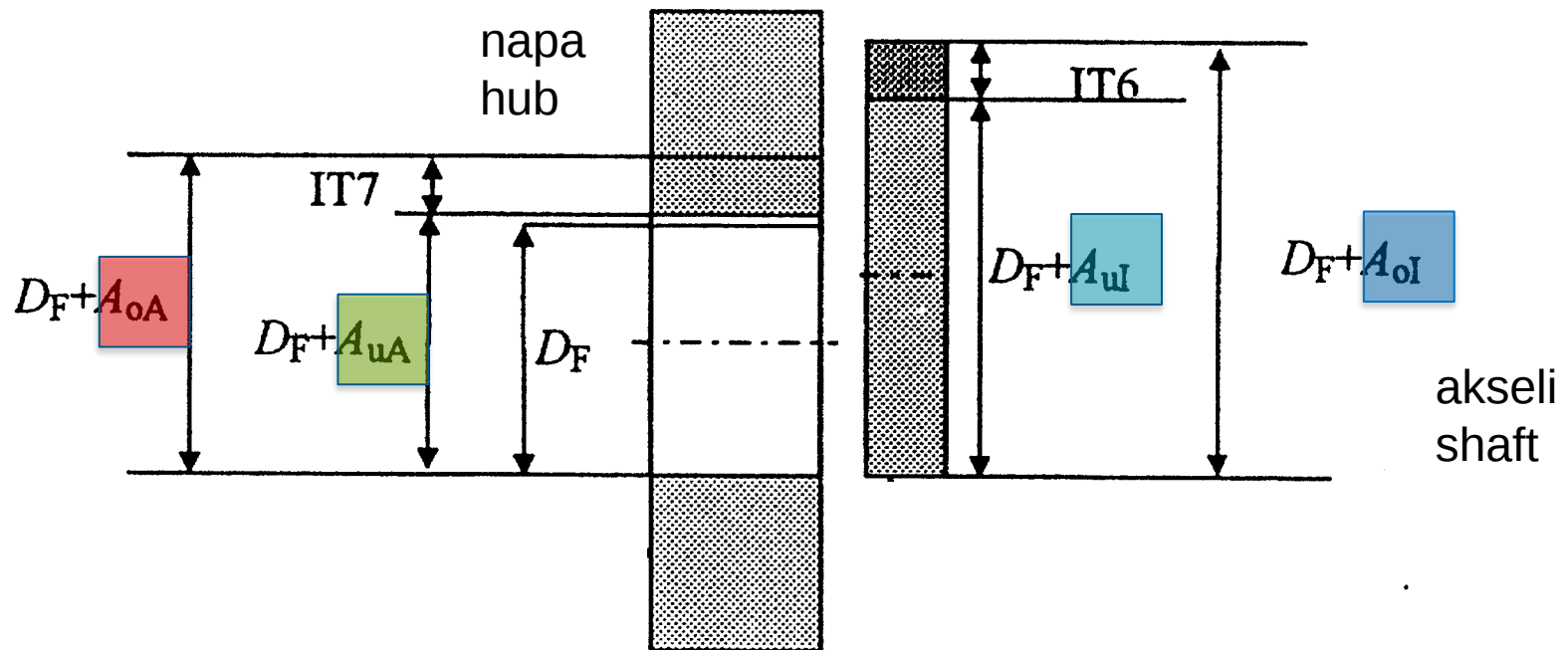


Puristusliitos ja kutistusliitos

Crimp and shrink connection

A_{oA} on navan sisähalkaisijan yläeromitta / the upper deviation of the inside diameter of the hub
 A_{uA} on navan sisähalkaisijan alaeromitta / is the lower deviation of the inside diameter of the hub

A_{oI} on akselin ulkohalkaisijan yläeromitta / is the upper deviation of the outside diameter of the shaft
 A_{uI} on akselin ulkohalkaisijan alaeromitta / is the lower deviation of the outside diameter of the shaft



Puristusliitos ja kutistusliitos

Crimp and shrink connection

todellinen sovite / actual fit $|P_i|$

- $|P_o| \leq |P_i| \leq |P_u| \quad (8)$

minimum crimp

actual parts, hub
and shaft

maximum crimp



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- **P_w tehollinen ahdistus / effective crimp**
 - Liittämisen yhteydessä tapahtuu pinnan karheushuippujen tasoittuminen, mikä pienentää kuormankantokykyä
 - surface roughness will always flatten / smooth down when connection is assembled → it will lower down load capability

$$|P_w| \leq |P| - 0,8 * (R_{zA} + R_{zI}) \quad (9)$$

P on sovite / is the fit

R_{zA} on navan profiilin syvyys / surface roughness of the hub

R_{zI} on akselin profiilin syvyys / surface roughness of the shaft



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- **R_z ja R_a välinen yhteys**

- R_z pinnankarheuden profiilinsyvyys
- R_a pinnankarheuden keskipoikkeama

- **Correlation between R_z ja R_a**

- R_z profile depth of surface roughness
- R_a mean deviation of the surface roughness

$R_z(\mu\text{m})$	0,16 0,25	0,4 0,63	1	1,6	2,5	4 6,3	10	16 25	40	63	100	160
$R_a(\mu\text{m})$	0,025	0,05	0,1	0,2	0,4	0,8	1,6	3,2	6,3	12,5	25	50



Puristusliitos ja kutistusliitos

Crimp and shrink connection

$$K = \frac{E_A}{E_I} * \left(\frac{1+Q_I^2}{1-Q_I^2} - \mu_I \right) + \frac{1+Q_A^2}{1-Q_A^2} + \mu_A \quad (10)$$

K on apusuure / K is auxiliary variable

- E_A on navan kimmomoduuli / is the elastic modulus of the hub
 - E_I on akselin kimmomoduuli / is the elastic modulus of the shaft
 - $\mu_A (= \nu)$ on navan suppeumaluku eli Poissonin vakio / is the Poisson's ratio of the hub
 - $\mu_I (= \nu)$ on akselin suppeumaluku eli Poissonin vakio / is the Poisson's ratio of the shaft
-
- $Q_A = D_F/D_{aA}$ on navan halkaisijasuhde / is the diameter ratio of the hub (11)
 - $Q_I = D_{il}/D_F$ on akselin halkaisijasuhde / is the diameter ratio of the shaft (12)
 - $Q_I = 0$ umpiakselille / solid shaft

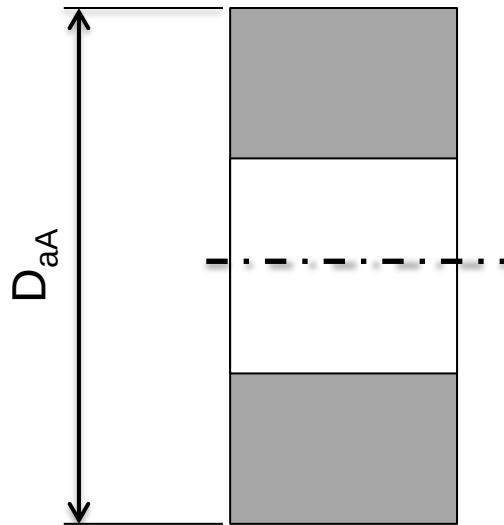


Puristusliitos ja kutistusliitos

Crimp and shrink connection

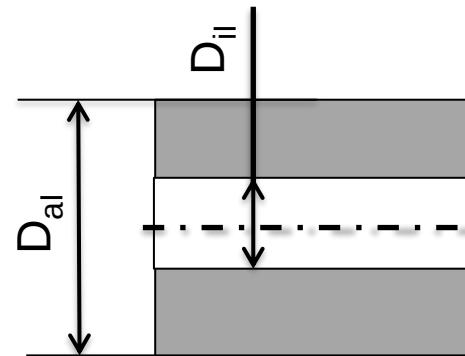
D_F = nominal diameter of connection

$$Q_A = \frac{D_F}{D_{aA}} \quad (11)$$



napa
hub

$$Q_I = \frac{D_{il}}{D_F} \quad (12)$$



akseli
shaft

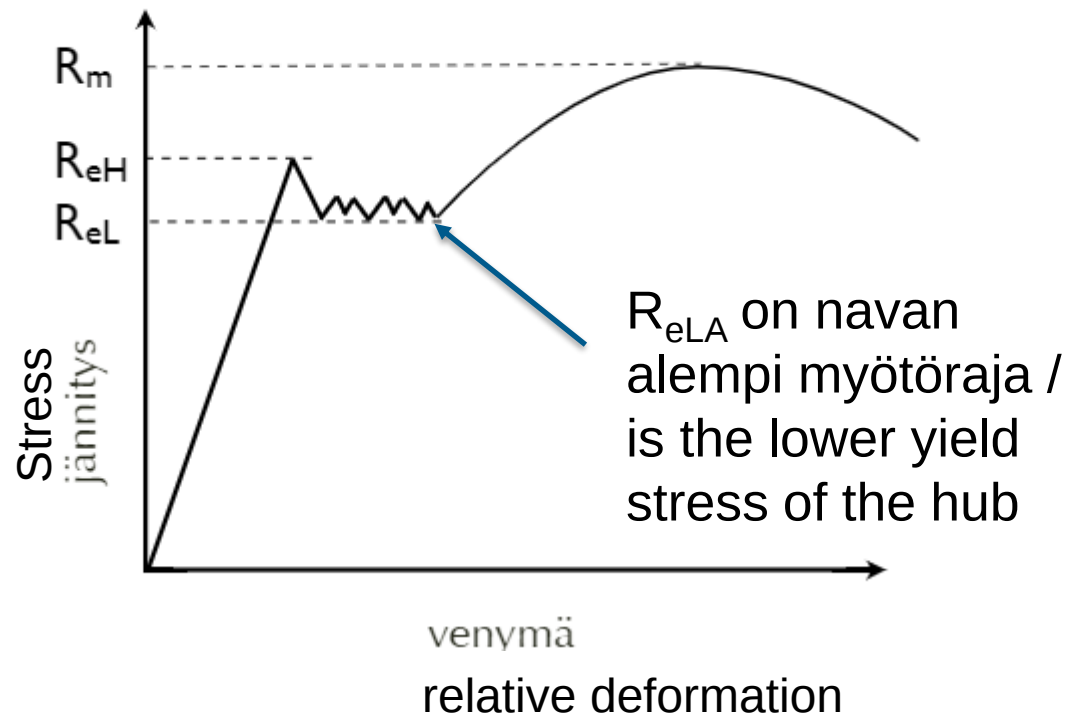
Puristusliitos ja kutistusliitos

Crimp and shrink connection

Ultimate tensile strength Murto-
lujuus

Higher yield stress Ylempi
myötöraja

Lower yield stress Alempi
myötöraja



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- kun pintapaine tunnetaan → suhteellinen tehollinen ahdistus ξ_w
- when the surface pressure is known → relative effective crimp ξ_w

$$\xi_w = \frac{|P_w|}{D_F} = K * \frac{p}{E_A} \quad (13)$$

- pintapaineen rajoitus akselin ja navan liitoksessa / limitation of the surface pressure in the connection of the hollow shaft and the hub
 - navan pintapaine / surface pressure of the hub

$$p \leq \frac{1 - Q_A^2}{\sqrt{3} * S_{pA}} * R_{eLA} \quad (14)$$

R_{eLA} on navan alempi myötöraja / is the lower yield stress of the hub

S_{pA} on varmuus pysyvään muodonmuutokseen nähden / is the safety factor towards permanent deformations

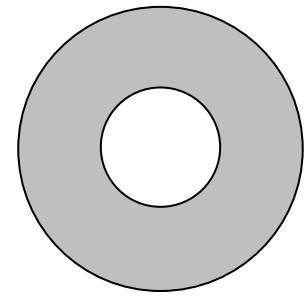
yleensä varmuusluku on suuruusluokkaa / normally safety factor should be

$S_{pA} = 1,2 \dots 1,25$



Puristusliitos ja kutistusliitos

Crimp and shrink connection



- pintapaineen rajoitus putkiakselin ja navan liitoksessa / limitation of the surface pressure in the connection of the hollow shaft and the hub
 - akselin pintapaine / surface pressure of the shaft

$$p \leq \frac{1 - Q_I^2}{\sqrt{3} * S_{pI}} * R_{eLI} \quad (15)$$

R_{eLI} on akselin alempi myötöraja / is the lower yield stress of the shaft

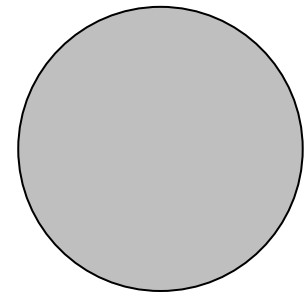
S_{pI} on varmuus pysyvään muodonmuutokseen nähden / is the safety factor towards permanent deformations

$S_{pI} = 1,1...1,2$ yleensä / normally



Puristusliitos ja kutistusliitos

Crimp and shrink connection



- pintapaineen rajoitus umpiakselin ja navan liitoksessa / limitation of the surface pressure in the connection of the solid shaft and the hub
 - akselin pintapaine / surface pressure of the shaft

$$p \leq \frac{2}{\sqrt{3} * S_{pI}} * R_{eLI} \quad (16)$$

R_{eLI} on akselin alempi myötöraja / is the lower yield stress of the shaft

S_{pI} on varmuus pysyvään muodonmuutokseen nähden / is the safety factor towards permanent deformations

$S_{pI} = 1,1 \dots 1,2$ yleensä / normally



Puristusliitos ja kutistusliitos

Crimp and shrink connection

- kun tehollinen ahdistus ξ_w tunnetaan $\rightarrow$ pintapaine p voidaan ratkaista
- when the effective ξ_w crimp is known $\rightarrow$ the surface pressure p can be solved

$$\xi_w = \frac{|P_w|}{D_F} = K * \frac{p}{E_A}$$

$$p = \xi_w * \frac{E_A}{K} = \frac{|P_w| * E_A}{K * D_F} \quad (17)$$



Puristusliitos ja kutistusliitos

Crimp and shrink connection

$$p_{\min} = \xi_w * \frac{E_A}{K} = \frac{|P_{w, \min}| * E_A}{K * D_F}$$

min effective crimp => minimum
pressure between parts =>
minimum load capacity (F, T)

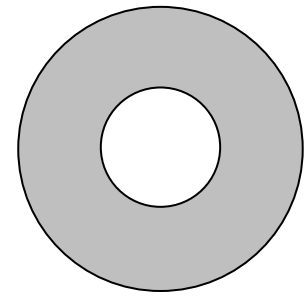
$$p_{\max} = \xi_w * \frac{E_A}{K} = \frac{|P_{w, \max}| * E_A}{K * D_F}$$

max effective crimp => maximum
pressure between parts => hub or
shaft can be damaged



Puristusliitos ja kutistusliitos

Crimp and shrink connection



- suhteellisen tehollisen ahdistuksen rajoitus putkiakselin ja navan liitoksessa
- limitation of the relative effective crimp in the connection of the hollow shaft and the hub

– napa / hub

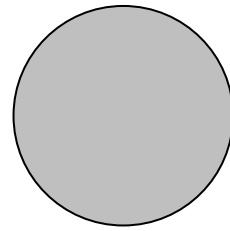
$$\xi_w \leq K * \frac{1 - Q_A^2}{\sqrt{3} * S_{pA}} * \frac{R_{eLA}}{E_A} \quad (18)$$

– putkiakseli / hollow shaft

$$\xi_w \leq K * \frac{1 - Q_I^2}{\sqrt{3} * S_{pI}} * \frac{R_{eLi}}{E_A} \quad (19)$$

Puristusliitos ja kutistusliitos

Crimp and shrink connection



- suhteellisen tehollisen ahdistuksen rajoitus umpiakselin ja navan liitoksessa, kun napa ja akseli ovat samaa materiaalia
- limitation of the relative effective crimp in the connection of the solid shaft and the hub, when the hub and the shaft are of same material

– napa / hub

$$\xi_w \leq \frac{2}{\sqrt{3} * S_{pA}} * \frac{R_{eLA}}{E} \quad (20)$$

S_{pA} on varmuus pysyvään muodonmuutokseen nähden / is the safety factor towards permanent deformations, (normally $S_{pA} = 1,2 \dots 1,25$)

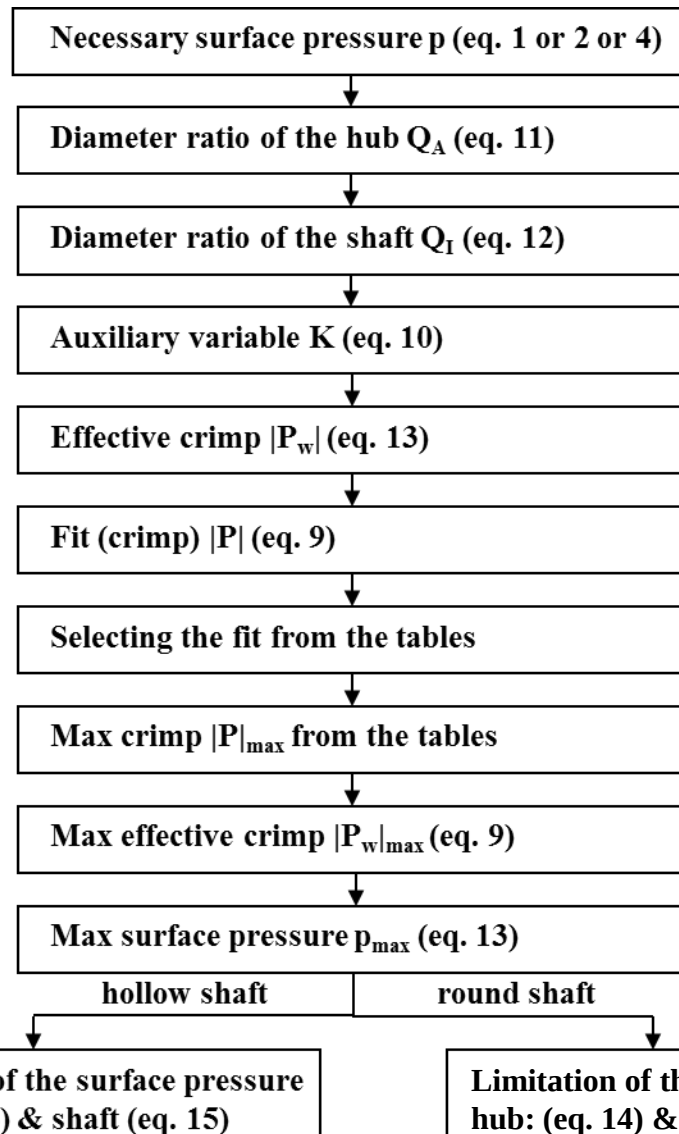
– umpiakseli / round shaft

$$\xi_w \leq \frac{4}{\sqrt{3} * (1 - Q_I^2) * S_{pI}} * \frac{R_{eLI}}{E} \quad (21)$$

S_{pI} on varmuus pysyvään muodonmuutokseen nähden / is the safety factor towards permanent deformations, (normally $S_{pI} = 1,1 \dots 1,2$)

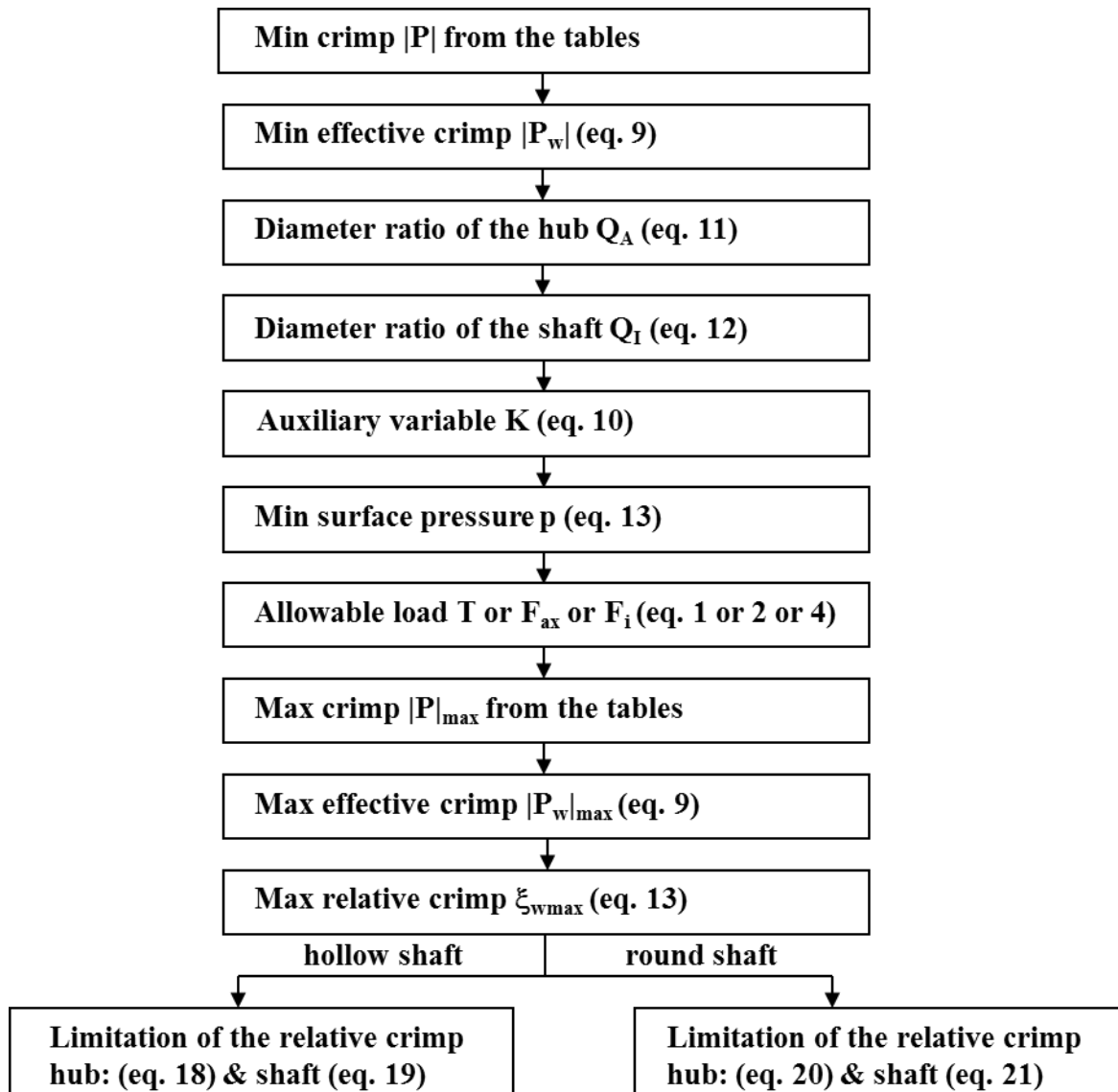
Calculation of crimp and shrink connection

a) The load is known, the necessary fit must be defined



Calculation of crimp and shrink connection

b) The fit is known, the allowable load must be defined



tolerances



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Bore tolerances (Hub)

H

Nominal dimension /
diameter [mm]

Asema		H																	
Asteet		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Nimellimitaryhmat	1	+0,8 0	+1,2 0	+2 0	+3 0	+4 0	+6 0	+10 0	+14 0	+25 0	+40 0	+60 0	+100 0	+140 0	—	—	—	—	—
	3	+0,8 0	+1,2 0	+2 0	+3 0	+4 0	+6 0	+10 0	+14 0	+25 0	+40 0	+60 0	+100 0	+140 0	+250 0	+400 0	+600 0	—	—
	6	+1 0	+1,5 0	+2,5 0	+4 0	+5 0	+8 0	+12 0	+18 0	+30 0	+48 0	+75 0	+120 0	+180 0	+300 0	+480 0	+750 0	—	—
	10	+1 0	+1,5 0	+2,5 0	+4 0	+6 0	+9 0	+15 0	+22 0	+36 0	+58 0	+90 0	+150 0	+220 0	+360 0	+580 0	+900 0	+1500 0	—
	18	+1,2 0	+2 0	+3 0	+5 0	+8 0	+11 0	+18 0	+27 0	+43 0	+70 0	+110 0	+180 0	+270 0	+430 0	+700 0	+1100 0	+1800 0	+2700 0
	30	+1,5 0	+2,5 0	+4 0	+6 0	+9 0	+13 0	+21 0	+33 0	+52 0	+84 0	+130 0	+210 0	+330 0	+520 0	+840 0	+1300 0	+2100 0	+3300 0
	50	+1,5 0	+2,5 0	+4 0	+7 0	+11 0	+16 0	+25 0	+39 0	+62 0	+100 0	+160 0	+250 0	+390 0	+620 0	+1000 0	+1600 0	+2500 0	+3900 0
	80	+2 0	+3 0	+5 0	+8 0	+13 0	+19 0	+30 0	+46 0	+74 0	+120 0	+190 0	+300 0	+460 0	+740 0	+1200 0	+1900 0	+3000 0	+4600 0
	120	+2,5 0	+4 0	+6 0	+10 0	+15 0	+22 0	+35 0	+54 0	+87 0	+140 0	+220 0	+350 0	+540 0	+870 0	+1400 0	+2200 0	+3500 0	+5400 0
	180	+3,5 0	+5 0	+8 0	+12 0	+18 0	+25 0	+40 0	+63 0	+100 0	+160 0	+250 0	+400 0	+630 0	+1000 0	+1600 0	+2500 0	+4000 0	+6300 0
	250	+4,5 0	+7 0	+10 0	+14 0	+20 0	+29 0	+46 0	+72 0	+115 0	+185 0	+290 0	+460 0	+720 0	+1150 0	+1850 0	+2900 0	+4600 0	+7200 0
	315	+6 0	+8 0	+12 0	+16 0	+23 0	+32 0	+52 0	+81 0	+130 0	+210 0	+320 0	+520 0	+810 0	+1300 0	+2100 0	+3200 0	+5200 0	+8100 0
	400	+7 0	+9 0	+13 0	+18 0	+25 0	+36 0	+57 0	+89 0	+140 0	+230 0	+360 0	+570 0	+890 0	+1400 0	+2300 0	+3600 0	+5700 0	+8900 0
	500	+8 0	+10 0	+15 0	+20 0	+27 0	+40 0	+63 0	+97 0	+155 0	+250 0	+400 0	+630 0	+970 0	+1550 0	+2500 0	+4000 0	+6300 0	+9700 0
	630	—	—	—	—	—	+44 0	+70 0	+110 0	+175 0	+280 0	+440 0	+700 0	+1100 0	+1750 0	+2800 0	+4400 0	—	—
	800	—	—	—	—	—	+50 0	+80 0	+125 0	+200 0	+320 0	+500 0	+800 0	+1250 0	+2000 0	+3200 0	+5000 0	—	—
	1000	—	—	—	—	—	+56 0	+90 0	+140 0	+230 0	+360 0	+560 0	+900 0	+1400 0	+2300 0	+3600 0	+5600 0	—	—
	1250	—	—	—	—	—	+66 0	+105 0	+165 0	+260 0	+420 0	+660 0	+1050 0	+1650 0	+2600 0	+4200 0	+6600 0	—	—
	1600	—	—	—	—	—	+78 0	+125 0	+195 0	+310 0	+500 0	+780 0	+1250 0	+1950 0	+3100 0	+5000 0	+7800 0	—	—
	2000	—	—	—	—	—	+92 0	+150 0	+230 0	+370 0	+600 0	+920 0	+1500 0	+2300 0	+3700 0	+6000 0	+9200 0	—	—
	2500	—	—	—	—	—	+110 0	+175 0	+280 0	+440 0	+700 0	+1100 0	+1750 0	+2800 0	+4400 0	+7000 0	+11000 0	—	—
	3150	—	—	—	—	—	+135 0	+210 0	+330 0	+540 0	+860 0	+1350 0	+2100 0	+3300 0	+5400 0	+8600 0	+13500 0	—	—

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Bore tolerances (Hub)

Nominal dimension /
diameter [mm]

		J			JS				
Asema		J			JS				
Asteet		6	7	8	1	2	3	4	5
1	∠	+2	+4	+6	+0,4	+0,6	+1	+1,5	+2
	∠	-4	-6	-8	-0,4	-0,6	-1	-1,5	-2
3	∠	+2	+4	+6	+0,4	+0,6	+1	+1,5	+2
	∠	-4	-6	-8	-0,4	-0,6	-1	-1,5	-2
6	∠	+5	+6	+10	+0,5	+0,75	+1,25	+2	+2,5
	∠	-3	-6	-8	-0,5	-0,75	-1,25	-2	-2,5
10	∠	+5	+8	+12	+0,5	+0,75	+1,25	+2	+3
	∠	-4	-7	-10	-0,5	-0,75	-1,25	-2	-3
18	∠	+6	+10	+15	+0,6	+1	+1,5	+2,5	+4
	∠	-5	-8	-12	-0,6	-1	-1,5	-2,5	-4
30	∠	+8	+12	+20	+0,75	+1,25	+2	+3	+4,5
	∠	-5	-9	-13	-0,75	-1,25	-2	-3	-4,5
50	∠	+10	+14	+24	+0,75	+1,25	+2	+3,5	+5,5
	∠	-6	-11	-15	-0,75	-1,25	-2	-3,5	-5,5
80	∠	+13	+18	+28	+1	+1,5	+2,5	+4	+6,5
	∠	-6	-12	-18	-1	-1,5	-2,5	-4	-6,5
120	∠	+16	+22	+34	+1,25	+2	+3	+5	+7,5
	∠	-6	-13	-20	-1,25	-2	-3	-5	-7,5
180	∠	+18	+26	+41	+1,75	+2,5	+4	+6	+9
	∠	-7	-14	-22	-1,75	-2,5	-4	-6	-9
250	∠	+22	+30	+47	+2,25	+3,5	+5	+7	+10
	∠	-7	-16	-25	-2,25	-3,5	-5	-7	-10
315	∠	+25	+36	+55	+3	+4	+6	+8	+11,5
	∠	-7	-16	-26	-3	-4	-6	-8	-11,5
400	∠	+29	+39	+60	+3,5	+4,5	+6,5	+9	+12,5
	∠	-7	-18	-29	-3,5	-4,5	-6,5	-9	-12,5
500	∠	+33	+43	+66	+4	+5	+7,5	+10	+13,5
	∠	-7	-20	-31	-4	-5	-7,5	-10	-13,5
630	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
800	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
1000	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
1250	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
1600	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
2000	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
2500	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-
3150	∠	-	-	-	-	-	-	-	-
	∠	-	-	-	-	-	-	-	-

Shaft tolerances

Nominal dimension /
diameter [mm]

Nimellimita- ryhmät	m			n		
	5	6	7	5	6	7
3	+6	+8	+12	+8	+10	+14
3	+2	+2	+2	+4	+4	+4
6	+9	+12	+16	+13	+16	+20
6	+4	+4	+4	+8	+8	+8
10	+12	+15	+21	+16	+19	+25
10	+6	+6	+6	+10	+10	+10
18	+15	+18	+25	+20	+23	+30
18	+7	+7	+7	+12	+12	+12
30	+17	+21	+29	+24	+28	+36
30	+8	+8	+8	+15	+15	+15
50	+20	+25	+34	+28	+33	+42
50	+9	+9	+9	+17	+17	+17
80	+24	+30	+41	+33	+39	+50
80	+11	+11	+11	+20	+20	+20
120	+28	+35	+48	+38	+45	+58
120	+13	+13	+13	+23	+23	+23
180	+33	+40	+55	+45	+52	+67
180	+15	+15	+15	+27	+27	+27
250	+37	+46	+63	+51	+60	+77
250	+17	+17	+17	+31	+31	+31
315	+43	+52	+72	+57	+66	+86
315	+20	+20	+20	+34	+34	+34
400	+46	+57	+78	+62	+73	+94
400	+21	+21	+21	+37	+37	+37
500	+50	+63	+86	+67	+80	+103
500	+23	+23	+23	+40	+40	+40
630	-	+70	+96	-	+88	+114
630	-	+26	+26	-	+44	+44
800	-	+80	+110	-	+100	+130
800	-	+30	+30	-	+50	+50
1000	-	+90	+124	-	+112	+146
1000	-	+34	+34	-	+56	+56
1250	-	+106	+145	-	+132	+171
1250	-	+40	+40	-	+66	+66
1600	-	+126	+173	-	+155	+203
1600	-	+48	+48	-	+78	+78
2000	-	+150	+208	-	+184	+242
2000	-	+58	+58	-	+92	+92
2500	-	+178	+243	-	+220	+285
2500	-	+68	+68	-	+110	+110
3150	-	+211	+286	-	+270	+345
3150	-	+76	+76	-	+135	+135

Nimellimita- ryhmät	p				r			
	5	6	7	8	5	6	7	8
3	+10	+12	+16	+20	+14	+16	+20	+24
3	+6	+6	+6	+6	+10	+10	+10	+10
6	+17	+20	+24	+30	+20	+23	+27	+33
6	+12	+12	+12	+12	+15	+15	+15	+15
10	+21	+24	+30	+37	+25	+28	+34	+41
10	+15	+15	+15	+15	+19	+19	+19	+19
18	+26	+29	+36	+45	+31	+34	+41	+50
18	+18	+18	+18	+18	+23	+23	+23	+23
30	+31	+35	+43	+55	+37	+41	+49	-
30	+22	+22	+22	+22	+28	+28	+28	-
50	+37	+42	+51	+65	+45	+50	+59	-
50	+26	+26	+26	+26	+34	+34	+34	-
80	+45	+51	+62	+78	+54	+60	+71	-
80	+32	+32	+32	+32	+41	+41	+41	-
120	+45	+51	+62	+78	+56	+62	+73	-
120	+32	+32	+32	+32	+43	+43	+43	-
180	+52	+59	+72	+91	+66	+73	+86	-
180	+37	+37	+37	+37	+51	+51	+51	-
250	+52	+59	+72	+91	+69	+76	+89	-
250	+37	+37	+37	+37	+54	+54	+54	-
315	+61	+68	+83	+106	+81	+88	+103	-
315	+43	+43	+43	+43	+63	+63	+63	-
400	+61	+68	+83	+106	+83	+90	+105	-
400	+43	+43	+43	+43	+65	+65	+65	-
500	+61	+68	+83	+106	+86	+93	+108	-
500	+43	+43	+43	+43	+68	+68	+68	-
630	+70	+79	+96	+122	+97	+106	+123	+149
630	+50	+50	+50	+50	+77	+77	+77	+77
800	+70	+79	+96	+122	+100	+109	+126	+152
800	+50	+50	+50	+50	+80	+80	+80	+80
1000	+70	+79	+96	+122	+104	+113	+130	+156
1000	+50	+50	+50	+50	+84	+84	+84	+84
1250	+79	+88	+108	+137	+117	+126	+146	+175
1250	+56	+56	+56	+56	+94	+94	+94	+94
1600	+79	+88	+108	+137	+121	+130	+150	+179
1600	+56	+56	+56	+56	+98	+98	+98	+98
2000	+87	+98	+119	+151	+133	+144	+165	+197
2000	+62	+62	+62	+62	+108	+108	+108	+108
2500	+87	+98	+119	+151	+139	+150	+171	+203
2500	+62	+62	+62	+62	+114	+114	+114	+114
3150	+95	+108	+131	+165	+153	+166	+189	+223
3150	+68	+68	+68	+68	+126	+126	+126	+126
4000	+95	+108	+131	+165	+159	+172	+195	+229
4000	+68	+68	+68	+68	+132	+132	+132	+132

Shaft tolerances

Nominal dimension /
diameter [mm]

Nimellimittä-ryhmät	s				t			
	5	6	7	8	5	6	7	8
< 3	+18 +14	+20 +14	+24 +14	+28 +14	—	—	—	—
> 3 ≤ 6	+24 +19	+27 +19	+31 +19	+37 +19	—	—	—	—
> 6 ≤ 10	+29 +23	+32 +23	+38 +23	+45 +23	—	—	—	—
> 10 ≤ 18	+36 +28	+39 +28	+46 +28	+55 +28	—	—	—	—
> 18 ≤ 24	+44 +35	+48 +35	+56 +35	+68 +35	—	—	—	—
> 24 ≤ 30	+44 +35	+48 +35	+56 +35	+68 +35	+50 +41	+54 +41	+62 +41	—
> 30 ≤ 40	+54 +43	+59 +43	+68 +43	+82 +43	+59 +48	+64 +48	+73 +48	—
> 40 ≤ 50	+54 +43	+59 +43	+68 +43	+82 +43	+65 +54	+70 +54	+79 +54	—
> 50 ≤ 65	+66 +53	+72 +53	+83 +53	+99 +53	+79 +66	+85 +66	+96 +66	—
> 65 ≤ 80	+72 +59	+78 +59	+89 +59	+105 +59	+83 +75	+94 +75	+105 +75	—
> 80 ≤ 100	+86 +71	+93 +71	+106 +71	+125 +71	+106 +91	+113 +91	+126 +91	—
> 100 ≤ 120	+94 +79	+101 +79	+114 +79	+133 +79	+119 +104	+126 +104	+139 +104	+158 +104
> 120 ≤ 140	+110 +92	+117 +92	+132 +92	+155 +92	+140 +122	+147 +122	+162 +122	+185 +122
> 140 ≤ 160	+118 +100	+125 +100	+140 +100	+163 +100	+152 +134	+159 +134	+174 +134	+197 +134
> 160 ≤ 180	+126 +108	+133 +108	+148 +108	+171 +108	+164 +146	+171 +146	+186 +146	+209 +146
> 180 ≤ 200	+142 +122	+151 +122	+168 +122	+194 +122	+186 +166	+195 +166	+212 +166	+238 +166
> 200 ≤ 225	+150 +130	+159 +130	+176 +130	+202 +130	+200 +180	+209 +180	+226 +180	+252 +180
> 225 ≤ 250	+160 +140	+169 +140	+186 +140	+212 +140	+216 +196	+225 +196	+242 +196	+268 +196
> 250 ≤ 280	+181 +158	+190 +158	+210 +158	+239 +158	+241 +218	+250 +218	+270 +218	+299 +218
> 280 ≤ 315	+193 +170	+202 +170	+222 +170	+251 +170	+263 +240	+272 +240	+292 +240	+321 +240
> 315 ≤ 355	+215 +190	+226 +190	+247 +190	+279 +190	+293 +268	+304 +268	+325 +268	+357 +268
> 355 ≤ 400	+233 +208	+244 +208	+265 +208	+297 +208	+319 +294	+330 +294	+351 +294	+383 +294
> 400 ≤ 450	+259 +232	+272 +232	+295 +232	+329 +232	+357 +330	+370 +330	+393 +330	+427 +330
> 450 ≤ 500	+279 +252	+292 +252	+315 +252	+349 +252	+387 +360	+400 +360	+423 +360	+457 +360

Nimellimittä-ryhmät	u				v			
	5	6	7	8	5	6	7	8
< 3	+22 +18	+24 +18	+28 +18	+32 +18	—	—	—	—
> 3 ≤ 6	+28 +23	+31 +23	+35 +23	+41 +23	—	—	—	—
> 6 ≤ 10	+34 +28	+37 +28	+43 +28	+50 +28	—	—	—	—
> 10 ≤ 14	+41 +33	+44 +33	+51 +33	+60 +33	—	—	—	—
> 14 ≤ 18	+41 +33	+44 +33	+51 +33	+60 +33	+47 +39	+50 +39	+57 +39	+66 +39
> 18 ≤ 24	+50 +41	+54 +41	+62 +41	+74 +41	+56 +47	+60 +47	+68 +47	+80 +47
> 24 ≤ 30	+57 +48	+61 +48	+69 +48	+81 +48	+64 +55	+68 +55	+76 +55	+88 +55
> 30 ≤ 40	+71 +60	+76 +60	+85 +60	+99 +60	+79 +68	+84 +68	+93 +68	+107 +68
> 40 ≤ 50	+81 +70	+86 +70	+95 +70	+109 +70	+92 +81	+97 +81	+106 +81	+120 +81
> 50 ≤ 65	+100 +87	+106 +87	+117 +87	+133 +87	+115 +102	+121 +102	+132 +102	+148 +102
> 65 ≤ 80	+115 +102	+121 +102	+132 +102	+148 +102	+133 +120	+139 +120	+150 +120	+166 +120
> 80 ≤ 100	+139 +124	+146 +124	+159 +124	+178 +124	+161 +146	+168 +146	+181 +146	+200 +146
> 100 ≤ 120	+159 +144	+166 +144	+179 +144	+198 +144	+187 +172	+194 +172	+207 +172	+226 +172
> 120 ≤ 140	+188 +170	+195 +170	+210 +170	+233 +170	+220 +202	+227 +202	+242 +202	+265 +202
> 140 ≤ 160	+208 +190	+215 +190	+230 +190	+253 +190	+246 +228	+253 +228	+268 +228	+291 +228
> 160 ≤ 180	+228 +210	+235 +210	+250 +210	+273 +210	+270 +252	+277 +252	+292 +252	+315 +252
> 180 ≤ 200	+256 +236	+265 +236	+282 +236	+308 +236	+304 +284	+313 +284	+330 +284	+356 +284
> 200 ≤ 225	+278 +258	+287 +258	+304 +258	+330 +258	+330 +310	+339 +310	+356 +310	+382 +310
> 225 ≤ 250	+304 +284	+313 +284	+330 +284	+356 +284	+360 +340	+369 +340	+386 +340	+412 +340
> 250 ≤ 280	+338 +315	+347 +315	+367 +315	+396 +315	+408 +385	+417 +385	+437 +385	+466 +385
> 280 ≤ 315	+373 +350	+382 +350	+402 +350	+431 +350	+448 +425	+457 +425	+477 +425	+506 +425
> 315 ≤ 355	+415 +390	+426 +390	+447 +390	+479 +390	+500 +475	+511 +475	+532 +475	+564 +475
> 355 ≤ 400	+460 +435	+471 +435	+492 +435	+524 +435	+555 +530	+566 +530	+587 +530	+619 +530
> 400 ≤ 450	+517 +490	+530 +490	+553 +490	+587 +490	+622 +595	+635 +595	+658 +595	+692 +595
> 450 ≤ 500	+567 +540	+580 +540	+603 +540	+637 +540	+687 +660	+700 +660	+723 +660	+757 +660



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