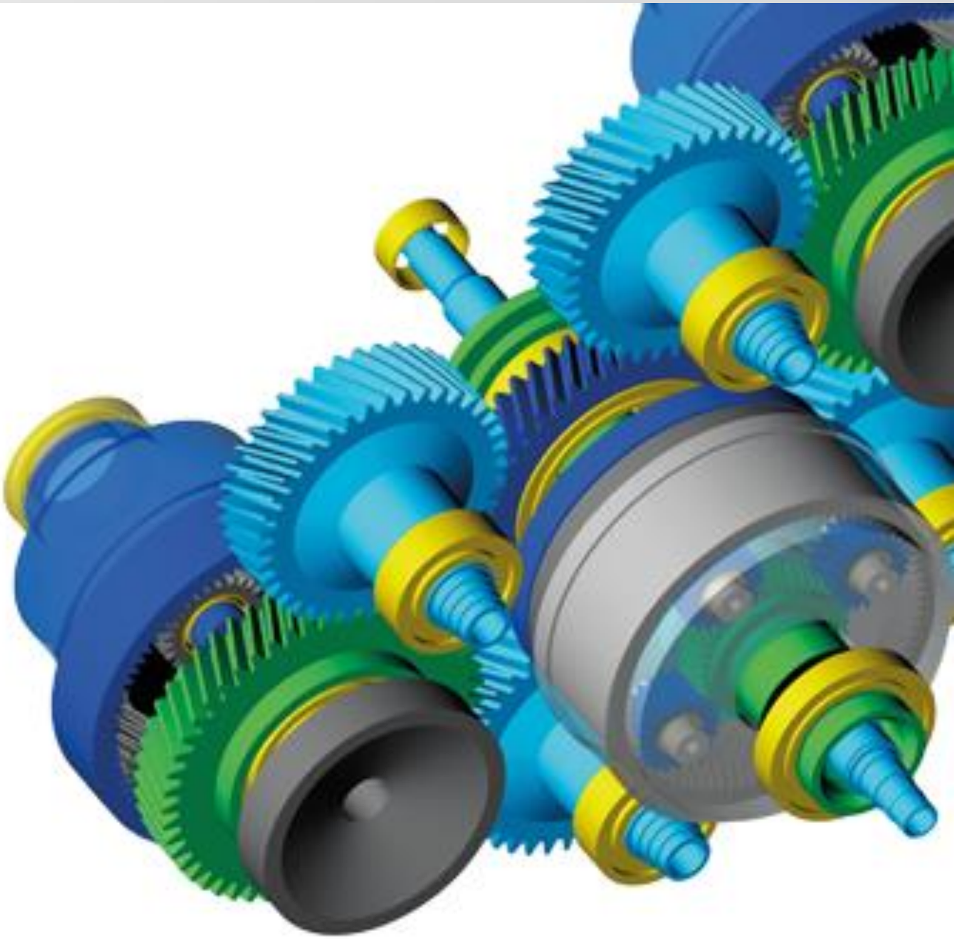
Spline connections



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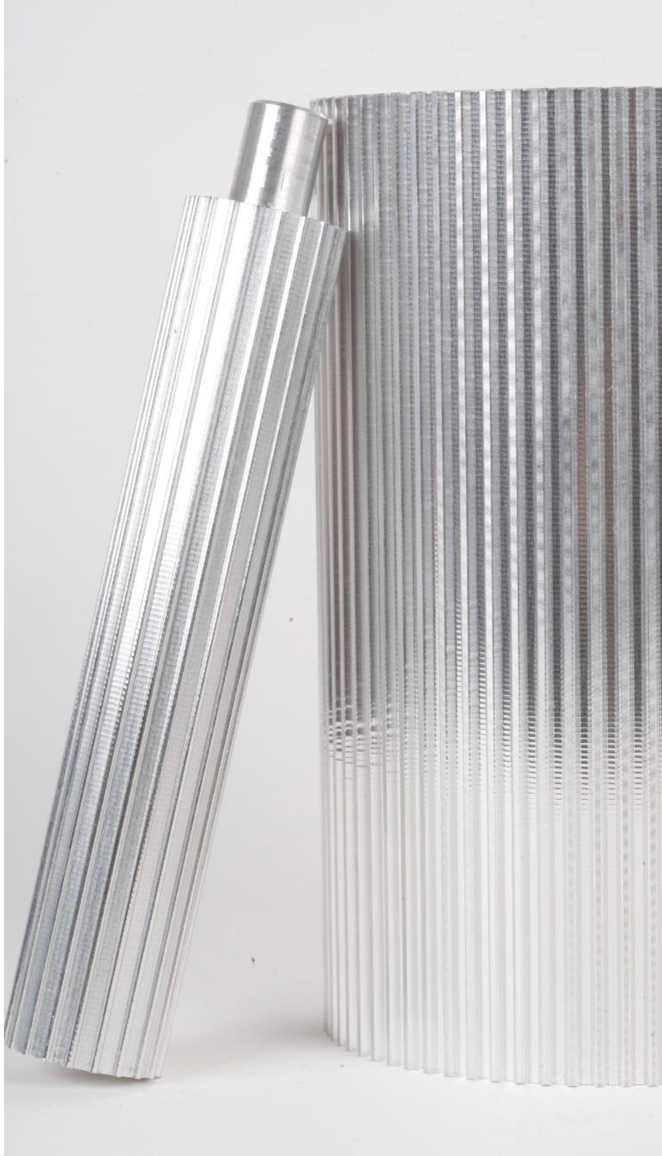
Splines

1. Can be assembled / disassembled easily
2. Axial movement possible
3. Can transmit high loads, including shock loads
4. Shear forces should be accounted for by centering
5. Involute profile, high pressure angle (30º, 37.5º, 45º)
6. Geometry along
   - DIN 5480
   - DIN 5481
   - DIN 5482
   - ISO 4156
   - ANSI B92.1
   - National standards (JIS, SFS 5125, …)



DIN 5480, Scope of application

Involute flanks

Pressure angle 30°

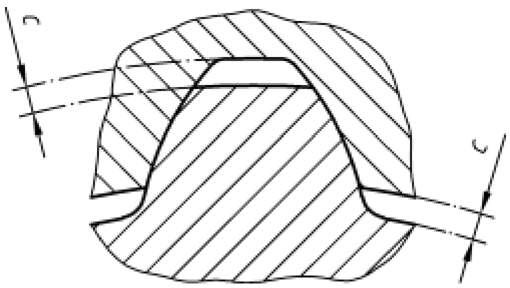
Usually flank centered, sometimes major or minor diameter fit

The reference diameters are adapted through profile shift

System of tolerances and fits includes tolerances for the effective form deviations to include their influence on the fit and backlash

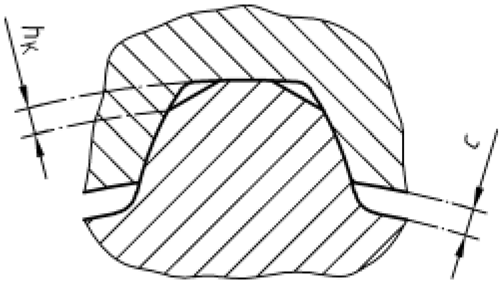
Flank centered fit

flanks serve to transmit torque and to center shaft and hub to each other



Fit and precision of centering are determined by tooth thickness allowances

Diameter centered fit



centering on root or tip diameter

Designation

flank centered spline connection (Hub and Shaft):

DIN 5480 – N 120 x 3 x 38 x 9H
DIN 5480 – W 120 x 3 x 38 x 8f

N, W: Hub or Shaft
nominal diameter dB
module
number of teeth
tolerance class and allowance

In KISSsoft the tolerance class (8, ..) is entered as quality, the allowance (f, H, ..) as tooth thickness tolerance

Spline Geometry (DIN 5480-1)

Reference profile

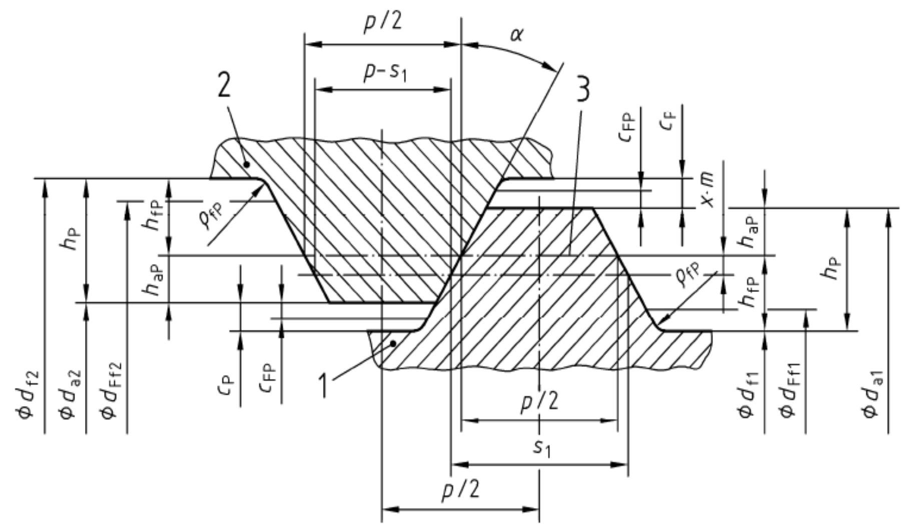
Pressure angle 30°

Addendum hap = 0.45 *m

Dedendum hfp:
broaching: 0.55 *m
hobbing: 0.6 *m
shaping: 0.65 *m
cold rolling: 0.84 *m

Root radius of the reference profile ρfp:
machining: 0.16 *m
cold rolling: 0.54 *m

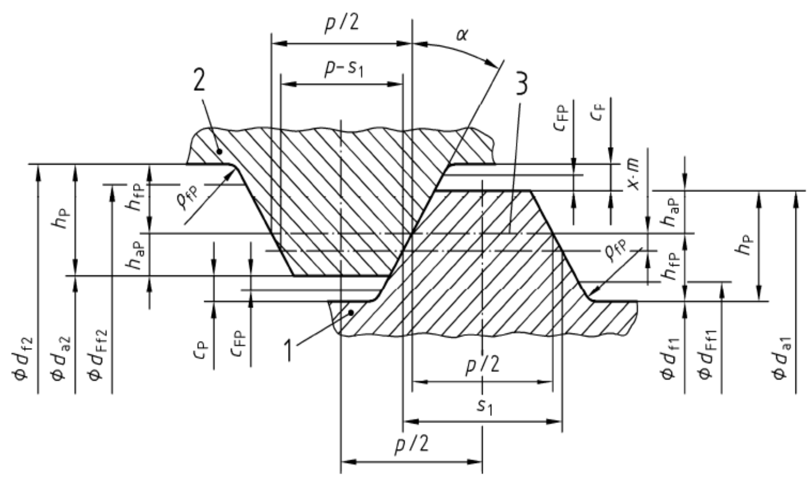
tip clearance cP = hfP-haP



Reference profile

Pitch diameter: d = m*z
Nominal diameter: dB=m*z+2*x*m+1.1*m
→ corresponds to bearing diameter

Tip diameter shaft da1 = m*z+2*x*m+0.9*m
→ **Reserve to bearing seat = 0.2*m**



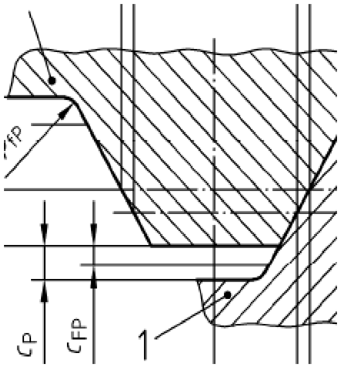
Reference profile

Form clearance cFP:
Distance of the root form diameter and active root diameter to ensure sufficient length of involute with runout errors

“manufacture method dependant reserve for involute shape”

broaching: 0.02*m, hobbing: 0.07*m, shaping and cold rolling: 0.12*m

Table 4 of the DIN gives a minimum form clearance based on d_B between 25 and 65 µm



Tooth gap / tooth thickness actual

The tooth gap / thickness on the pitch diameter in radian measure without single manufacturing deviations

Tooth gap / tooth thickness effective

The tooth gap / thickness on the pitch diameter in radian measure including single manufacturing deviations (largest deviation on left and right flank)

Terms of single deviations

profile deviation F_{α}
Deviation from required involute.

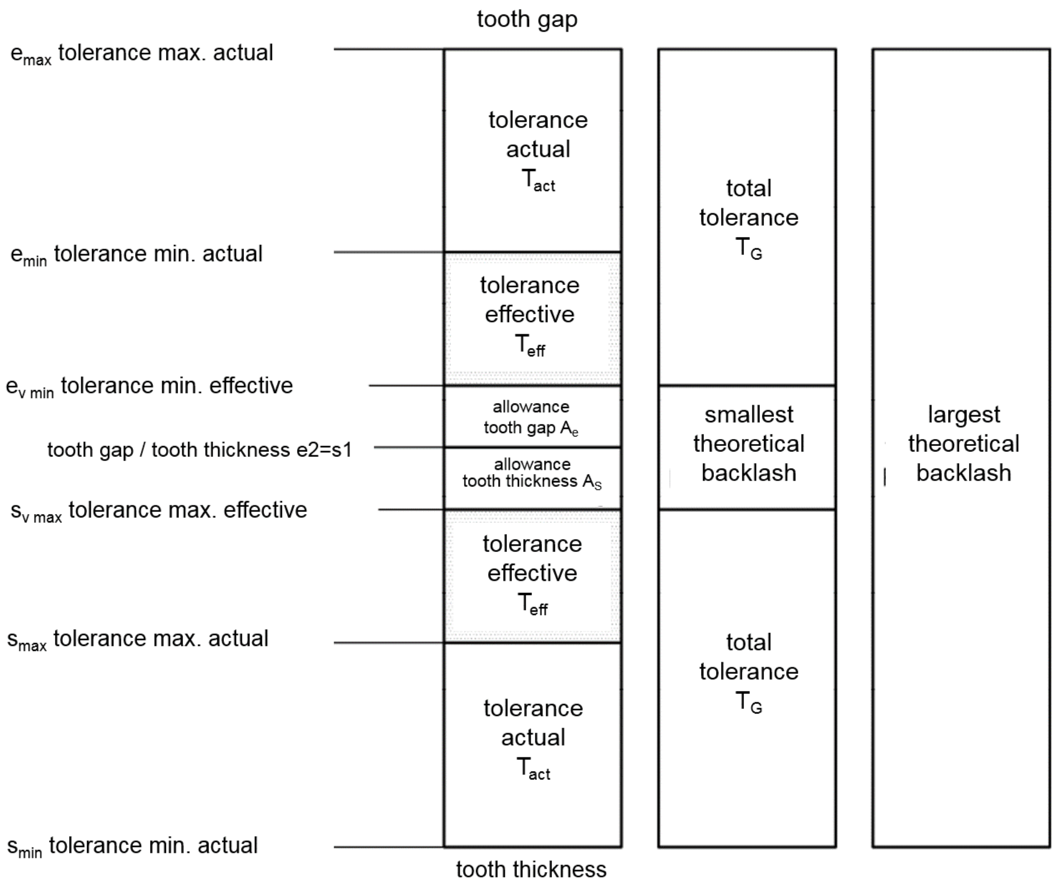
helix deviation F_{β}
Deviation from required flank line.

pitch deviation F_{p}
deviation of all tooth flanks from the required pitch

Tolerance system tooth gap / tooth thickness

The difference of the tooth gap (on hub, e2) to the tooth thickness (on shaft, s1) determines the circumferential backlash.

The largest theoretical backlash includes allowances and tolerances, the smallest theoretical backlash includes the allowances.



Tolerance system tooth gap / tooth thickness: tolerance

The total tolerance TG includes the tolerance actual T_{act} and the tolerance effective T_{eff}

To achieve the desired backlash the whole tolerance may not be covered by the tooth thickness tolerance. The single tooth deviations lead angle and pressure angle deviation and pitch errors additionally reduce the backlash after joining.

To achieve the required fit after joining the total tolerance is divided into two tolerance ranges:

tolerance actual T_{act}

Includes tooth thickness deviations

tolerance effective T_{eff}

Includes single tooth deviations and their influence on the fit of all left and right flanks of all teeth

Spline Geometry (DIN 5480-1)

Tolerance actual T_{act}

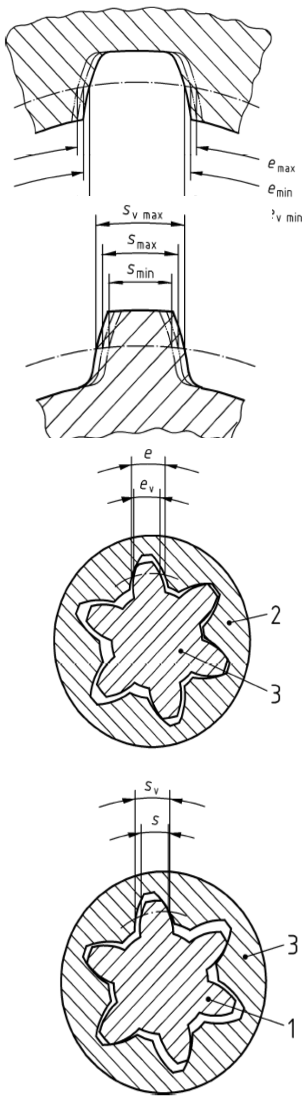
Measurable manufacturing tolerance for the tooth gap or tooth width. Takes into account wear of tool, positioning accuracy of tool, heat influences, production through erosion.

Measured with measuring <u>rollers</u> or measuring <u>balls</u>.

Tolerance effective T_{eff}

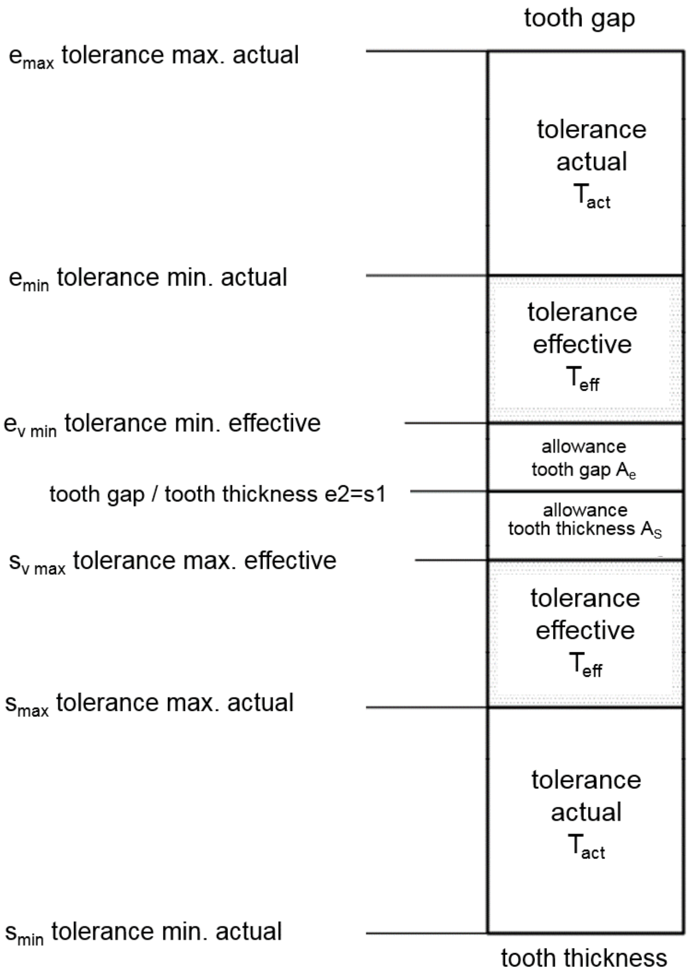
Superposition of all single deviations creates an effective measure of the tooth gap, which is smaller than the measurable actual measure, or a larger tooth thickness than the measurable actual thickness for the shaft.

Is measured with a <u>gauge</u> which will ensure compliance with the effective tolerance.



Tolerance system tooth gap / tooth thickness: calculation of tolerances

Zahnlücke	max. actual	$e_{max} = e_2 + A_e + T_G = e_2 + A_e + T_{act} + T_{eff}$
Zahnlücke	min. actual Ref.	$e_{min} = e_2 + A_e + T_{eff}$
Zahnlücke	min. effective	$e_{vmin} = e_2 + A_e$
Zahndicke	max. effective	$s_{vmax} = s_1 + A_s$
Zahndicke	max. actual Ref.	$s_{max} = s_1 + A_s - T_{eff}$
Zahndicke	min. actual	$s_{min} = s_1 + A_s - T_G = s_1 + A_s - T_{act} - T_{eff}$

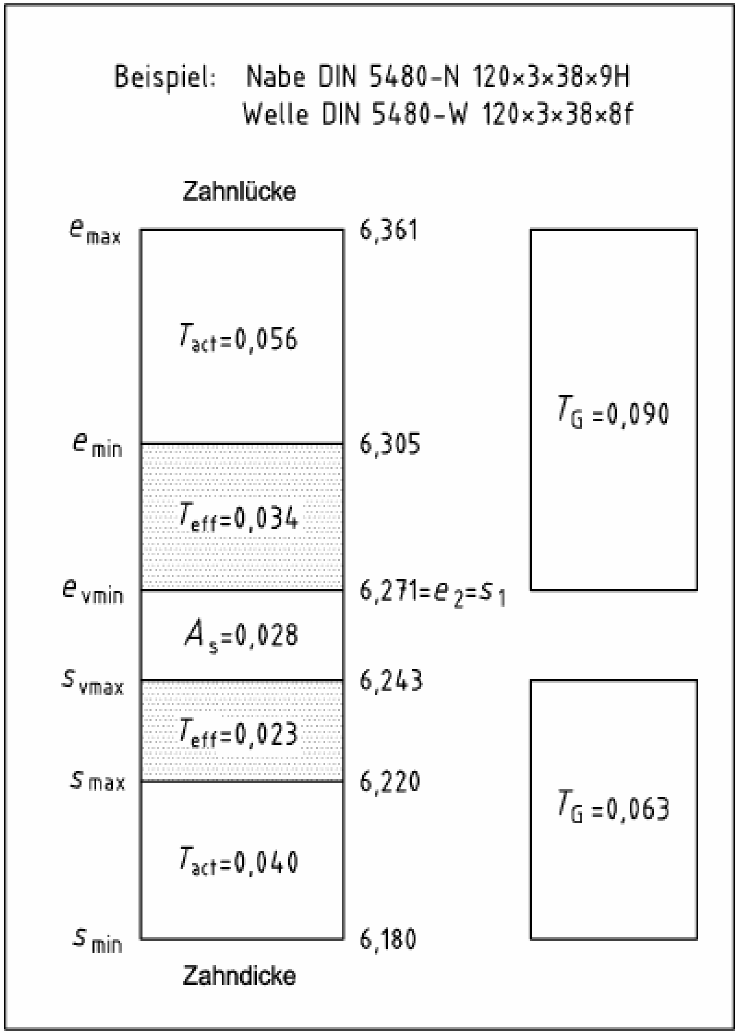


Tolerance system tooth gap / tooth thickness: calculation of tolerances - example

The hub has allowance 0 because of allowance series H was chosen.

Therefore in this example:

e_{vmin} = e2



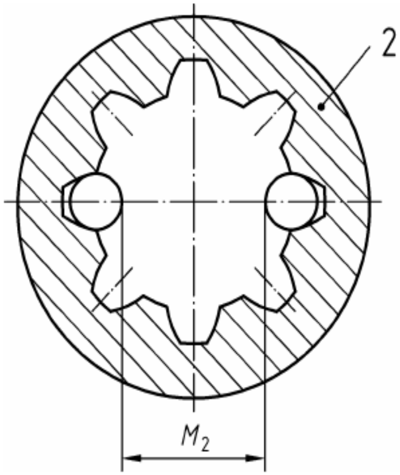
Drawing data - example

Nabe DIN 5480 – N120 × 3 × 38 × 9H			Welle DIN 5480 – W120 × 3 × 38 × 8f		
Zähnezahl	z	38	Zähnezahl	z	38
Modul	m	3	Modul	m	3
Eingriffswinkel	α	30°	Eingriffswinkel	α	30°
Fußkreisdurchmesser	d_{f2}	120 + 0,76	Kopfkreisdurchmesser	d_{a1}	119,40 h11
Fußformkreisdurchmesser	d_{Ff2}	119,49 min.	Fußformkreisdurchmesser	d_{Ff1}	113,91 max.
Kopfkreisdurchmesser	d_{a2}	114 H11	Fußkreisdurchm. kaltgew.	d_{f1}	113,4 – 1,74
Zahnlücke max. actual	e_{max}	6,361	Zahndicke max. effective	s_{vmax}	6,243
Zahnlücke min. actual Ref.	e_{min}	6,305	Zahndicke max. actual Ref.	s_{max}	6,220
Zahnlücke min. effective	e_{vmin}	6,271	Zahndicke min. actual	s_{min}	6,180
Messkreisdurchmesser	D_M	5,250	Messkreisdurchmesser	D_M	6,000
Maß zwi. Messkreisen max.	M_{2max}	109,266	Maß über Messkreise max. Ref.	M_{1max} Ref.	(126,017)
Maß zwi. Messkreisen min. Ref.	M_{2min} Ref.	(109,169)	Maß über Messkreise min.	M_{1min}	125,956

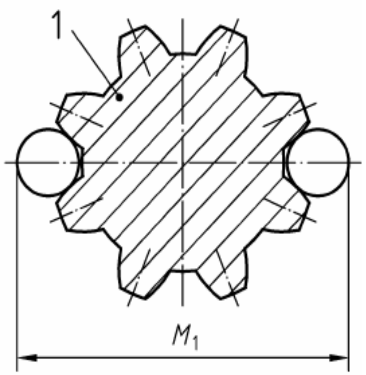
Terms for testing tooth gap / tooth thickness

Measure between / over rollers

dimension to determine the tooth gap / tooth thickness actual



Maß zwischen 2 Messkreisen M_2

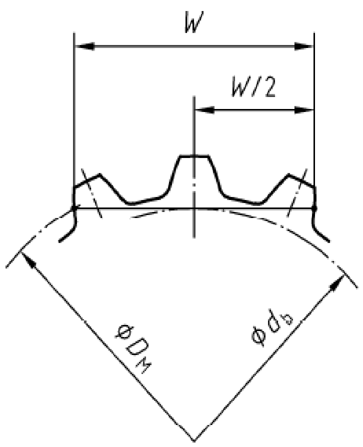


Maß über 2 Messkreise M_1

Terms for testing tooth gap / tooth thickness

Base tangent length

Measure for the determination of the tooth thickness actual in a sectional plane tangential to the base cylinder from left to right tooth flank



Terms for testing tooth gap / tooth thickness

Sectoral toothed no-go gauge
Gauge to check for compliance with the tolerance limit of the tooth gap max. actual and the tooth thickness min. actual

Fully-toothed good gauge
Teaching to check for compliance with the tolerance limit of the tooth gap max. effective and the tooth thickness min. effective

Furthermore, the test is possible with a fully-toothed circumferential backlash measuring device.

Test criteria

Tooth gap / tooth thickness actual

For the tooth gap of internal toothing and tooth thickness of external teeth, manufacturing tolerances are required. This is the manufacturing tolerance actual.

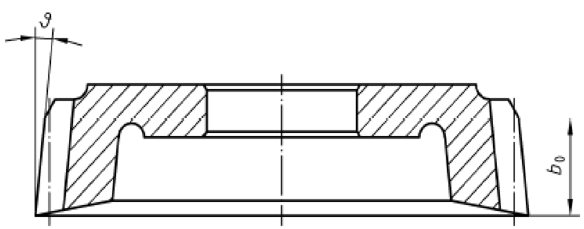
Tooth gap / tooth thickness effective

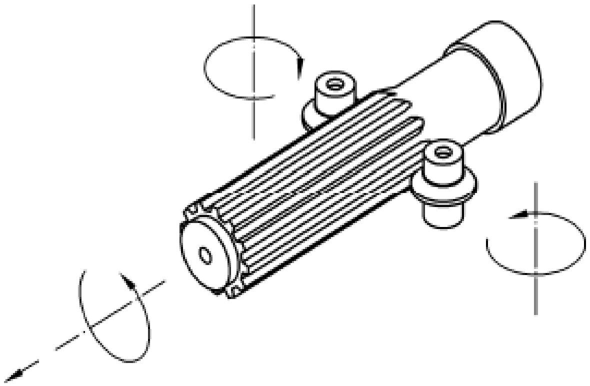
The fit is produced over all left and right tooth flanks of all teeth. The tooth flanks are affected by deviations of the profile, the flank line and the pitch. Deviations of this type reduce the clearance in a toothed connection so strongly that this reduction effect must be taken into account. The individual deviations overlap and can be fairly well estimated with:

$$\text{Betrag effective} = \sqrt{F_{\alpha}{}^{2} + F_{\beta}{}^{2} + F_{p}{}^{2}}$$

Tools

To manufacture the shafts, hobs, cutting wheels and cold-rolling tools can be used. For internal splines (hubs), broaching tools can be used.





Failure modes:

- Breaking of the shaft through torsion or bending
- Breaking of the hub
- Failure due to bending or shearing of the teeth
- Flank pressure too high: main criteria for spline strength calculation

The strength calculation is carried out according to

- DIN 5466
- Niemann

The methods yield very different results. The method according to Niemann is more useful, since there is more experience with this method than with the DIN 5466. The DIN 5466 is not recommended.

The strength calculation mainly covers splines under torque load.

Failure modes:

- Failure of the shaft due to torsion and/or bending
- Rupture of the hub
- Failure due to bending or shear of the teeth
- Contact pressure to high: main criterion for spline analysis

Strength analysis according to

- DIN 5466
- Niemann

The methods yield very different results. The method according to Niemann is more useful, since there is more experience with this method than with the DIN 5466. The DIN 5466 is not recommended.

Strength analysis covers mainly torque load condition.

Contact pressure p on flank $$p = \frac{T}{r_w \cdot z} \frac{\cos \alpha_w}{l \cdot h_w} \cdot k_{\varphi\beta} \cdot k_1$$

For the fatigue analysis or if a load spectrum is available, then the torque is set equal to the equivalent torque: $T = T_{eq} = K_A * T_{nenn}$

For the static load, T is set to: $T = T_{max}$

Z: number of teeth

r_W: see figure below

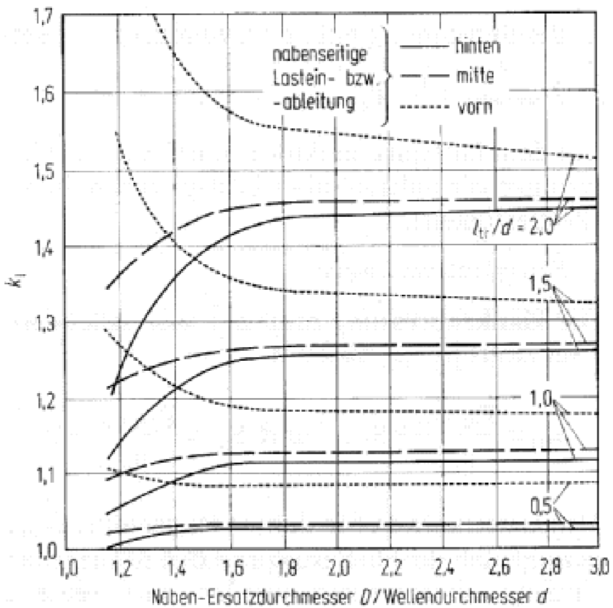
l: length of connection

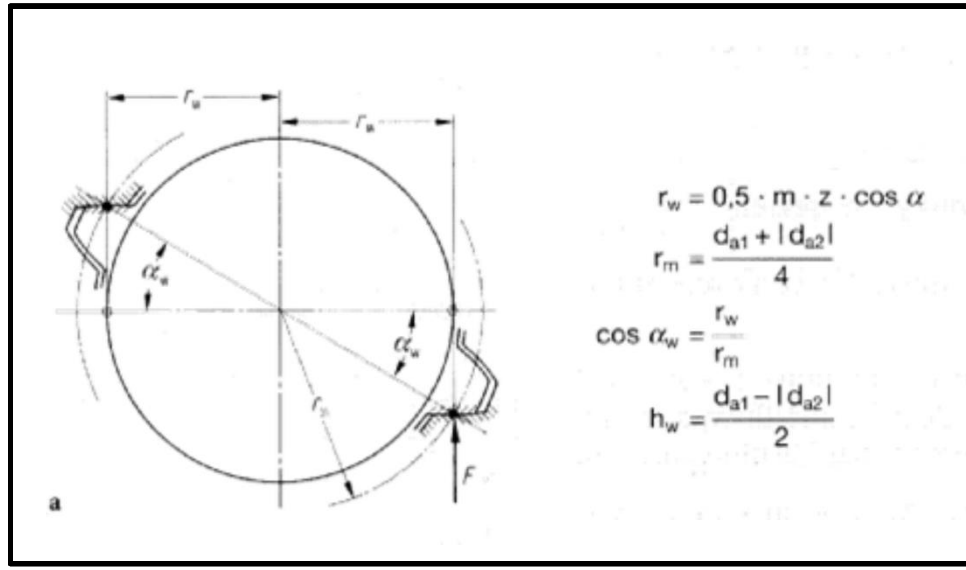
h_W: load carrying height

$k_{\varphi\beta}$: Load distribution factor (function of accuracy, figure below)

k_1: Length and load introduction factor (see figure below)

Contact stress, Niemann





Form fit	Keys		Splines with involute flanks					
	Number		Tolerance fields acc. to DIN 5480					
	1	2	H5/IT4	H7/IT7	H8/IT8	H9/IT9	H11/IT11	max
$K_{\varphi\beta}$ for T_{eq}	1	1.3	1.1	1.3	1.5	2	4	z/2
$K_{\varphi\beta}$ for T_{max}	1	1.1	1.0	1.1	1.3	1.7	3	

Permissible contact stress is calculated along DIN 6892

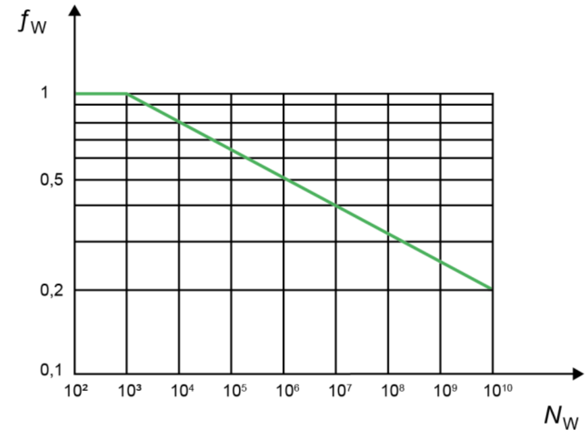
$p_{1,2eq} < f_W * p_{zul}$ for fatigue strength
$p_{1,2max} < f_L * p_{zul}$ for static strength

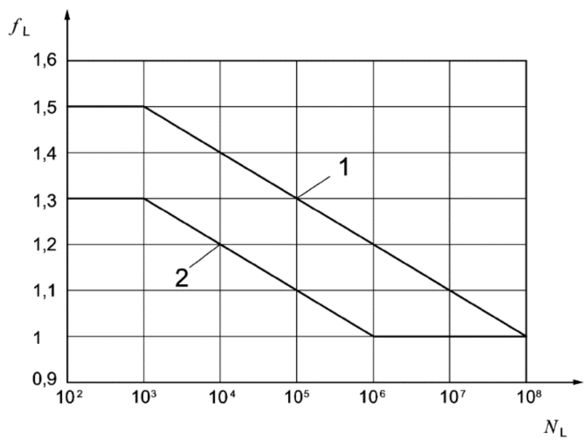
$p_{zul} = f_S * f_H * R_{p02}$ for ductile materials
$p_{zul} = f_S * R_m$ for brittle materials

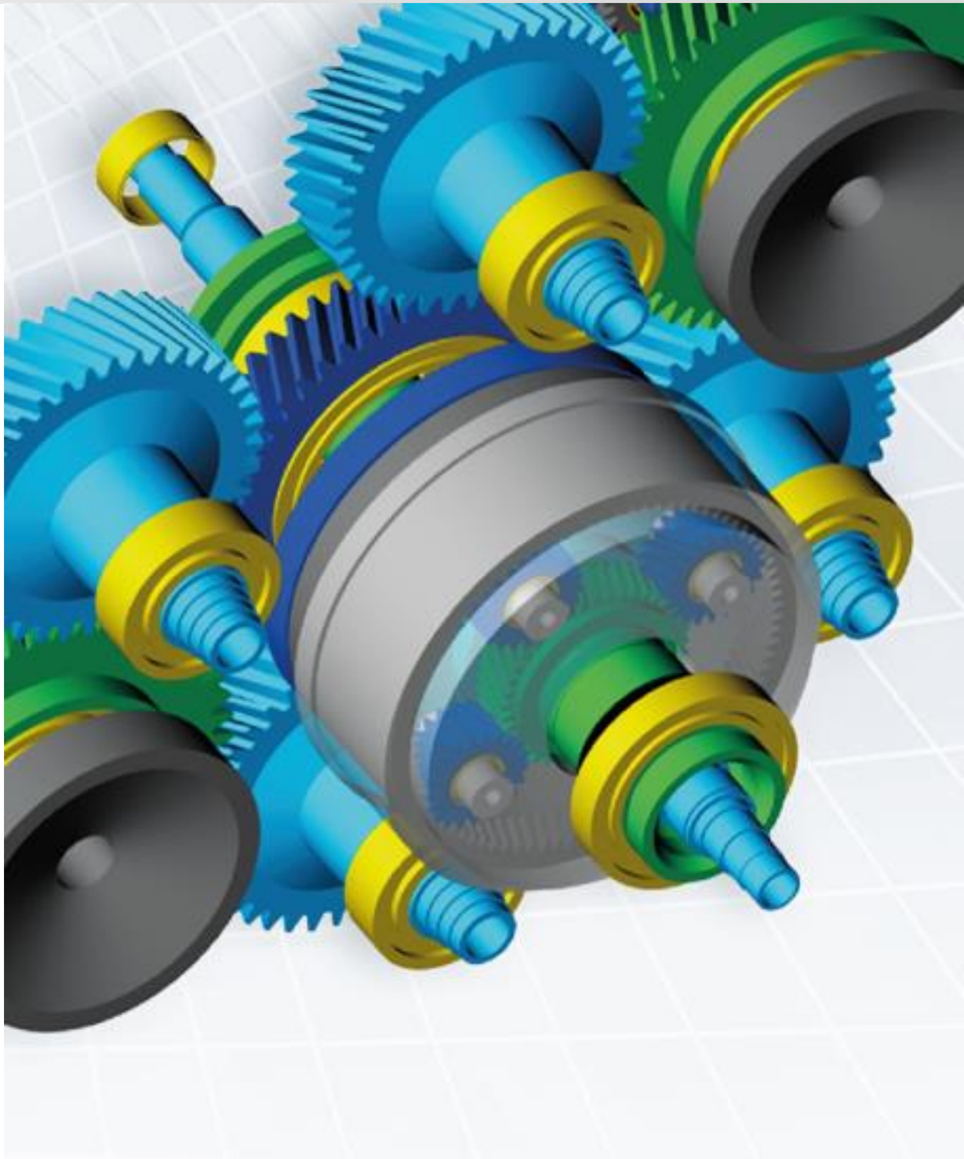
This proof has to be done for the shaft and the hub.

Contact strength, Niemann

- Alternating load direction factor f_W
  - Considers number of changes N_W in load direction
- Peak load frequency factor f_L
  - For proof against peak torque (static proof), considers frequency / number of peaks N_L during life of key
  - Different values for brittle (line 2) or ductile (line 1) materials are used
- Support factor f_S
  - Supporting effect as observed with parts under compressive stress
  - Listed in tables in standard according to material type
- Surface hardening factor f_H
  - If hardened surfaces are used
  - Listed in tables in standard according to material type







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