Příloha 2) Výpočet Ozubeného hřebenu v programu KissSoft

KISSsoft Release 03/2018

Team

File

Name : VYPOCET_OZUBENEHO_HREBENU
Changed by: Marek Štosek on: 05.05.2020 at: 09:24:09

RACK ANALYSIS (CYLINDRICAL GEAR)

Drawing or article number:
Gear 1: 0.000.0
Gear 2: 0.000.0

Calculation method Plastic according to VDI 2545:1981 (YF Method C)

		---- Pinion ---------- Rack -
Power (W)	[P]	200.195
Speed (1/min)	[n]	1068.0
Torque (Nm)	[T]	1.790
Application factor	[KA]	1.25
Required service life (h)	[H]	500.00
Gear driving (+) / driven (-)		+ -

Working flank gear 1: Right flank
Sense of rotation gear 1 clockwise
Gearbox type: Gear with partly closed housing

1. TOOTH GEOMETRY AND MATERIAL

(geometry calculation according to ISO 21771:2007, DIN ISO 21771)

		---- Pinion ---------- Rack -		
Running centre distance (mm)	[a]	80.000		
Centre distance tolerance		ISO 286:2010 Measure js7		
Rack height (mm)	[Hz]	50.000		
Normal module (mm)	[mn]	2.0000		
Pressure angle at normal section (°)	[alfn]	20.0000		
Helix angle at reference circle (°)	[beta]	0.0000		
Number of teeth	[z]	30		
Facewidth (mm)	[b]	16.00	20.00	
Hand of gear	Spur gear			
Chamfer facewidth (mm)	[bK]	1.00	1.00	
Accuracy grade	[Q-DIN3961:1978]	6		6
Inner diameter (mm)	[di]	0.00	6096.01	
Inner diameter of gear rim (mm)	[dbi]	0.00	0.00	

Material
Gear 1: POM (VDI2545), Thermoplastic (POM, PPA, etc.), untreated
VDI2545 [S B F Wd C]
Woehler line tooth root stress from file Z014-100.DAT
S-N curve (Woehler line) Hertzian pressure from file Z014-100.DAT
Gear 2: POM (VDI2545), Thermoplastic (POM, PPA, etc.), untreated
VDI2545 [S B F Wd C]

Woehler line tooth root stress from file Z014-100.DAT
S-N curve (Woehler line) Hertzian pressure from file Z014-100.DAT

			------- GEAR 1	-------- GEAR 2 --
Tooth root temperature (°C)	[TR]		58.6	50.1
Flank temperature (°C)	[TF]		74.0	50.2
(Indications for the calculation of temperature: See chapter 8)				
Tooth root strength at NL (N/mm²)	[σFadm]		31.10	40.30
Strength against Hertzian pressure at NL (N/mm²)	[σHadm]		23.80	37.40
Tensile strength (N/mm²)	[σB]		51.61	56.35
Yield point (N/mm²)	[σS]		46.72	50.96
Young's modulus (N/mm²)	[E]		2440	2673
Poisson's ratio	[v]		0.440	0.440
Roughness average value DS, flank (µm)	[RAH]		0.00	0.00
Roughness average value DS, root (µm)	[RAF]		0.00	0.00
Mean roughness height, Rz, flank (µm)	[RZH]		0.00	0.00
Mean roughness height, Rz, root (µm)	[RZF]		0.00	0.00

Gear reference profile 1 :

Reference profile	1.25 / 0.38 / 1.0 ISO 53:1998 Profil A		
Dedendum coefficient	[hfP*]	1.250	
Root radius factor	[rhofP*]	0.380	(rhofPmax*= 0.472)
Addendum coefficient	[haP*]	1.000	
Tip radius factor	[rhoaP*]	0.000	
Protuberance height coefficient	[hprP*]	0.000	
Protuberance angle	[alfprP]	0.000	
Tip form height coefficient	[hFaP*]	0.000	
Ramp angle	[alfKP]	0.000	
	not topping		

Gear reference profile 2 :

Reference profile	1.25 / 0.38 / 1.0 ISO 53:1998 Profil A		
Dedendum coefficient	[hfP*]	1.250	
Root radius factor	[rhofP*]	0.380	(rhofPmax*= 0.472)
Addendum coefficient	[haP*]	1.000	
Tip radius factor	[rhoaP*]	0.000	
Protuberance height coefficient	[hprP*]	0.000	
Protuberance angle	[alfprP]	0.000	
Tip form height coefficient	[hFaP*]	0.000	
Ramp angle	[alfKP]	0.000	
	not topping		

Summary of reference profile gears:

Dedendum reference profile	[hfP*]	1.250	1.250
Tooth root radius Refer. profile	[rofP*]	0.380	0.380
Addendum Reference profile	[haP*]	1.000	1.000
Protuberance height coefficient	[hprP*]	0.000	0.000
Protuberance angle (°)	[alfprP]	0.000	0.000
Tip form height coefficient	[hFaP*]	0.000	0.000
Ramp angle (°)	[alfKP]	0.000	0.000

Type of profile modification: none (only running-in)

Tip relief (µm)	[Ca]	19.5	19.5

Lubrication type Dry-running

Ambient temperature (°C)	[TU]	50.000

		---- Pinion ---------- Rack -	
Transverse module (mm)	[mt]	2.000	
Pressure angle at pitch circle (°)	[alft]	20.000	
Working transverse pressure angle (°)	[alfwt]	20.000	
Working pressure angle at normal section (°)	[alfwn]	20.000	
Helix angle at operating pitch circle (°)	[betaw]	0.000	
Base helix angle (°)	[betab]	0.000	
Sum of profile shift coefficients	[Summexi]	1.0000	
Profile shift coefficient	[x]	1.0000	0.0000
Tooth thickness (Arc) (module) (module)	[sn*]	2.2987	1.5708
Tip alteration (mm)	[k*mn]	0.000	0.000
Reference diameter (mm)	[d]	60.000	48.000
Base diameter (mm)	[db]	56.382	
Tip diameter (mm)	[da,Hz]	68.000	50.000
(mm)	[da,Hz.e/i]	68.000 / 67.990	50.000 / 49.995
Tip diameter allowances (mm)	[Ada,AHz.e/i]	0.000 / -0.010	0.000 / -0.005
Tip form diameter (mm)	[dFa]	68.000	50.000
(mm)	[dFa.e/i]	68.000 / 67.990	50.000 / 49.995
Active tip diameter (mm)	[dNa.e/i]	68.000 / 67.990	50.000 / 49.995
Operating pitch diameter (mm)	[dw]	60.000	50.025
Root diameter (mm)	[df]	59.000	45.500
Generating Profile shift coefficient	[xE.e/i]	0.9519 / 0.9244	-0.0481 / -0.0756
Manufactured root diameter with xE (mm)	[df.e/i]	58.808 / 58.698	45.404 / 45.349
Theoretical tip clearance (mm)	[c]	0.505	0.505
Effective tip clearance (mm)	[c.e/i]	0.676/ 0.586	0.676/ 0.586
Active root diameter (mm)	[dNf]	60.010	47.017
(mm)	[dNf.e/i]	60.051 / 59.980	47.036 / 47.002
Root form diameter (mm)	[dFf]	60.000	46.174
(mm)	[dFf.e/i]	59.810 / 59.704	46.078 / 46.022
Reserve (dNf-dFf)/2 (mm)	[cF.e/i]	0.174 / 0.085	1.013 / 0.925
Addendum (mm)	[ha = mn * (haP*+x)]	4.000	2.000
(mm)	[ha.e/i]	4.000 / 3.995	2.000 / 1.995
Dedendum (mm)	[hf = mn * (hfP*-x)]	0.500	2.500
(mm)	[hf.e/i]	0.596 / 0.651	2.596 / 2.651
Roll angle at dFa (°)	[xsi_dFa.e/i]	38.631 / 38.613	
Roll angle to dNa (°)	[xsi_dNa.e/i]	38.631 / 38.613	
Roll angle to dNf (°)	[xsi_dNf.e/i]	21.004 / 20.795	
Roll angle at dFf (°)	[xsi_dFf.e/i]	20.283 / 19.956	
Tooth height (mm)	[h]	4.500	4.500
Virtual gear no. of teeth	[zn]	30.000	
Normal tooth thickness at tip circle (mm)	[san]	0.715	1.686
(mm)	[san.e/i]	0.642 / 0.590	1.619 / 1.576
Normal space width at root circle (mm)	[efn]	1.324	1.322
(mm)	[efn.e/i]	1.330 / 1.334	1.287 / 1.267
Max. sliding velocity at tip (m/s)	[vga]	0.975	-0.008
Specific sliding at the tip	[zetaa]	0.459	-0.007
Specific sliding at the root	[zetaf]	0.007	-0.847
Sliding factor on tip	[Kga]	-0.291	-0.002
Sliding factor on root	[Kgf]	0.002	0.291
Pitch on reference circle (mm)	[pt]	6.283	
Base pitch (mm)	[pbt]	5.904	
Transverse pitch on contact-path (mm)	[pet]	5.904	
Length of path of contact (mm)	[ga, e/i]	8.732 (8.776/ 8.664)	
Length T1-A (mm)	[T1A]	10.276 (10.232/ 10.335)	
Length T1-B (mm)	[T1B]	13.103 (13.103/ 13.094)	
Length T1-C (mm)	[T1C]	10.201 (10.202/ 10.201)	

Length T1-D (mm)	[T1D]	16.180 (16.136/ 16.239)
Length T1-E (mm)	[T1E]	19.007 (19.007/ 18.998)
Diameter of single contact point B (mm)	[d-B]	62.174 (62.174/ 62.167)
Diameter of single contact point D (mm)	[d-D]	65.008 (64.964/ 65.067)
Transverse contact ratio	[eps_a]	1.479
Transverse contact ratio with allowances	[eps_a.e/m/i]	1.486 / 1.477 / 1.467
Overlap ratio	[eps_b]	0.000
Total contact ratio	[eps_g]	1.479
Total contact ratio with allowances	[eps_g.e/m/i]	1.486 / 1.477 / 1.467

2. FACTORS OF GENERAL INFLUENCE

		---- Pinion ---------- Rack -
Nominal circum. force at pitch circle (N)	[Ft]	59.7
Axial force (N)	[Fa]	0.0
Radial force (N)	[Fr]	21.7
Normal force (N)	[Fnorm]	63.5
Nominal circumferential force per mm (N/mm)	[w]	4.26
Only as information: Forces at operating pitch circle:		
Nominal circumferential force (N)	[Ftw]	59.7
Axial force (N)	[Faw]	0.0
Radial force (N)	[Frw]	21.7
Circumferential speed reference circle (m/s)	[v]	3.36
Circumferential speed operating pitch circle (m/s)	[v(dw)]	3.36
Correction coefficient	[CM]	0.800
Gear body coefficient	[CR]	1.000
Basic rack factor	[CBS]	0.975
Material coefficient	[E/Est]	0.012
Singular tooth stiffness (N/mm/µm)	[c']	0.203
Meshing stiffness (N/mm/µm)	[cg]	0.277
Dynamic factor	[KV]	1.000
Face load factor - flank	[KHb]	1.000
- Tooth root	[KFb]	1.000
- Scuffing	[KBb]	1.000
Transverse load factor - flank	[KHa]	1.000
- Tooth root	[KFa]	1.000
- Scuffing	[KBa]	1.000

Number of load cycles (in mio.)	[NL]	32.040	3.265
Rack length (mm)	[l]		1850.000

3. TOOTH ROOT STRENGTH

Calculation of Tooth form coefficients according method: C

		---- Pinion ----------	Rack -
Calculated with manufacturing profile shift	[xE.e]	0.9519	-0.0481
Tooth form factor	[YF]	1.98	1.98
Stress correction factor	[YS]	1.00	1.00
Working angle (°)	[alfFen]	33.45	20.00

Bending moment arm (mm)	[hF]	4.16	3.91
Tooth thickness at root (mm)	[sFn]	4.73	4.87
Tooth root radius (mm)	[roF]	0.76	0.76

(hF* = 2.078/ 1.955 sFn* = 2.365/ 2.433 roF* = 0.382/ 0.380)
(den/hen (mm) =
68.000/ 50.000 dsFn/hsFn(mm) = 59.454/ 45.784 alfsFn(°) = 30.00/ 30.00 qs = 3.093/ 3.202)

Contact ratio factor	[Yeps]		0.676	
Helix angle factor	[Ybet]		1.000	
Effective facewidth (mm)	[beff]	16.00		18.00
Nominal stress at tooth root (N/mm²)	[sigF0]	2.50		2.22
Tooth root stress (N/mm²)	[sigF]	3.12		2.77
Permissible bending stress at root from data tables				
Notch sensitivity factor	[YdrelT]	1.000		1.000
Surface factor	[YRrelT]	1.000		1.000
size factor (Tooth root)	[YX]	1.000		1.000

Notice: When using Wohler lines from data files, the factors YdrelT, YRrelT, YX
will be interpolated according to the breakpoints NLstatic and NLendurance following ISO.

Finite life factor	[YNT]	1.000		1.000
	[YdrelT*YRrelT*YX*YNT]	1.000		1.000
Alternating bending factor (mean stress influence coefficient)	[YM]		1.000	1.000
Stress correction factor	[Yst]		1.00	
Yst*sigFlim (N/mm²)	[sigFE]	31.10		40.30
Permissible tooth root stress (N/mm²)	[sigFP=sigFG/SFmin]	22.21		28.79
Limit strength tooth root (N/mm²)	[sigFG]	31.10		40.30
Required safety	[SFmin]	1.40		1.40
Safety for tooth root stress	[SF=sigFG/sigF]	9.97		14.52
Transmittable power (W)	[WRating]	1425.71		2076.89

4. SAFETY AGAINST PITTING (TOOTH FLANK)

		---- Pinion ---------- Rack -
Zone factor	[ZH]	2.502
Elasticity factor (√N/mm²)	[ZE]	22.438
Contact ratio factor	[Zeps]	0.917
Helix angle factor	[Zbet]	1.000
Effective facewidth (mm)	[beff]	14.00
Nominal contact stress (N/mm²)	[sigH0]	13.65
Contact stress at operating pitch circle (N/mm²)	[sigHw]	15.26

Lubrication coefficient at NL	[ZL]	1.000	1.000
Speed coefficient at NL	[ZV]	1.000	1.000
Roughness coefficient at NL	[ZR]	1.000	1.000
Material pairing coefficient at NL	[ZW]	1.000	1.000

Notice: When using Wohler lines from data files, the factors ZL, ZV, ZR, ZW
will be interpolated according to the breakpoints NLstatic and NLendurance following ISO.

Finite life factor	[ZNT]	1.000	1.000
	[ZL*ZV*ZR*ZNT]	1.000	1.000
Limited pitting is permitted:	No		
Size factor (flank)	[ZX]	1.000	1.000
Permissible contact stress (N/mm²)	[sigHP=sigHG/SHmin]	23.80	37.40
Pitting stress limit (N/mm²)	[sigHG]	23.80	37.40
Required safety	[SHmin]	1.00	1.00

Safety factor for contact stress at operating pitch circle

	[SHw]	1.56	2.45
Transmittable power (W)	[WRating]	312.29	490.74

4a. WEAR

Line load at reference diameter (N/mm)	[w]	4.26	
Line load at reference diameter (N/mm)	[K_A*K_γ*K_V*$K_{H\beta}$*$K_{H\alpha}$*w]	5.33	
Loss factor	[H_V]	0.177	
Length of active flank (mm)	[l_{Fl}]	4.51	3.15
Wear factor ($mm^3/Nm/10^6$)	[k_W]	3.40000	3.40000
Data from file k_{W1}: Z014-100.DAT			
Data from file k_{W2}: Z014-100.DAT			
Normal tooth thickness in pitch circle (mm)	[s_n]	4.60	3.14
Maximum permissible wear (%)	[W_{limit}]	15.00	
Permissible wear on flank (mm)	[δ_{Wlimn}]	0.69	0.47
Wear removal (mm)	[δ_{Wn}]	0.14307	0.02086
Wear removal (mg)	[=lFL*b*z*ro*δWn]	385.1	3924.0
Required safety	[S_{Wmin}]	1.10	
Safety against wear	[S_W]	4.82	22.59

Calculation for safety against shearing for plastics

Normal tooth thickness in the active root diameter (mm)	[s_{dNf}-δWn]	4.37	3.75
Shearing stress (N/mm²)	[τ_{nom}]	0.98	1.14
Notch effect coefficient	[K_T]	1.25	1.25
Permitted shearing strength (N/mm²)	[τ_B]	17.32	22.45
Required safety	[S_{Tmin}]	2.50	
Safety shearing	[S_T]	14.21	15.82

$\tau_B = 0.557 * \sigma_{Fadm}$; $S_T = \tau_B / (\tau_{nom} * K_T)$

Calculation of local wear with speeds and load distribution according to method A:
Calculation was not carried out. (Contact analysis under load is required.)

Important note:
the kw wear coefficients are usually determined using a plastic/steel pairing..
The coefficients may be very different if pairings of other materials are used..
This calculation is designed to give an indication of possible service life,
however it has not yet been checked exhaustively in real life..

5. BENDING

According to VDI2545:1981

Tooth deformation (µm)	[fa]	27.929
Permissible tooth deformation (µm)	[fazul]	200.000
Required safety	[Sdel]	1.000
Safety against deformation	[Sdelmin]	7.161

Experimental method using tooth stiffness according ISO6336:2006:

Tooth deformation (µm)	[faExp]	20.483	6.612
Permissible tooth deformation (µm)	[fazulExp]	143.531	143.531
Required safety	[Sdel]	1.000	
Safety against clamping	[SdelExp]	7.007	21.709

6. MEASUREMENTS FOR TOOTH THICKNESS

		---- Pinion ---------- Rack -	
Tooth thickness deviation		DIN 3967 cd25	DIN 3967 cd25
Tooth thickness allowance (normal section) (mm)	[As.e/i]	-0.070 / -0.110	-0.070 / -0.110
Number of teeth spanned	[k]	5.000	
(Internal toothing: k = (Measurement gap number)			
Base tangent length (no backlash) (mm)	[Wk]	28.778	
Actual base tangent length ('span') (mm)	[Wk.e/i]	28.712 / 28.674	
(mm)	[ΔWk.e/i]	-0.066 / -0.103	
Diameter of contact point (mm)	[dMWk.m]	63.263	
Theoretical diameter of ball/pin (mm)	[DM]	4.308	3.889
Effective diameter of ball/pin (mm)	[DMeff]	4.500	4.000
Radial single-ball measurement backlash free (mm)	[MrK]	35.506	51.532
Radial single-ball measurement (mm)	[MrK.e/i]	35.444 / 35.408	51.436 / 51.381
Diameter of contact point (mm)	[dMMr.m]	64.093	
Diametral measurement over two balls without clearance (mm)	[MdK]	71.011	
Diametral two ball measure (mm)	[MdK.e/i]	70.887 / 70.816	
Diametral measurement over pins without clearance (mm)	[MdR]	71.011	
Measurement over pins according to DIN 3960 (mm)	[MdR.e/i]	70.887 / 70.816	
Measurement over 3 pins (axial) according to AGMA 2002 (mm)			
	[dk3A.e/i]	70.887 / 70.816	
Chordal tooth thickness (no backlash) (mm)	[sc]	4.593	3.142
Actual chordal tooth thickness (mm)	[sc.e/i]	4.523 / 4.483	3.072 / 3.032
Reference chordal height from da.m (mm)	[ha]	4.086	1.997
Tooth thickness (Arc) (mm)	[sn]	4.597	3.142
(mm)	[sn.e/i]	4.527 / 4.487	3.072 / 3.032
Backlash free center distance (mm)	[aControl.e/i]	79.807 / 79.696	
Backlash free center distance, allowances (mm)	[jta]	-0.193 / -0.304	
Tip clearance (mm)	[c0.i(aControl)]	0.298	0.298
Centre distance allowances (mm)	[Aa.e/i]	-0.015 / 0.015	
Circumferential backlash from Aa (mm)	[jtw_Aa.e/i]	0.011 / -0.011	
Radial clearance (mm)	[jrw]	0.319 / 0.178	
Circumferential backlash (transverse section) (mm)	[jtw]	0.231 / 0.129	
Normal backlash (mm)	[jnw]	0.217 / 0.121	
Torsional angle for fixed rack:			
Entire torsional angle (°)	[j.tSys]	0.0044/ 0.0025	

7. GEAR ACCURACY

		---- Pinion ---------- Rack -	
According to DIN 3961:1978			
Accuracy grade	[Q-DIN3961]	6	6
Profile form deviation (µm)	[ff]	6.00	6.00
Profile slope deviation (µm)	[fHa]	5.00	5.00
Total profile deviation (µm)	[Ff]	8.00	8.00
Helix form deviation (µm)	[fbf]	4.00	4.00
Helix slope deviation (µm)	[fHb]	8.00	8.00
Total helix deviation (µm)	[Fb]	9.00	9.00
Normal base pitch deviation (µm)	[fpe]	7.00	7.00
Single pitch deviation (µm)	[fp]	7.00	7.00
Adjacent pitch difference (µm)	[fu]	9.00	9.00

Total cumulative pitch deviation (µm)		[Fp]	25.00	25.00
Sector pitch deviation over z/8 pitches (µm)		[Fpz/8]	15.00	15.00
Runout (µm)		[Fr]	16.00	16.00
Tooth Thickness Variation (µm)		[Rs]	10.00	10.00
Single flank composite, total (µm)		[Fi']	26.00	26.00
Single flank composite, tooth-to-tooth	(µm)	[fi']	11.00	11.00
Radial composite, total (µm)		[Fi"]	20.00	20.00
Radial composite, tooth-to-tooth (µm)		[fi"]	8.00	8.00

According to DIN 58405:1972 (Feinwerktechnik):

Tooth-to-tooth composite error (µm)	[fi"]	9.00	9.00
Composite error (µm)	[Fi"]	25.00	25.00
Axis alignment error (µm)	[fp]	13.60	13.60
Flank direction error (µm)	[fbeta]	5.00	5.00
Runout (µm)	[Trk, Fr]	24.00	24.00

(Tolerances of rack following DIN 3961:1978 mit der Zähnezahl und dem Teilkreis des Ritzels berechnet)

Axis alignment tolerances (recommendation acc. to ISO TR 10064-3:1996, Quality 6)

Maximum value for deviation error of axis (µm)	[fSigbet]	21.71 (Fb=19.00)
Maximum value for inclination error of axes (µm)	[fSigdel]	43.43

8. ADDITIONAL DATA

Exponent kappa (temperature calculation)	[ExpKappa]	0.400	
Coefficient of friction	[mum]	0.200	
Loss factor	[HV]	0.177	
Coefficient for frequency of running	[KstEDf]	1.000	
Casing surface (m²)	[Oberflache]	163.72800	
Gear power loss (W)	[PVZ]	7.090	
(Meshing efficiency (%)	[etaz]	0.000)	
Tooth root temperature (°C)	[TR]	58.6	50.1
Flank temperature (°C)	[TF]	74.0	50.2
Heat transfer coefficient, root	[KF]	0.0	0.0
Heat transfer coefficient, flank	[KH]	0.0	0.0

9. MODIFICATIONS AND TOOTH FORM DEFINITION

Data for the tooth form calculation :
Data not available.

10. SERVICE LIFE, DAMAGE

Required safety for tooth root	[SFmin]	1.40
Required safety for tooth flank	[SHmin]	1.00
Required safety for wear	[SWmin]	1.10

Service life (calculated with required safeties):

System service life (h)	[Hatt]	2191

Tooth root service life (h)	[HFatt]	1e+006	1e+006
Tooth flank service life (h)	[HHatt]	1.906e+004	1e+006

Wear service life (h) [HWatt] 2191 1.027e+004
Note: The entry 1e+006 h means that the Service life > 1,000,000 h.

Damage calculated on the basis of the required service life [H] (500.0 h)

F1%	F2%	H1%	H2%	W1%	W2%
0.00	0.00	2.62	0.02	22.82	4.87

Damage calculated on basis of system service life [Hatt] (2191.0 h)

F1%	F2%	H1%	H2%	W1%	W2%
0.00	0.00	11.50	0.08	100.00	21.34

Calculation of the factors required to define reliability R(t) according to B. Bertsche with Weibull distribution:
R(t) = 100 * Exp(-((t*fac - t0)/(T - t0))^b) %; t (h)

Gear		fac	b	t0	T	R(H)%
1	Tooth root	64080	1.7	9.654e+029	1.484e+030	100.00
1	Tooth flank	64080	1.3	1.101e+009	5.245e+009	100.00
2	Tooth root	6529	1.7	9.654e+029	1.484e+030	100.00
2	Tooth flank	6529	1.3	1.674e+010	7.973e+010	100.00

Reliability of the configuration for required service life (%) 100.00 (Bertsche)

REMARKS:
- Specifications with [.e/i] imply: Maximum [e] and Minimal value [i] with consideration of all tolerances
  Specifications with [.m] imply: Mean value within tolerance
- For the backlash tolerance, the center distance tolerances and the tooth thickness deviation are taken into account. Shown is the maximal and the minimal backlash corresponding the largest resp. the smallest allowances
  The calculation is done for the operating pitch circle.

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