KISSsoft
Calculation programs for machine design

KISSsoft 03/2017 – 教程 8

圆柱齿轮副的校核

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1 任务

本教程将会介绍如何在 KISSsoft 软件中输入已有的齿轮副参数。

对于一对已有的圆柱齿轮副，需要执行如下步骤：

- 在 KISSsoft 中输入必要的数据
- 依据 ISO6336 进行分析
- 以文档列出计算结果

1.1 输入数据

将以下数据输入 KISSsoft 软件，详细内容会在本教程第二部分介绍：

1.1.1 功率参数

Power [P]（功率）	3.5	kW
Speed [n] at drive（转速）	2500	1/min (Gear1 driving)
Application factor [K_A]（应用系数）	1.35	
Service life [H]（工作寿命）	750	h

1.1.2 几何参数

Normal module [m_n]（法向模数）	1.5	mm
Helix angle at reference circle [ß]（分度圆螺旋角）	25	°
Pressure angle at normal section [α_n]（法向压力角）	20	°
Number of teeth [z] Gear1/Gear2（齿数 齿轮 1/齿轮 2）	16 / 43	
Face width [b] Gear1/Gear2（齿宽 齿轮 1/齿轮 2）	14 / 14.5	mm
Center distance [a]（中心距）	48.9 ±0.03	mm
Profile shift coefficient [x] Gear 1 (pinion)（变位系数 齿轮 1）	0.3215	

1.1.3 齿廓参数

	Dedendum coefficient [h^*_{FP}]（齿根高系数）	Root radius coefficient [ρ^*_{fP}]（齿根半径系数）	Addendum coefficient [h^*_{aP}]（齿顶高系数）
Gear 1 (pinion)（齿轮 1）	1.25	0.3	1.0
Gear 2（齿轮 2）	1.25	0.3	1.0

1.1.4 其他参数

材料：

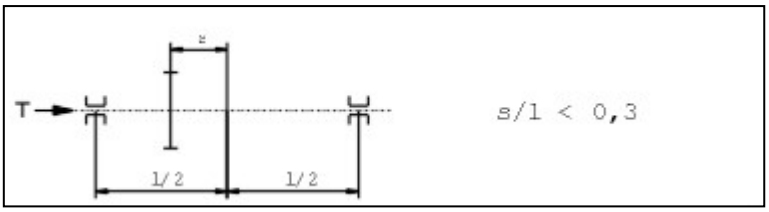
	Material（材料）	Hardness data（硬化数据）	σFlim	σHlim
Gear 1 (pinion)（齿轮 1）	15 CrNi 6	case-hardened HRC 60	430 N/mm²	1500 N/mm²
Gear 2（齿轮 2）	15 CrNi 6	case-hardened HRC 60	430 N/mm²	1500 N/mm²

润滑：

Grease lubrication（脂润滑）	Microlube GB 00	80 °C

公法线长度偏差：

	No. of teeth spanned [k]（跨齿数）	Max. base tangent length [Wkmax]（最大公法线长度）	Min. base tangent length [Wkmin]（最小公法线长度）
Gear 1 (pinion)（齿轮 1）	3	11.782 mm	11.758 mm
Gear 2（齿轮 2）	6	25.214 mm	25.183 mm

Quality [Q] (DIN 3961)（精度等级）	8 / 8
Tooth trace modification（齿向修形）	End relief（齿根修形）
Contact pattern（接触斑点）	not verified or inappropriate（装配时无检验调整）
Type of pinion shaft（轴的结构）	 小齿轮轴的载荷情况 ISO 6336 图 13a；l = 53 mm; s = 5.9 mm; dsh = 14 mm

2 解决步骤

2.1 运行软件

软件安装并激活之后，用户便可以运行软件。通常，用户可以通过点击“开始→Program Files→KISSsoft 03-2017→KISSsoft 03-2017”来打开程序。随后，会出现如下界面：

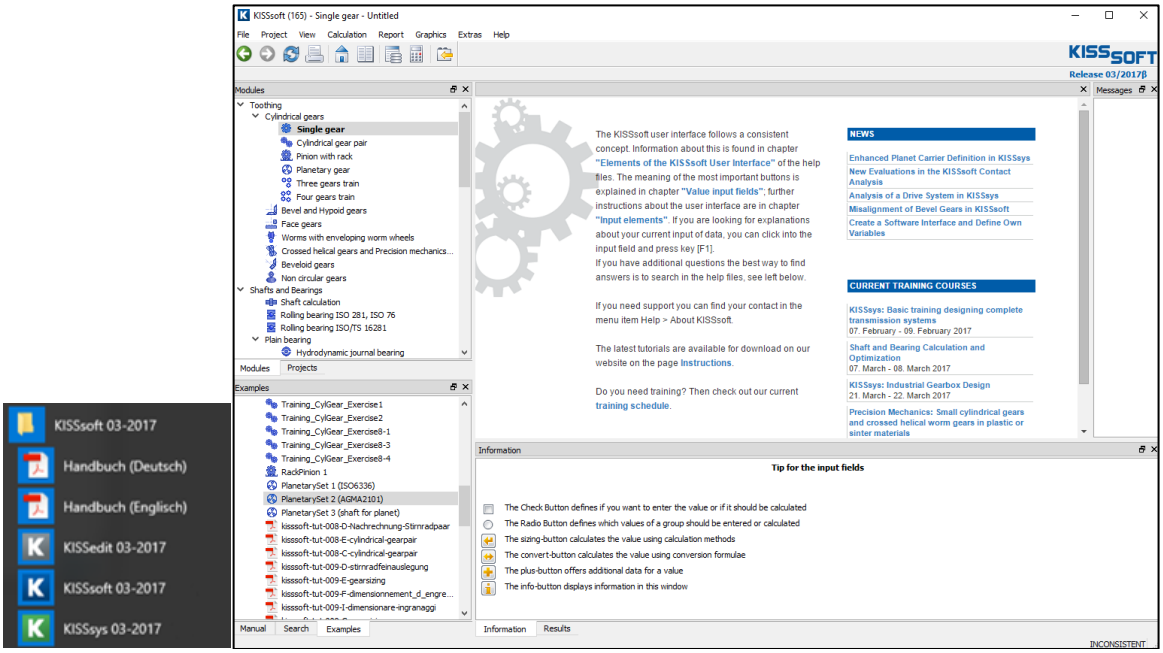


图 1. 运行 KISSsoft，初始界面

2.2 选择一个计算模块

在模块树窗口中，选择“**Modules**”标签，打开圆柱齿轮副计算模块：

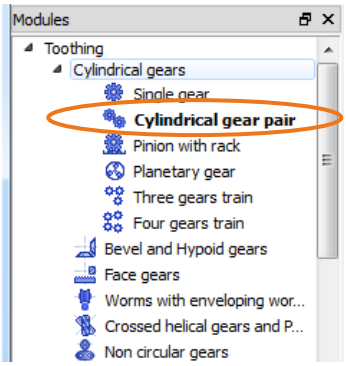


图 2. 打开圆柱齿轮副计算模块

出现的 KISSsoft 输入界面如下：

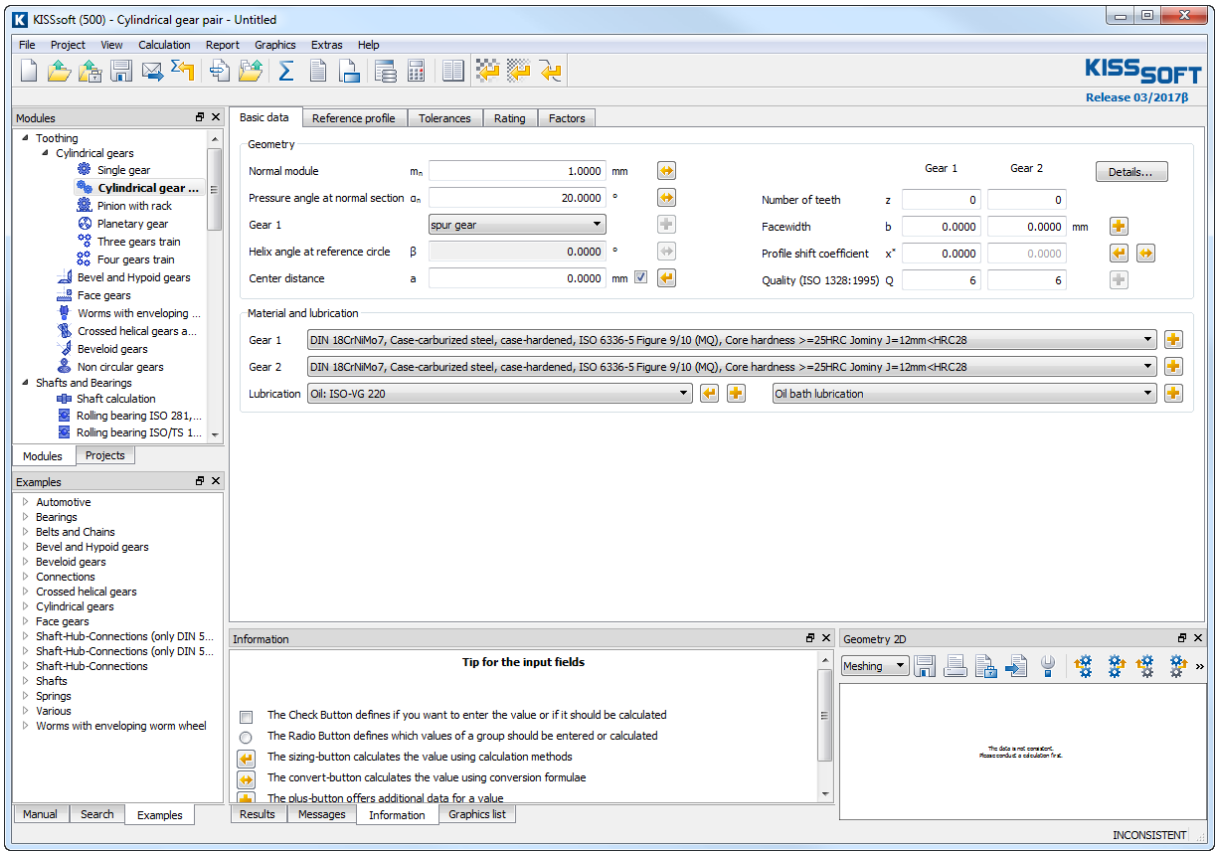


图 3.　KISSsoft 中圆柱齿轮副参数输入窗口

以下章节会介绍如何输入齿轮副参数。

2.3 齿轮副几何参数

在“**Basic data**”的输入界面，“Geometry”部分，输入法向模数（1.5 mm），压力角（20°），螺旋角（25°），中心距（48.9 mm），齿数（16/43），齿宽（14/14.5 mm），变位系数（0.3215/...）以及精度等级（8/8）。用户不能直接输入齿轮 2 的变位系数，因为这个参数是根据中心距和齿轮 1 的变位系数计算出来的。

或者，用户可以点击选型按钮 ，让软件自动推荐一个符合要求的参数。同时，无论用户使用哪一种计算标准，都可以设置合适的精度等级。

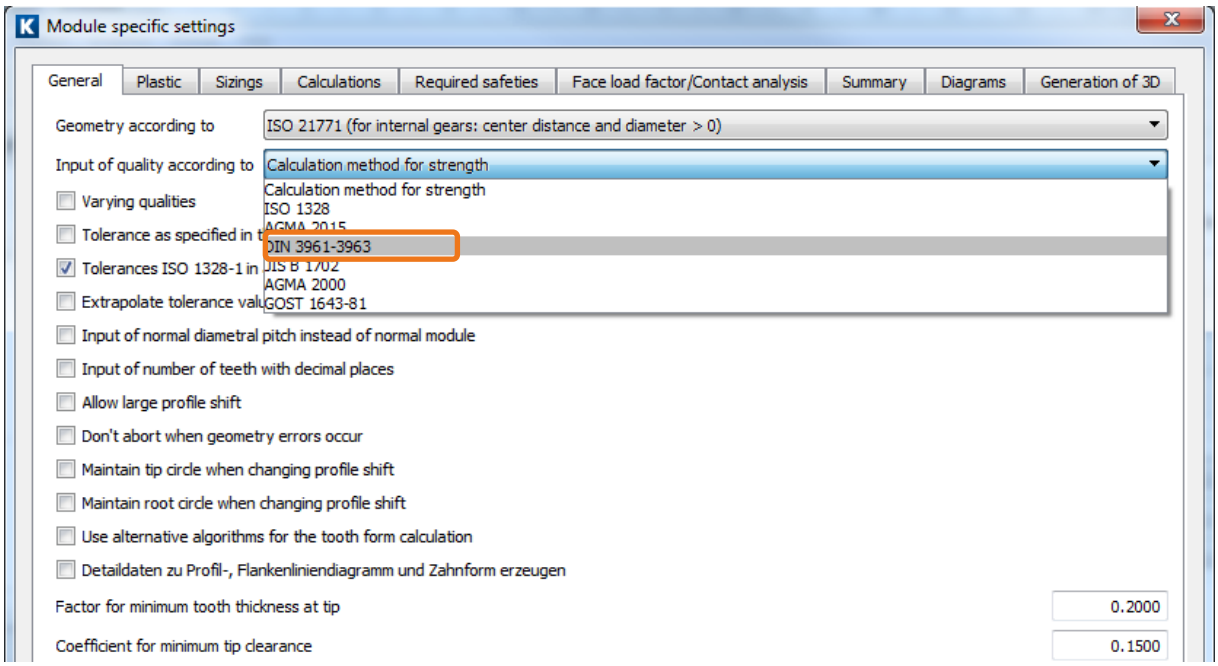


图 4.　模块的特殊设置，精度等级并不取决于计算标准

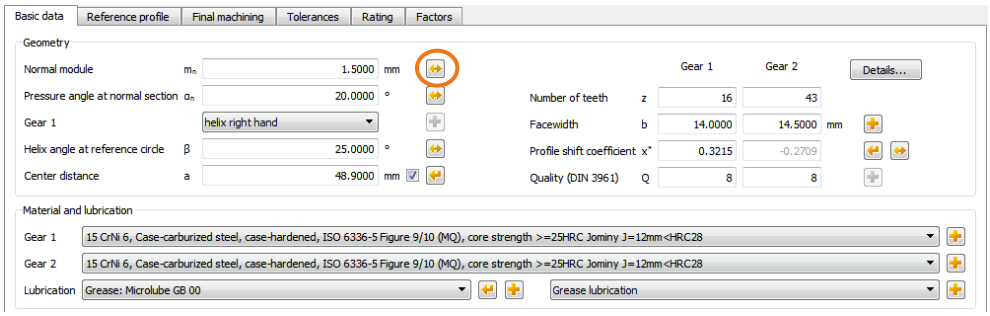


图 5.　输入窗口—“Basic data 基本参数”，“Geometry（几何数据）”

点击输入框右边的转换计算按钮 ，用户可以输入一些额外的参数，或者输入其余参数来计算得到这个参数。如果需要输入角度，在输入框中单击右键，会弹出另一个窗口，用户可以在其中输入度、分、秒：

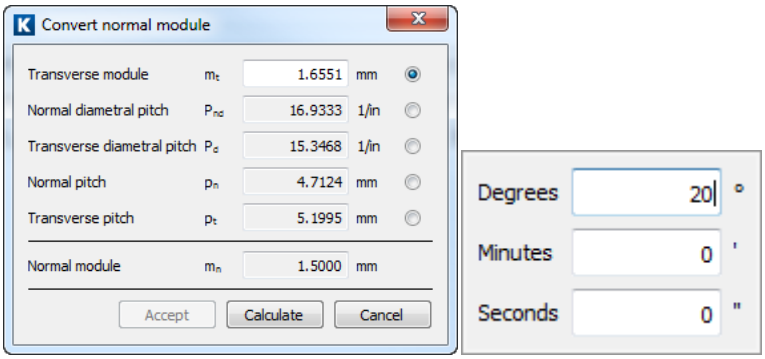


图 6.　输入其他参数计算法向模数；输入角度

2.4 定义工况和计算标准

打开“**Rating**”界面，在“Strength”部分输入工况数据：需要的工作寿命（750h），应用系数（1.35）。在本案例中，通过输入功率（3.5kw）和转速（2500 1/min）来定义扭矩。在其余情况下，如果用户要输入扭矩来计算功率，只需要将输入框右边的选择按钮由扭矩设置成功率即可。在“Details”窗口中，用户可以输入更多和强度相关的参数。

请注意，为了正确地定义载荷，用户需要选择哪一个齿轮为参考齿轮来定义工况（输入齿轮-齿轮 1）。
在左上角的计算标准下拉列表中，选择合适的计算标准。在本案例中，需要换成 ISO 6336 Method B。

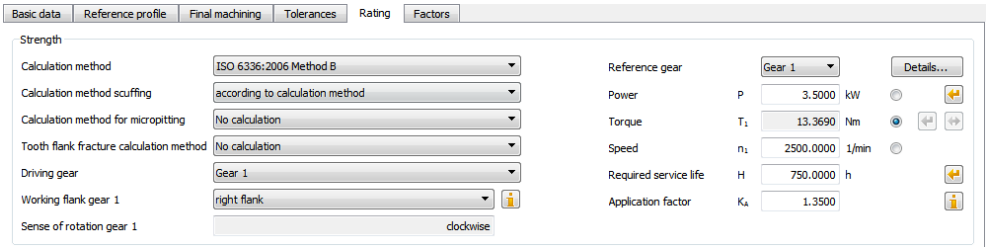


图 7.　输入窗口 – “Rating 校核”，“Strength 强度”

在“**Factors**”标签下，在“Face load factor/contact analysis”窗口，用户可以输入齿面载荷分布系数 $K_{H\beta}$ 。用户可以直接输入（在下拉列表中选择“Own Input”），也可以点击输入框边上的附加计算按钮 进行计算。
用户必须选择接触斑点的位置，在“Position of Contact pattern 接触斑点的位置”下拉列表中选择“not verified or inappropriate 装配时无检验调整”。

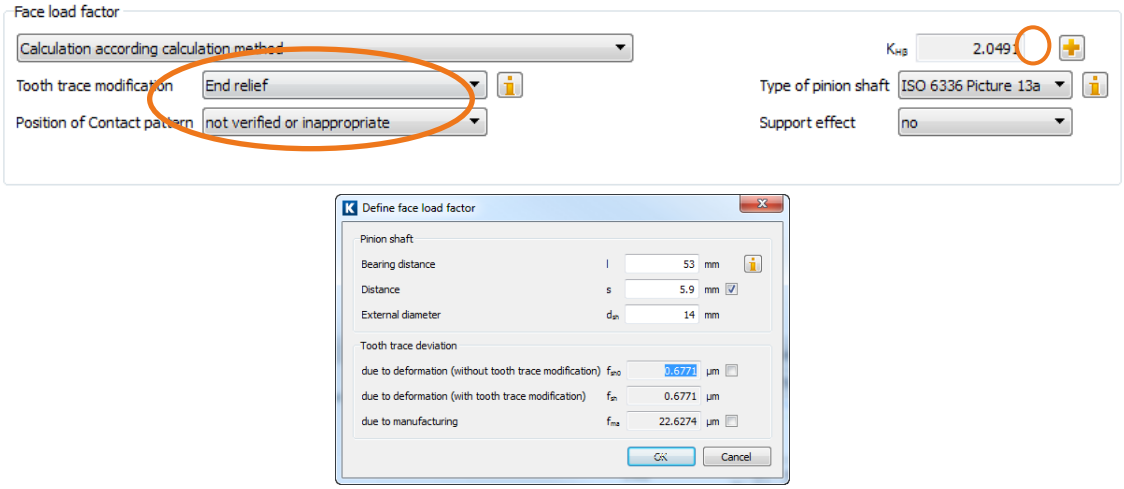


图 8.　定义齿面载荷分布系数

计算齿面载荷分布系数，需要输入以下数据：：
齿向修形（本案例中如图 8）。
轴的布局。点击“Type of pinion shaft”右边的信息按钮，会出现如图 9 中的右边部分的窗口。在本案例中，如图 9 选择图 A。点击附加计算按钮后，选择输入框右边的勾选框，用户便可以输入距离 l 和 s。

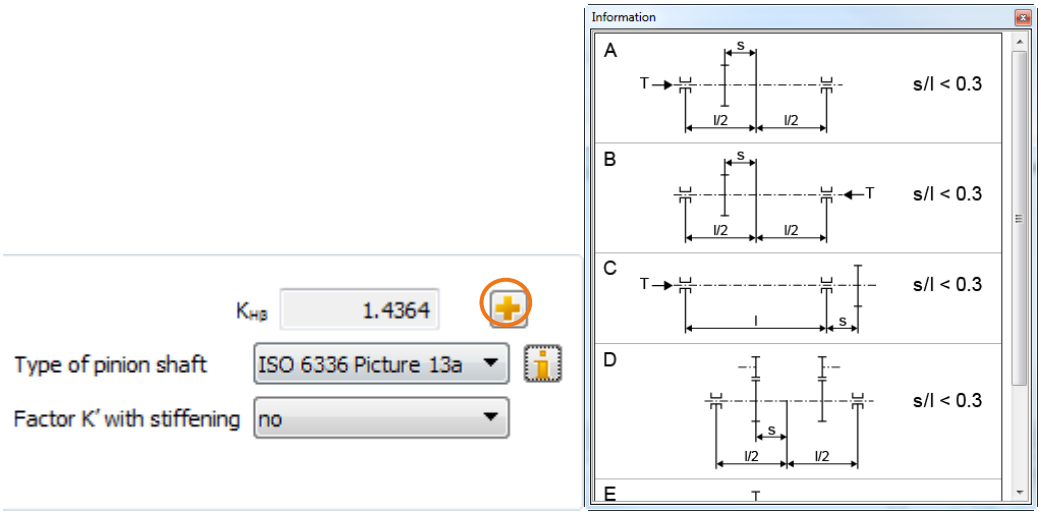


图 9.　定义齿面载荷分布系数

请注意：

需要轴上布局来计算齿面载荷分布系数 $K_{H\beta}$。ISO 6336 （或者 DIN 3990）提供了 5 种不同的布局，用户可以在其中选择自己需要的一种。图 9 中右边部分列出了 A 到 E 五种布局。

齿面载荷分布系数 $K_{H\beta}$ 定义的是载荷沿着齿宽的非线性分布。用户可以询问 KISSsoft AG 要求一些特别的指导：文档“kisssoft-anl-072-E-Contact-Analysis-Cylindrical-Gears.pdf”会有进一步介绍。

2.5 材料和润滑

在“**Basic data**”标签下，用户可以在“Material and lubrication”输入部分，在下拉列表中选择齿轮材料。本案例中使用的是 15 Cr Ni 6, case-carburized steel。

用户也可以选择润滑油和润滑方式。

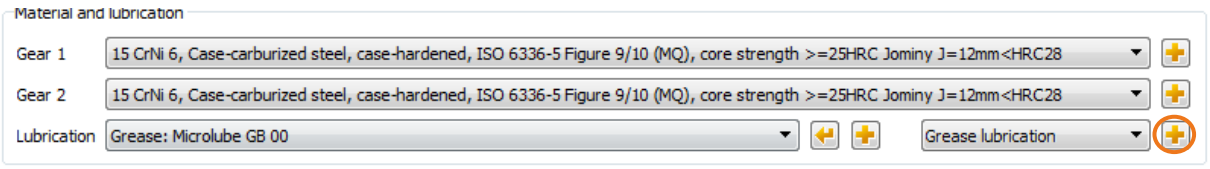


图 10.　输入窗口– “Basic data 基本参数”，“Material and Lubrication 材料和润滑”

点击润滑方式右边的加号按钮 ，定义润滑油温度。

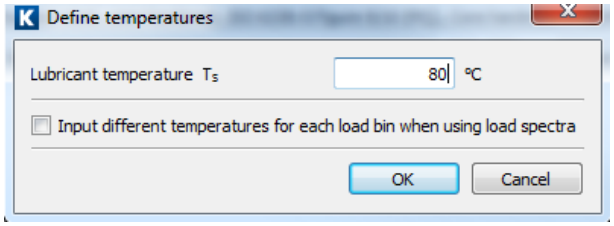


图 11.　定义润滑油温度

2.6 基准齿廓

用户可以在“**Reference profile**”标签下，输入齿轮 1 和齿轮 2 的更多数据，例如基准齿廓，齿根高系数，齿根半径系数，以及齿顶高系数。

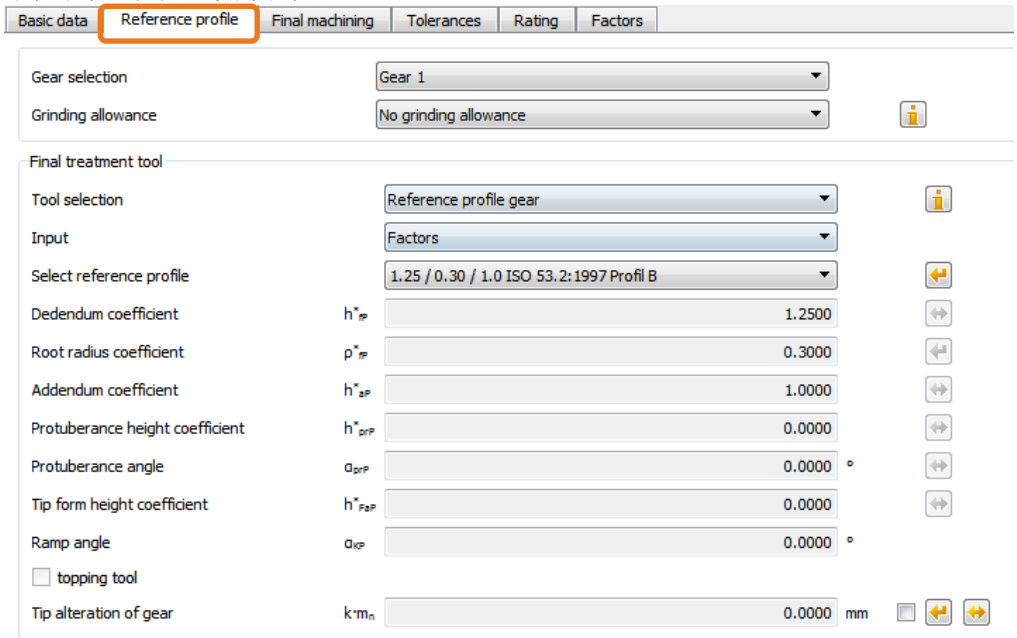


图 12.　输入窗口 – “Reference profile 基准齿廓”标签

2.7 公差

用户可以在“**Tolerance**”标签下定义齿厚误差。在实际案例中，通常只需要规定有效的公法线长度公差和跨齿数。输入这些数值后，KISSsoft 软件会计算出正确的齿厚公差。

在本案例中，用户有两种方法输入中心距公差：在下拉列表中选择，或者按照下图所示直接输入数值。

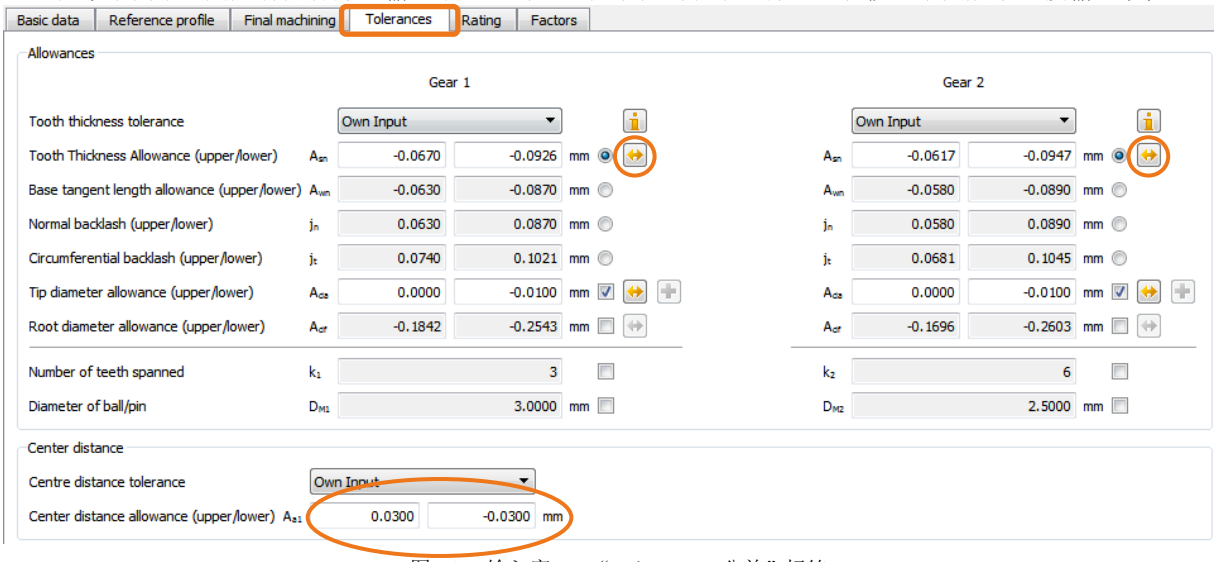


图 13.　输入窗口 – “Tolerances 公差”标签

按照如下方法输入公法线长度：在“**Tolerances**” 标签下，“Allowances”部分，点击齿厚偏差输入框边上的转换按钮 。

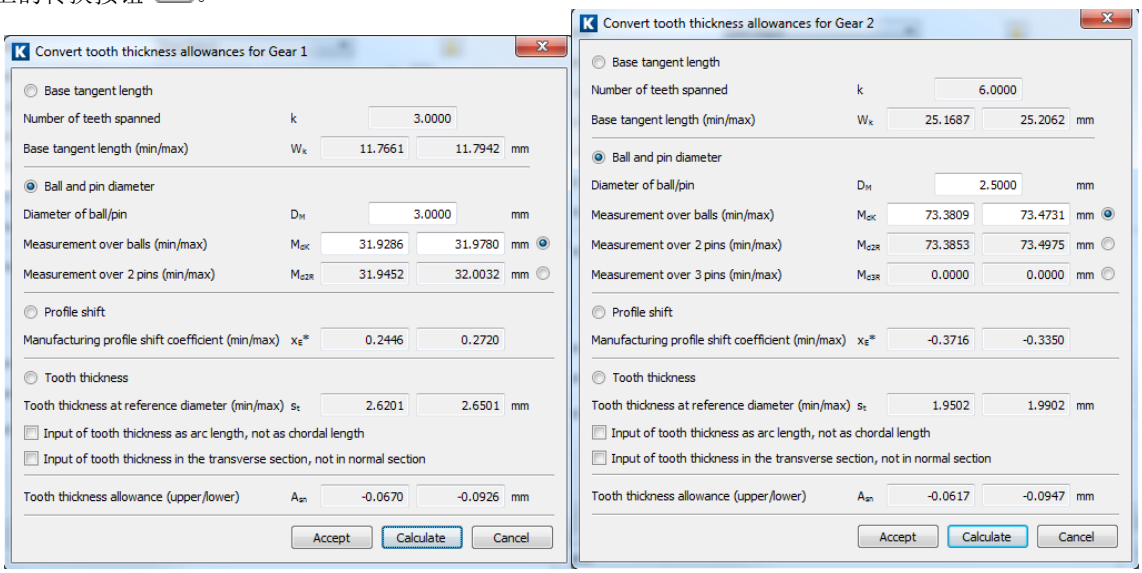


图 14.　计算公法线长度

用户可以在这里输入跨齿数和公法线长度（min/max），然后点击 Calculate。计算结束后，点击 **Accept**，计算结果便会转移到主界面中。

注意：在定义了两个齿轮的变位系数之前，用户不可以输入偏差值。否则会得到一个错误值，用户只能重复刚刚的过程，来得到正确结果。

注意：用户也可以在前面一步就设置跨齿数，方法是：在“Tolerance”标签下的“Allowances”部分输入窗口，选择“Number of teeth spanned”边上的勾选框，然后便可以输入跨齿数。用户也可以在计算界面中输入。



图 15. 输入窗口“Tolerances 公差”标签，“Allowances 偏差”

2.8 润滑

在“Basic data”标签下，“Material and lubrication”部分的输入窗口，只用于输入各种不同润滑方式的润滑温度。在输入润滑温度的确切数值时，用户可以在前面的下拉列表中选择其他油润滑或者脂润滑的润滑方式。

油润滑或者脂润滑的润滑温度“**Lubricant temperature**”定义了齿轮本体的基本温度。 所以，“**Lubricant temperature**” 对于计算润滑油的有效运动粘度也很重要。“**Ambient temperature**” 并不影响计算（见章节 2.5）。

“Ambient temperature” 只在干摩擦（dry run）时定义基本温度。在本案例中，齿轮齿体的温度会影响计算。

其余情况：

- 蜗轮： 需要输入“**Ambient temperature**” 的值来计算温度安全系数。
- 塑料齿轮：塑料齿轮的强度很大程度上取决于齿轮的温度，用户必须在这里输入相应的温度。

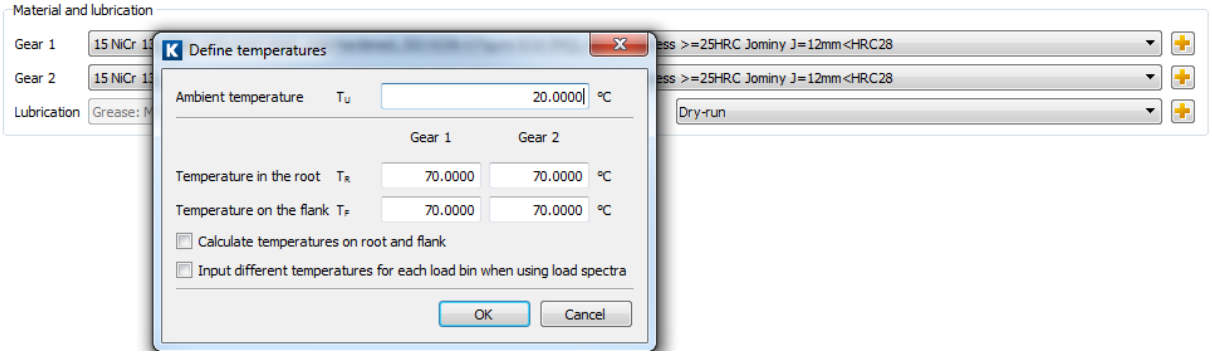


图 16. 输入干摩擦的温度

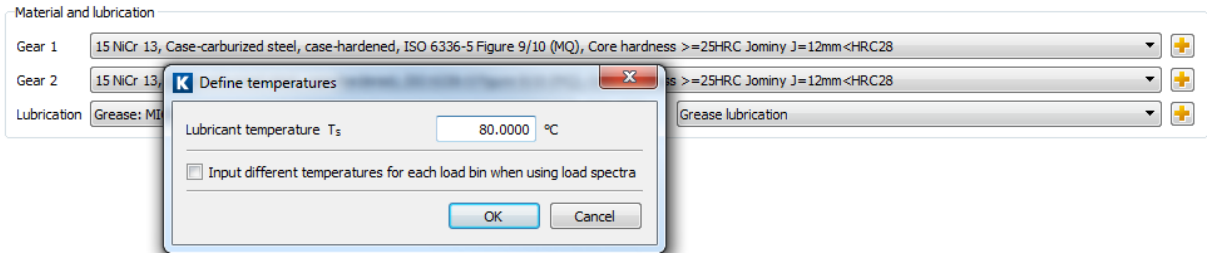


图 17. 输入脂润滑的润滑温度

2.9 计算

点击工具栏中的  按钮或者点击“F5”来运行计算。由于接触斑点未经实际验证，软件会弹出一个信息窗口提示 $K_{H\beta}$ 值太高。

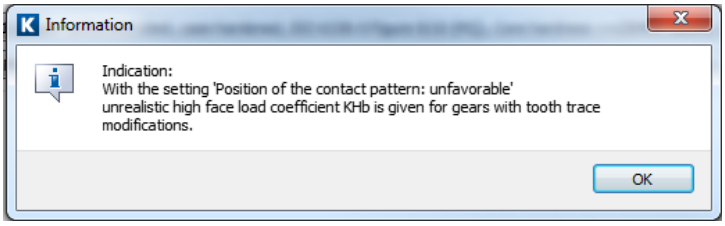


图 18. 计算之后的信息窗口

这代表 $K_{H\beta}$ 的计算是用一种不符合实际的接触斑点进行的。如果用户可以在车间进行测试，便可以看到在软件中假定的接触斑点是否和现实一致。

如果用户已经完全正确得完成了本教程，得到的强度计算结果应该和下图中标示的一致。

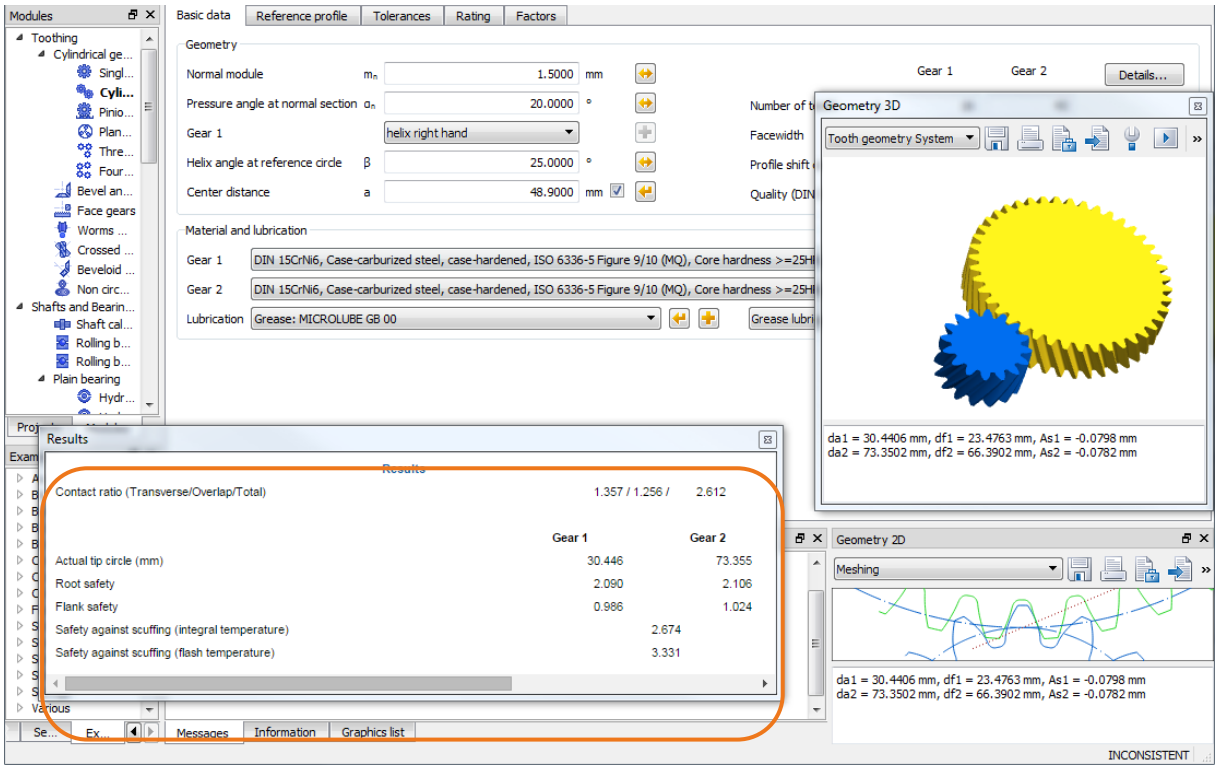


图 19. 本教程最后的结果

2.10报告

KISSsoft Release 03/2017 β

KISSsoft-Entwicklungs-Version KISSsoft AG CH-8608 BUBIKON

File

Name : Tutorial-008_ISO
Description: KISSsoft Tutorial
Changed by: mhoffmann on: 21.02.2017 at: 11:37:13

Important hint: At least one warning has occurred during the calculation:

1-> Indication:
With the setting 'Position of the contact pattern: unfavorable'
unrealistic high face load coefficient KHb is given for gears with tooth trace modifications.

2-> Mesh gear 1 - 2 :
The face load coefficient is very high.
The formulas for the calculation according ISO or DIN sometimes results
in values that are too high. We recommend that you use the
KISSsoft shaft module to calculate KHb more accurate.

CALCULATION OF A HELICAL GEAR PAIR

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

Calculation method ISO 6336:2006 Method B

		------- GEAR 1	-------- GEAR 2 --
Power (kW)	[P]	3.500	
Speed (1/min)	[n]	2500.0	930.2
Torque (Nm)	[T]	13.4	35.9
Application factor	[KA]	1.35	
Required service life (h)	[H]	750.00	
Gear driving (+) / driven (-)		+	-

Working flank gear 1: Right flank
Sense of rotation gear 1 clockwise

1. TOOTH GEOMETRY AND MATERIAL

(geometry calculation according to DIN 3960:1987)

		------- GEAR 1	-------- GEAR 2 --
Center distance (mm)	[a]	48.900	
Centre distance tolerance		ISO 286:2010 Measure js7	
Normal module (mm)	[mn]	1.5000	
Pressure angle at normal section (°)	[alfn]	20.0000	
Helix angle at reference circle (°)	[beta]	25.0000	
Number of teeth	[z]	16	43
Facewidth (mm)	[b]	14.00	14.50
Hand of gear		right	left
Accuracy grade	[Q-DIN 3961:1978]	8	8

Inner diameter (mm)	[di]	0.00	0.00
Inner diameter of gear rim (mm)	[dbi]	0.00	0.00

Material

Gear 1: DIN 15CrNi6, Case-carburized steel, case-hardened
ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jominy J=12mm<HRC28

Gear 2: DIN 15CrNi6, Case-carburized steel, case-hardened
ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jominy J=12mm<HRC28

		------- GEAR 1 --------	GEAR 2 --
Surface hardness		HRC 60	HRC 60
Material quality according to ISO 6336:2006 Normal (Life factors ZNT and YNT >=0.85)			
Fatigue strength. tooth root stress (N/mm²)	[σFlim]	430.00	430.00
Fatigue strength for Hertzian pressure (N/mm²)	[σHlim]	1500.00	1500.00
Tensile strength (N/mm²)	[σB]	1000.00	1000.00
Yield point (N/mm²)	[σS]	685.00	685.00
Young's modulus (N/mm²)	[E]	206000	206000
Poisson's ratio	[v]	0.300	0.300
Roughness average value DS, flank (µm)	[RAH]	0.60	0.60
Roughness average value DS, root (µm)	[RAF]	3.00	3.00
Mean roughness height, Rz, flank (µm)	[RZH]	4.80	4.80
Mean roughness height, Rz, root (µm)	[RZF]	20.00	20.00

Gear reference profile 1 :

Reference profile	1.25 / 0.30 / 1.0 ISO 53:1998 Profil B	
Dedendum coefficient	[hfP*]	1.250
Root radius factor	[rhofP*]	0.300 (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 / 0.30 / 1.0 ISO 53:1998 Profil B	
Dedendum coefficient	[hfP*]	1.250
Root radius factor	[rhofP*]	0.300 (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*]	0.300	0.300
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]	2.0	2.0
Lubrication type				Grease lubrication	
Type of grease				Grease: MICROLUBE GB 00	
Lubricant base				Mineral-oil base	
Kinem. viscosity	base oil at	40 °C (mm²/s)	[nu40]	700.00	
Kinem. viscosity	base oil at	100 °C (mm²/s)	[nu100]	35.00	
FZG-Test A/8.3/90	step		[FZGtestA]	12	
Specific density at 15 °C (kg/dm³)			[roOil]	0.930	
Grease temperature (°C)			[TS]	80.000	

		------- GEAR 1 --------	GEAR 2 --
Overall transmission ratio	[itot]	-2.688	
Gear ratio	[u]	2.688	
Transverse module (mm)	[mt]	1.655	
Pressure angle at pitch circle (°)	[alft]	21.880	
Working transverse pressure angle (°)	[alfwt]	22.100	
	[alfwt.e/i]	22.136 / 22.063	
Working pressure angle at normal section (°)	[alfwn]	20.199	
Helix angle at operating pitch circle (°)	[betaw]	25.034	
Base helix angle (°)	[betab]	23.399	
Reference centre distance (mm)	[ad]	48.824	
Sum of profile shift coefficients	[Summexi]	0.0506	
Profile shift coefficient	[x]	0.3215	-0.2709
Tooth thickness (Arc) (module) (module)	[sn*]	1.8048	1.3736
Tip alteration (mm)	[k*mn]	0.000	0.000
Reference diameter (mm)	[d]	26.481	71.168
Base diameter (mm)	[db]	24.574	66.041
Tip diameter (mm)	[da]	30.446	73.355
(mm)	[da.e/i]	30.446 / 30.436	73.355 / 73.345
Tip diameter allowances (mm)	[Ada.e/i]	0.000 / -0.010	0.000 / -0.010
Tip form diameter (mm)	[dFa]	30.446	73.355
(mm)	[dFa.e/i]	30.446 / 30.436	73.355 / 73.345
Active tip diameter (mm)	[dNa]	30.446	73.355
Active tip diameter (mm)	[dNa.e/i]	30.446 / 30.436	73.355 / 73.345
Operating pitch diameter (mm)	[dw]	26.522	71.278
(mm)	[dw.e/i]	26.529 / 26.515	71.296 / 71.260
Root diameter (mm)	[df]	23.696	66.605
Generating Profile shift coefficient	[xE.e/i]	0.2601/ 0.2367	-0.3275/ -0.3577
Manufactured root diameter with xE (mm)	[df.e/i]	23.511 / 23.441	66.436 / 66.345
Theoretical tip clearance (mm)	[c]	0.375	0.375
Effective tip clearance (mm)	[c.e/i]	0.522 / 0.447	0.519 / 0.454
Active root diameter (mm)	[dNf]	25.050	68.670
(mm)	[dNf.e/i]	25.068 / 25.037	68.693 / 68.652
Root form diameter (mm)	[dFf]	24.894	67.921
(mm)	[dFf.e/i]	24.820 / 24.794	67.816 / 67.761
Reserve (dNf-dFf)/2 (mm)	[cF.e/i]	0.137 / 0.109	0.466 / 0.418
Addendum (mm)	[ha=mn*(haP*+x+k)]	1.982	1.094
(mm)	[ha.e/i]	1.982 / 1.977	1.094 / 1.089
Dedendum (mm)	[hf=mn*(hfP*-x)]	1.393	2.281
(mm)	[hf.e/i]	1.485 / 1.520	2.366 / 2.412
Roll angle at dFa (°)	[xsi_dFa.e/i]	41.909 / 41.870	27.702 / 27.682
Roll angle to dNa (°)	[xsi_dNa.e/i]	41.909 / 41.870	27.702 / 27.682
Roll angle to dNf (°)	[xsi_dNf.e/i]	11.549 / 11.186	16.400 / 16.270
Roll angle at dFf (°)	[xsi_dFf.e/i]	8.135 / 7.696	13.371 / 13.160
Tooth height (mm)	[h]	3.375	3.375
Virtual gear no. of teeth	[zn]	20.960	56.329

Normal tooth thickness at tip circle (mm)	[san]		0.874			1.225		
(mm)	[san.e/i]	0.806 /	0.771		1.166 /	1.127		
Normal-tooth thickness on tip form circle (mm)	[sFan]		0.874			1.225		
(mm)	[sFan.e/i]	0.806 /	0.771		1.166 /	1.127		
Normal space width at root circle (mm)	[efn]		0.000			1.352		
(mm)	[efn.e/i]	0.000 /	0.000		1.388 /	1.409		
Max. sliding velocity at tip (m/s)	[vga]		1.436			0.919		
Specific sliding at the tip	[zetaa]		0.610			0.591		
Specific sliding at the root	[zetaf]		-1.443			-1.567		
Mean specific sliding	[zetam]			0.603				
Sliding factor on tip	[Kga]		0.414			0.265		
Sliding factor on root	[Kgf]		-0.265			-0.414		
Pitch on reference circle (mm)	[pt]			5.200				
Base pitch (mm)	[pbt]			4.825				
Transverse pitch on contact-path (mm)	[pet]			4.825				
Lead height (mm)	[pz]		178.407			479.470		
Axial pitch (mm)	[px]			11.150				
Length of path of contact (mm)	[ga, e/i]		6.555 (	6.588 /	6.502)			
Length T1-A, T2-A (mm)	[T1A, T2A]	2.432(	2.399/	2.477)	15.965(	15.965/	15.954)	
Length T1-B (mm)	[T1B, T2B]	4.162(	4.162/	4.154)	14.235(	14.202/	14.277)	
Length T1-C (mm)	[T1C, T2C]	4.989(	4.980/	4.998)	13.408(	13.384/	13.432)	
Length T1-D (mm)	[T1D, T2D]	7.257(	7.224/	7.302)	11.140(	11.140/	11.129)	
Length T1-E (mm)	[T1E, T2E]	8.987(	8.987/	8.979)	9.410(	9.377/	9.452)	
Length T1-T2 (mm)	[T1T2]		18.397 (	18.364 /	18.430)			
Diameter of single contact point B (mm)	[d-B]	25.945(	25.945/	25.940)	71.916(	71.890/	71.949)	
Diameter of single contact point D (mm)	[d-D]	28.540(	28.506/	28.585)	69.698(	69.698/	69.691)	
Addendum contact ratio	[eps]	0.829(	0.830/	0.825)	0.530(	0.535/	0.523)	
Minimal length of contact line (mm)	[Lmin]			19.611				
Transverse contact ratio	[eps_a]			1.359				
Transverse contact ratio with allowances	[eps_a.e/m/i]		1.365 /	1.357 /	1.348			
Overlap ratio	[eps_b]			1.256				
Total contact ratio	[eps_g]			2.614				
Total contact ratio with allowances	[eps_g.e/m/i]		2.621 /	2.612 /	2.603			

2. FACTORS OF GENERAL INFLUENCE

		------- GEAR 1 -------- GEAR 2 --
Nominal circum. force at pitch circle (N)	[Ft]	1009.7
Axial force (N)	[Fa]	470.8
Radial force (N)	[Fr]	405.5
Normal force (N)	[Fnorm]	1185.6
Nominal circumferential force per mm (N/mm)	[w]	72.12
Only as information: Forces at operating pitch circle:		
Nominal circumferential force (N)	[Ftw]	1008.1
Axial force (N)	[Faw]	470.8
Radial force (N)	[Frw]	409.4
Circumferential speed reference circle (m/s)	[v]	3.47
Circumferential speed operating pitch circle (m/s)	[v(dw)]	3.47
Running-in value (µm)	[yp]	1.1
Running-in value (µm)	[yf]	0.9
(Tolerances fpe, ff, fHb according to tolerances in section 7)		
Correction coefficient	[CM]	0.800
Gear body coefficient	[CR]	1.000
Basic rack factor	[CBS]	0.975
Material coefficient	[E/Est]	1.000

Singular tooth stiffness (N/mm/µm)	[c']	12.156	
Meshing stiffness (N/mm/µm)	[cgalf]	15.426	
Meshing stiffness (N/mm/µm)	[cgbet]	13.112	
Reduced mass (kg/mm)	[mRed]	0.00235	
Resonance speed (min-1)	[nE1]	48315	
Resonance ratio (-)	[N]	0.052	
Subcritical range			
Running-in value (µm)	[ya]	1.1	
Bearing distance l of pinion shaft (mm)	[l]	53.000	
Distance s of pinion shaft (mm)	[s]	5.900	
Outside diameter of pinion shaft (mm)	[dsh]	14.000	
Load in accordance with Figure 13, ISO 6336-1:2006	[-]	0	
0:a), 1:b), 2:c), 3:d), 4:e)			
Coefficient K' according to Figure 13, ISO 6336-1:2006	[K']	0.80	
Without support effect			
Tooth trace deviation (active) (µm)	[Fby]	16.36	
from deformation of shaft (µm)	[fsh*B1]	2.56	
(fsh (µm) = 3.66, B1= 0.70, fHb5 (µm) = 5.50)			
Tooth trace: with end relief			
Position of Contact pattern: not verified or inappropriate			
from production tolerances (µm)	[fma*B2]	15.84	
(B2= 0.70)			
Tooth trace deviation, theoretical (µm)	[Fbx]	19.24	
Running-in value (µm)	[yb]	2.89	
Dynamic factor	[KV]	1.049	
Face load factor - flank	[KHb]	2.049	
- Tooth root	[KFb]	1.729	
- Scuffing	[KBb]	2.049	
Transverse load factor - flank	[KHa]	1.324	
- Tooth root	[KFa]	1.324	
- Scuffing	[KBa]	1.324	
Helical load factor scuffing	[Kbg]	1.242	
Number of load cycles (in mio.)	[NL]	112.500	41.860

3. TOOTH ROOT STRENGTH

Calculation of Tooth form coefficients according method: B

		------- GEAR 1	-------- GEAR 2 --
Calculated with manufacturing profile shift	[xE.e]	0.2601	-0.3275
Tooth form factor	[YF]	1.38	1.68
Stress correction factor	[YS]	2.14	1.84
Working angle (°)	[alfFen]	21.76	19.00
Bending moment arm (mm)	[hF]	1.53	1.85
Tooth thickness at root (mm)	[sFn]	3.14	3.15
Tooth root radius (mm)	[roF]	0.65	0.82

(hF* = 1.021/ 1.231 sFn* = 2.093/ 2.102 roF* = 0.431/ 0.545)
(den (mm) =
32.728/ 84.649 dsFn(mm) = 23.995/ 67.030 alfsFn(°) = 30.00/ 30.00 qs = 2.426/ 1.930)

Helix angle factor	[Ybet]	0.792	
Deep tooth factor	[YDT]	1.000	
Gear rim factor	[YB]	1.00	1.00

Effective facewidth (mm)	[beff]	14.00	14.50	
Nominal stress at tooth root (N/mm²)	[sigF0]	112.82	113.68	
Tooth root stress (N/mm²)	[sigF]	365.81	368.58	
Permissible bending stress at root of Test-gear				
Notch sensitivity factor	[YdrelT]	0.999	0.994	
Surface factor	[YRrelT]	0.957	0.957	
size factor (Tooth root)	[YX]	1.000	1.000	
Finite life factor	[YNT]	0.930	0.949	
	[YdrelT*YRrelT*YX*YNT]	0.889	0.902	
Alternating bending factor (mean stress influence coefficient)	[YM]	1.000		1.000
Stress correction factor	[Yst]	2.00		
Yst*sigFlim (N/mm²)	[sigFE]	860.00	860.00	
Permissible tooth root stress (N/mm²)	[sigFP=sigFG/SFmin]	588.17	596.97	
Limit strength tooth root (N/mm²)	[sigFG]	764.63	776.05	
Required safety	[SFmin]	1.30	1.30	
Safety for tooth root stress	[SF=sigFG/sigF]	2.09	2.11	
Transmittable power (kW)	[kWRating]	5.63	5.67	

4. SAFETY AGAINST PITTING (TOOTH FLANK)

		------- GEAR 1	-------- GEAR 2 --
Zone factor	[ZH]	2.291	
Elasticity factor (√N/mm²)	[ZE]	189.812	
Contact ratio factor	[Zeps]	0.858	
Helix angle factor	[Zbet]	1.050	
Effective facewidth (mm)	[beff]	14.00	
Nominal contact stress (N/mm²)	[sigH0]	757.63	
Contact stress at operating pitch circle (N/mm²)	[sigHw]	1485.27	
Single tooth contact factor	[ZB,ZD]	1.00	1.00
Contact stress (N/mm²)	[sigHB, sigHD]	1485.27	1485.27
Lubrication coefficient at NL	[ZL]	1.096	1.093
Speed coefficient at NL	[ZV]	0.974	0.975
Roughness coefficient at NL	[ZR]	0.937	0.939
Material pairing coefficient at NL	[ZW]	1.000	1.000
Finite life factor	[ZNT]	0.975	1.014
	[ZL*ZV*ZR*ZNT]	0.976	1.014
Limited pitting is permitted:	No		
Size factor (flank)	[ZX]	1.000	1.000
Permissible contact stress (N/mm²)	[sigHP=sigHG/SHmin]	1541.56	1601.73
Pitting stress limit (N/mm²)	[sigHG]	1464.48	1521.64
Required safety	[SHmin]	0.95	0.95
Safety factor for contact stress at operating pitch circle			
	[SHw]	0.99	1.02
Safety for stress at single tooth contact	[SHBD=sigHG/sigHBD]	0.99	1.02
(Safety regarding transmittable torque)	[(SHBD)^2]	0.97	1.05
Transmittable power (kW)	[kWRating]	3.77	4.07

4b. MICROPITTING ACCORDING TO ISO/TR 15144-1:2014

Calculation did not run. (Lubricant: Load stage micropitting test is unknown.)

5. SCUFFING LOAD CAPACITY

Calculation method according to ISO TR 13989:2000

The calculation for scuffing load capacity does not cover grease.
The FZG-Test stage [FZGtestA] is only estimated for grease.
The calculation can only serve as a rough guide.!

Lubrication coefficient (for lubrication type)	[XS]	1.200		
Scuffing test and load stage	[FZGtest]	FZG - Test A / 8.3 / 90 (ISO 14635 - 1)		12
Multiple meshing factor	[Xmp]	1.000		
Relative structure coefficient (Scuffing)	[XWrelT]	1.000		
Thermal contact factor (N/mm/s^.5/K)	[BM]	13.780	13.780	
Relevant tip relief (µm)	[Ca]	2.00	2.00	
Optimal tip relief (µm)	[Ceff]	6.31		
Ca taken as optimal in the calculation (0=no, 1=yes)		0		0
Effective facewidth (mm)	[beff]	14.000		
Applicable circumferential force/facewidth (N/mm)	[wBt]	277.180		
Kbg = 1.242, wBt*Kbg = 344.283				
Angle factor	[Xalfbet]	0.990		
(ε1:0.829, ε2:0.530)				

Flash temperature-criteria		
Lubricant factor	[XL]	0.811
Tooth mass temperature (°C)	[theMi]	94.24
theMi = theoil + XS*0.47*Xmp*theflm	[theflm]	25.25
Scuffing temperature (°C)	[theS]	342.71
Coordinate gamma (point of highest temp.)	[Gamma]	0.801
[Gamma.A]=-0.513 [Gamma.E]=0.801		
Highest contact temp. (°C)	[theB]	158.87
Flash factor (°K*N^-.75*s^.5*m^-.5*mm)	[XM]	50.058
Approach factor	[XJ]	1.000
Load sharing factor	[XGam]	0.957
Dynamic viscosity (mPa*s)	[etaM]	66.26 (80.0 °C)
Coefficient of friction	[mym]	0.074
Required safety	[SBmin]	2.000
Safety factor for scuffing (flash temperature)	[SB]	3.331

Integral temperature-criteria		
Lubricant factor	[XL]	1.000
Tooth mass temperature (°C)	[theMC]	99.24
theMC = theoil + XS*0.70*theflaint	[theflaint]	22.90
Integral scuffing temperature (°C)	[theSint]	357.16
Flash factor (°K*N^-.75*s^.5*m^-.5*mm)	[XM]	50.058
Running-in factor (well run in)	[XE]	1.000
Contact ratio factor	[Xeps]	0.282
Dynamic viscosity (mPa*s)	[etaOil]	66.26 (80.0 °C)
Mean coefficient of friction	[mym]	0.101
Geometry factor	[XBE]	0.364
Meshing factor	[XQ]	1.000
Tip relief factor	[XCa]	1.261
Integral tooth flank temperature (°C)	[theint]	133.59
Required safety	[SSmin]	1.800
Safety factor for scuffing (intg.-temp.)	[SSint]	2.674
Safety referring to transmittable torque	[SSL]	5.172

6. MEASUREMENTS FOR TOOTH THICKNESS

		------- Gear 1 ------	Gear 2 --		
Tooth thickness deviation		Own Input			Own Input
Tooth thickness allowance (normal section) (mm)	[As.e/i]	-0.067 / -0.093		-0.062 / -0.095	
Number of teeth spanned	[k]	3.000		6.000	
Base tangent length (no backlash) (mm)	[Wk]	11.845		25.272	
Actual base tangent length ('span') (mm)	[Wk.e/i]	11.782 / 11.758		25.214 / 25.183	
(mm)	[ΔWk.e/i]	-0.063 / -0.087		-0.058 / -0.089	
Diameter of contact point (mm)	[dMWk.m]	26.843		69.973	
Theoretical diameter of ball/pin (mm)	[DM]	2.789		2.496	
Effective diameter of ball/pin (mm)	[DMeff]	3.000		2.500	
Radial single-ball measurement backlash free (mm)	[MrK]	16.053		36.846	
Radial single-ball measurement (mm)	[MrK.e/i]	15.989 / 15.964		36.760 / 36.714	
Diameter of contact point (mm)	[dMMr.m]	27.596		70.166	
Diametral measurement over two balls without clearance (mm)	[MdK]	32.107		73.644	
Diametral two ball measure (mm)	[MdK.e/i]	31.978 / 31.929		73.473 / 73.381	
Diametral measurement over pins without clearance (mm)	[MdR]	32.107		73.691	
Measurement over pins according to DIN 3960 (mm)	[MdR.e/i]	31.978 / 31.929		73.520 / 73.428	
Measurement over 2 pins (free) according to AGMA 2002 (mm)	[dk2f.e/i]	0.000 / 0.000		73.460 / 73.368	
Measurement over 2 pins (transverse) according to AGMA 2002 (mm)	[dk2t.e/i]	0.000 / 0.000		73.567 / 73.475	
Measurement over 3 pins (axial) according to AGMA 2002 (mm)	[dk3A.e/i]	31.978 / 31.929		73.520 / 73.428	
Chordal tooth thickness (no backlash) (mm)	[sc]	2.704		2.060	
Actual chordal tooth thickness (mm)	[sc.e/i]	2.637 / 2.611		1.998 / 1.965	
Reference chordal height from da.m (mm)	[ha]	2.037		1.103	
Tooth thickness (Arc) (mm)	[sn]	2.707		2.060	
(mm)	[sn.e/i]	2.640 / 2.615		1.999 / 1.966	
Backlash free center distance (mm)	[aControl.e/i]	48.723 / 48.641			
Backlash free center distance, allowances (mm)	[jta]	-0.177 / -0.259			
dNf.i with aControl (mm)	[dNf0.i]	24.816		68.300	
Reserve (dNf0.i-dFf.e)/2 (mm)	[cF0.i]	-0.002		0.242	
Tip clearance (mm)	[c0.i(aControl)]	0.200		0.208	
Centre distance allowances (mm)	[Aa.e/i]	0.013 / -0.013			
Circumferential backlash from Aa (mm)	[jtw_Aa.e/i]	0.010 / -0.010			
Radial clearance (mm)	[jrw]	0.272 / 0.165			
Circumferential backlash (transverse section) (mm)	[jtw]	0.217 / 0.132			
Normal backlash (mm)	[jnw]	0.185 / 0.113			
Torsional angle at entry with fixed output:					
Entire torsional angle (°)	[j.tSys]	0.9382/ 0.5710			

7. GEAR ACCURACY

		------- GEAR 1 --------	GEAR 2 --
According to DIN 3961:1978			
Accuracy grade	[Q-DIN3961]	8	8
Profile form deviation (µm)	[ff]	12.00	12.00
Profile slope deviation (µm)	[fHa]	10.00	10.00
Total profile deviation (µm)	[Ff]	16.00	16.00

Helix form deviation (µm)		[fbf]	8.00	8.00
Helix slope deviation (µm)		[fHb]	16.00	16.00
Total helix deviation (µm)		[Fb]	18.00	18.00
Normal base pitch deviation (µm)		[fpe]	13.00	14.00
Single pitch deviation (µm)		[fp]	13.00	14.00
Adjacent pitch difference (µm)		[fu]	17.00	18.00
Total cumulative pitch deviation (µm)		[Fp]	38.00	49.00
Sector pitch deviation over z/8 pitches (µm)		[Fpz/8]	24.00	31.00
Runout (µm)		[Fr]	27.00	32.00
Tooth Thickness Variation (µm)		[Rs]	15.00	19.00
Single flank composite, total (µm)		[Fi']	44.00	52.00
Single flank composite, tooth-to-tooth	(µm)	[fi']	21.00	21.00
Radial composite, total (µm)		[Fi'']	33.00	40.00
Radial composite, tooth-to-tooth (µm)		[fi'']	13.00	16.00

According to DIN 58405:1972 (Feinwerktechnik):

Tooth-to-tooth composite error (µm)	[fi'']	14.00	16.00
Composite error (µm)	[Fi'']	40.00	45.00
Axis alignment error (µm)	[fp]	13.69	13.69
Flank direction error (µm)	[fbeta]	9.00	9.00
Runout (µm)	[Trk, Fr]	56.00	65.00

Axis alignment tolerances (recommendation acc. to ISO TR 10064-3:1996, Quality 8)

Maximum value for deviation error of axis (µm)	[fSigbet]	39.75 (Fb= 21.00)
Maximum value for inclination error of axes (µm)	[fSigdel]	79.50

8. ADDITIONAL DATA

Maximal possible centre distance (eps_a=1.0)	[aMAX]	49.577	
Mass (g)	[m]	63.09	436.69
Total mass (g)	[m]	499.78	
Moment of inertia (system with reference to the drive):			
calculation without consideration of the exact tooth shape			
single gears ((da+df)/2...di) (kg*m²)	[TraeghMom]	5.779e-006	0.0002673
System ((da+df)/2...di) (kg*m²)	[TraeghMom]	4.279e-005	
Torsional stiffness at entry with driven force fixed:			
Torsional stiffness (MNm/rad)	[cr]	0.028	
Torsion when subjected to nominal torque (°)	[delcr]	0.028	
Mean coeff. of friction (acc. Niemann)	[mum]	0.098	
Wear sliding coef. by Niemann	[zetw]	0.819	
Gear power loss (kW)	[PVZ]	0.061	
(Meshing efficiency (%)	[etaz]	98.257)	
Sound pressure level (according to Masuda)	[dB(A)]	50.5	

Indications for the manufacturing by wire cutting:

Deviation from theoretical tooth trace (µm)	[WireErr]	400.3	149.6
Permissible deviation (µm)	[Fb/2]	9.0	9.0

9. MODIFICATIONS AND TOOTH FORM DEFINITION

Data for the tooth form calculation :

Calculation of Gear 1

Tooth form, Gear 1, Step 1: Automatic (final machining)

haP*= 1.071, hfP*= 1.250, rofP*= 0.300

Calculation of Gear 2

Tooth form, Gear 2, Step 1: Automatic (final machining)

haP*= 1.070, hfP*= 1.250, rofP*= 0.300

10. SERVICE LIFE, DAMAGE

Required safety for tooth root	[SFmin]	1.30	
Required safety for tooth flank	[SHmin]	0.95	
Service life (calculated with required safeties):			
System service life (h)	[Hatt]	2523	
Tooth root service life (h)	[HFatt]	1e+006	1e+006
Tooth flank service life (h)	[HHatt]	2523	6780

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] (750.0 h)

F1%	F2%	H1%	H2%
0.00	0.00	29.73	11.06

Damage calculated on basis of system service life [Hatt] (2522.7 h)

F1%	F2%	H1%	H2%
0.00	0.00	100.00	37.21

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	150000	1.7	9.654e+029	1.484e+030	100.00
1	Tooth flank	150000	1.3	3.411e+008	1.625e+009	100.00
2	Tooth root	55814	1.7	9.654e+029	1.484e+030	100.00
2	Tooth flank	55814	1.3	3.411e+008	1.625e+009	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.
- Calculation of Zbet according Corrigendum 1 ISO 6336-2:2008 with Zbet = 1/(COS(beta)^0.5)
- Details of calculation method:
  cg according to method B
  KV according to method B
  KHb, KFb according method C
  fma following equation (64), fsh following (57/58), Fbx following (52/53/57)
  KHa, KFa according to method B
- The logarithmically interpolated value taken from the values for the fatigue strength and the static strength, based on the number of load cycles, is used for coefficients ZL, ZV, ZR, ZW, ZX, YdrelT, YRrelT and YX..

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