KISSsoft Exercise 3

Bevel Gear 03

Sizing of a Face Hobbing hypoid gearset

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1 Purpose of exercise

In this exercise, we will design a Face hobbing bevel gearset, then change it into a hypoid gearset. It is an industrial application, lapped.

- Sizing of a new bevel gear set
- Selection of the size of cutter head and check the influence to the root strength
- Comparison of a bevel gear to a hypoid gear regarding strength and efficiency
- Optimization of hypoid gear set using fine sizing

2 Task

Initial data:

Bevel type:	Face hobbing, lapped
Material:	16 MnCr5
Oil:	ISO VG 68, oil bath
Gear quality:	8 as per ISO 17485
Hand of spiral:	Pinion left hand (LH)
Rating standard:	ISO 10300:2014
Power:	P = 24 kW
Speed (at pinion):	n = 3‘000 upm
Required lifetime:	5000 h
Operation mode:	Drive side
Application factor:	$K_A = 1.1$
Mounting factor:	$K_{H\beta\text{-}be} = 1.1$
Manufacturing process:	Ring gear non-generating

2.1 Step 1

Do a first sizing using the functionality „Rough sizing“. Check the strength at the bevel gear set (without offset).

Sizing data:
The required safeties are $S_{Fmin} = 1.4$ and $S_{Hmin} = 1$.

Transmission ratio:	3.9
Gear set ratios:	$b/m_n = 10$, $R_e/b = 3.0$
Spiral angle:	30°
Cutter head size:	Sizing with ratio of involute / outer cone distance = 0.9

2.2 Step 2

Choose the cutter head from the list of ISO 23509. The smallest possible cutter head is to be preferred, due to the positive V/H (E/P) behavior and benefit to the root strength.

Compare the root safety SF in ISO 10300, if the bigger cutter head is taken instead of the smaller cutter head.

2.3 Step 3

Change the calculation to hypoid and add the offset. Define the blanks. Compare the strength and the blanks in 2D graph „System“.

The offset is 15% of the ring gear outer diameter.

2.4 Step 4

Optimize the hypoid design with the „fine sizing” functionality. Check for an optimal solution with same ring gear diameter.

Sizing data:

Offset: between 10% and 25% of ring gear outer diameter

The focus of the optimization should be on pinion root strength and efficiency (method acc. to WECH). Second priority are high contact ratio (for noise) and low axial forces on pinion.

3 Solution

3.1 Step 1

Input of initial data

In tab “Basic data”, select the following gear geometry settings:

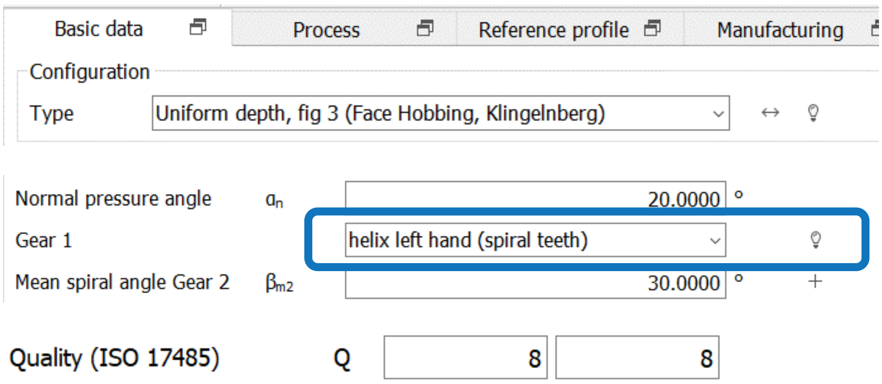

Figure 3.1-1 Choose “Uniform depth” in tab «Basic data», set hand of spiral and enter the gear quality number.

Select the gear material and use a lubricant as shown below:

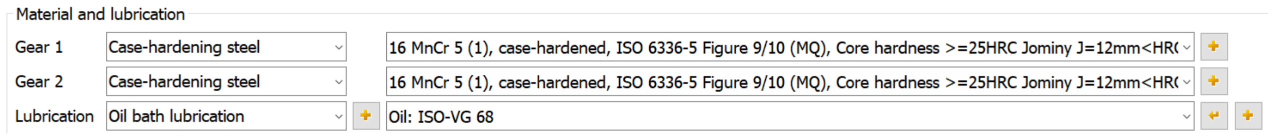

Figure 3.1-2 Gear material and lubrication in tab «Basic data»

Define the load data and select the rating method in tab “Strength”.

Note that the working flank is initially defined as right flank, which results in ‘Coast’ condition. Change the working flank gear 1 to ‘left flank’.

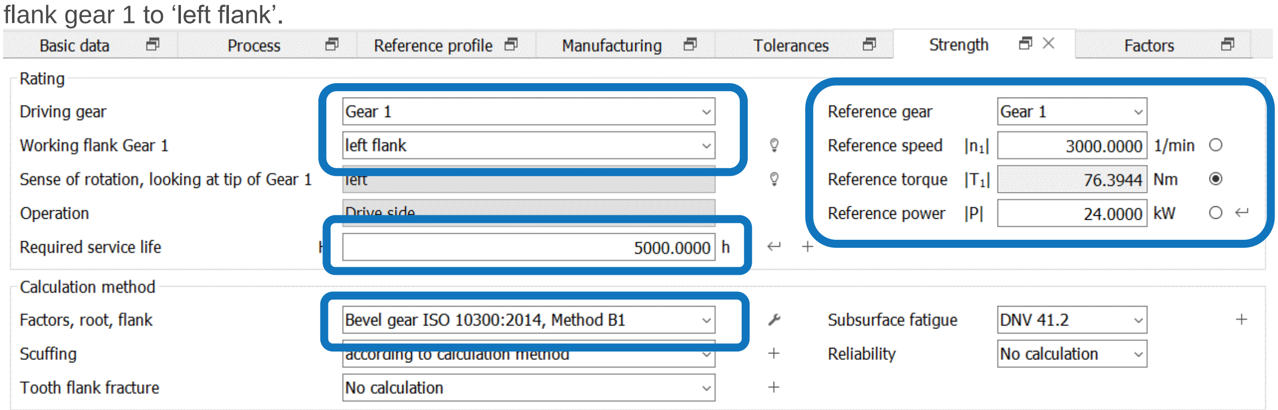

Figure 3.1-3 Select rating method ISO 10300:2014 B1, enter power and speed and set required life to 5000 h. Also change the working flank to ‘left flank’.

In the tab “Factors”, the application factor and mounting factor are defined.

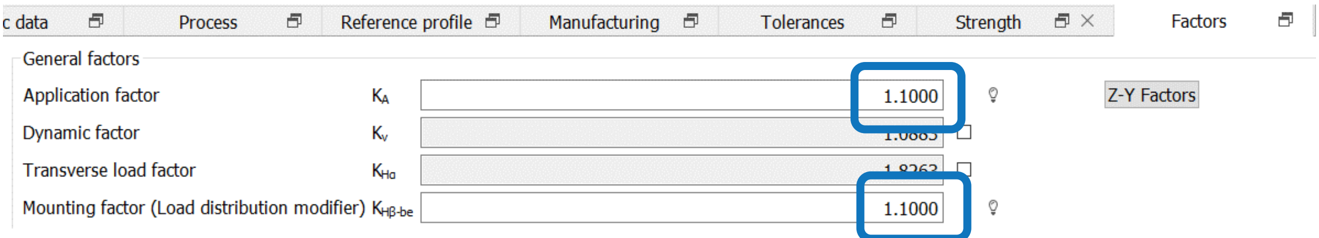

Figure 3.1-4 Set mounting factor $K_{H\beta\text{-}be}$ = 1.10 and the application factor K_A = 1.10.

Before sizing of the bevel gear, the required safeties are to be entered.

Under ‘calculation – settings’ the required safeties are defined. For an easier display, the option ‘Safeties are not depending on size’ may be used.

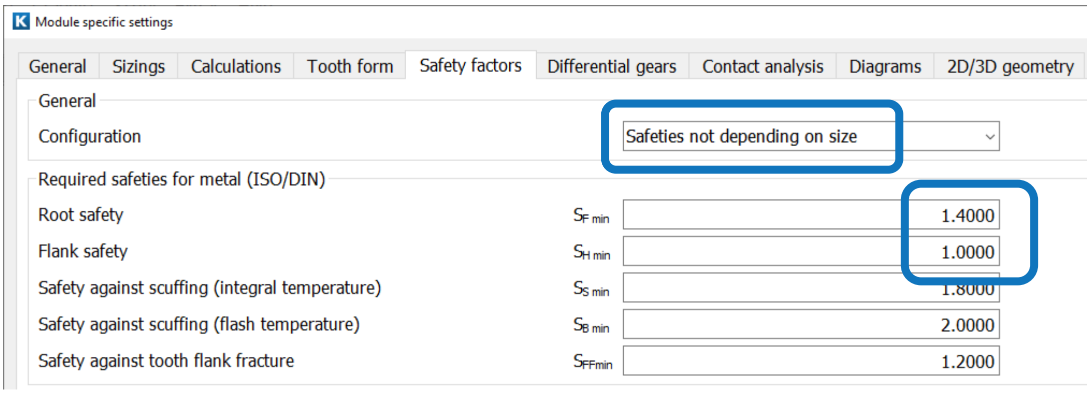

Figure 3.1-5 Enter the required safety factors in ‘module specific settings’.

Now we start using the rough sizing function. Enter the required ratio and the mean helix angle at 30°, press “Calculate” and “Accept”.

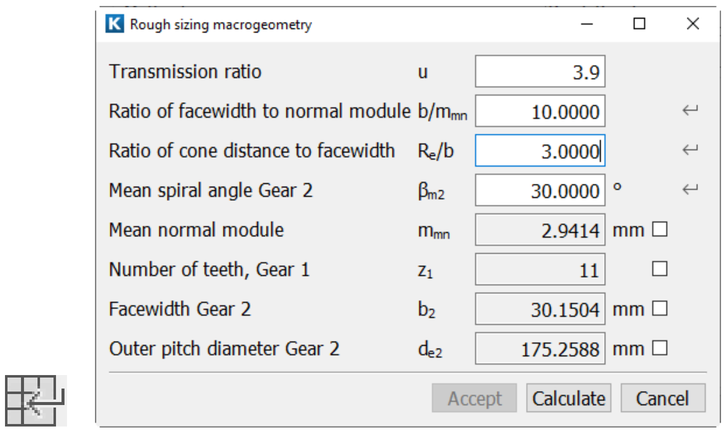

Figure 3.1-6 Use of rough sizing function to get a first proposal for the bevel gear set

You will see that the pinion number of teeth is reasonable (a reasonable range is e.g. 11-16). In the tab “Process”, set up the manufacturing process for ring gear as formate (non-generating) and use the sizing button for the cutter head.

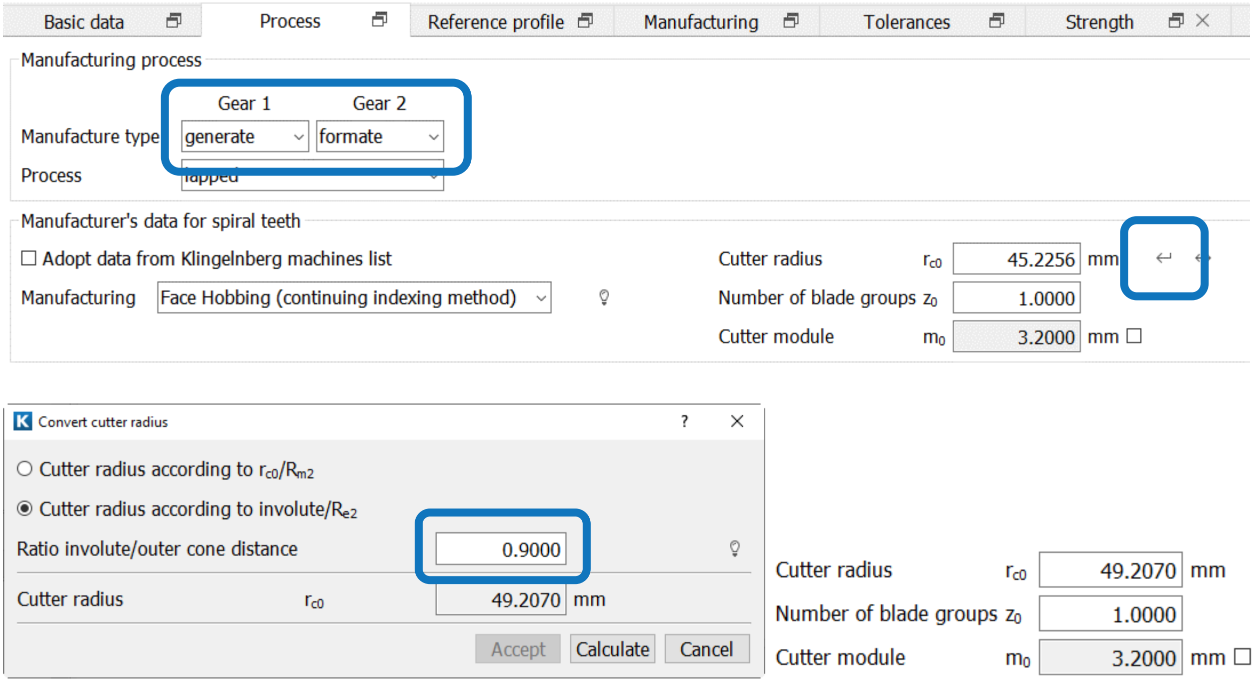

Figure 3.1-7 Setting of manufacturing process and sizing of cutter head with ratio involute / outer cone = 0.9.

The strength results can be checked now. Due to the simplified sizing algorithm, deviations from the required safety values may show up.

Results (basic calculation)			
General			
Transverse contact ratio	[ε_α]	1.234	
Overlap ratio	[ε_β]	1.387	
Operation mode	Drive side		
Components		**Gear 1**	**Gear 2**
Outer tip diameter (mm)	[d_{ae}]	52.984	176.090
Root safety	[S_F]	2.336	1.979
Flank safety	[S_H]	0.997	1.040
Safety factor for scuffing (flash-temp)	[S_B]	4.118	

Figure 3.1-8 Bevel gear safety factors after rough sizing.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-1.Z70

3.2 Step 2

The cutter head size is the nominal radius, on which the blades of the tool are arranged. They come with standard sizes.

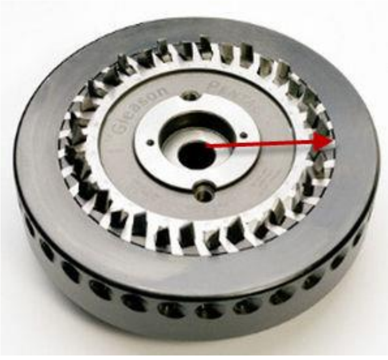

Figure 3.2-1 Face Hobbing cutter head. Radius is defined from center to the cutting edge of the blade.

In tab “Process”, the info graphic for the tools according to the ISO 23509 is available.

Face Hobbing		**Face Milling**
Two-blade cutter (outer and inner blade per group)		
Cutter radius r_{c0}, mm	**Number of blade groups,** z_0	**Cutter diameter,** $2{\cdot}r_{c0}$, in
30	7	2.50
51	7	3.25
64	11	3.50
64	13	3.75
76	7	4.375
76	13	5.00
76	17	6.00
88	11	7.50
88	17	9.00
88	19	10.5
100	5	12
105	13	14
105	19	16
125	13	18
150	17	/
175	19	/
		mm
		500, 640, 800, 1000

Figure 3.2-2 Available cutter radius of standardized cutter heads

We choose the smallest possible cutter due to the centralized contact pattern behaviour under load.

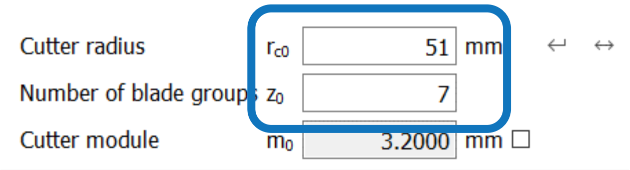

Figure 3.2-3 Enter the cutter radius and the number of blades in tab “Process”.

With this we have finalized the design and manufacturing of a bevel gear set (not a hypoid yet). Rerun the calculation to find:

Results (basic calculation)			
General			
Transverse contact ratio	[ε_α]	1.234	
Overlap ratio	[ε_β]	1.387	
Operation mode	Drive side		
Components		**Gear 1**	**Gear 2**
Outer tip diameter (mm)	[d_{ae}]	53.994	179.447
Root safety	[S_F]	2.459	2.083
Flank safety	[S_H]	0.996	1.039
Safety factor for scuffing (flash-temp)	[S_B]	3.919	

Figure 3.2-4 Gear rating results with above manufacturing data.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-2200-jl-public_Step-2.Z70

3.3 Step 3

We now compare a bevel gear set with a hypoid gear set. For the current bevel design, we find the efficiency according to calculation method “Wech”. To calculate the efficiency of the bevel gear set with the method “Wech”, we deactivate the scuffing calculation and select the method “Wech” in the module specific settings.

14.2 Gear power loss and coefficient of friction		
Calculation according to	Wech	
Coefficient of friction	[μ_m]	0.073
The coefficient of friction μ_m can vary depending on calculation method.		
Compound velocity (m/s)	[vΣ]	6.951
Loss factor	[HV]	0.180
Gear power loss (kW)	[PVZ]	0.314
Meshing efficiency (%)	[ηz]	98.691

Figure 3.3-1 Report, information on efficiency, for bevel gear set

Now we enter an offset of 15% (here 27 mm) to calculate a corresponding hypoid gear set. We now observe a massive increase in root safety due to the hypoid offset. Due to the increased diameter of the pinion, lower forces result.

		Gear 1	Gear 2	Details...
Number of teeth	z	11	43	
Facewidth	b	37.0000	30.7253	mm
Profile shift coefficient	x_{hmn}	0.4300	-0.4300	
Tooth thickness modification factor	x_{smn}	0.0650	-0.0650	
Quality (ISO 17485)	Q	8	8	
Shaft angle	Σ	90.0000		°
Hypoid offset	a	27.0000		mm

Figure 3.3-2 Enter the hypoid offset of 27mm.

Calculation method	
Factors, root, flank	Hypoid gears ISO 10300:2014, Method B1
Scuffing	ISO/TS 10300-20:2021
Tooth flank fracture	No calculation

Figure 3.3-3 Change the calculation method in the tab ‘strength’ from bevel results for hypoid gear set.

Results (basic calculation)			
General			
Transverse contact ratio	[ε_α]	1.080	
Overlap ratio	[ε_β]	1.682	
Operation mode	Drive side		
Components		**Gear 1**	**Gear 2**
Outer tip diameter (mm)	[d_{ae}]	75.106	180.137
Root safety	[S_F]	4.687	3.889
Flank safety	[S_H]	1.567	1.634
Safety factor for scuffing (flash-temp)	[S_B]	2.956	

Figure 3.3-4 Increased safety numbers for hypoid gear set for root bending strength and contact stress.

In the 2D system graphics we can now clearly see the increased size of the pinion:

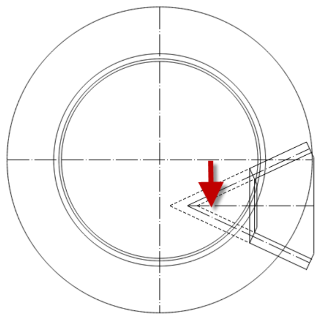

Figure 3.3-5 Increased pinion size for hypoid gear set.

The hypoid gear shows a drop in efficiency and the scuffing safety (see report):

14.2 Gear power loss and coefficient of friction

Calculation according to	Wech	
Coefficient of friction	[μ_m]	0.027
The coefficient of friction μ_m can vary depending on calculation method.		
Compound velocity (m/s)	[$v\Sigma$]	0.016
Gear power loss (kW)	[PVZ]	0.456
Meshing efficiency (%)	[ηz]	98.101

Check the influence factor of limit pressure angle under additional data.

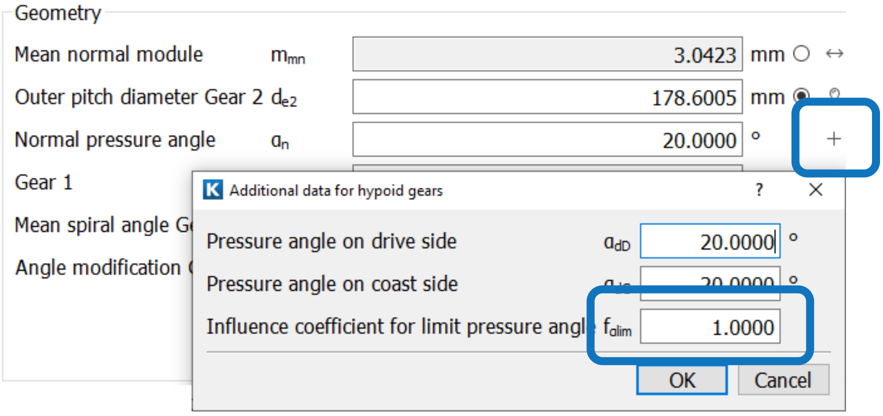

Figure 3.3-6 Input of influence coefficient of limit pressure angle under ‘additional data for hypoid gears’

Also, check the several pressure angles such as ‘design (nominal) pressure angle’, ‘generated pressure angle’ and ‘effective pressure angle’ in the report.

5.2 Basic data

------- Gear 1 ----------------- Gear 2 -------

No modification at tip circle

Overall transmission ratio	[itot]	-3.909
Gear ratio	[u]	3.909
Nominal pressure angle - drive side (°)	[αdD]	20.0000
Nominal pressure angle - coast side (°)	[αdC]	20.0000
Limit pressure angle (°)	[αlim]	-1.3577
Generated pressure angle - drive side (°)	[αnD]	18.6423
Generated pressure angle - coast side (°)	[αnC]	21.3577
Effective pressure angle - drive side (°)	[αeD]	20.0000
Effective pressure angle - coast side (°)	[αeC]	20.0000

Figure 3.3-7 Report, information on pressure angles

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-3.Z70

3.4 Step 4

Use the fine sizing function e.g. as shown below. Set parameters as considered suitable and run the fine sizing function:

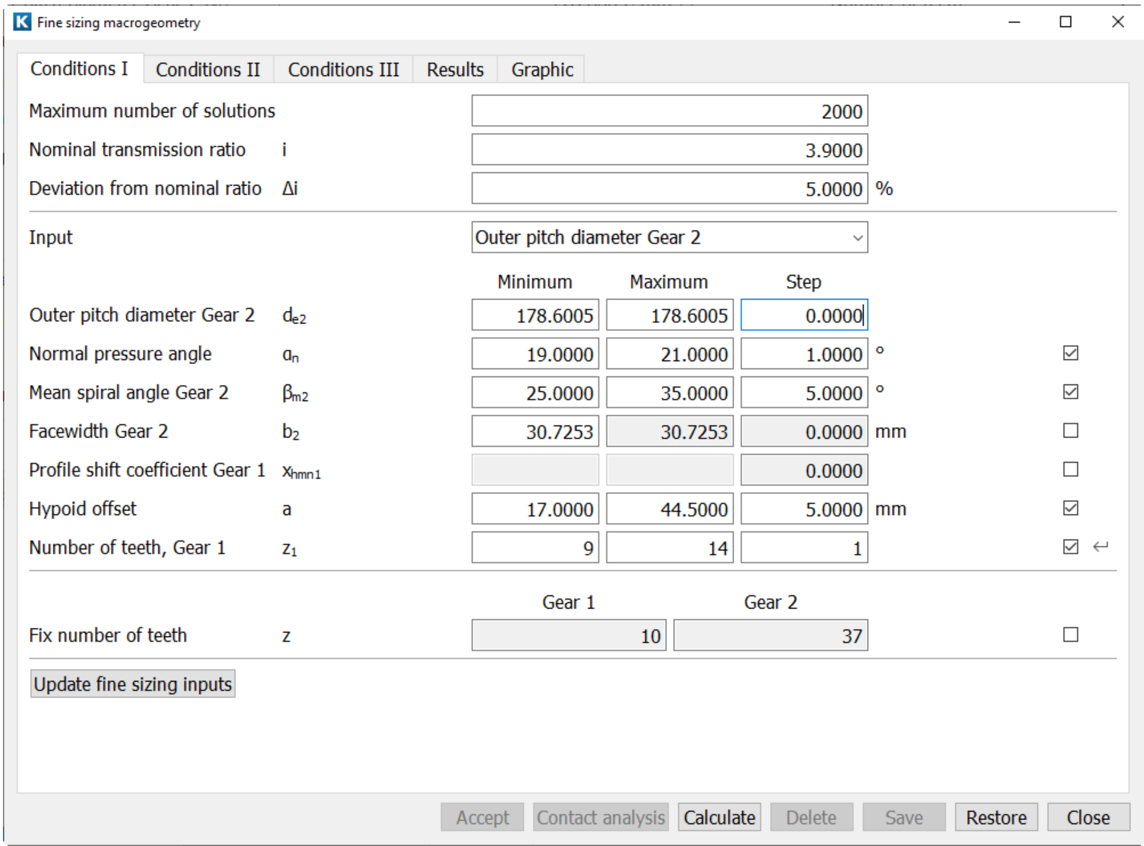

Figure 3.4-1 Possible input data for fine sizing functionality.

We find a high number of possible solutions. We use the graphical representation of the solutions to compare the efficiency and root strength of pinion depending on the hypoid offset.

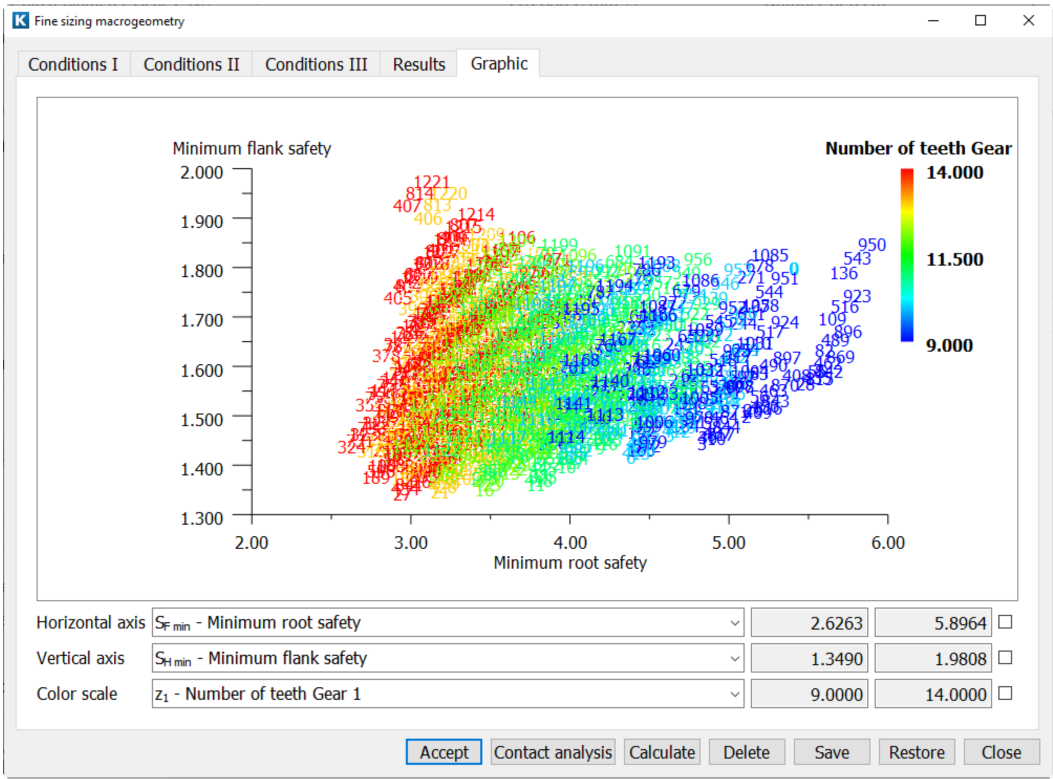

Figure 3.4-2 Minimum root and flank safety are shown, depending on the varying number of teeth on pinion.

Look at (as a function of offset, number of teeth on pinion, etc.)

- Efficiency
- Flank strength
- Gear (and hence bearing) forces (radial and axial, typically pinion bearings are more critical)

It is up to the design engineer to now select a suitable solution.

See file Exercise-Bevel-03-sizing_hypoid_face_hobbing-v2200-jl-public_Step-4.Z70