KISSsoft 2019 – Tutorial 9

Cylindrical Gear Fine Sizing

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Sharing Knowledge

Contents

1 Task

1.1 Task

A cylindrical gear pair is to be designed such that it has a service life of 5,000 h when transmitting a power of 5 kW at an input speed of 400 rpm (application factor = 1.25). The ratio shall be 1:4 (reducing speed) and 18CrNiMo7-6 is to be used as the gear material. The cylindrical gear pair is to be optimized to achieve the best possible noise/contact ratio. Strength verification is to be performed as specified in ISO 6336 Method B.

1.2 Starting gear pair calculation (cylindrical gear pair)

You can call KISSsoft as soon as the software has been installed and activated. Usually you start the program by clicking «Start→Program Files→KISSsoft 03-2019→KISSsoft». This opens the following KISSsoft user interface:

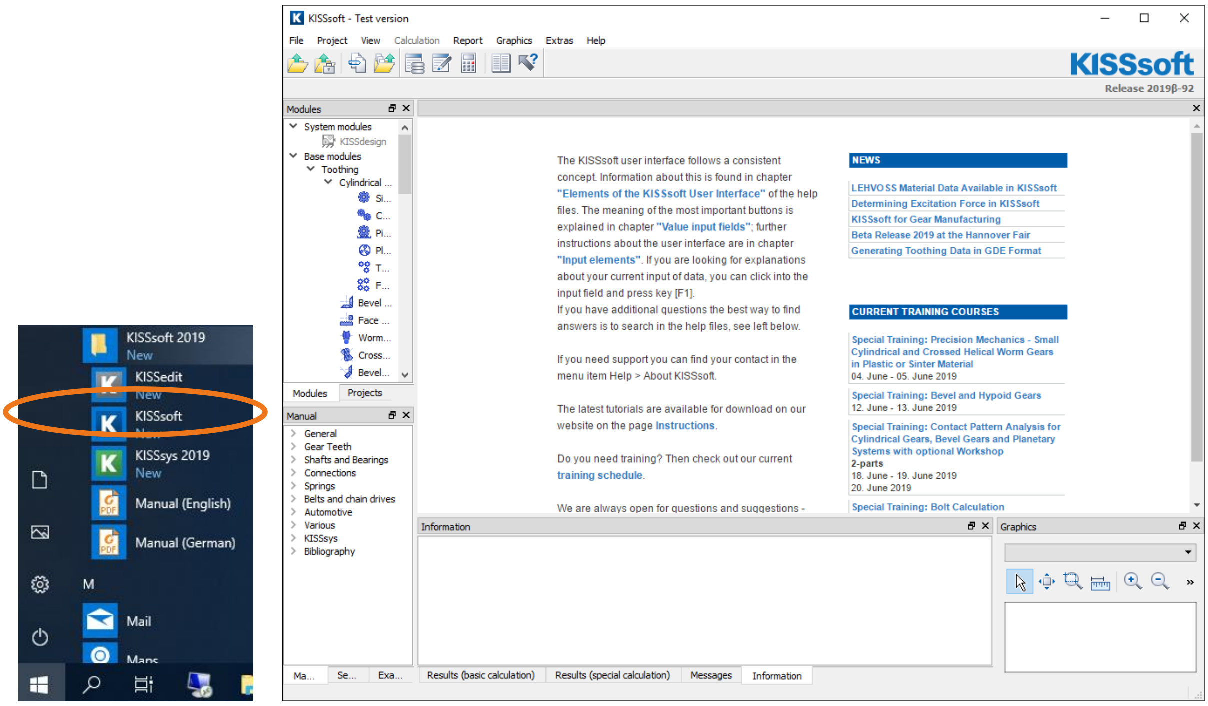


Figure 1. Starting KISSsoft, initial window

In the **«Modules»** tab, click on the «Cylindrical gear pair» calculation in the module tree window:

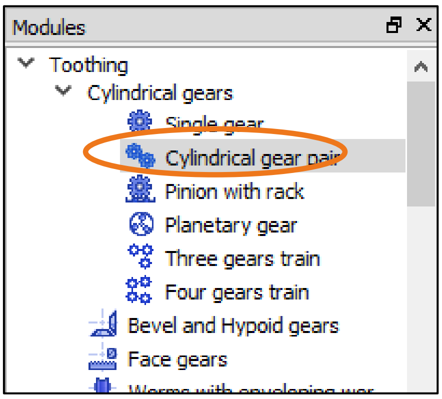


Figure 2. Call the cylindrical gear calculation

To open the example used in this tutorial, click on «File/Open» and select «Tutorial-009-Step1» (to «Tutorial-009-Step5») or select it from the **«Examples»** tab. Each section in this tutorial describes which file you need to open (as shown below).

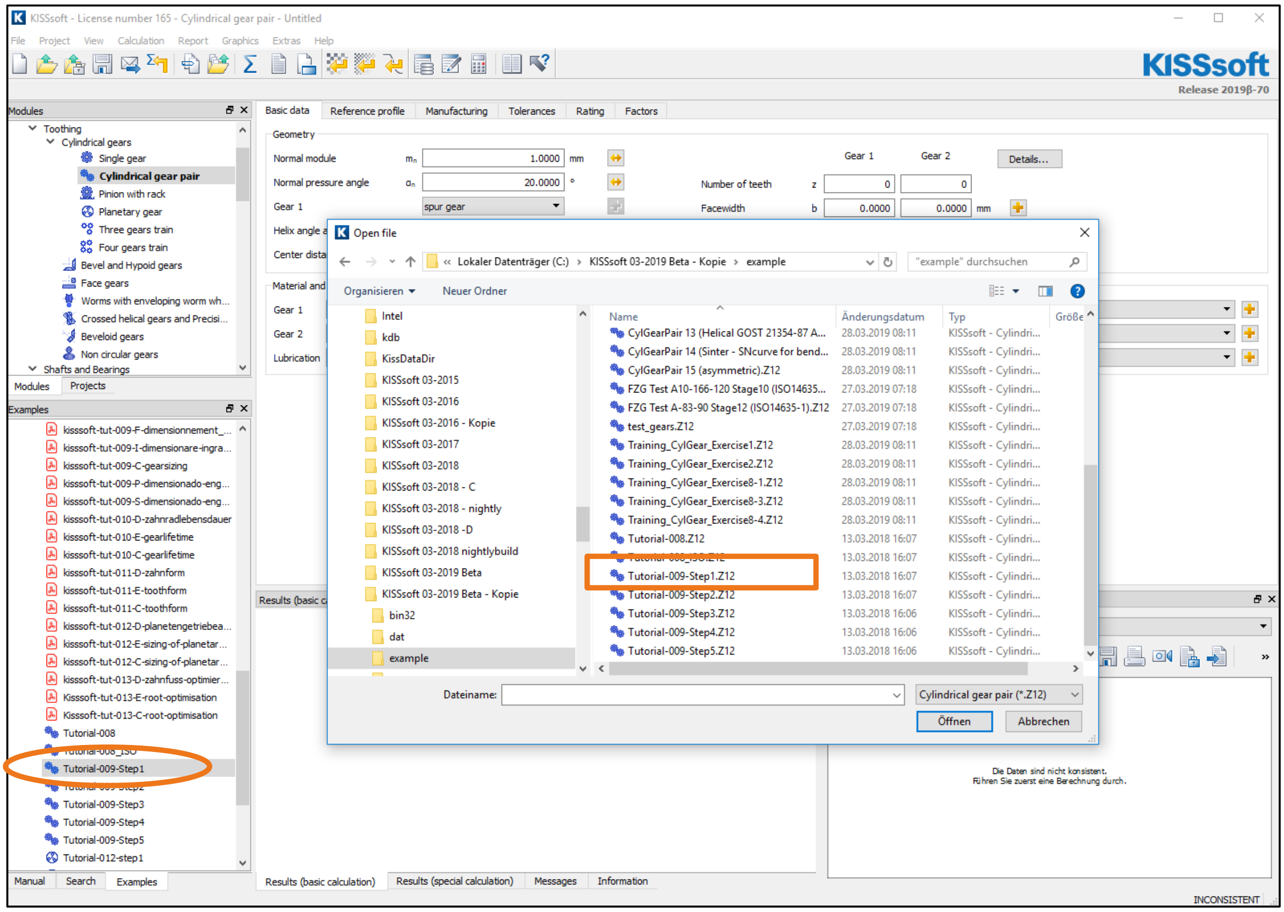


Figure 3. Options for opening the example files used in this tutorial at different stages of progress

2 Rough Sizing of a Cylindrical Gear Pair

2.1 Preparing the calculation

Before you can start the rough sizing process, you must enter the basic toothing parameters to the Basic data and Rating tabs. In the Basic data tab, input the material 18CrNiMo7-6 in the Material and lubrication group.

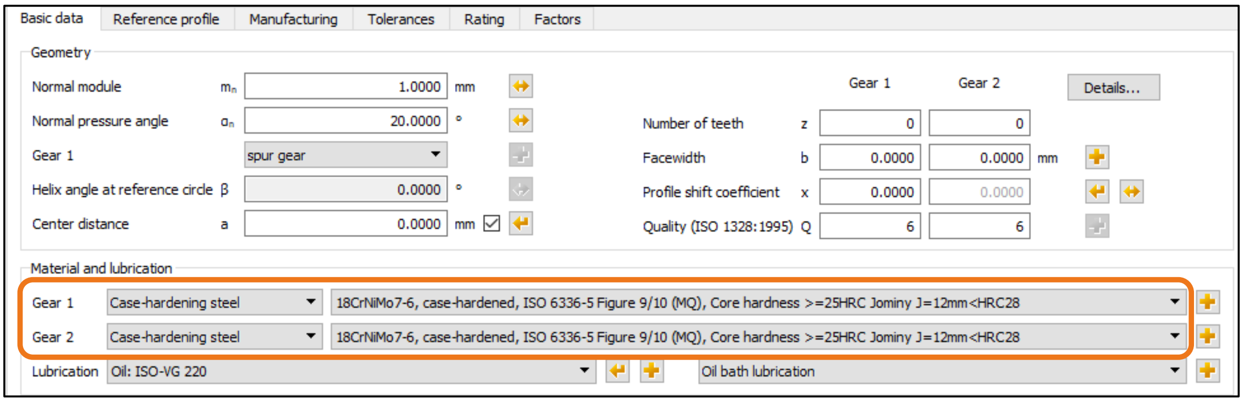


Figure 4. Materials in the Basic data tab

The safety factors that are to be achieved can be specified in the module specific settings dialog in the «Required safeties» tab.

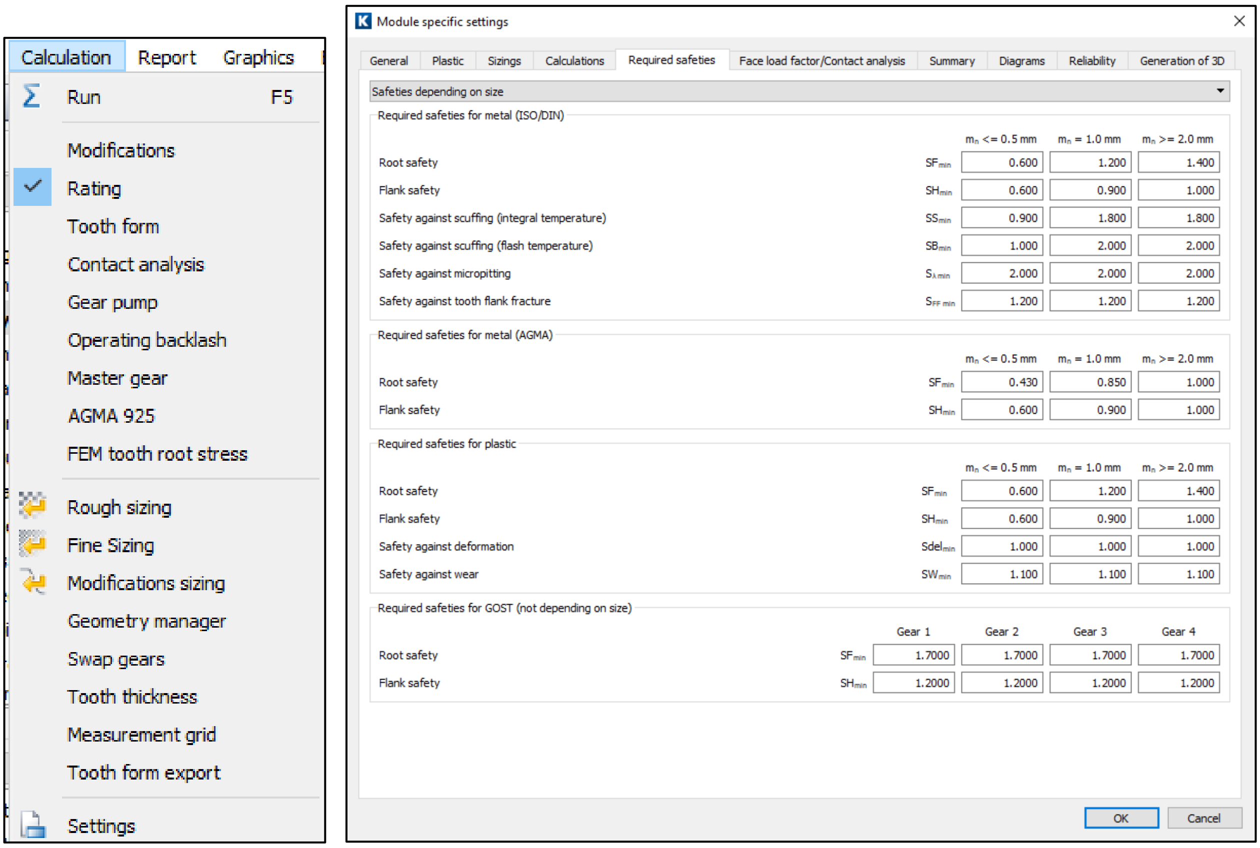


Figure 5. Module specific settings – Specified safeties

Then click **«Calculation»→ «Rating»** to open In the Rating tab where you input the data for service life, power, input speed and application factor, along with the calculation method for the strength verification.

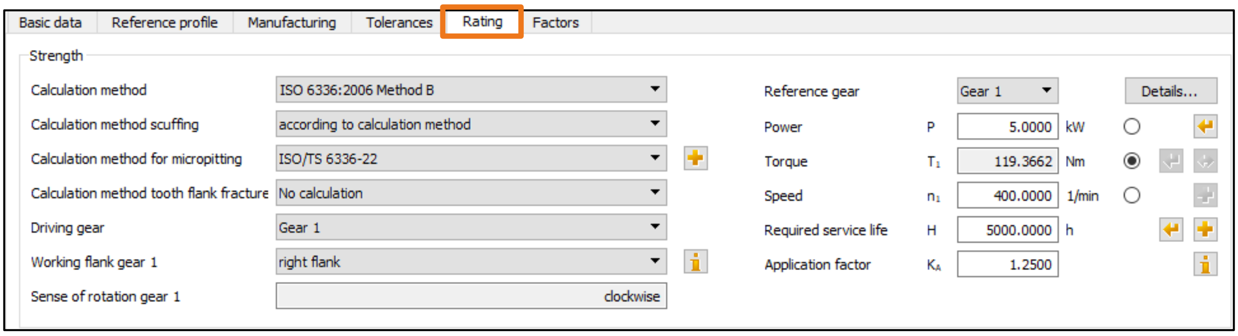


Figure 6. Toothing data in the Rating tab

To access this stage of the calculation directly, open the «Tutorial-009-Step1» file.

2.2 Call the rough sizing function

Use the Rough sizing function to create a sensible initial layout for a cylindrical gear stage. To do this, input the required key data after you call the Rough sizing function by clicking **«Calculation»→ «Rough sizing»** in the Rough sizing screen.

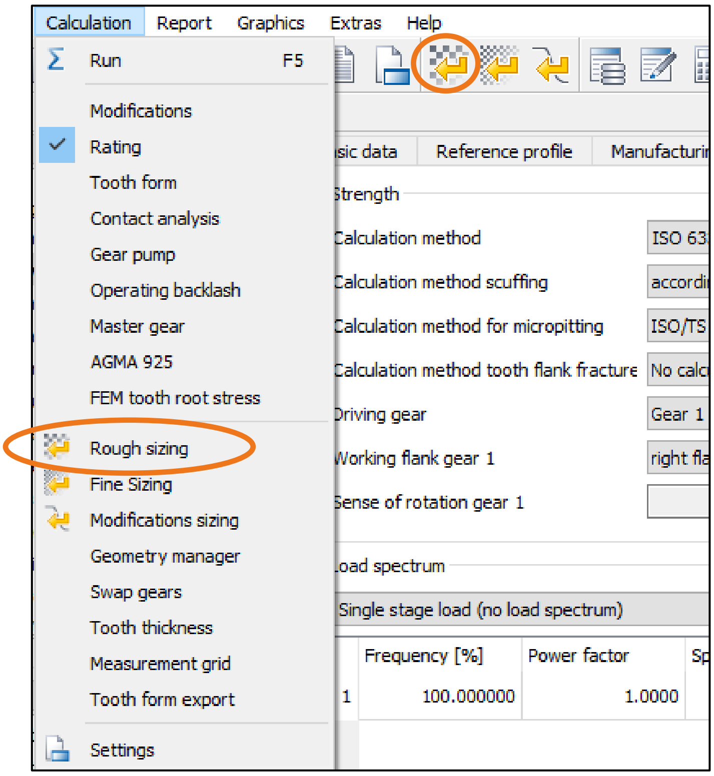


Figure 7. Call Rough sizing

The most important is to define the required ratio (including the permitted variation as a percentage – **here 5%**). You can also predefine the required helix angle or center distance. The helix angle depends on the type of bearing used with the shaft. The helix angle may be larger or smaller, depending on how much axial force the bearings can support. The helix angle can be optimized later on during fine sizing. Here, in the rough sizing function, you should only input an approximate value for the helix angle, or «zero» for spur gear. In the lower part of the **«Rough sizing»** input window you can enter additional data such as the range of number of teeth on the pinion, the geometry proportions, and the center distance.

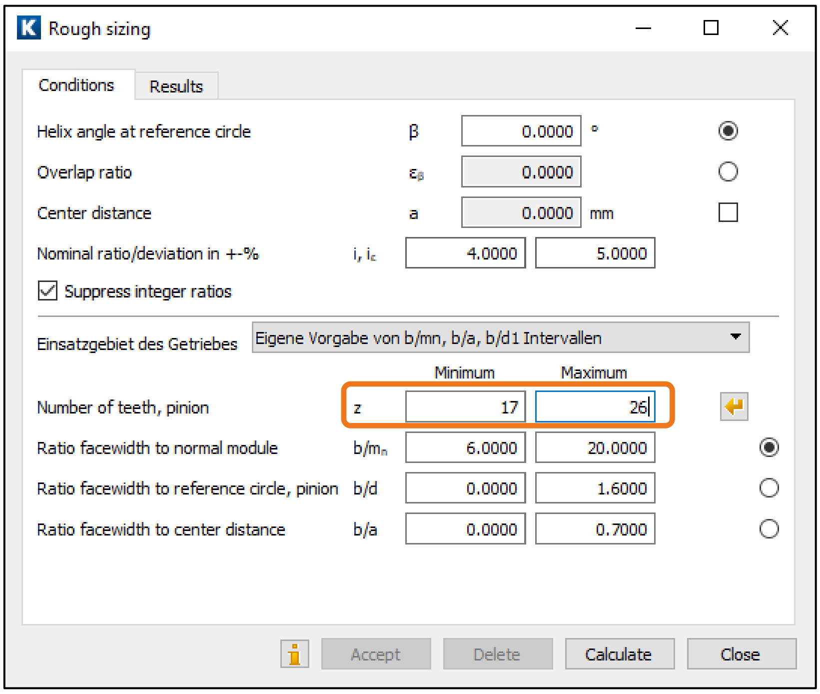
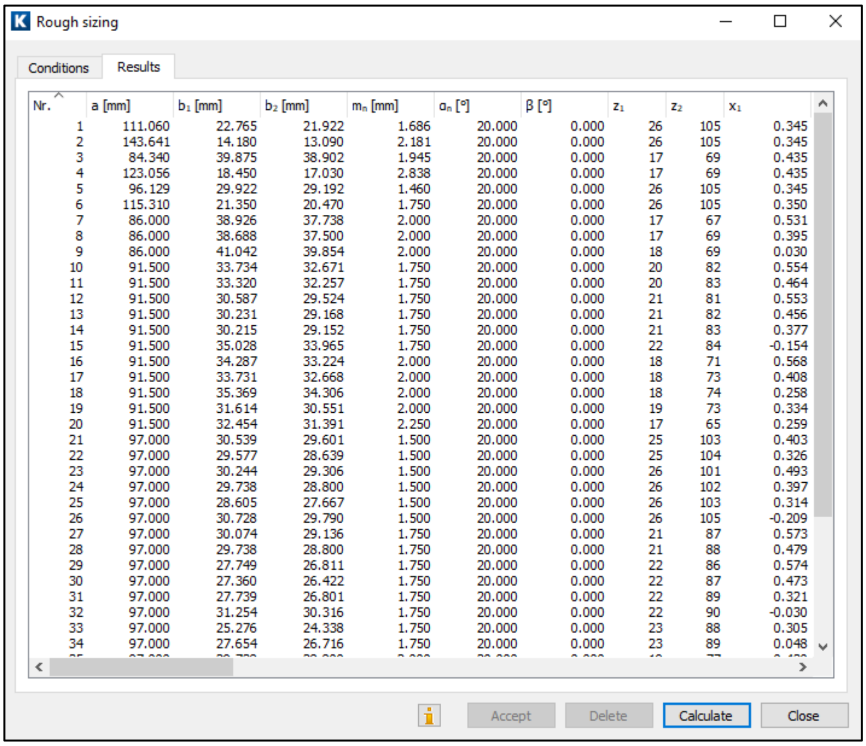


Figure 8. Rough sizing input window - Specifying the number of teeth, gear 1 and 2

When you click the Calculate button in rough sizing, KISSsoft calculates a number of different solutions for a gear pair that meets the specified conditions. These solutions are then displayed in the list shown below.



Nr.	a [mm]	b_1 [mm]	b_2 [mm]	m_n [mm]	α_n [°]	β [°]	z_1	z_2	x_1
1	111.060	22.765	21.922	1.686	20.000	0.000	26	105	0.345
2	143.641	14.180	13.090	2.181	20.000	0.000	26	105	0.345
3	84.340	39.875	38.902	1.945	20.000	0.000	17	69	0.435
4	123.056	18.450	17.030	2.838	20.000	0.000	17	69	0.435
5	96.129	29.922	29.192	1.460	20.000	0.000	26	105	0.345
6	115.310	21.350	20.470	1.750	20.000	0.000	26	105	0.350
7	86.000	38.926	37.738	2.000	20.000	0.000	17	67	0.531
8	86.000	38.688	37.500	2.000	20.000	0.000	17	69	0.395
9	86.000	41.042	39.854	2.000	20.000	0.000	18	69	0.030
10	91.500	33.734	32.671	1.750	20.000	0.000	20	82	0.554
11	91.500	33.320	32.257	1.750	20.000	0.000	20	83	0.464
12	91.500	30.587	29.524	1.750	20.000	0.000	21	81	0.553
13	91.500	30.231	29.168	1.750	20.000	0.000	21	82	0.456
14	91.500	30.215	29.152	1.750	20.000	0.000	21	83	0.377
15	91.500	35.028	33.965	1.750	20.000	0.000	22	84	-0.154
16	91.500	34.287	33.224	2.000	20.000	0.000	18	71	0.568
17	91.500	33.731	32.668	2.000	20.000	0.000	18	73	0.408
18	91.500	35.369	34.306	2.000	20.000	0.000	18	74	0.258
19	91.500	31.614	30.551	2.000	20.000	0.000	19	73	0.334
20	91.500	32.454	31.391	2.250	20.000	0.000	17	65	0.259
21	97.000	30.539	29.601	1.500	20.000	0.000	25	103	0.403
22	97.000	29.577	28.639	1.500	20.000	0.000	25	104	0.326
23	97.000	30.244	29.306	1.500	20.000	0.000	26	101	0.493
24	97.000	29.738	28.800	1.500	20.000	0.000	26	102	0.397
25	97.000	28.605	27.667	1.500	20.000	0.000	26	103	0.314
26	97.000	30.728	29.790	1.500	20.000	0.000	26	105	-0.209
27	97.000	30.074	29.136	1.750	20.000	0.000	21	87	0.573
28	97.000	29.738	28.800	1.750	20.000	0.000	21	88	0.479
29	97.000	27.749	26.811	1.750	20.000	0.000	22	86	0.574
30	97.000	27.360	26.422	1.750	20.000	0.000	22	87	0.473
31	97.000	27.739	26.801	1.750	20.000	0.000	22	89	0.321
32	97.000	31.254	30.316	1.750	20.000	0.000	22	90	-0.030
33	97.000	25.276	24.338	1.750	20.000	0.000	23	88	0.305
34	97.000	27.654	26.716	1.750	20.000	0.000	23	89	0.048

Figure 9. Cylindrical gear - rough sizing, results

Right-hand mouse click in the results list to select the criteria you want to use, such as center distance a, width b, etc.

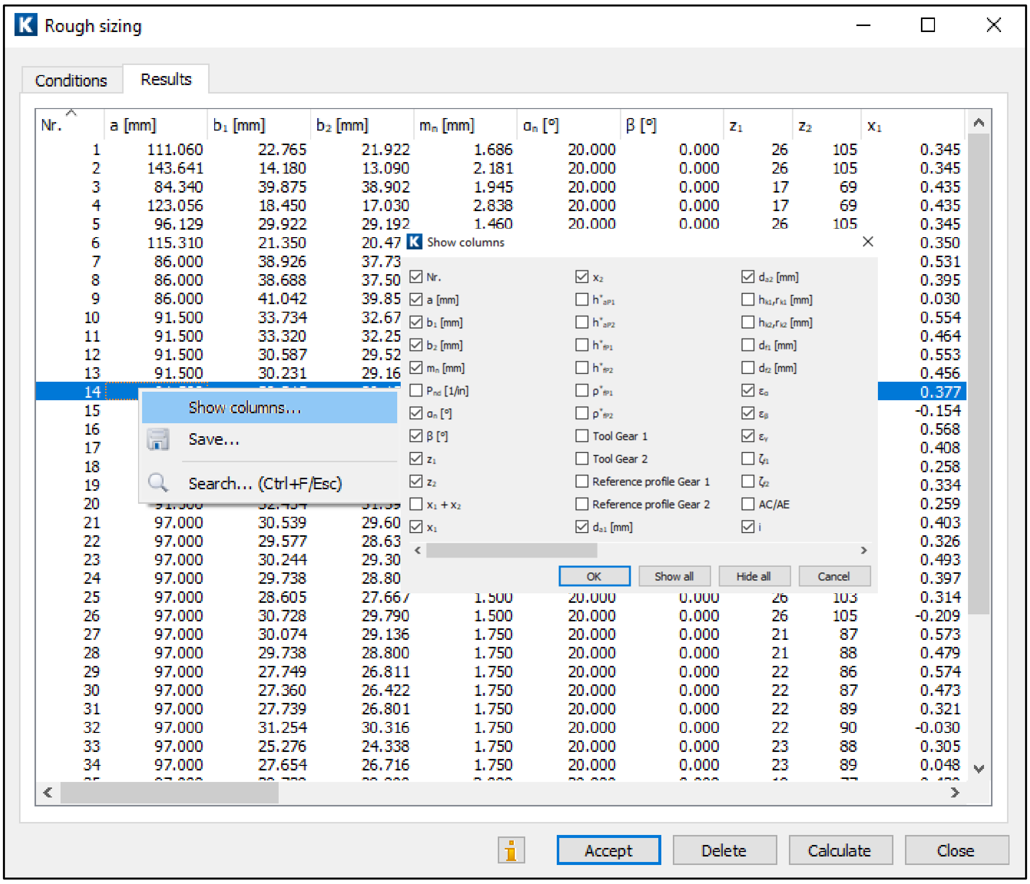


Figure 10. Show columns

To select a particular solution (in this case with a center distance of 91.5 mm), select it from the list and click the **«Accept»** button to transfer it, and then click **«Close»** to close the window.

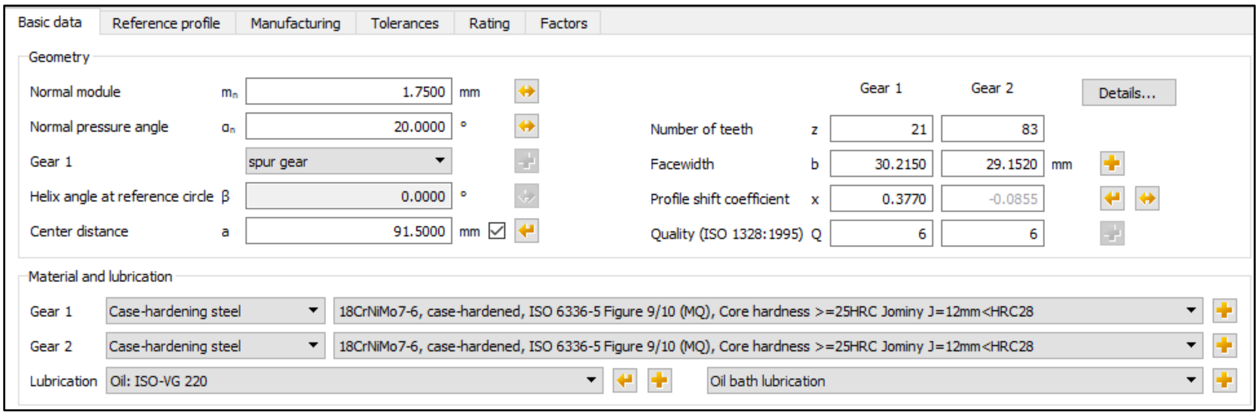


Figure 11. Normal module, number of teeth, width, profile shift and center distance shown as suggested by KISSsoft

To access this stage of the calculation directly, open the «Tutorial-009-Step2» file.

2.3 Modifications

You can now modify the proposed values. For example, for the gear width you can input a pinion width of 30 mm and a gear width of 29 mm (directly in the appropriate fields).
In the tab **«Reference profile»** you can modify the reference profile in the drop-down list.

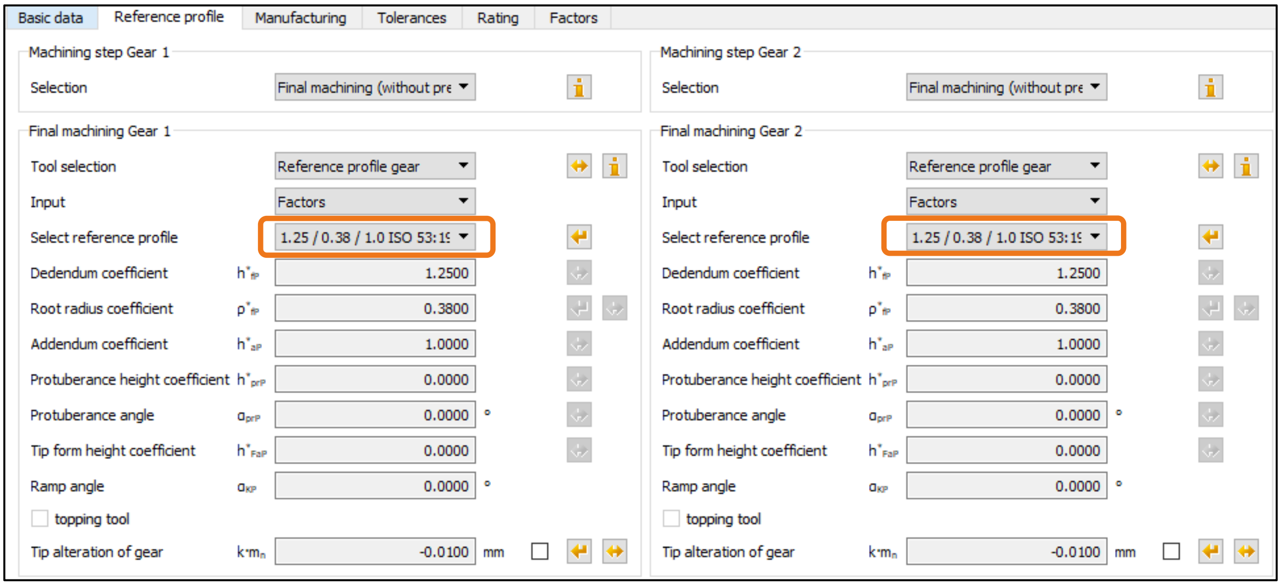


Figure 12. «Reference profile» tab, information about the reference profile

You can modify the profile shift of gear 1 (gear 2 is then sized accordingly) as follows: Click the Sizing button in the figure below to open the **«Sizing of profile shift coefficient»** dialog window that displays proposed values for a number of profile shift coefficients (see Figure 14):

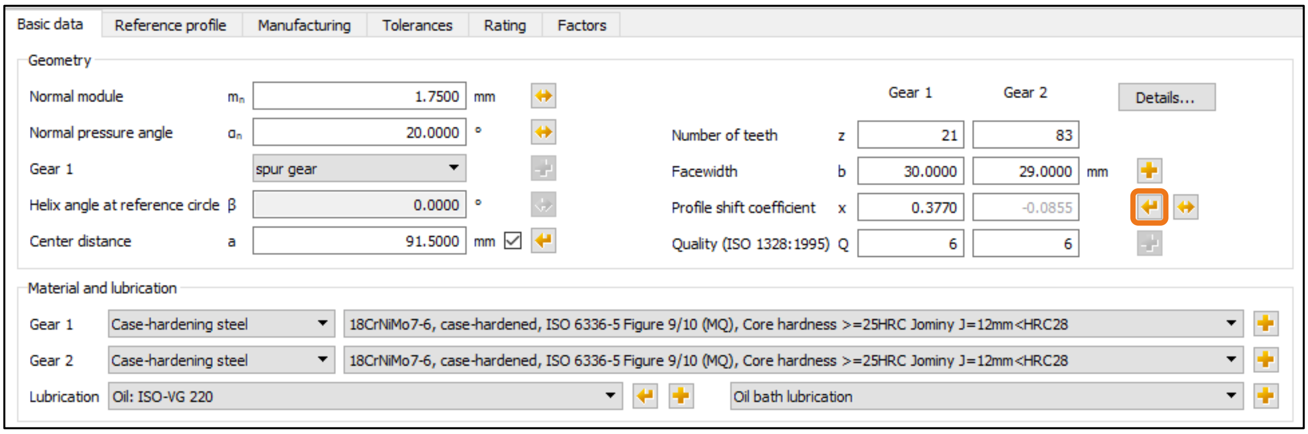
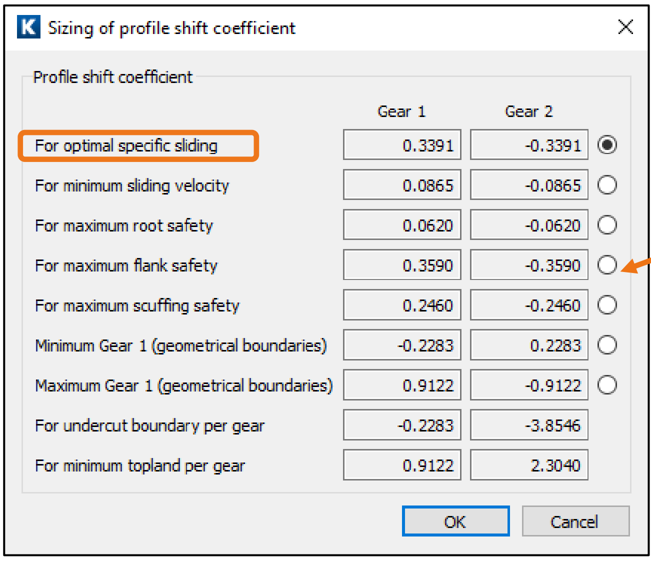


Figure 13. Open dialog window; Size profile shift coefficients



- Various methods for sizing the profile shift coefficient
- Sensible suggestions for the profile shift coefficient
- Maximum and minimum (minimum topland without undercut)

Figure 14. Dialog window; Size profile shift coefficients

If you use different criteria, the KISSsoft system proposes suitable profile shift coefficients. In this example you want to balance specific sliding. Click the **«Radio Button»** to display the required proposal on the right-hand side and then click **«OK»** to accept it.
The profile shift coefficient x is then transferred to the input window of the **«Basic data»** tab, «Geometry» group.
Then, either click on the icon in the tool bar or press «F5» to calculate the complete geometry, the root and flank safeties, the safety against scuffing, and the resulting contact ratio (see **Fehler! Verweisquelle konnte nicht gefunden werden.** below). The results should now look like this (however, minor variations are possible, for example in the calculated profile shift coefficient):

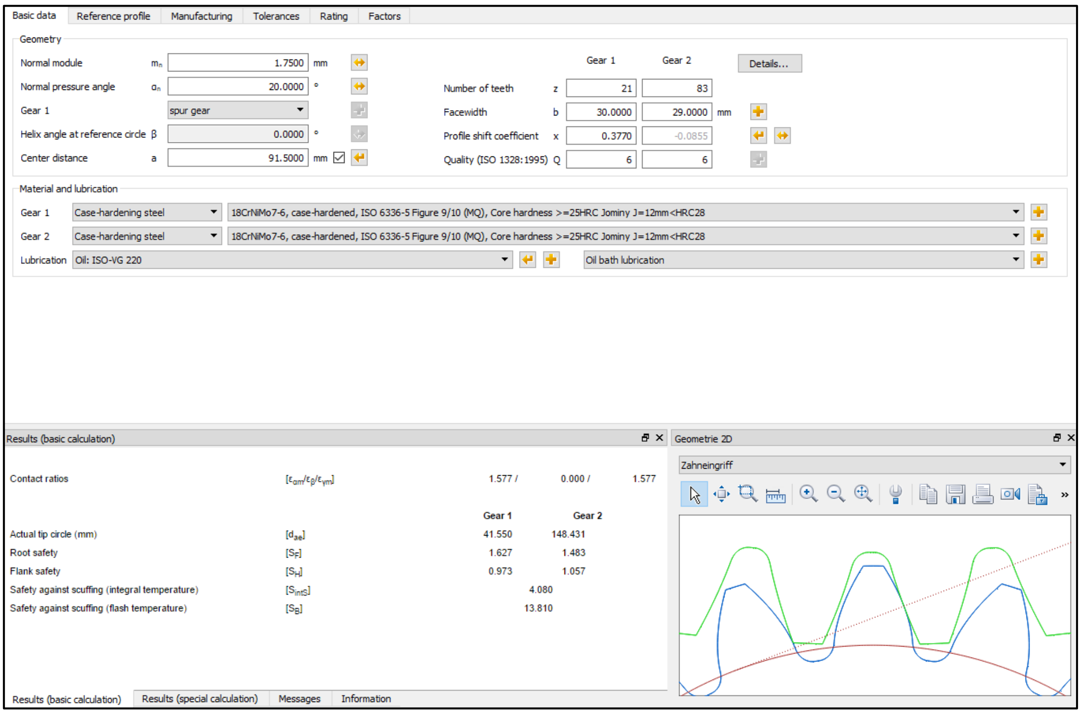


Figure 15. Modified profile shift coefficient, results overview after calculation has run

To access this stage of the calculation directly, open the «Tutorial-009-Step3» file

3 Fine Sizing

3.1 Starting the fine sizing function

Now that you have used the rough sizing function to define a gear pair that can transmit the required power, you can optimize this gear's noise emission and strength characteristics. Just as for rough sizing, go to **«Calculation»**, then select **«Fine Sizing»** to open the **«Fine Sizing»** screen, where you can perform the fine sizing functions.

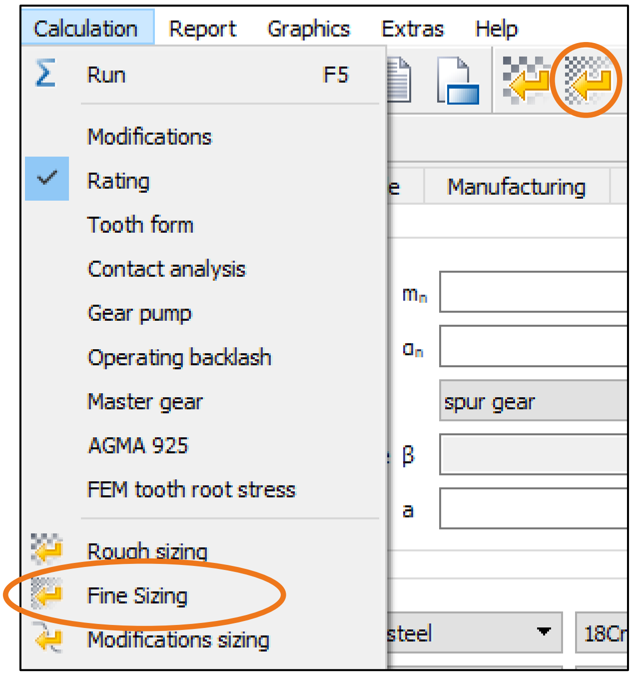


Figure 16. Starting «Fine Sizing»

Here you can define ranges (and intervals) for the following parameters. The KISSsoft system will then search these ranges for a suitable gear pair solution.

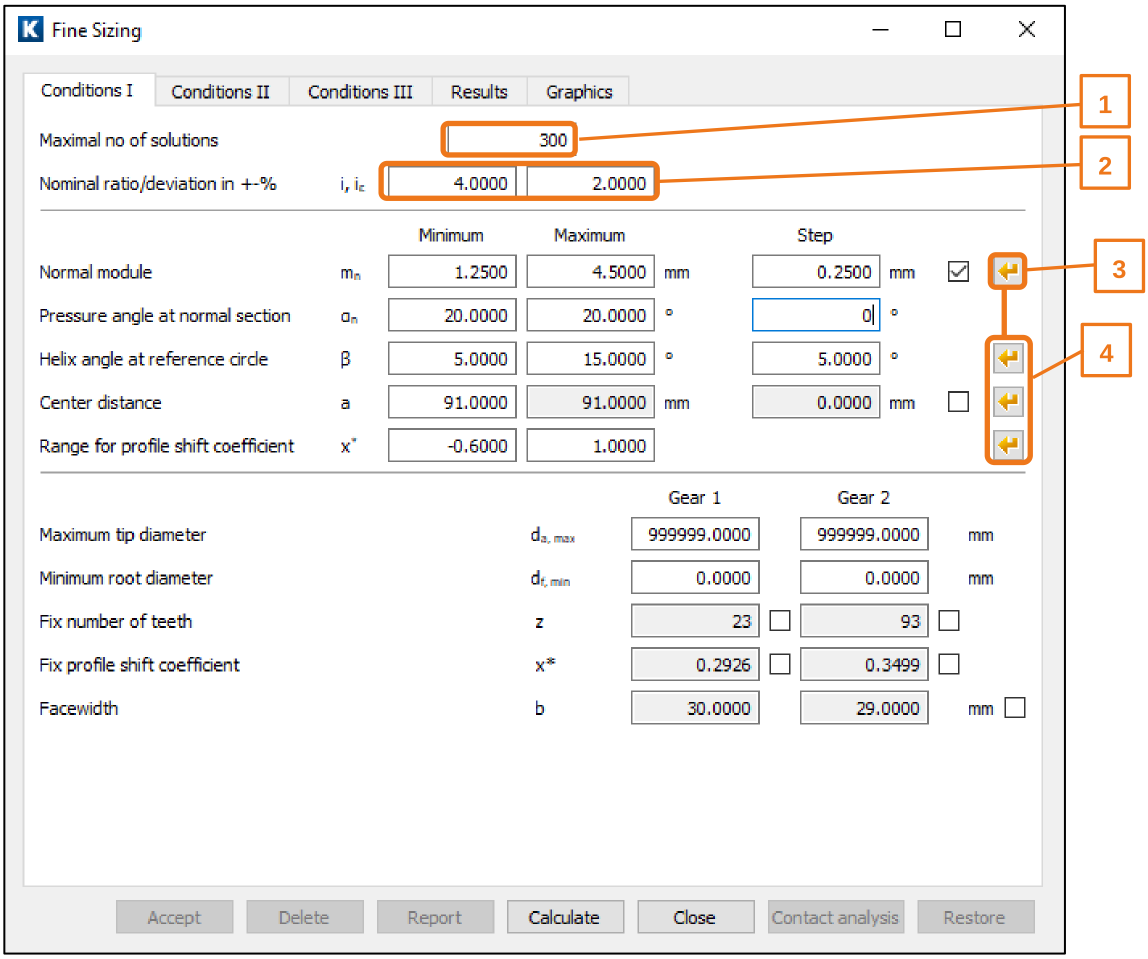


Figure 17. Input window - Fine sizing, input parameter ranges

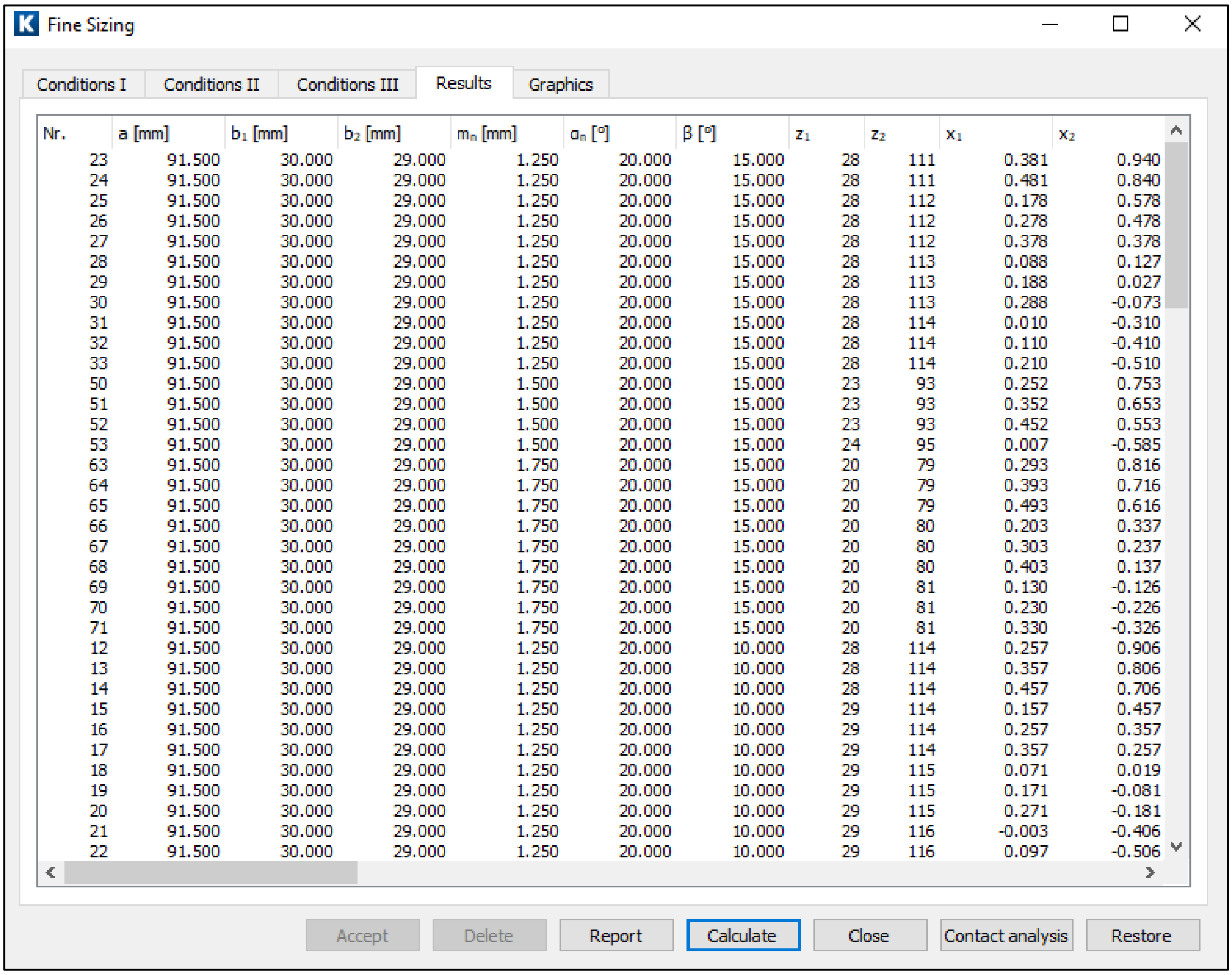
(1) Set to 300
(2) Define the required ratio (4) and permissible error (2%)
(3) Click the Sizing buttons to have KISSsoft propose sensible ranges for the **«Normal module»**, **«Helix angle»**, **«Center distance»** and **«Range for profile shift coefficient»** parameters
(4) Specify whether the center distance is to be fixed or variable

- Range for normal module (1.25 …4.5)
- Range for helix angle (5°…15°)
- Range for center distance (select «variable center distance» option here)
  (A note about the sizing of this value has already been output as the result of the rough sizing process.)

You can also predefine these parameters:
- Upper limit for the tip diameter
- Minimum active root diameter
- Fix the number of teeth for one or both gears (enable the checkbox for the relevant gear; if 0: number of teeth is variable)
- Specify the profile shift for one or both gears (enable the checkbox for the relevant gear)

For this example, make the settings shown in Figure 17. Then click **«Calculate»** (button at the bottom) to call the sizing function. The algorithm then finds all possible gear combinations that match the values you have input.

Once the calculation process has finished, you see a list of all the solutions the system found (see Figure 18). In this example, the aim is to find a gear pair with low noise emissions. You can now sort the results by the required criterion (e.g. ε_α, ε_β, or ε_γ), to find the best solution (depending on the selected strategy ε_α and ε_β if possible as whole numbers or ε_γ if possible as a whole number). Double-click on the required variant or click «Accept» to transfer and calculate the result. If the result produced is not the optimum solution, you can always select a different variant until you find the best possible result.
In this case, solution 50 has been selected.



Nr.	a [mm]	b_1 [mm]	b_2 [mm]	m_n [mm]	α_n [°]	β [°]	z_1	z_2	x_1	x_2
23	91.500	30.000	29.000	1.250	20.000	15.000	28	111	0.381	0.940
24	91.500	30.000	29.000	1.250	20.000	15.000	28	111	0.481	0.840
25	91.500	30.000	29.000	1.250	20.000	15.000	28	112	0.178	0.578
26	91.500	30.000	29.000	1.250	20.000	15.000	28	112	0.278	0.478
27	91.500	30.000	29.000	1.250	20.000	15.000	28	112	0.378	0.378
28	91.500	30.000	29.000	1.250	20.000	15.000	28	113	0.088	0.127
29	91.500	30.000	29.000	1.250	20.000	15.000	28	113	0.188	0.027
30	91.500	30.000	29.000	1.250	20.000	15.000	28	113	0.288	-0.073
31	91.500	30.000	29.000	1.250	20.000	15.000	28	114	0.010	-0.310
32	91.500	30.000	29.000	1.250	20.000	15.000	28	114	0.110	-0.410
33	91.500	30.000	29.000	1.250	20.000	15.000	28	114	0.210	-0.510
50	91.500	30.000	29.000	1.500	20.000	15.000	23	93	0.252	0.753
51	91.500	30.000	29.000	1.500	20.000	15.000	23	93	0.352	0.653
52	91.500	30.000	29.000	1.500	20.000	15.000	23	93	0.452	0.553
53	91.500	30.000	29.000	1.500	20.000	15.000	24	95	0.007	-0.585
63	91.500	30.000	29.000	1.750	20.000	15.000	20	79	0.293	0.816
64	91.500	30.000	29.000	1.750	20.000	15.000	20	79	0.393	0.716
65	91.500	30.000	29.000	1.750	20.000	15.000	20	79	0.493	0.616
66	91.500	30.000	29.000	1.750	20.000	15.000	20	80	0.203	0.337
67	91.500	30.000	29.000	1.750	20.000	15.000	20	80	0.303	0.237
68	91.500	30.000	29.000	1.750	20.000	15.000	20	80	0.403	0.137
69	91.500	30.000	29.000	1.750	20.000	15.000	20	81	0.130	-0.126
70	91.500	30.000	29.000	1.750	20.000	15.000	20	81	0.230	-0.226
71	91.500	30.000	29.000	1.750	20.000	15.000	20	81	0.330	-0.326
12	91.500	30.000	29.000	1.250	20.000	10.000	28	114	0.257	0.906
13	91.500	30.000	29.000	1.250	20.000	10.000	28	114	0.357	0.806
14	91.500	30.000	29.000	1.250	20.000	10.000	28	114	0.457	0.706
15	91.500	30.000	29.000	1.250	20.000	10.000	29	114	0.157	0.457
16	91.500	30.000	29.000	1.250	20.000	10.000	29	114	0.257	0.357
17	91.500	30.000	29.000	1.250	20.000	10.000	29	114	0.357	0.257
18	91.500	30.000	29.000	1.250	20.000	10.000	29	115	0.071	0.019
19	91.500	30.000	29.000	1.250	20.000	10.000	29	115	0.171	-0.081
20	91.500	30.000	29.000	1.250	20.000	10.000	29	115	0.271	-0.181
21	91.500	30.000	29.000	1.250	20.000	10.000	29	116	-0.003	-0.406
22	91.500	30.000	29.000	1.250	20.000	10.000	29	116	0.097	-0.506

Figure 18. List of all the solutions found in the particular parameter range

Press the **«Report»** button to evaluate the most important properties of this solution in a report.

Analysis of the results (Assessment of important characteristics)

Comment:

No.	= Number of the variant
diff_i	= Deviation from the nominal ratio in %
kg	= Weight in kg
Slide	= Specific sliding (maximum value)
v.Slide	= Sliding velocity (m/s, maximum value)
AC/AE	= Begin working depth AC / working depth AE (Friction)
del_cg	= Variant on the stiffness during rolling (N/mm/mym)
1-eta	= Losses in % (1.0-total efficiency)
Safety	= Safety (Tooth root and flank, 0 = high, 1 = medium, 2 = low) (SF-min: 0.60/ 1.20/ 1.40 SH-min: 0.60/ 0.90/ 1.00)
Summary	= Overall assessment (weighted) (50.0%:del_cg 20.0%:diff_i 100.0%:kg 35.0%:Slide 0.0%:v.Slide 0.0%:AC/AE 10.0%:1-eta 100.0%:Safety)

(For this table it can be said in general: the smaller the value the better!)

No.	diff_i	kg	Slide	v.Slide	AC/AE	del_cg	1-eta	Safety	Summary
1	-1.724	4.011	0.608	0.164	0.431	1.198	1.022	1.483	0.687
2	-0.862	4.038	1.006	0.161	0.519	0.949	1.111	1.468	0.676
3	-0.862	4.028	0.838	0.163	0.471	0.948	1.100	1.478	0.679
...									
138	0.000	3.890	2.536	0.485	0.333	0.361	3.094	1.243	0.581
139	0.000	3.941	2.347	0.389	0.419	0.302	2.662	1.312	0.608
140	0.000	3.913	1.601	0.417	0.367	0.277	2.788	1.279	0.590

Analysis of the results
(with the variant index in decreasing order)

Best variants for accurate ratio: 5 6 7 21 22 25 26 27 36 37 ...
Best solutions for weight: 138 135 137 140 134 133 131 132 129 136 ...
Best variants relative to friction (AC/AE): 138 133 135 127 121 132 134 130 131 137 ...
Best solutions for stiffness: 33 32 31 30 29 28 27 26 25 121 ...
Best variants for strength: 53 69 66 63 62 70 67 64 68 90 ...
Best overall variants (summary) : 66 67 68 53 63 69 64 70 71 65 ...

Figure 19. Evaluation of the solutions

Important note: The description of the method of approach here has deliberately been kept as short as possible. In practice it is very important that you carefully read through the **«Analysis of results»** list in the fine sizing function. It is quite likely that the second or third best solution (in terms of noise emission) should be preferred for other reasons. Displaying the variants as graphics in the **«Graphics»** tab can also help you make the right decision:

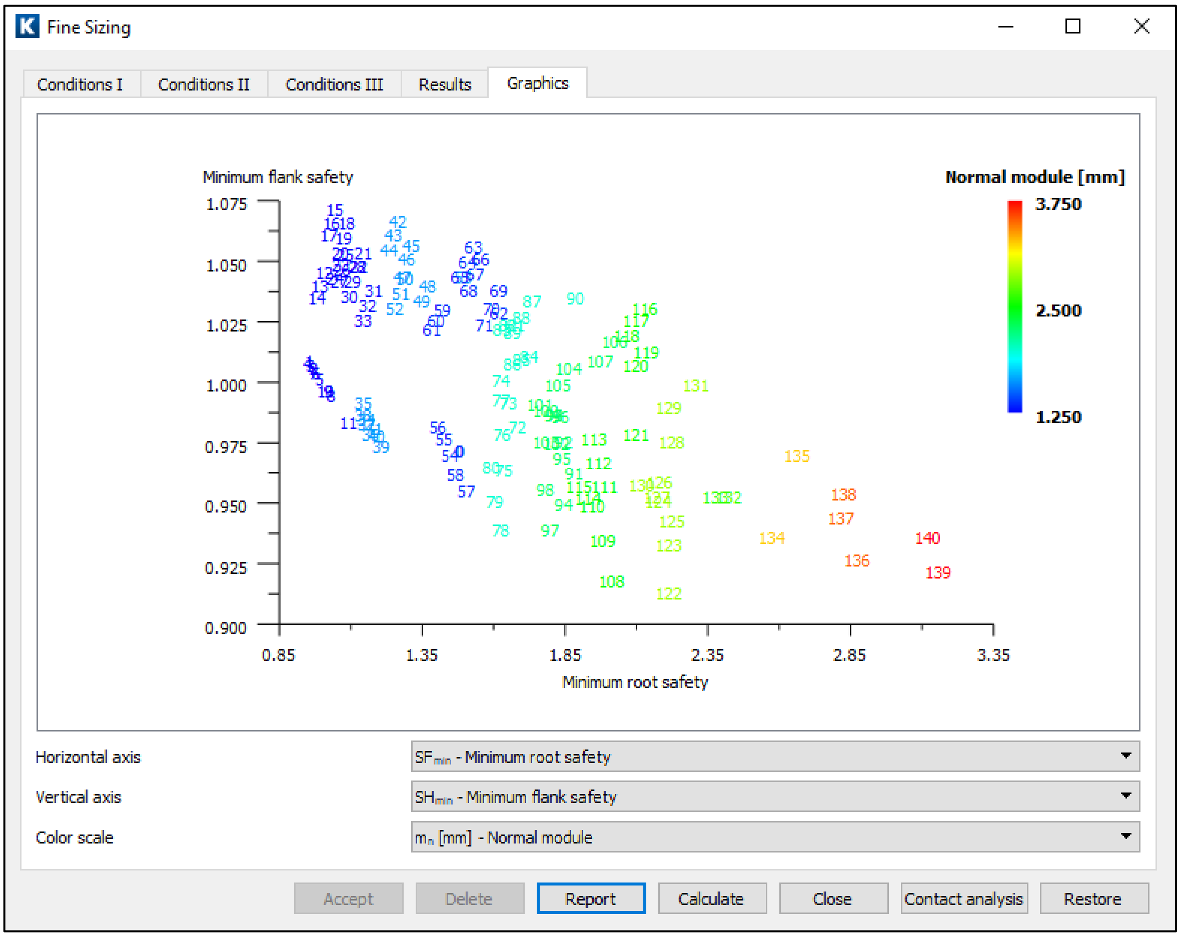
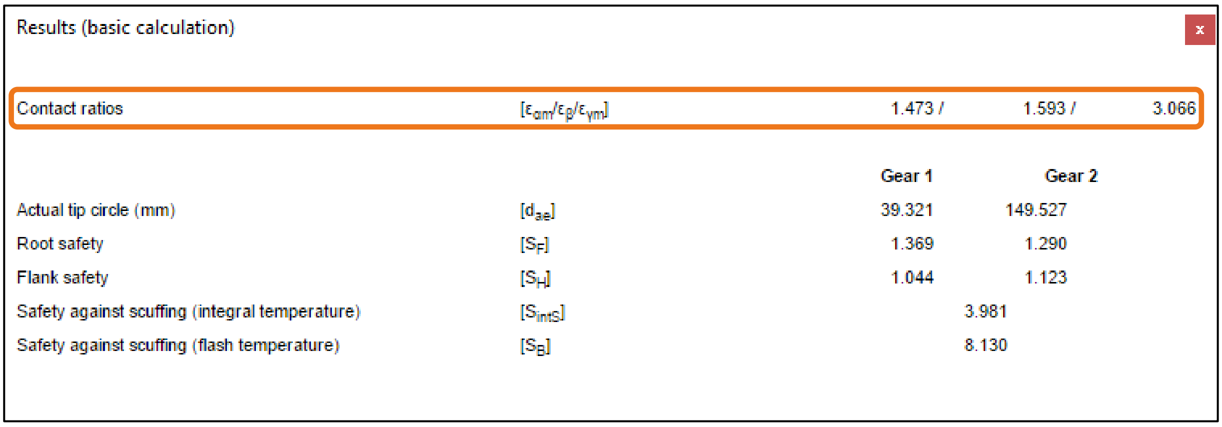


Figure 20. Graphic display of all the solutions

This graphic can help you find the best possible solution more easily (in this case, in terms of tooth root/flank safety). You can then select it under **«Results»** and transfer it to the calculation.

3.2 Results of the fine sizing function

The total contact ratio is now barely above 3, i.e. the variations in stiffness across the contact are very small (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The gear will therefore generate fewer vibrations.



Results (basic calculation)

Contact ratios	[$\varepsilon_{\alpha m}$/ε_β/$\varepsilon_{\gamma m}$]	1.473 /	1.593 / 3.066
		Gear 1	Gear 2
Actual tip circle (mm)	[d_{ae}]	39.321	149.527
Root safety	[S_F]	1.369	1.290
Flank safety	[S_H]	1.044	1.123
Safety against scuffing (integral temperature)	[S_{intS}]	3.981	
Safety against scuffing (flash temperature)	[S_B]	8.130	

Figure 21. Results of fine sizing (profile shift, helix angle, number of teeth)

To access this stage of the calculation directly, open the «Tutorial-009-Step4» file.

The resulting tooth form is then displayed in a graphics window under «2D geometry». Here, you can either click the button or double-click the left-hand mouse button in the gray area to make it into a floating window and enlarge it:

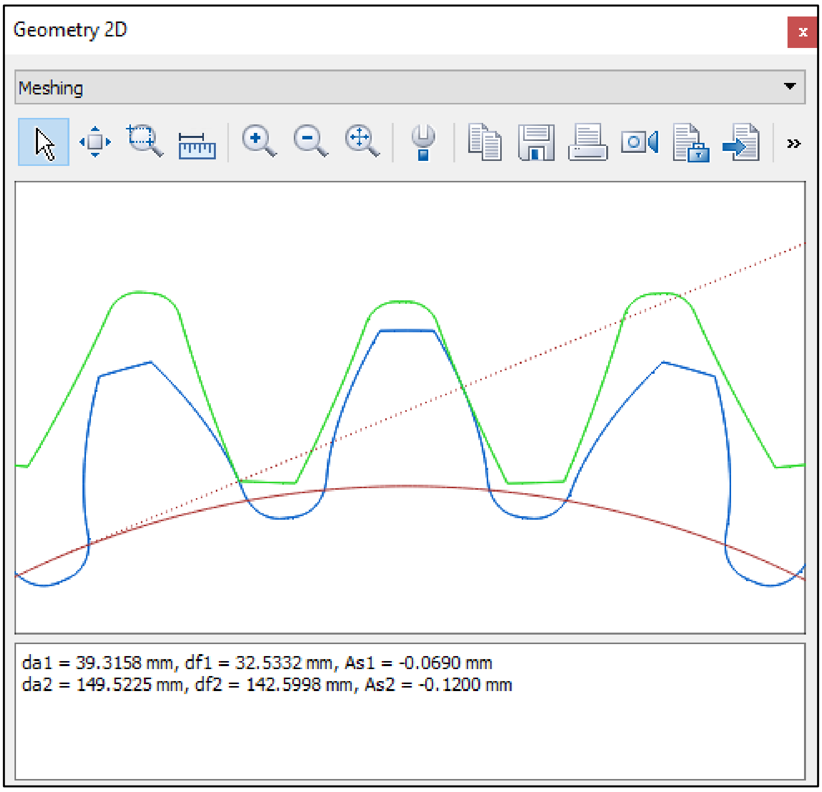


Figure 22. Resulting tooth form (base circles and path of contact shown in red)

To display the stiffness curve above the meshing, click **«Graphics»→ «Evaluation»→Theoretical contact stiffness»**:

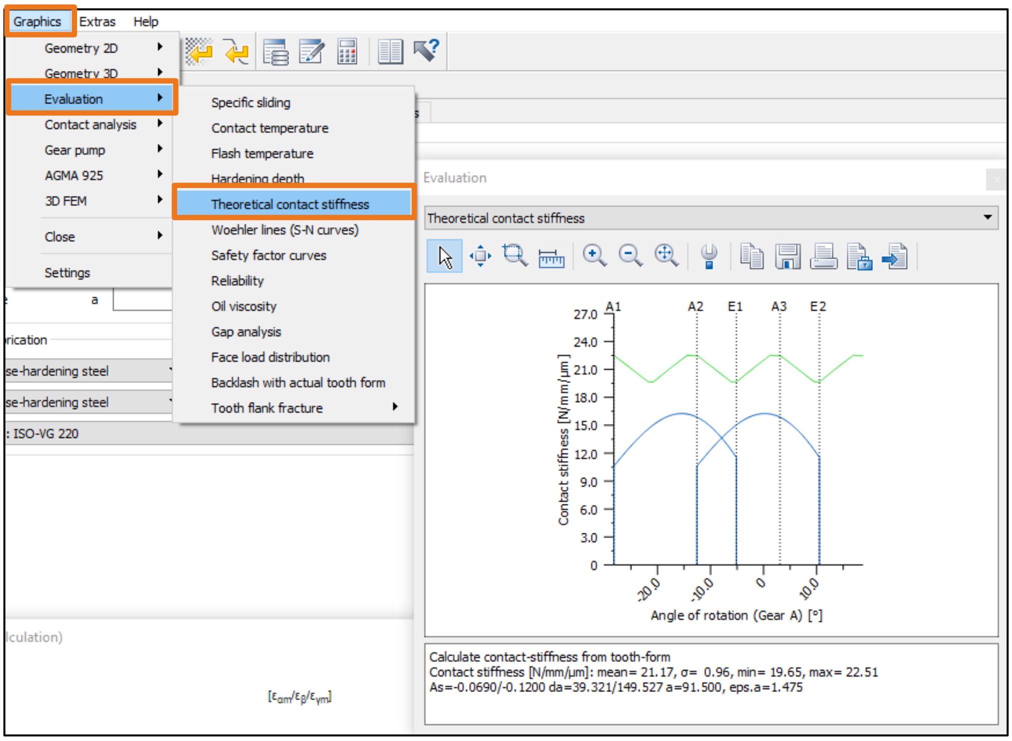


Figure 23. Course of theoretical meshing stiffness

3.3 Sizing a deep tooth form

In the next step you can further improve the selected solution. To do this, increase the transverse contact ratio ε_α to 2. If you want to calculate a tip relief later on, you will need a higher contact ratio because this will be reduced by the tip relief. You should now also increase the resulting contact ratio by sizing a deep tooth form (you can define the target size in the **«Module specific setting»**, in the **«Sizings»** tab).

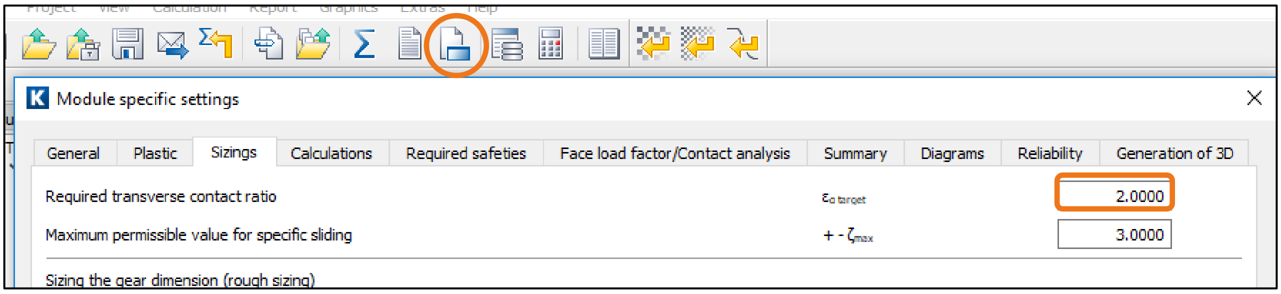


Figure 24. Module specific settings

To size a deep tooth form, call the Fine Sizing function again and then set the flag in the **«Sizing of deep tooth form»** checkbox under **«Conditions III»**. Then click the Calculate button to calculate new values.

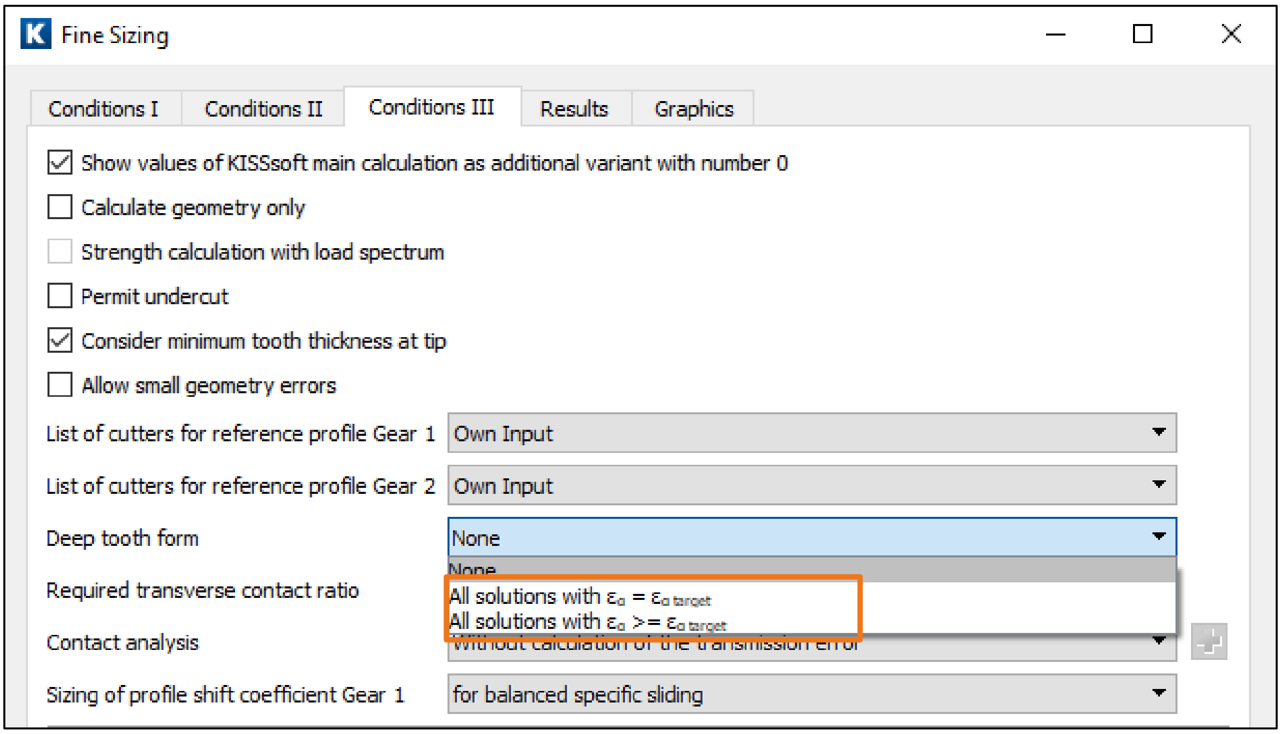


Figure 25. Settings in Fine Sizing, select «Sizing of deep tooth forms»

Now the overall favored solution is number 48. You can now select this variant by clicking **«Accept»** to transfer the gear data for this variant. When you now size a deep tooth form, the reference profiles have been changed.

The gear data now appears again in the main screen (changed number of teeth, helix angle, profile shift) and the new results calculated immediately when they are accepted:

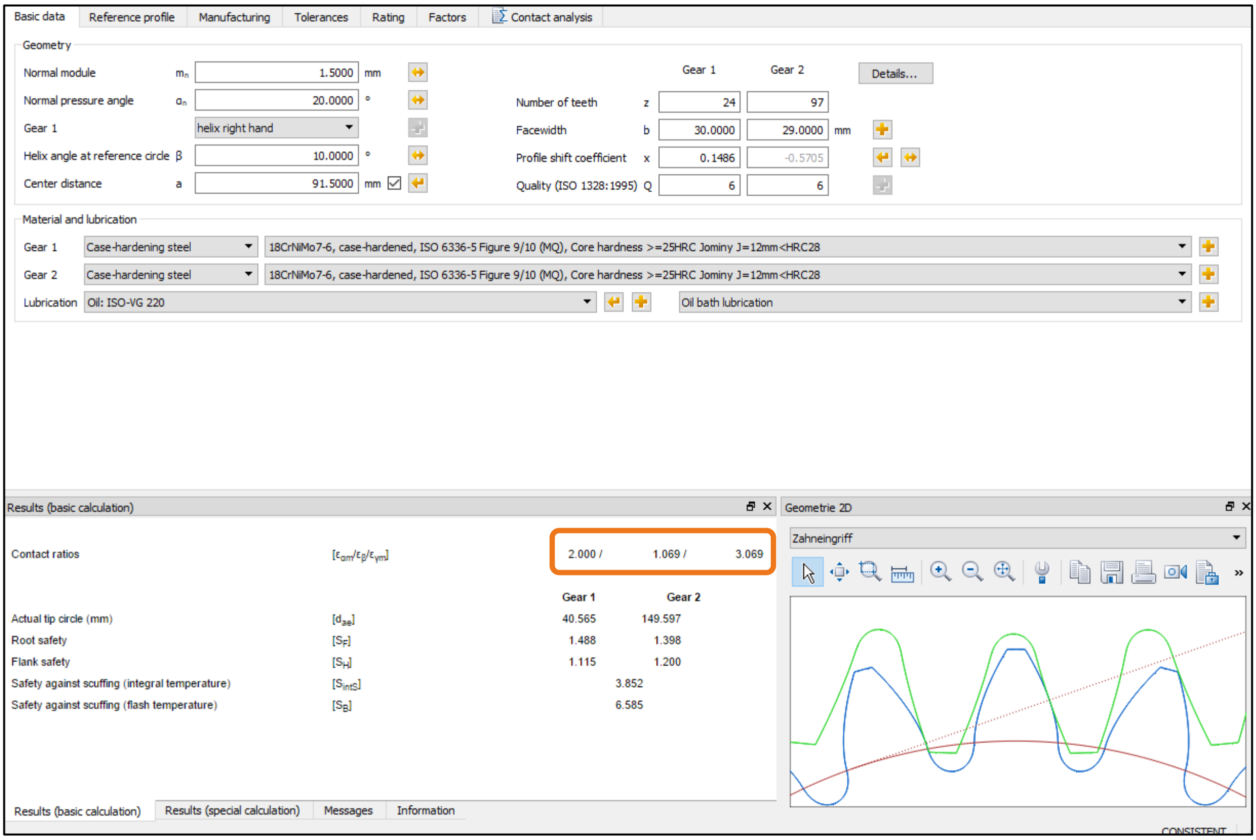


Figure 26.   New gear data and results, in particular contact ratio

To access this stage of the calculation directly, open the «Tutorial-009-Step5» file.

The resulting tooth form is then displayed in a graphics window under «2D geometry». Here, you can either click the button or double-click the left-hand mouse button in the gray area to make it into a floating window and enlarge it:

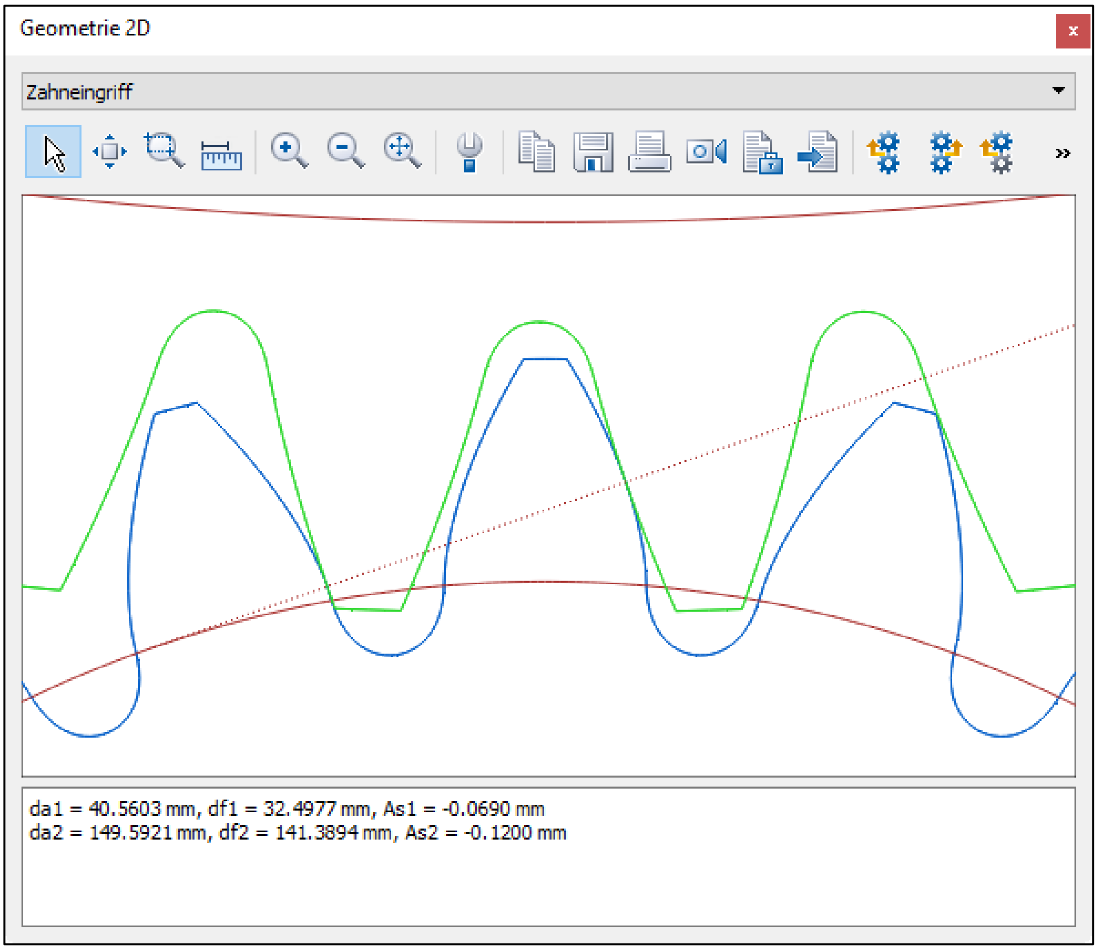


Figure 27. Resulting deep tooth form

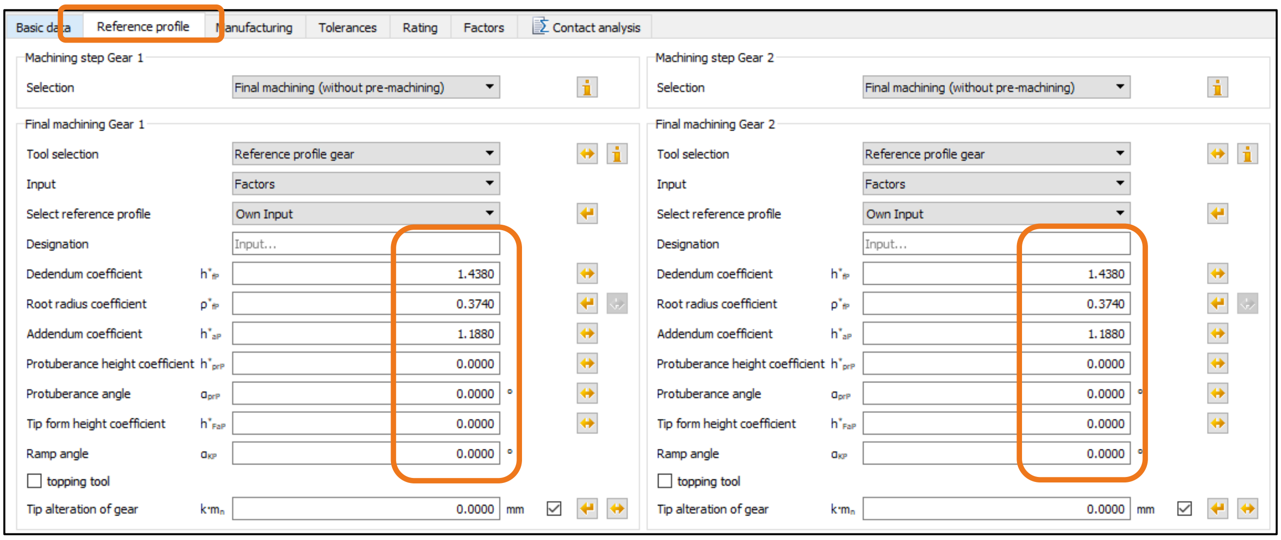


Figure 28. Viewing the reference profile for a deep tooth form in the «Reference profile» tab

The resulting contact ratio is now very close to 3, which results in very even contact stiffness:

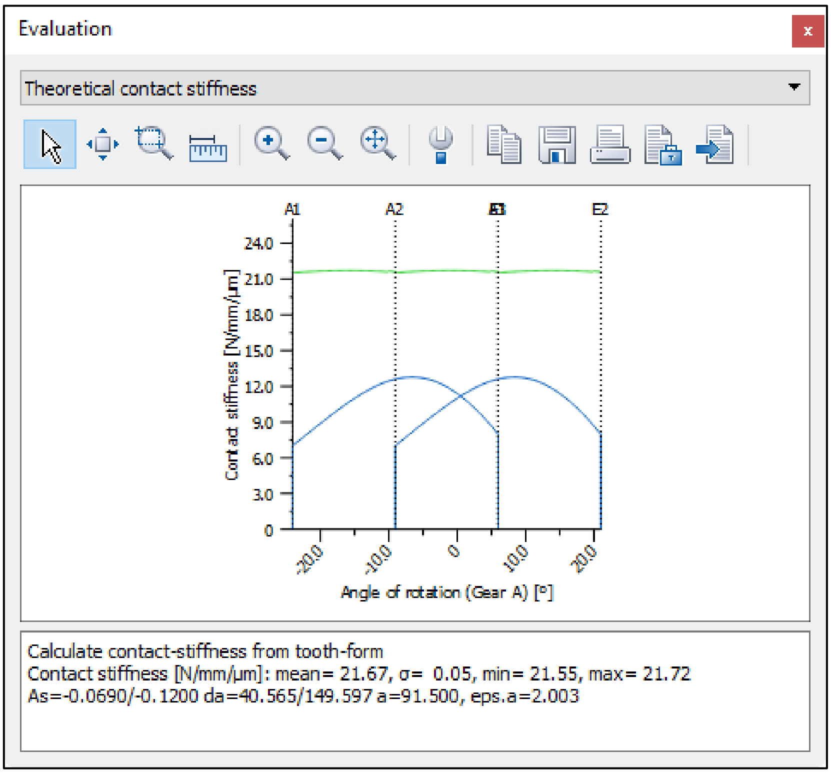


Figure 29. Theoretical contact stiffness curve across the contact

3.4 Further details about strength analysis

For a final gear strength analysis, you must input values for lubrication and for the face load factor:

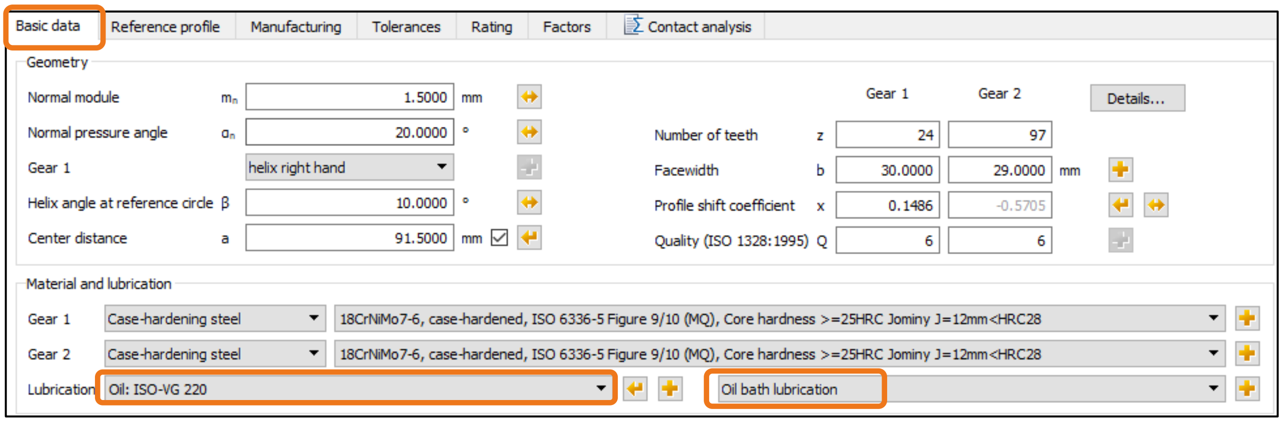


Figure 30. Inputting lubrication data

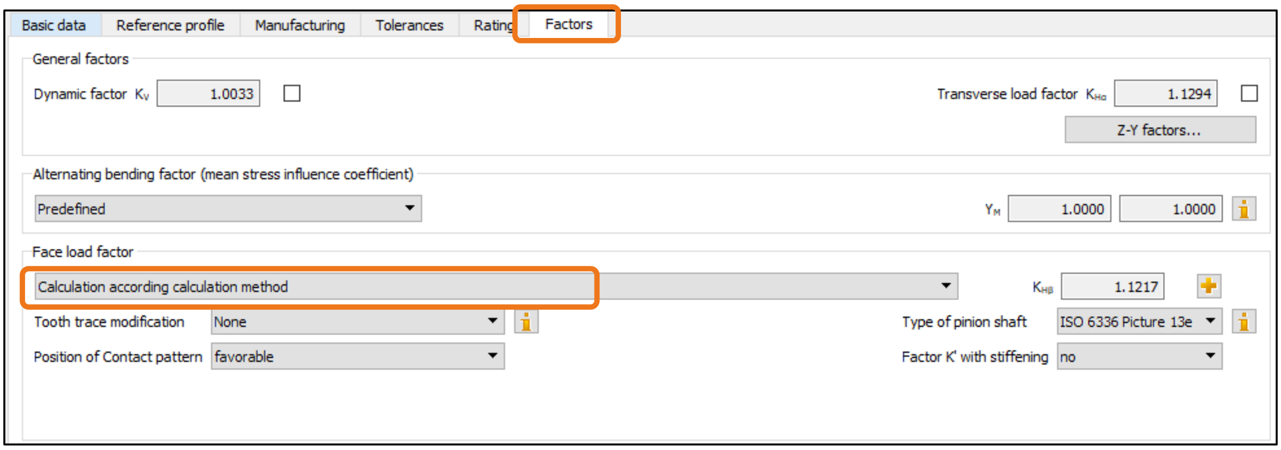


Figure 31. Calling the input window for the face load factor

You can select the lubrication type as well as the lubricant itself directly in the drop-down list (shown here on the left and right). You can also use the database tool to add to the list of lubricants.

Click the Plus button (lower right-hand marking in the Materials and Lubrication group, see Figure 31) to specify the lubricant temperature.

Input the operating and ambient or housing temperature in the **«Operating backlash»** tab (see the marked texts in the next figure).

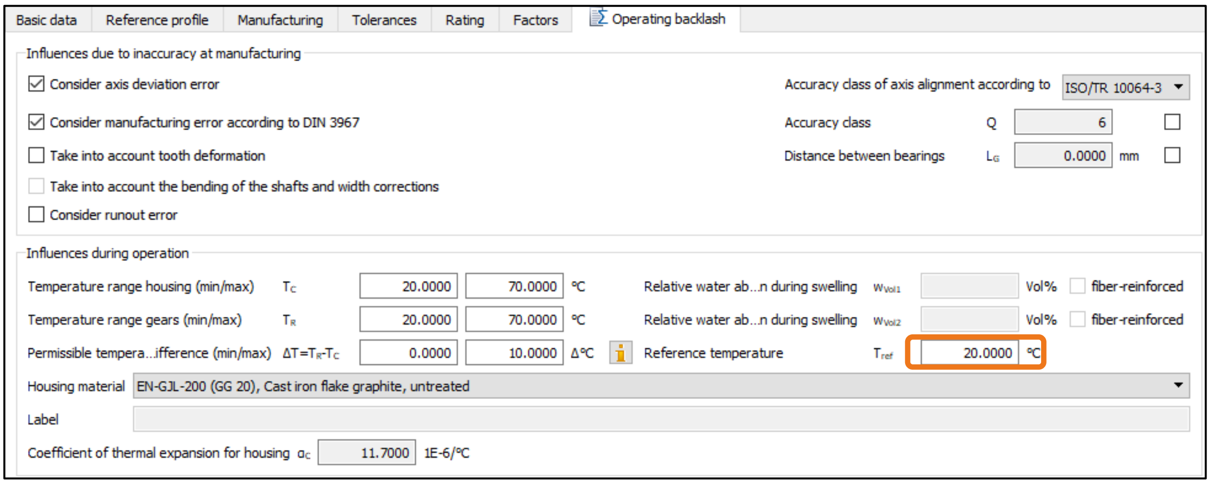
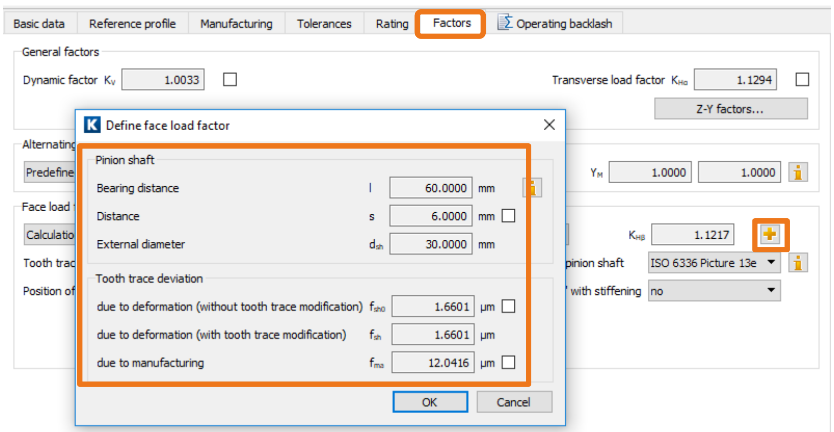


Figure 32. Operating backlash



The face load factor can be determined using Methods A, B or C.

You will find more information about this in separate instructions in «kisssoft-anl-072-D-Kontaktanalyse-Stirnradberechnung» which you can request from KISSsoft Support.

However, you do not usually need to make any changes here.

Figure 33. Entering other parameters, especially values for setting the face load factor

Important note:
If the strength analysis or service life calculation is relevant for evaluating the variant calculated by the fine sizing function, you must input the values listed above before you perform fine sizing.