KISSsoft

Drivetrain Design Solutions

KISSsoft 03/2018 – Tutorial 10

Lifetime analysis of cylindrical gears

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Sharing Knowledge

Contents

1 Task

1.1 Task

To analyze the strength of a helical gear pair as specified in ISO 6336, Method B. A load spectrum is used in this example. The safety factors, service life and permissible power rating are to be calculated.

The following data is specified for this helical gear pair:

	Gear 1	**Gear 2**
Module [mm]	6	6
Helix angle [degrees]	5	5
Pressure angle [degrees]	20	20
Number of teeth [-]	25	76
Width [mm]	44	43
Material	18CrNiMo7-6 case-hardened	18CrNiMo7-6 case-hardened
Nominal torque [Nm]	3360	follows
Nominal speed [Rpm]	440	follows
Application factor [-]	1.25	1.25
Required service life [h]	20’000	20’000

The following load spectrum is to be used:

Frequency [%]	**Speed factor [%]**	**Torque factor [%]**
10	20	20
20	50	30
40	80	90
30	100	100

2 Calling the program

2.1 Starting the software

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 03-2018→KISSsoft 03-2018». This opens the following KISSsoft user interface:

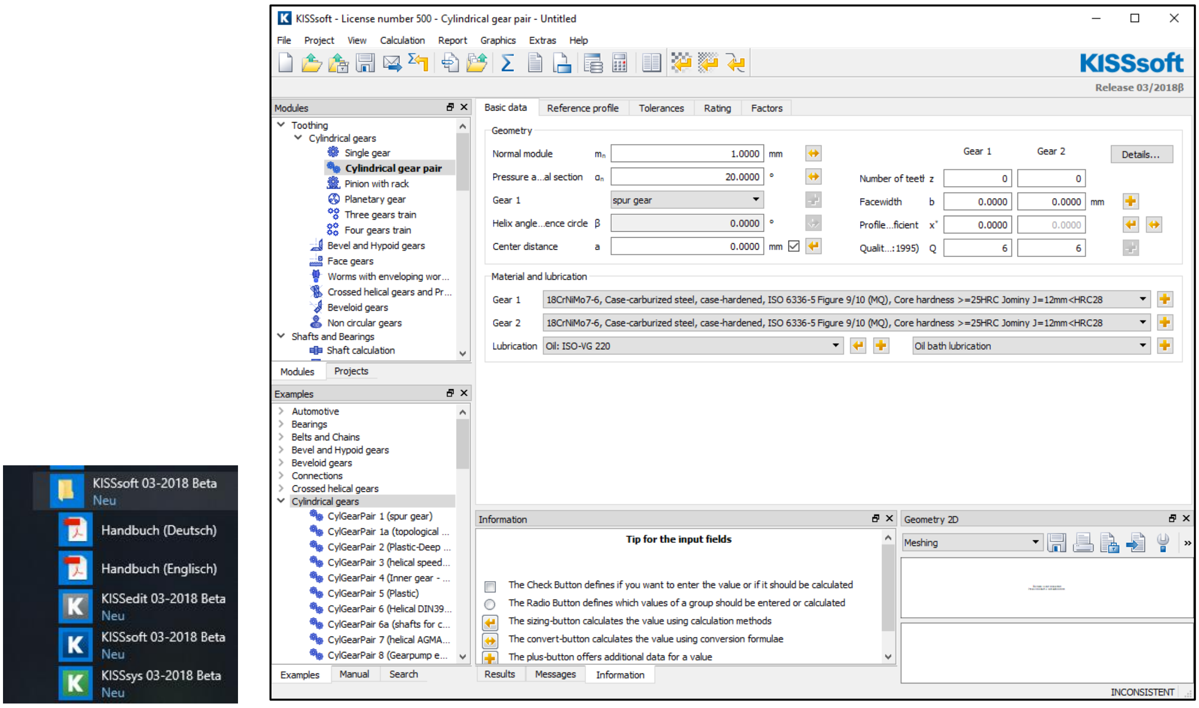


Figure 1. Starting KISSsoft, initial window

3 Entering the data

3.1 Inputting the load spectrum

KISSsoft provides a range of different options for you to input load spectra. If the load spectrum is stored in the database it is also available to other calculations. In contrast, if you use the «**Own input**» option to enter the load spectrum, it is only available to the current calculation.

3.1.1 Database: direct entry

After you have opened the database tool as shown in Figure 2 with authorization to write data to it (you may have to run KISSsoft as the Administrator), you now have a range of options for defining load spectra in the database. Select **«Load spectra»** from the list and click on **«Edit»** to call the appropriate table.

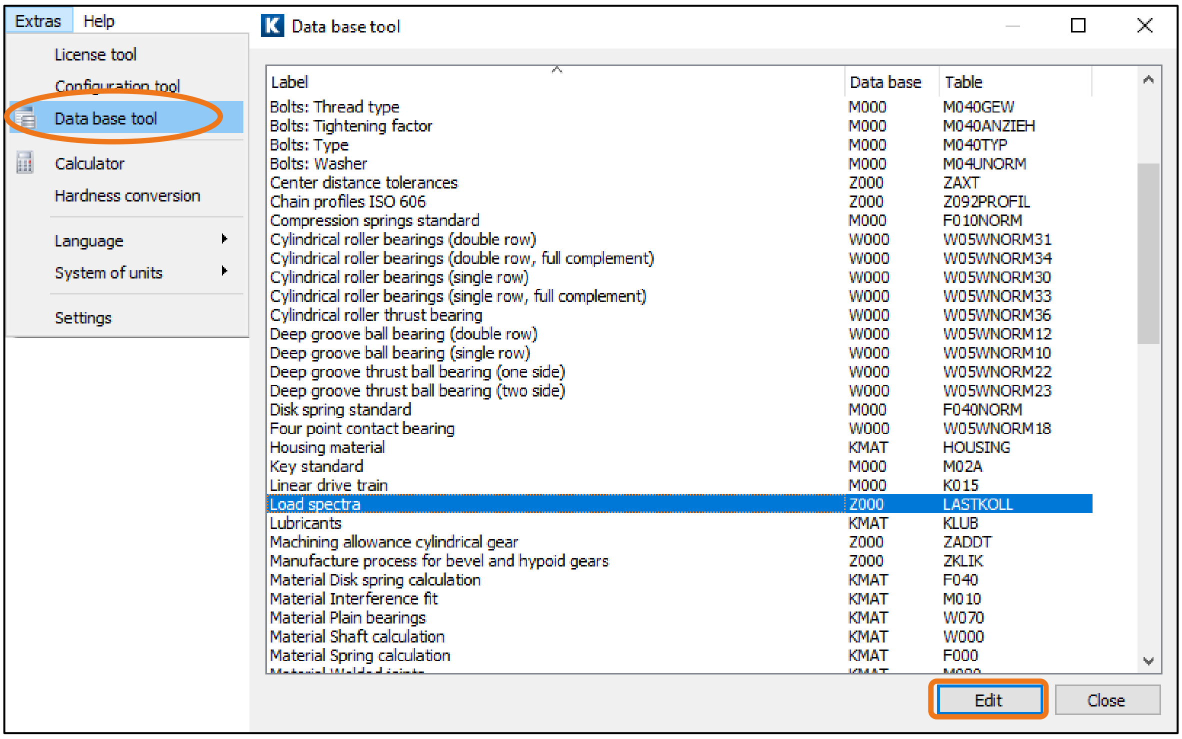


Figure 2. Calling the load spectrum database

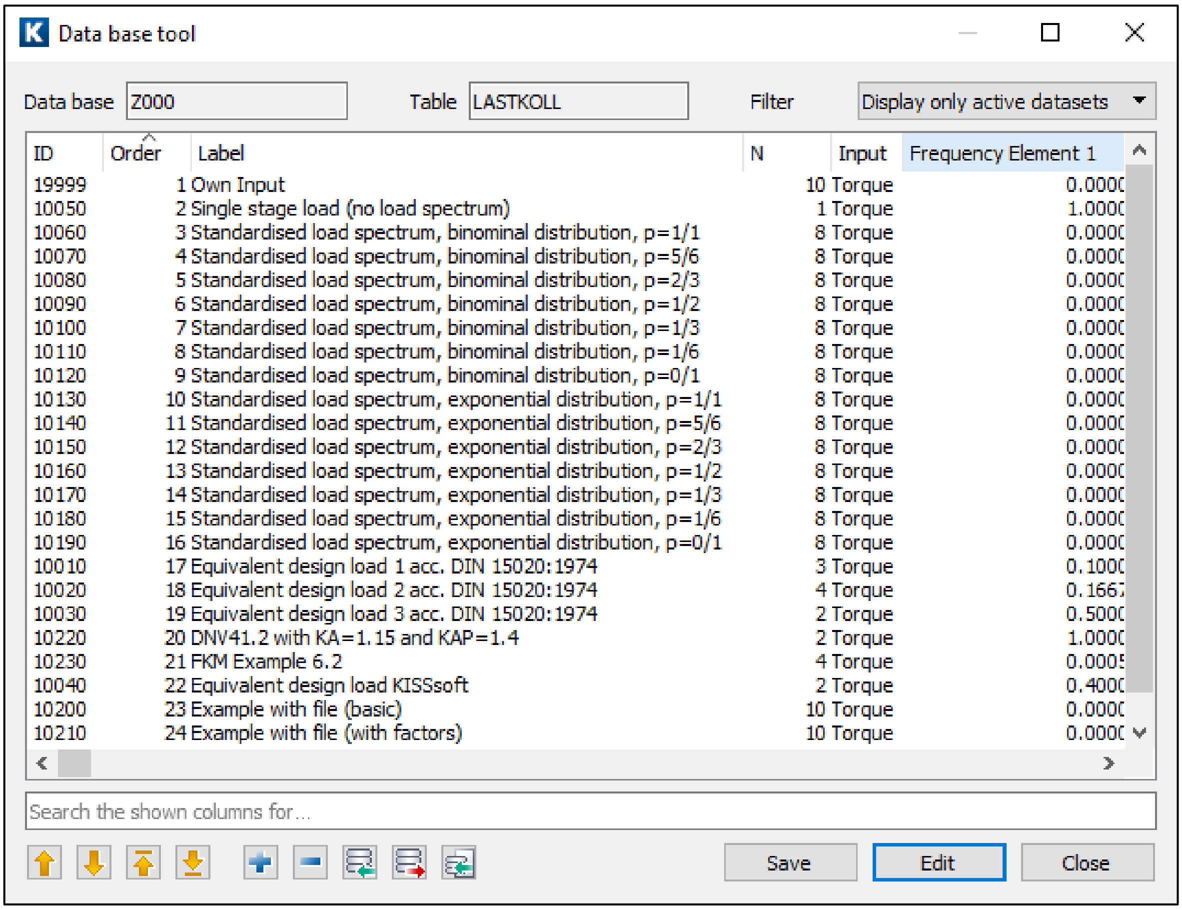


Figure 3. Creating a new data record

Click  to create a new data record. If a data record is marked, its data is copied and «_NEW» is appended to its label. If no data record is marked, a new one will be created. Now enter a description. You now see information about the «frequency, load or torque factors and speed factors» for the corresponding load level elements. You can also specify whether the load spectrum refers to the torque or the transmitted power. Once you have finished entering data for this load spectrum, click **«OK»** and then click **«Save»** to save this data record. Then click **«Close»** to close the database tool and return to the KISSsoft system's initial screen. The load spectrum is now available for analysis.

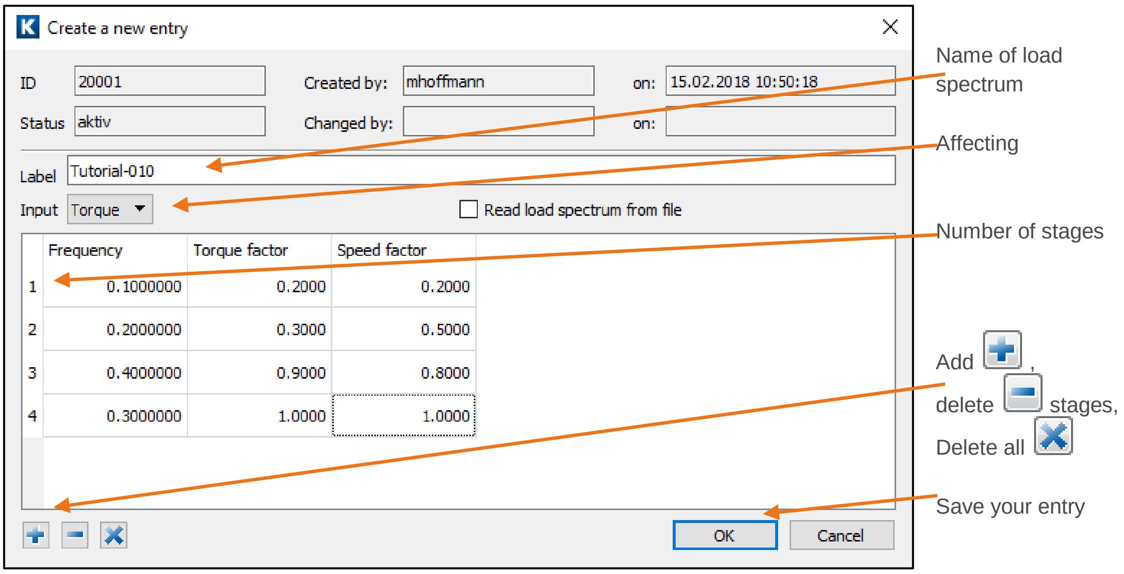


Figure 4. Inputting the load spectrum

3.1.2 Database: data input from a file

You can also transfer a load spectrum to the database in a file. To do this, enter the required load spectrum (without the face load alternating bending factors, and load distribution factor, for each load element) in a text editor as shown below (see Example_DutyCycle.dat):

Frequency, torque/power, speed
For example:

0.1	0.2	0.2
0.2	0.3	0.5
0.4	0.9	0.8
0.3	1.0	1.0

If these factors are required/present for each load element for the calculation, you must define the load spectrum as shown in Example_DutyCycleWithFactors.dat.

This file is saved as a file with the file extension *.**dat** (in this example «Example-Tut-010.dat», for preference in the …\KISSsoft 03-2017\ext\DAT folder (for more information, see Figure 5) or in any other folder (for more information see Figure 6).
In the KISSsoft installation folder you will find a folder called C:\Programs\KISSsoft 03-2017\ext\DAT. If you store files with the file extension *.dat in this folder, the KISSsoft system will be able to find them automatically. In this case, you only need to enter the following:

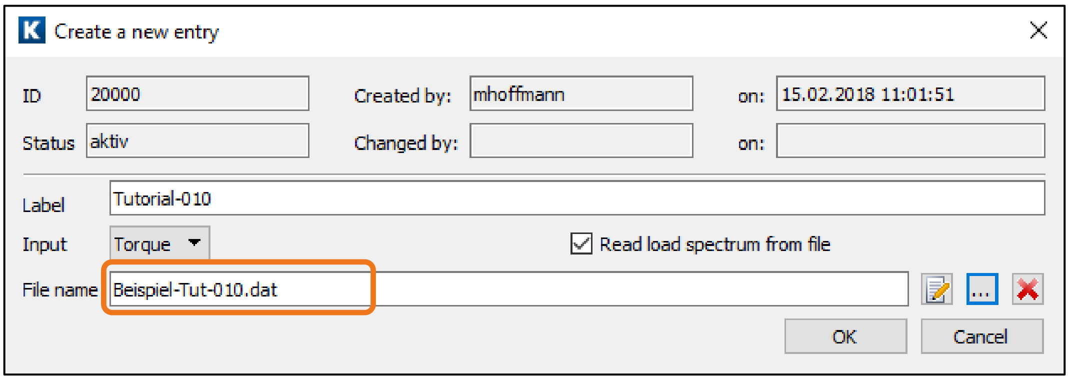


Figure 5. Input of the name of the file in which the load spectrum was saved

If you save the file with the load spectrum to a different folder, you must also store the entire path + file name in the «File name» field. If the path name is too long, follow the steps described above:

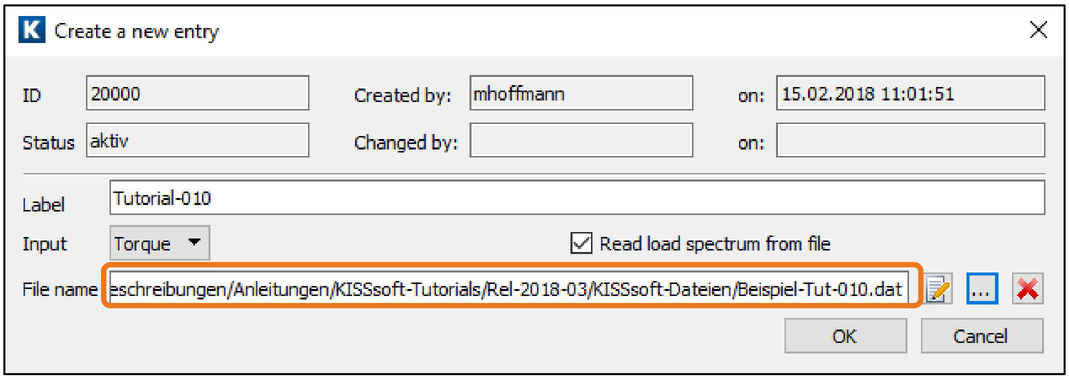
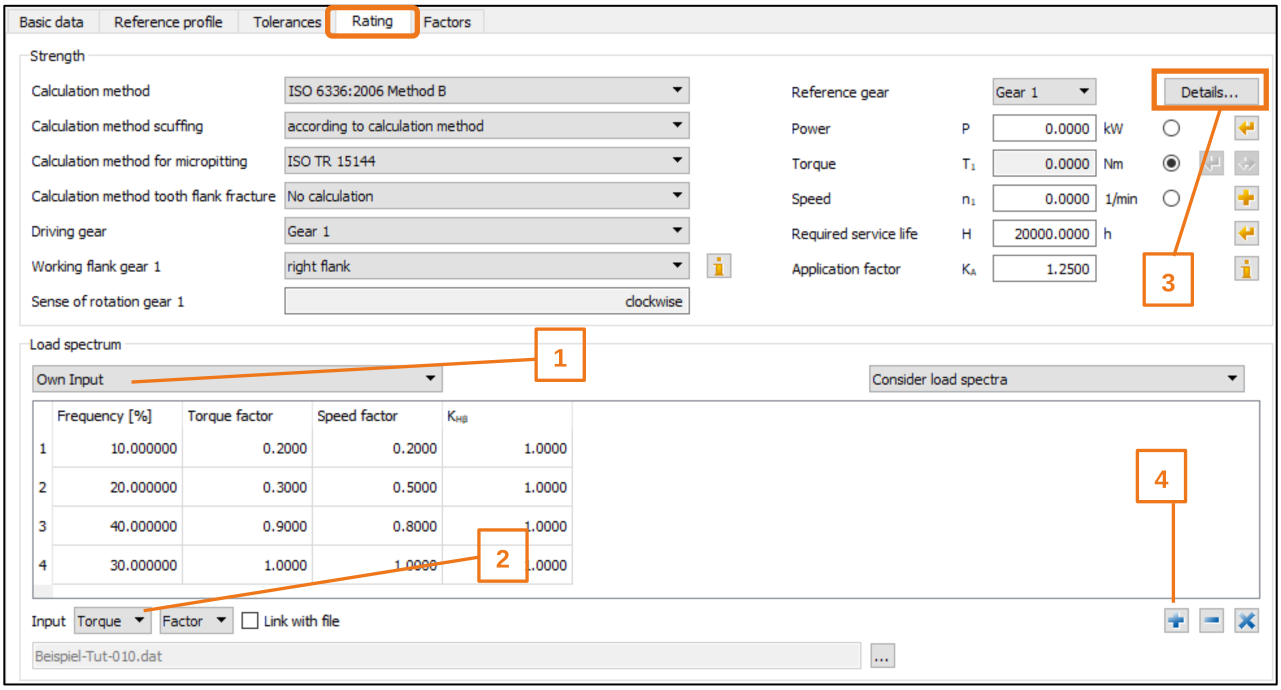


Figure 6. Input of the entire path including the file name

3.1.3 Own input

Alternatively you can define load spectra in the Rating tab. Here you can also use load spectra with or without the face load and alternating bending factors, and load distribution factor, for each load element.

If, as in this example, you want to define a load spectrum without these factors, you must make the following settings in the Factors and Rating tabs:



	Frequency [%]	Torque factor	Speed factor	$K_{H\beta}$
1	10.000000	0.2000	0.2000	1.0000
2	20.000000	0.3000	0.5000	1.0000
3	40.000000	0.9000	0.8000	1.0000
4	30.000000	1.0000	1.0000	1.0000

Figure 7. Call up the «Own Input» load spectrum

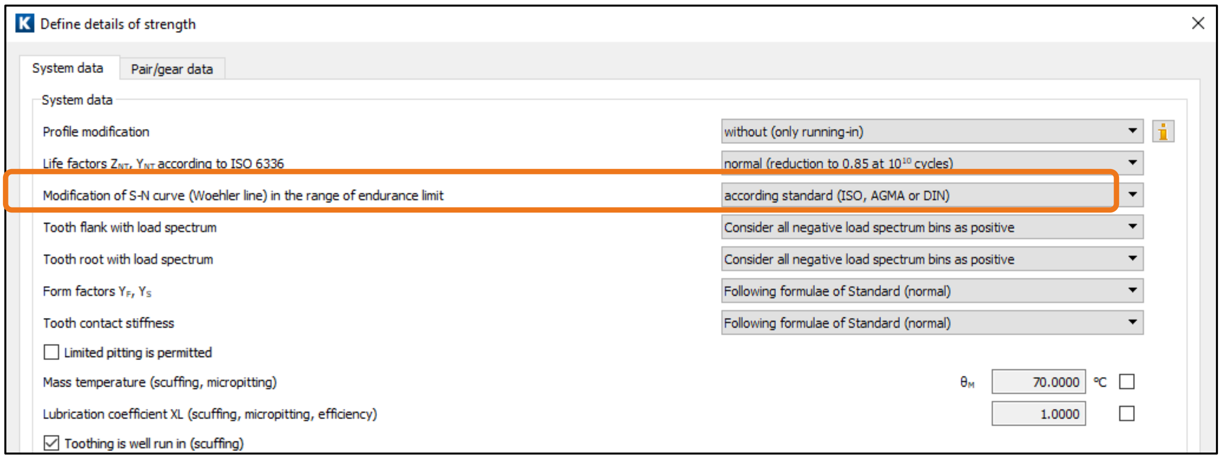


Figure 8. Definition of the range of endurance limit of the Woehler line

(1) Type of load spectrum (database spectrum (predefined and generated by the user), Own Input)

(2) Type of input: for example, power/torque related, factors or absolute values or imported from a file

(3) Definition of the range of endurance limit of the Woehler line

(4) «Insert a load spectrum element», «Delete a load spectrum element», «Delete all entries»

3.2 Inputting toothing data

To call the cylindrical gear calculation, go to the modules tree window in the KISSsoft main screen. There, click the **«Modules»** tab and then click **«Cylindrical gear pair»**. Then input the toothing data specified below:

In the Basic data tab:

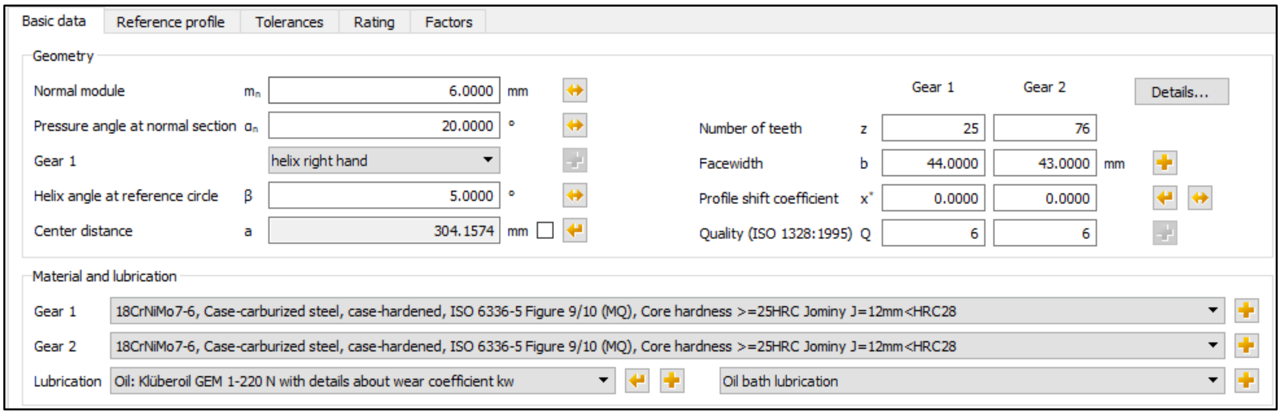


Figure 9. Inputting toothing and load data

In the Rating tab:

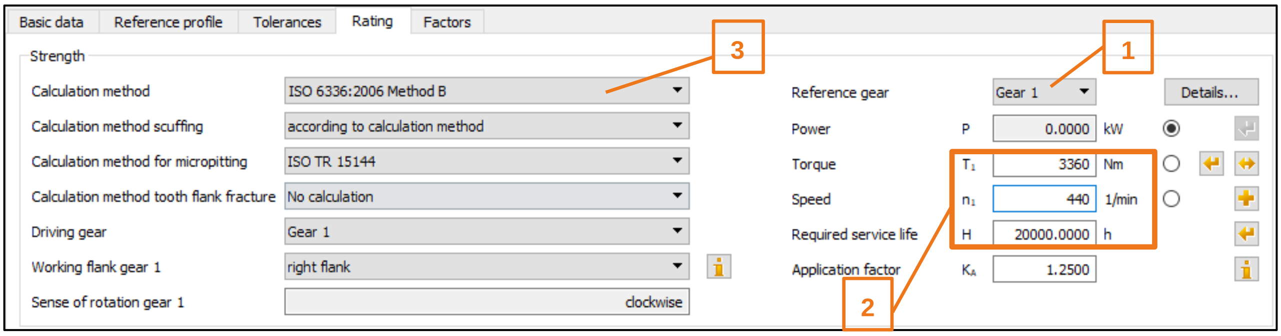


Figure 10. Inputting toothing and load data

(1) Reference gear
(2) Load: here you must input two of the three values (speed, torque, power)
(3) Calculation method

3.3 Defining further parameters

3.3.1 Center distance

Click the Sizing button to the right of the Center distance input field to define the center distance. At this point, no profile shift coefficient has been defined and therefore the total profile shift coefficient is zero. To calculate the center distance, click «Calculate» and then transfer this value to the main screen by clicking «Accept».

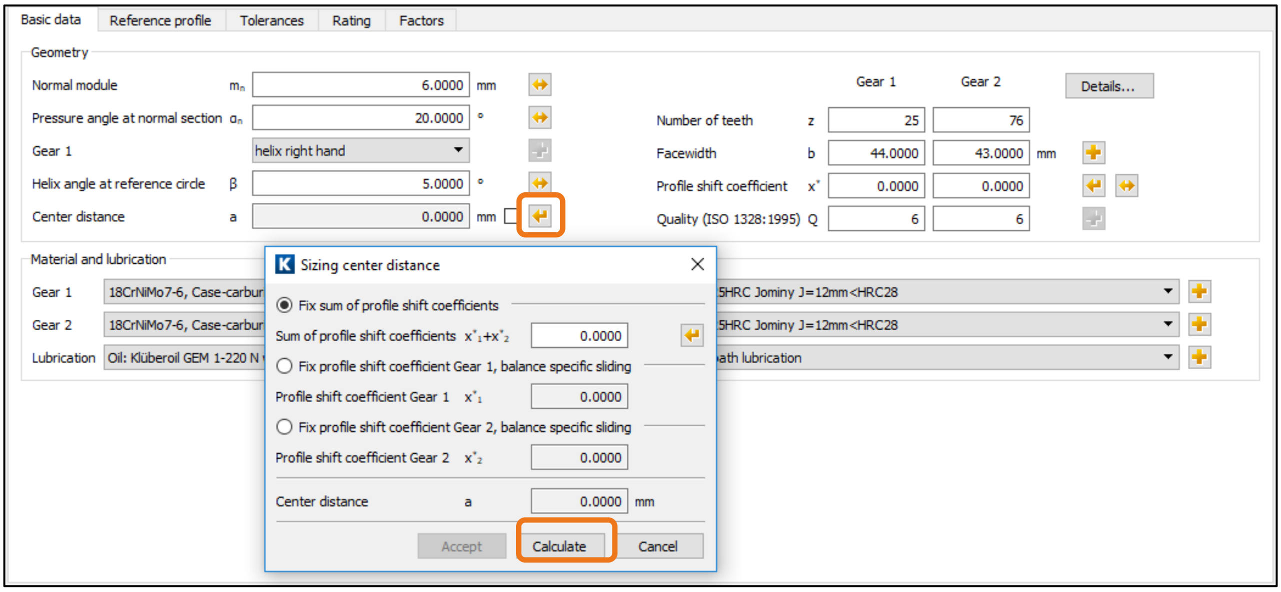


Figure 11. Calculation of the center distance with a predefined sum of profile shift coefficients (here zero)

3.3.2 Profile shift coefficient

You should select profile shift coefficients so that the minimum specific, balanced sliding is achieved. To do this, click the Sizing button next to the profile shift.

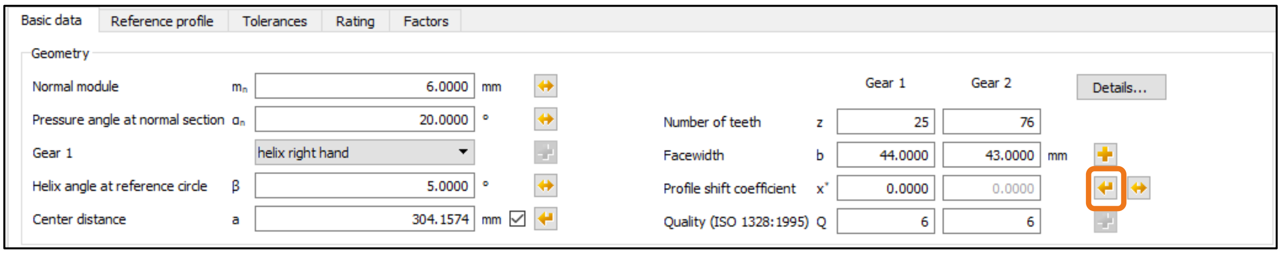
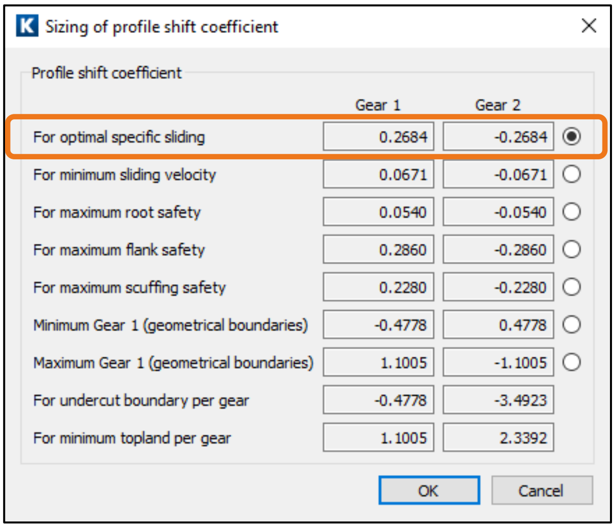


Figure 12. «Sizing button» for the profile shift coefficient



You then see the resulting profile shift coefficients for different criteria. In this example, you should select profile shift coefficients for the «For optimal specific sliding» criterion.

Figure 13. Sizing profile shift coefficients

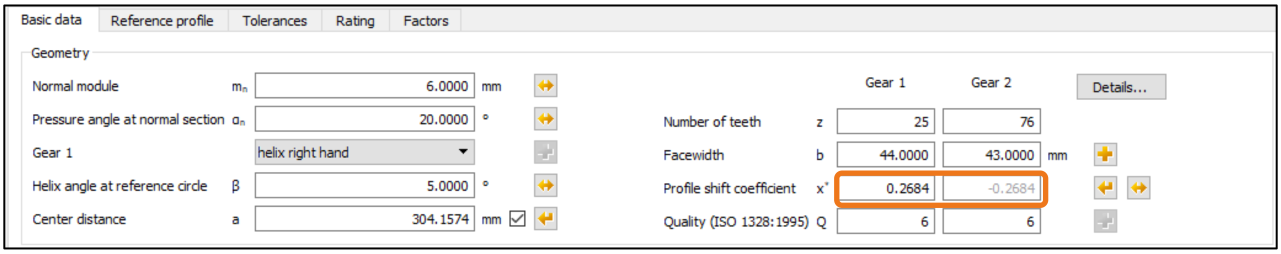


Figure 14. Calculated profile shift coefficients

The center distance is a theoretical value. It is set to 304.2 mm (overwrite the value directly in the screen). To make the required changes to the profile shift coefficients, click Σ (Calculate). This is a minor change that does not affect specific sliding. When you perform the analysis, the system also defines the safety factors for the specified nominal load. The results then appear in the lower part of the window.

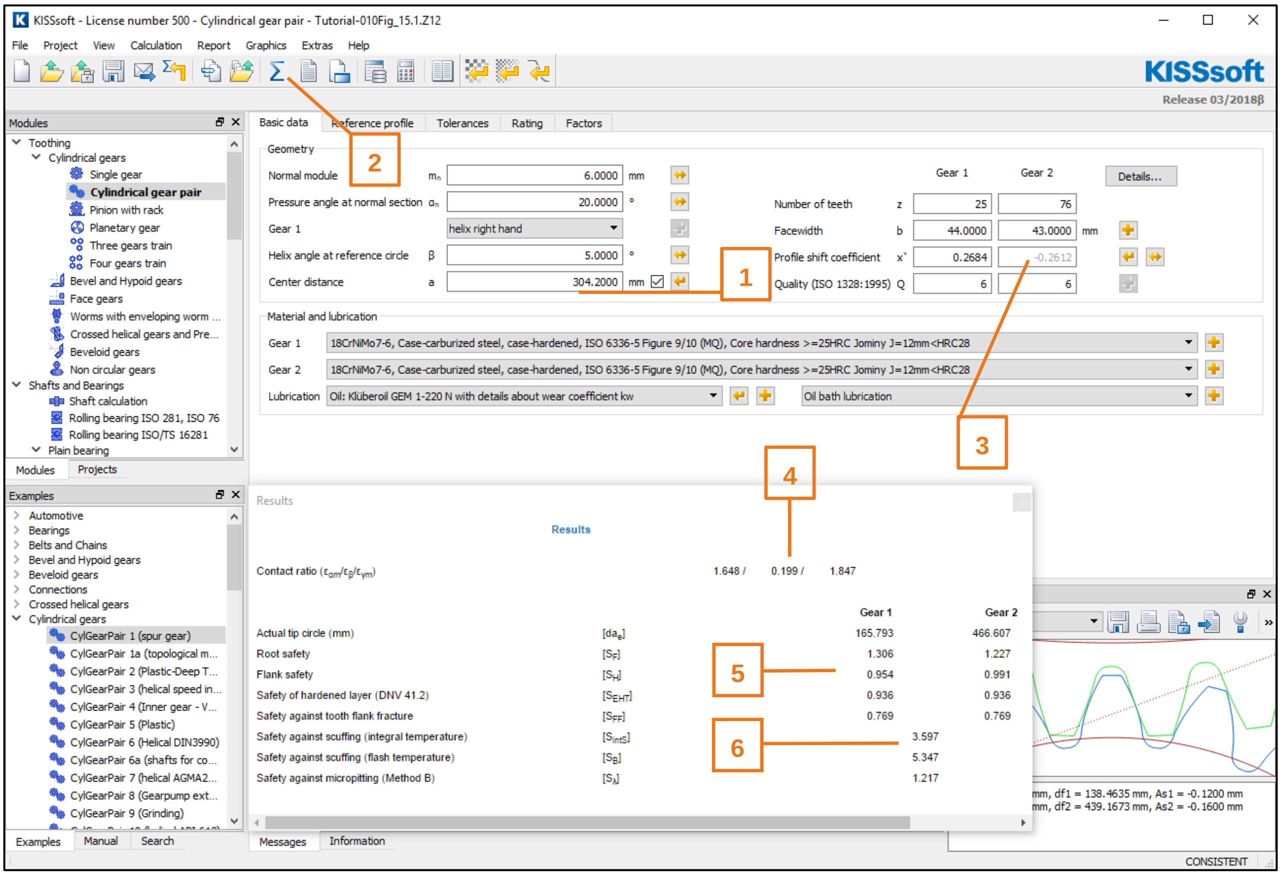


Figure 15. Gear pair with a sensible center distance, profile shift coefficients, and the first results under nominal load

(1) Manually defined center distance
(2) Call the analysis
(3) Slight change to profile shift
(4) Resulting contact ratio
(5) Resulting safety factors at nominal load
(6) Resulting safety against scuffing

You can now observe specific sliding by clicking **«Graphics»→ «Evaluation» →«Specific sliding»**:

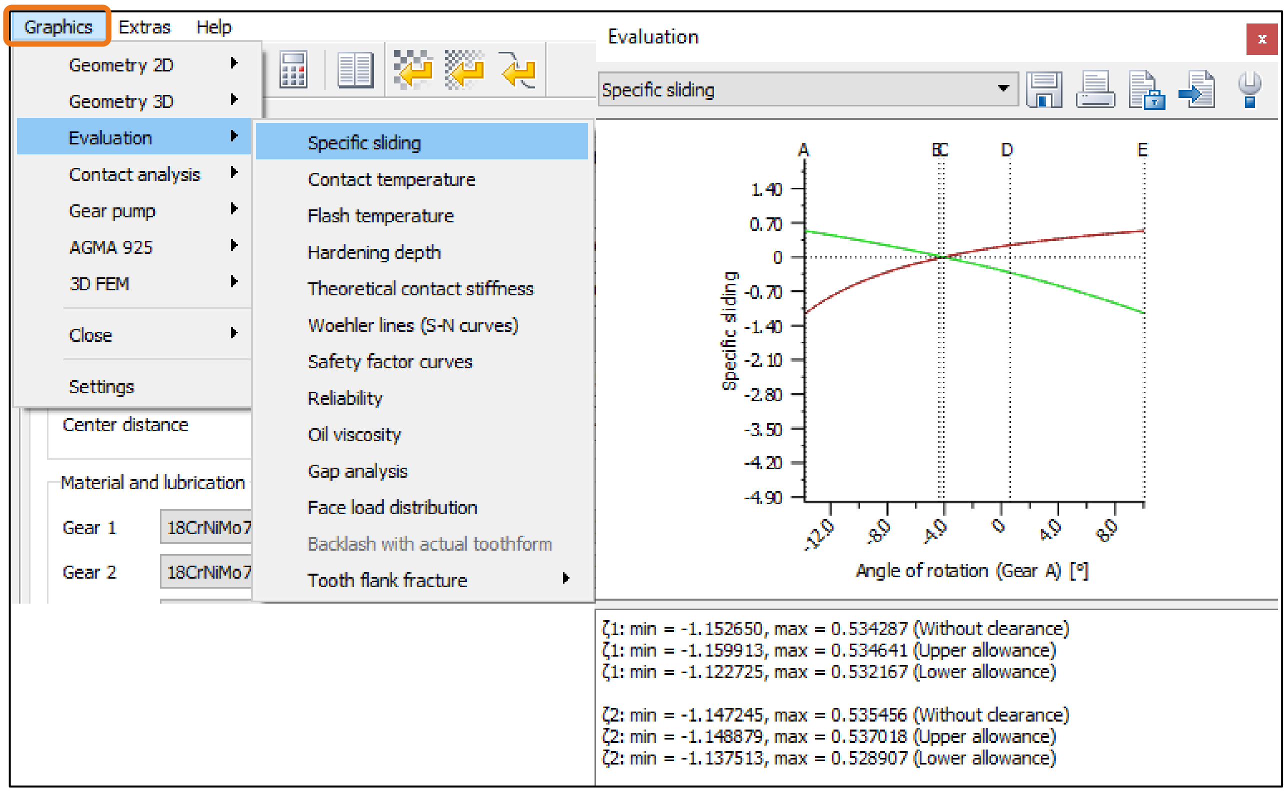


Figure 16. Call the graphic to illustrate specific sliding

3.3.3 Lubrication

You can select the lubrication type and lubricant directly in the main screen. To specify the lubricant temperature, click the Plus button to the right of the lubrication type. You can also input data about the ambient temperature in the **«Operating backlash»** tab.

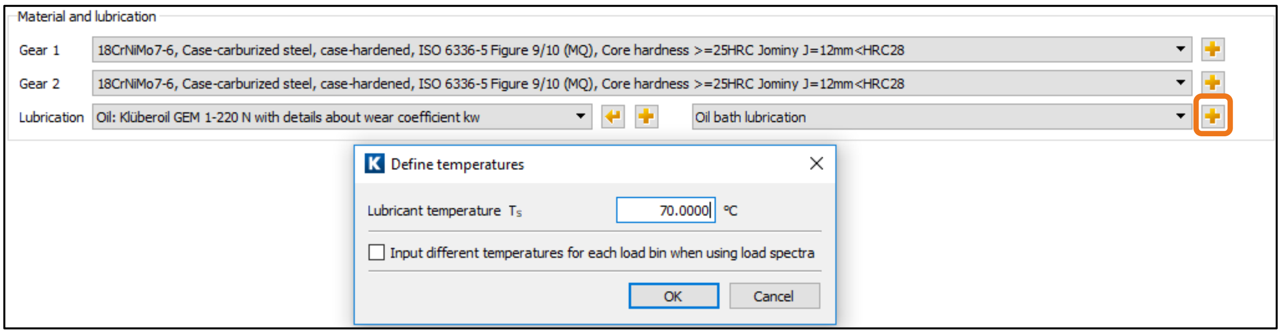


Figure 17. Details about lubrication

4 Strength analysis with load spectra

4.1 Resulting service life with required safety factors

In the first step, you must define the service life in hours, taking into account a required safety factor. The required safety factors for different settings and modules are inserted automatically by the software. In module-specific settings these safety factors are predefined for each specific module and can differ according to whether metal (as stated in DIN, ISO and AGMA) or plastic materials are used.

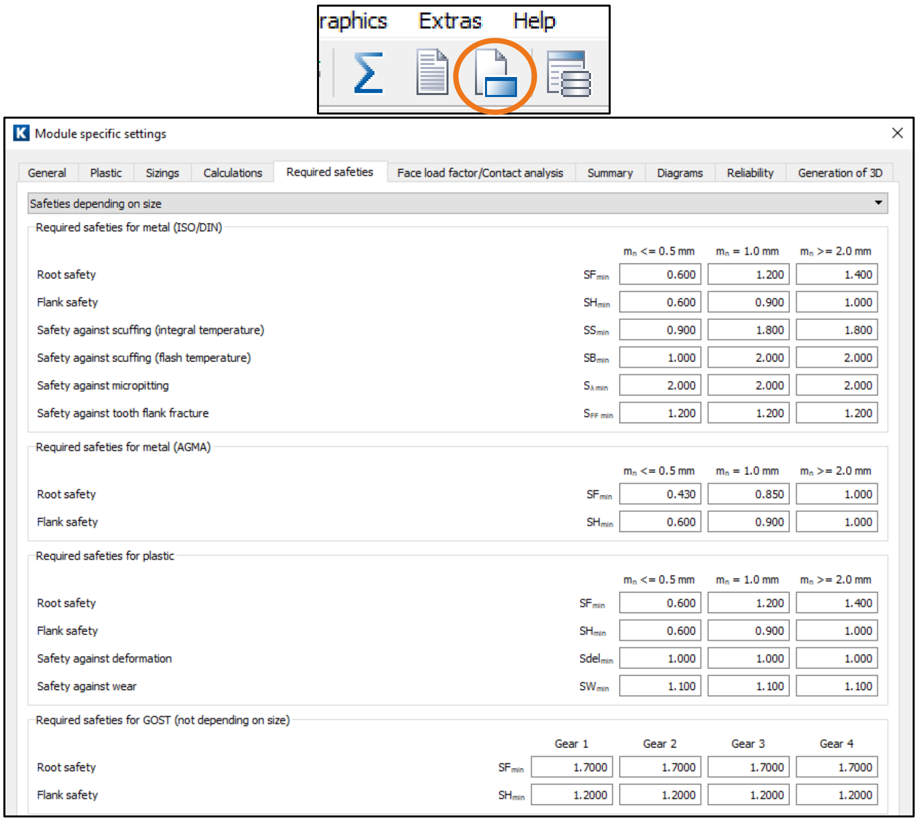


Figure 18. Predefined setting of the required safeties

You can also input your own values in the **«Required safeties»** tab.
To do this, select **«Safeties are not depending on size»** from the drop-down list and input your own values:

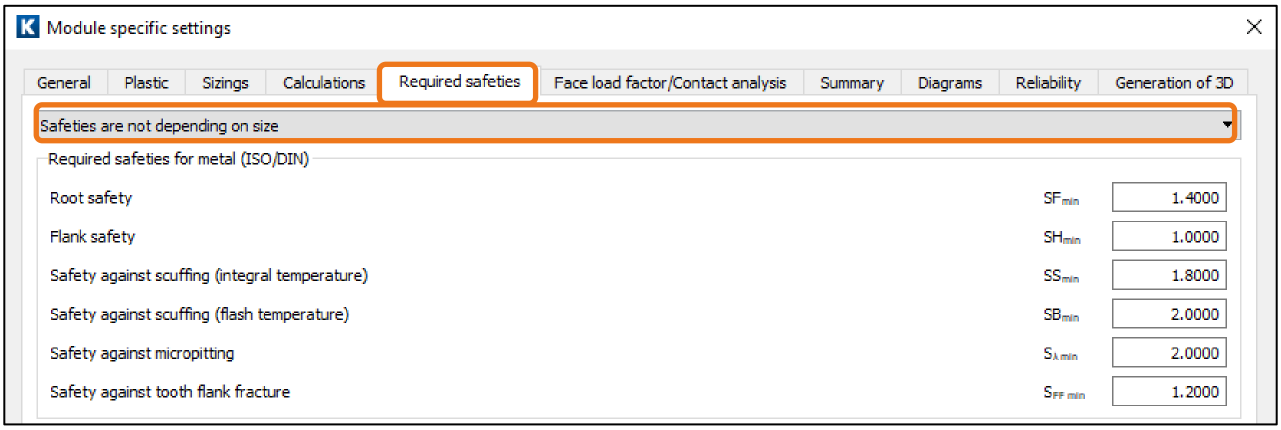


Figure 19. Setting the required safeties

To calculate the resulting service life whilst taking into account the load spectrum defined in the task, input the load spectrum elements as described in section 3.1.3.

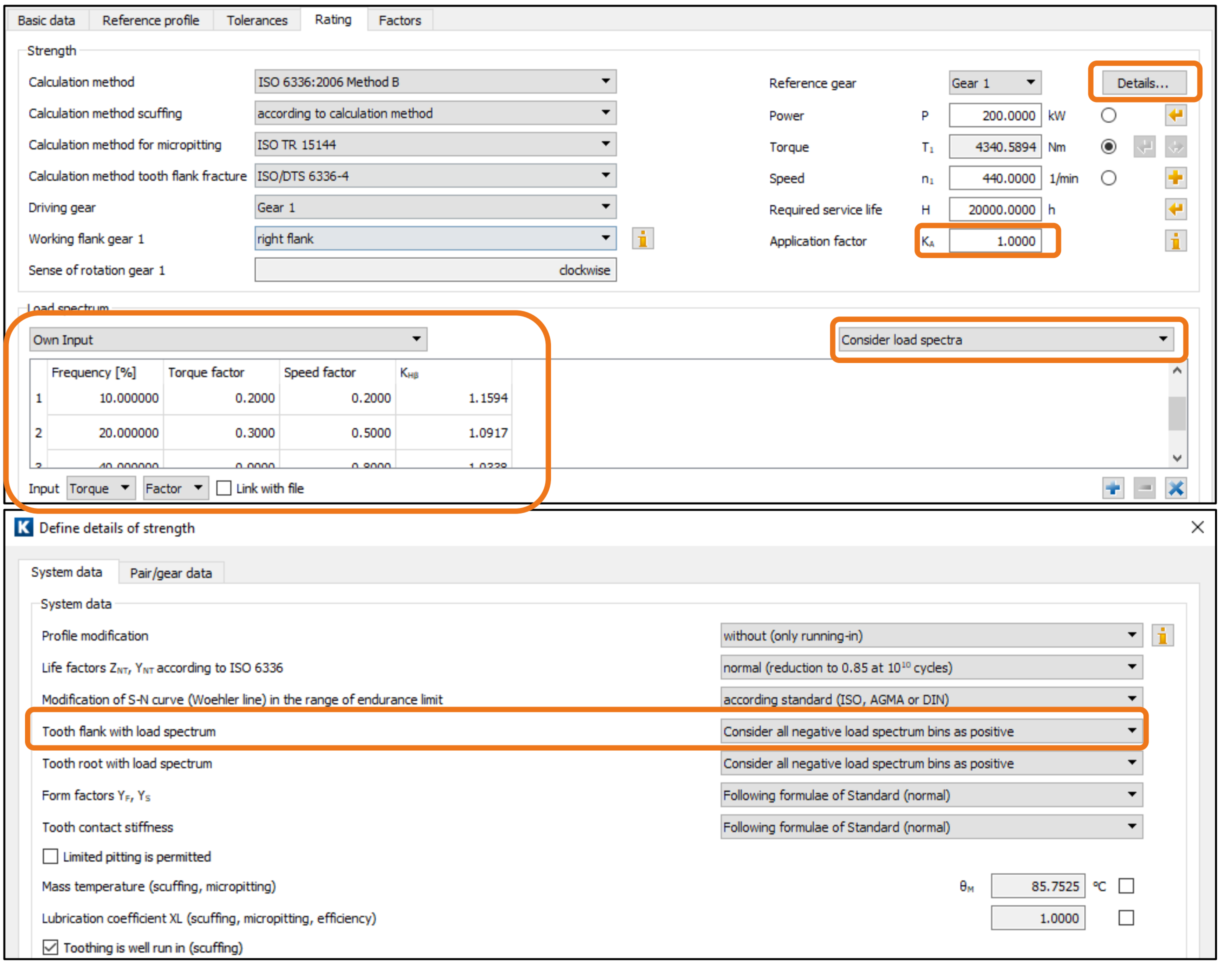


Figure 20. Defined load spectrum

Now set the application factor to 1.00, which is the usual setting when you are working with load spectra. (However, this value can be greater than 1.00 depending on which application/defaults are being used.) In addition, you can apply different modifications of the endurance limit range. Press «F1» to display the online help for more information about this. The calculation is then performed when you click (Calculate) or press F5.

Then perform the analysis with **200 kW**. Click **«Report»→ «Service life»** to display the results in a report.

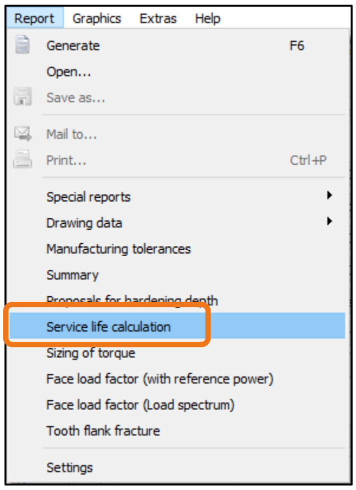


Figure 21. Recording service life

Calculation of service life

Load data

		------- GEAR 1	-------- GEAR 2 --
Power (kW)	[P]	200.000	
Speed (1/min)	[n]	440.0	144.7
Torque (Nm)	[T]	4340.6	13195.4
Application factor	[KA]	1.00	

Load spectrum

Own Input
Number of bins in the load spectrum: 4
Reference gear: 1

Bin	Frequency	Power	Speed	Torque	Coefficients						Temperature
No.	[%]	[kW]	[1/min]	[Nm]	KV	KHβ	KHα	Kγ	YM1	YM2	OilTemp
1	10.00000	8.0000	88.0	868.1179	1.0076	1.1594	1.1046	1.0000	1.0000	1.0000	70
2	20.00000	30.0000	220.0	1302.1768	1.0152	1.0917	1.0242	1.0000	1.0000	1.0000	70
3	40.00000	144.0000	352.0	3906.5304	1.0163	1.0338	1.0000	1.0000	1.0000	1.0000	70
4	30.00000	200.0000	440.0	4340.5894	1.0199	1.0338	1.0000	1.0000	1.0000	1.0000	70

Numbers of load cycles

Bin	Frequency	Load cycles	
1	10.00000	10560000	3473684
2	20.00000	52800000	17368421
3	40.00000	168960000	55578947
4	30.00000	158400000	52105263

S-N curve (Woehler line) in the endurance domain according: according to standard

Notice:
Calculation-method according to:

- ISO 6336-6 / DIN3990-6

During the calculation all the load factors (ISO6336/DIN3990: KV, KHb, KFb; AGMA2001: Knu, Km, ..) for each load spectrum bin are calculated separately.

Notice:
Calculation with methods ISO6336 and AGMA 2001 results in a reduction of resistance in the domain of fatigue resistance (from circa 10^7 to 10^10 cycles).
The lifetime calculation takes this into account (also with the S-N curve (Woehler Curve) of the Miner type).

Results

Calculation with load spectrum

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

Service life (calculated with required safeties):

System service life (h)	[Hatt]	400	
Tooth root service life (h)	[HFatt]	399.6	497.5
Tooth flank service life (h)	[HHatt]	6992	2.422e+004

Damage calculated on the basis of the required service life [H] (20000.0 h)

No.	F1%	F2%	H1%	H2%
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	23.19	521.86	49.49	14.29
4	4982.16	3498.49	236.55	68.27
Σ	5005.36	4020.35	286.04	82.56

Damage calculated on basis of system service life [Hatt] (399.6 h)

No.	F1%	F2%	H1%	H2%
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.46	10.43	0.99	0.29
4	99.54	69.89	4.73	1.36
Σ	100.00	80.32	5.71	1.65

Damage calculated on basis of individual service life HFatt & HHatt

	HFatt1	HFatt2	HHatt1	HHatt2
(h)	399.6	497.5	6992	2.422e+004
No.	F1%	F2%	H1%	H2%
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.46	12.98	17.30	17.30
4	99.54	87.02	82.70	82.70
Σ	100.00	100.00	100.00	100.00

Most critical duty cycle elements for Scoring (SB, Sint), Tooth Flank Fracture (SFF), hardened layer (SEHT) and Micropitting (Slam)
SEHT: 4

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	19536	1.7	7.536e+006	1.158e+007	0.00
1	Tooth flank	19536	1.3	1.231e+008	5.866e+008	61.29
2	Tooth root	6426	1.7	3.086e+006	4.743e+006	0.00
2	Tooth flank	6426	1.3	1.403e+008	6.686e+008	100.00

Reliability of the configuration for required service life (%) 0.00 (Bertsche)

Classification according to F.E.M. (Edition 1.001, 1998)

Spectrum factor	[km]	0.598
Spectrum class	[L]	4
Application class (predefined service life)	[T]	7
Machine class (predefined service life)	[M]	8
Application class (achievable service life)	[T]	1
Machine class (achievable service life)	[M]	3

Figure 22. Calculation report for the load spectrum calculation

The resulting system service life with the required safety factors is 435h.
The interim values for $K_{H\beta}$ (in this example) will be calculated using the selected method (in this example ISO 6336) and transferred to the specific load spectrum element.

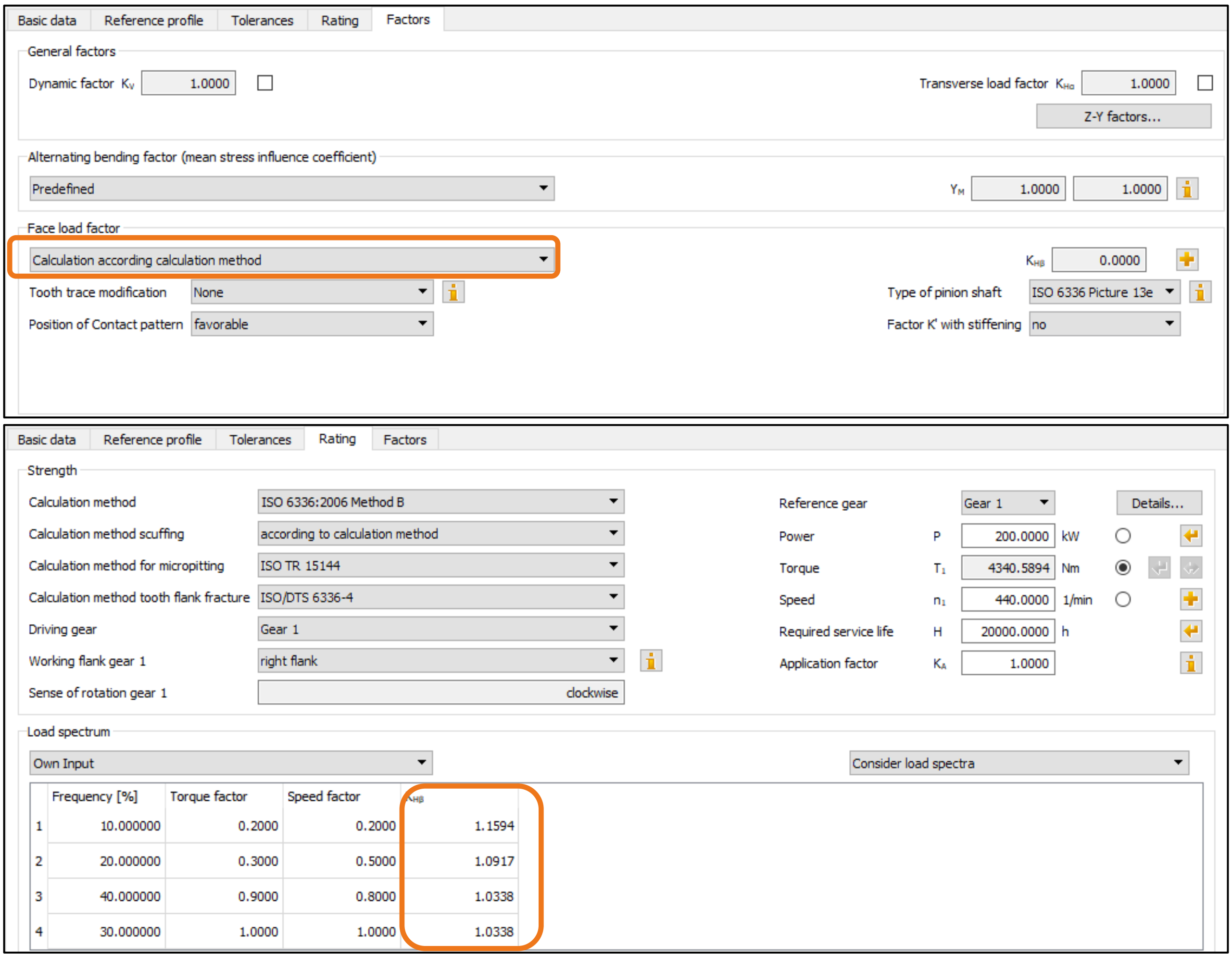


Figure 23. Display interim calculations for each individual step etc.

4.2 Resulting safety factors for a required service life

After you have specified a required service life in the «Strength» group, this analysis is performed simultaneously when you run **«Calculations with load spectra»**. The calculation is performed with one iteration. The results are displayed in the **«Results»** window.

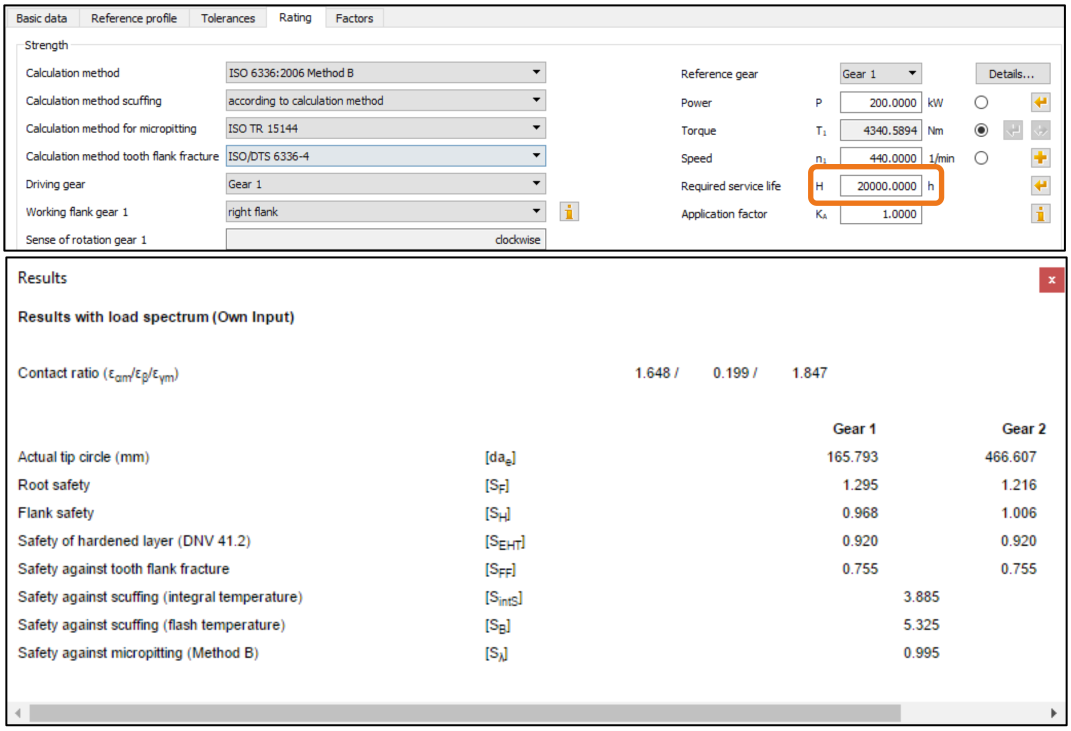


Figure 24. Results of safety factors with load spectra for the required service life

4.3 Calculating maximum permissible torque

Similarly, click the Sizing button to define the maximum transmissible power. In this case, the specified speed, required service life and the necessary safety factors are taken into account.

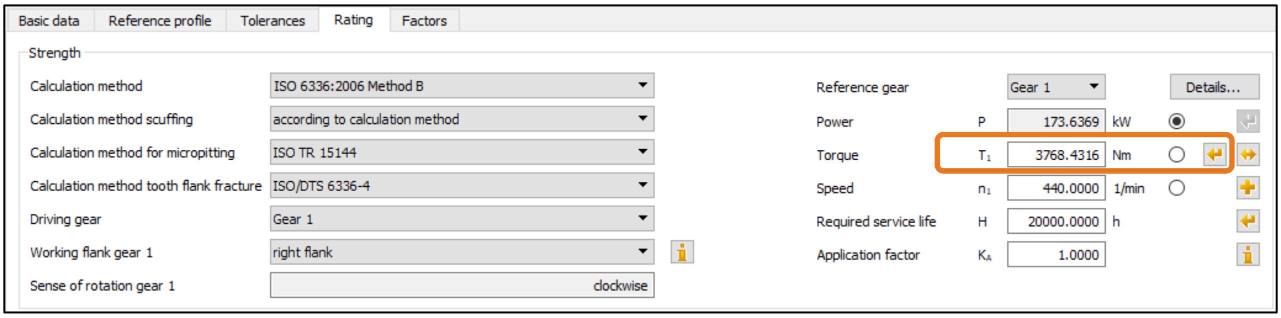
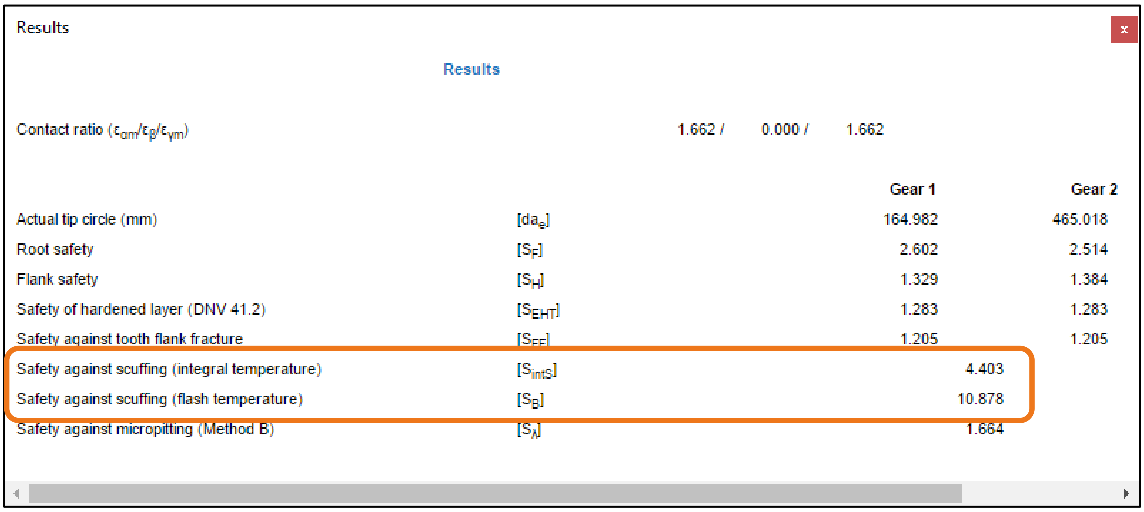


Figure 25. Calculating maximum permissible torque

5 Additional calculations

5.1 Safety against scuffing

In the lower part of the main window, you can also see safeties against scuffing for integral or flash temperature criteria:



Results

Results

Contact ratio ($\varepsilon_{\alpha m}/\varepsilon_{\beta}/\varepsilon_{\gamma m}$) 1.662 / 0.000 / 1.662

		Gear 1	Gear 2
Actual tip circle (mm)	[da_e]	164.982	465.018
Root safety	[S_F]	2.602	2.514
Flank safety	[S_H]	1.329	1.384
Safety of hardened layer (DNV 41.2)	[S_{EHT}]	1.283	1.283
Safety against tooth flank fracture	[S_{FF}]	1.205	1.205
Safety against scuffing (integral temperature)	[S_{intS}]	4.403	
Safety against scuffing (flash temperature)	[S_B]	10.878	
Safety against micropitting (Method B)	[S_λ]	1.664	

Figure 26. Safety factors against scuffing

You can show the progression of the flash temperature across the contact by clicking **«Graphics»→«Evaluation»→«Flash temperature»**, see Figure 27. If you now click **«Calculation»→ «Modifications»** (see Figure 28), for example the program sizes a tip relief (here optimized for 75% nominal load and 50% manufacturing tolerance) and transfers the changed tooth form [Accept data] (this is shown in the message displayed in Figure 29), you can therefore change the progression of flash temperature in the tip area.

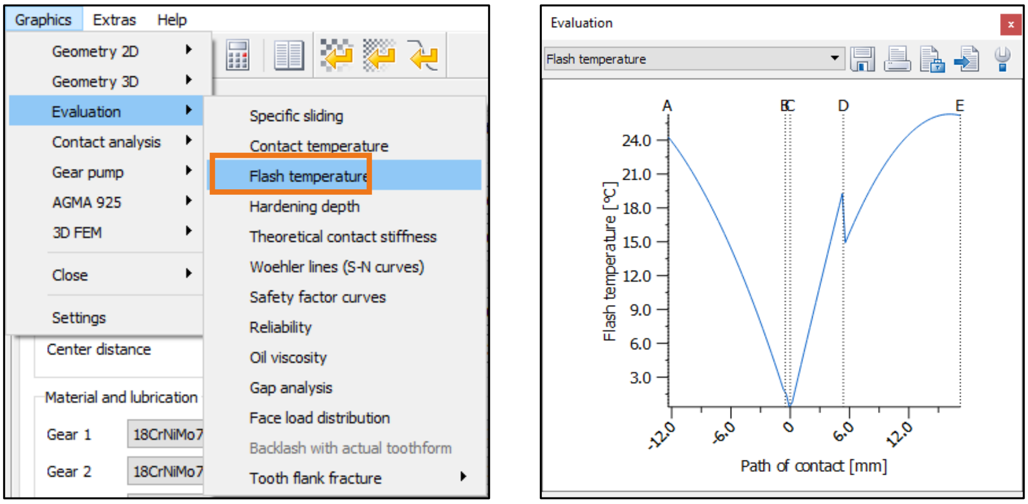


Figure 27. Flash temperature progression over the unmodified tooth form

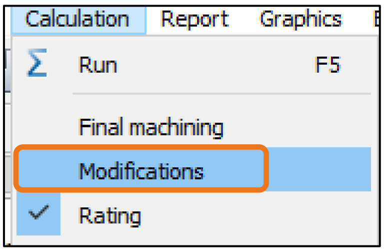
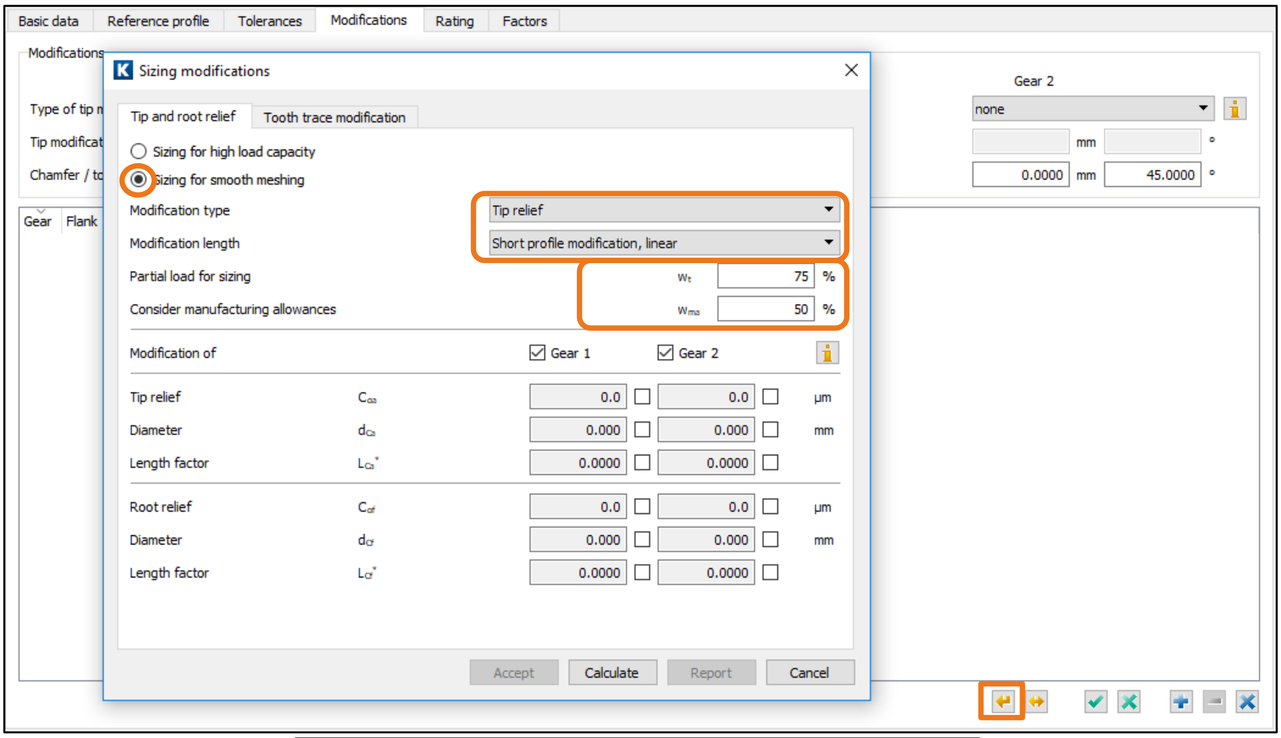


Figure 28. Call to the profile correction screen, sizing of a tip relief for 75% of nominal load etc.



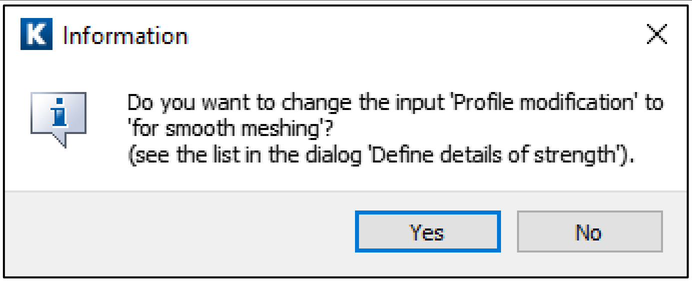


Figure 29. Message you see after clicking the [Accept] button

Gear	Flank	Type of modification	Value [µm]	Factor 1	Factor 2	Status	Information
Gear 1	both	Tip relief, linear	39.1000	0.9869		active	dCa=159.150mm, ξ=30.038°
Gear 2	both	Tip relief, linear	39.1000	0.9869		active	dCa=460.547mm, ξ=22.570°

Figure 30. Input the correction.

If you now click **«Calculation»** again in the cylindrical gear main screen (F5), the system defines the safety factor against scuffing using the predefined nominal load. Here you should note that these factors are now higher than previously. Compare these values with Figure 26 and Figure 31.

Results

Results

Contact ratio ($\varepsilon_{\alpha m}/\varepsilon_{\beta}/\varepsilon_{\gamma m}$) 1.662 / 0.000 / 1.662

		Gear 1	Gear 2
Actual tip circle (mm)	[da_e]	164.982	465.018
Root safety	[S_F]	2.602	2.514
Flank safety	[S_H]	1.329	1.384
Safety of hardened layer (DNV 41.2)	[S_{EHT}]	1.283	1.283
Safety against tooth flank fracture	[S_{FF}]	1.205	1.205
Safety against scuffing (integral temperature)	[S_{intS}]	4.861	
Safety against scuffing (flash temperature)	[S_B]	11.920	
Safety against micropitting (Method B)	[S_λ]	2.160	

Figure 31. Scuffing safeties, integral and flash temperature criterion

If you now calculate the flash temperature progression again by clicking **«Graphics»→«Evaluation»→«Flash temperature»**, you will see that the flash temperature has reduced at the tooth tip to the gear tooth mass temperature.

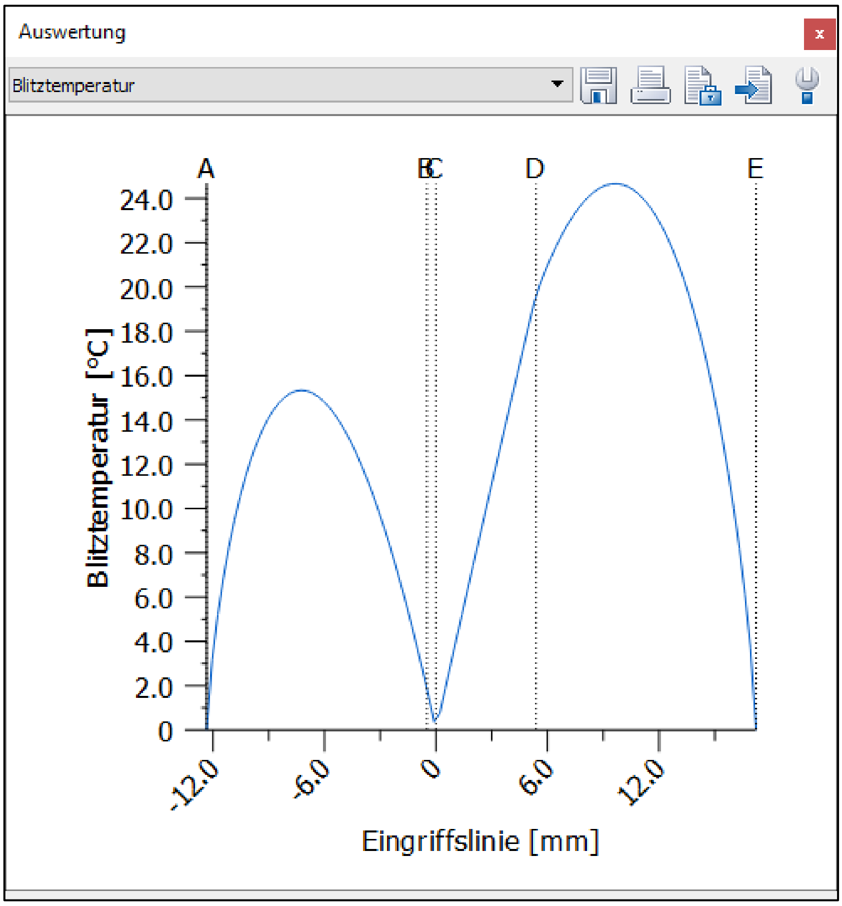


Figure 32. Progression of flash temperature after tip relief

5.2 Necessary hardening depth

To estimate the necessary hardening depth, use the progression of the shear stress level as the result of Hertzian pressure. Click **«Graphics»→«Evaluation»→«Hardening depth»** to get the stress distribution. We recommend you try to achieve a hardening depth that is twice the depth of the shear stress maximum. If the gear is ground after implementation/hardening, you must add the grinding allowance to the recommended hardening depth.

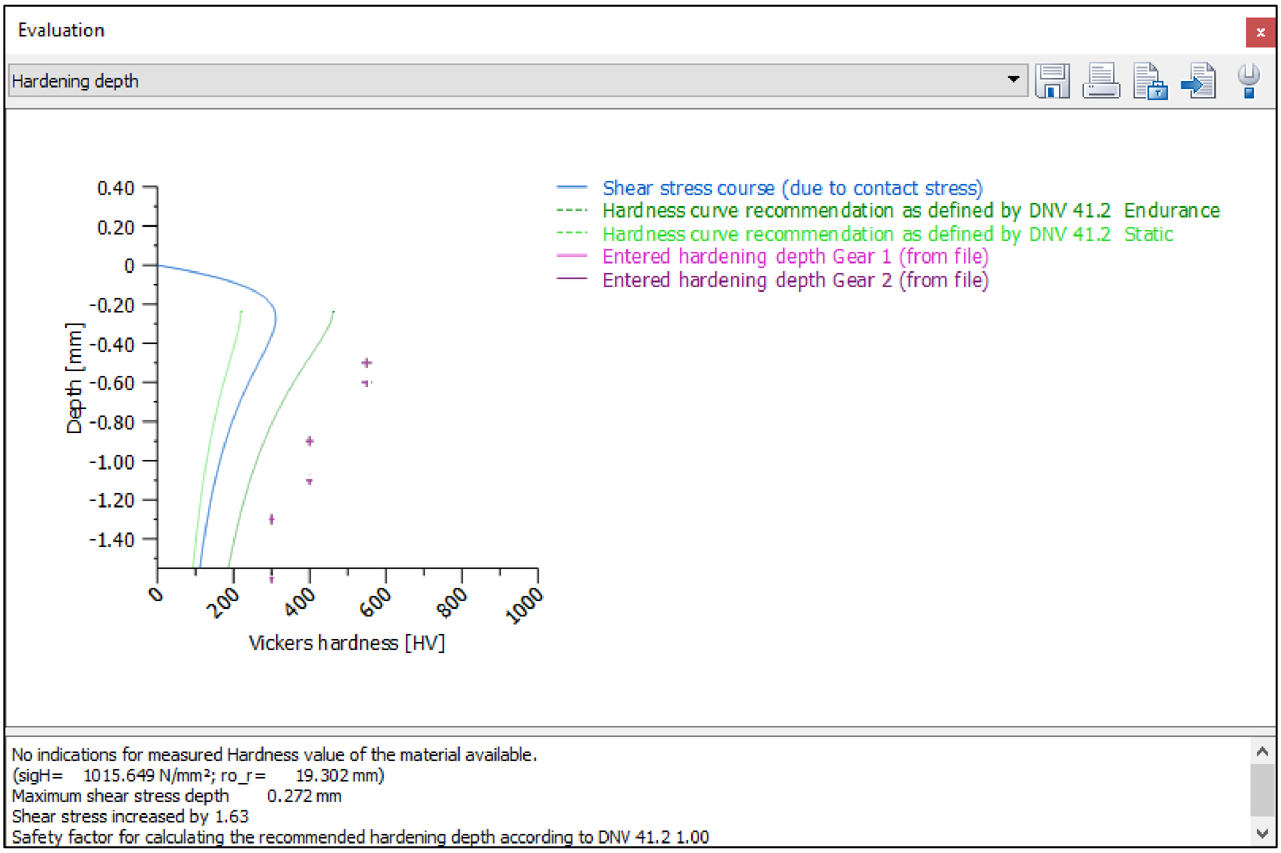


Figure 33. Display showing shear stress across the tooth depth, recommended hardening depth