

KISSsoft 03/2016 – Tutorial 11

Tooth Form Optimizations, Tooth Form Modifications specifically for Plastic, Sintered, Wire-eroded and Form-forged Gears

KISSsoft AG

Rosengartenstrasse 4
8608 Bubikon
Switzerland

Tel: +41 55 254 20 50
Fax: +41 55 254 20 51
info@KISSsoft.AG
www.KISSsoft.AG

Contents

| | | |
|-----|--|----|
| 1 | Introduction | 3 |
| 1.1 | Summary of the design strategy | 3 |
| 1.2 | Introduction | 3 |
| 2 | Defining Tooth Geometry | 4 |
| 2.1 | Introduction | 4 |
| 2.2 | Tip-rounding | 4 |
| 2.3 | Minimum tooth thickness at the tip | 9 |
| 2.4 | Geometry changes for a predefined reference profile | 10 |
| 2.5 | Changing geometry by varying the reference profile | 10 |
| 2.6 | Eliminating contact shock by correcting the tooth form | 11 |
| 2.7 | Optimizing the tooth root | 15 |
| 2.8 | Checking the meshing | 16 |
| 2.9 | Checking for seizure in the gears | 18 |
| 3 | Strength calculation..... | 19 |
| 3.1 | Introduction | 19 |
| 3.2 | Input your own data for plastics | 19 |
| 3.3 | Strength calculation with consideration of effective tooth form..... | 22 |
| 4 | Defining the Tooth Thickness Deviation | 25 |
| 4.1 | Introduction | 25 |
| 4.2 | Calculating operating backlash..... | 25 |
| 4.3 | Increasing operating backlash | 27 |
| 5 | Calculating the injection mould | 29 |
| 5.1 | Introduction | 29 |
| 5.2 | Modifying the injection mold to compensate for shrinkage | 29 |
| 5.3 | Display the eroding wire / spark gap | 32 |
| 5.4 | Monitoring the wire diameter during erosion | 34 |
| 5.5 | Calculating a 3D mold | 35 |

1 Introduction

1.1 Summary of the design strategy

These instructions describe a strategy for optimizing the design of gears that are manufactured using alternative methods (injection molding, sintering, forging etc.). These special methods for sizing and optimizing gears manufactured using these methods are integrated in the KISSsoft calculation software.

The sizing process involves these steps:

- Define the approximate sizes (module, face width, etc) using the strength calculation
- Define allowances
- Optimize tooth depth (aim: achieve effective transverse contact ratio 2.0 whilst taking into account tip rounding, running-in curve for noise reduction)
- Tip-rounding
- Optimize running-in curve/profile modification (aim: noise reduction, improve wear safety)
- Optimize root fillet (increase the root safety factor)
- Determine a mould for the manufacturing process

1.2 Introduction

Nowadays, gears are increasingly manufactured from plastics because the development of new materials has made them able to achieve increasingly higher load capacities. The special properties of plastics allow them to be used in many more areas than steel. A designer can therefore select the best possible plastic material for their particular application. Some of the most important properties, to be taken into consideration, when designing a gear pair, are therefore its load capacity, resistance to wear, damping characteristics, stiffness and also noise development.

Metallic gears are usually manufactured with a hobbing process. In contrast, plastic gears are usually injection molded. If the mold is produced by a wire erosion process, the tooth form can be optimized at no additional cost. In a hobbing process, this is only possible with expensive, special tools. However, the standard injection molding process does not achieve a particularly good accuracy grade and, once again, this is a problem that can only be solved by implementing specific measures. Gears that have been modified in this way are referred to as hybrid tooth forms in the technical literature.

The KISSsoft calculation software includes a large number of special methods for sizing and optimizing plastic gears. These procedures are fully integrated into a comprehensive, modern software system that enables you to develop and monitor both standard and hybrid toothing.

2 Defining Tooth Geometry

2.1 Introduction

You can change tooth geometry in many different ways to achieve the optimum ratio of meshing. Depending on the importance of the targets to be achieved, such as low noise emission, low vibration, strength, slip, stiffness and balance, you must prioritize the measures to be taken.

When you start this optimization process, we recommend you set the following defaults:

2.2 Tip-rounding

For tooth forms produced using a molding process, the tooth tip edges must be rounded, because corners can never be created accurately in injection molding. It is a good idea to input this data in the main screen for gear 1 and gear 2. This ensures that all the most important data (such as contact ratio, etc.) can be calculated whilst taking the tip rounding into account.

This is illustrated in the following example: KISSsoft provides an example file for this specific calculation. Open this file in the cylindrical gear calculation module:

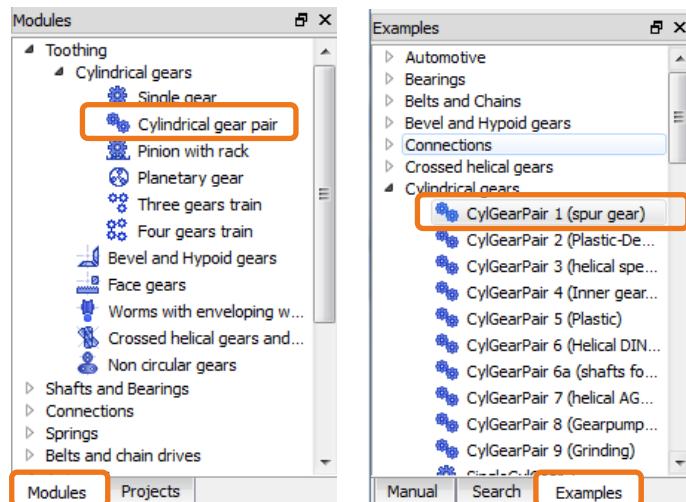


Figure 1. Opening the cylindrical gear calculation module and then the CylGearPair 1 (spur gear) example file

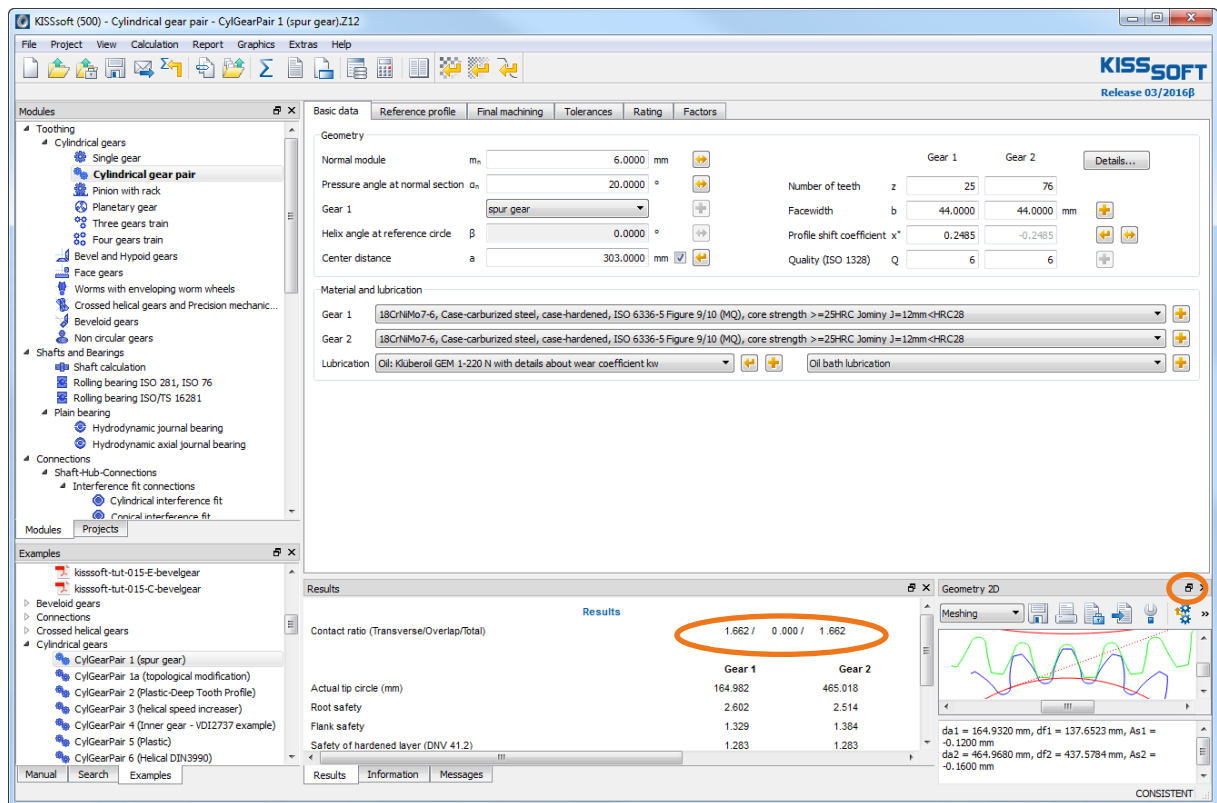



Figure 2. Example file for plastic gears, after running "Σ"

Either click on the  icon in the Tool bar or press "F5" to calculate the toothings shown in this example. Without tip-rounding the contact ratio would be 1.662. You can see the tooth form as a graphic in the lower part of the window. You can also view the tooth form here and move it to the required position (see the marking on the lower right in Figure 2).

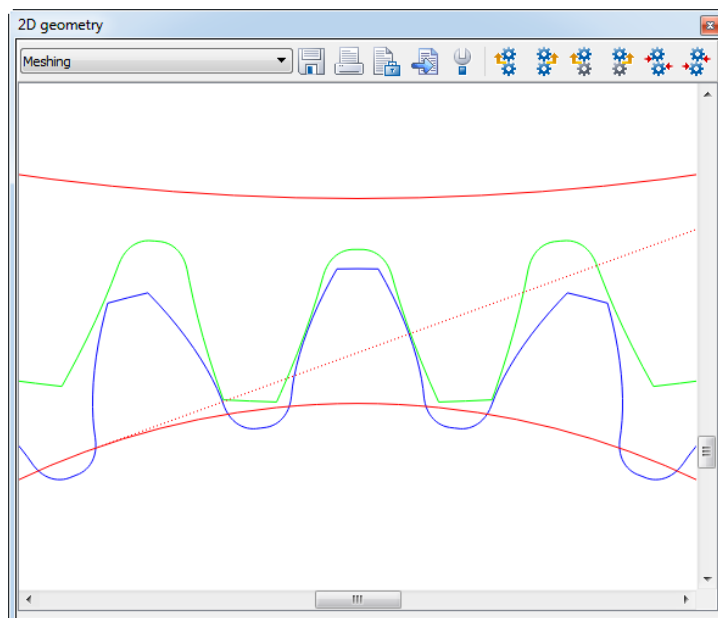


Figure 3. Tooth form display

You should now save this tooth form locally. To do this, open the **"Property browser"** (1). Then enable the tooth form of Gear 1 (2) and click the **"Save"** button (3). This opens an information window. Here you can make any necessary changes (for example, color) and additional entries (4). Click on **"OK"** (5) to save the

tooth form of Gear 1. Follow this procedure again to save the tooth form of Gear 2. You can now view the changes you have made to the tooth form. After this, you can close the **"Property browser"**.

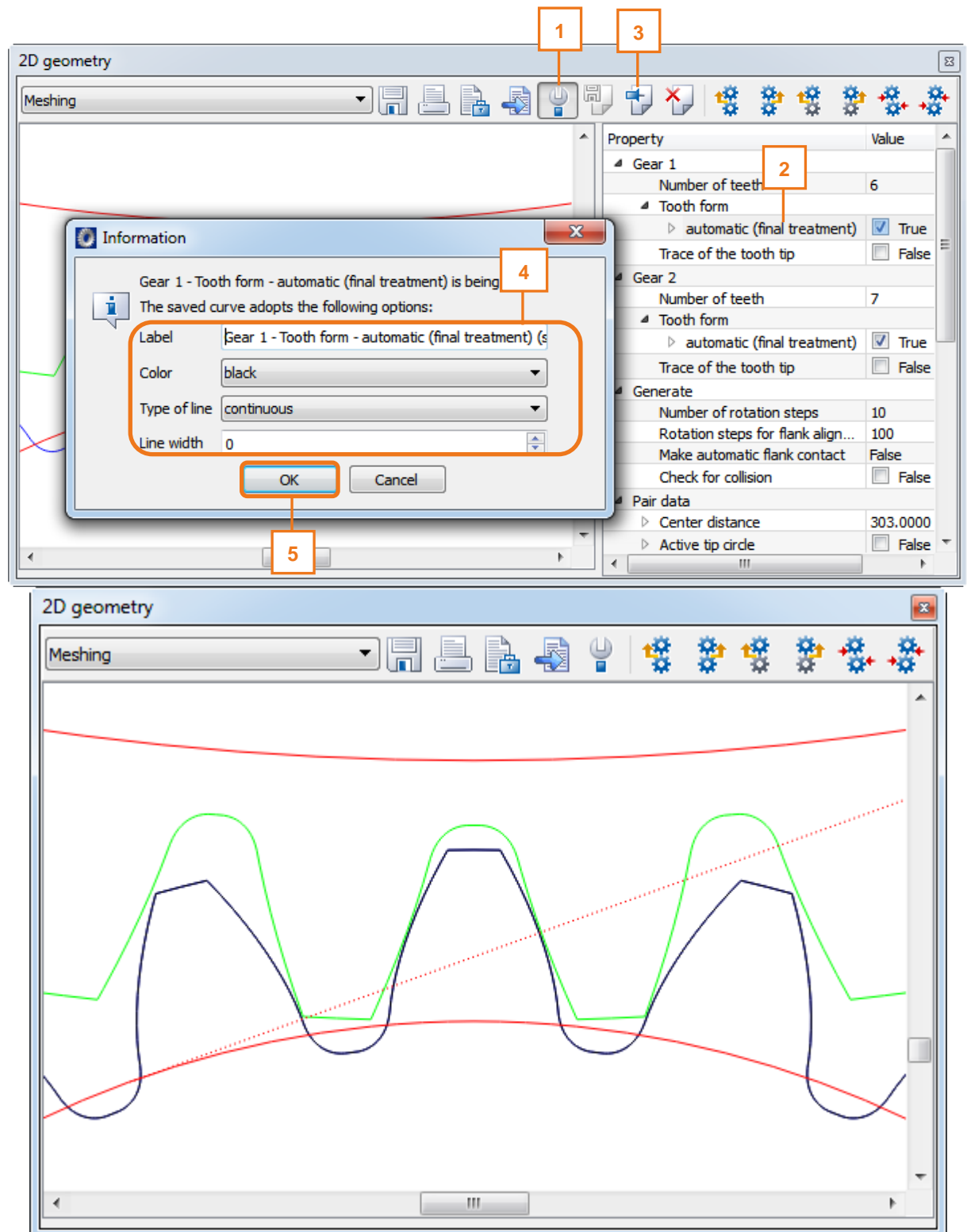



Figure 4. Saving a tooth form

The tip rounding is defined as follows in the **"Modifications"** tab (add the tab via **"Calculation"** → **"Modifications"**) for Gear 1 and Gear 2 (see Figure 5):

| Basic data | Reference profile | Final machining | Tolerances | Modifications | Rating | Factors |
|---|-------------------|-----------------|------------|---------------|--------|---------|
| <div>Modifications</div> <div> <div>Gear 1</div> <div> Type of tip modification: Rounding in transverse section </div> <div> Tip modification: r_k 2.0000 mm </div> <div> Chamfer / tooth end: $b_{\alpha}, \delta_{\alpha k}$ 0.0000 mm 45.0000 </div> </div> <div> <div>Gear 2</div> <div> Type of tip modification: Rounding in transverse section </div> <div> Tip modification: 2 mm </div> <div> Chamfer / tooth end: 0.0000 mm 45.0000 </div> </div> | | | | | | |

Figure 5. Definition of tip rounding, in this case 2 mm radius

Then click on  to repeat the calculation and accept the rounding. If you look carefully at the graphic, you will see the rounding on the teeth. The original tooth form is also displayed (in black/green or blue).

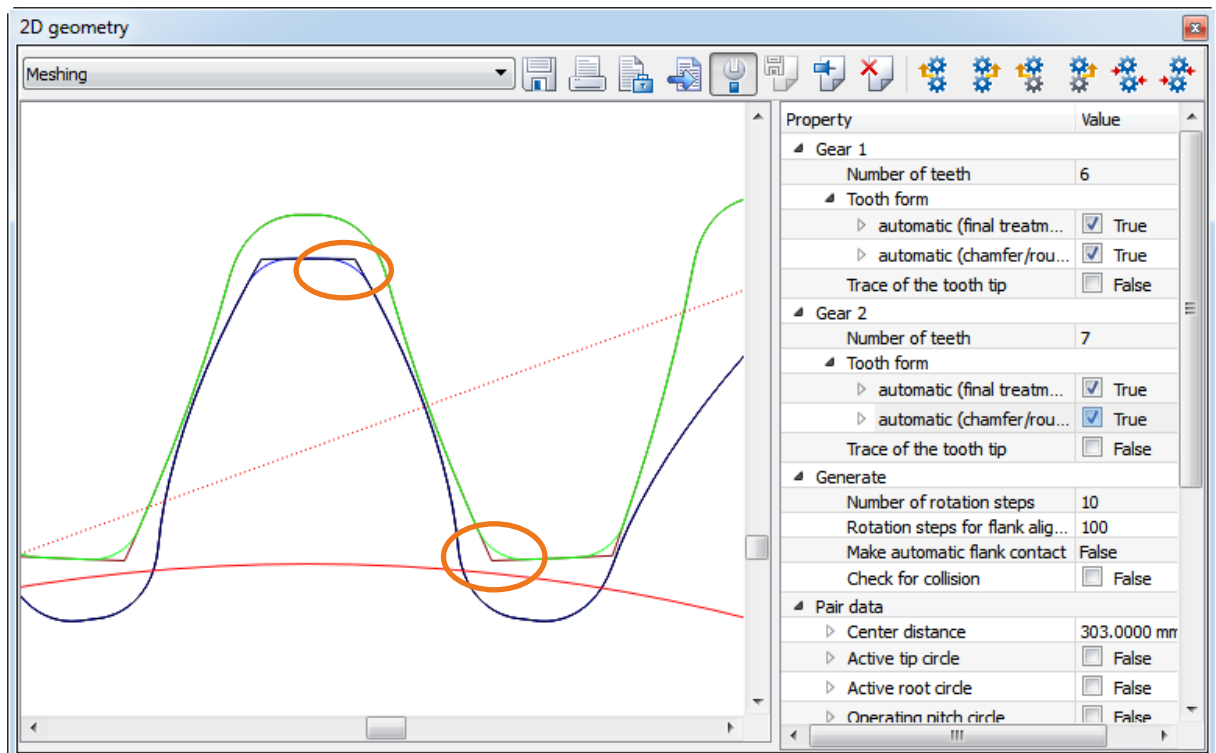


Figure 6. Rounded tooth tip

Important note:

When you save the tooth form, all previous calculation operations are also active.

In some cases, it may be better to monitor the changes you have made by activating and deactivating each individual step of the calculation.

You can also reset the graphic properties. This happens automatically when you change the display in the geometry window. Alternatively, you can select "Extras" → "Configuration tool" in the "Settings" tab and click on "Graphics" "Reset".

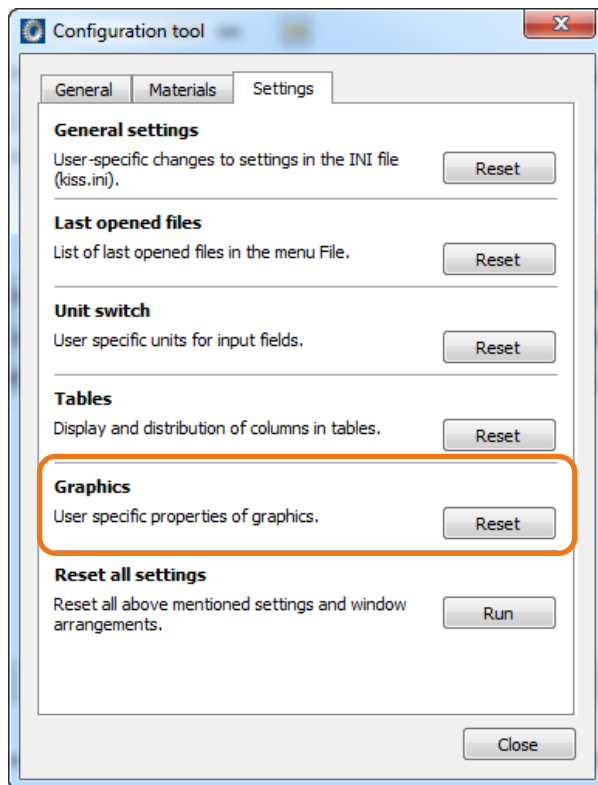


Figure 7. Resetting "Graphic properties"

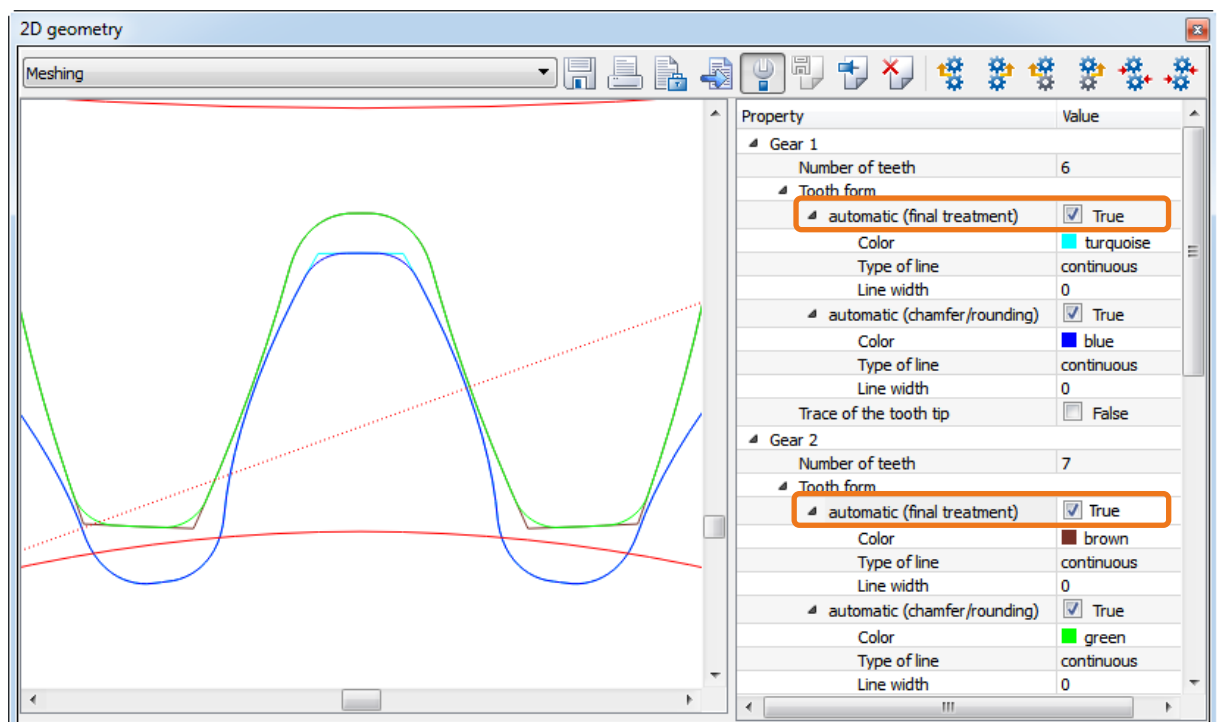


Figure 8. Activating all calculation operations

In the main screen, the value calculated for the contact ratio has dropped to 1.365:

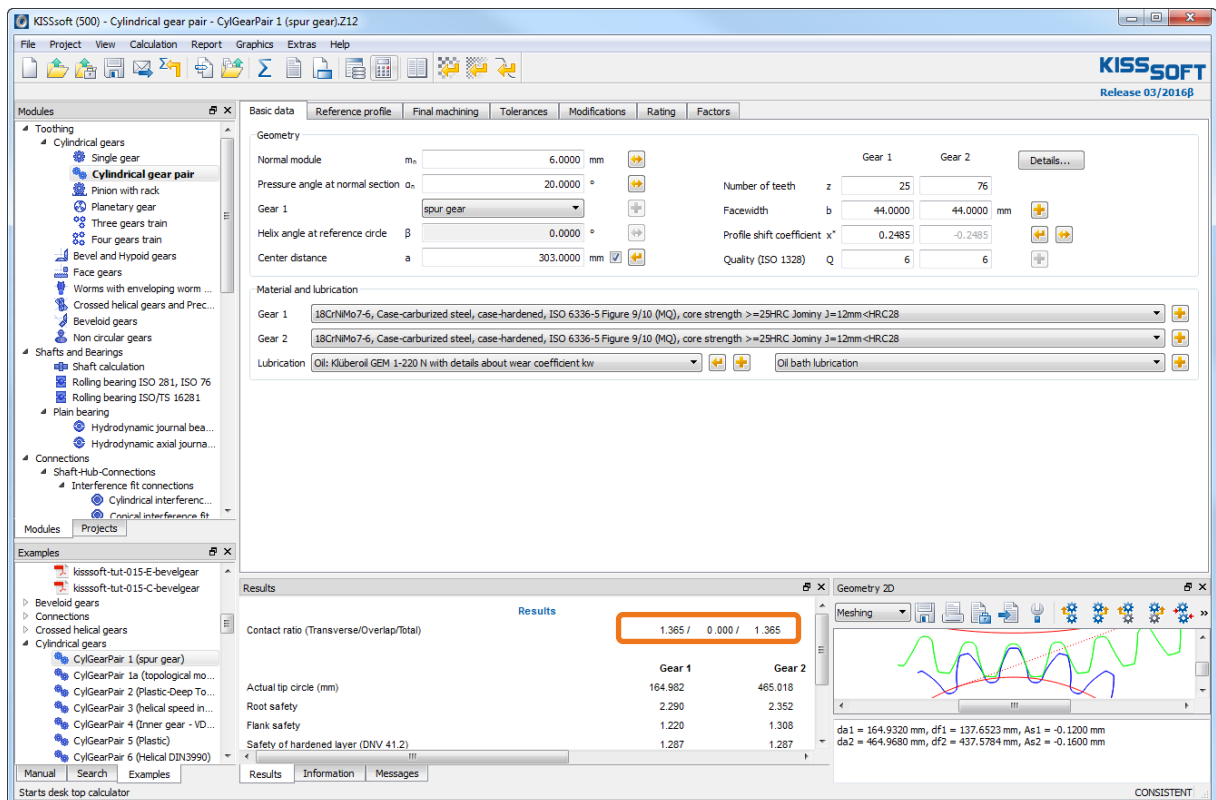


Figure 9. Reduction of contact ratio as the result of tip rounding

2.3 Minimum tooth thickness at the tip

In the KISSsoft system, the default value for the necessary minimum tooth thickness is 0.2·module. However, for plastic gears (with tip rounding) this value is rather low. You should set it to 0.4·module instead. Do this in "**Module specific settings**" in the "**General**" tab:

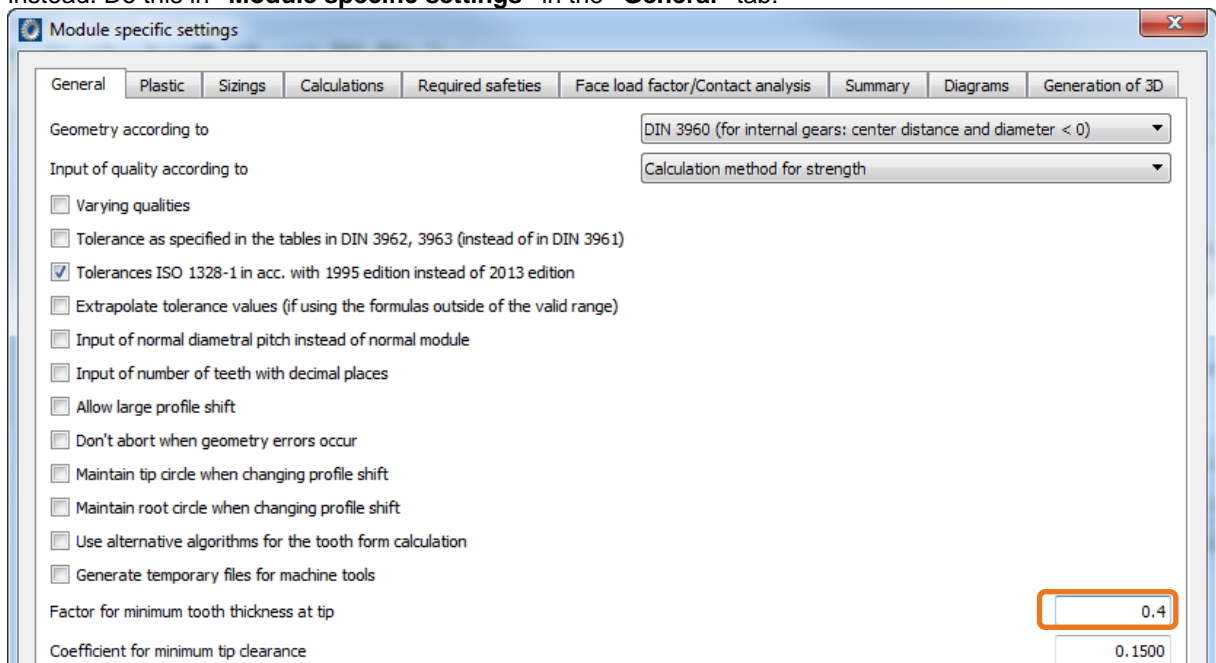


Figure 10. Specifying the necessary minimum tooth thickness at the tip in the module specific settings

Essential and effective measures for optimizing geometry are shown in the following chapters.

2.4 Geometry changes for a predefined reference profile

You can significantly alter the tooth geometry by varying the module, pressure angles, helix angle and profile shift of a specific reference profile. In particular, for helically toothed cylindrical gears, you can usually find an optimum solution with this approach. Here, the KISSsoft provides an especially effective tool for optimizing the design. The fine sizing functions generate all the possible solutions for a particular problem and then classify the results according to the relevant operating criteria.

To call the Fine Sizing module, click on "**Calculation→ Fine Sizing**". KISSsoft Tutorial 009 contains more detailed information about this.

The Fine Sizing screen:

| | | Minimum | Maximum | Step |
|-------------------------------------|------------|----------|-------------|-----------|
| Maximal no of solutions | | 250 | | |
| Nominal ratio/deviation in +/-% | i, i_z | 3.0400 | 5.0000 | |
| Normal module | m_n | 6.0000 | 6.0000 mm | 0.0000 mm |
| Pressure angle at normal section | α_n | 20.0000 | 20.0000 ° | 0.0000 ° |
| Helix angle at reference circle | β | 0.0000 | 0.0000 ° | 0.0000 ° |
| Center distance | a | 303.0000 | 303.0000 mm | 0.0000 mm |
| Range for profile shift coefficient | x^* | -0.6000 | 1.0000 | |

| | | Gear 1 | Gear 2 | |
|-------------------------------|---------------|-------------|-------------|----|
| Maximum tip diameter | $d_{a, \max}$ | 999999.0000 | 999999.0000 | mm |
| Minimum root diameter | $d_{f, \min}$ | 0.0000 | 0.0000 | mm |
| Fix number of teeth | z | 0 | 0 | |
| Fix profile shift coefficient | x^* | 0.0000 | 0.0000 | |
| Facewidth | b | 44.0000 | 44.0000 | mm |

Figure 11. Cylindrical gear Fine Sizing

2.5 Changing geometry by varying the reference profile

If you change the reference profile (usually by increasing the tooth depth) you will also change the profile contact ratio. To ensure the tooth forms produce as little noise as possible and run smoothly, you should try to achieve a profile contact ratio of 2.0 (or even higher). This minimizes the stiffness jump caused by changing from single to double contact. Although you can achieve the required contact ratio by generating a suitable reference profile, interference is usually caused when the gears are actually manufactured. For this reason, only a limited number of solutions are possible. To enable you to work on this problem more effectively, the KISSsoft Fine sizing design functions allow you to select all the possible solutions for a required transverse contact ratio and then display these options.

To select this method, go to the "**Cylindrical gear Fine Sizing**" screen and select the "**Conditions III**" tab to open the appropriate screen:

Fine Sizing

Conditions I | Conditions II | **Conditions III** | Results | Graphics

☒ Show values of KISSsoft main calculation as additional variant with number 0

☐ Calculate geometry only

☐ Strength calculation with load spectrum

☐ Permit undercut

☒ Reject results with specific sliding higher than $> [3]$

☒ Consider minimum tooth thickness at tip

☐ Allow small geometry errors

☐ Suppress integer gear ratios

List of cutters for reference profile: None

Deep tooth form: All solutions with $\epsilon_\alpha \geq \epsilon_{\alpha \text{ target}}$

Required transverse contact ratio: $E_\alpha \text{ target}$ 2.0000

Contact analysis: Without calculation of the transmission error

☐ Suspend results which do not meet required safety factors

Sizing of profile shift coefficient Gear 1: for balanced specific sliding

Minimum number of teeth: Z_{\min} 9

Factor for minimum between root form diameter and active root diameter: $(d_{\text{NE}} - d_{\text{P}}) / m_n$ 0.0100

Factor for minimum between root form diameter and base circle: $(d_{\text{FE}} - d_b) / m_n$ 0.0100

Accept Delete Report **Calculate** Close Contact analysis

Figure 12. Sizing of deep tooth forms

Here, select **"Sizing of deep tooth form"**.

You can either specify the required transverse contact ratio directly or use a predefined value. This predefined value is set in the main menu under **"Calculation → Settings"** in the **"Sizings"** tab.

2.6 Eliminating contact shock by correcting the tooth form

When a gear pair is rotating, the impact of two pairs of teeth in the meshing is referred to as "contact shock". The more inaccurate the meshing and the greater the deformation of the teeth under load, the greater the levels of noise produced by this impact. For this reason, if you are working with plastic gears, the involute at the tip is modified by a relief curve (profile modification). If you are working with metallic gears, this process is called profile modification at the tip, although in this case the correction is usually much smaller due to the greater stiffness of these materials. The curve is usually applied to the tip of both gears. However, as an alternative (for example, in rack drives), it can also be applied to only one gear, but then both in the tip and the root. The relief curve consists of three increasingly narrower arcs, which are calculated automatically in the KISSsoft system and then integrated in the tooth form.

In the KISSsoft system, you can input profile modifications in two different ways:

A) In the "Modifications" tab

This new option is available from version 03-2008 onwards.

In the **"Modifications"** tab you can specify different types of modifications to the tip and/or the root.

The advantage is that any modifications you make here are documented in the main report. This means the data is easier to input and to view.

We recommend you use this variant from version 03-2008 onwards. The instructions are given in another tutorial. Variant B) is described here.

B) In the "Tooth form" tab (as previously)

You input tip reliefs and relieve curves as part of the tooth form calculation. To do this, open the **"Tooth form"** tab:

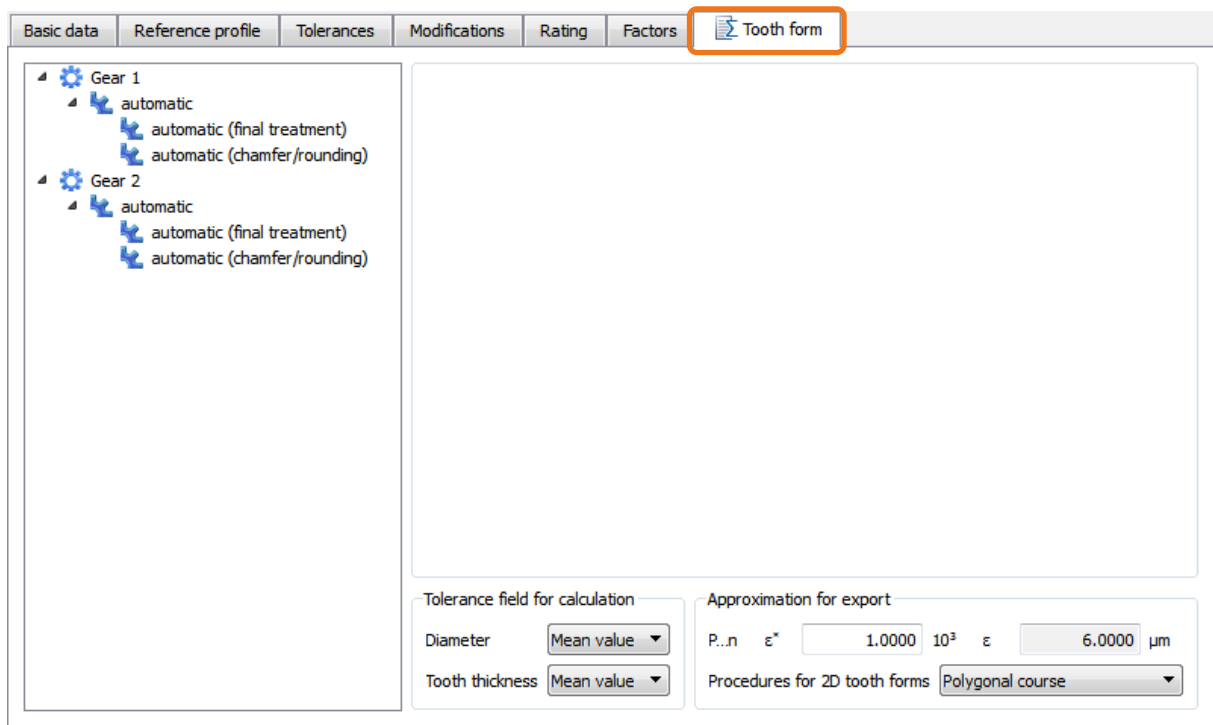


Figure 13. Calculating the tooth form

The default setting for the calculation here is "automatic". This means the cutter data used to generate the tooth form is taken automatically from the reference profile defined in the main screen.

Click the right-hand mouse button on "automatic" to open a selection menu of possible calculation operations. Then click the left-hand mouse button to insert the operation you require.

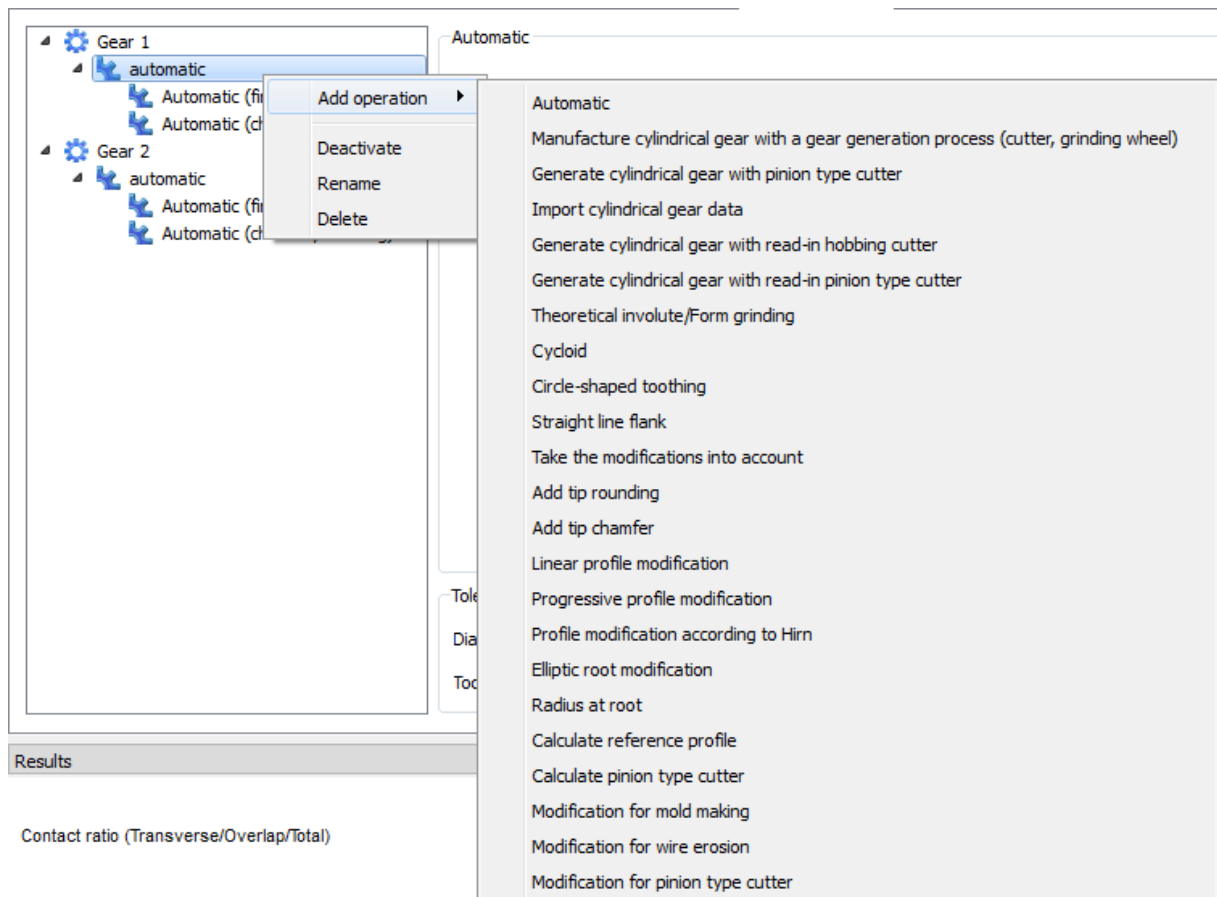


Figure 14. Possible tooth form operations Gear 1

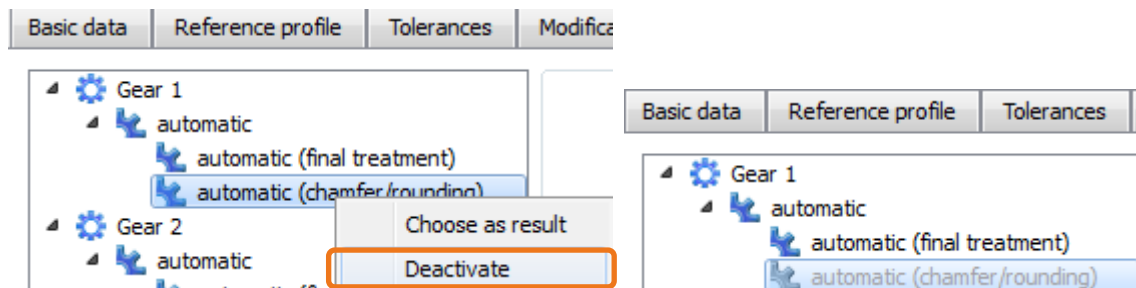


Figure 15. Taking into account "Deactivate tip rounding" on Gear 1

You cannot generate tip rounding automatically. In this example, as other tooth form modifications are involved (for example, profile modification), tip rounding must be the last operation that is performed. This is why you should deactivate this processing step here.

After the basic gear geometry has been defined, you can modify the involute. Various methods for doing this have been integrated in the software. You can select: linear or progressive profile modification, running-in curve from three circular pitches as defined by H. Hirn [1]; each of which can be combined with tip chamfer or tip rounding. In this case, you must specify the correction height (diameter at which the correction begins) and the tip relief. Each value has a sizing function which proposes optimum values based on the profile contact ratio, accuracy grade, material type (plastic or metal), stiffness and load. By modifying the **"Factors for tip rounding"** you can even specify the shape of the curve (in the "Progressive profile modification" option)!

In a progressive profile modification, you can improve the length of contact and the local lubrication properties compared to those achieved by a linear profile modification. The formulae for these profile modifications are defined as follows:

Linear correction: $\delta s(r) = Ca * \delta r / \delta r_K$

Progressive correction: $\delta s(r) = Ca * (\delta r / \delta r_K)^{Exp}$

δs Profile relief (tooth thickness modification)

r Radius of any point on the tooth form

Ca Profile relief at the tip circle

δr $ra - r$

δr_K $ra - ra_K$

ra Tip circle radius

ra_K Radius, at which the correction begins

Exp = Factor/5

Factor: Range 1-20, usually in the range 5-10

(you can input your own value here)

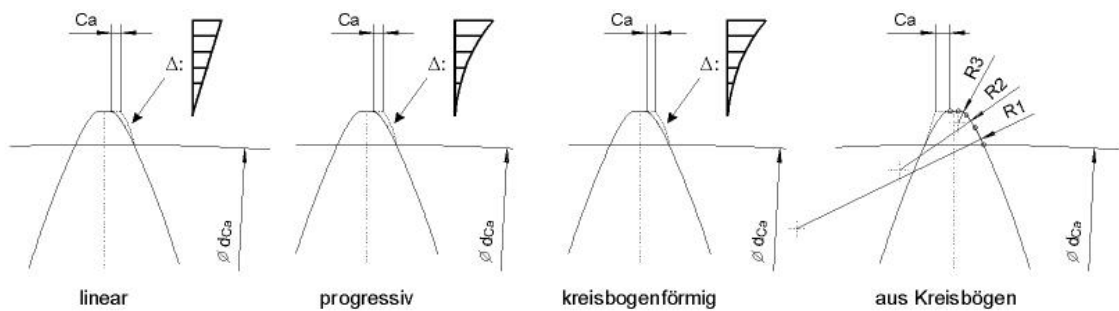



Figure 16. Types of profile modification

Click the sizing button  to the right of the **"Modification starting at diameter"** input field to obtain a reasonable suggestion for the beginning and size of the tip relief.

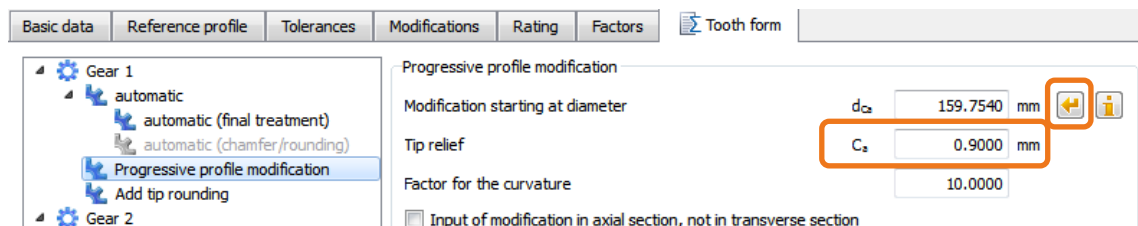


Figure 17. Suggested tip relief

If the gear is to be manufactured by molding processes (injection molding or sintering), it is essential that all the corners are rounded. You can input the rounding radius at the tip independently of which profile modification you select. You can also select the **"Add tip rounding"** option for the rounding radius at the tip.

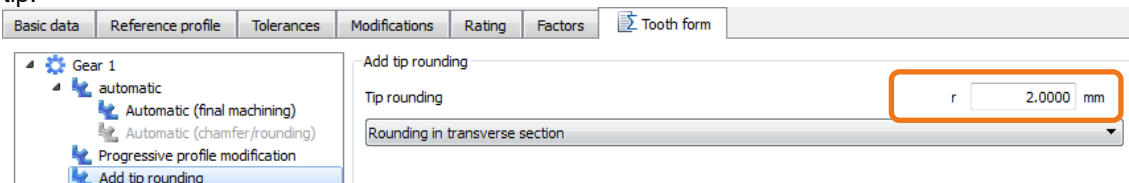


Figure 18. Add tip rounding

You will find the best factor by trial and error. You can view the tooth contact and tooth form in greater detail by opening the "Meshing" window in the screen (marking in the bottom right of the window).

To compare the different settings you make when modifying the tooth form, save the last tooth form you calculated as shown in Figure 4.

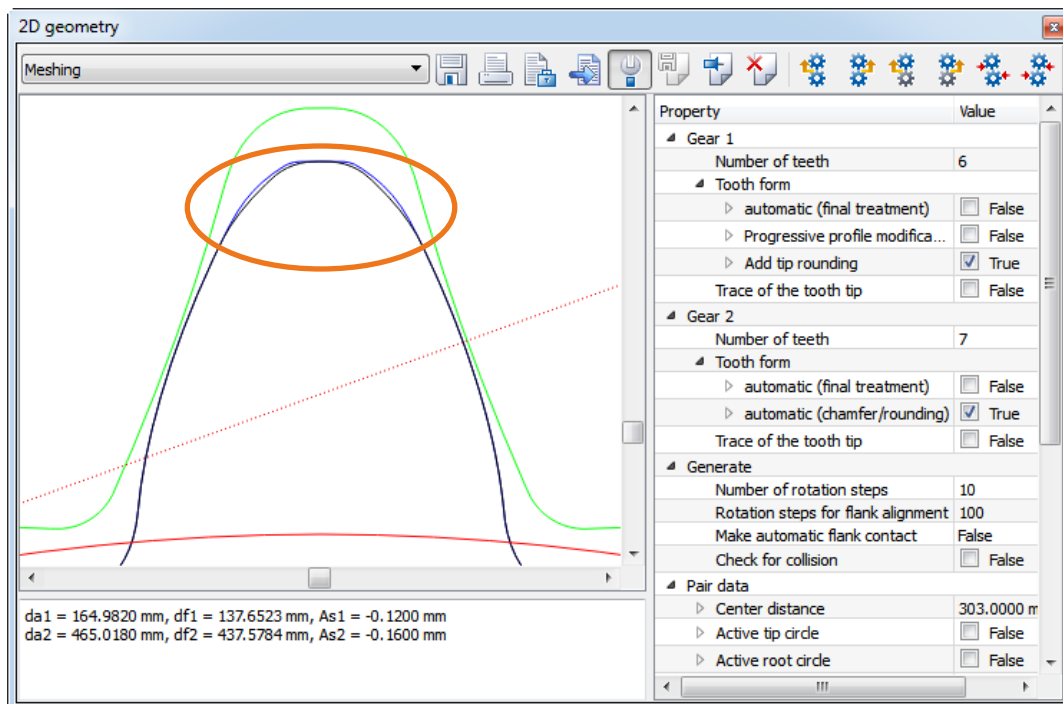


Figure 19. Comparing tooth form modifications

First, go to the main screen and click on the **"Tooth form"** tab. In the saved, active calculation, the **"Progressive profile modification"** calculation step had 10 as its **"Factor for tip rounding"**. In the **"Add tip rounding"** calculation step it had a **"Tip rounding"** of $r = 2$ mm. The calculation is run again, but this time the **"Factor for tip rounding"** is 18 and the **"Tip rounding"** is $r = 1$ mm.

2.7 Optimizing the tooth root

The fatigue safety factor can be significantly improved by using a large radius at the transition from the involute in the root fillet. If gears are manufactured by a hobbing process, it is sometimes difficult to achieve optimum rounding even when using tools with well-rounded tips. However, by making a suitable modification (below the usable root diameter) you can greatly improve the safety factor.

This modification can be VERY useful if you want to eliminate undercut from the tooth form (see next figure).

The KISSsoft system can also perform this modification automatically.

You input and calculate optimized tooth root rounding as part of the tooth root calculation by clicking "Elliptic root modification" and then entering data exactly as you do for tip reliefs as described in 2.6.

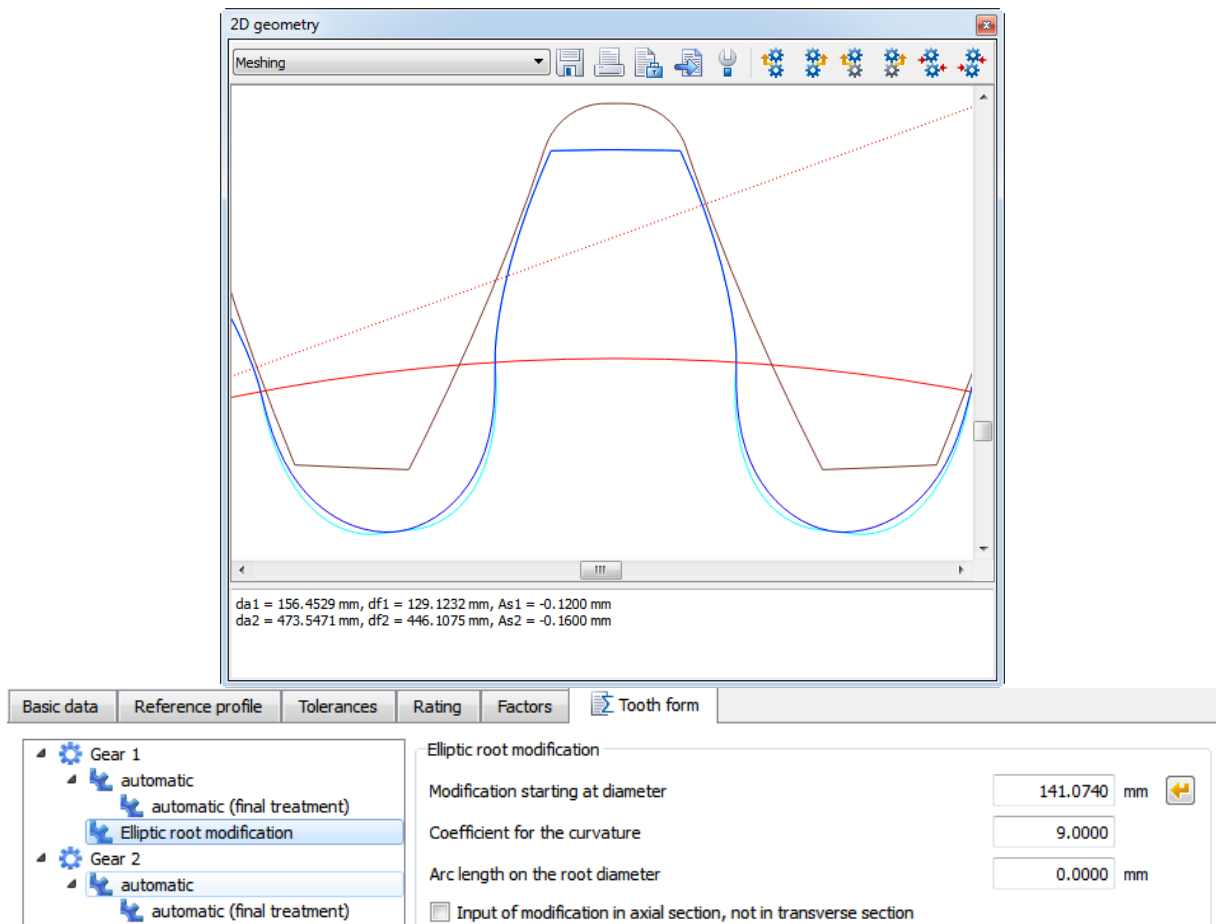



Figure 20. Root form without (light turquoise [cyan], with undercut) and with (dark blue) optimization

Important: If used in combination with a running-in curve or tip rounding on the counter gear, the start of root rounding can also be applied above the arithmetic root form circle. If this happens, it is essential you check the meshing (see next section).

2.8 Checking the meshing

After you have optimized the tooth form, we strongly recommend you check the precision of the gear meshing. The contact between the gears should always be in the area of the actual involute. A crash between the teeth, especially from the tip of the driving gear to the foot of the driven gear, can cause a great deal of damage. You should perform the check using the minimum center distance value (and, for safety reasons, also with the maximum center distance). You can input the center distance directly in the screen.

The **"Check for collisions"** function is very useful if you need to check if the meshing is correct. Click this checkbox to activate the collision check. Then position the flank to the right or to the left by clicking the

appropriate icon  **"Flank to the left or right"**. A black square shows you if the flanks touch each other. If a collision occurs, this square is red.

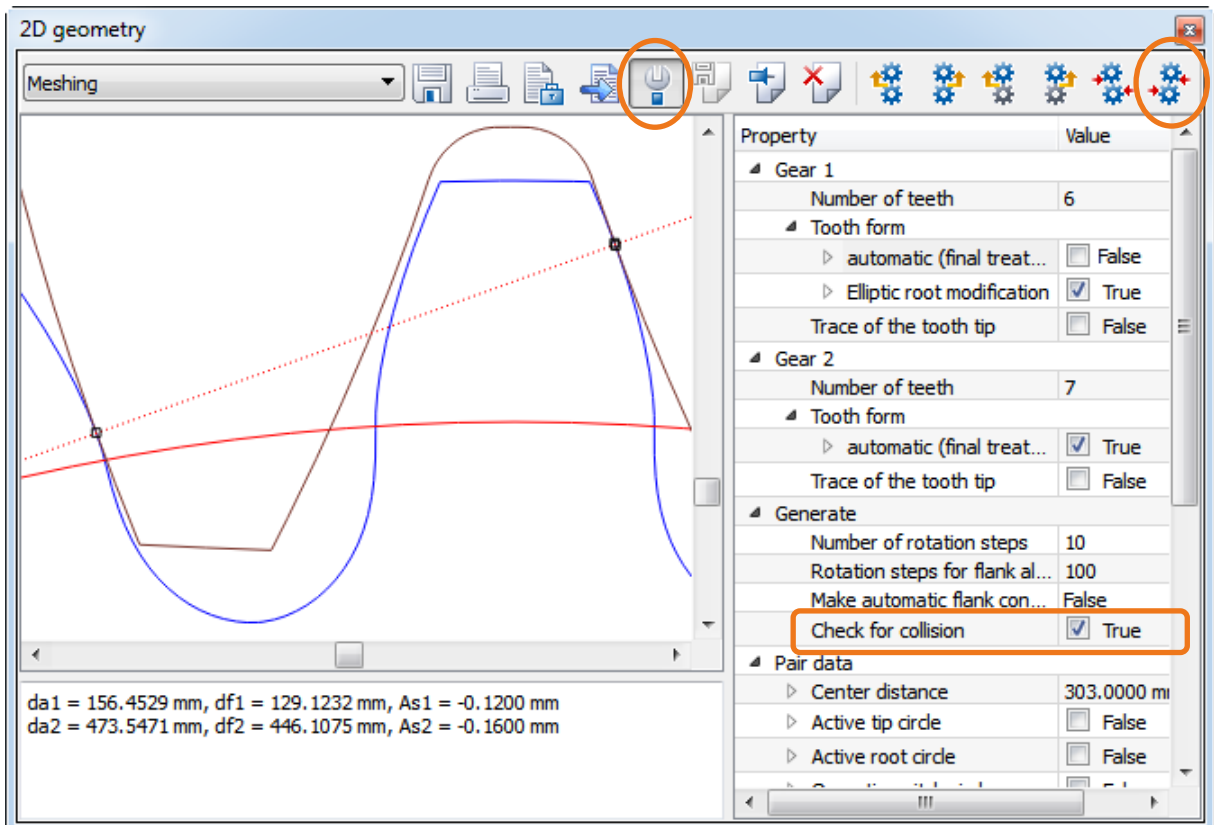



Figure 21. Activating collision check

Click the  **"Properties"** icon to display the Settings graphic on the right so you can enable the collision check.

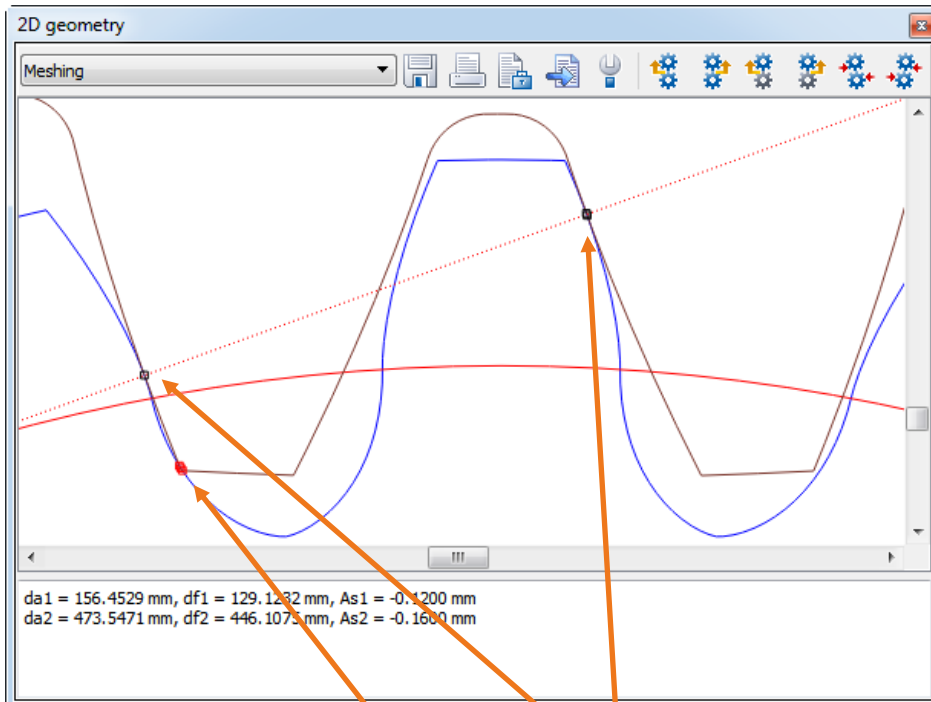


Figure 22. Collision check

"Crash"

Correct contact

2.9 Checking for seizure in the gears

You can prevent the gears from seizing by using an appropriate tooth thickness deviation (as described in section 4). If you cannot make the tooth thickness deviation as large as theoretically required (because for example, the remaining tooth thickness would be much too small) or if another reason may cause the gears to jam, you must check this carefully:

When the gears are run together, the teeth should jam before the tip encounters the root circle (i.e. clearance must still be present for backlash 0.0.) This important fact is taken directly from real life and must be noted because impacts at the root are more serious than seizing between the flanks.

In KISSsoft, you can do this directly in the **"Meshing"** window by reducing the center distance until no more backlash is present. In this situation, clearance must still be present between the tip of one gear and the root circle of the other!

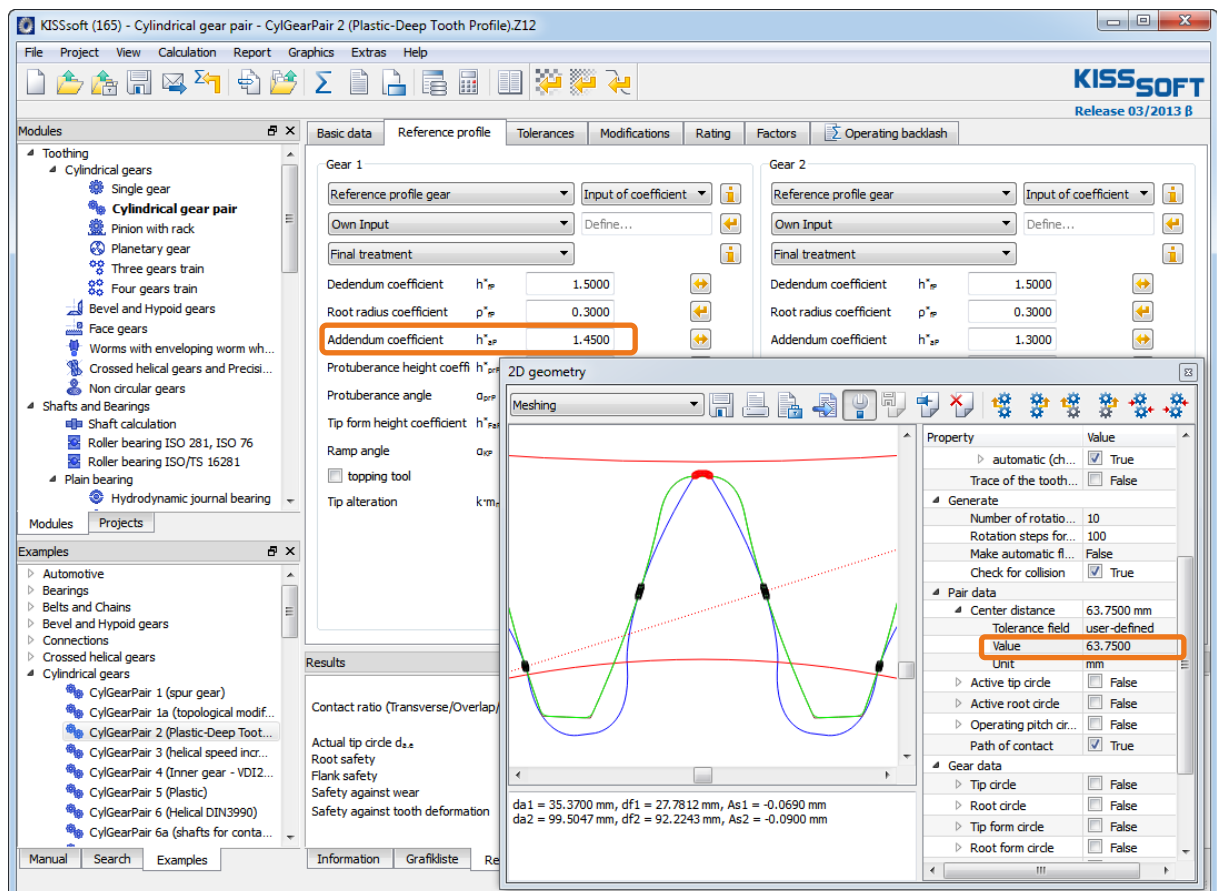


Figure 23. This is a BAD example: When backlash is removed, the tip of Gear 1 is already deep within the root area of Gear 2!

3 Strength calculation

3.1 Introduction

When designing and optimizing gears, it is especially important that you calculate the root, flank and wear safety factors for the projected service life of the gear.

Just like steel gears, the material property values for plastic gears (root resistance and flank strength) depend greatly on the number of cycles. They are also greatly influenced by temperature and the type of lubrication (oil, grease or dry).

Whereas only a single value is needed to calculate the tooth root strength of a steel gear (for example, tooth root fatigue strength [σ_{Flim}] for 17 CrNiMo6: 525 N/mm²), you need several diagrams for plastic gears. This data is stored in the KISSsoft system in separate diagrams for oil, grease lubrication or dry run. This data is processed automatically in the calculation. This means you can easily modify material data yourself. You will find more detailed information in our manual, especially in the "Materials for gears", "Plastic as specified in VDI 2545 ...", "Plastics" sections.

3.2 Input your own data for plastics

The KISSsoft materials database already contains data about a few plastics. If you already know the plastics data, you can save it to the KISSsoft database using the method described below. The example here uses the "POM" material that is already present:

To open the database tool, click on **"Extras" -> "Data base tool"**, open the materials database, and enable data for gear calculation:

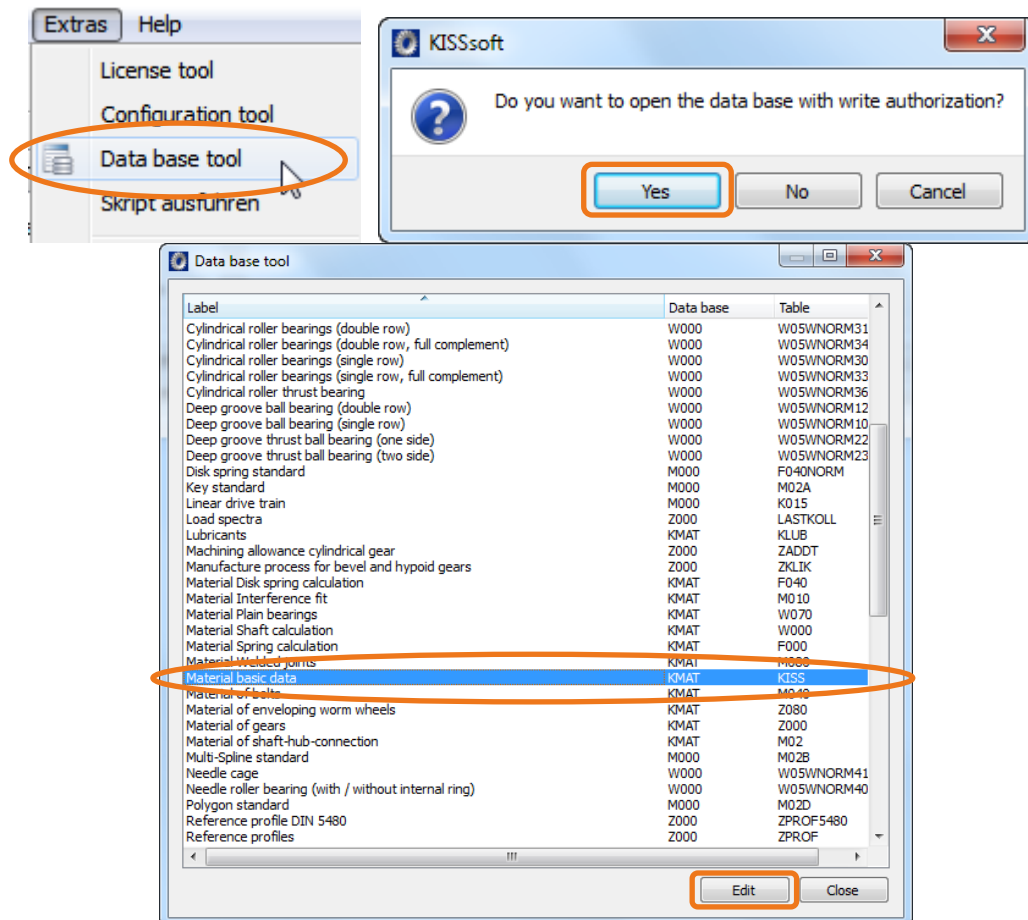


Figure 24. Opening the example analysis

Before you can generate a new material, it must be made available to the materials database. Click **"Material basic data"** to define this basic data. Then click **[Edit]** to open the appropriate database tool. Click **"+"** to generate a new data record so you can edit it. If you have already selected a material, this data is transferred to the new data record and a new material description is created. You can then modify any of the fields as required.

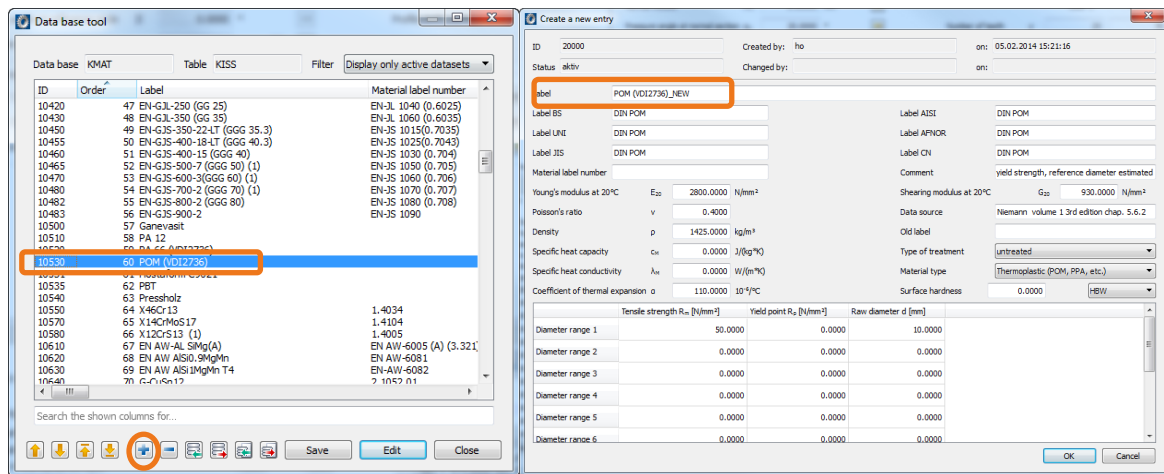


Figure 25. Generating a new data record

Click **[OK]** to confirm your entries and close the "Edit entry" menu to return to the database tool. Then click **[Save]** to save the data. A message then appears to tell you that you have successfully modified the database.

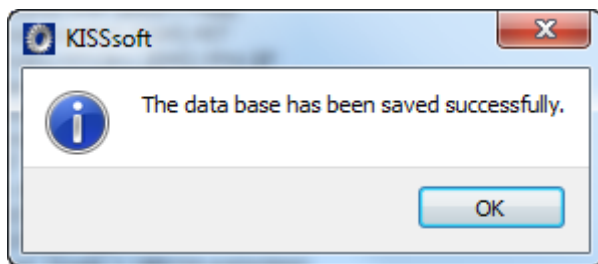


Figure 26. Database with a new data record that has been successfully changed and saved

The next sections use the material POM (already present in KISSsoft), to show you which entries are required. These are the **"Material basic data"** and the **module-specific data**, in this case, for **"Material Gears"**

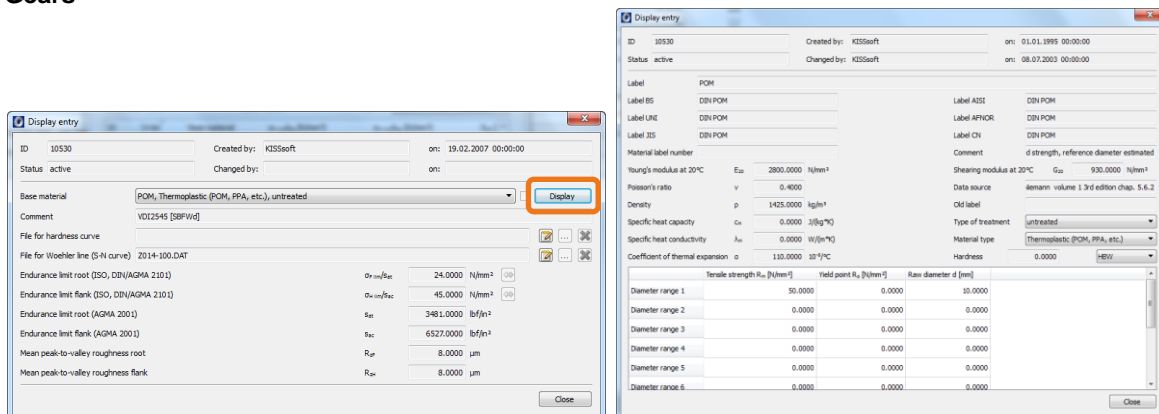


Figure 27. "Material basic data" - Module-specific data "Material Gears" for plastic

The most important information is the entry under **"File for Woehler line"**, shown by the marking in Figure 27. This is where you input the name of the file in which the temperature and lubricant dependent data is stored. You should store this file in the installation folder (usually C:\Programs\KISSsoft-03-2016\ext\dat):

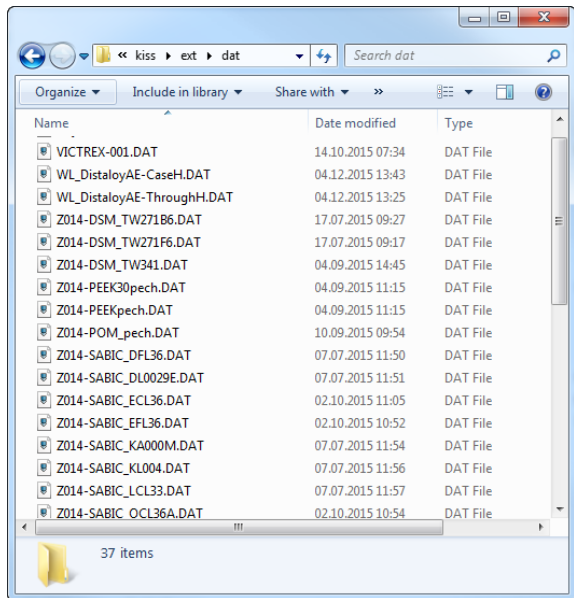


Figure 28. Storing your own plastics data

You can now store the material data you are about to input in its own file (you can give this file any name you like). The best way to do this is to copy an existing plastic file (for example, the Z014-100.DAT file for POM), rename it and then edit it as required.

Extract from Z014-100.DAT (for POM): Young's modulus

(One-dimensional table with Young's modulus, dependent on temperature)

```
:TABLE FUNCTION Young's modulus
      INPUT X ToothTempRoot TREAT LINEAR
DATA   -20      0      20      40      60      80      100      120
      4400    3950    3500    2950    2400    1800    1400    950
END
```

Extract from Z014-100.DAT (for POM): Flank strength with oil lubrication

(Two-dimensional table with sig.Hlim dependent on temperature: Columns and load cycles: lines)

```
-- Data for flank strength with oil lubrication
-- From Niemann, diagram 22.4/4, for PA66, oil lubrication
:TABLE FUNCTION FlankenSigHNOel
      INPUT X ToothTempFlank TREAT LINEAR
      INPUT Y Load change    TREAT LOG
DATA
      20      40      60      80      100      120
0      120    115    108    99    91    76
1E5    120    115    108    99    91    76
1E6    95     90     85     78    68    57
1E7    70     67     63     58    50    40
1E8    52     50     47     44    37    28
1E9    45     42     40     38    32    25
1E10   43     41     38     36    30    24
1E11   43     41     38     36    30    23
1E99   43     41     38     36    30    23
END
```

3.3 Strength calculation with consideration of effective tooth form

The calculations of the root strength according to the methods in the VDI 2545, VDI 2736, DIN 3990, ISO 6336 or AGMA 2001 use a simplified model for calculating the root stress, in which the stress is calculated for a nominally defined cross section (at a point of the 30 degree tangent on the root fillet in DIN or ISO). However, for gears with a pressure angle that varies greatly from 20° or with verified root rounding (see below), this cross section can be a long way from the cross section that is subject to the greatest load. The "Graphical method" used in KISSsoft (according to the procedure described by Obsieger in "Die Konstruktion") therefore performs the calculation, exactly in accordance with the corresponding formulae used in the selected calculation method (Y_F and Y_S as specified in DIN, ISO, AGMA), in approximately 50 cross-sections in the entire root area from the mid tooth depth to the root, and can therefore determine which cross-section has the greatest bending stress. This data is then used in the calculation. This gives a much more accurate calculation procedure which can also be used to calculate non-involute tooth forms. For more information, refer to the relevant section in this manual.

To activate this "Graphical method" in KISSsoft: Go to the **"Rating"** tab and click the **[Details]** button on the far right of the screen. This opens a drop down list under **"Form factors Y_F , Y_S "** in which you select **"Using graphical method"**.

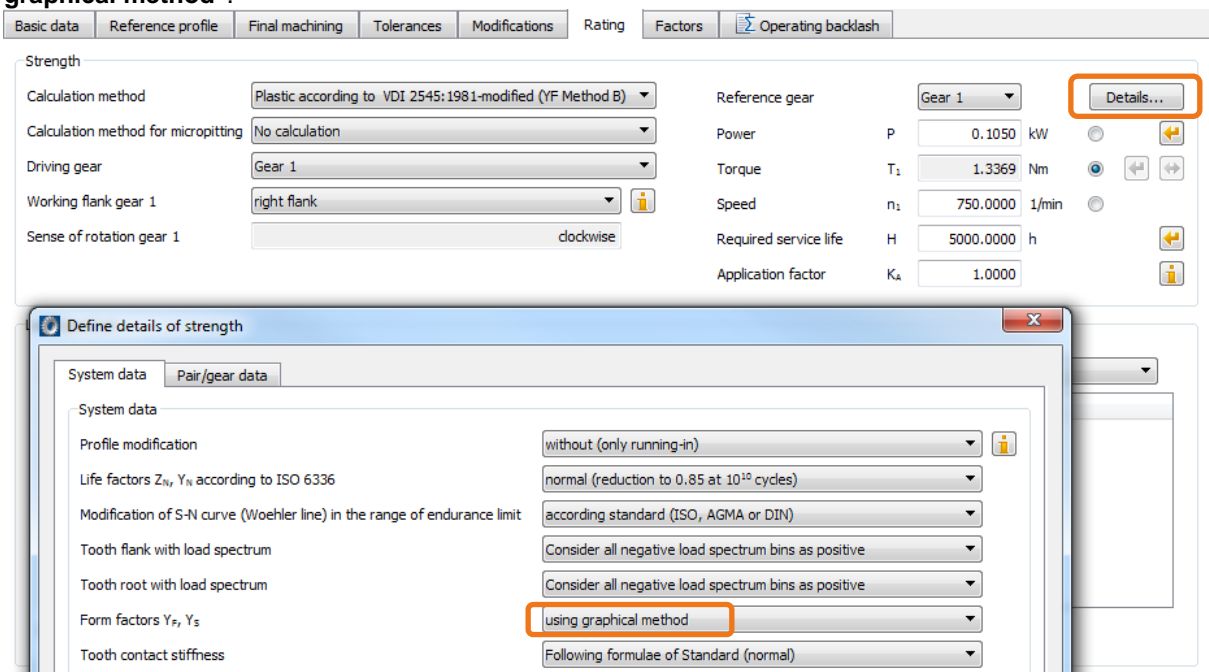


Figure 29. Activating strength calculation using the graphical method

Now, each calculation will first automatically calculate the tooth form and derive Y_S and Y_F from it.

You can also display tooth root strain at the tooth root in the KISSsoft system. To do this, enter the required settings in the **"Contact analysis"** tab and then run the calculation.

Basic data | **Reference profile** | Final machining | Tolerances | Modifications | Rating | Factors | **Contact analysis** | Operating backlash

Contact data

Single normal pitch deviation f_{pt} μm

Coefficient of friction μ

Manufacturing allowances

Contact analysis

Accuracy of calculation

Partial load for calculation W_t % ☐ Consider load spectrum

☐ Load distribution calculated with: $K_H \cdot K_A \cdot K_V \cdot T_{nom}$ %

Axis alignment

Centre distance tolerance

Center distance a mm

☐ Iterative wear calculation

Maximum permitted wear per step Δw

Maximum no. of iterations

Figure 30. Calculating the contact analysis

The current status of the calculations is displayed whilst the calculation is actually running.

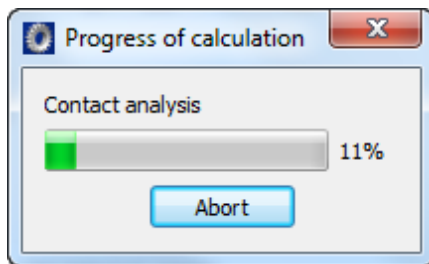
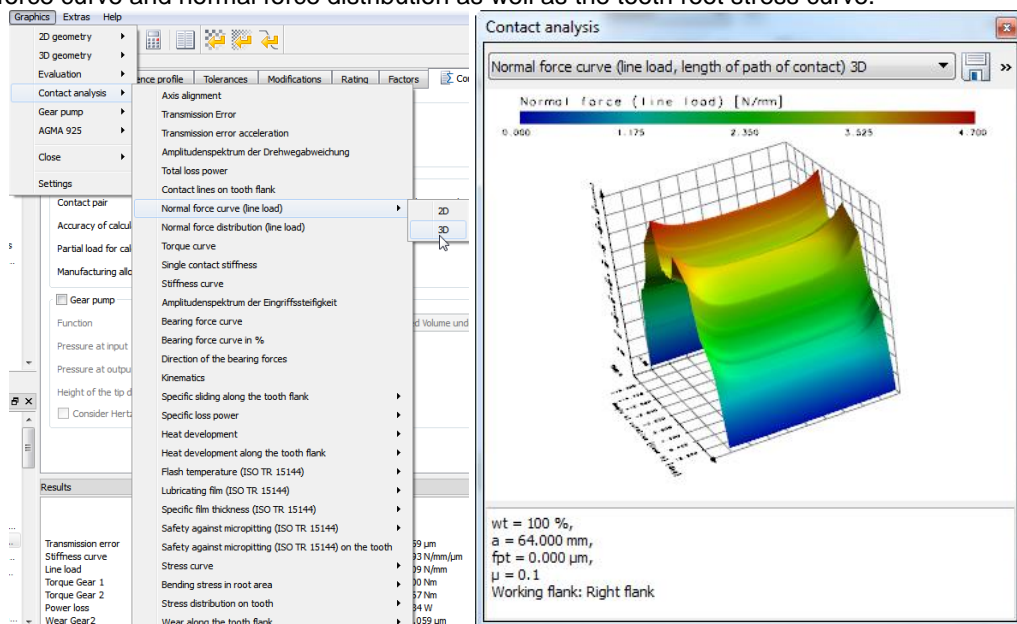


Figure 31. Progress of the contact analysis calculation

You can then select the graphic you require from **"Graphics" → "Contact analysis"**, as in our example, the normal force curve and normal force distribution as well as the tooth root stress curve.



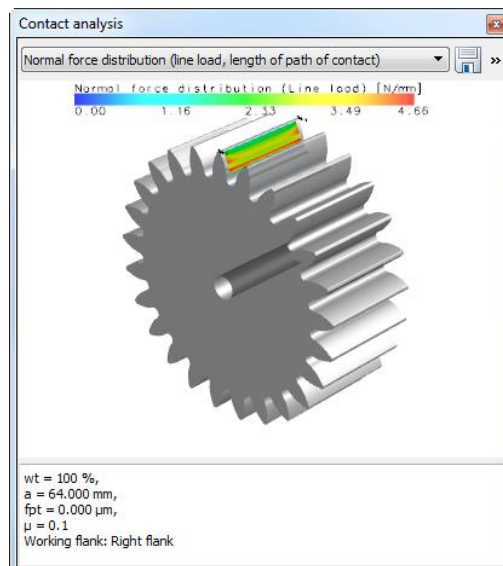


Figure 32. Normal force curve of a meshing using the example given in the "CylGearPair 2" file

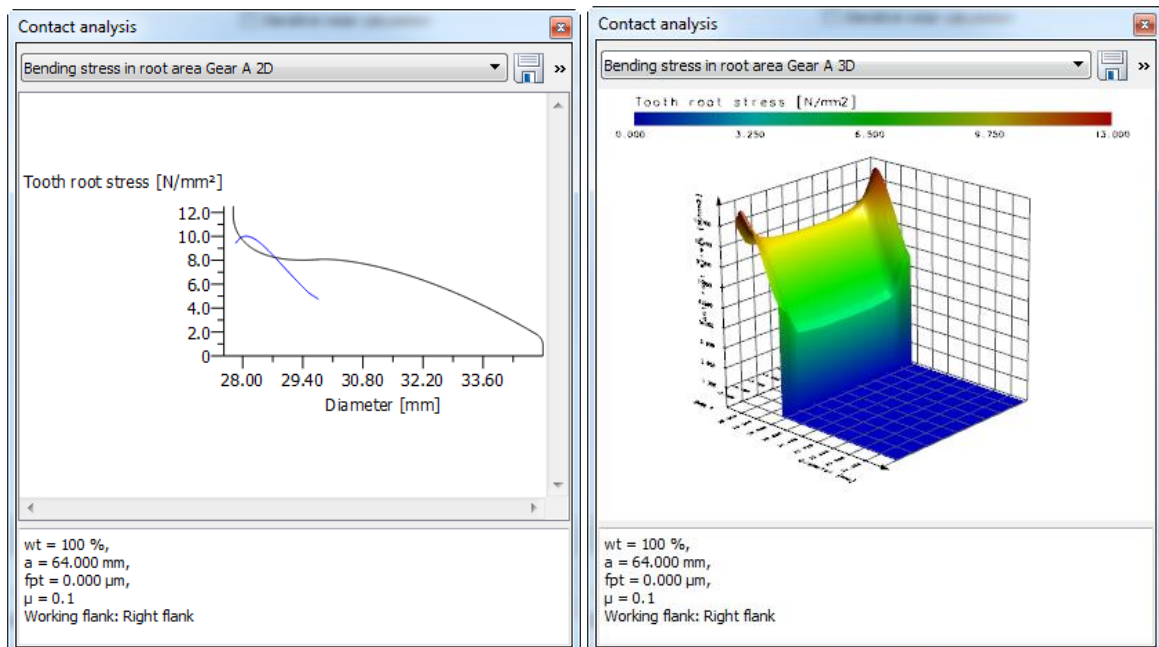


Figure 33. Tooth root stresses, progression in the root area of Gear 1

4 Defining the Tooth Thickness Deviation

4.1 Introduction

In the precision engineering industry, the relative deviations (allowance/tooth thickness) are usually much higher for gears with module 1.0 or greater. If the relative center distance tolerance is large, and the accuracy grade is low, you must select a deviation that is large enough to prevent the gears from seizing during operation. In addition, many plastics have a tendency to absorb water over time and thus swell up.

Experience has shown that it is a good idea to determine the necessary deviation first when you start designing the gear. There is no point in optimizing a tooth form in great detail (as described in this tutorial) and then finding out later on that the excessively large deviation will "devour" the carefully optimized tooth thickness at the tip!

Use the method specified in DIN 3967 to define the deviation. To do this, you must already know the operating temperatures and the thermal expansion coefficients of the gears and their housing. You must also take the swelling into consideration. Here, polyamide (PA6) is the most critical plastic (swells up to 2% due to water absorption).

4.2 Calculating operating backlash

KISSsoft provides an example file of a plastic gear calculation called "CylGearPair 5". Open this file in the cylindrical gear calculation module:

Here you must note the selected tolerances for Gear 1, Gear 2 and the Center distance:

The screenshot shows the 'Allowances' tab in the KISSsoft software. It displays a table of tolerances for Gear 1 and Gear 2, and the Center distance. The table is organized into columns for each parameter and rows for different tolerance types. The 'Tooth thickness tolerance' is set to 'DIN 3967 cd25' for both gears. The 'Tooth thickness...e (upper/lower)' values are -0.0540 and -0.0840 mm for Gear 1, and -0.0700 and -0.1100 mm for Gear 2. The 'Base tangent le...e (upper/lower)' values are -0.0515 and -0.0801 mm for Gear 1, and -0.0668 and -0.1049 mm for Gear 2. The 'Normal backlash (min/max)' values are 0.0515 and 0.0801 mm for Gear 1, and 0.0668 and 0.1049 mm for Gear 2. The 'Circumferential...lash (min/max)' values are 0.0540 and 0.0840 mm for Gear 1, and 0.0700 and 0.1100 mm for Gear 2. The 'Tip diameter al...e (upper/lower)' values are 0.0000 and -0.0100 mm for Gear 1, and 0.0000 and -0.0100 mm for Gear 2. The 'Root diameter ... (upper/lower)' values are -0.1713 and -0.2664 mm for Gear 1, and -0.2220 and -0.3489 mm for Gear 2.

Figure 34. Preselected tolerances for Gear 1, Gear 2 and Center distance

Before you then run the operating backlash calculation, you must click "**Σ**" (calculate) to calculate the intermeshing. Then click on the "**Operating backlash**" tab to calculate the operating backlash:

The screenshot shows the 'Operating backlash' tab in the KISSsoft software. It displays various settings for calculating operating backlash. The 'Influences due to inaccuracy at manufacturing' section includes checkboxes for 'Consider axis deviation error', 'Consider manufacturing error according to DIN 3967', and 'Consider runout error'. The 'Accuracy class of axis alignment according to ISO 10064' is set to 'Q'. The 'Distance between bearings L₀' is set to '88.0000 mm'. The 'Influences during operation' section includes input fields for 'Temperature range ho T_c', 'Temperature range ge T_n', 'Permissib... (min/max) T_{ref}', 'Relative water absorption during swelling w_{sw1}', 'Relative water absorption during swelling w_{sw2}', and 'Reference temperature T_{ref}'. The 'Housing material' is set to 'EN-GJL-200 (GG 20), Cast iron flake graphite, untreated, ISO 6336-5 Figure 3c/4c (MQ)'. The 'Coefficient of thermal expansion for housing α_c' is set to '11.7000 1E-6/°C'. Arrows point from text labels to specific settings: 'Influence of manufacturing accuracy (axis alignment)' points to the 'Accuracy class' dropdown, 'Influence of temperature on expansion of the housing and gear bodies' points to the temperature range inputs, and 'Select material for housing' points to the 'Housing material' dropdown.

Figure 35. Settings for calculating operating backlash.

This example "CylGearPair 5", is defined so that the gears will seize during operation. When you calculate the operating backlash, these warning messages will appear:

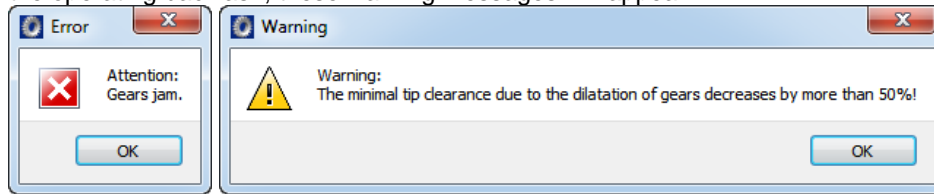


Figure 36. Error messages: "Gears jam" warning message: Tooth tips collide

Click the button to the right of (create report) to display this report:

| | | | | |
|---|--------|---------------|--------------|--------|
| Results : | | | | |
| Change of center distance by: | | | | |
| Warming | (mm) | [DaC] | 0.026 | Casing |
| | (mm) | [DaW] | -0.247 | Gears |
| Backlash change due to: | | | | |
| Center distance tolerances | (mm) | [Dja.e/i] | 0.012/-0.012 | |
| Swelling due to absorption of water | (mm) | [DjQ] | 0.000 | |
| Warming | (mm) | [Djtheta min] | -0.170 | |
| Misalignment of axes | (mm) | [DjSigmabeta] | -0.006 | |
| Mesh single deviation | (mm) | [DjF] | -0.015 | -0.015 |
| <u>Theoretical backlash (Reference circle)</u> | | | | |
| - Circumferential backlash | | | | |
| | (min.) | (mm) | [jt.i] | 0.112 |
| | (max.) | (mm) | [jt.e] | 0.206 |
| <u>Theoretical backlash (Operating pitch circle)</u> | | | | |
| - Circumferential backlash | | | | |
| | (min.) | (mm) | [jtw.i] | 0.113 |
| | (max.) | (mm) | [jtw.e] | 0.207 |
| <u>Acceptance-backlash</u> | | | | |
| - Circumferential backlash | | | | |
| | (min.) | (mm) | [jtw.a.i] | 0.100 |
| | (max.) | (mm) | [jtw.a.e] | 0.200 |
| <u>Smallest operating backlash</u> | | | | |
| - Temperature combination | | | | |
| Gear body temperature | (°C) | [TR] | 50.00 | |
| Case body temperature | (°C) | [TC] | 50.00 | |
| - Circumferential backlash | | | | |
| | (min.) | (mm) | [jtwop.i] | -0.070 |
| | (max.) | (mm) | [jtwop.e] | 0.030 |
| - Normal backlash | | | | |
| | (min.) | (mm) | [jnwop.i] | -0.066 |
| | (max.) | (mm) | [jnwop.e] | 0.028 |
| - Radial clearance | | | | |
| | (min.) | (mm) | [jrwop.i] | -0.086 |
| | (max.) | (mm) | [jrwop.e] | 0.037 |
| - Torsional angle with fixed gear 1 | | | | |
| | (min.) | (°) | [Dphit.i] | 0.0000 |
| | (max.) | (°) | [Dphit.e] | 0.0294 |

Figure 37. Extract from the operating backlash calculation report

The negative values for circumferential backlash show that the gear pair will jam.

4.3 Increasing operating backlash

In the worst case, the circumferential backlash may be -0.070 mm (see the yellow text marked above). To prevent the gears from seizing, this value must be greater than zero. The software issues a message telling you the minimum amount by which you should modify the tooth thickness allowance.


Proposed value for the smallest possible tooth thickness allowance (jtw.i = 0):
 Tooth thickness allowance (up.) (mm) [Asn.e] -0.090 -0.106
 (lower) (mm) [Asn.i] -0.120 -0.146

Figure 38. Suggestion made by the software

To do this, change the tooth thickness deviation (make the teeth thinner). Both gears are reduced by 0.04 mm (to increase the circumferential backlash by 0.08 mm to ensure it remains positive). To do this, go to the **"Tolerances"** tab, set tooth thickness deviation to **"Own input"** and increase each circumferential backlash by 0.04 mm (for the lower and the upper allowance of both gears):

Figure 39. Original state (tolerance cd25 as specified in DIN3967)

Figure 40. Increase to the circumferential backlash for both gears, each by 0.04mm

After this, click  (Calculate) to run the meshing again and recalculate the operating backlash – as described above. This time, no warning appears (because the gears do not jam) and you see a positive operating backlash in the report:

| | | | | |
|---|--------|------|-----------|-------|
| <u>Smallest operating backlash</u> | | | | |
| - Temperature combination | | | | |
| Gear body temperature | (°C) | [TR] | | 50.00 |
| Case body temperature | (°C) | [TC] | | 50.00 |
| - Circumferential backlash | | | | |
| | (min.) | (mm) | [jtwop.i] | 0.011 |
| | (max.) | (mm) | [jtwop.e] | 0.111 |
| - Normal backlash | | | | |
| | (min.) | (mm) | [jnwop.i] | 0.010 |
| | (max.) | (mm) | [jnwop.e] | 0.104 |
| - Radial clearance | | | | |
| | (min.) | (mm) | [jrwop.i] | 0.013 |
| | (max.) | (mm) | [jrwop.e] | 0.136 |
| ... | | | | |

Figure 41. Extract from the operating backlash calculation report. The operating backlash is now positive

5 Calculating the injection mould

5.1 Introduction

The theoretical tooth form, which has been optimized as described above, is calculated by KISSsoft using the mid-value of the tooth thickness deviations. The results is the required tooth form, which can then be transferred to a CAD program via the DXF or IGES interface. You can, for example, use this contour to monitor gears manufactured using a projection process.

You can also mathematically define the injection mould. When plastic gears are manufactured using an injection process, a certain amount of shrinkage occurs as the plastic solidifies. The injection mould is therefore designed to be slightly larger in order to compensate for this shrinkage. To achieve this, the tooth form is expanded both radially and tangentially. Radial expansion gives an aspect ratio change in the radial direction (i.e. each point on the tooth outer contour is shifted in a straight line from the center point). Tangential expansion causes a thickening of the tooth and a corresponding reduction in the tooth gap. To calculate the injection mould in KISSsoft, you can predefine the required radial expansion at the tooth tip and at the root as well as the tangential expansion as a percentage.

5.2 Modifying the injection mold to compensate for shrinkage

To enable these modifications, click the **"Tooth form"** tab to open the tooth form calculation. Then add the other operations to the operation already enabled in that tab "automatic (Rack)".

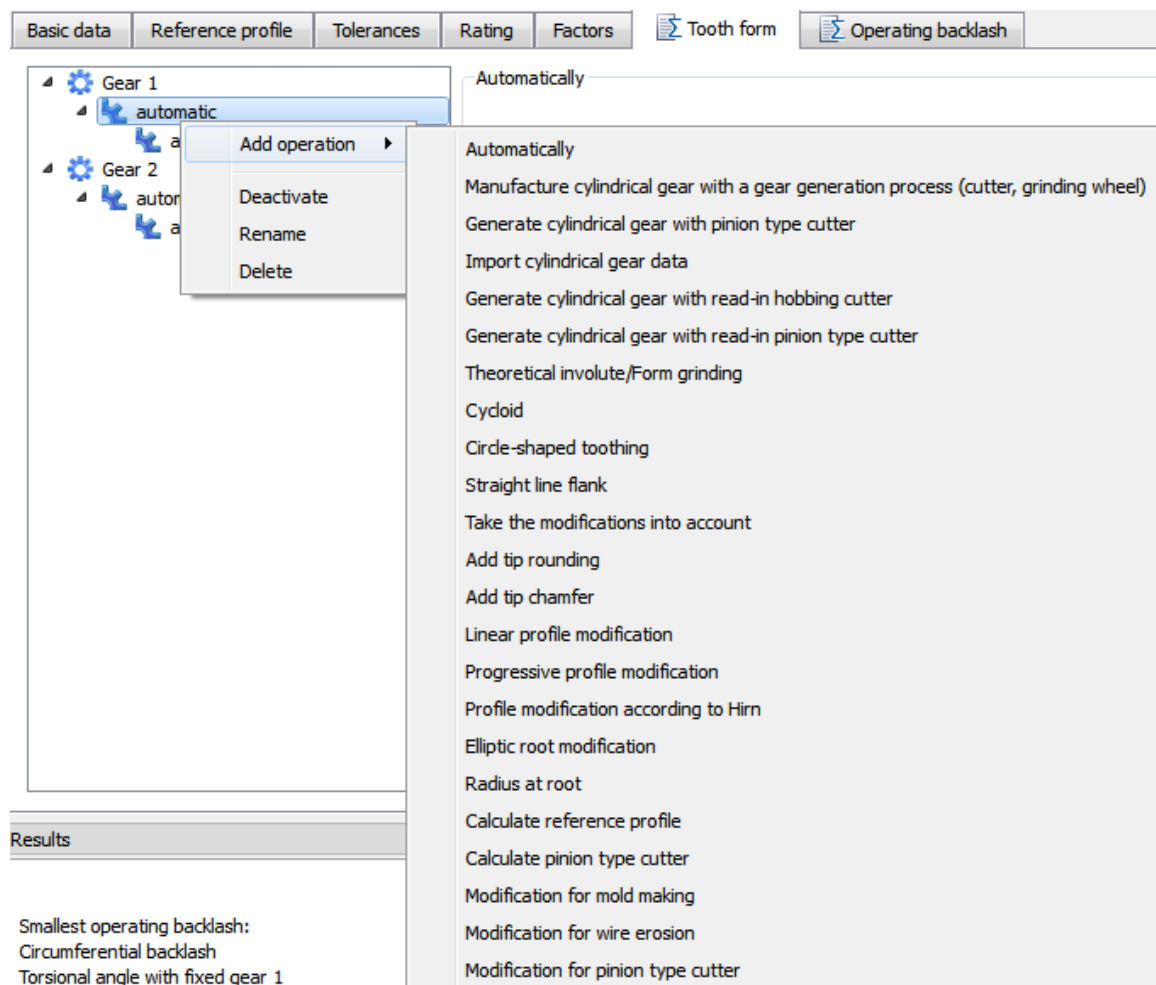



Figure 42. Tooth form calculation with modifications for molding

You can now input the radial and tangential expansion. The resulting tooth form is now calculated with  and can be displayed with "2D":

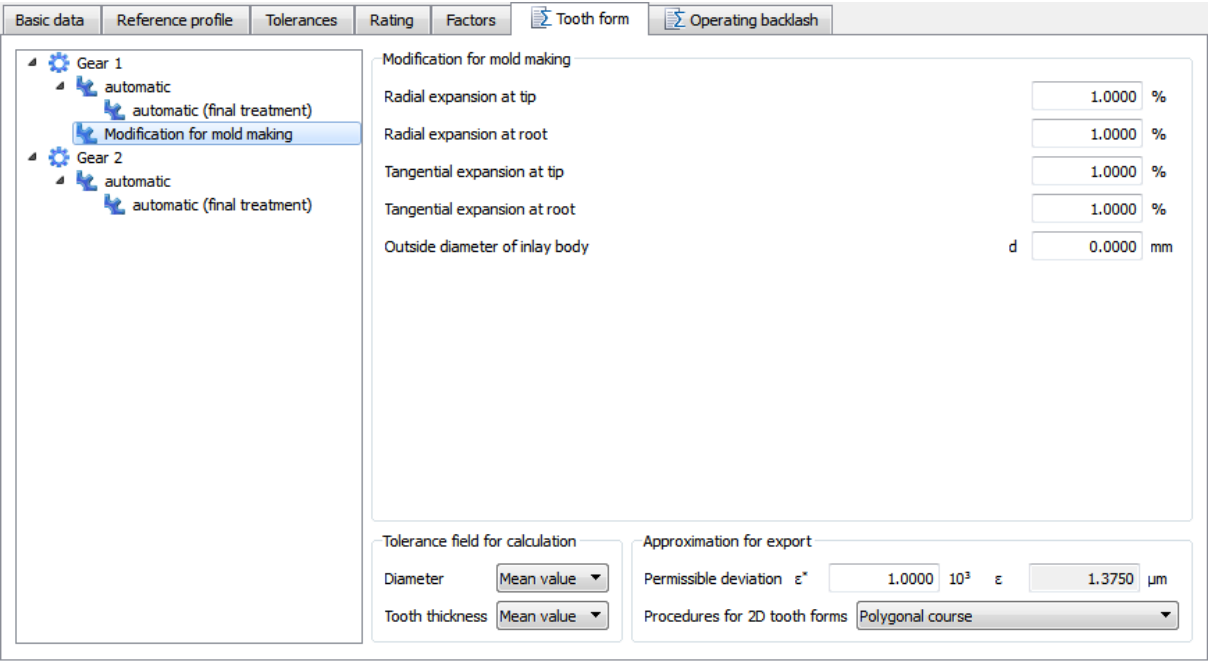
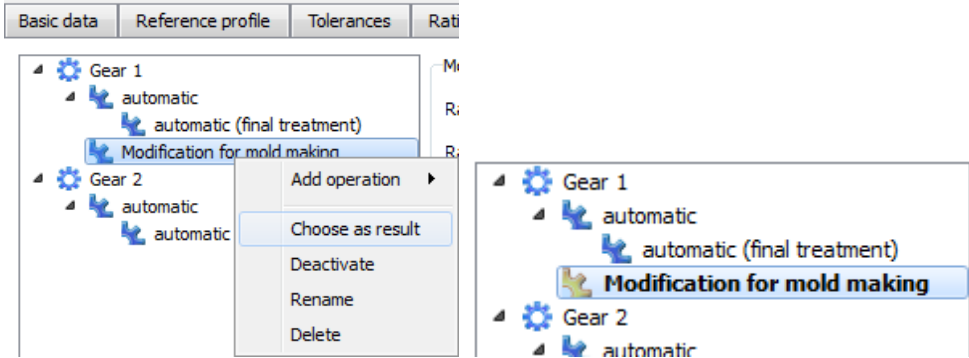


Figure 43. Calling the display of the gear pair

Note: Before you can display the modified tooth form, you must enable "Modification for mold making" ("Choose as result").



The icon color yellow shows that this operation is used for the display!

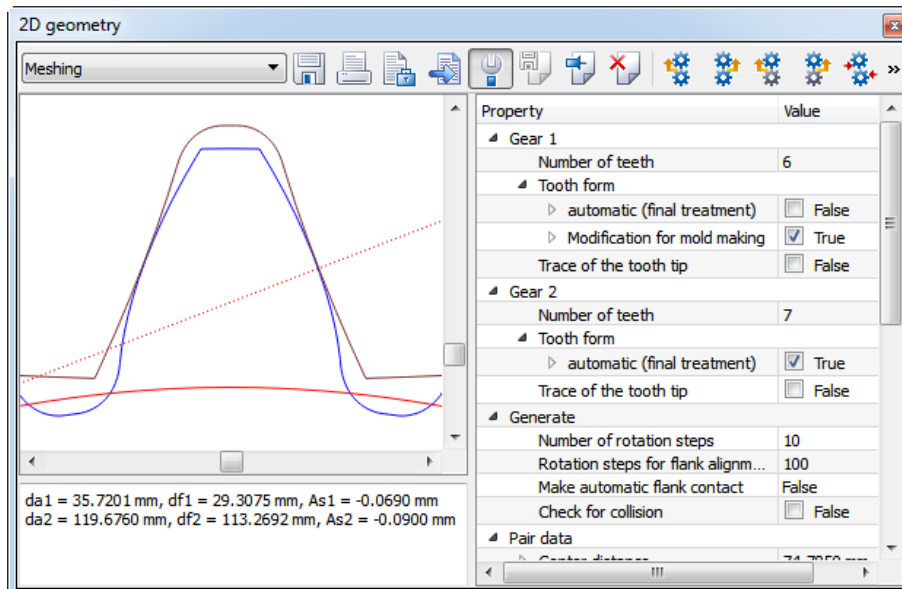


Figure 44. Display of the gears, increased by the pre-defined shrinkage

If you want to use these tooth forms to manufacture molds, it is a good idea to export them individually. Under "**Permissible deviation**" you can input a value ϵ^* to specify the maximum deviation permitted for the tooth form and also which type of approximation you want to achieve. You can then open the "**2D geometry**" graphics window directly below to display the tooth forms of Gear 1 and Gear 2.

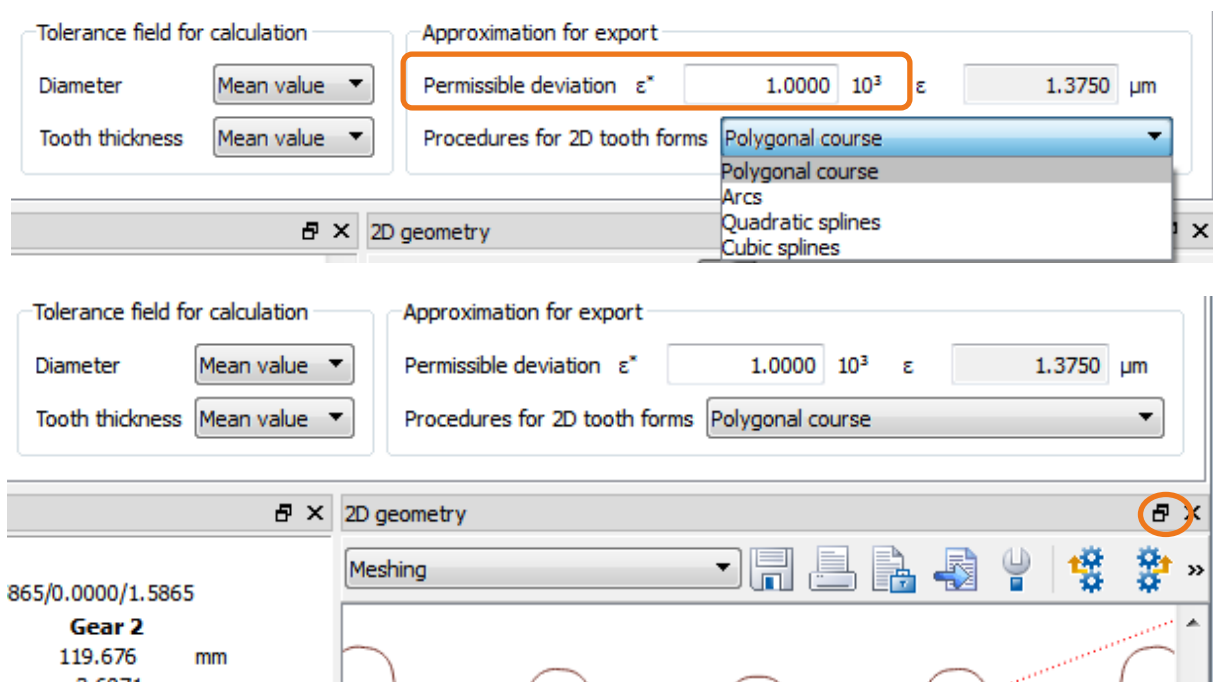


Figure 45. Permissible deviation; Open graphics window

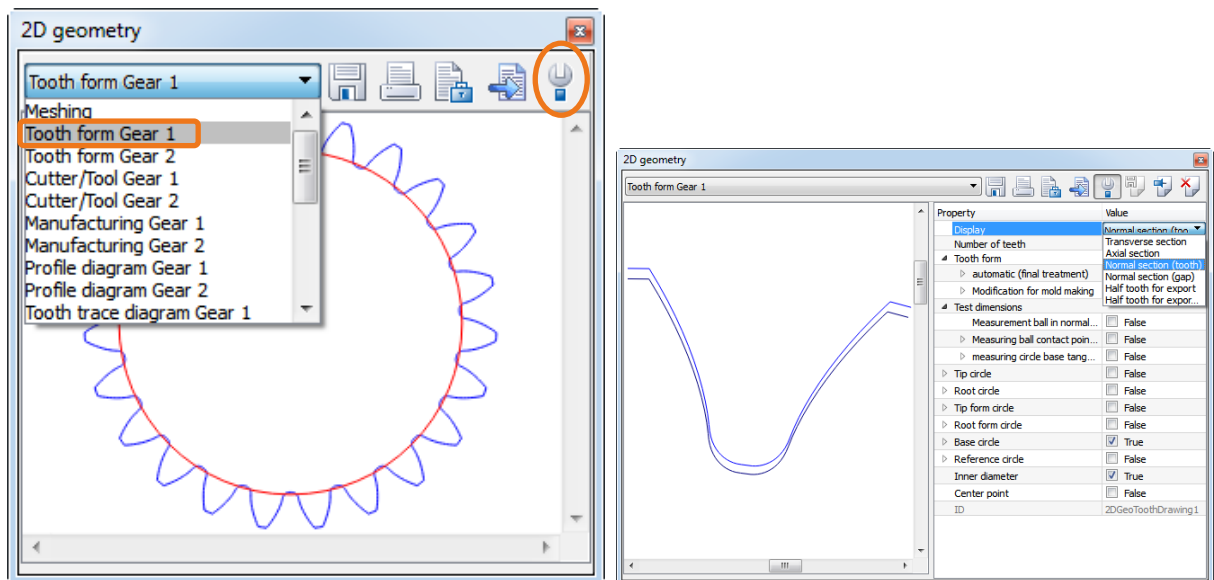


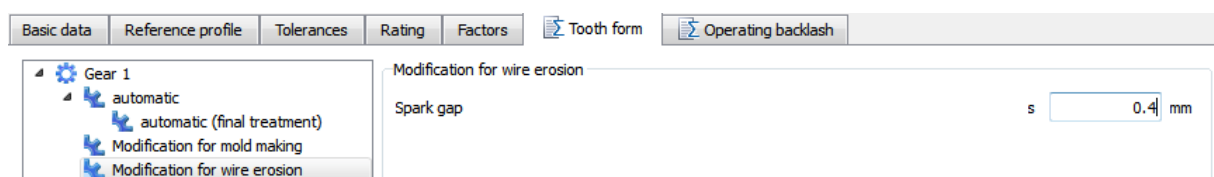
Figure 46. Calling the display of the tooth form for a single gear and exporting the tooth form in DXF or IGES format

It is essential you check the title of the graphic: The left-hand screen shows the expanded tooth form (shown with a mold modification). In the right-hand screen you also see the UN-modified tooth form shown in "black". You use this procedure to display the tooth form expanded by the specified shrinkage as specified in Figure 43.

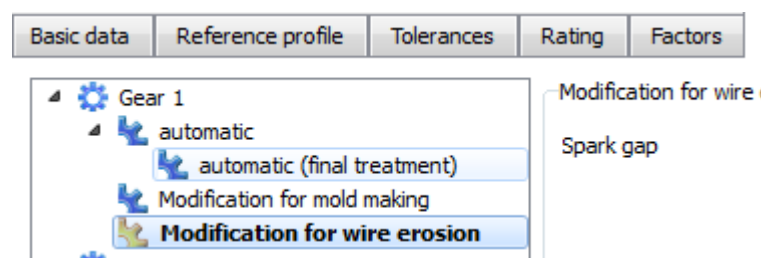
5.3 Display the eroding wire / spark gap

In addition, when you calculate the injection mold you can also take the spark gap into account when you define the eroding wire. During the eroding process, the spark gap is the clearance between the eroding wire and the material that will form the mold. The eroding wire must therefore be thinner than the spark gap. For eroding wires used to form teeth, the tooth will be correspondingly thinner. If the mold is formed by wire erosion, you can use the same procedure (spark gap plus wire radius) to also define the feed path of the wire.

Add the "Modification for wire erosion" option to ensure that the spark gap can be taken into consideration.



Note: To display the modified tooth form, you still need to enable the "Modification for wire erosion" option ("Choose as result")



Original tooth form:

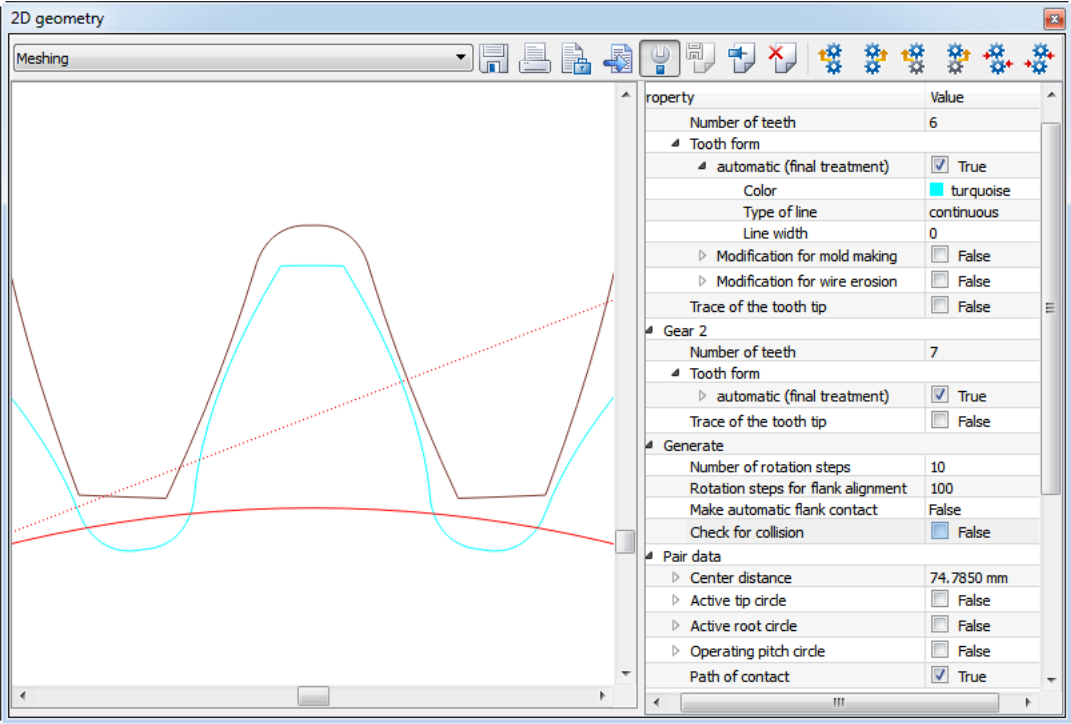
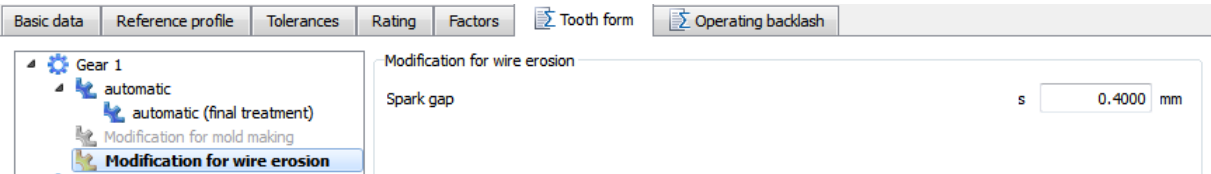


Figure 47. Tooth form without modifications



If a positive value has been predefined for the spark gap, the tooth form will be enlarged (to compensate for the spark gap).

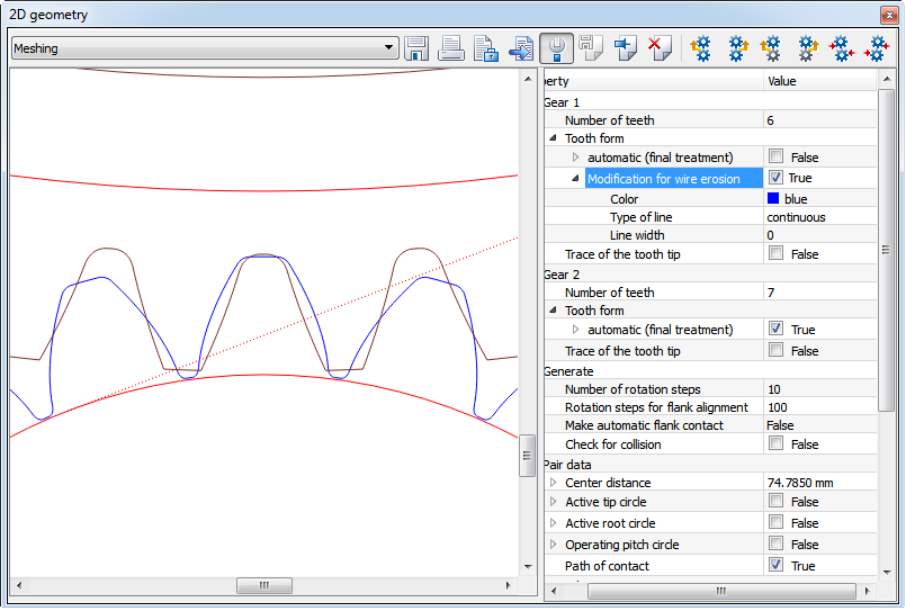
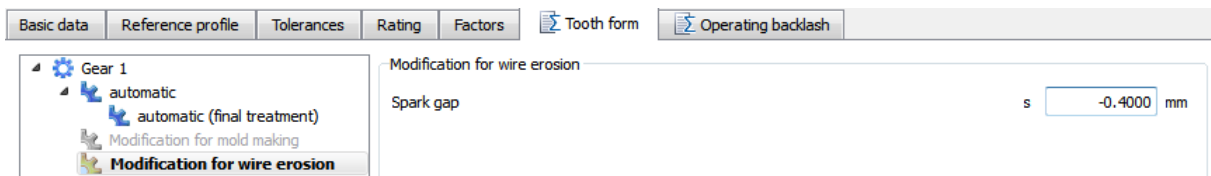


Figure 48. Tooth form shown with a 0.4 mm spark gap



If a negative value has been specified for the spark gap, the tooth form is displayed as if an eroding wire had been passed under the displayed mould.

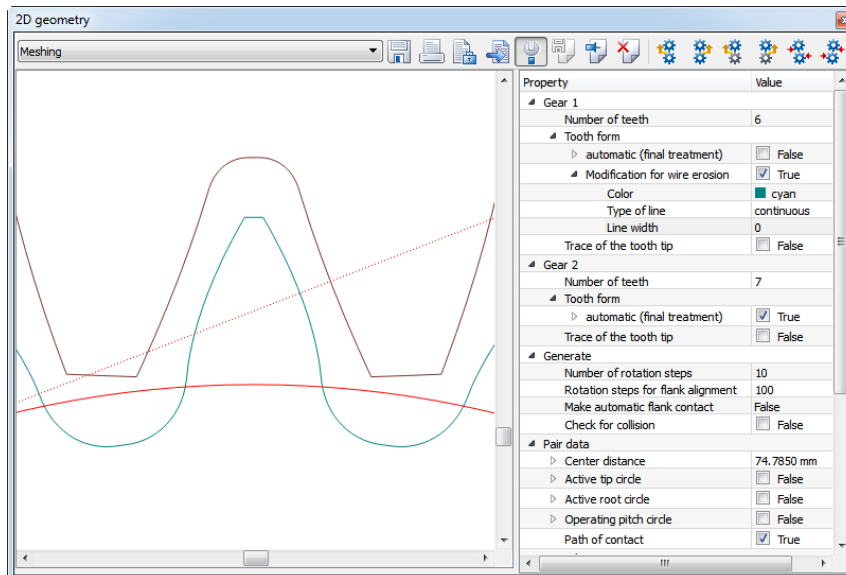


Figure 49. Tooth form shown with a -0.4 mm spark gap

5.4 Monitoring the wire diameter during erosion

If the injection mold is produced by wire erosion, you must check whether the wire you want to use is fit for this purpose. To do this, work through the following steps in the **"Tooth form"** tab. Then import the "CylGearPair 5" example file again. These next calculation steps are all performed in the **"Tooth form"** tab:

Insert **"Modification for wire erosion"** with negative spark gap, which corresponds to half the wire diameter. Then insert **"Modification for wire erosion"** again, but this time with a positive value for half the wire diameter. You then need to enable **"Choose as result"**. In the graphic properties, set all the calculation steps to **"True"**.

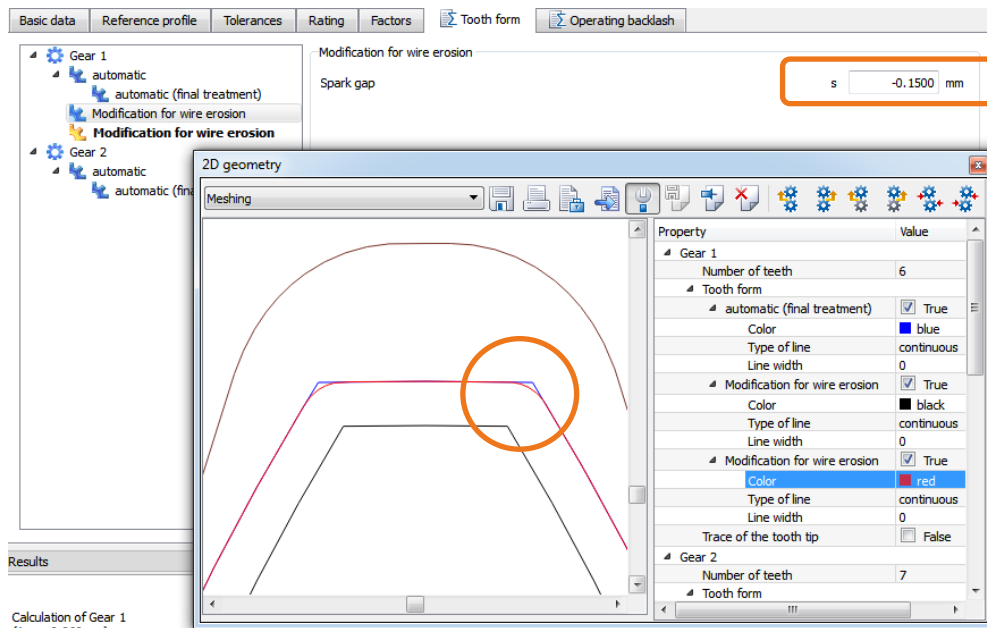


Figure 50. Input of half the diameter of the eroding wire as the "spark gap"

You now see all the calculation steps in the tooth form geometry. The black curve shows the path traveled by the center point of the eroding wire. The red contour shows the contour generated by this process, the blue contour is the target contour.

5.5 Calculating a 3D mold

3D data can be generated in the usual manner (as for a 2D export) directly via the diskette icon from the 3D graphic. This data can then be stored. You can use either the Parasolid or STEP formats to do this.

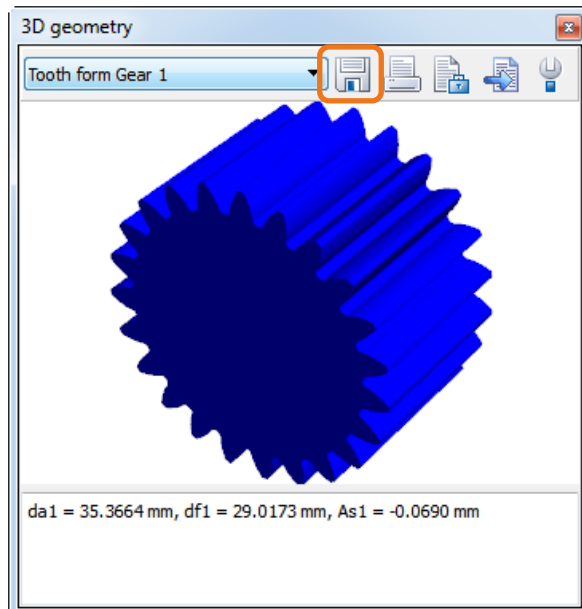


Figure 51. Geometry export