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

1 Introduction

1.1 Summary of the design strategy

These instructions describe a strategy for optimizing the design of gears that are manufactured using moulding methods (injection moulding, 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 height (aim: achieve effective transverse contact ratio 2.0 whist taking into account tip rounding, running-in curve for noise reduction)
- Tip-rounding
- Optimize running-in curves/profile correction (aim: improving the wear safety factor)
- Optimize root fillet (increased the root safety factor)
- Determine a mould for the manufacturing process

1.1 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 material for their particular application. In doing so, they define the most important properties of a gear pair, such as load capability, resistance to wear, compression ratio, stiffness and noise emissions.

Metallic gears are usually manufactured in a milling process. In contrast, plastic gears are usually injection moulded. If the mould is produced by a wire erosion process, the tooth form can be optimized at no additional cost. In a milling process, this is only possible with expensive, specialist tools. However, the injection moulding process does not achieve a particularly good toothing quality 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 tooth forms.

2 Defining tooth geometry

2.1 Introduction

You can change tooth geometry in many different ways to achieve the optimum ratio of tooth contact. Depending on the importance of the targets to be achieved, such as low noise emission, low vibration, strength, sliding, 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 moulding process, the tooth tip edges must be rounded, because corners can never be created accurately in injection moulding. It is a good idea to input this data in the main screen for gear 1 and gear 2. As a result, all the most important data (such as contact ratio, etc.) will then be calculated to include tip-rounding.

This is now illustrated in an example: The KISSsoft system has a tutorial file for this calculation. This is "Tutorial - 011". Open this file in the cylindrical gear calculation module:

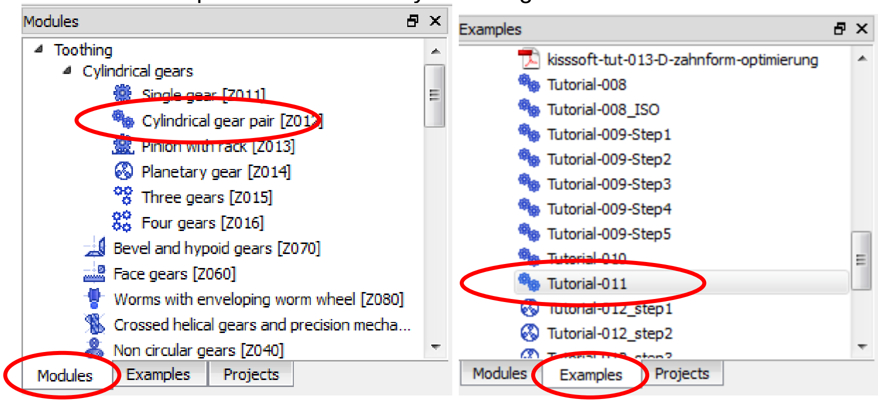


Figure 2.1 Opening cylindrical gear calculation and the tutorial file

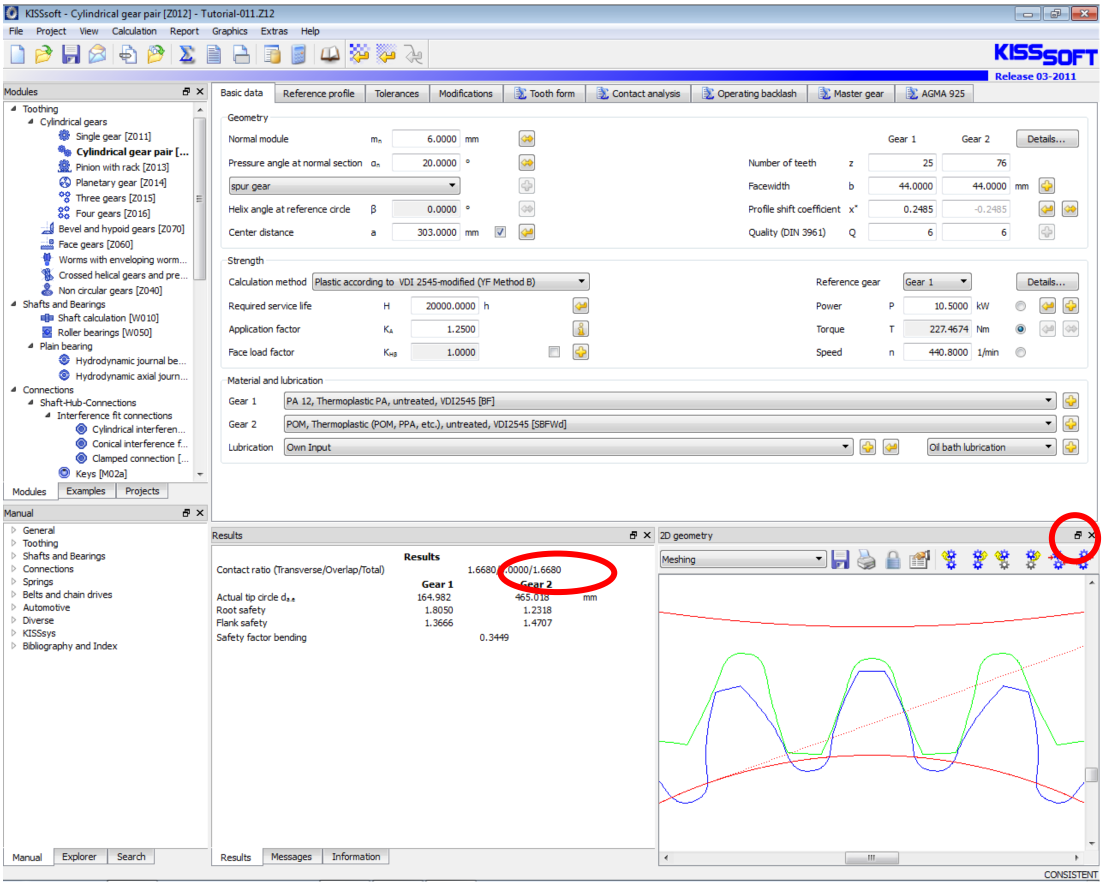


Figure 2.2 Example file for plastic gears, after calculation ("Σ")

Click Σ in the tool bar or press "F5" to calculate the tooth form data. Without tip-rounding the contact ratio would be 1.6680. 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 of Figure 2.2).

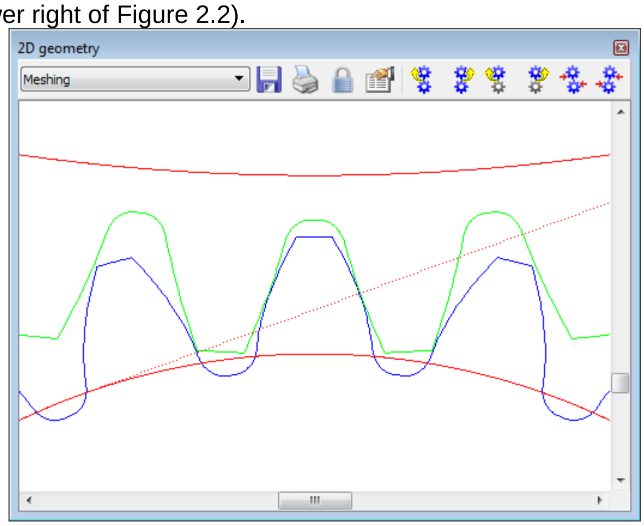


Figure 2.3 Tooth form display

You should now save the tooth form locally. To do this, open the **"Property browser"** (1). Activate 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). Then click "OK" (5) to save Gear 1's tooth form. Follow this procedure again to save Gear 2's tooth form. You can now view the changes you have made to the tooth form. Then, close the **"Property browser"**.

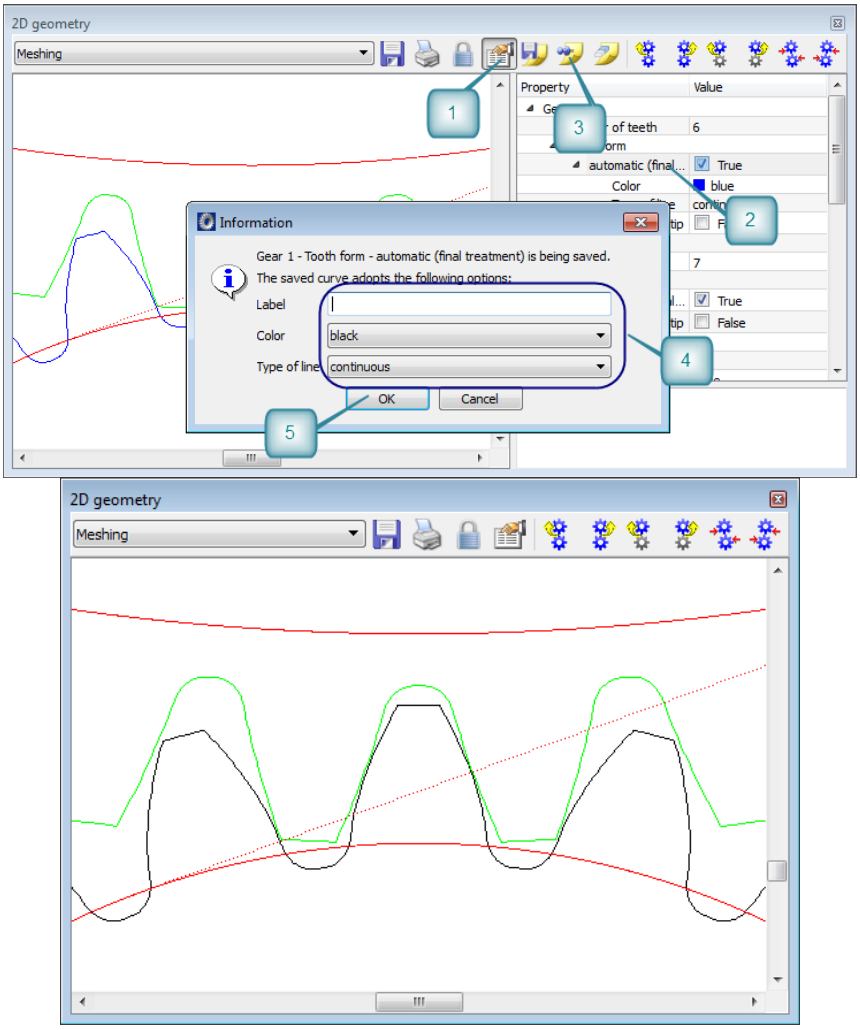


Figure 2.4 Saving the tooth form

To define the tip-rounding, go to the **"Modifications"** tab (see the uppermost marking in Figure 2.5) and input the relevant values for Gear 2 and Gear 5:

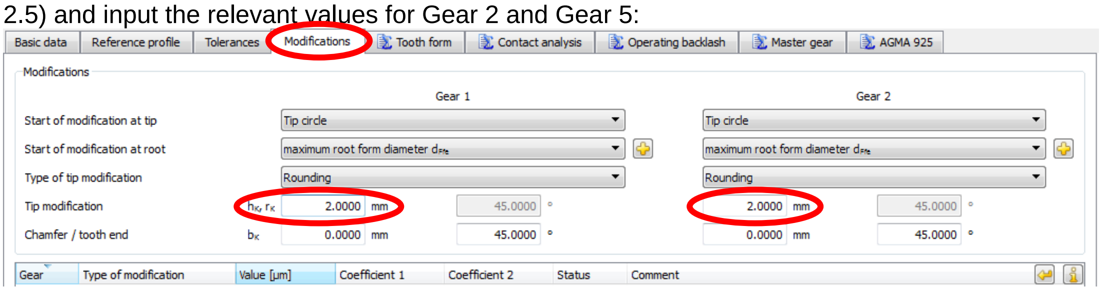


Figure 2.5 Defining tip rounding, here 2 mm radius

Then click on  to apply the changes. 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).

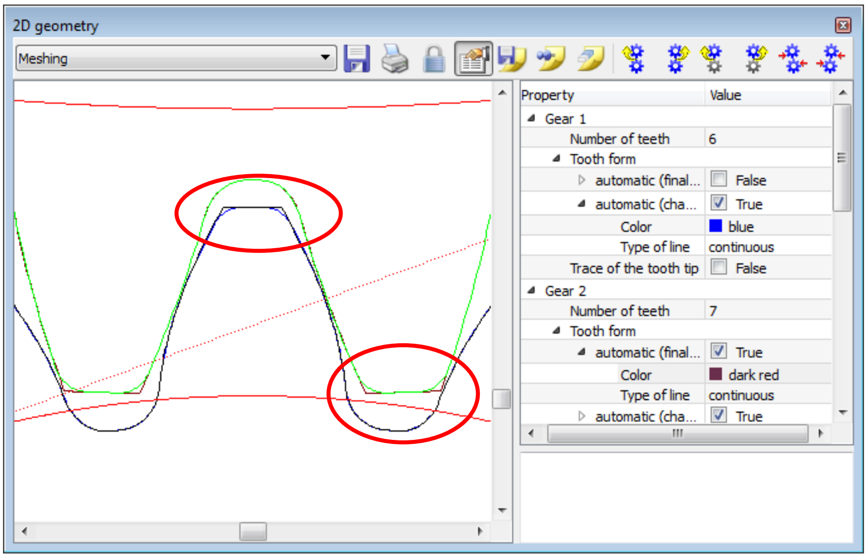


Figure 2.6 Rounded tooth tip

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, click **"Extras"→"Configuration tool"** in the **"Settings"** tab and, in **"Graphics"**, click **"Delete"**.

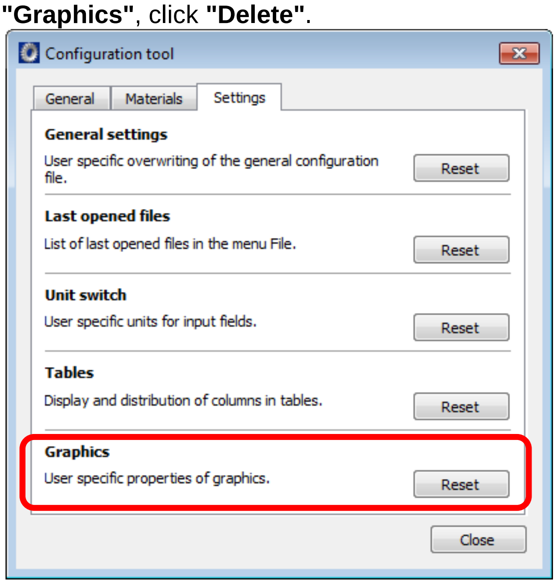


Figure 2.7 Resetting "Graphic properties"

You now see a warning message. As you can further modify the tooth form in the next steps, you can therefore simply close this message by clicking **"OK"**.

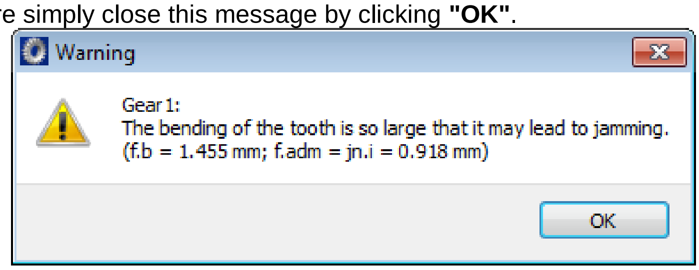


Figure 2.8 "Warning message: tooth deformation"

Note:

The reasons for this may be, for example, an increase in backlash, a profile modification or different materials.

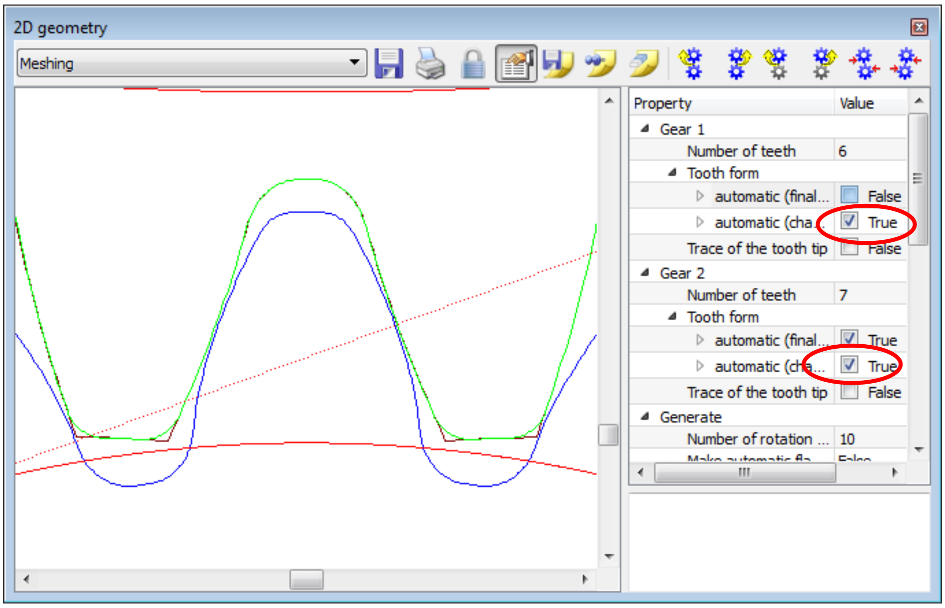


Figure 2.9 Activating all calculation operations

In the main screen, the value calculated for the contact ratio has dropped to 1.3639:

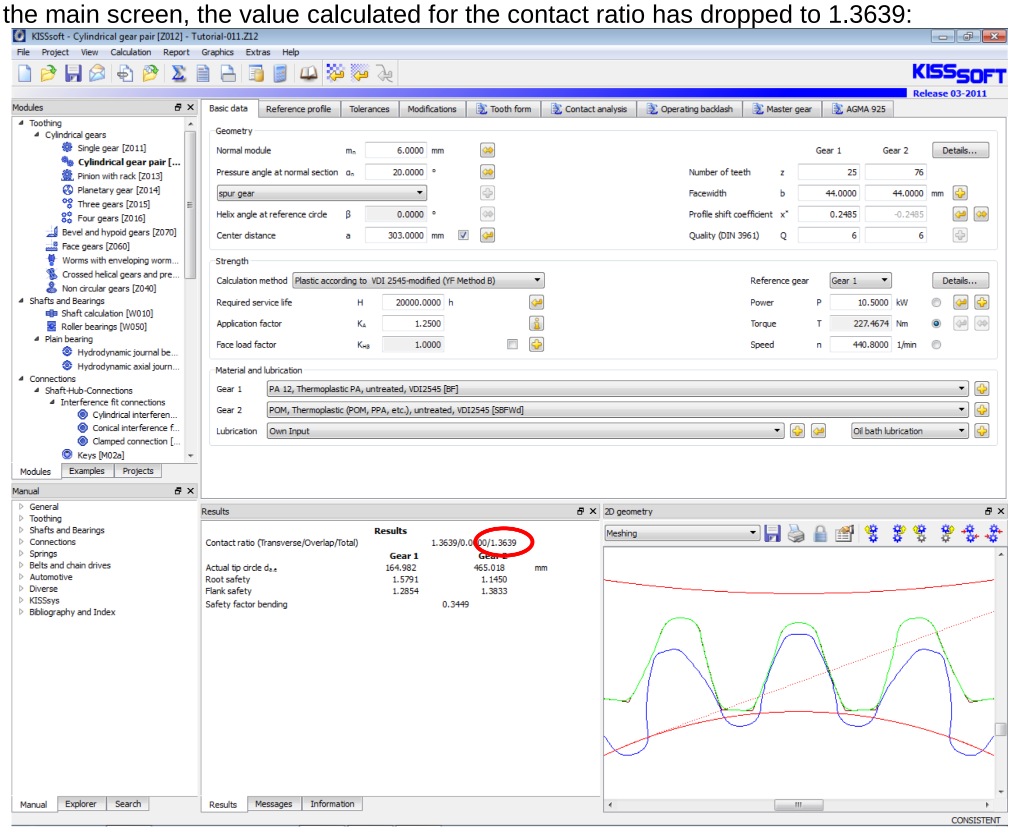


Figure 2.10 Reduction of contact ratio as the result of tip rounding

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. To do this, go to **"Module specific settings"** in the **"General"** tab:

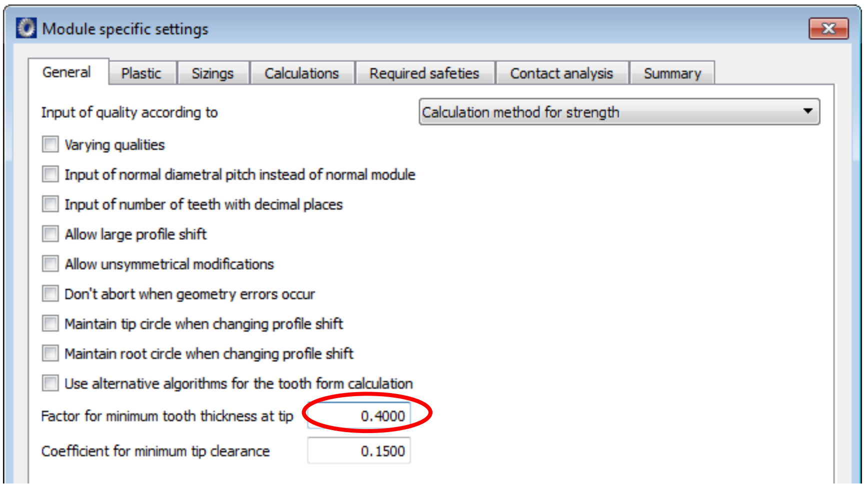


Figure 2.11 Specifying the necessary minimum tooth thickness at the tip in module-specific settings

Essential and effective measures for optimizing geometry are:

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 software programs provide 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.

You call the fine sizing procedure from **"Calculation"→"Fine Sizing"**. KISSsoft Tutorial 009 contains more detailed information about this.

The Fine Sizing screen:

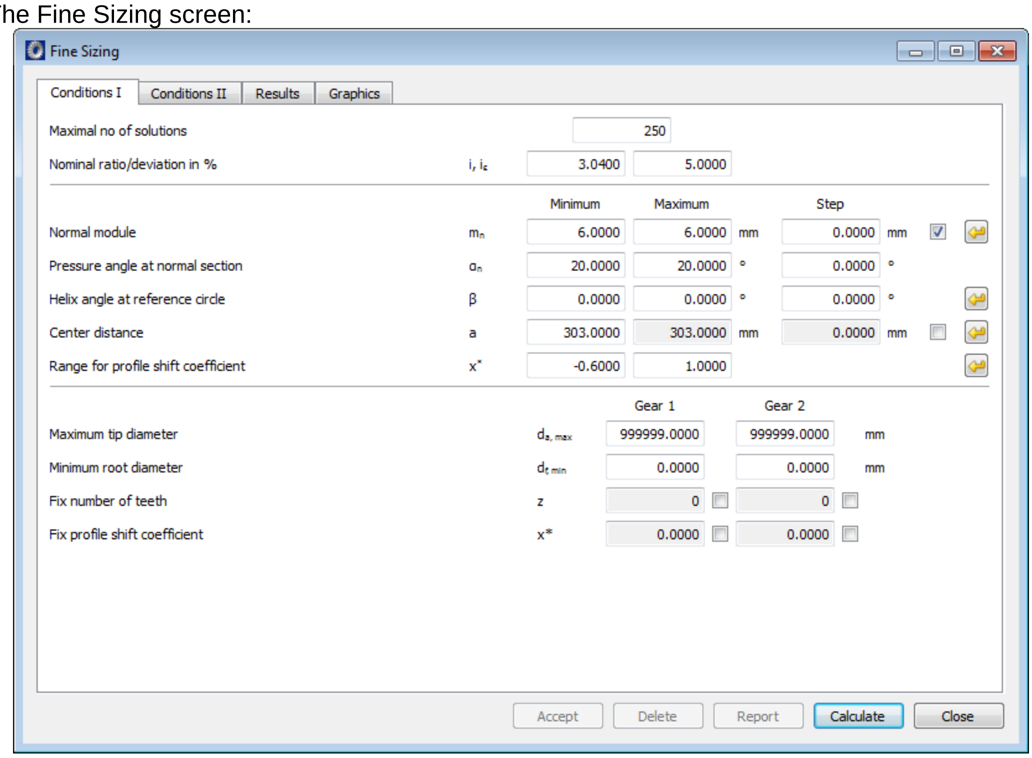


Figure 2.12 Cylindrical gear-Fine Sizing

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 predefined target profile contact ratio and then display these options.

To activate this method, go to the **"Cylindrical gear Fine Sizing"** screen and click the **"Conditions II"** tab. This opens the relevant screen:

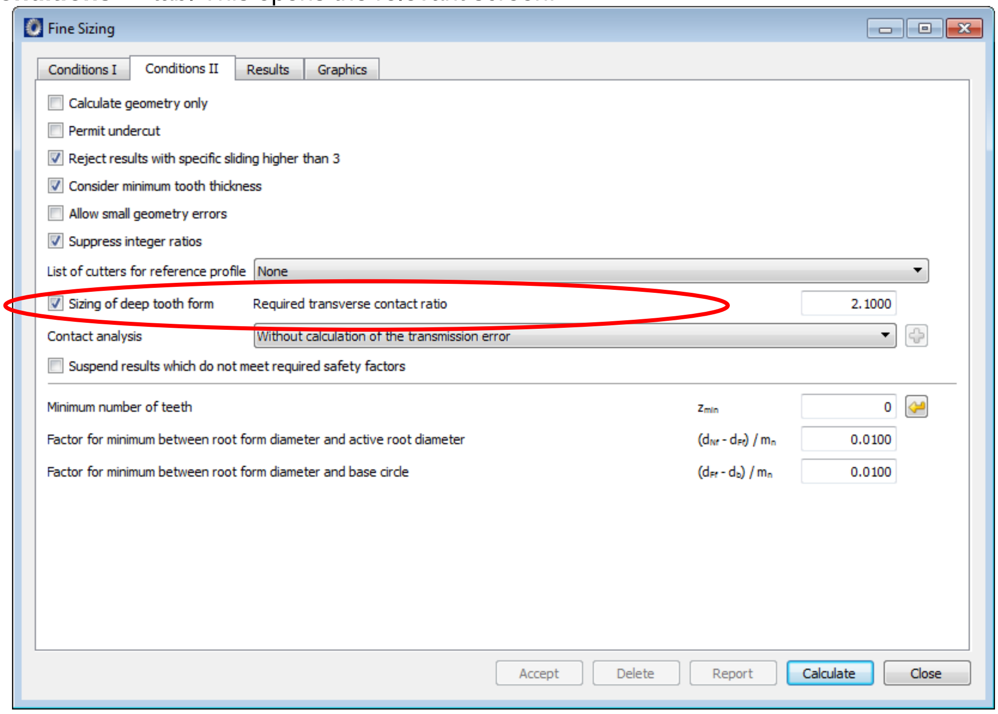


Figure 2.13 Sizing a deep tooth form

Here, set a flag in the **"Sizing of deep tooth form"** checkbox.

You can either specify the required transverse contact ratio directly or use a predefined value. The required profile contact ratio then appears 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 meshes, the contact of the two new gear teeth causes 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.

<u>In the KISSsoft system, you can input profile modifications in two different ways</u>

A) In the "Modifications" tab

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

In the **"Modifications"** tab you can input linear and arc-shaped modifications to the tip and/or root.
The benefit 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. However, Variant B), below, is described here.

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

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

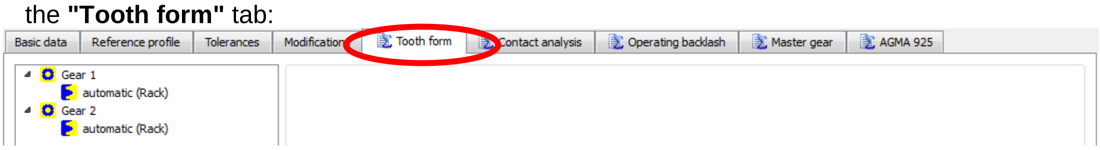


Figure 2.14 Tooth form calculation

The default setting here is "automatic". This means the tool data is generated automatically to match the reference profile defined in the main screen.
Right-hand mouse click on "automatic" to view a menu detailing other operations. Then click the left-hand mouse button to add the required operation.

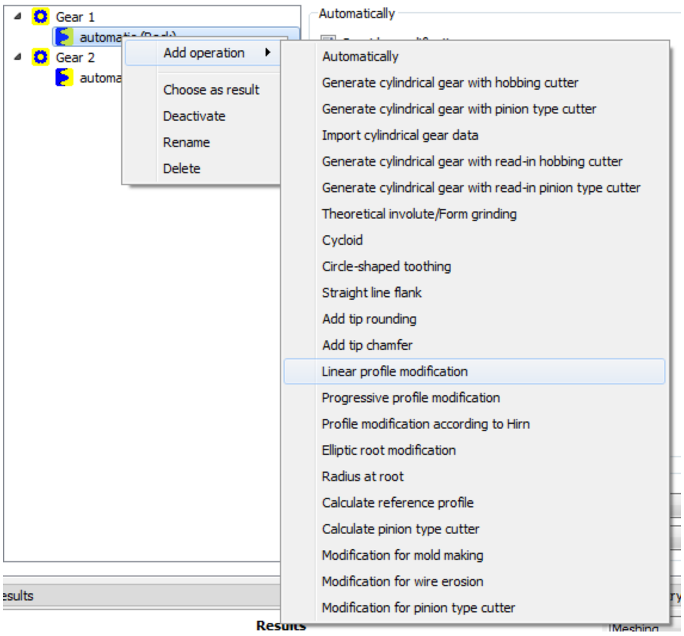


Figure 2.15 Possible operations for the tooth form on Gear 1

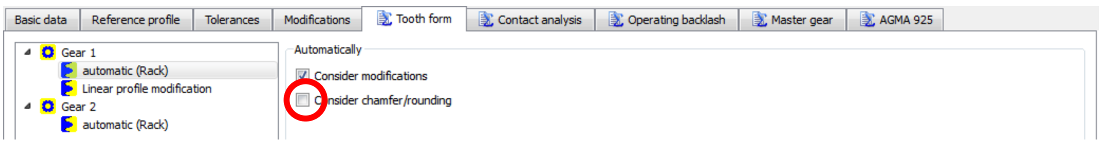


Figure 2.16 Taking into account deactivated tip rounding on Gear 1

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. For this reason, delete the flag 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. The options here are: linear or progressive profile correction, running-in curve consisting of three circular pitches as specified 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, toothing quality, material type (plastic or metal), stiffness and load. By changing the **"Factor for tip rounding"**, you can even change the shape of the curve (in the "Progressive profile correction" option)!

In a progressive profile correction, 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: $\delta s(r) = Ca * \delta r / \delta rK$

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

δs	Profile relief (tooth thickness modification)
r	Radius at an arbitrary point on the tooth form
Ca	Profile relief on the tip circle
δr	ra – r
δrK	ra – raK
ra	Tip circle radius
raK	Radius at the beginning of the correction
Exp	= Factor/5

Factor: range 1-20, usually in the range 5 to 10 (you can input your own value here)

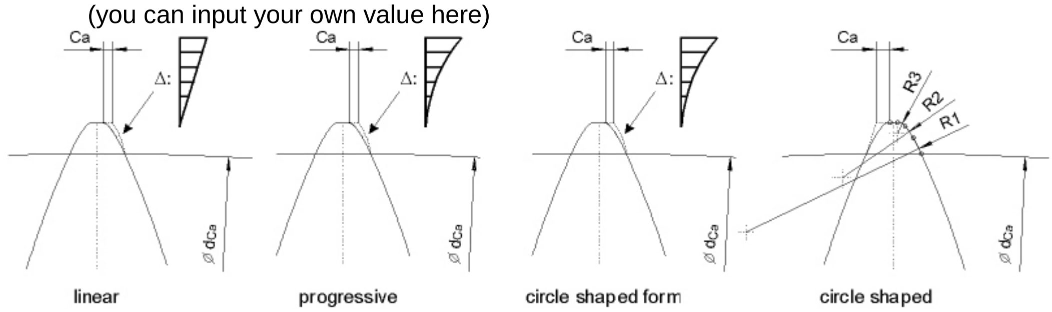


Figure 2.17 Profile correction types

Click the Sizing button  to the right of the **"Modification starting at diameter"** input field to tell the program to calculate suitable values for the beginning and size of the tip relief.

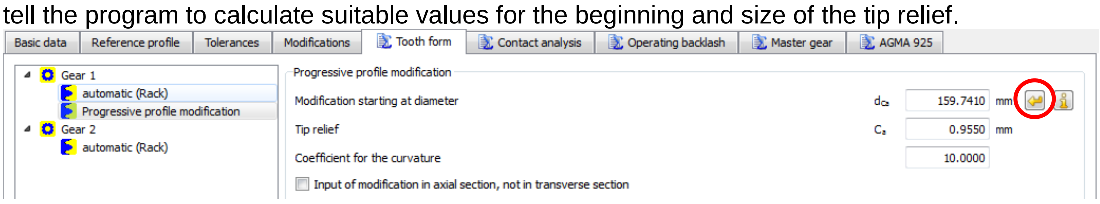


Figure 2.18 Suggested tip relief

If the gear is to be manufactured by moulding processes (injection moulding 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 use the **"Add tip rounding"** option to add a rounding radius to the tip.

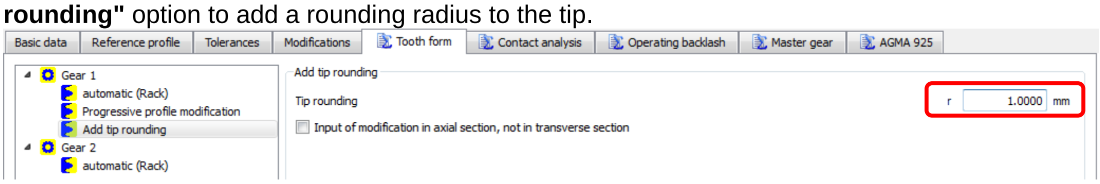


Figure 2.19 Adding tip rounding

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 tooth contact window in the screen (shown circled in red at the bottom right of the window).

To compare the different settings generated when you modify the tooth form, save the last tooth form that was calculated as shown in Figure 2.4.

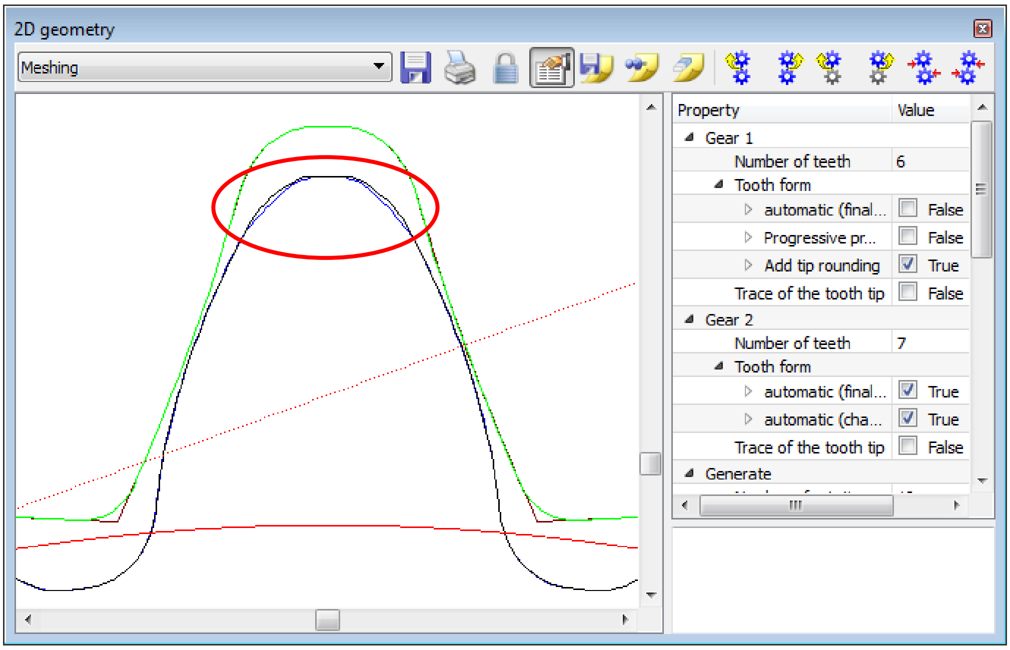


Figure 2.20 Comparing tooth tip modifications

First click the **"Tooth form"** tab in the main screen. In the calculation step for **"Progressive profile modification"** the stored, active calculation has a **"Factor for tip rounding"** of 18. In the **"Add tip rounding"** calculation step it has a **"Tip rounding"** of r=1 mm. Run the calculation again. Now the **"Factor for tip rounding"** is 10 and the **"Tip rounding"** is r=2 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 filet. If gears are manufactured by a generating 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 overall tooth form calculation, in "Elliptical tooth root modifications" in exactly the same way as tip relief as described in 2.6.

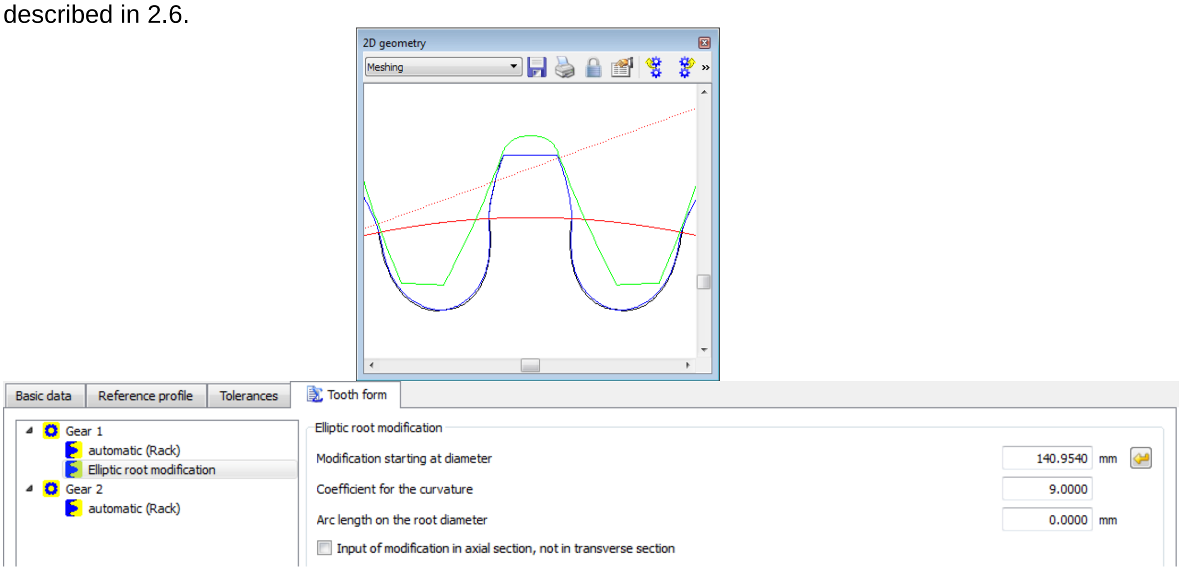
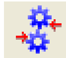


Figure 2.21 Root form without (black, with undercut) and with (blue) optimization

Important: If used with a running-in curve or tip rounding on the mating gear, the start of the filet may encroach above the root 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 root 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.

A useful tool for checking that the meshing is correct is the **"Check for collision"** function. Click this checkbox to activate the collision check. Then click the relevant icon  **"Flank left or right"** to size the flank to the left or the right. A black square shows you if the flanks touch each other. If a collision occurs, this square is red.

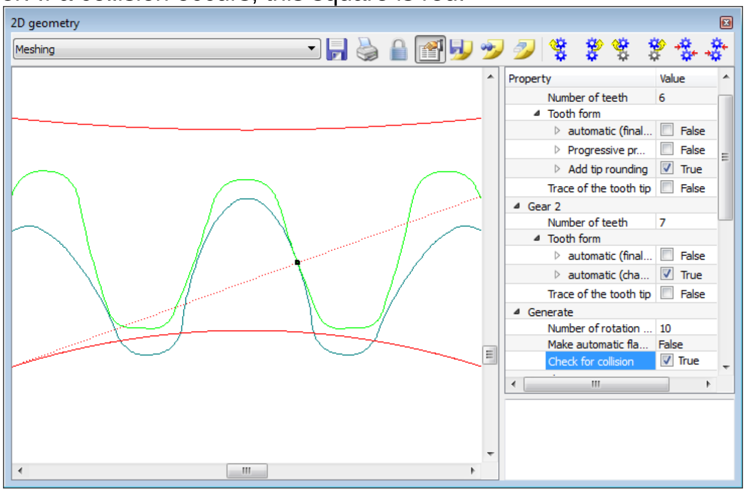


Figure 2.22 Activating the collision check

Click  **"Properties"** to display the settings to the right of the graphic. You can then activate the collision check.

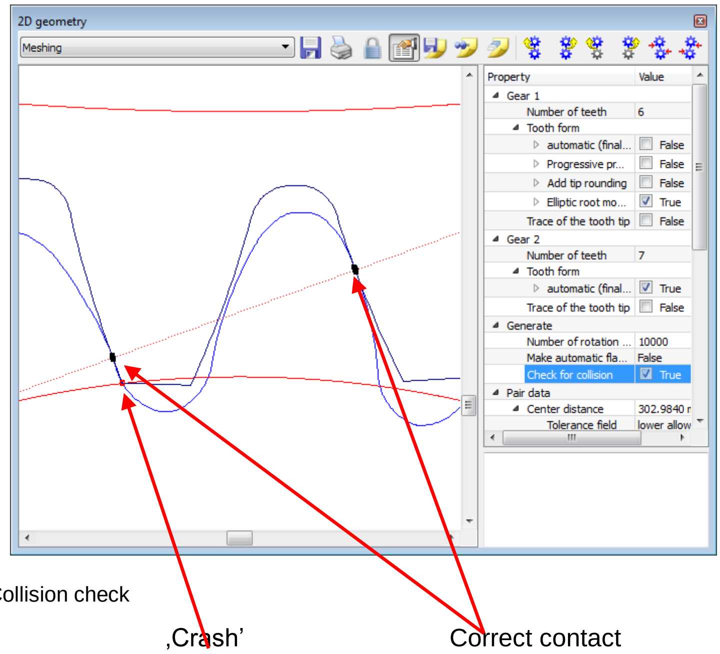


Figure 2.23 Collision check

‚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. minimum 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 the KISSsoft system, you perform this check directly in the **"Tooth contact"** window by reducing the center distance until the backlash is removed. In this situation, clearance must still be present between the tip of one gear and the root circle of the other!

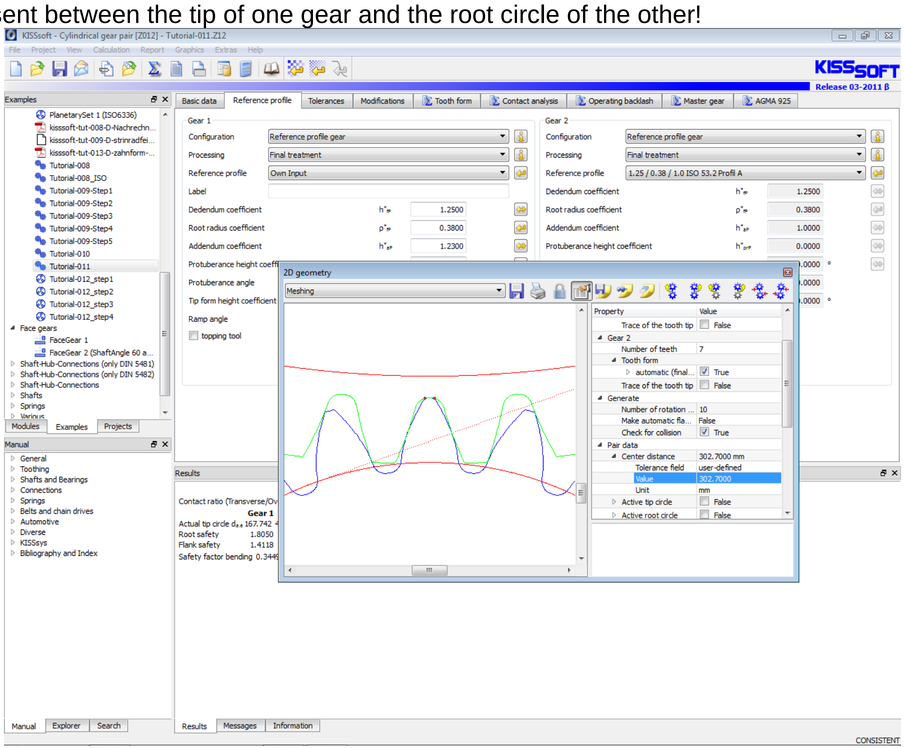


Figure 2.24 This is a BAD example: after the backlash has been removed, the tip of Gear1 is already deep in the root area of Gear2!

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 none (dry run)).

Whereas for steel, the root strength calculation depends on a single value (for example, root resistance [σ_{Flim}] of 17 CrNiMo6: 525 N/mm2), you will 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 information about this in the manual, especially in the sections "Materials for gears", "Plastics as specified in VDI 2545", "Plastics".

3.2 Input your own data for plastics

The KISSsoft material database already contains data about some 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:

Start the database tool by clicking **"Extras"->"Database tool"**, open the material database, and click on data for the gear calculation:

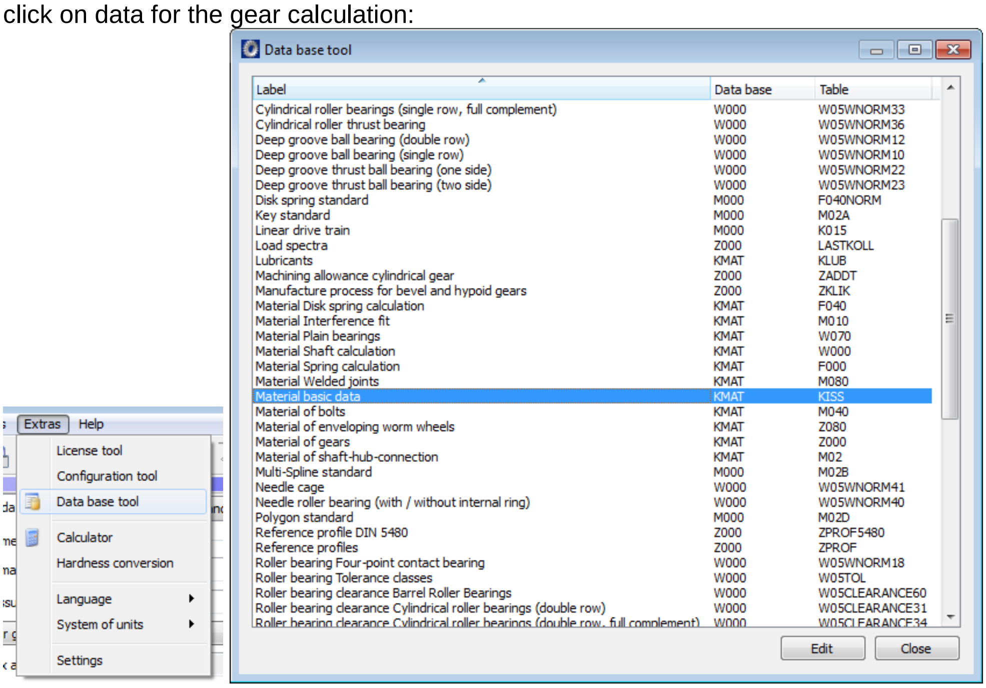


Figure 3.1 Opening the gear material database

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. To define a data set, click **"+"**. You can then edit this data set. If you have already selected a material, this data is transferred to the new data set and a new material description is created.

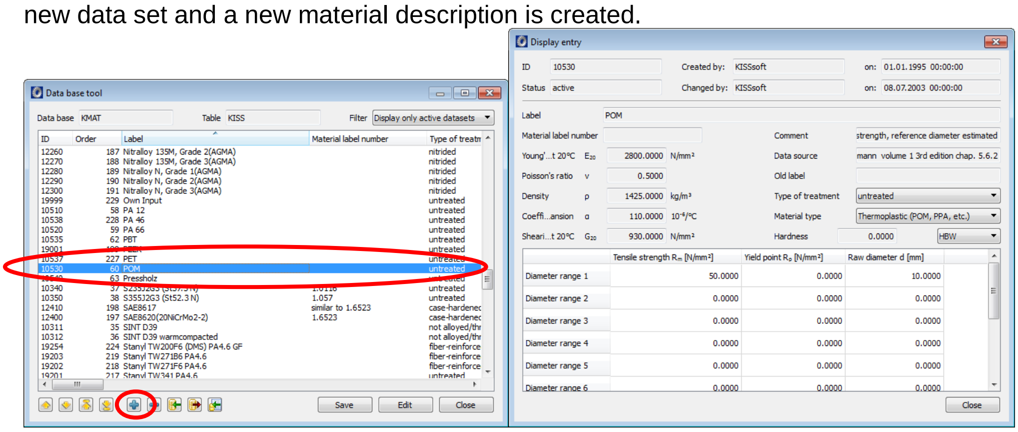


Figure 3.2 Generating a new data record

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

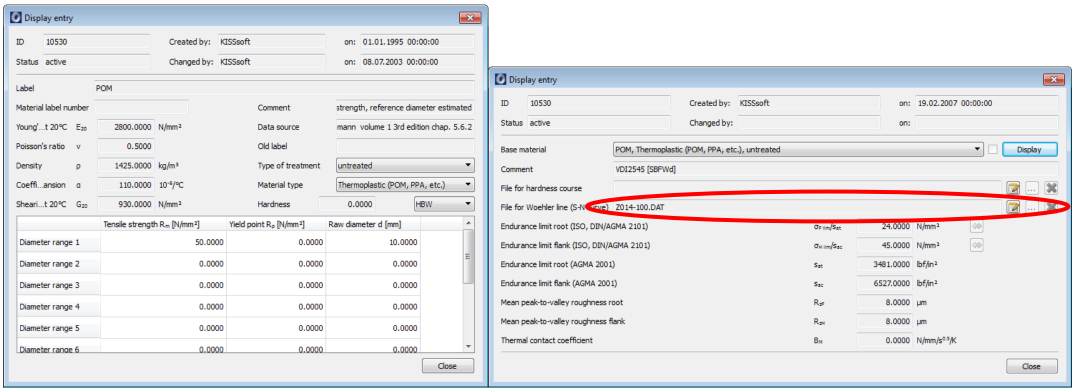


Figure 3.3 "Material basic data" module-specific data "Gear material" for plastic

The most important information is the entry under **"File for Woehler line"**, as shown in Figure . This is where you input the name of the file in which the temperature and lubricant dependent data is stored. You must save this file in the installation folder (usually C: \Programs\KISSsoft-03-2011\ext\dat):

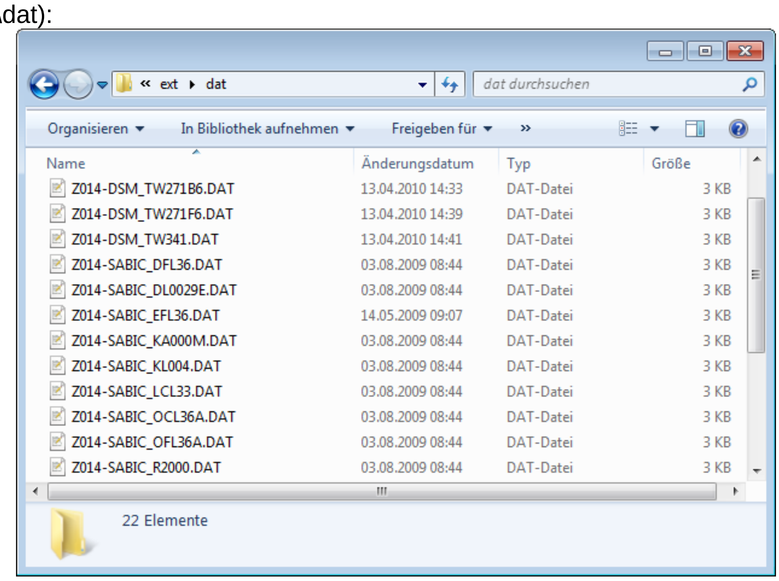


Figure 3.4 Location for saving own plastic data

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). To do this, we recommend you copy an existing plastic file (for example, the file Z014-100.DAT for POM), rename it and then edit it.

Extract from Z014-100. DAT (for POM): Young's modulus
(One-dimensional table with Young's modulus, dependent on temperature)

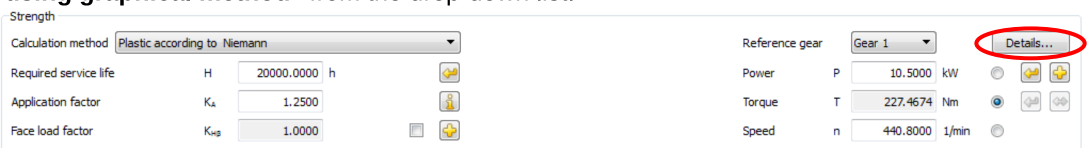
```
: TABLE FUNCTION ElastizitatsModul
 INPUT X ZahnTempFuss TREAT LINEAR
DATA
 -20 0 20 40 60 80 100 120
 4400 3950 3500 2950 2400 1800 1400 950
END
```

Extract from Z014-100. DAT (for POM): Flank strength with oil lubrication
(two-dimensional table with sig. Hlim depending 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 VDI2545, DIN3990, ISO6336 or AGMA2001 standards 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 filet in DIN or ISO). However, for gears with a pressure angle that varies greatly from 20 degrees 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 performs the calculation exactly according to the corresponding formulae of the selected calculation methods (YF and YS in DIN, ISO, AGMA) in approximately 50 cross sections in the root region from the mid-tooth height to the root, and determines the cross section with the highest 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.
How to activate this "graphical method" in the KISSsoft system. When you input the strength, right-hand click the Details button. In the next screen, under **"Form factors YF and YS"**click **"using graphical method"** from the drop-down list.



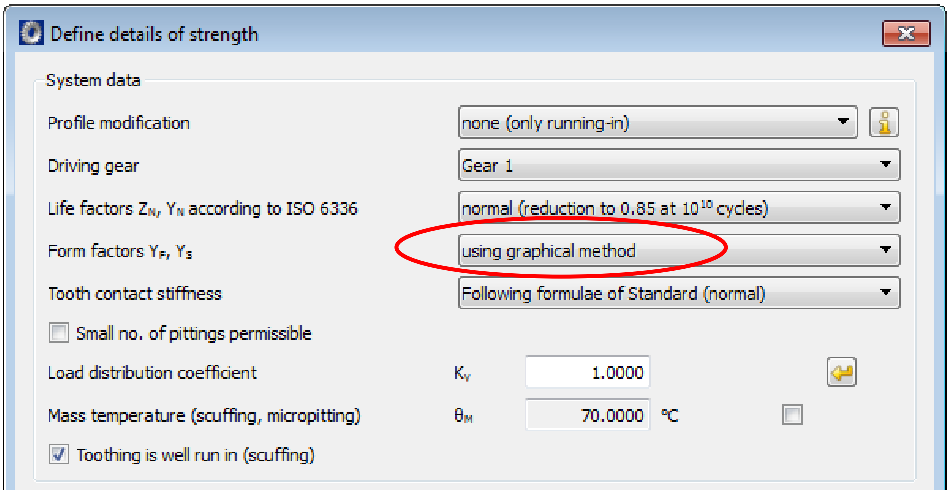


Figure 3.5 Activating strength calculation using the graphical method

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

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

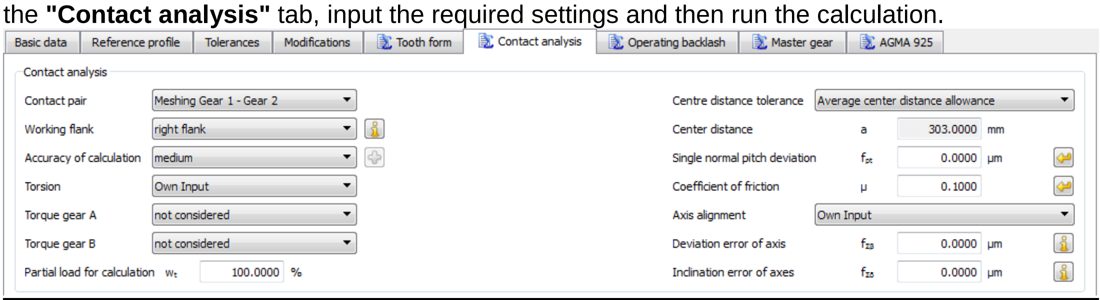


Figure 3.6 Calculating the Contact analysis

Then, under **"Graphics"→"Contact analysis"**, select the graphic you require, like the stress curve 2D shown in our example.

Here you see the effective tooth root strain in Gear 1 and Gear 2 during the contact shown in dark blue and green. The light blue curve shows the progression of Hertzian surface pressure.

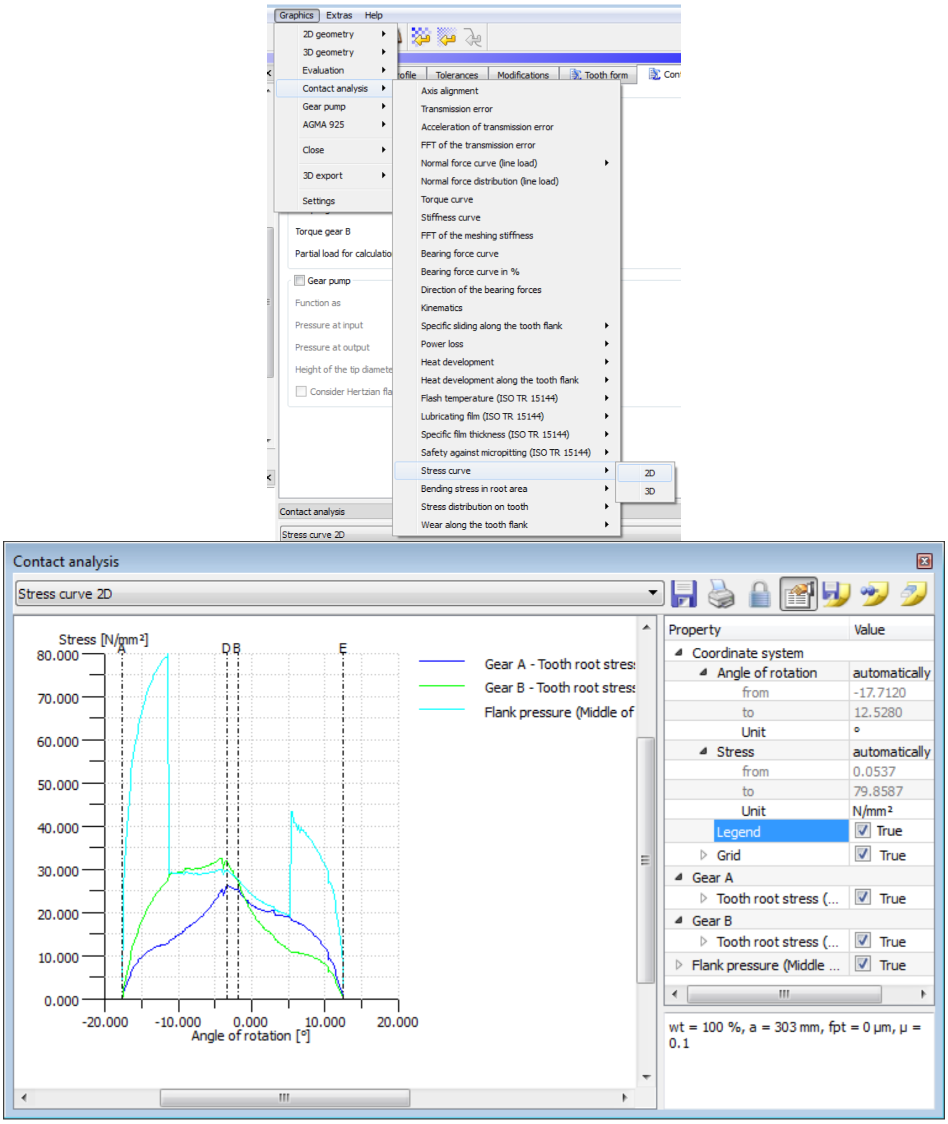


Figure 3.7 Tooth root stresses and Hertzian pressure, progressions over meshing using the example in the "Tutorial-3.Z31" file with modifications (progressive profile rounding, "Factor for tip rounding" 10 and "Tip rounding" r=12 mm)

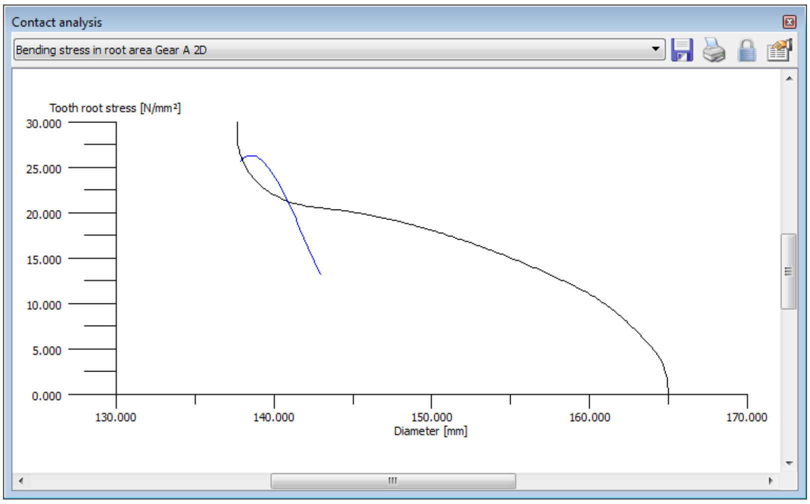


Figure 3.8 Tooth root stresses, progression in the tooth root

4 Defining the Tooth Thickness Deviation

4.1 Introduction

In the precision engineering industry, the relative deviations (tooth thickness deviation) are usually much higher for gears with module 1.0 or greater. If the relative center distance tolerance is large, and the tooth quality 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 to 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 detail (as described below) and then discovering that your carefully designed gear gets "chewed up" at its tip because the deviation is too great!

Use the method specified in DIN3967 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 is the most critical plastic (swells up to 2% due to water absorption).

4.2 Calculating operating backlash

The KISSsoft system provides an example file for calculating plastic gears "CylGearPair 2 (Plastic-Deep Tooth Profile)". 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:

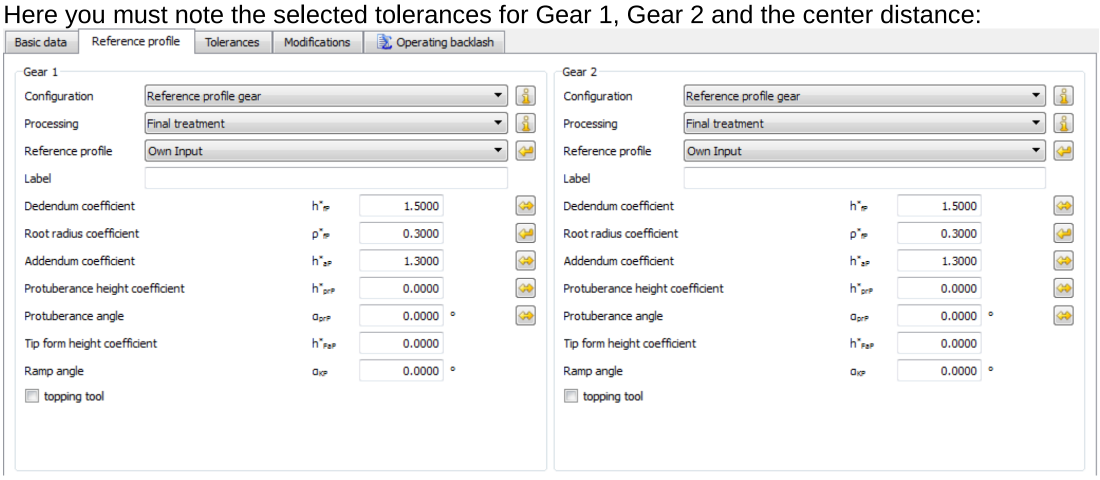


Figure 4.1 Preselected tolerances for Gear 4, Gear 33 and center distance

Before you can calculate the operating backlash, click **"Σ"** (calculate) to calculate the intermeshing. After this, click the **"Operating backlash"** tab to call the operating backlash calculation:

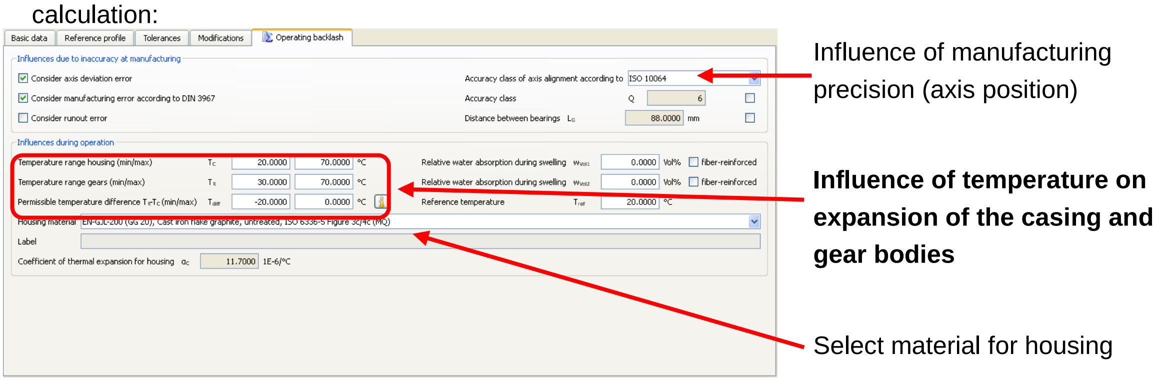


Figure 4.2 Settings for operating backlash calculation

This example is defined so that seizing may occur during operation. This opens the following KISSsoft user interface:

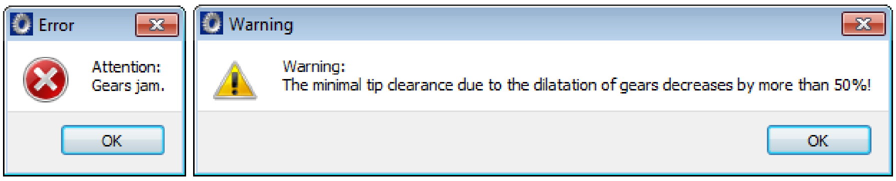


Figure 4.3 Error messages: Warning message "Gears jam": tooth tips collide

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

```
Results :
Change of center distance by:
Warming                                    (mm)      [DaC]                   0.037
Casing
                                           (mm)      [DaW]                  -0.211
Gears

Backlash change due to:
Center distance tolerances                 (mm)      [Dja.e/i]         0.006/-0.006
Swelling due to absorption of water        (mm)      [DjQ]                    0.000
Warming                                    (mm)      [Djtheta]               -0.114
Misalignment of axles                      (mm)      [DjSigmabeta]           -0.006
Mesh single deviation                      (mm)      [DjF]                   -0.014

Theoretical backlash
- Circumferential backlash
                          (min.)           (mm)      [jt.i]                   0.118
                          (max.)           (mm)      [jt.e]                   0.201

Acceptance-backlash
- Circumferential backlash
                          (min.)           (mm)      [jta.i]                  0.102
                          (max.)           (mm)      [jta.e]                  0.186

Smallest operating backlash
- Temperature combination
    Gear body temperature                  (°C)      [TR]                     70.00
    Case body temperature                  (°C)      [TC]                     70.00
- Circumferential backlash
                          (min.)           (mm)      [jtw.i]                 -0.105
                          (max.)           (mm)      [jtw.e]                 -0.021
- Normal backlash
                          (min.)           (mm)      [jnw.i]                 -0.100
                          (max.)           (mm)      [jnw.e]                 -0.020
- Radial clearance
                          (min.)           (mm)      [jrw.i]                 -0.154
                          (max.)           (mm)      [jrw.e]                 -0.031

- Torsional angle with fixed gear 1
                          (min.)           (°)       [Dphit.i]               0.0000
                          (max.)           (°)       [Dphit.e]               0.0000
```

Figure 4.4 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 -0.105mm (see the yellow text marked above). To prevent the gears from seizing, this value must be greater than zero. To do this, change the tooth thickness deviation (make the teeth thinner). Both gears are reduced by 0.06 mm (to increase the circumferential backlash by 0.12 mm to ensure it remains positive). To do this, go to the **"Tolerances"** tab and set tooth thickness tolerance to **"Own Input"**. Then increase the circumferential backlash by 0.06 mm in each case (for the lower and also the upper deviation of both gears):

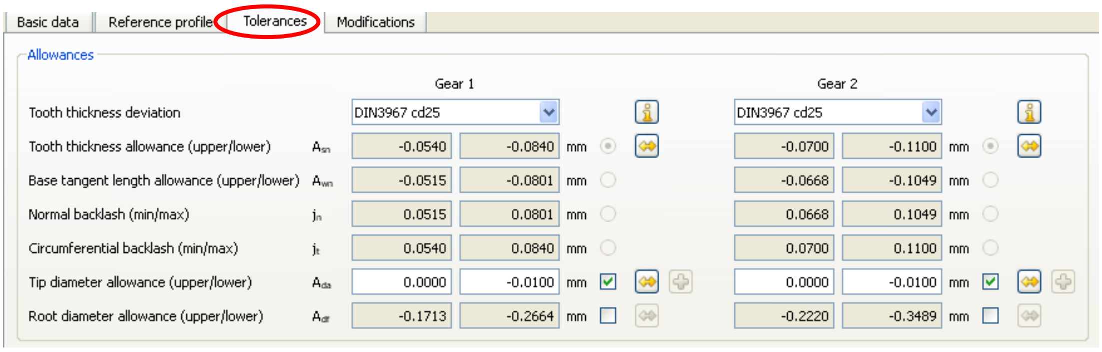


Figure 4.5 Original state (tolerance cd4 as specified in DIN37)

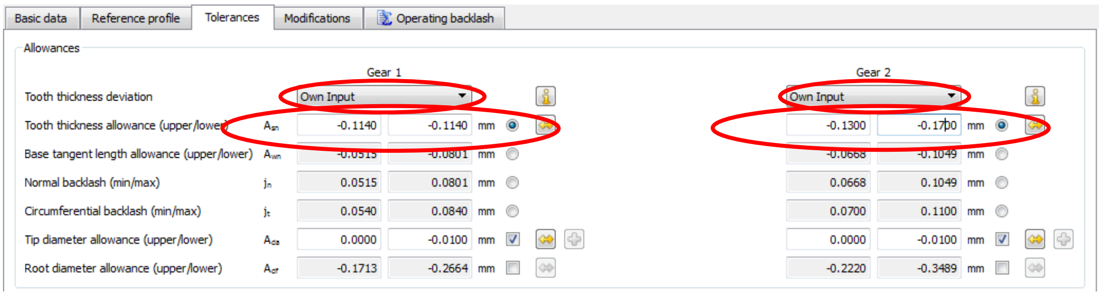


Figure 4.6 Increase the circumferential backlash for both gears by 0.1 mm each

After you have input this data, click (calculate) again to recalculate the tooth form and then rerun the operating backlash calculation as described above. This time, no warning appears (because the gears do not jam) and you see a positive operating backlash in the report:

```
. ..
Smallest operating backlash
- Temperature combination
    Gear body temperature                (°C)     [TR]                         70.00
    Case body temperature                (°C)     [TC]                         70.00
- Circumferential backlash
                          (min.)         (mm)     [jtw.i]                      0.015
                          (max.)         (mm)     [jtw.e]                      0.069
- Normal backlash
                          (min.)         (mm)     [jnw.i]                      0.014
                          (max.)         (mm)     [jnw.e]                      0.066
- Radial clearance
                          (min.)         (mm)     [jrw.i]                      0.022
                          (max.)         (mm)     [jrw.e]                      0.101

- Torsional angle with fixed gear 1
                          (min.)         (°)      [Dphit.i]                    0.0180
                          (max.)         (°)      [Dphit.e]                    0.0823
```

Figure 4.7 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 the KISSsoft system, using the mid-value of the tooth thickness deviations. The results in 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 the KISSsoft system, 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 mould to compensate for shrinkage

To activate these modifications, click the **"Tooth form"** tab to call the tooth form calculation and then add the additional operations to the existing operation "automatic (Rack)".

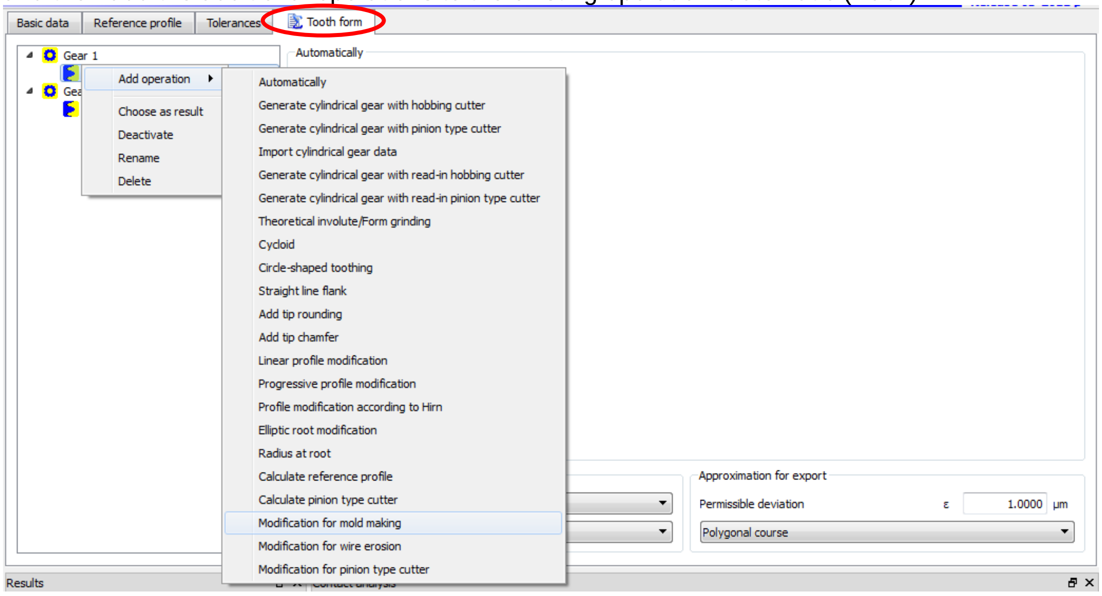


Figure 5.1 Tooth form calculation with modifications for mould construction

You can now input the radial and tangential expansion. Click Σ to calculate the resulting tooth form and then click **"2D"** to display it:

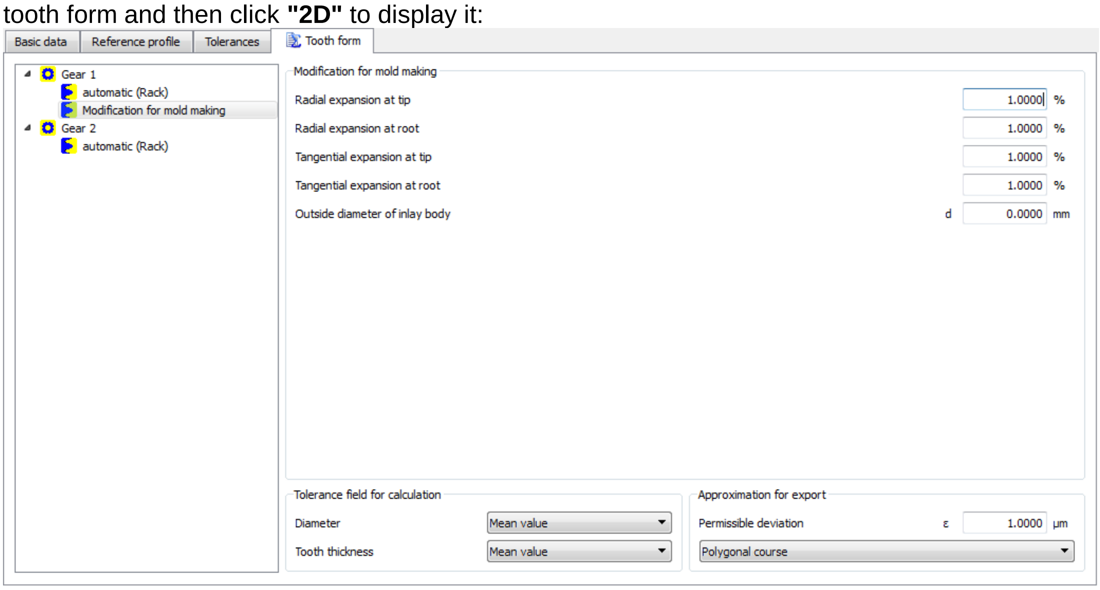
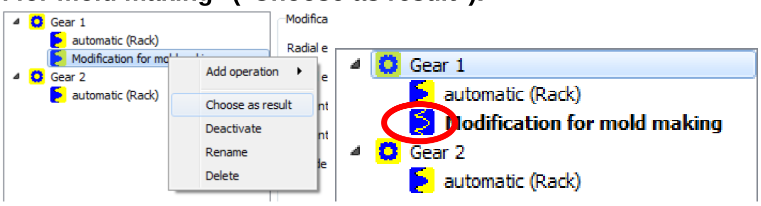


Figure 5.2 Calling the gear pair display

<u>Note:</u> Before you can display the modified tooth form display, you must first activate "Modification for mold making" ("Choose as result").



The color blue indicates that this operation is used for the display!

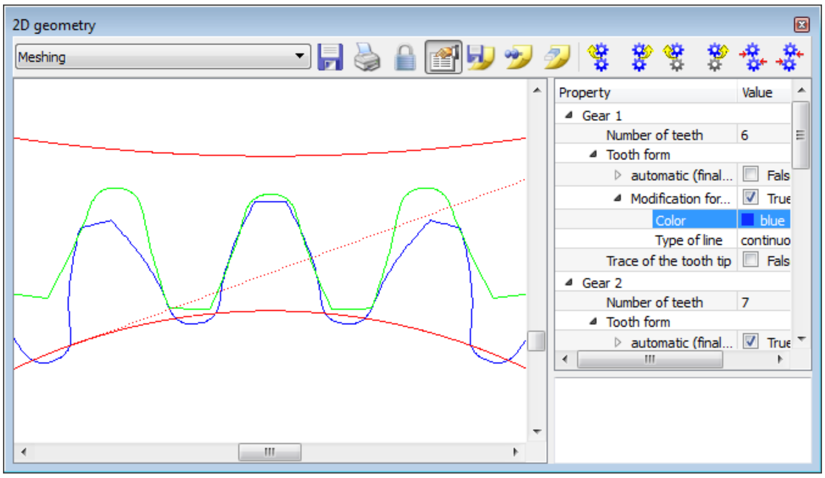


Figure 5.3 Displaying the gears, expanded by the specified shrinkage

If you want to use these tooth forms to manufacture moulds, it is a good idea to export them individually. Under **"Permissible deviation"**, you can input a value in µ to specify the maximum size of the tooth form deviation. You can now open the graphic window immediately to display the tooth form of Gear 1 and Gear 2.

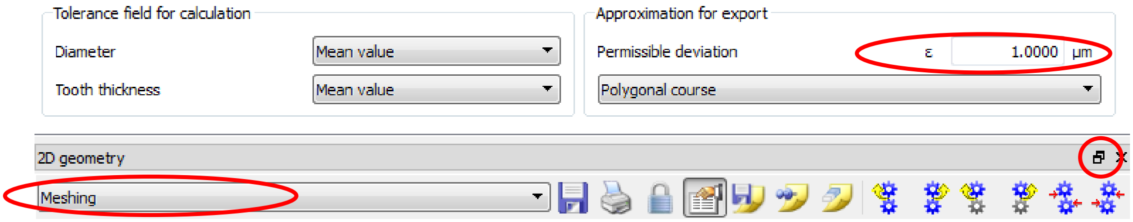


Figure 5.4 Permissible deviation; open graphic window

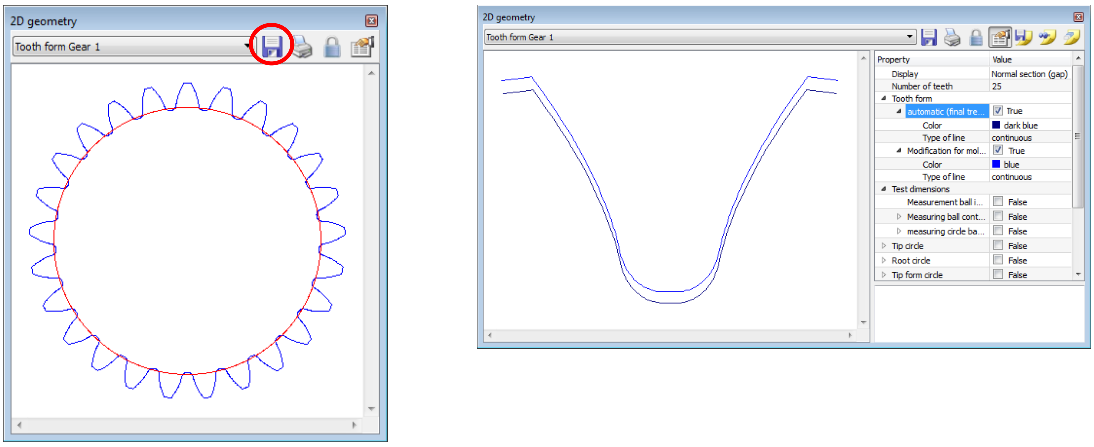


Figure 5.5 Calling the tooth form display for a single gear and exporting the tooth form to DXF or IGES

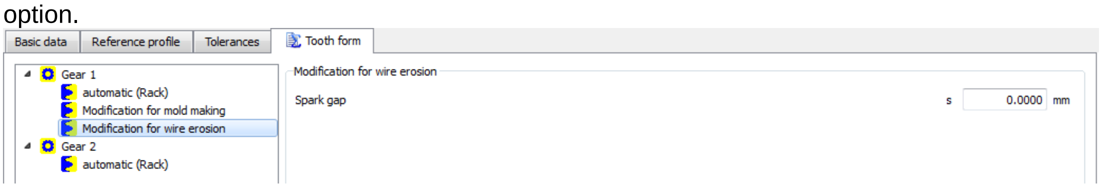
It is essential you check the title of the graphic. In the left-hand graphic you see the expanded tooth form (shown with mould construction modification). In the right-hand image you also see the NON modified tooth form in "black".

You use this procedure to display the tooth form expanded by the specified shrinkage as in Figure

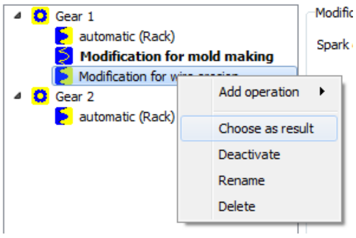
5.3 Display the eroding wire/spark gap

In addition, when you calculate the injection mould 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 mould. 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 mould 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.
To take the spark gap into consideration, you must also use the "Modification for wire erosion" option.



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



Original tooth form:

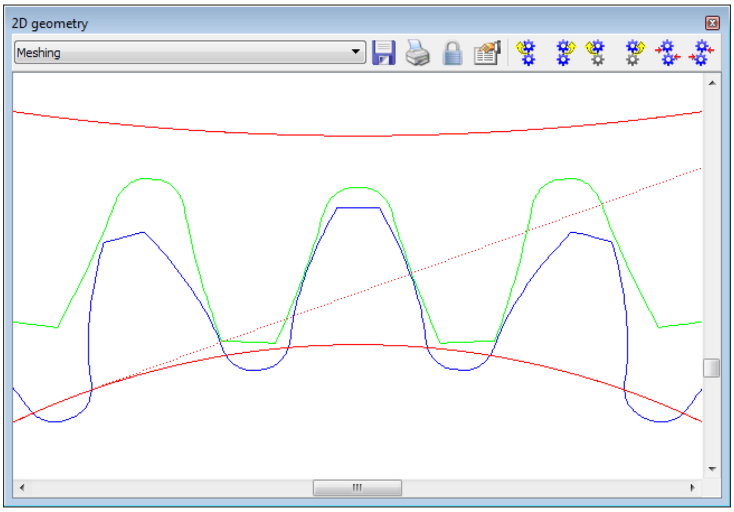
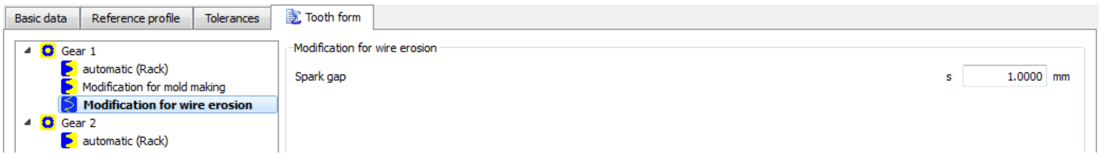


Figure 5.6 Tooth form without modifications



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

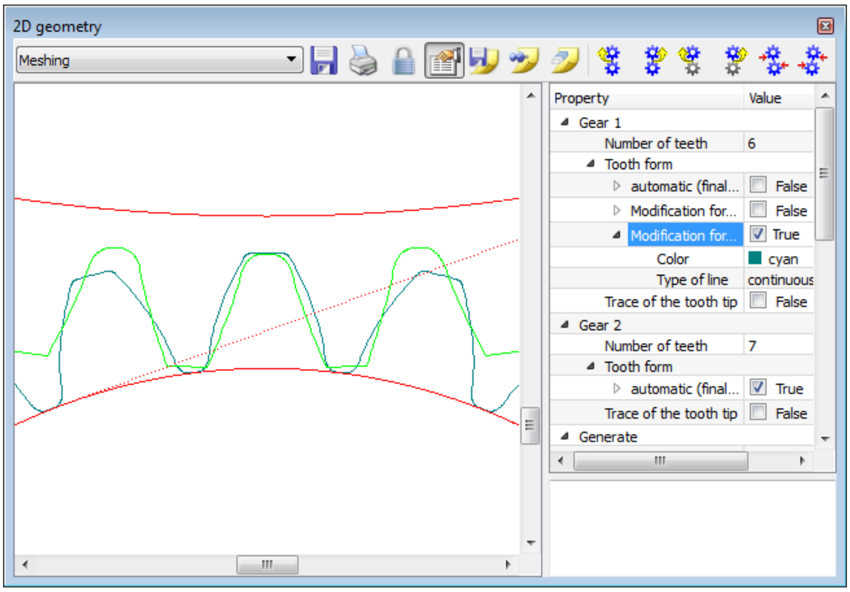
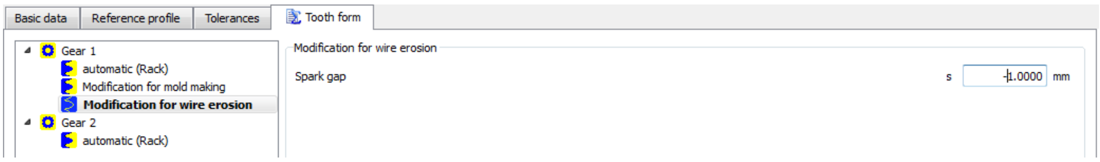


Figure 5.7 Tooth form with a 1 mm spark gap



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.

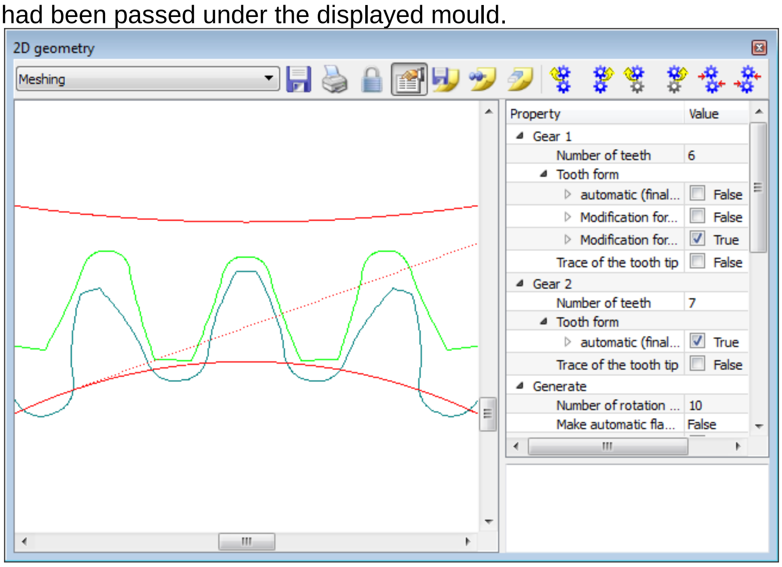


Figure 5.8 Tooth form with a -1 mm spark gap

5.4 Monitoring the wire diameter during erosion

If the injection mould is produced by wire erosion, you must check whether the wire you want to use is fit for this purpose. To do this, follow these steps in the "**Tooth form"** tab. Reload the example file "Tutorial-011.Z12". Then work through these calculation steps in the **"Tooth form"** tab:

Add **"Modification for wire erosion"** with a negative spark gap, which corresponds to half the wire's diameter. Then click **"Modification for wire erosion"** again, but this time the half wire diameter is positive. Then click **"Choose as result"**. Now switch all the settings in the graphics properties to **"True"** for all calculation steps.

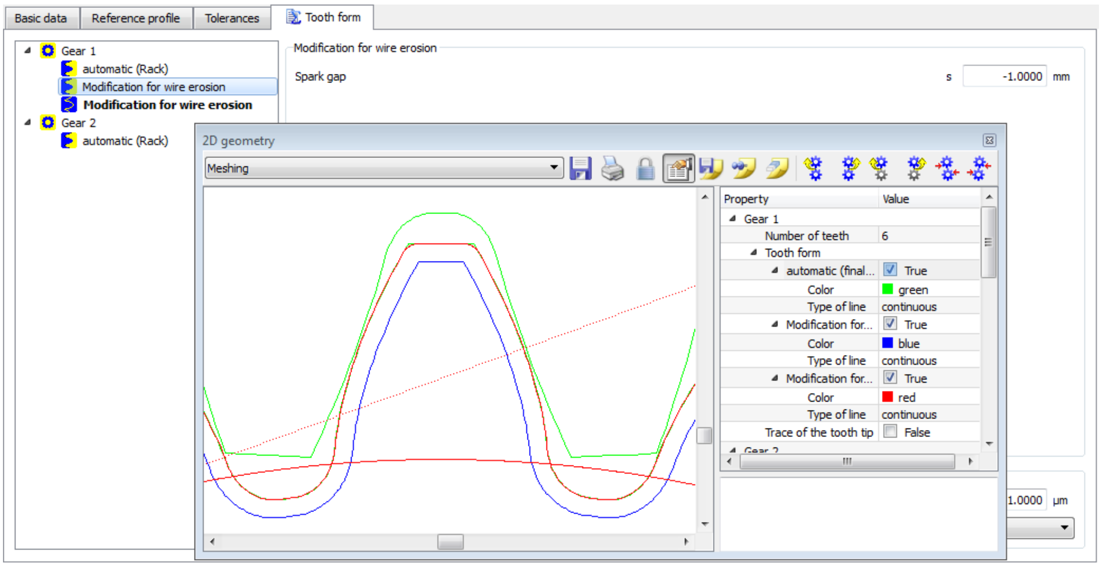


Figure 5.9 Inputting half the diameter of the eroding wire as the "spark gap"

You now see all the calculation steps in the tooth form geometry. The blue curve shows the mid point of the path along which the cutting wire travels. The red contour shows the generated contour whereas the black line is the target contour.

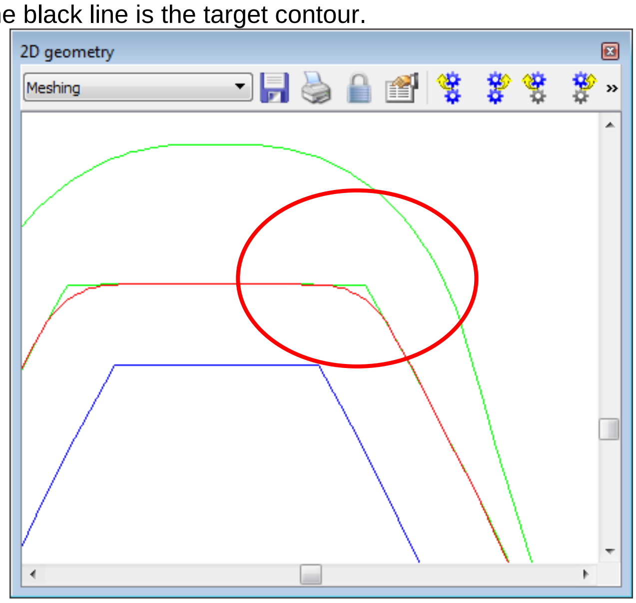


Figure 5.10 Check

5.5 Calculating a 3D mould

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 STEP formats to do this.

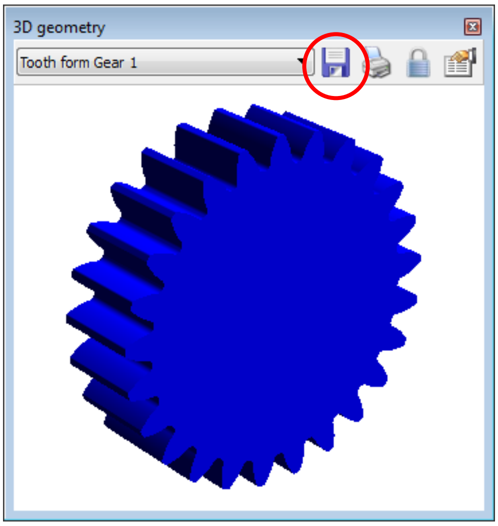


Figure 5.11 Geometry export