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KISSsoft Tutorial: Tooth Root Optimization

1 Overview

1.1 Task

This tutorial shows how tooth root geometry influences tooth strength and how it can be optimized. It recommends you use the "Graphical method" if you want to study the root strength of non-standard root geometry.
To do this, you use the strength calculation and tooth geometry calculation.

1.2 Results

Three different root geometries are to be examined:

1. resulting root geometry, with a tool root radius factor ρ^*_{fP}=0.38
2. resulting root geometry, with a tool root radius factor ρ^*_{fP}=0.45
3. optimized root geometry (elliptical rounding)

The following results for safety factors are found when you use a combination of ISO 6336 and ISO 6336 and the "Graphical method":

	SF based on sizing specified in ISO6336	SF based on sizing specified in ISO6336 with the "Graphical method
Geometry 1 (∗fP=0.38)	2.5940	2.4966
Geometry 2 (∗fP=0.45)	2.7584	2.6756
Geometry 3 (elliptical)	2.7584*	2.8868
Improvement from Geometry 1 to Geometry 3	6%*	16%

Table 1.1 Comparison of calculated safety factors for tooth root bending strength safety factors depending on method

As you can clearly see, by optimizing the root geometry, the safety factor against bending failure has been increased by 16%. However, this optimized root rounding requires a special tool (modified cutter). For this reason, we recommend you use this method for mass production (e.g. by form grinding) or if the gears are manufactured by wire erosion or sintering.
*Note: if you use the unmodified ISO 6336 method (or other methods like DIN 3990 or AGMA 2001) you cannot estimate a modified root geometry. You can see this because the results from Geometry 2 to Geometry 3 do not change.

1.3 Theory

The value ρ_{fP} is the radius of the root of the reference profile of the gear as shown below:

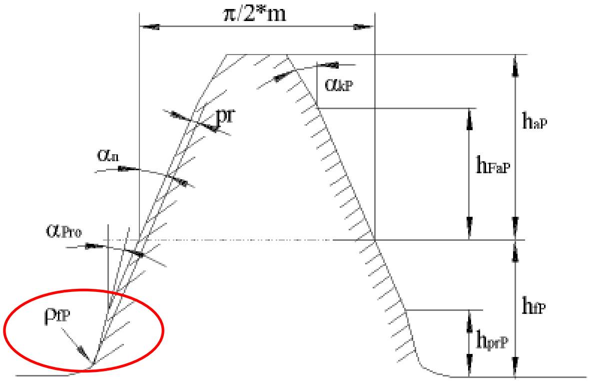
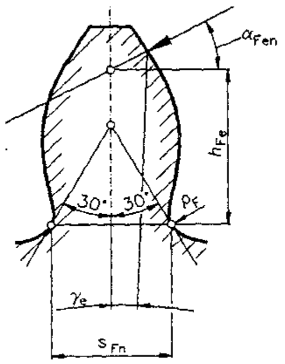


Figure 1.1 Reference profile of the gear, ρfP

The strength rating specified in ISO 6336 uses only a single point in the root where factors YF and YS are calculated. This point is defined by the contact between a tangent to the root intersecting the symmetry line at a 30° angle and the root itself. YF and YS are then calculated as shown in formulas (2) and (3). The resulting root stress is then calculated in accordance with formula.



Method B:

$$\sigma_{FO-B} = \frac{F_t}{b m_n} \cdot Y_F \cdot Y_S \cdot Y_\beta$$

Method C:

$$\sigma_{FO-C} = \frac{F_t}{b m_n} \cdot Y_{Fa} \cdot Y_{Sa} \cdot Y_\varepsilon \cdot Y_\beta$$

$$\sigma_F = \sigma_{FO} \cdot K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha} \leq \sigma_{FP} \quad (1)$$

$$Y_F = \frac{\frac{6 \cdot h_{Fe}}{m_n} \cdot \cos \alpha_{Fen}}{\left(\frac{s_{Fn}}{m_n}\right)^2 \cdot \cos \alpha_n} \quad (2)$$

$$Y_S = (1.2 + 0.13 \cdot L) \cdot q_s^{\left[\frac{1}{1.21 + \frac{2.3}{L}}\right]}$$

$$L = \frac{s_{Fn}}{h_{Fe}}, q_s = \frac{s_{Fn}}{2 \rho_F} \quad (3)$$

Figure 1.2 Calculating the tooth root stress as specified in ISO 6336

The actual construction of the root rounding therefore implies a larger or smaller degree of error.

KISSsoft therefore includes a modification in the calculation methods, allowing for the calculation of YF and YS factors along the whole of the root. In this case, the point at which the product of YF*YS reaches the maximum is taken as the point where the strength rating is performed.

This is the only method that allows you to evaluate the effect of optimized root roundings.

1.4 Other contents of this tutorial

In section 2, the root safety factor is calculated according to the unmodified ISO 6336 method (Method B). However, you cannot use this method to take into account the effect of root optimization. The root safety factor is therefore only calculated for Geometry 1 and 2.

In section 3, the root safety is then calculated using the graphical method (an optional modification to ISO 6336 by KISSsoft). Here you can clearly see the effect of optimized root rounding.

The comparison between the calculated results is shown in **Table 1.1**

Further explanations and comments are given in section 4.

All calculations/changes are performed only for Gear 1.

2 Strength calculation as specified in ISO6336

2.1 For Geometry 1 (ρ^*_{fP}=0.38)

To open the example used in this tutorial, click "File/Open" and select **"CylGearPair 1 (spur gear)"** or click the "**Example"** tab.

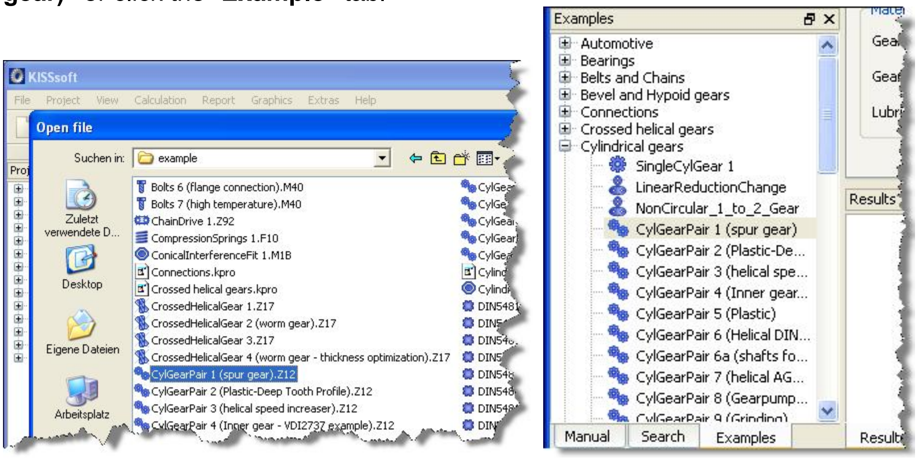


Figure 2.1 Open example calculation "CylGearPair 2 (spur gear)"

The selected calculation method is ISO 6336, Method B. To check which reference profile was used, click the **"Reference profile"** tab. In this example a standard reference profile (1.25/0.38/1.00) as specified in ISO 53.2 profile A has been used.

Figure 2.2 Selected calculation method

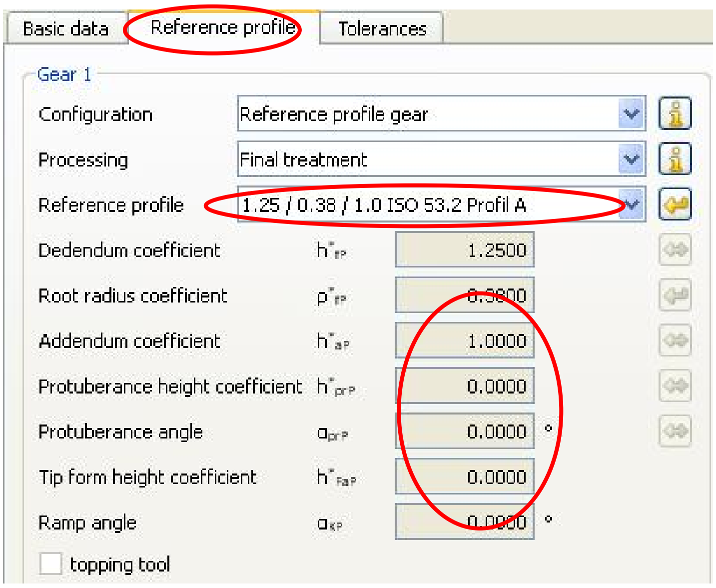


Figure 2.3 Standard reference profile as used for first calculation

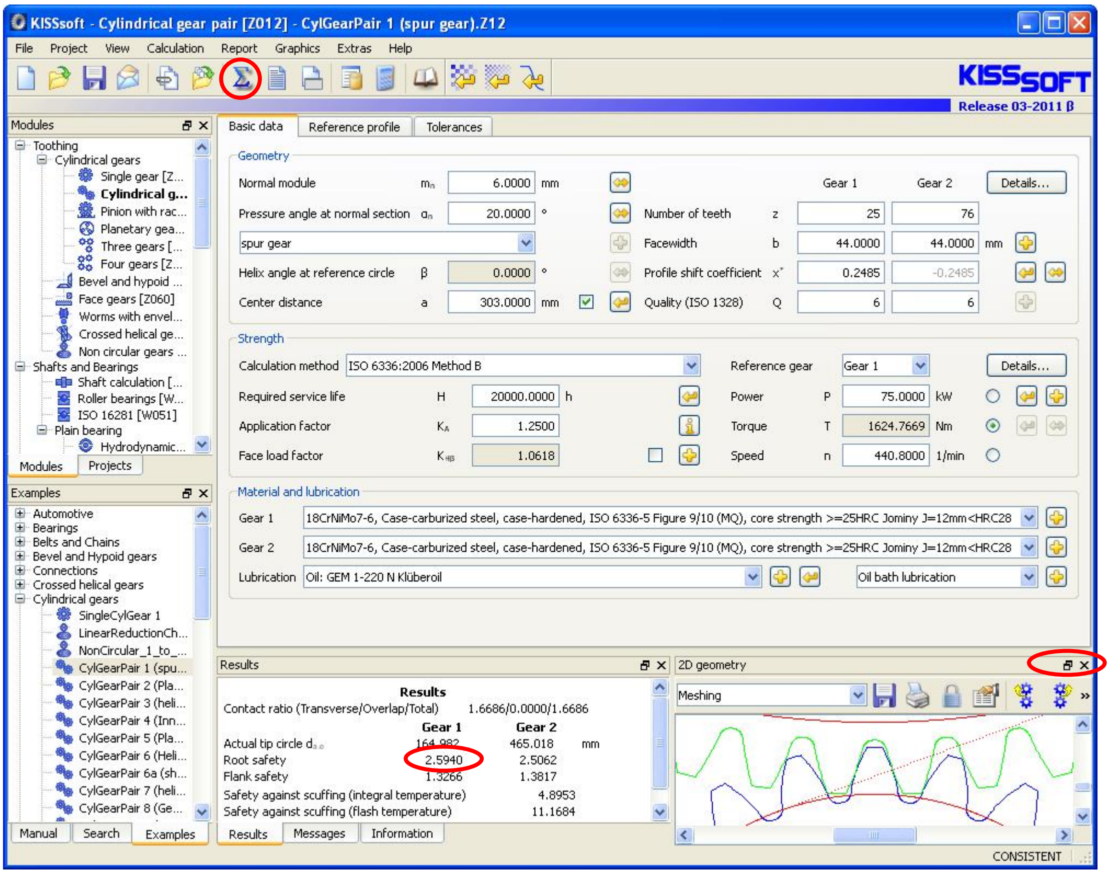


Figure 2.4 Result of calculating the safety factor of the tooth root stress in Gear 1

The resulting tooth form is displayed in a graphics window. Click the button (upper right marking) to make it into a floating window and enlarge it. You can save the tooth forms so they can be compared later on. To do this, follow the steps marked in **Figure 2.5**

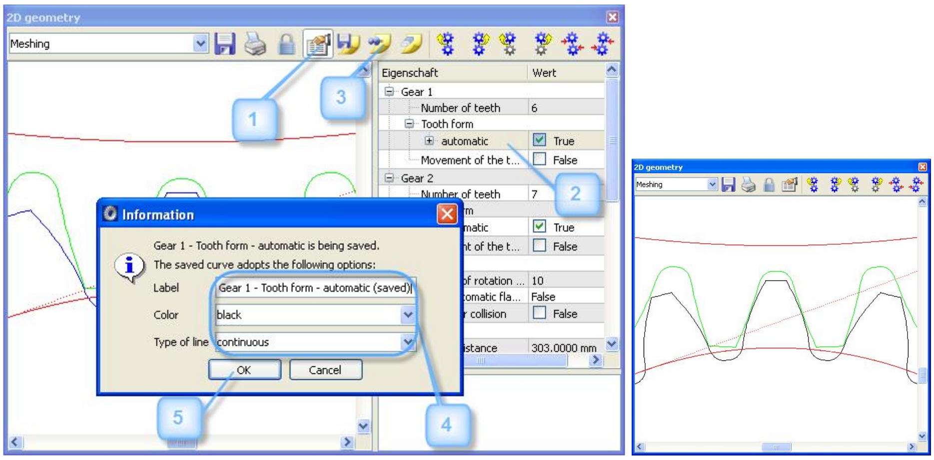


Figure 2.5 Resulting tooth form with ρ*fP =0.38

2.2 For Geometry 2 ($\rho^*_{fP} = 0.45$)

The first step is to determine the maximum possible value for ρ^*_{fP}. To do this, go to the drop-down list for the reference profile and select **"Own Input"**. Click the sizing button to determine a value of 0.4719 for ρ^*_{fP}. The maximum permitted value is for ρ^*_{fP}=0.4719.

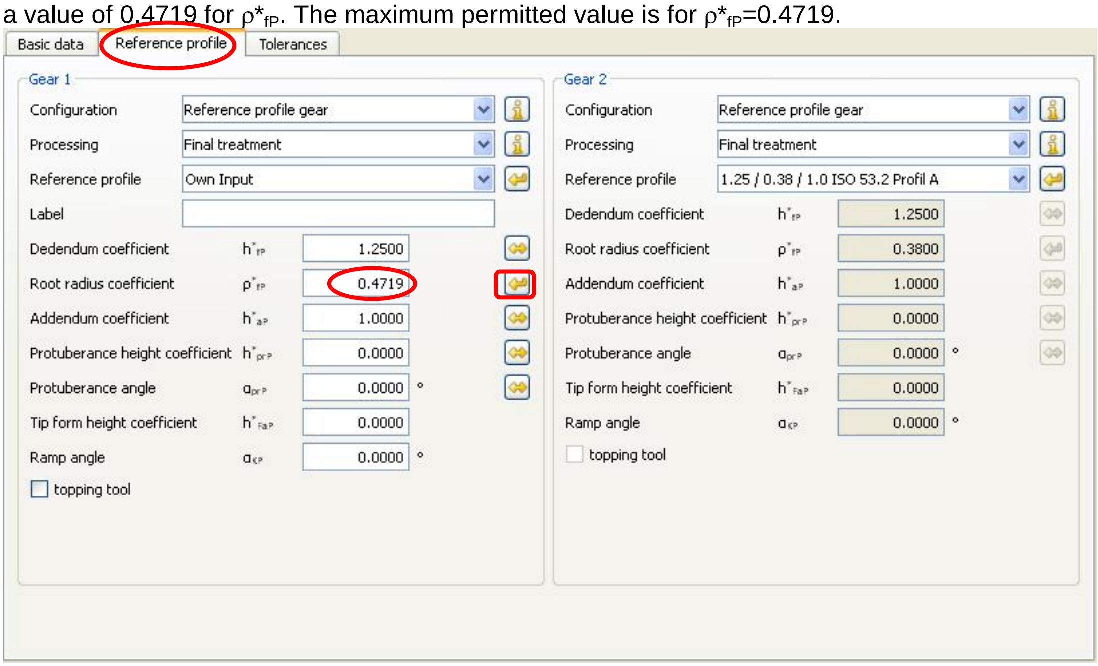


Figure 2.6 Modification of ρ*fP

This changes the input value for ρ^*_{fP}. Input ρ^*_{fP}=0.45. Now click  or press "F5" to perform the calculation. No warning messages are issued here.

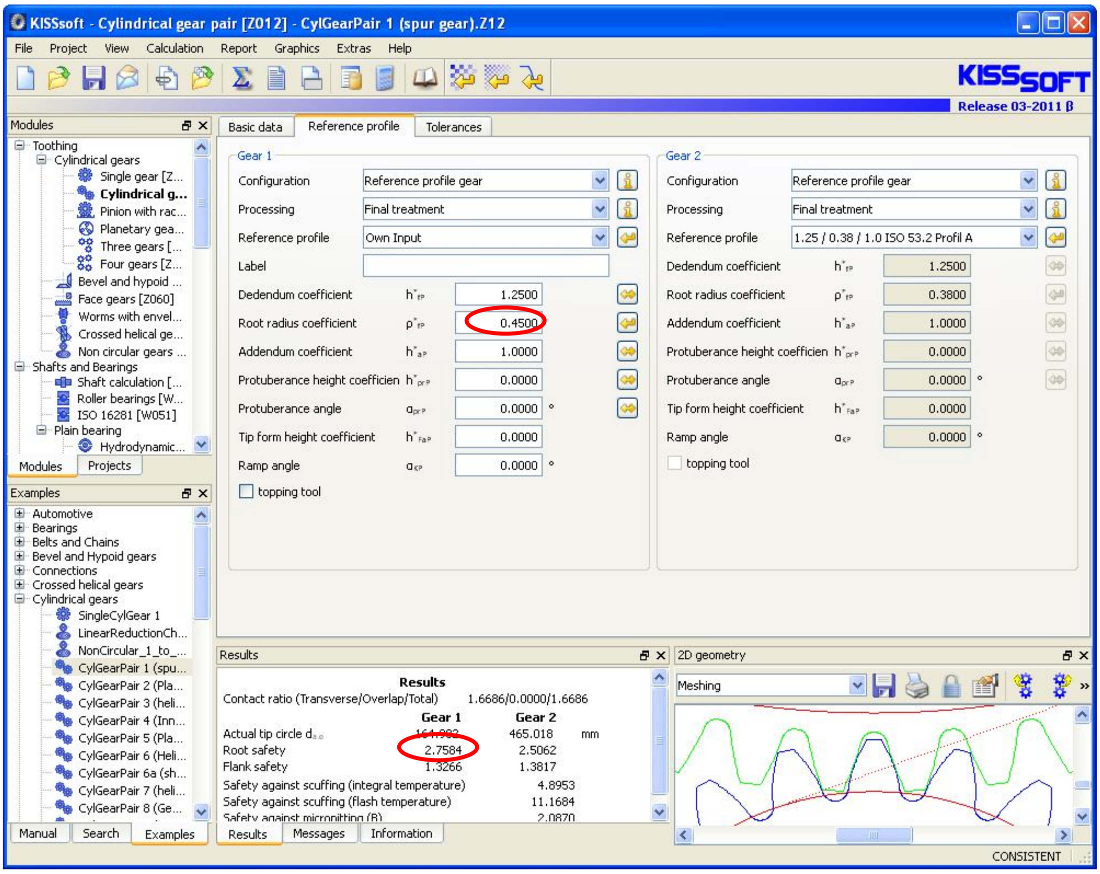


Figure 2.7 Result of root safety with changed ρ*fP =0.45 for Gear 1

The safety factor of the root has been increased:

In the 2D graphic you can see both the old and new tooth form (use the "+"/"-" buttons to change its size). The blue curve is the tooth form generated with ρ^*_{fP}=0.45. The black curve is the old tooth form with ρ^*_{fP}=0.38, that was saved previously.

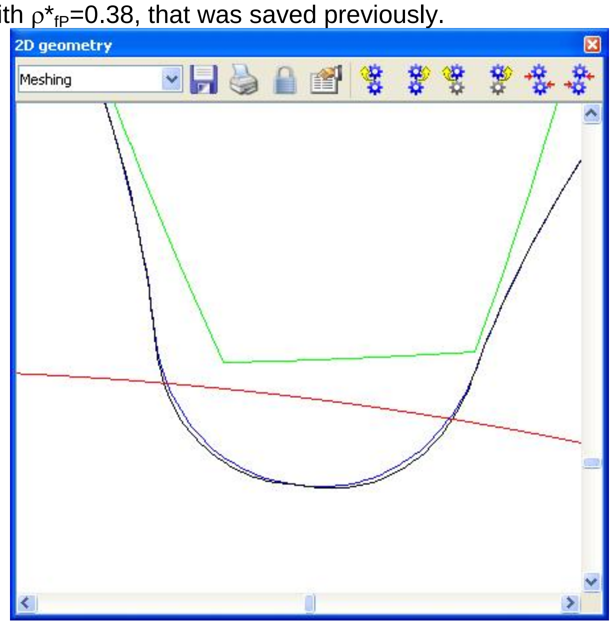


Figure 2.8 Comparison of tooth roundings (old/black with ρ*fP=0.38, new/blue with ρ*fP=0.45)

2.3 For Geometry 3 (elliptical root rounding)

You cannot perform this calculation because the strength rating specified in ISO6336 is only based on the reference profile. Therefore you cannot use ISO6336 to calculate the effect of a modified root rounding that is not based on a normal rack profile. For this reason, you should use the **"Graphical method"** as shown in the next section.

3 Strength calculation with the "Graphical method"

3.1 For Geometry 1 (ρ^*_{fP} =0.38)

In the **"Reference profile"** tab, reset the value for ρ^*_{fP} to ρ^*_{fP}=0.38. Then go to the **"Basic data"** tab.

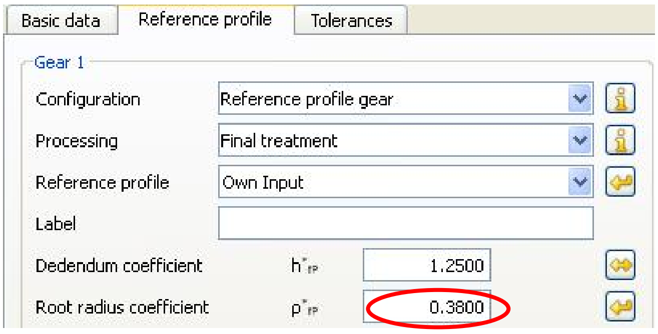


Figure 3.1 Resetting ρ*fP to ρ*fP=0.38

Now activate the **"using graphical method"** option. Go to the **"Basic data"** tab in the "Strength" group and click on **"Details"**. This opens the "Define details of strength" window. There, select **"using graphical method"** from the drop-down list next to tooth form factors YF;YS. Click **"OK"** to confirm the entry and close the window.

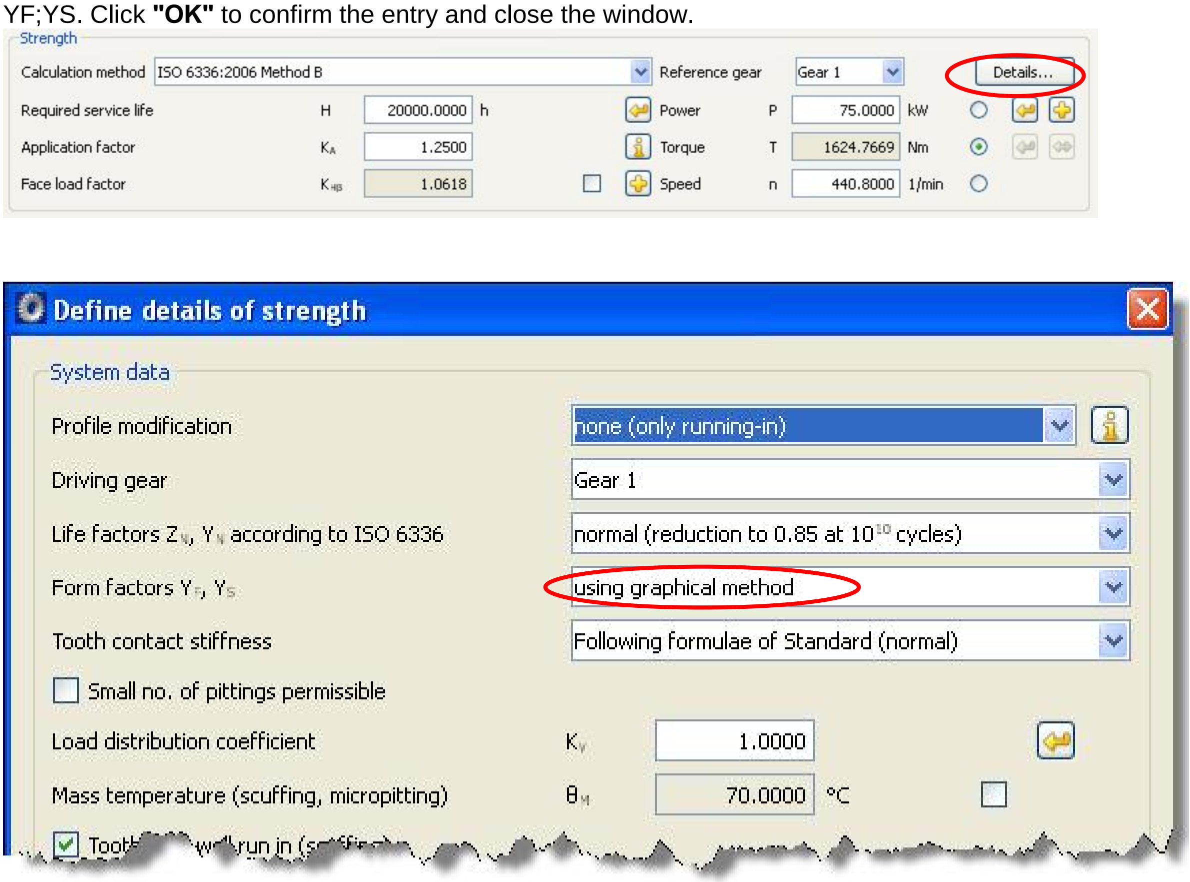


Figure 3.2 Activating calculation method using the "Graphical method".

Then click Σ or press "F5" to repeat the strength calculation. Note that the safety factor is now somewhat lower.

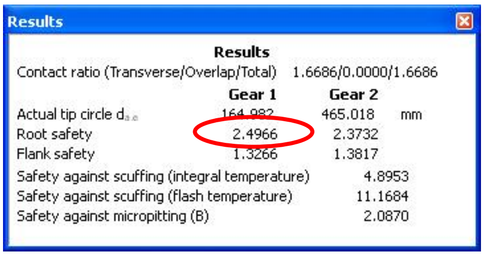


Figure 3.3 Calculation of resulting safety factor for Gear 1 with ρ*fP =0.38 using the "Graphical" method

3.2 For Geometry 2 (ρ^*_{fP}= 0.45)

In the "Reference profile" tab, reset the value for ρ^*_{fP} to ρ^*_{fP}=0.45. Click **"Σ"** or press F5 to perform the strength calculation.

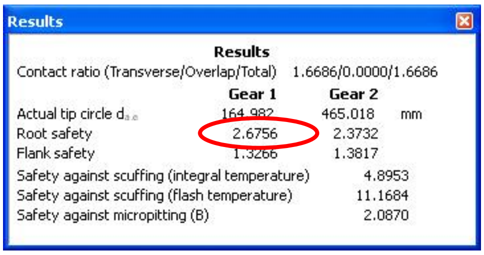


Figure 3.4 Calculation of resulting safety factor for Gear 1 with ρ*fP =0.45 using the "Graphical" method

3.3 For Geometry 3 (elliptical root rounding)

To add the elliptical root modification, start the tooth form calculation by selecting the "Tooth form" tab.

Figure 3.5 Opening tooth form calculation

In the next window you can see how to add the **"Elliptic foot modification"** operation by right-clicking on **"Automatic"**.

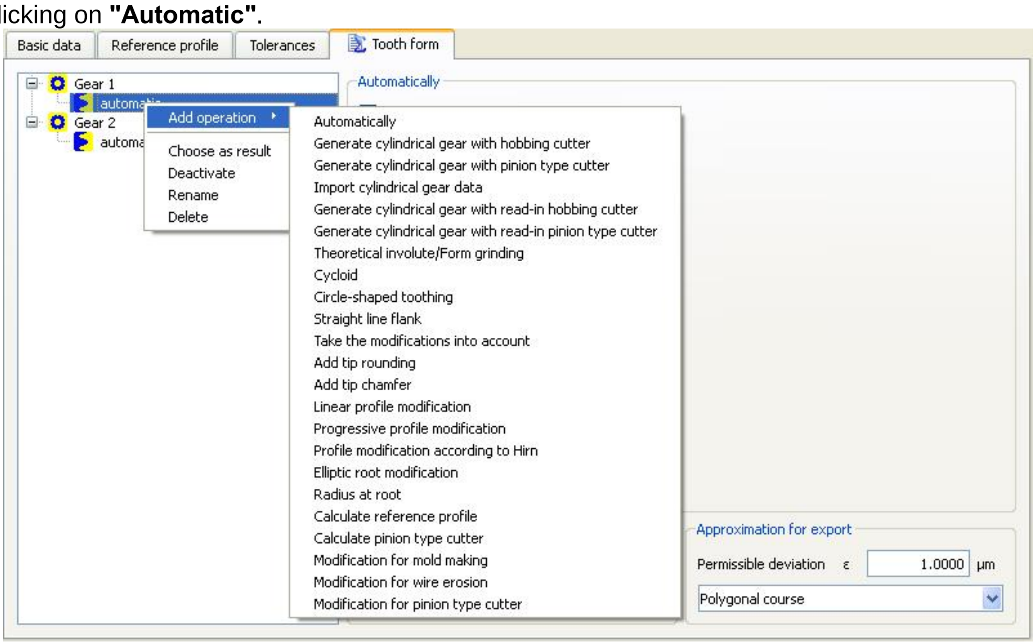


Figure 3.6 Adding the elliptical root modification

Then click [icon] to the right of the **"Modification from diameter"** field to define where the elliptical root modification is to start. Click the right-hand mouse button on the **"Elliptic root modification"** icon and select **"Choose as result"** to ensure that this tooth is modified.

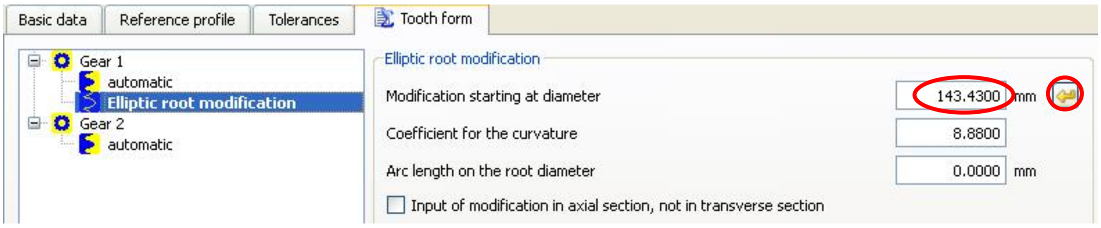


Figure 3.7 Starting the modification, activating the calculation step

Back in the **"Basic data"** tab, you can now calculate the strength (after the tooth geometry has been calculated) by clicking [icon] or pressing "F5". The safety factor for Gear 1 has changed:

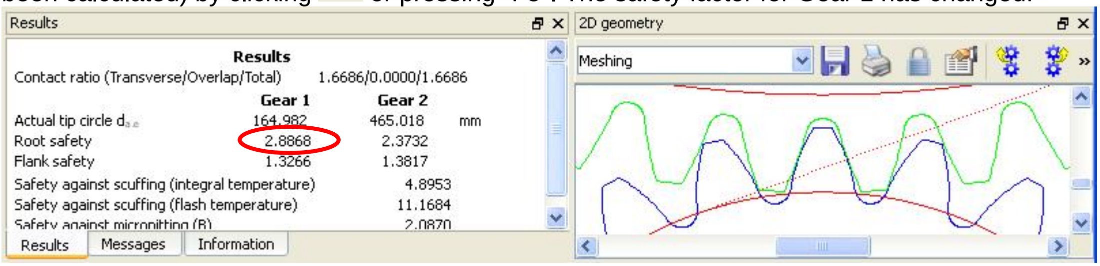


Figure 3.8: Calculation result with optimized tooth root rounding

4 Notes and explanations

4.1 Calculation step: "Automatically"

When you open the tooth form calculation the first manufacturing step is already visible and the default setting is "Automatically".

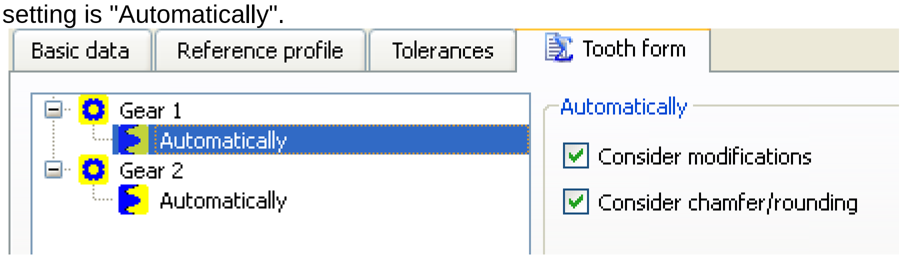


Figure 4.1 Default setting in tooth form calculation

This step is based on the reference profile defined in the **"Reference profile"** tab.

Therefore, when you add the elliptical root modification, there is either no difference (or only a minor difference), depending on whether ρ^*_{fP} =0.38 or ρ^*_{fP} =0.45 has already been defined in the **"Reference profile"** tab. This is because the elliptical modification is only the second manufacturing step. (The first one is a generating step using the "Automatically" setting, based on the reference profile defined in the "Reference profile" tab). This is why the newly calculated tooth form is so similar.

However, if you change the **"Factor for root rounding"** value, you can modify the shape of the elliptical curve. The **"Curve length at root diameter"** value defines the length of a circular arc between two elliptical sections.

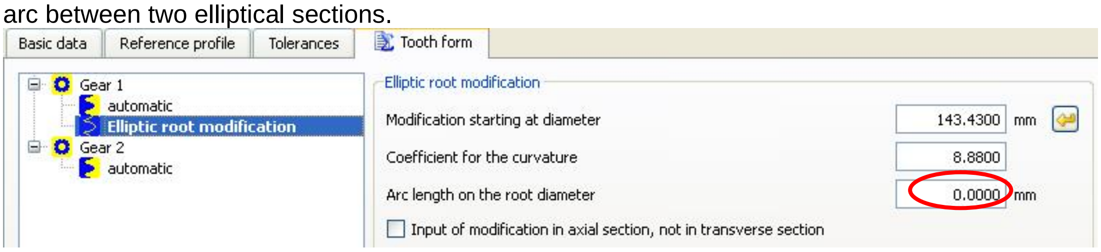


Figure 4.2 Root rounding factor

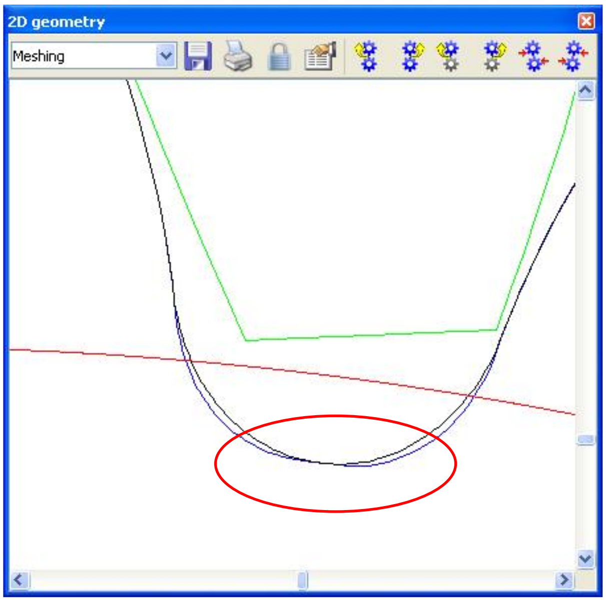


Figure 4.3 Defining the factor for root rounding and arc length on the root radius

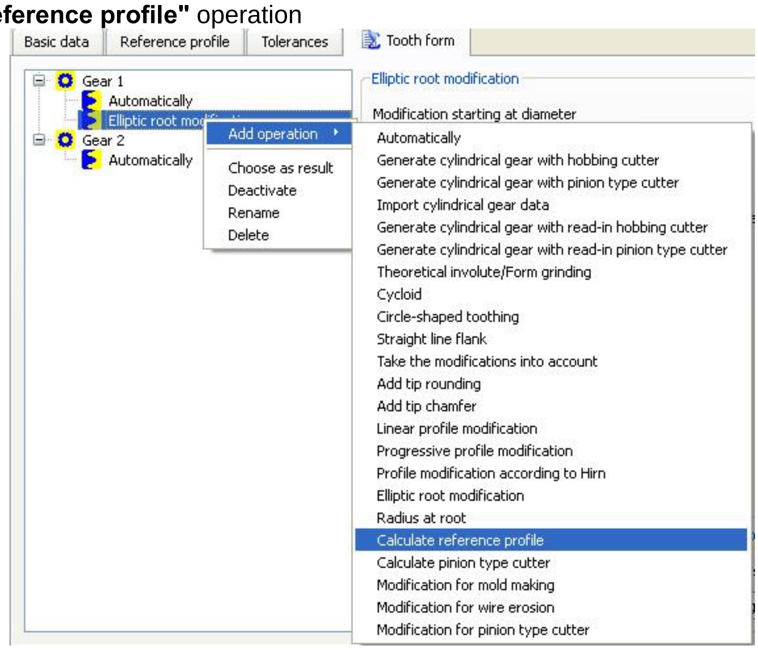
4.2 Calculating internal gears

For internal gears, the calculation according to DIN3990, ISO6336 and AGMA2001 is actually quite inaccurate (however, the situation will be better in the proposed new version of ISO6336). For this reason we recommend that you use the **"Graphical method"** if you want to calculate internal gears. To use the **"Graphical method"** you require module ZA15.

4.3 Calculating a tool profile to manufacture an elliptical root

To calculate the geometry of a tool that will, in turn, generate all the elliptical modifications described above, you must:

Click the right-hand mouse button after the **"Elliptic foot modification"** operation to add the **"Calculate reference profile"** operation



and then select this as the result.

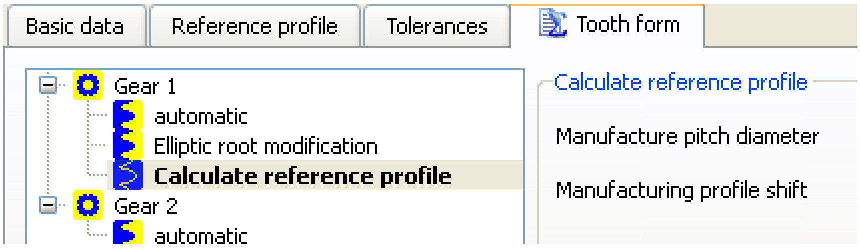


Figure 4.4 Adding "Calculate reference profile"

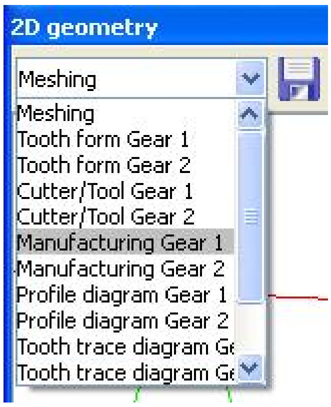


Figure 4.5 Selecting manufacturing for Gear 1

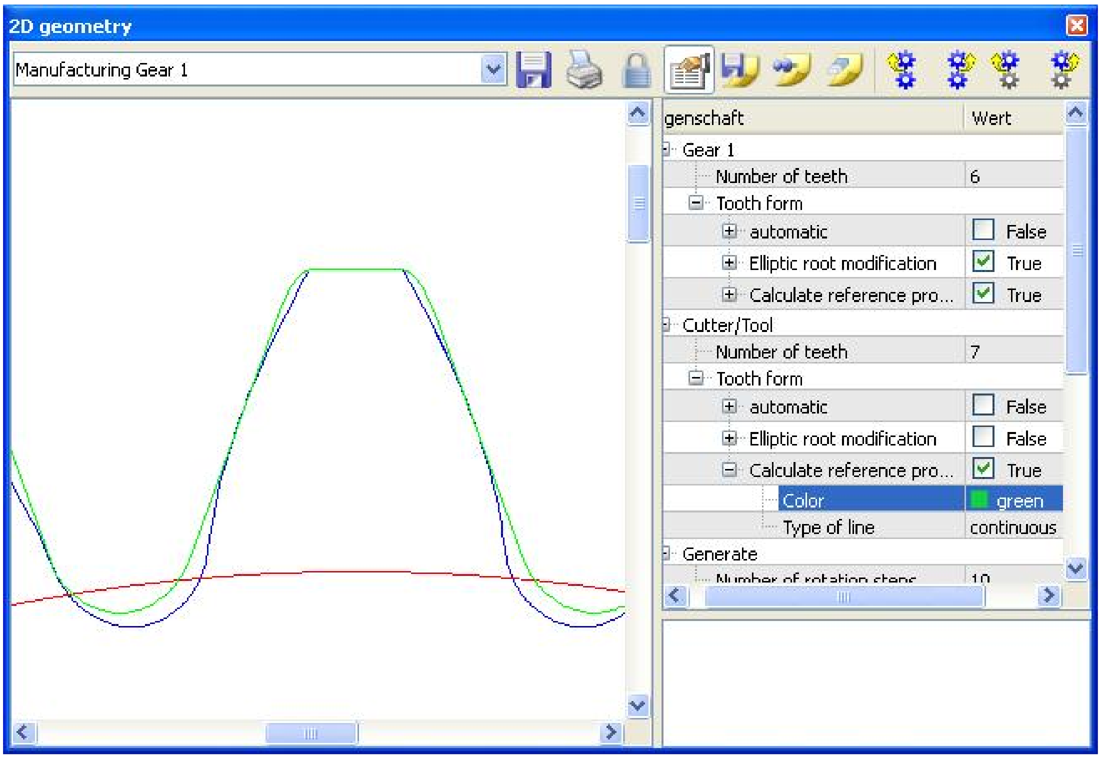


Figure 4.6 Displaying manufacturing of Gear 1

Finally, display the tool. In the graphics window, select **"Tool Gear 1"** from the list to display the tool geometry. You can now export the tool geometry in order to create the tool.

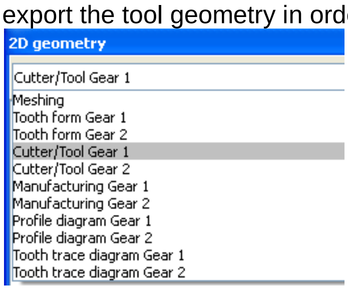


Figure 4.7 Displaying selection for Tool Gear 1

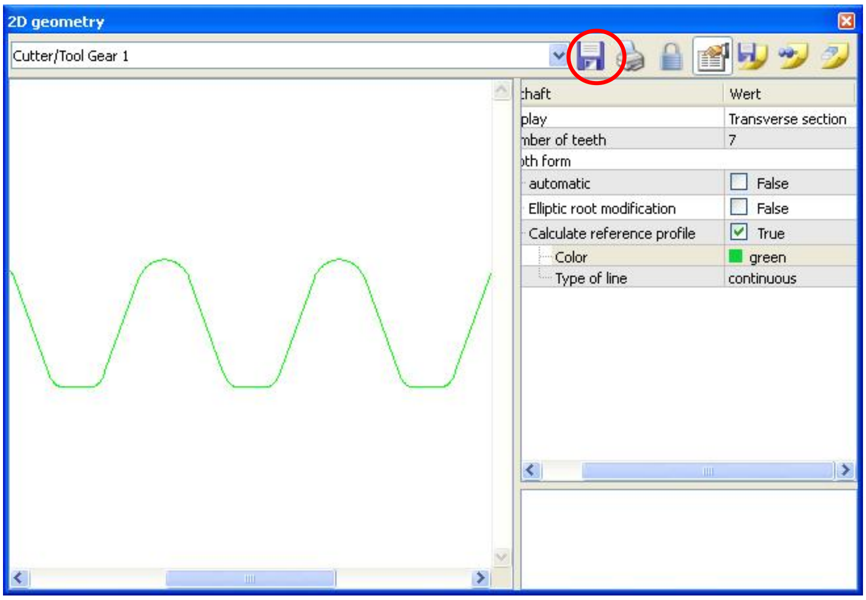


Figure 4.8 Tool display

You can now export the tool to DXF or IGES.