KISSsoft
Drivetrain Design Solutions

KISSsoft 2019 – Tutorial 13

Tooth root optimization

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Sharing Knowledge

Contents

1 Overview

1.1 Task

This tutorial shows how tooth root geometry influences tooth root stress and how it can be optimized. If you want to evaluate the tooth root stress of a non-standard geometry, it is recommended to use the «graphical method». 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 $\rho^*_{fP} = 0.38$
2. resulting root geometry, with a tool root radius factor $\rho^*_{fP} = 0.45$
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 with the «graphical method»:

Table 1. Comparison of calculated safety factors for tooth root bending strength safety factors depending on method.

	SF based on sizing specified in ISO 6336	SF based on sizing specified in ISO 6336 with the graphical method
Geometry 1 ($\rho^*_{fP} = 0.38$)	2.602	2.504
Geometry 2 ($\rho^*_{fP} = 0.45$)	2.767	2.684
Geometry 3 (elliptical)	2.767*	2.775
Improvement from Geometry 1 to Geometry 3	13%*	11%

By optimizing the root geometry, the safety factor against root failure was increased by 13%. 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, sintering or injection moulding.
* Note: If you use the unmodified ISO 6336 method (or other methods like DIN3990 or AGMA2001) 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 root radius of the reference profile of the gear as shown below:

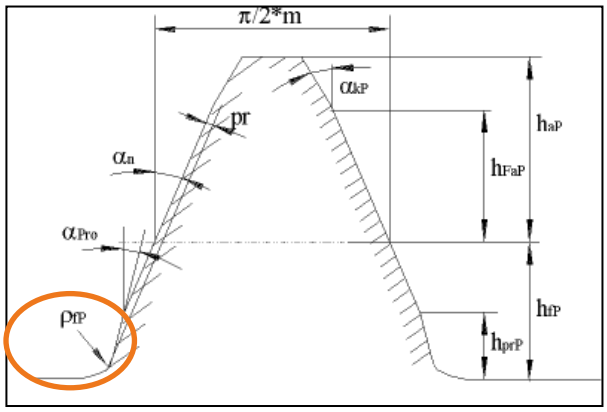
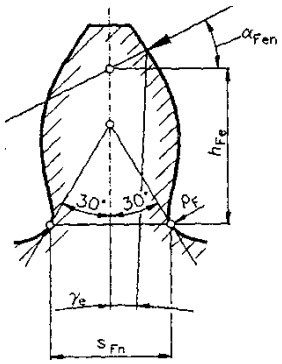


Figure 1. Reference profile of the gear, ρ_{fP}

The strength rating specified in ISO 6336 uses only a single point in the root where factors Y_F and Y_S 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. Y_F and Y_S are then calculated as shown in equations (2) and (3). The resulting tooth root stress is then calculated in accordance with equation (1).



Method B:

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

Method C:

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

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

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

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

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

Figure 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.
By taking the actual root form into account, the KISSsoft system allows you to perform the calculation at each point in the tooth root area for tooth form Y_F and the stress correction factor Y_S. In this case, the point at which the product of $Y_F \cdot Y_S$ 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 an 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.

Further explanations and comments are given in section 4.

All calculations/changes are performed only for gear 1.

2 Strength calculation as specified in ISO 6336

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 «**Examples**» tab.

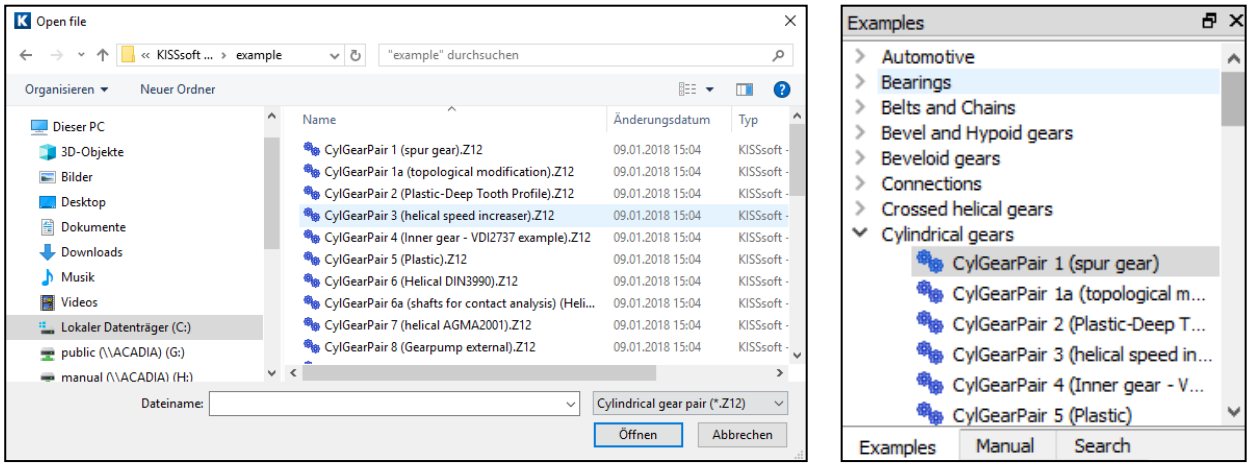


Figure 3. Opening example calculation «CylGearPair 1 (spur gear)».

The selected calculation method is ISO 6336, Method B. Click on the **«Reference profile»** tab to see which reference profile is being used. This example used a standard reference profile (1.25/0.38/1.00) as specified in ISO 53.2 profile A.

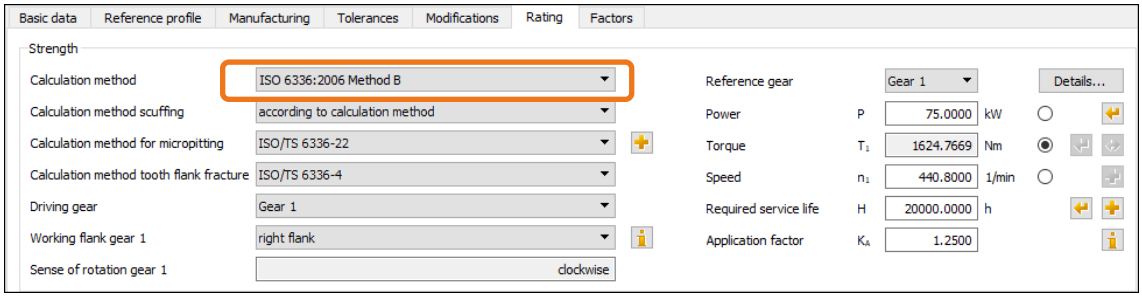


Figure 4. Selected calculation method

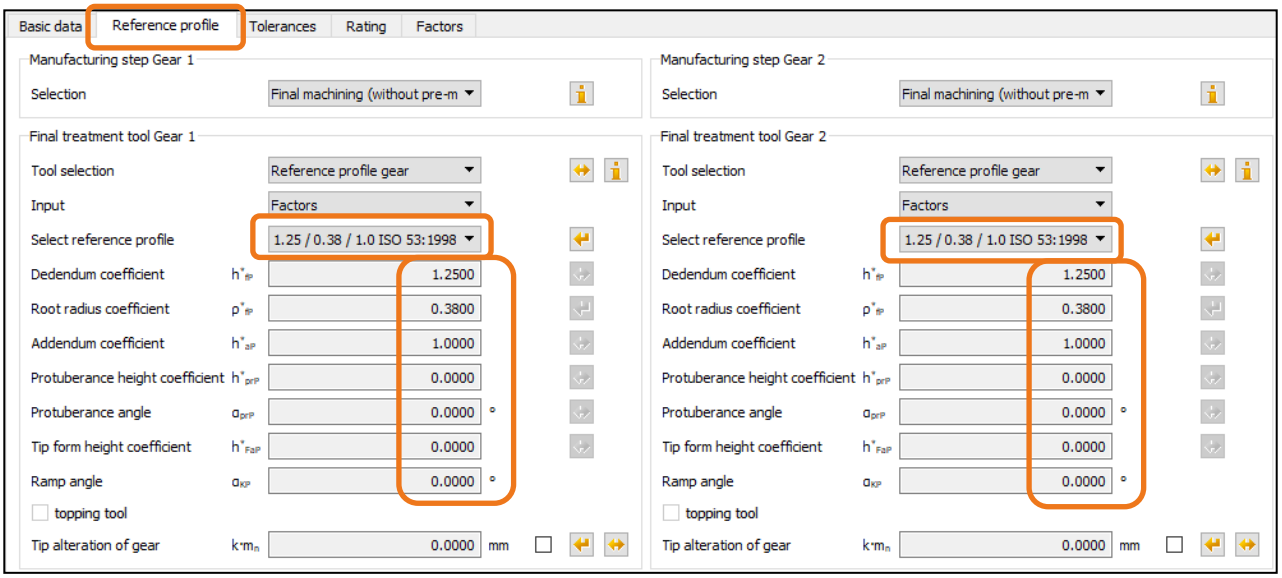


Figure 5. Standard reference profile for the first calculation

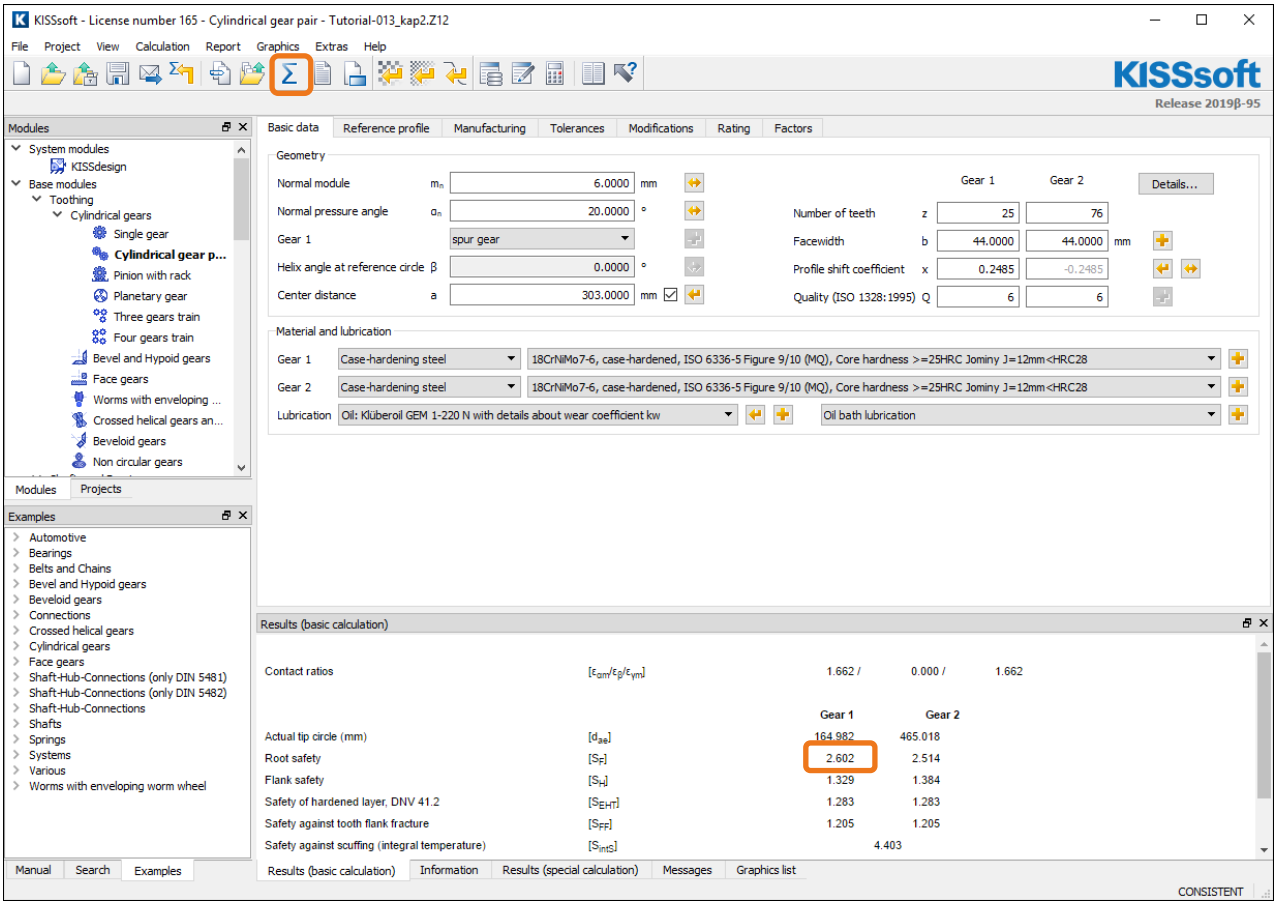


Figure 6. Result of calculating the safety factor of the tooth root stress in Gear 1

The resulting tooth form is displayed in a graphics window. You can save the tooth forms so they can be compared later on. To do this, follow the steps marked in Figure 7.

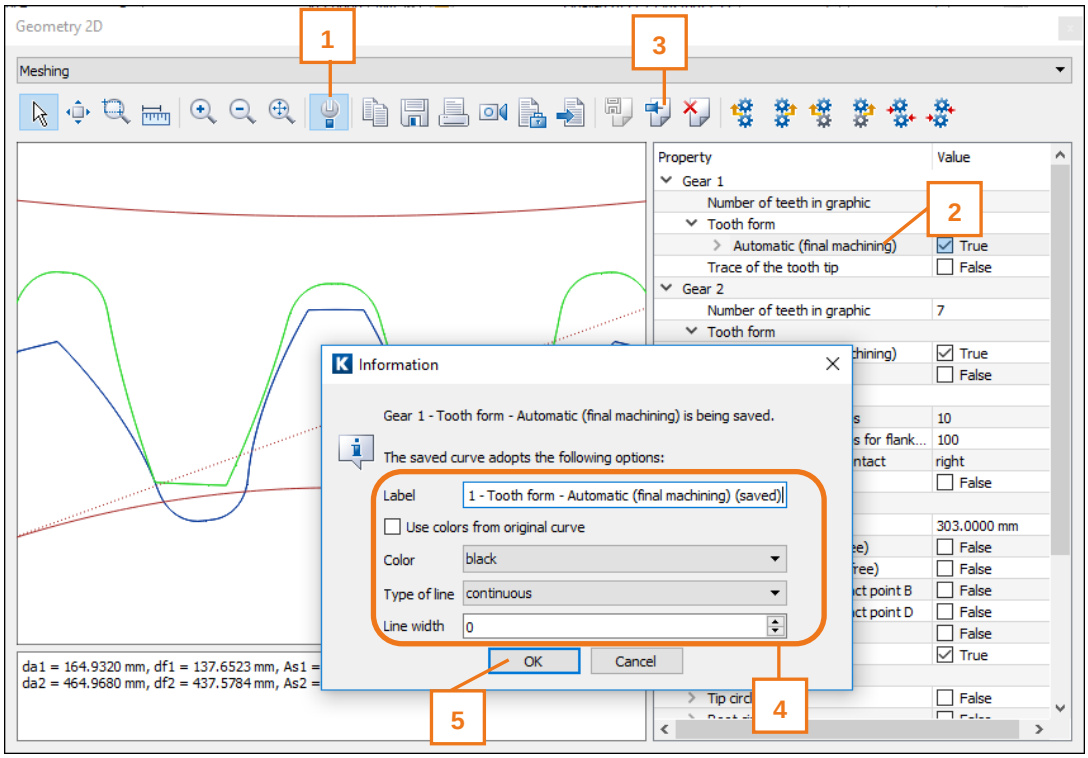


Figure 7. Save the resulting tooth form (ρ^*_{fP} = 0.38)

2.2 For Geometry 2 (ρ^*_{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 max ρ^*_{fP}. The maximum permitted value is for ρ^*_{fP} = 0.471.

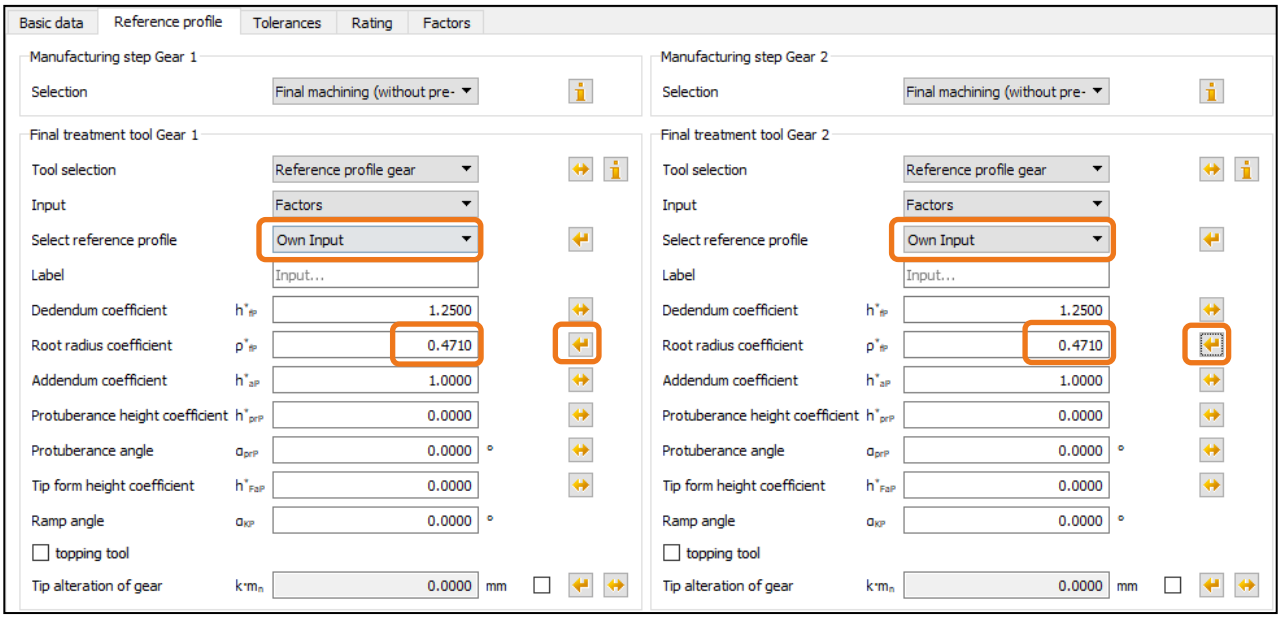


Figure 8. Modification of ρ^*_{fP}

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

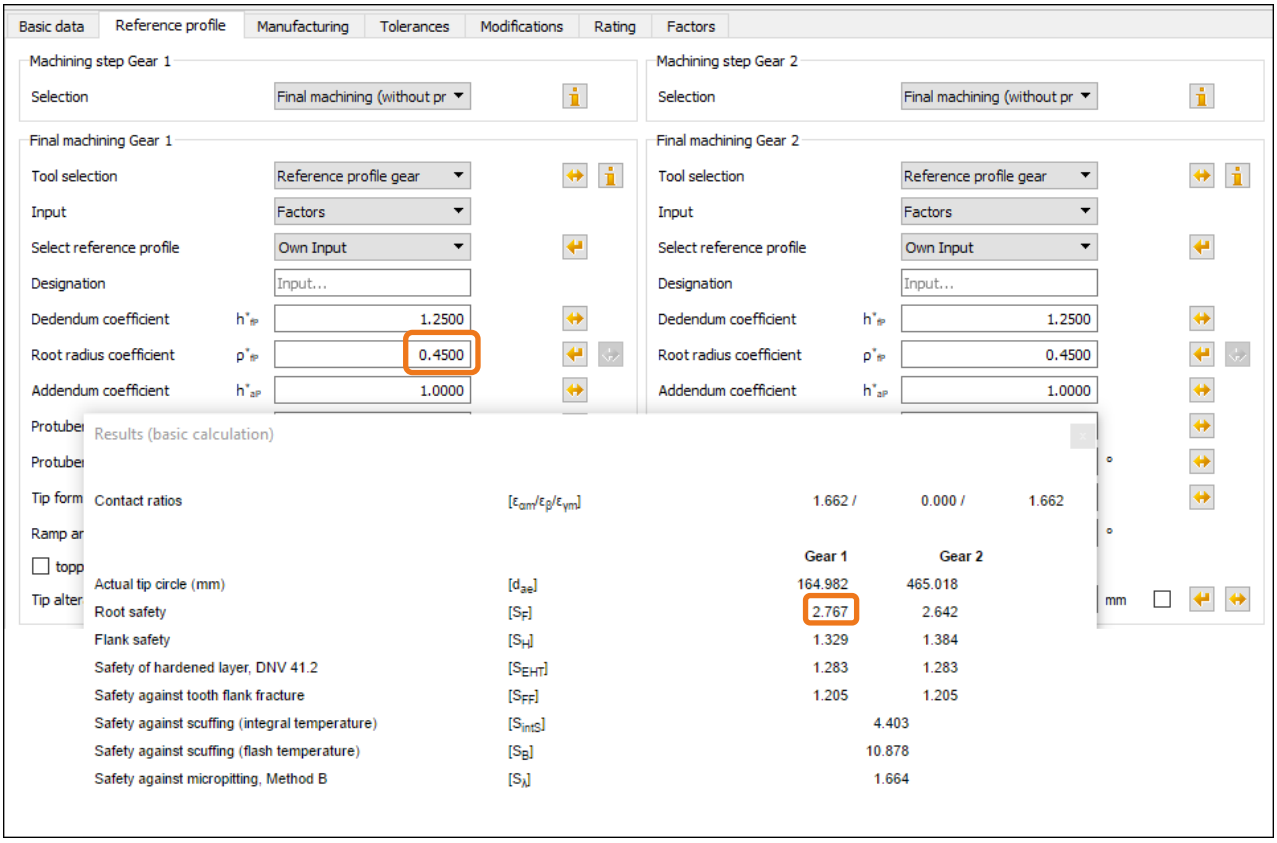


Figure 9. Result of root safety with changed ρ^*_{fP} = 0.45 for Gear 1

The safety factor of the root has increased to 2.767.

In the 2D graphic you can see both the old and new tooth form. 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, which was saved previously.

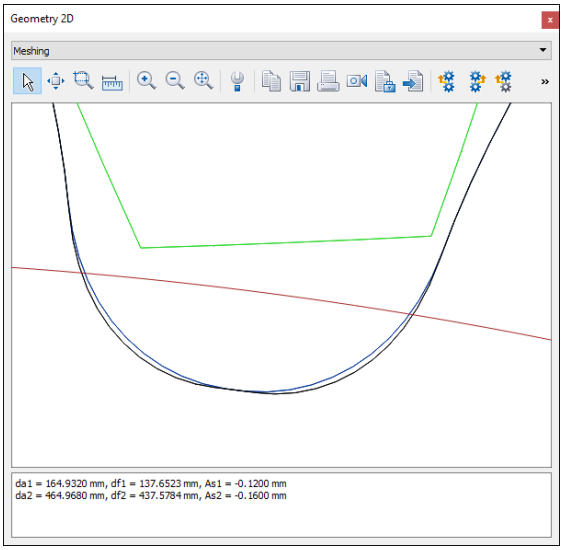


Figure 10. Comparison of tooth roundings (old/black with ρ^*_{fP} = 0.38, new/blue with ρ^*_{fP} = 0.45)

2.3 For Geometry 3 (elliptical root rounding)

You cannot perform this calculation because the strength rating specified in ISO 6336 is only based on the reference profile. Therefore you cannot use ISO 6336 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 using 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 **«Rating»** tab.

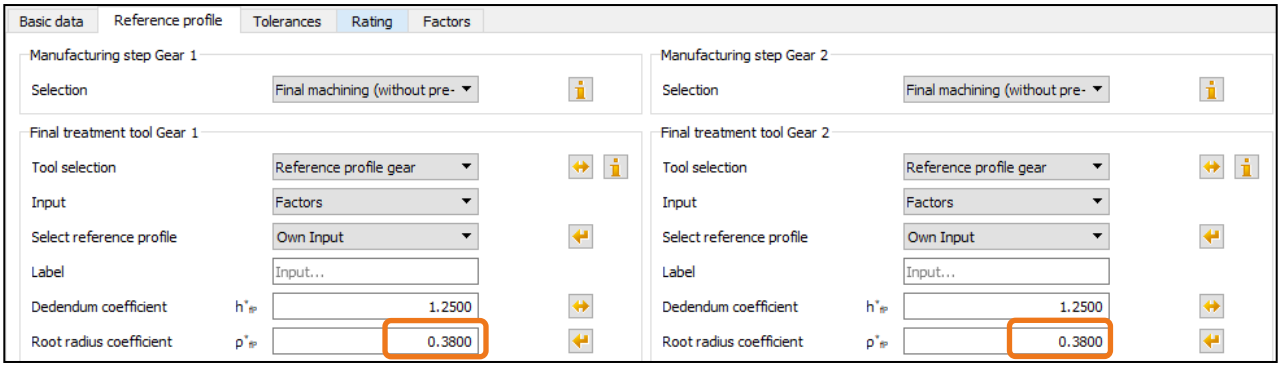


Figure 11. Resetting ρ^*_{fP} to ρ^*_{fP} = 0.38

Now activate the **«using graphical method»** option. Go to the **«Rating»** tab and click on **«Details»**. This opens the «Define details of rating» window. There, select **«using graphical method»** from the drop-down list next to tooth form factors Y_F, Y_S. Click **«OK»** to confirm the entry and close the window.

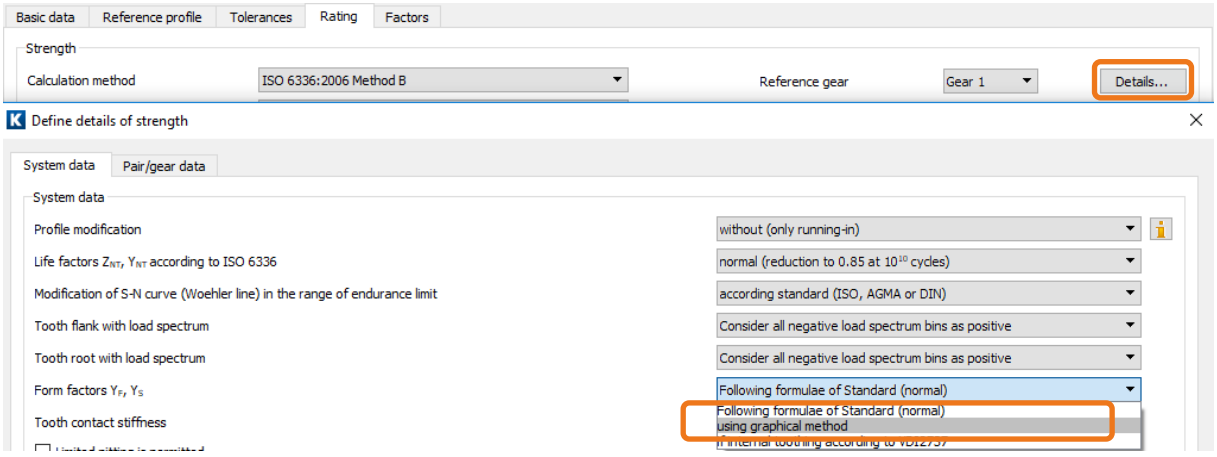


Figure 12. Activating the calculation method using the «graphical method»

Then click  or press «F5» to repeat the strength calculation. Note that the safety factor is now lower.

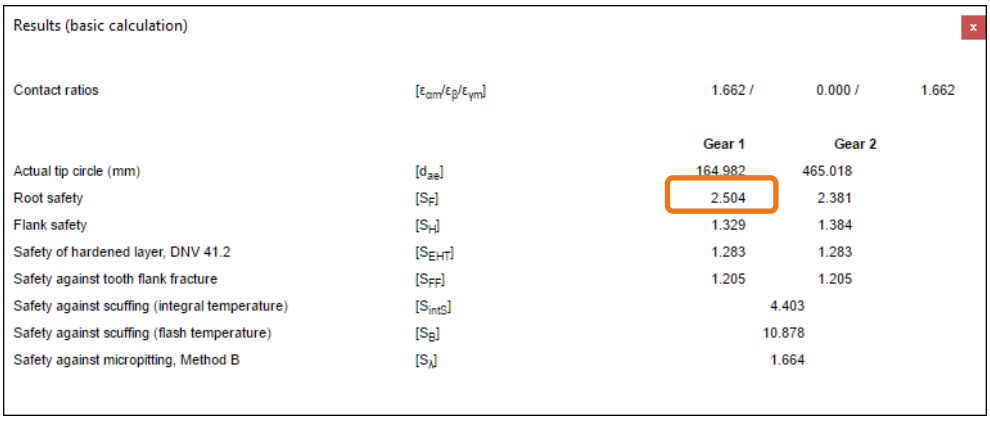


Figure 13. Calculation of resulting safety factor for Gear 1 with ρ^*_{fP} = 0.38 using the «graphical» method

3.2 For Geometry 2 (ρ^*_{fP} = 0.45)

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

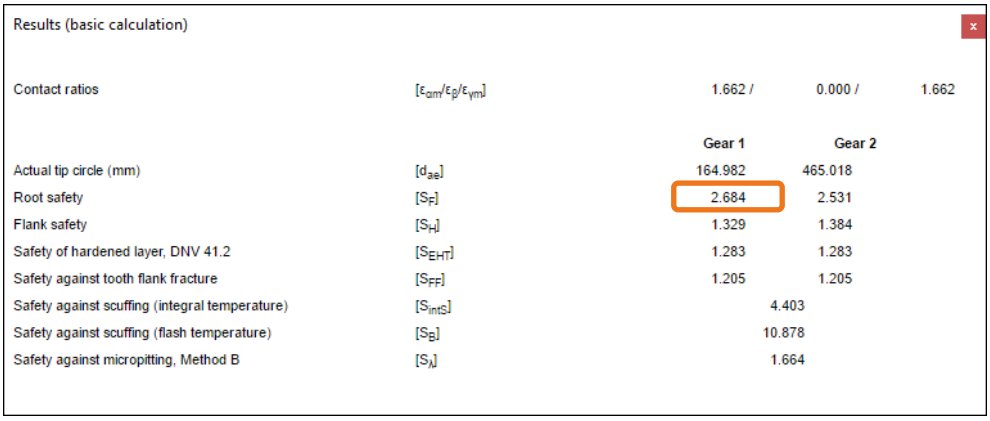


Figure 14. Calculation of resulting safety factor for Gear 1 with ρ^*_{fP} = 0.45 using the «Graphical» method

3.3 For Geometry 3 (elliptical root rounding)

To add the elliptical root modification, start the tooth form calculation by clicking on the «Tooth form» tab.

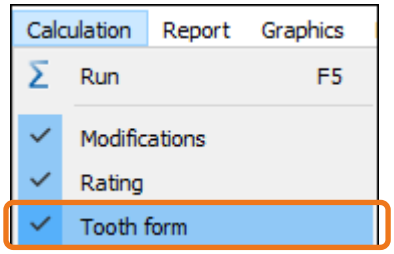


Figure 15. Opening the tooth form calculation

In the next window you can see how to add the **«Elliptic root modification»** operation by clicking the right-hand mouse button on **«automatic»**.

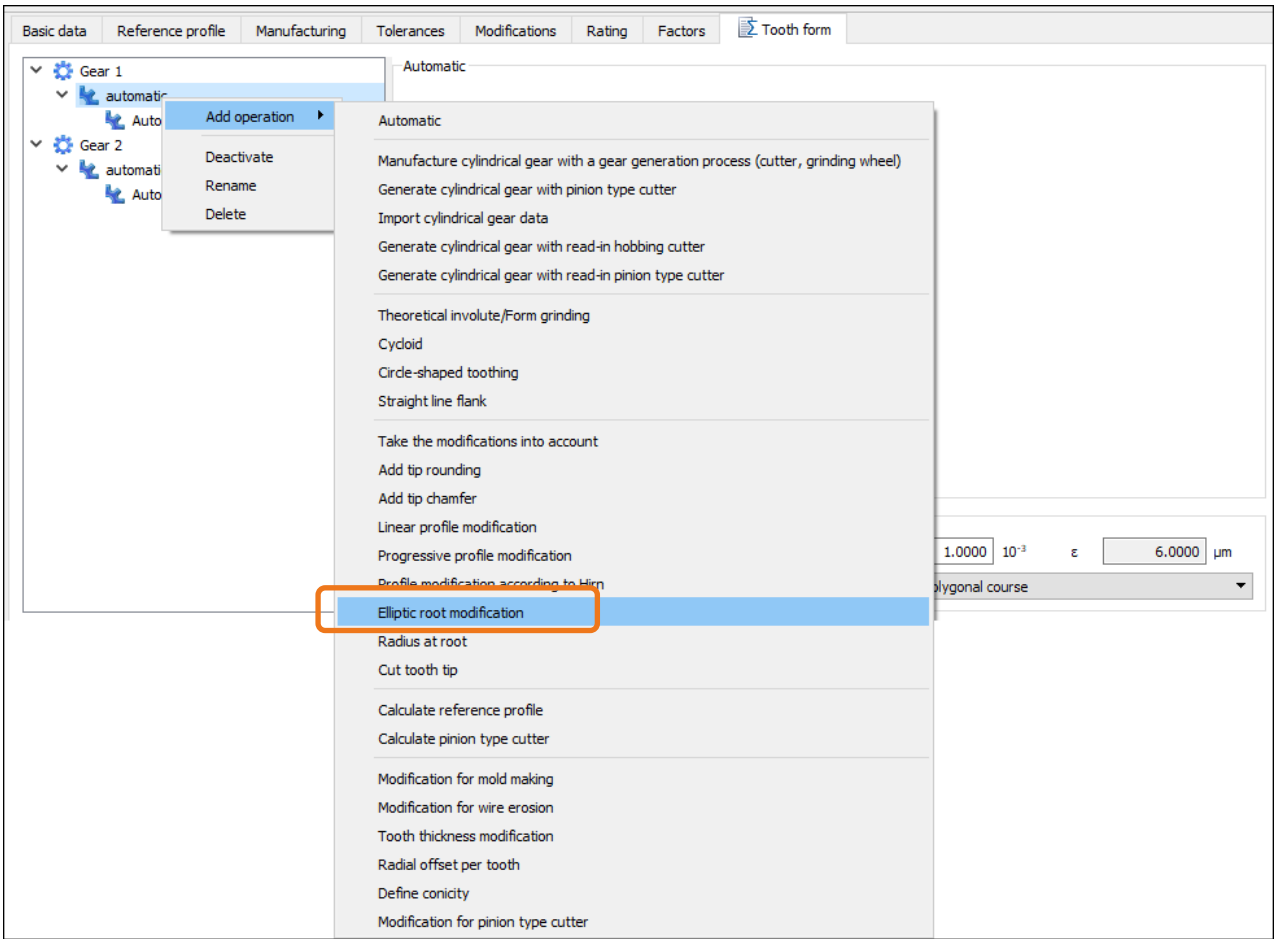
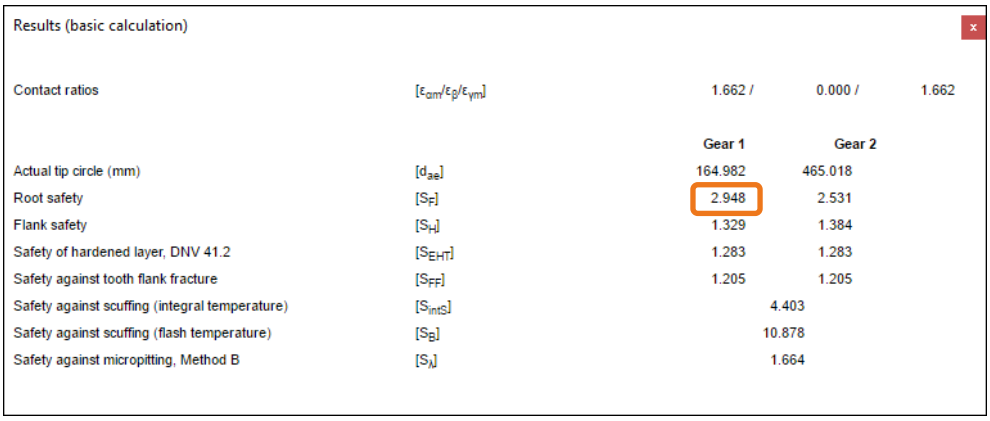


Figure 16. Adding an elliptical root modification

Then click to the right of the **«Modification starting at diameter»** field to define where the elliptical root modification is to start. Enter a value of 5 as "Coefficient for the curvature" and 0.01 mm as "Arc length on the root diameter"

Figure 17. Starting the modification, enabling the calculation step.

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



Results (basic calculation)

Contact ratios	$[\varepsilon_{\alpha m}/\varepsilon_{\beta}/\varepsilon_{\gamma m}]$	1.662 /	0.000 /	1.662
		Gear 1	**Gear 2**	
Actual tip circle (mm)	$[d_{ae}]$	164.982	465.018	
Root safety	$[S_F]$	2.948	2.531	
Flank safety	$[S_H]$	1.329	1.384	
Safety of hardened layer, DNV 41.2	$[S_{EHT}]$	1.283	1.283	
Safety against tooth flank fracture	$[S_{FF}]$	1.205	1.205	
Safety against scuffing (integral temperature)	$[S_{intS}]$	4.403		
Safety against scuffing (flash temperature)	$[S_B]$	10.878		
Safety against micropitting, Method B	$[S_M]$	1.664		

Figure 18. Result of the calculation with optimized tooth root rounding.

4 Notes and explanations

4.1 Calculation step: «automatic»

When you open the tooth form calculation the first manufacturing step is already visible, and the default setting is «automatic».

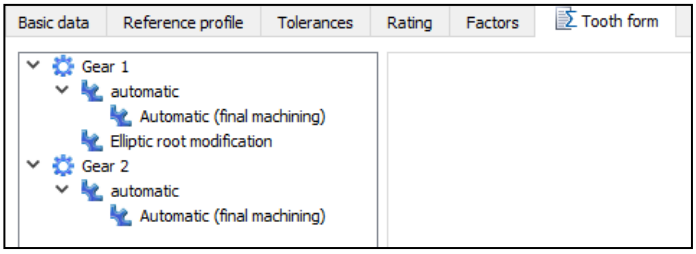


Figure 19. Default setting in the tooth form calculation

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 $\rho^*_{fP} = 0.38$ or $\rho^*_{fP} = 0.45$ 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 that uses the «automatic» 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 **«Coefficient for curvature»** value, you can modify the shape of the elliptical curve. The **«Arc length on the root diameter»** value defines the length of a circular arc between two elliptical sections.

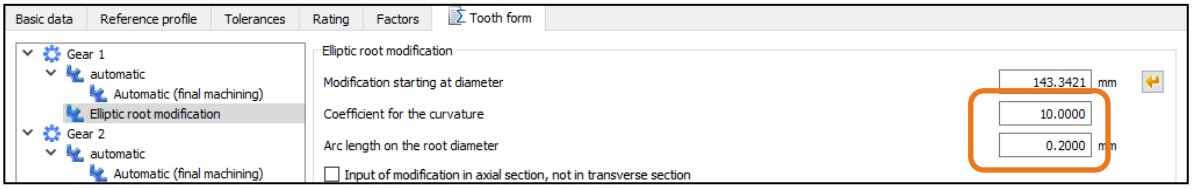


Figure 20. Factor for elliptical root rounding

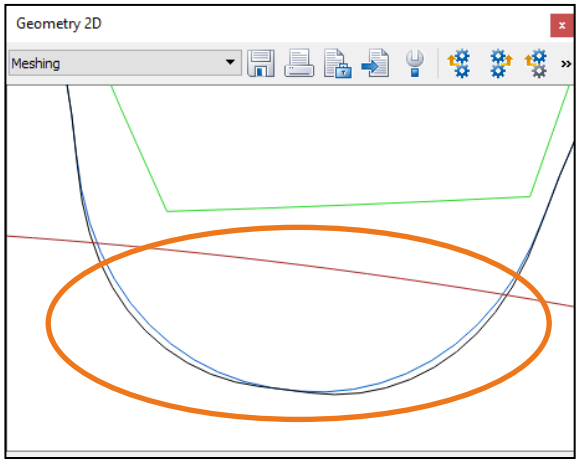


Figure 21. Defining the factor for root rounding and arc length on the root radius

4.2 Calculating internal gears

For internal gears, the calculation according to DIN 3990, ISO 6336 and AGMA 2001 is actually quite inaccurate (however, the situation is better in the version of ISO 6336:2006). For this reason, we recommend you use the **«graphical method»** if you want to calculate internal gears. You will need module ZA15 if you want to use the **«graphical method»**.

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 calculation steps including the elliptical modification, you must:
Click the right-hand mouse button after the **«Elliptic root modification»** operation to add the **«Calculate reference profile»** operation

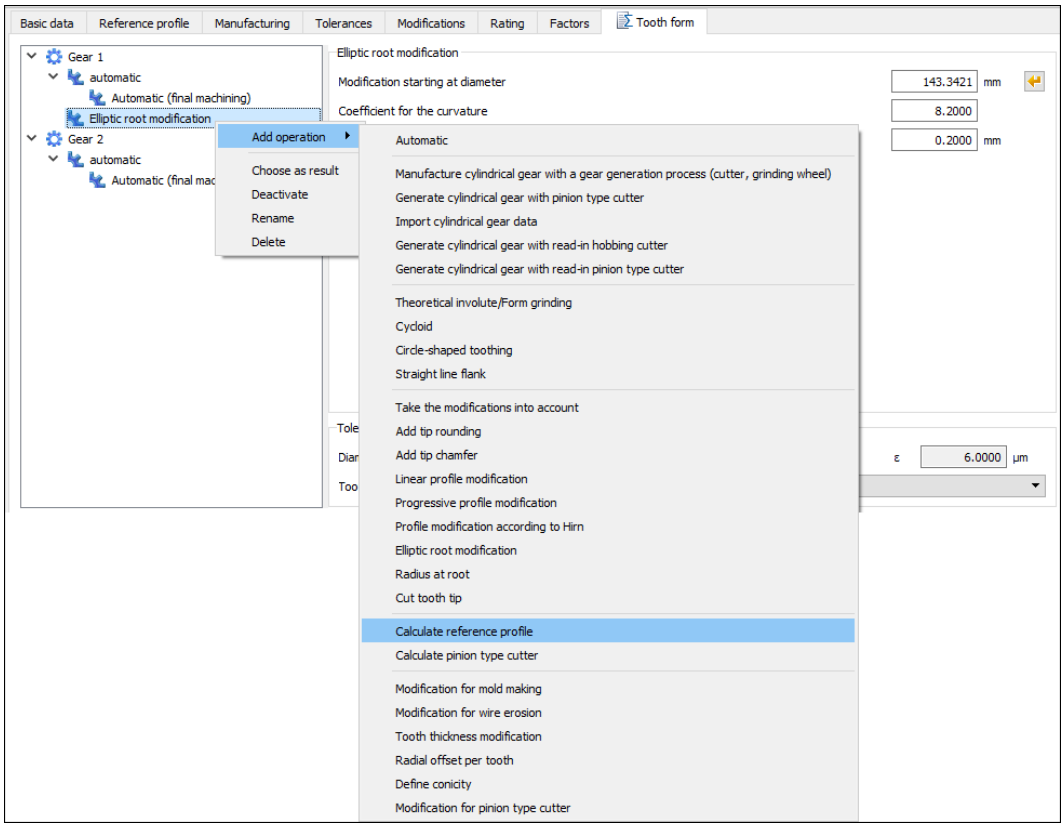
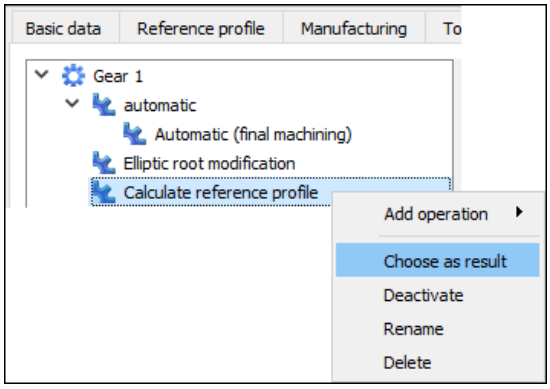


Figure 22. Add «Calculate reference profile» operation

and then select this as the result.



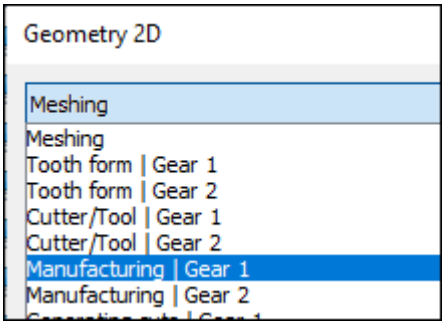


Figure 23. Select Manufacturing Gear 1.

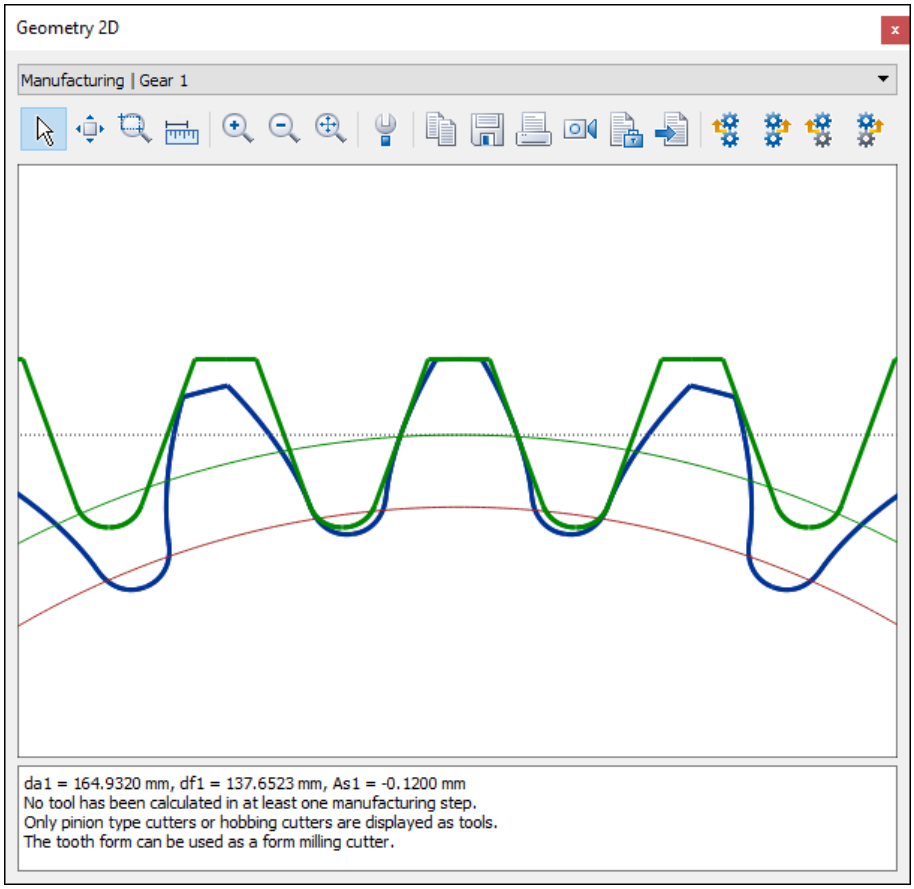


Figure 24. Display Manufacturing Gear 1

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

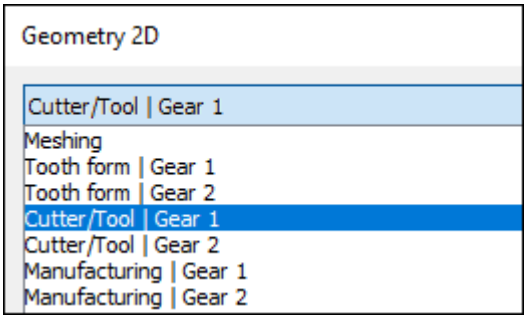


Figure 25. Displaying the selection Cutter/Tool Gear 1.

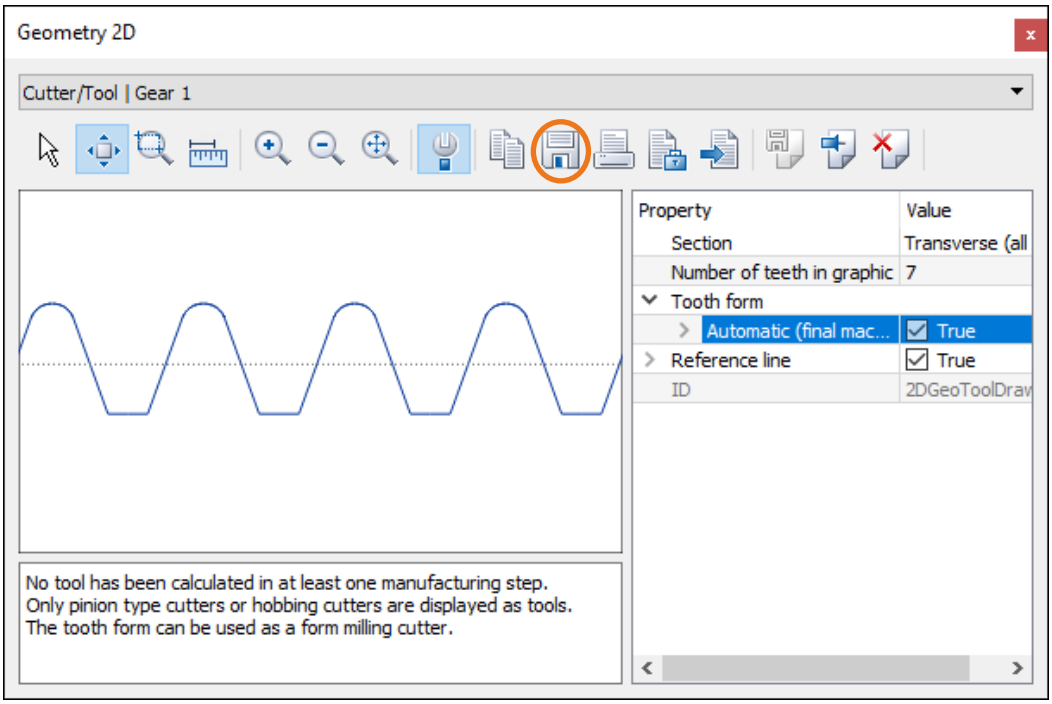


Figure 26. Displaying the cutter/tool.

You can now save the tool as DXF or IGES.