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MESYS Tutorial: Cylindrical Gear Pair 02

1 Introduction

1.1 Use case

In this tutorial, a helical gear stage is analyzed. In particular, the tooth root stress calculation according to ISO 6336-3 and with FEM is examined. Various root fillets, geometries, and factors are considered and compared. Further influences on the bending stresses are examined. No strength verification is performed, i.e., the allowable stresses are not considered.

1.2 Objective

Tutorial	Property
Suitable for	Users, familiar with the tutorial *Cylindrical Gear Pair 01*.
Prerequisites	MESYS license (test license, commercial license).
Learning objectives	Learn about advanced inputs specifically for tooth root strength. Understand the integrated FEM calculation.
MESYS file	*MESYS-Tutorial-Cyl_gearpair_02-v25.mCGP*.

1.3 Table of contents

1.4 Task

Step	Task
1	Start MESYS, open file MESYS-Tutorial-Cyl_gearpair_02-ww-v2500.mCGP, customize results overview. Run calculation, arrange graphics, record reference values.
2	Activate FEM calculations, determine stress values. Compare with reference values.
3	Calculate tooth root stresses for various influences and manufacturing methods • With and without protuberance. • With and without final machining allowance. • With and without final machining notch.
4	Compare tooth root geometry and resulting stresses for manufacturing with a hob and with a shaper cutter.
5	Comparative FEM calculation for calculation in the normal section and calculation on the virtual spur gear.
6	Consider the effect of reversed bending.

Table 1-1 Task definition.

2 Implementation , step 1

2.1 Start MESYS and settings

Start MESYS by double-clicking on file MesysCylGearPair64.exe. The file is located in the installation directory, typically in C:\Program Files\MESYS 12-2025. This launches the cylindrical gear pair calculation.

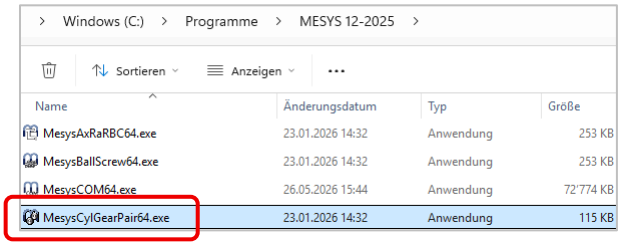

Figure 2-1 Start of the gear calculation via the corresponding *.exe in the installation directory.

Open file *MESYS-Tutorial-Cyl_gearpair_02-ww-v2500.mCGP* via *File/Open*.

In *Extras/Settings*, relevant settings are predefined and self-explanatory. The option *Show all messages* should be selected so that errors, warnings, and information are noticed especially at the beginning of using MESYS.

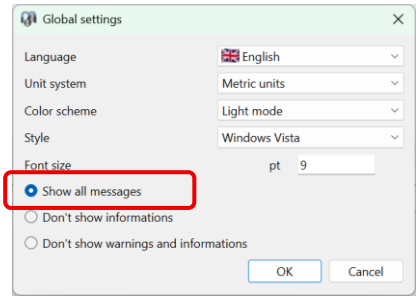

Figure 2-2 *Extras/Settings* with default settings.

In the *General* tab, the fields *Project name* and *Description* allow free comments on the calculation file.

Critical is the selection *Geometry for load capacity calculation = Nominal dimension with minimum tooth thickness for* Y_F/Y_S. As per ISO 6336-1, section 6.1, the lowest manufacturing profile shift, i.e. the smallest tooth thickness, is to be used for its calculation.

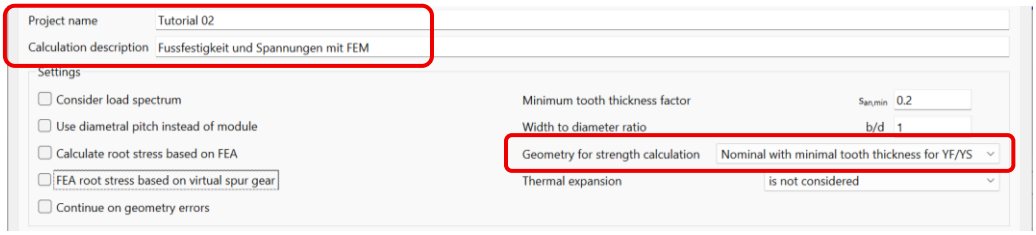

Figure 2-3 Tab *General*, *Project name* and *Calculation description*

2.2 K - factors

In the *Geometry* tab, it can be seen that the gear quality is assumed to be ideal by setting the *Tolerance class ISO 1328* to 1 R30. The goal is to achieve K_v = 1.00 and $K_{H\alpha}$ = 1.00 in order to minimize or eliminate their influence on the calculated tooth root stress. In the same direction, the input *Speed* = 1 rpm and K_A = 1.00. In the *Details for Strength* tab, the load distribution factor K_γ = 1.00 and the face load factor $K_{H\beta}$ = 1.00 are set accordingly. This is not practical, but results in the K factors playing no role in the tooth root stress calculation, i.e., K = 1.00.

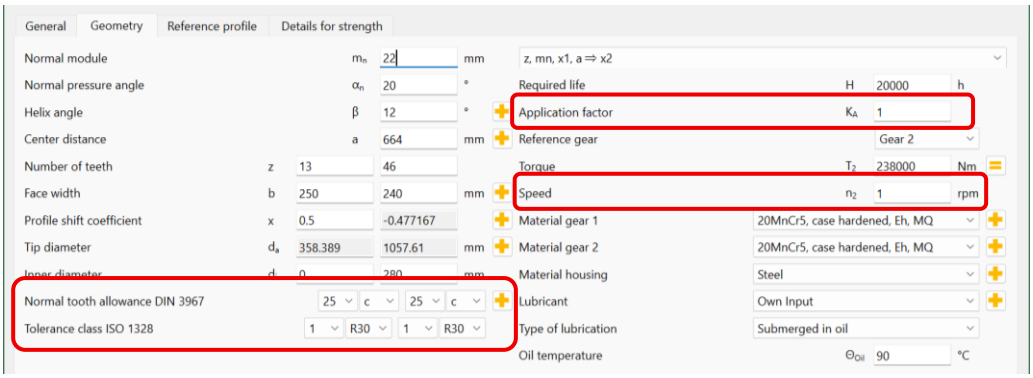

Figure 2-4 Tab *Geometry*, note gear quality, speed and application factor.

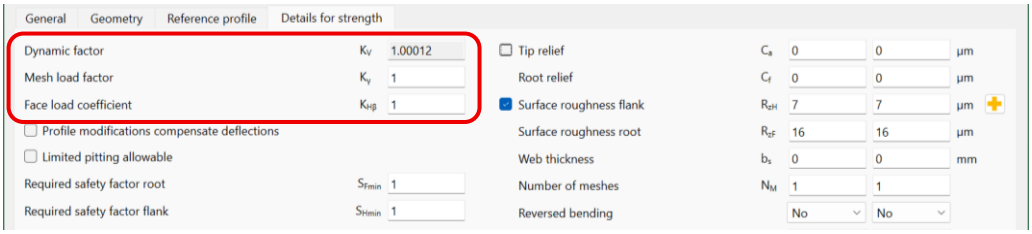

Figure 2-5 Tab *Geometry*, note *Dynamic factor*, *Mesh load factor*, *Face load coefficient*.

2.3 Configuration Result Overview

For the summary of the tooth root stresses, the results overview is adapted. It is opened via *Extras/Result overview*.

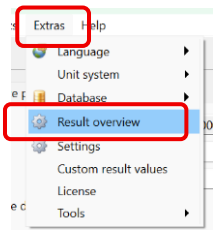

Figure 2-6 Menu *Extras/Result overview*.

The right side table content is removed via the «x» button to prepare it for a new setup.

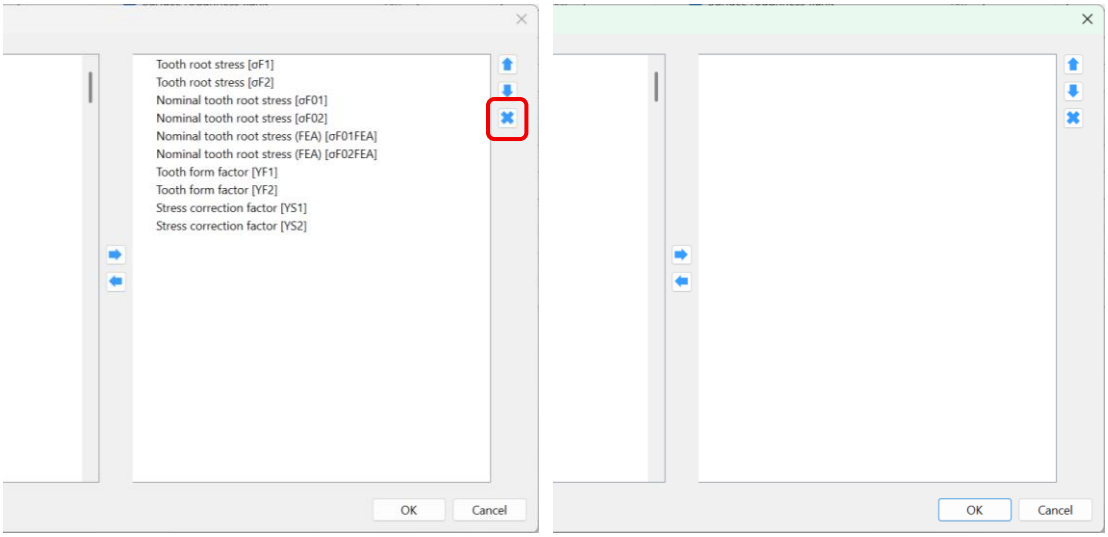

Figure 2-7 Delete content via the «x» button.

To display the tooth root stresses and other properties of interest here, they are selected on the left and transferred to the right part via the «->» arrow.

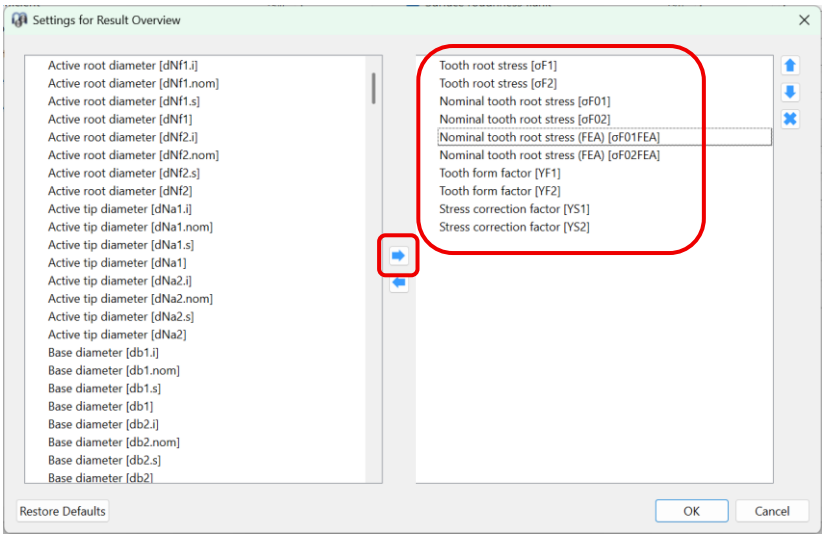

Figure 2-8 Selection and transfer of the results of interest.

The selected results are then visible in the Results overview window.

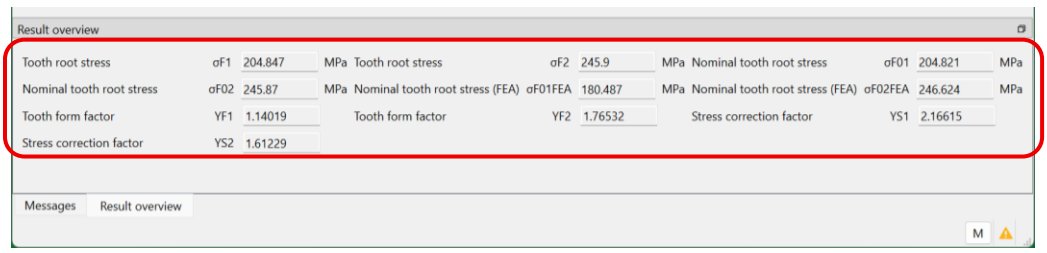

Figure 2-9 *Result overview* showing the activated results.

2.4 Reference results

According to ISO 6336-, the tooth root stress σ_F is equal the nominal tooth root stress σ_{F0}, multiplied the K-factors, i.e. $\sigma_F = \sigma_{F0}*K_A*K_\gamma*K_v*K_{F\beta}*K_{F\alpha}$. In this tutorial $\sigma_F = \sigma_{F0}$ applies, as all K–factors are set to K = 1.00. No FEM calculation is done yet. Hence, the stress values are not yet shown. The following reference values are noted.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	204.85	MPa
Tooth root stress Gear 2	σ_{F2}	245.90	MPa
Nominal tooth root stress Gear 1	σ_{F01}	204.82	MPa
Nominal tooth root stress Gear 2	σ_{F02}	245.87	MPa
Form factor Gear 1	Y_{F1}	1.14	-
Form factor Gear 2	Y_{F2}	1.77	-
Stress correction factor Gear 1	Y_{S1}	2.17	-
Stress correction factor Gear 2	Y_{S2}	1.61	-

Table 2-1 Reference values tooth root, calculation along ISO 6336-3. The small deviations between nominal tooth root stress and tooth root stress are due to the dynamic factor being calculated.

3 Implementation, step 2

3.1 Activation of the FEM calculation

In the *General* tab, enable the flag *Calculate root stress based on FEM* and run the calculation again. The tooth root stresses for pinion and gear are then displayed in the results overview.

Figure 3-1 Activate FEM calculation in tab *General*, run calculation, tooth root stress from FEM calculation in the *Result overview*.

Open graphics showing the von maximum principal stresses in the menu *Graphics/Tooth root stress (2D) Gear 1* and *Graphics/Tooth root stress (2D) Gear 2*. Open *Diagram options* via right-click in the graphic, and also open *Graphics/Options* via right-click in the graphic. Make settings as shown below. With the option *Show mesh*, the edges of the finite elements become visible, allowing the mesh to be displayed. For examining stress distributions, it is generally advisable not to display the mesh.

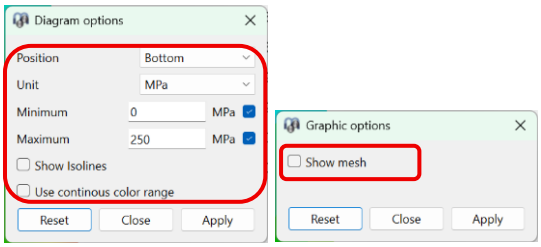

Figure 3-2 Options for display of fringe plots.

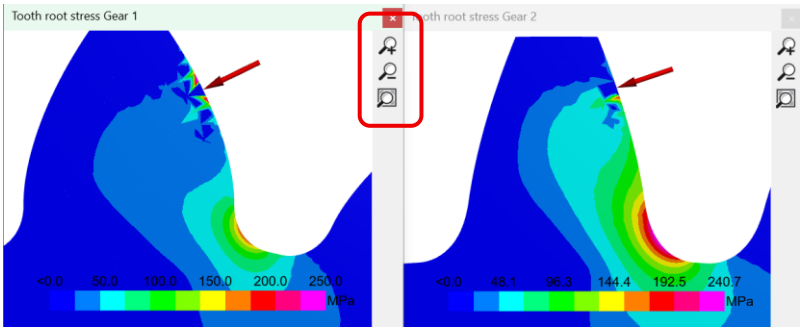

Figure 3-3 Maximum principal stress Gear 1 and Gear 2. Load application at the highest point of single tooth contact.

Zooming is done via the mouse wheel or the corresponding buttons as shown above. The display of the entire gear segment is achieved via the *Fit To Window* button.

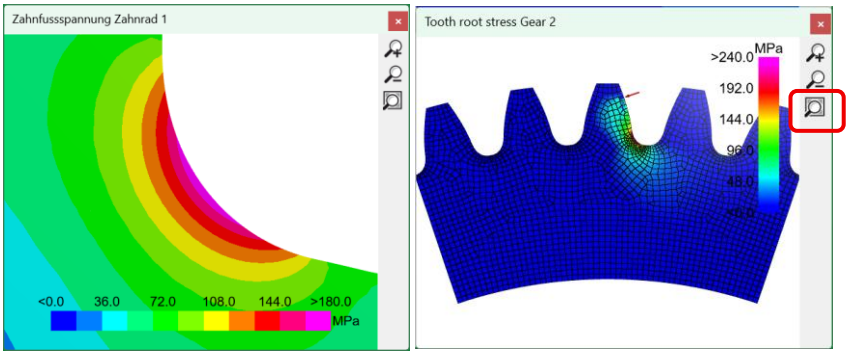

Figure 3-4 Left: Tooth root stress (2D) Gear 1, zoomed in, mesh not displayed, color bar not continuous. Right: Tooth root stress (2D) Gear 2, entire model.

Via right-click and selecting *Freeze content*, the graphics can be frozen. The timestamp is displayed in the title bar.

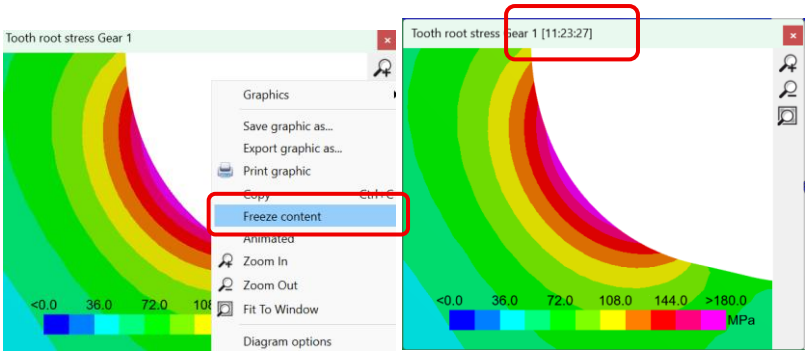

Figure 3-5 Left: Freezing the graphic. Right: Display of the time at which the graphic was frozen.

3.2 Resulting stress levels

Above table is then extended to the below.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	204.85	MPa
Tooth root stress Gear 2	σ_{F2}	245.90	MPa
Nominal tooth root stress Gear 1	σ_{F01}	204.82	MPa
Nominal tooth root stress Gear 2	σ_{F02}	245.87	MPa
Form factor Gear 1	Y_{F1}	1.14	-

Form factor Gear 2	Y_{F2}	1.77	-
Stress correction factor Gear 1	Y_{S1}	2.17	-
Stress correction factor Gear 2	Y_{S2}	1.61	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	180.31	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	240.69	MPa

Table 3-1 Reference values tooth root, calculation along ISO 6336-3 and tooth root stresses from FEM calculation.

3.3 Comparison

For Gear 1, the difference between the result from the calculation according to ISO, σ_{F01} = 204.85 MPa, and the result from the FEM calculation with σ_{F01FEA} = 180.31 MPa is significant. For Gear 2, the difference with σ_{F02} = 245.87 MPa to σ_{F02FEA} = 240.69 MPa is minimal.

4 Implementation, step 3

4.1 Input and calculation, protuberance

In the graphic *Graphics/Gear engagement*, the gear mesh is shown.

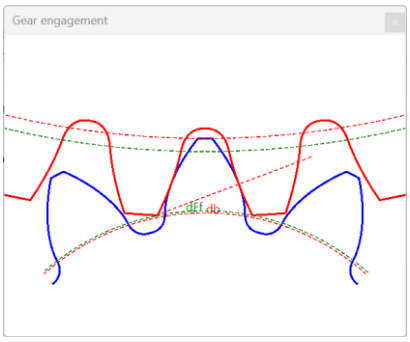

Figure 4-1 Gear mesh.

In the Reference Profile tab, we now enter a protuberance angle of α_{prP} = 10° and a protuberance height of h_{prP} = 0.4*mn.

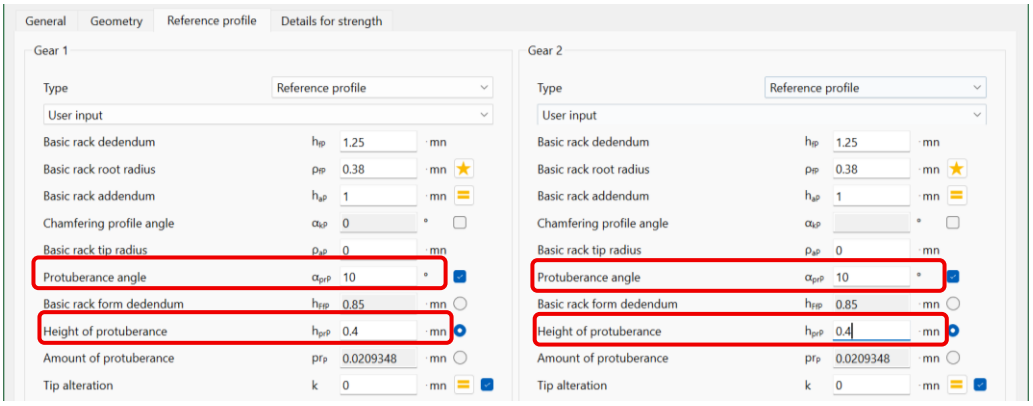

Figure 4-2 Input of *Protuberance angle* and *Height of protuberance* in the tab *Reference profile*.

After the calculation, the tooth engagement is provided with the protuberance. In the graphic *Graphics/Manufacturing Gear 1*, the protuberance on the reference profile of the tool is visible.

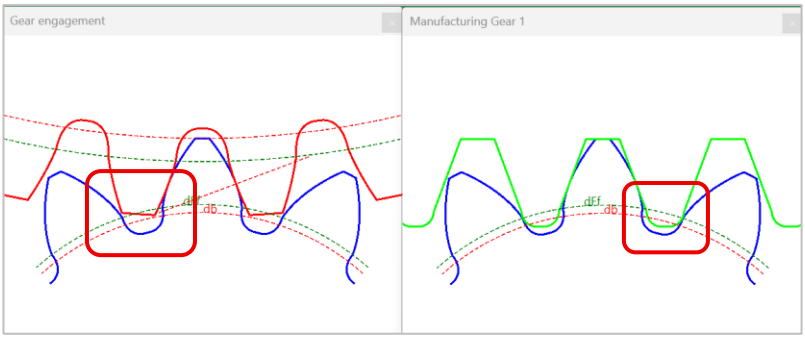

Figure 4-3 Left: Engagement, gears with undercut. Right: Engagement of tool reference profile to gear, tool with protuberance.

The definitions according to ISO 21771-1 apply to the tool, analogously to the gear.

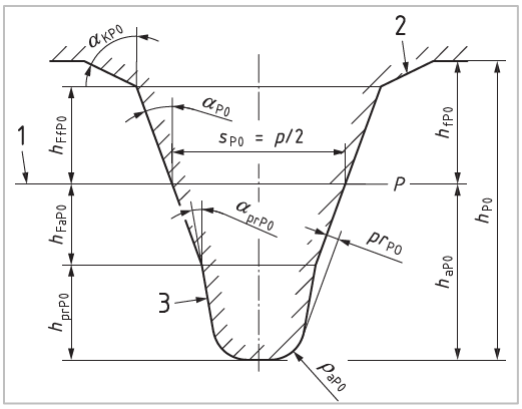

Figure 4-4 Reference profile of the pre-machining tool with protuberance, according to ISO 21771-1.

The calculation is performed. In the graphics in the menu *Graphics/Tooth root stress (2D) Gear 1* and *2*, we find the following stress distributions.

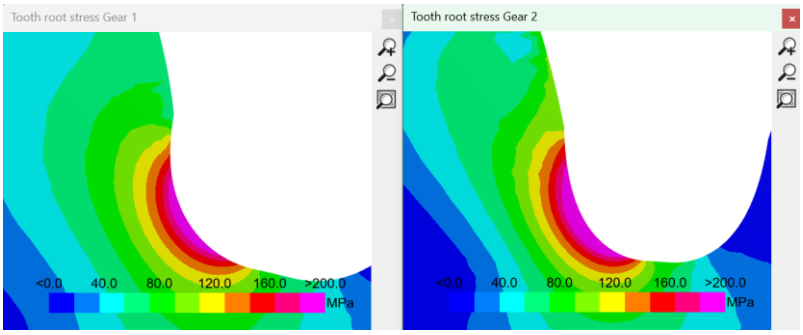

Figure 4-5 Tooth root stress Gear 1 and Gear 2, color bar upper value limited to 200 MPa.

Now, the tabulated values are

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	259.533	MPa
Tooth root stress Gear 2	σ_{F2}	266.693	MPa
Nominal tooth root stress Gear 1	σ_{F01}	259.486	MPa
Nominal tooth root stress Gear 2	σ_{F02}	266.646	MPa
Form factor Gear 1	Y_{F1}	1.64	-
Form factor Gear 2	Y_{F2}	1.98	-
Stress correction factor Gear 1	Y_{S1}	1.91	-
Stress correction factor Gear 2	Y_{S2}	1.59	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	227.16	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	261.30	MPa

Table 4-1 Calculation with protuberance, calculation according to ISO 6336-3 and tooth root stresses from the FEM calculation.

Compared to Table 3-1, the stresses calculated with FEM have increased. It is interesting to see how the tooth root form factors Y_F have increased. This is because the protuberance creates an undercut or, more generally, a reduction of the tooth thickness at the critical cross-section. The stress correction factors Y_S have decreased slightly since the fillet now has a larger radius, but the reduction cannot compensate for the increase in the form factors.

File *MESYS-Tutorial-Cyl_gearpair_02_01-ww-v2500.mCGP*

4.2 Maximize root rounding

Using the «*» button, the tip fillet radius on the tool, ρ_{aP0}, is maximized.

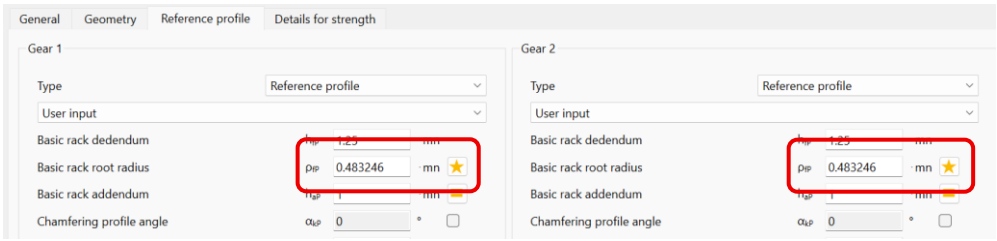

Figure 4-6 Maximize tool tip rounding or gear root rounding.

After recalculating (F5), the now lower stresses and the following values are found.

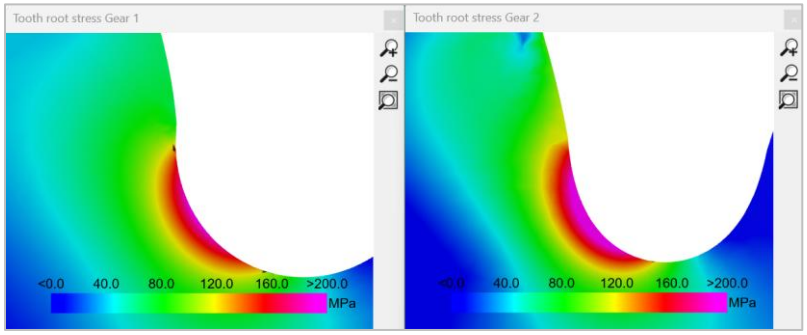

Figure 4-7 Tooth root stresses with maximized tip radius on the tool.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	224.15	MPa
Tooth root stress Gear 2	σ_{F2}	245.26	MPa
Nominal tooth root stress Gear 1	σ_{F01}	224.11	MPa
Nominal tooth root stress Gear 2	σ_{F02}	245.22	MPa
Form factor Gear 1	Y_{F1}	1.45	-
Form factor Gear 2	Y_{F2}	1.82	-
Stress correction factor Gear 1	Y_{S1}	1.87	-
Stress correction factor Gear 2	Y_{S2}	1.56	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	196.38	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	253.57	MPa

Table 4-2 Calculation with protuberance and maximized tip fillet radius on the tool, calculation according to ISO 6336-3 and tooth root stresses from the FEM calculation.

The reduction in stresses from σ_{F01FEA} = 227.16 to σ_{F01FEA} = 196.38 for Gear 1 and from σ_{F01FEA} = 261.30 to σ_{F01FEA} = 253.57 for Gear 2 differs, being more pronounced for Gear 1.

File *MESYS-Tutorial-Cyl_gearpair_02_02-ww-v2500.mCGP*

4.3 Considering machining allowance

In the *Reference profile* tab, the type is switched to *Hob* and the *Machining allowance* q = 0.01*m_n, the *Finishing tool addendum* h_{aP0F} = 1.10*m_n, and the *Finishing too tip radius* ρ_{aP0F} = 0.05*mn are entered for Gear 1 and Gear 2.

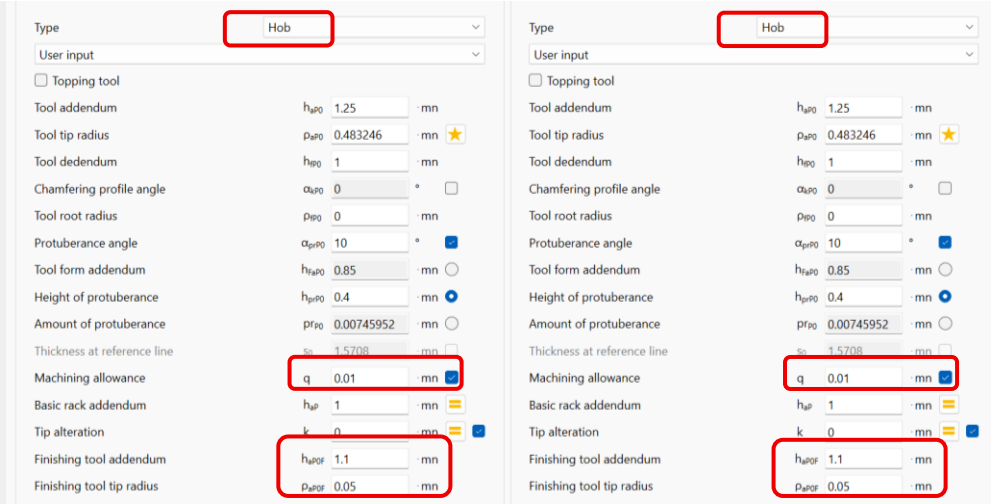

Figure 4-8 Input for the finish machining.

After the calculation, finish machining notches are visible since the protuberance is too small compared to the machining allowance.

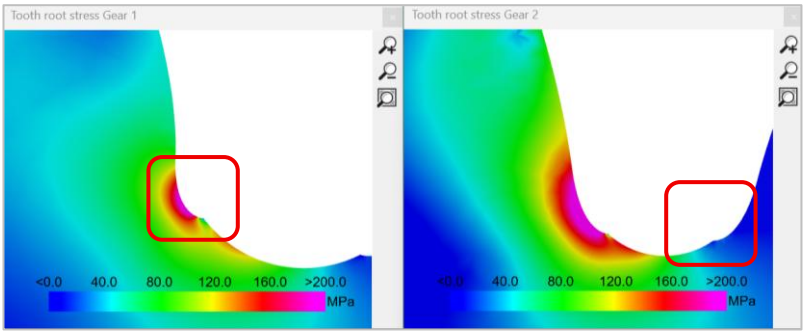

Figure 4-9 Notches in the tooth root of Gear 1 and Gear 2.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	182.37	MPa
Tooth root stress Gear 2	σ_{F2}	231.01	MPa
Nominal tooth root stress Gear 1	σ_{F01}	182.35	MPa
Nominal tooth root stress Gear 2	σ_{F02}	230.98	MPa
Form factor Gear 1	Y_{F1}	1.06	-
Form factor Gear 2	Y_{F2}	1.69	-
Stress correction factor Gear 1	Y_{S1}	2.08	-
Stress correction factor Gear 2	Y_{S2}	1.58	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	246.43	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	296.83	MPa

Table 4-3 Calculation with protuberance and maximized tip fillet radius on the tool, calculation according to ISO 6336-3 and tooth root stresses from the FEM calculation.

File *MESYS-Tutorial-Cyl_gearpair_02_03-ww-v2500.mCGP*

The stress peak is now located in the finish machining notch and depends on the tip radius of the finishing tool. If we increase this from ρ_{aP0F} = 0.05 to ρ_{aP0F} = 0.10, we find σ_{F01FEA} = 218.55 MPa instead of σ_{F01FEA} = 246.43 MPa for Gear 1.

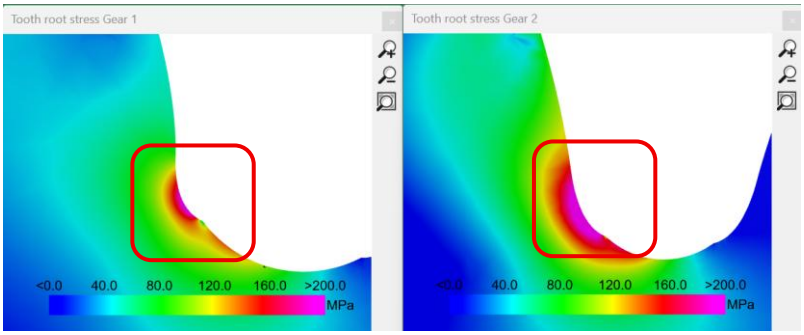

Figure 4-10 Finish machining notches in the root of Gear 1 and Gear 2. Radius increased.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	182.37	MPa
Tooth root stress Gear 2	σ_{F2}	231.01	MPa
Nominal tooth root stress Gear 1	σ_{F01}	182.35	MPa
Nominal tooth root stress Gear 2	σ_{F02}	230.98	MPa
Form factor Gear 1	Y_{F1}	1.06	-
Form factor Gear 2	Y_{F2}	1.69	-
Stress correction factor Gear 1	Y_{S1}	2.08	-
Stress correction factor Gear 2	Y_{S2}	1.58	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	218.55	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	277.93	MPa

Table 4-4 Calculation with protuberance and maximized tip fillet radius on the tool, calculation according to ISO 6336-3 and tooth root stresses from the FEM calculation.

File *MESYS-Tutorial-Cyl_gearpair_02_04-ww-v2500.mCGP.*

5 Implementation, step 4

5.1 Renewed reference calculation

Open file *MESYS-Tutorial-Cyl_gearpair_02-REL25.mCGP* via *File/Open* and run the calculation. We again find the following values.

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	204.85	MPa
Tooth root stress Gear 2	σ_{F2}	245.90	MPa
Nominal tooth root stress Gear 1	σ_{F01}	204.82	MPa
Nominal tooth root stress Gear 2	σ_{F02}	245.87	MPa
Form factor Gear 1	Y_{F1}	1.14	-
Form factor Gear 2	Y_{F2}	1.77	-
Stress correction factor Gear 1	Y_{S1}	2.17	-
Stress correction factor Gear 2	Y_{S2}	1.61	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	180.31	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	240.69	MPa

Table 5-1 Reference values tooth root, calculation according to ISO 6336-3 and FEM calculation. Tool is hob.

In the menu *Graphics/Manufacturing Gear 1* and *2*, the rack-shaped tool, the hob, is displayed. In the menu *Graphics/Tooth root stress (2D) Gear 1* and *2*, the tooth root stresses are shown as a fringe plots.

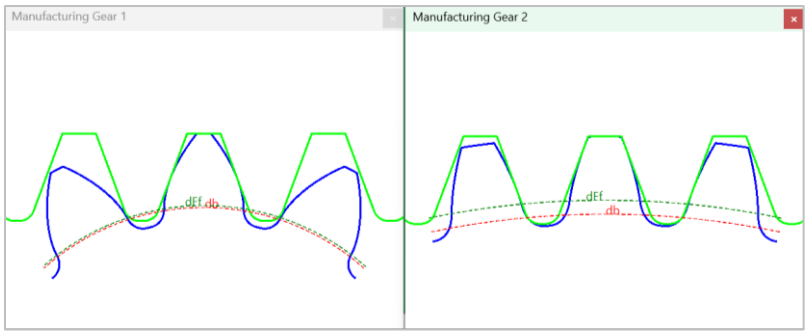

Figure 5-1 Gear (blue) in engagement with the rack-shaped tool (green). Left: Gear 1. Right: Gear 2.

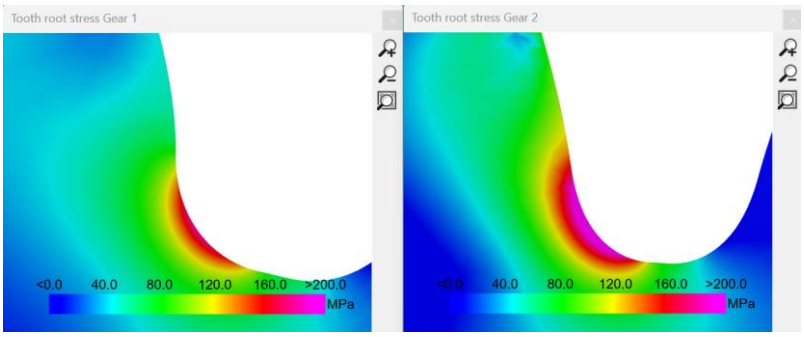

Figure 5-2 Tooth root stress from the FEM calculation. Color scale limited to 200 MPa. Left: Gear 1. Right: Gear 2.

5.2 Use of shaper cutter

In the *Reference profile* tab, instead of the reference profile input (where the reference profile of the gear is entered, from which the reference profile of the rack-shaped tool is

derived and used to generate the tooth form), the *Shaper cutter* input is now selected. The number of teeth and the profile shift of the shaper cutter are given as $z_0 = 23$ and $x_0 = 0.10$. After the calculation (F5), the graphics in the menu *Graphics/Gear engagement*, *Graphics/Manufacturing Gear 1* and *2*, *Tooth root stress (2D) Gear 1* and *2* are examined.

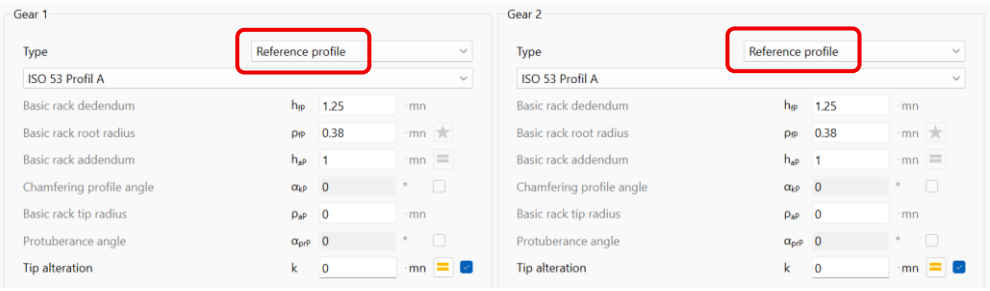

Figure 5-3 Tab *Reference profile* input *Reference profile* for both gear 1 and gear 2

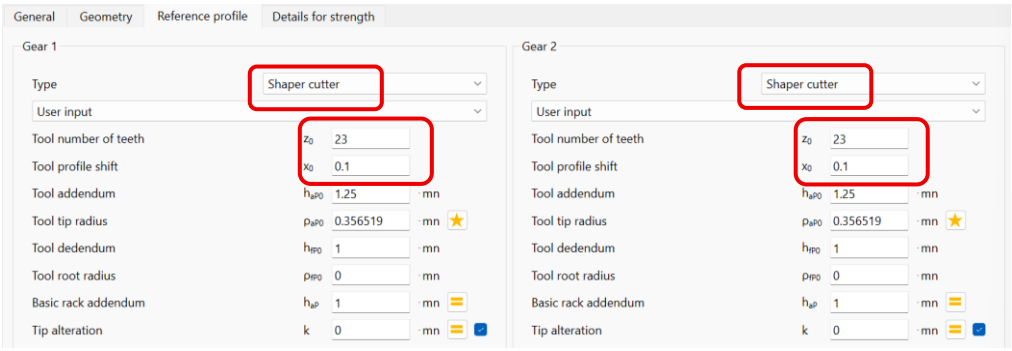

Figure 5-4 Tab *Reference profile* input *Shaper cutter*, for gear 1 and gear 2.

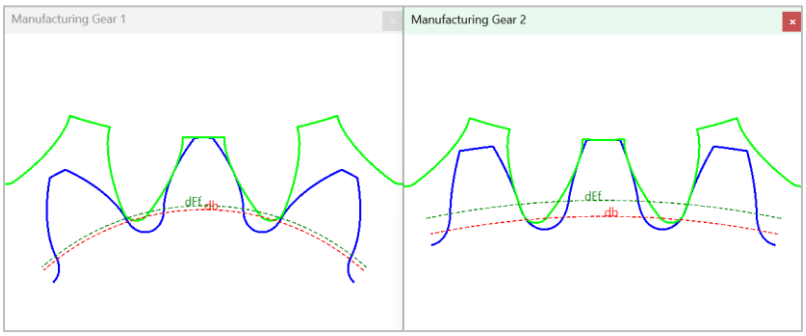

Figure 5-5 Manufacturing Gear 1 and Gear 2, each with a shaper cutter.

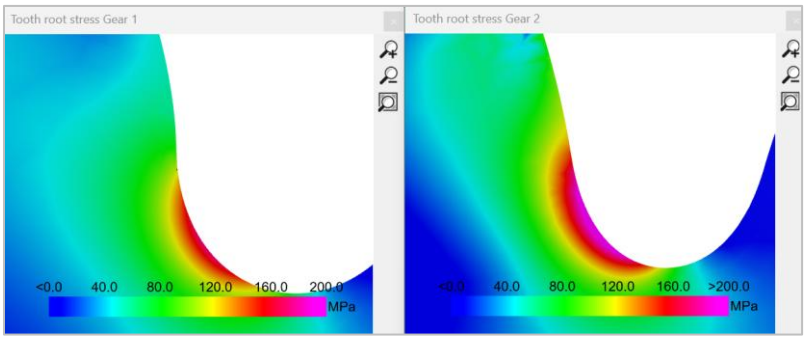

Figure 5-6 Tooth root stresses, tooth form generated with shaper cutter.

The tabular values are now as follows

Property	Symbol	Value	Unit
Tooth root stress Gear 1	σ_{F1}	192.85	MPa
Tooth root stress Gear 2	σ_{F2}	222.62	MPa
Nominal tooth root stress Gear 1	σ_{F01}	192.83	MPa
Nominal tooth root stress Gear 2	σ_{F02}	222.59	MPa
Form factor Gear 1	Y_{F1}	1.19	-
Form factor Gear 2	Y_{F2}	1.71	-
Stress correction factor Gear 1	Y_{S1}	1.95	-
Stress correction factor Gear 2	Y_{S2}	1.51	-
Nominal tooth root stress (FEM) Gear 1	σ_{F01FEA}	175.31	MPa
Nominal tooth root stress (FEM) Gear 2	σ_{F02FEA}	223.47	MPa

Table 5-2 Tooth root values, calculation according to ISO 6336-3 and FEM calculation. Tool is a shaper cutter.

File *MESYS-Tutorial-Cyl_gearpair_02_05-ww-v2500.mCGP*.

6 Implementation, step 5

6.1 Renewed reference calculation

Open file *MESYS-Tutorial-Cyl_gearpair_02-REL25.mCGP* via *File/Open* and run the calculation. We again find the following values as per Table 5-1.

6.2 Cylindrical gear sections

The FEM calculations above are performed at the normal section. In the normal section and in the axial section of an involute helical gear, the flank form is no longer involute.

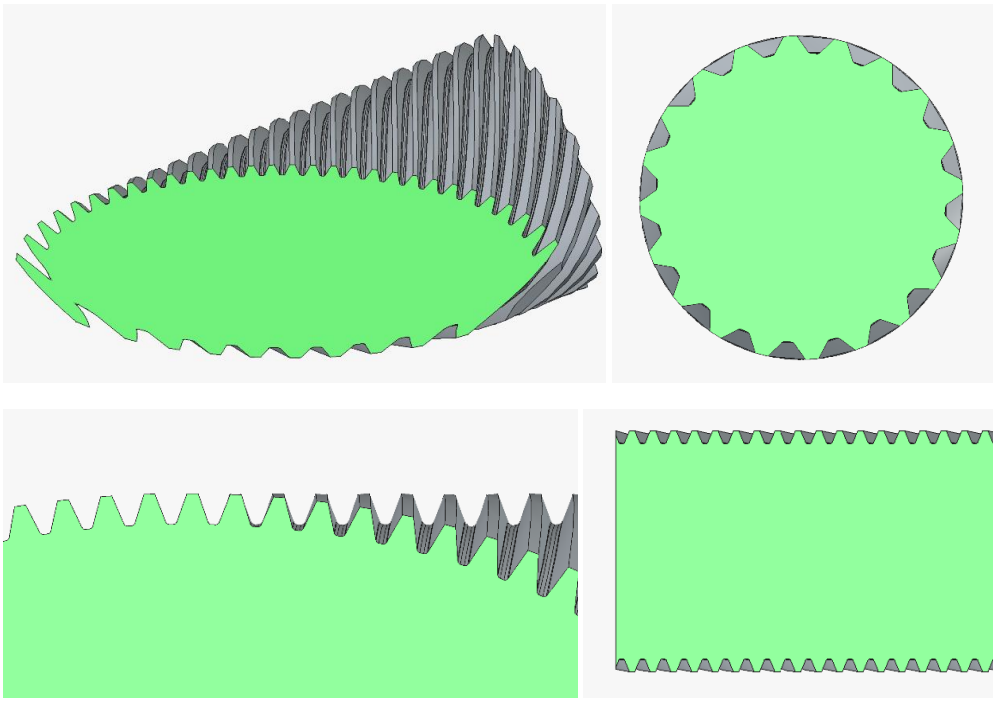

Figure 6-1 Top left: Normal section, perspective view. Top right: Transverse section. Bottom left: Normal section. Bottom right: Axial section.

In the calculation according to ISO 6336, a virtual spur gear (ISO 6336 uses the term "virtual spur gear", DIN 3990 uses the term "equivalent spur gear") is used for helical gears. This is generated such that it has a tooth form that closely approximates that of the helical gear in the normal section. This preserves the properties, e.g., tooth root thickness of the helical gear in the normal section. In MESYS, the calculation is possible both at the normal section of the helical gear and at the virtual spur gear. In the *General* tab, selecting *Calculate root stress based on FEA* calls up the calculation at the normal section. If the flag *FEA root stress based on virtual spur gear* is additionally enabled, the FEM calculation is performed on the virtual spur gear instead.

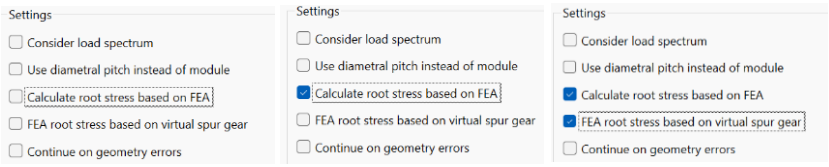

Figure 6-2 *General* tab, selection of the FEM tooth root stress calculation. Left: No calculation. Center: Calculation at the normal section. Right: Calculation at the virtual spur gear.

First, the calculation at the normal section is performed by enabling the first flag and disabling the second flag, see figure above, center. Open graphics *Tooth root stress (2D) Gear 1* and *2*, *Tooth root stress Gear 1* and *2*. Select graphic settings for *Tooth root stress (2D) Gear 1* and *2* as follows.

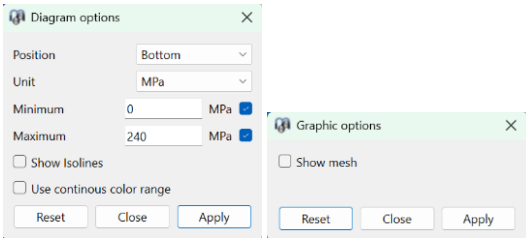

Figure 6-3 Left: Diagram Options. Right: Graphics Options.

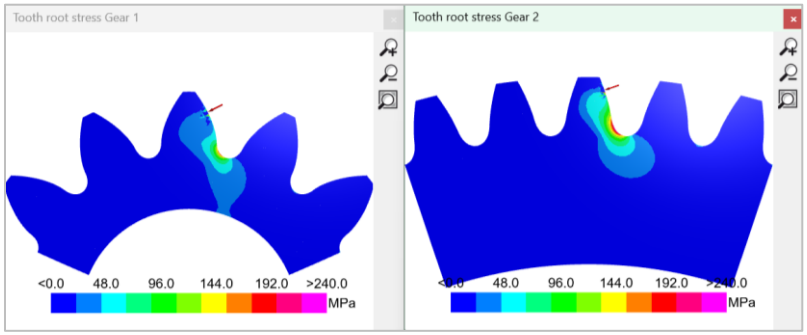

Figure 6-4 Von Mises stress distribution at Gear 1 and Gear 2, in the normal section.

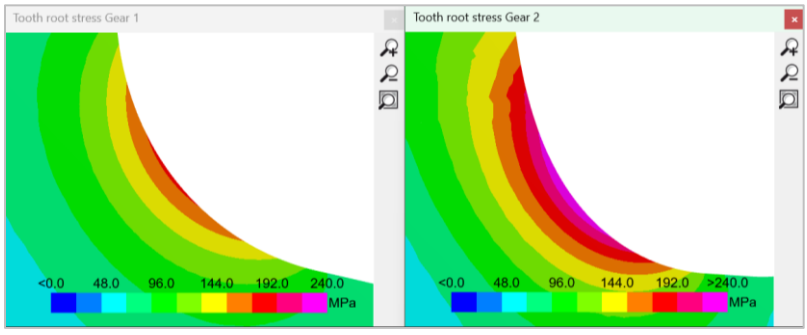

Figure 6-5 Maximum principal stress distribution at Gear 1 and Gear 2, in the normal section, detail view.

The following graphics show the stress at the surface of the root, from left to right from the root base toward the flank. Note that *sigl* is the first principal stress, which is to be compared with the stresses according to ISO 6336. *sigM* is the von Mises stress.

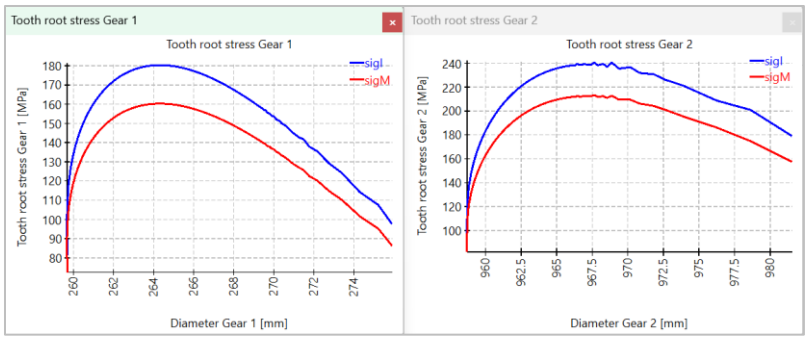

Figure 6-6 Stress distribution at the surface of the tooth root, in the normal section.

The calculation is now repeated, this time with the flag *FEA root stress based on virtual spur gear* enabled. The graphics are now as follows.

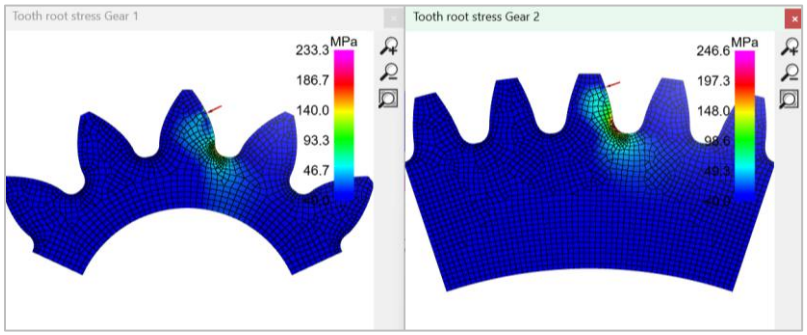

Figure 6-7 Maximum principal stress distribution at Gear 1 and Gear 2, at the virtual spur gear.

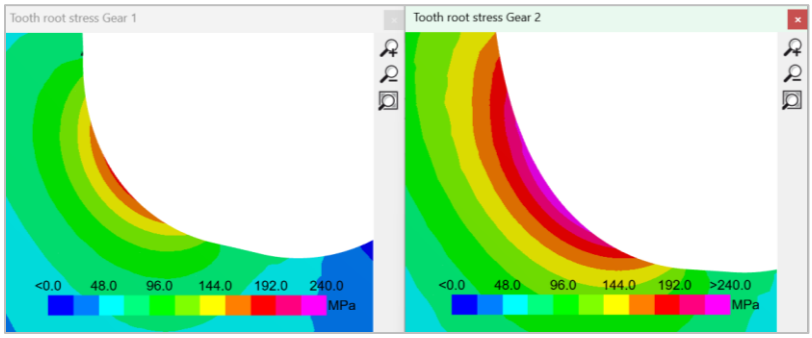

Figure 6-8 Maximum principal stress distribution at Gear 1 and Gear 2, at the virtual spur gear, detail.

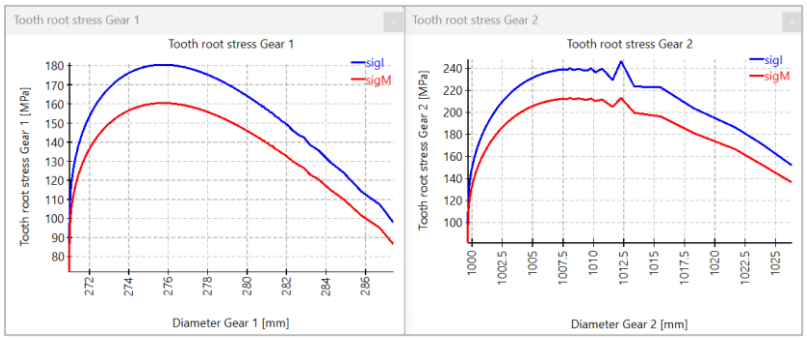

Figure 6-9 Stress distribution at the surface of the tooth root, at the virtual spur gear.

In direct comparison (above for tooth root stress at the normal section, below for at the virtual spur gear), only minimal differences are apparent.

This confirms for this case that the approach via the virtual spur gear as used in ISO 6336 for the tooth root stress calculation is accurate.

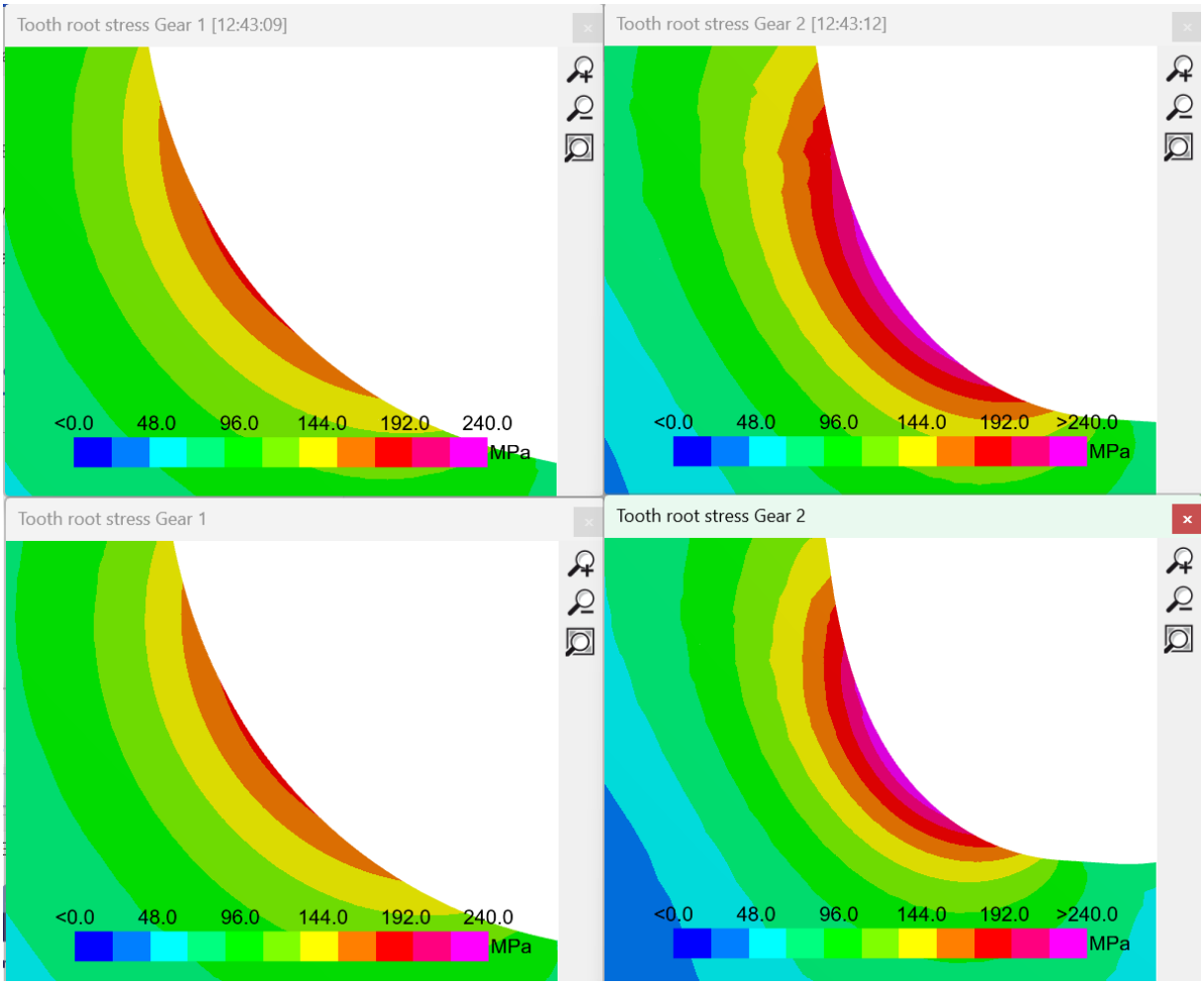

Figure 6-10 Left: Gear 1. Right: Gear 2. Top: Calculation at the normal section. Bottom: Calculation at the virtual spur gear. Maximum principal stress.

7 Implementation, step 6

7.1 Renewed reference calculation

Open file *MESYS-Tutorial-Cyl_gearpair_02-REL25.mCGP* via *File/Open* and run the calculation. We again find the following values as per Table 5-1.

7.2 Influence of the mean stress level

In the calculations above, the acting stresses in the tooth root were examined. If the tooth is loaded not only in one direction but in both directions, the stress level does not change. This is the case, for example, with a planet gear. In mesh with the sun gear, the tooth is bent in one direction, in mesh with the ring gear in the other direction. The angle of the force direction and the point of force application may differ slightly, and accordingly the tooth root stress in the two meshes may also differ slightly.

The influence of the stress cycle with tensile and compressive stress is accounted for via the mean stress influence factor. For the case of reverse bending, this is set to 0.70 in ISO 6336-5, section 5.3.3, and the allowable stresses are multiplied by it. In the informative Annex B of ISO 6336-3, an extended calculation for the mean stress influence factor Y_M is available. Since this is informative only and not normative, a reverse bending factor can be entered directly in MESYS.

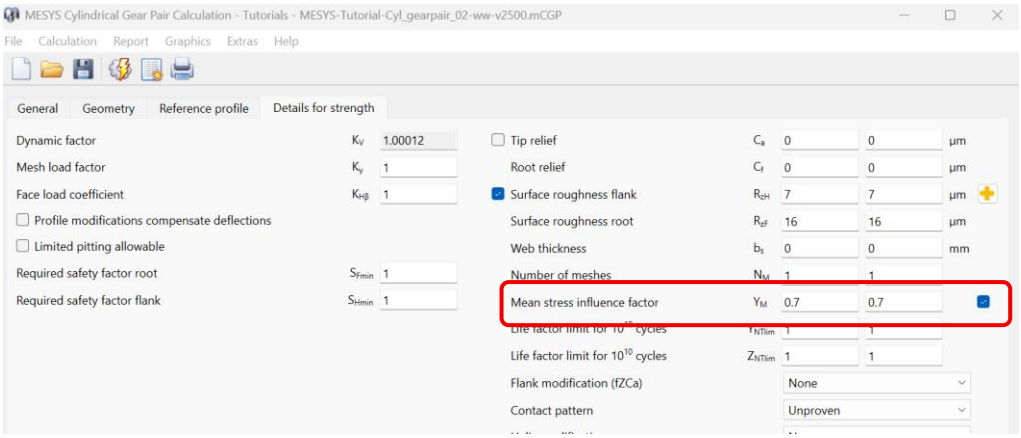

Figure 7-1 Input of mean stress influence factor Y_M, in tab *Details for strength*.

This means that this factor does not affect the actual stresses, but the allowable stresses. After running the calculation, the report shows the below values.

Nominal tooth root stress	σF0	204.8215	245.8699 MPa
Tooth root stress	σF	204.8469	245.9004 MPa
Tooth root stress limit	σFG	806.2467	890.1866 MPa
Safety factor for tooth breakage	SF	3.9359	3.6201

Figure 7-2 Tooth root strength, information in the report, for reference calculation with Y_M = 1.00, i.e. without reverse bending.

After entering Y_M = 0.70 for both gears and running the calculation, the modified tooth root strength, the resulting modified tooth root safety factor, and the tooth root stress are as follows.

Nominal tooth root stress	σF0	204.8215	245.8699 MPa
Tooth root stress	σF	204.8469	245.9004 MPa
Tooth root stress limit	σFG	564.3727	623.1307 MPa
Safety factor for tooth breakage	SF	2.7551	2.5341

Figure 7-3 Tooth root strength, information in the report, for reference calculation with $Y_M = 0.70$, i.e. with reverse bending.

The occurring stresses, nominal tooth root stress and tooth root stress, are the same in both cases. The tooth root stress limit was $\sigma_{FG} = 806.25$ MPa and is now $\sigma_{FG} = 806.25$ MPa * 0.70 = 564.37 MPa. The mean stress influence factor is $Y_M = 0.70$. Accordingly, the tooth root safety factor S_F decreases.