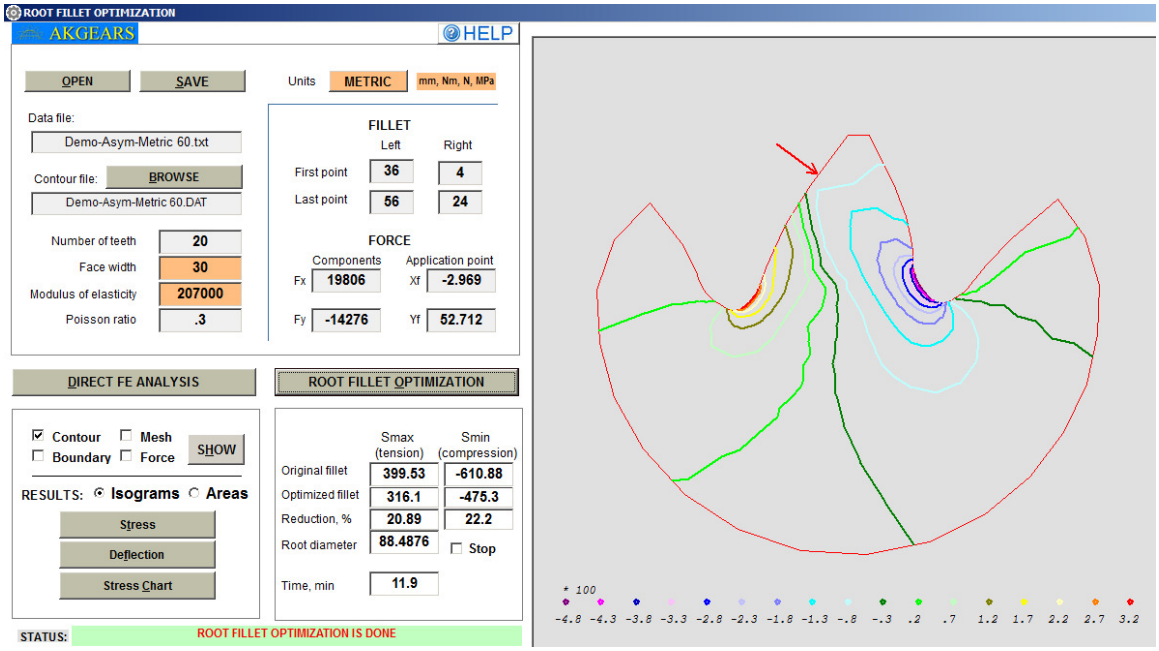
Gear Tooth Root Fillet Optimization Program

User manual



AKGears' gear tooth root fillet optimization program optimizes the gear tooth root fillet to minimize bending stress concentration. This program is applicable to external, internal, and gear rack teeth with symmetric or asymmetric profiles. A detailed description of the gear tooth root fillet optimization technique is described in the following book *A.L. Kapelevich, Direct Gear Design, CRC Press, 2013.*

1. Input data

The application comes with a number input samples that can be found in My Documents\AKGears\Root Fillet Optimization folder. Click Open and select one of the samples or a previously saved input file. This will populate the interface with file data.
Use input data segment of the user interface is shown in the Fig. 1 to manually add/change input parameters. The input data file with extension .txt contains the user interface data and the gear tooth profile – contour file with extension .dat.
Input data segment of the user interface is shown in the Fig. 1.

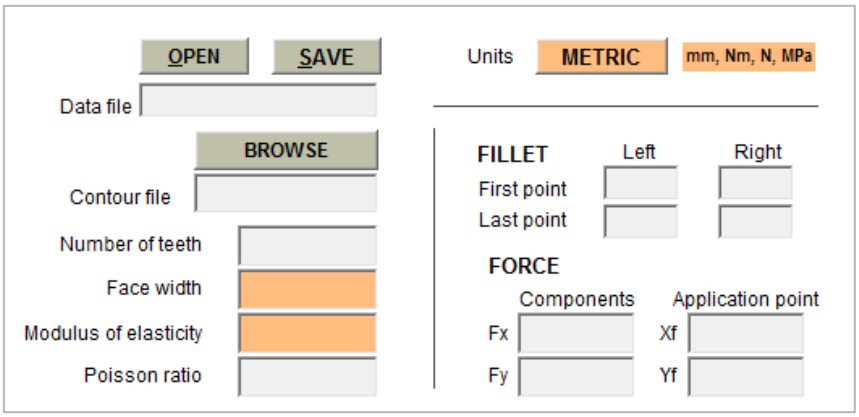
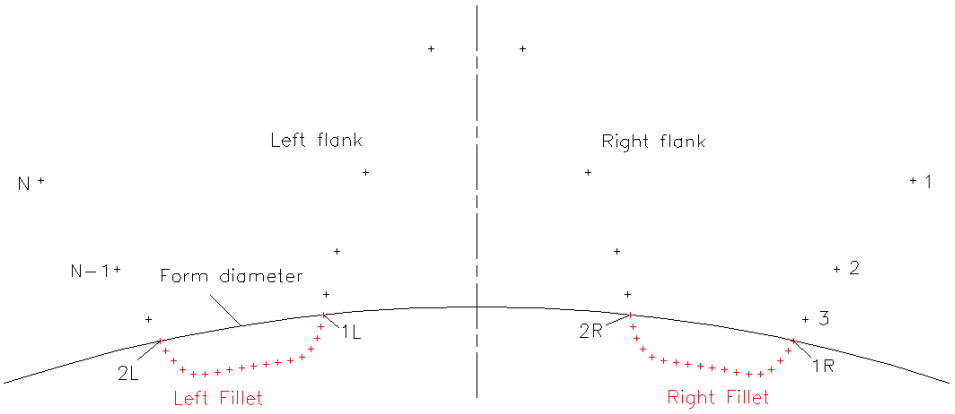


Fig. 1. Input data block of the user interface

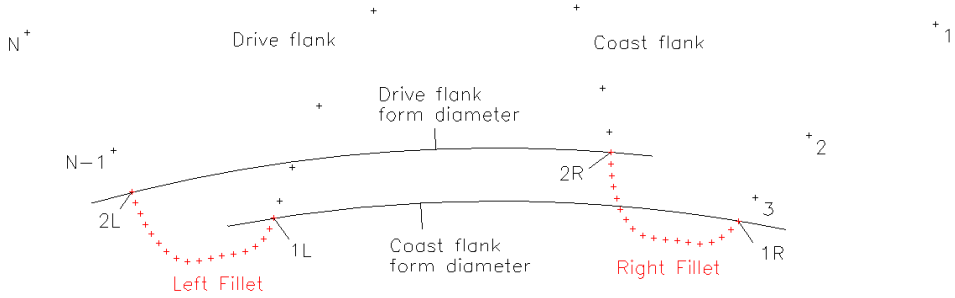
The input data file with extension .txt contains the user interface data and the gear tooth profile – contour file with extension .dat. Newly created or changed input data file can be saved with extension .txt by clicking SAVE button.

1.1. Gear tooth profile – Contour file (with extension .dat)

Tooth root fillet optimization program does not create the intial tooth contour file. This file is constructed in CAD software based on gear design results. The gear tooth profile is a data file presented by the X, Y, Z coordinates of points. **Numeration of these points must be consecutive from right to left. If numeration of the tooth profile points is inconsecutive, calculation will be stopped and a note "Tooth profile points are not in order. Calculation is stopped" will appear. If numeration of the tooth profile points is from left to right, calculation will be stopped and a note "Tooth profile points are numbered from left (first point) to right (last point). They should be numbered from right (first point) to left (last point). Calculation is stopped" will appear.** The number of points N varies from about 50 to 150. Greater number of points provides more accurate optimization results but requires more time to calculate. Typically a profile of 80-90 points will result in good optimization accuracy within reasonable time period.



a



b

Fig. 2. Gear tooth profile points; a – symmetric tooth, b – asymmetric tooth

Left and right initial root fillet points are shown in red in Fig. 2. For more accurate root fillet presentation and better optimization results the neighboring root fillet points should be located closer to each other than the tooth flank points.

The number of fillet points is usually 30-40% of the total number of the tooth points N. These points should be evenly distributed along the initial root fillet profile. **The best optimization result (minimal stress concentration) is achieved, if the initial root fillet profile is constructed as a trajectory of the mating gear tooth tip in tight (backlashless) mesh.** This initial fillet profile is calculated by the Direct Gear Design method. Other curves can also be used for initial location of the root fillet points as long as these curves exclude interference with the mating gear tooth tip in tight (backlashless) mesh. The root fillet profiles are connected to the tooth flanks profiles in the points 1R and 1L of the start, and the points 2R and 2L the end of the root fillets. These points lay on the coast and drive form diameters accordingly (Fig.

2b). For symmetric tooth gears these points should lay on a single form diameter symmetricly located relative to the vertical axis and (Fig. 2a).
The initial location of the root fillet points should not create sharp angles with the tooth flanks profiles, as shown in Fig.3.

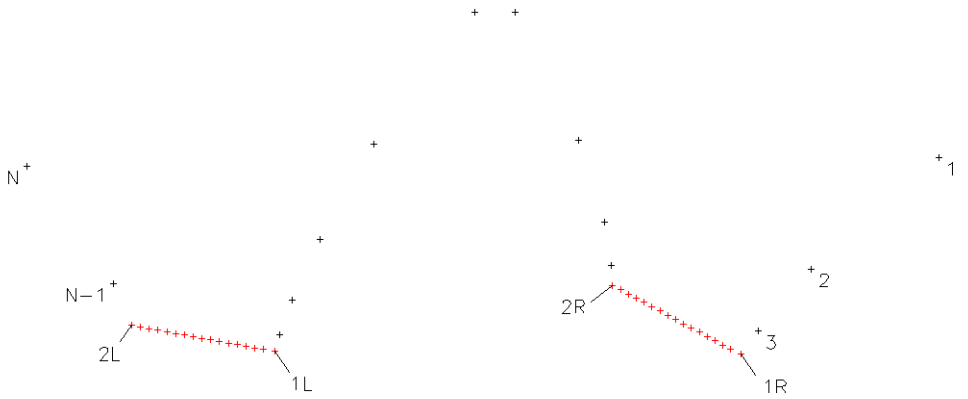


Fig. 3. Unacceptable initial location of the root fillet points

The location of the root fillet points will be changed during optimization process (Fig. 4), however, the optimized root fillet points will not be placed inside or above the initial root fillet profile, because it would lead to possible interference with the mating tooth tip.

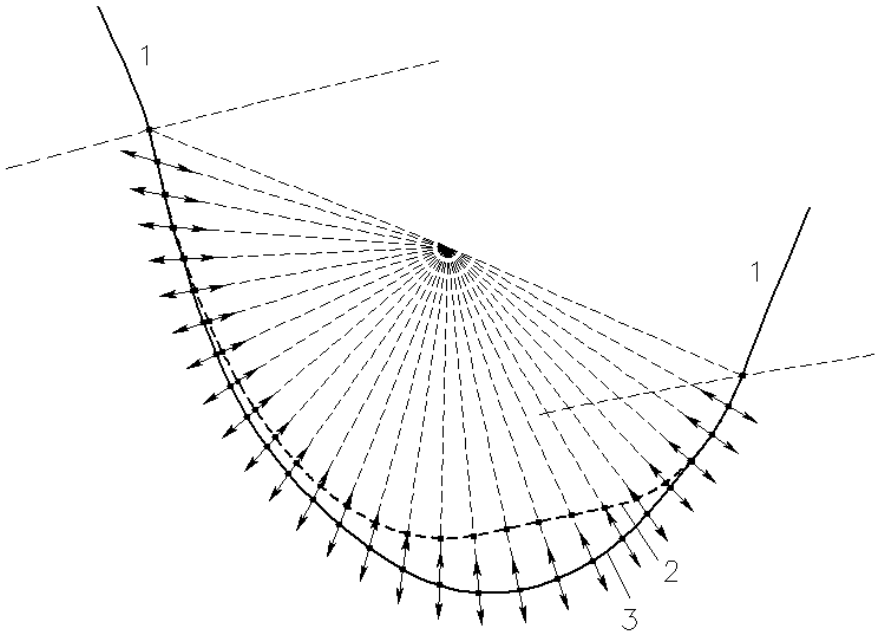


Fig. 4. Tooth fillet profile optimization; 1 – involute tooth flanks, 2 – initial fillet profile, 3 – optimized fillet profile.

1.2. Dimensional unit system: Metric or English system should be selected.

1.3. Number of gear teeth.

This program is applicable for gears with a whole or a fractional number of teeth. It is very important that the tooth profile presented by the X, Y coordinates of points (see 2.1) is constructed for the selected number of teeth. In other words, the angle between the left and right root fillets should be equal 360° divided by a number of teeth.

1.4. Face width

Gear face width should be in selected dimensional units mm or inches.

1.5. Modulus of elasticity and Poisson ratio

The modulus of elasticity and the Poisson ratio of chosen gear material are used for the tooth deflection calculation. Modulus of elasticity should be in selected dimensional units MPa or psi.

1.6. Root fillet points

First (1R and 1L) and last (2R and 2L) points of the right and left root fillets indicate optimization areas of the tooth profiles. It is important to have these points located on the form diameters (Fig. 2). **A number of points of the right and left root fillets must be the same. It is critical that an angle between the corresponding points of the left and right root fillets must be equal 360° divided by a number of teeth. Otherwise root fillet optimization will be stopped and a note "Please check and correct the first and last fillet points numbers for the left and right fillets" will appear.**

1.7. Force and its application point (Fig. 5)

Force is applied to the drive (left) tooth flank and presented by its x and y components Fx and Fy. Force components Fx and Fy should be in selected dimensional units N or lb.

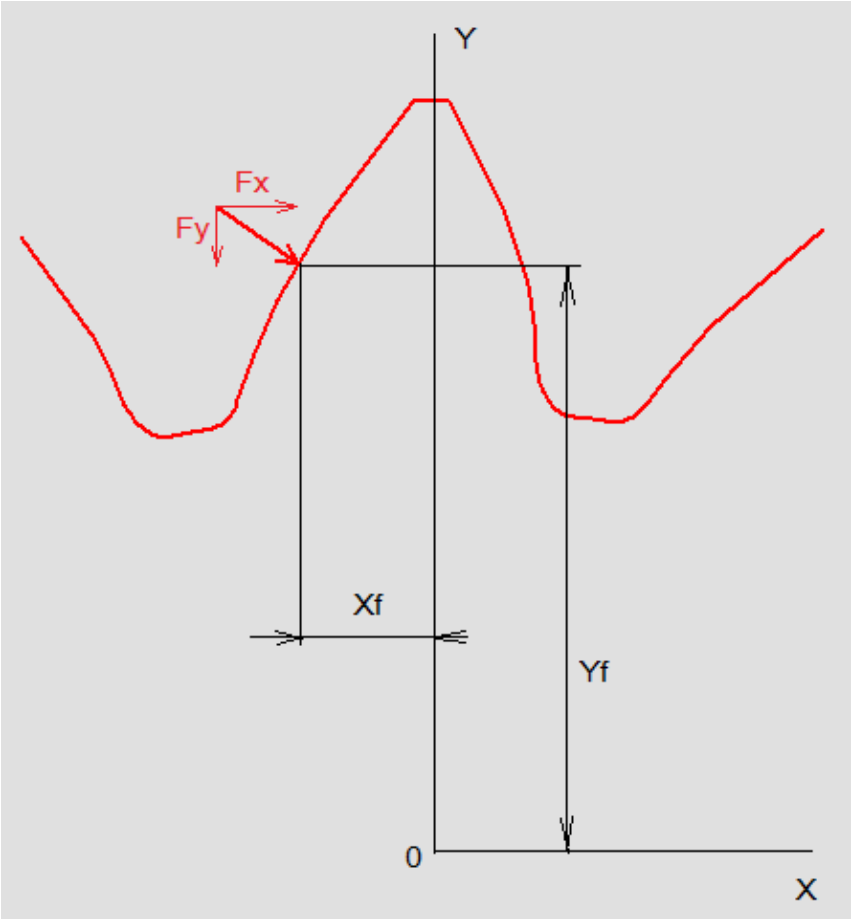


Fig. 5. Force and its application point

The force application point is presented by its coordinates Xf and Yf from the gear center with coordinates X,Y =0. This point should be located on the drive (left) tooth flank, but not necessarily coincide with one of the tooth profile points. Typically it is the highest single tooth contact point.

2. Program operation and results

The program has two operating modes “DIRECT FE ANALYSIS” and “ROOT FILLET OPTIMIZATION”

2.1. Direct FE Analysis mode

The “DIRECT FE ANALYSIS” button starts the FEA of the initial gear tooth profile by using the input data (number of teeth, face width, material properties, load components and application point coordinate, and settings).

Time of calculation varies depending on the total number of tooth profile points and computer performance. For example, for a 50 point tooth profile it is about 2-10 seconds, for a 150 point tooth profile it is about 1-2 minutes.

When the calculation is completed, the status bar indicates “DIRECT FE ANALYSIS is done”. The stress isogram image will appear on the program interface screen field (Fig. 6).

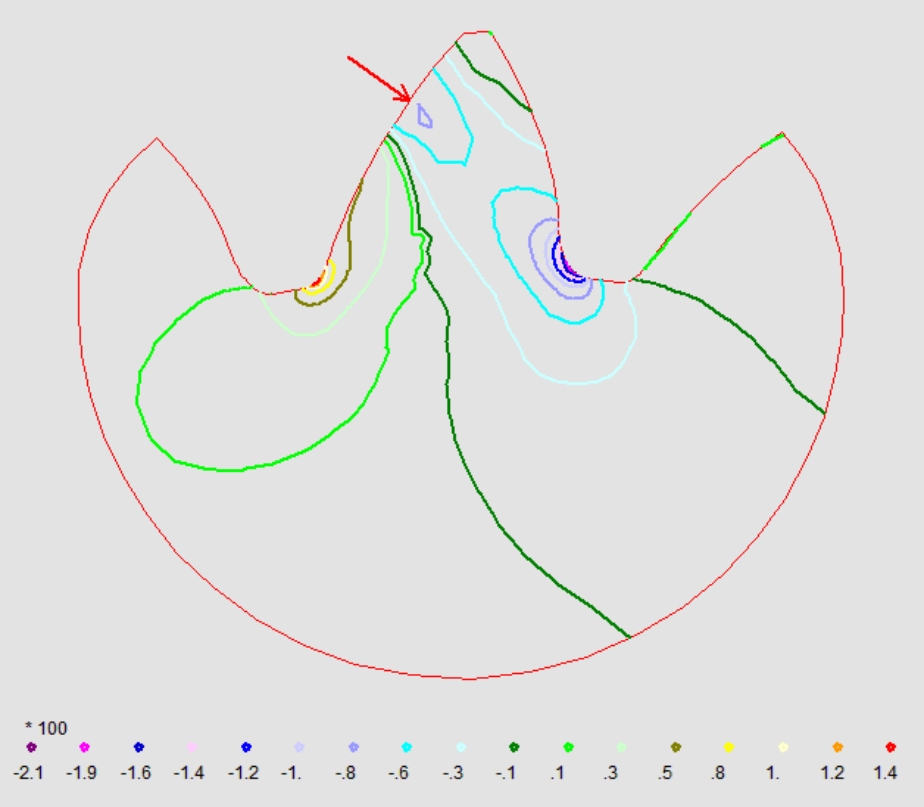


Fig. 6. Stress chart presented by isograms

By marking (or unmarking) separately or simultaneously the checkboxes “Contour”, “Boundary”, “Mesh”, “Force” and using the “SHOW” button (Fig. 7) the corresponding images will appear on the screen area (see Table 1)

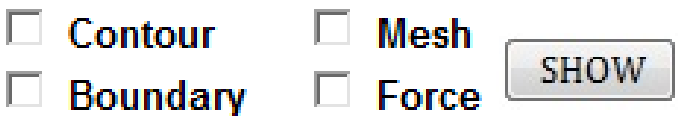
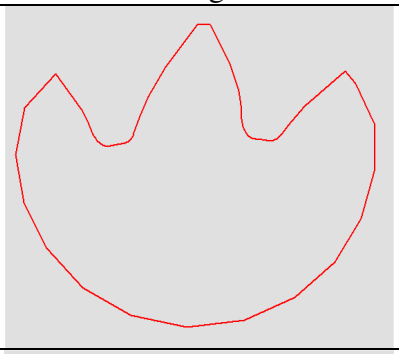
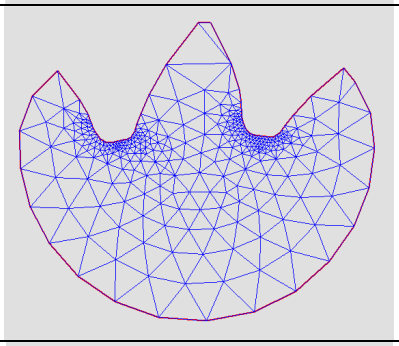
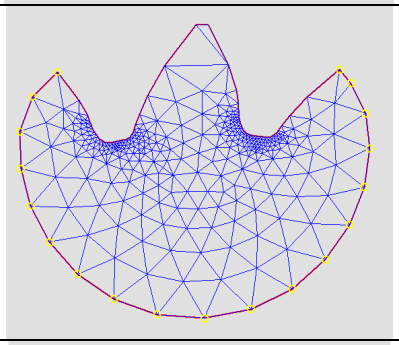
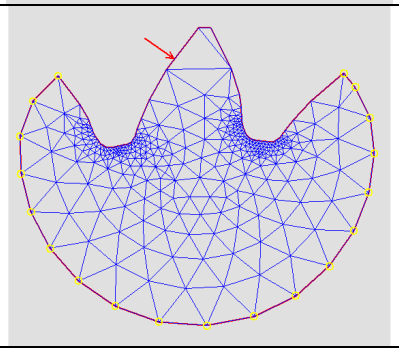


Fig. 7. Image selection commands

Table 1

Image selection command	Image
“Contour” checkbox + SHOW	
“Contour” and “Mesh” checkboxes + SHOW	
“Contour”, “Mesh”, and “Boundary” checkboxes + SHOW	
“Contour”, “Mesh”, “Boundary”, and “Force” checkboxes + SHOW	

If the “Mesh” checkbox is marked, the screen images can be zoomed in on by clicking the left button on the mouse or touch pad or zoomed out by clicking the right button.

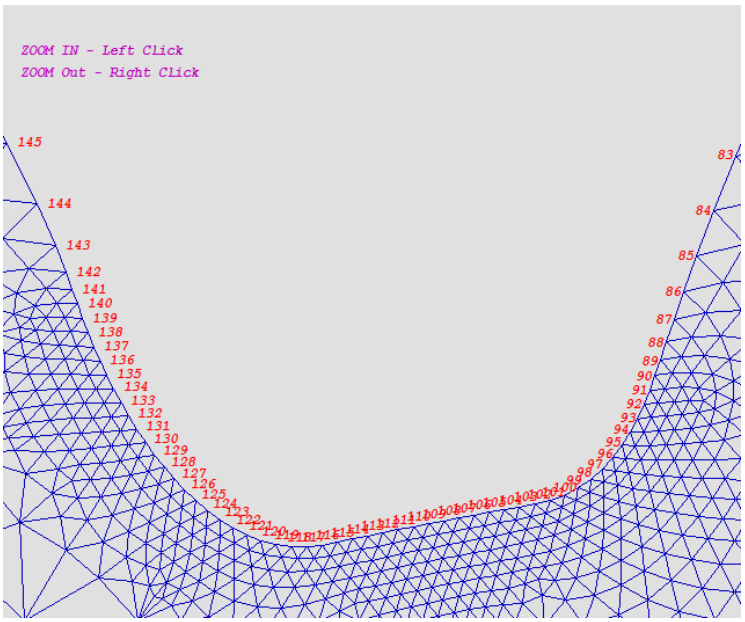


Fig. 8. Zooming in or out the FE mesh image

The Direct FE Analysis results are shown as the “Original fillet” Smax – maximum tensile stress equal to a maximum value of the main stress S1, the Smin – minimum compressive stress equal to a maximum value of the main stress S2 with a sign (-) minus, and the original fillet root diameter value (Fig. 9).

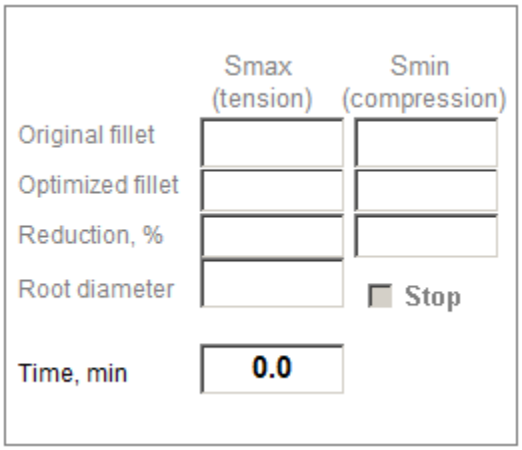


Fig. 9. Direct FE Analysis calculation results

Graphic stress images presented as isograms or areas according to the selection (Fig.10) can be shown on the program interface screen field as stress isograms (Fig. 6) or as colored areas (Fig. 11).

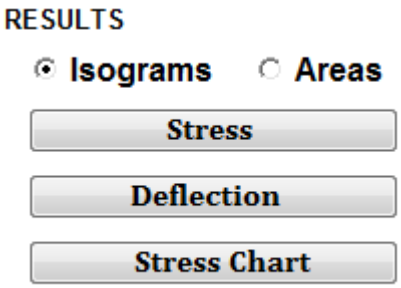


Fig. 10 Results presentation commands

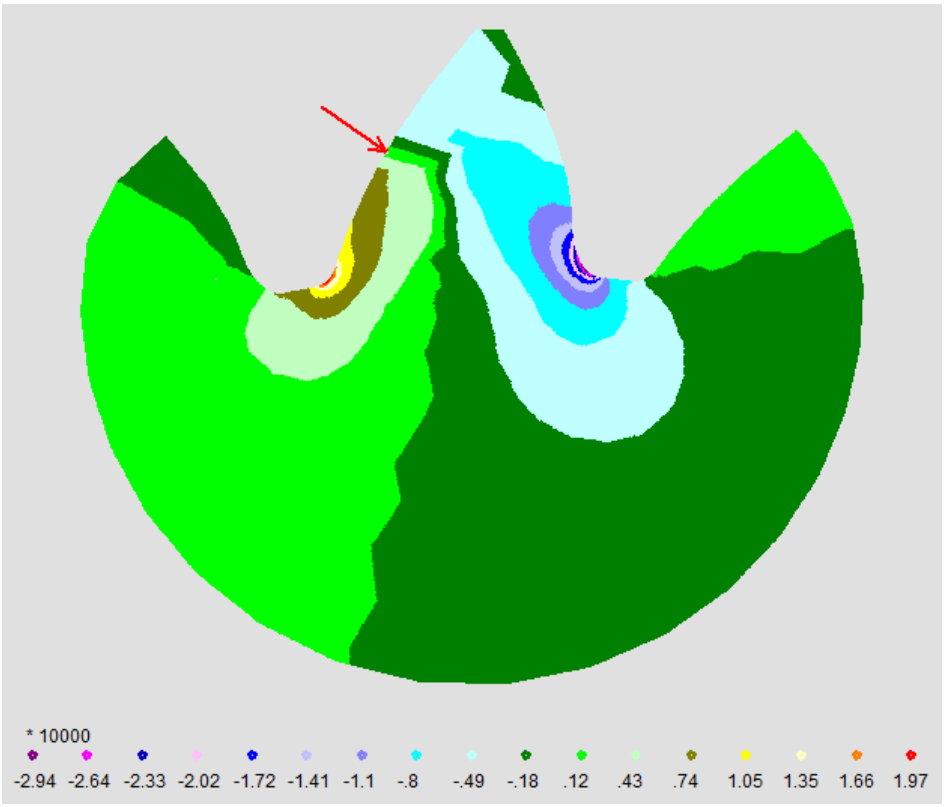


Fig. 11. Stress chart presented by colored areas

The exaggerated tooth deflection is shown when the “Deflection” button is pressed (Fig. 12).

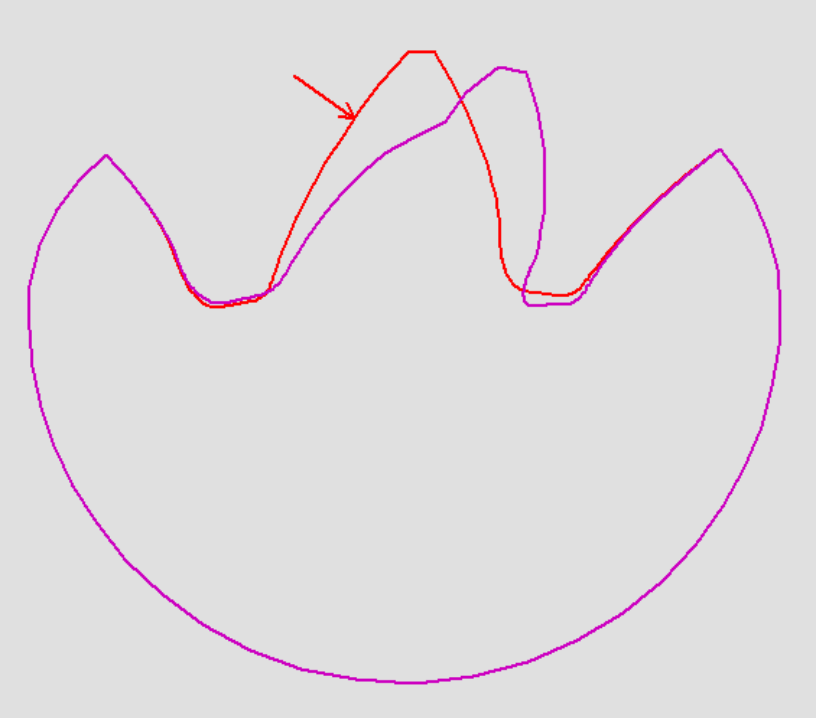


Fig. 12. Tooth Deflection

The tooth surface stress chart is shown when the “Stress Chart” button is pressed (Fig. 13).

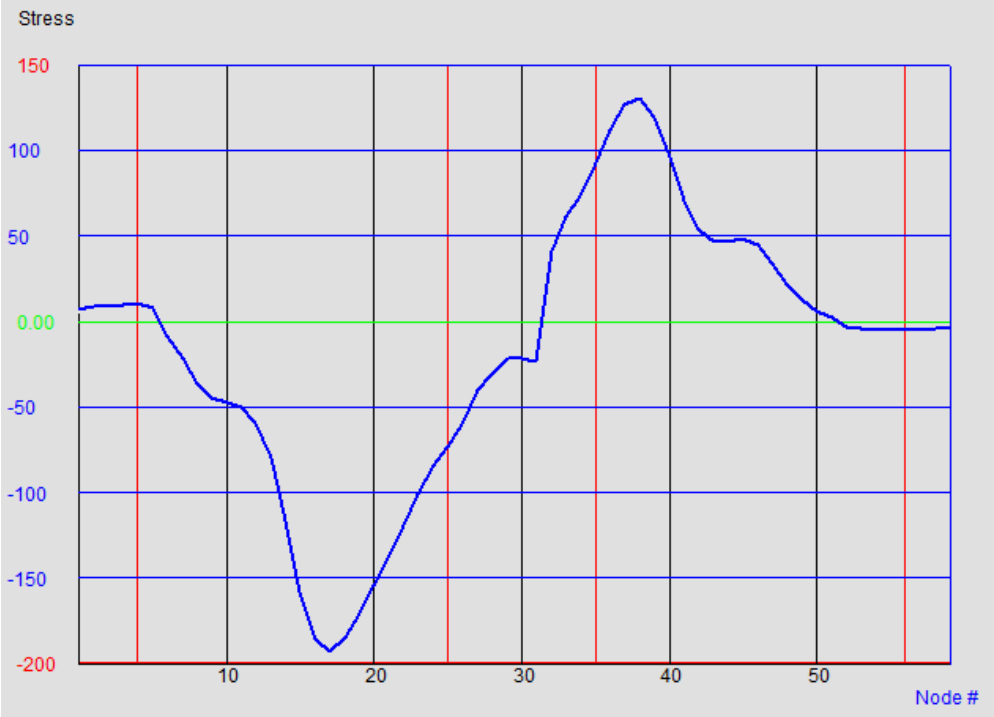


Fig. 13. Tooth surface stress chart

The tooth surface maximum and Von Mises stresses are presented in the generated Stress.txt file as functions of the tooth profile points and their X, Y – coordinates. This file also contains the maximum tooth deflection value, related tooth profile point number and its X and Y – coordinates.

2.2. Root Fillet Optimization mode

The "ROOT FILLET OPTIMIZATION" button starts the root fillet optimization process using the initial gear tooth profile and input data (number of teeth, face width, material properties, load components and application point coordinate, settings, and first and last point of the root fillets).
This calculation mode alters the root fillet tooth profile point (FE nodes) locations to achieve minimum stress concentration.

Root fillet optimization is complete when the stress reduction result cannot be improved and the calculation is stopped. Time of optimization varies depending on the number of the root fillet points and computer performance. For example, for a 60 point tooth profile with 21 root fillet points it is about 10-20 minutes, for a150 point tooth profile with 51 root fillet points it is about 40-60 minutes. These numbers correspond to the root fillet optimization of asymmetric teeth. The symmetric tooth root fillet optimization takes noticeably less time.

Root fillet optimization can be stopped anytime before it is completed by checking the "Stop" checkbox (Fig. 14).

Fig. 14. Optimization stoppage checkbox

When the calculation is completed or stopped, the status bar indicates "ROOT FILLET OPTIMIZATION is done" and the final signal sounds.

When the root fillet optimization is done the results are shown as the "Optimized fillet" Smax – maximum tensile stress, Smin – minimum compressive stress, stress reduction in %, and the optimized fillet root diameter value (Fig. 15).

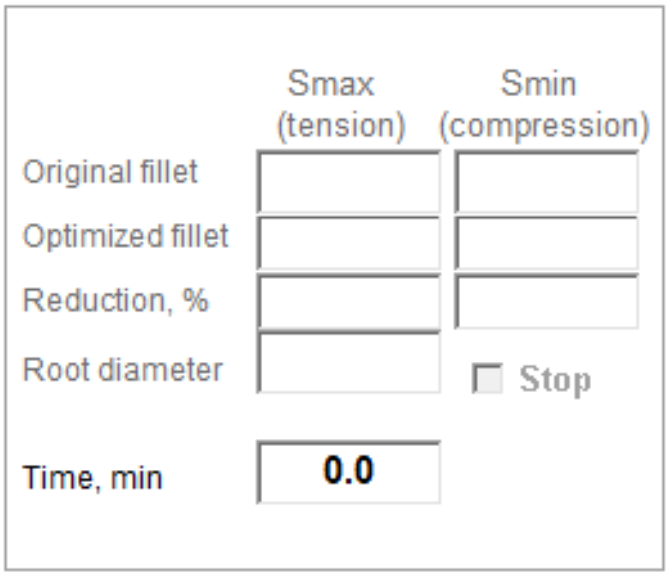
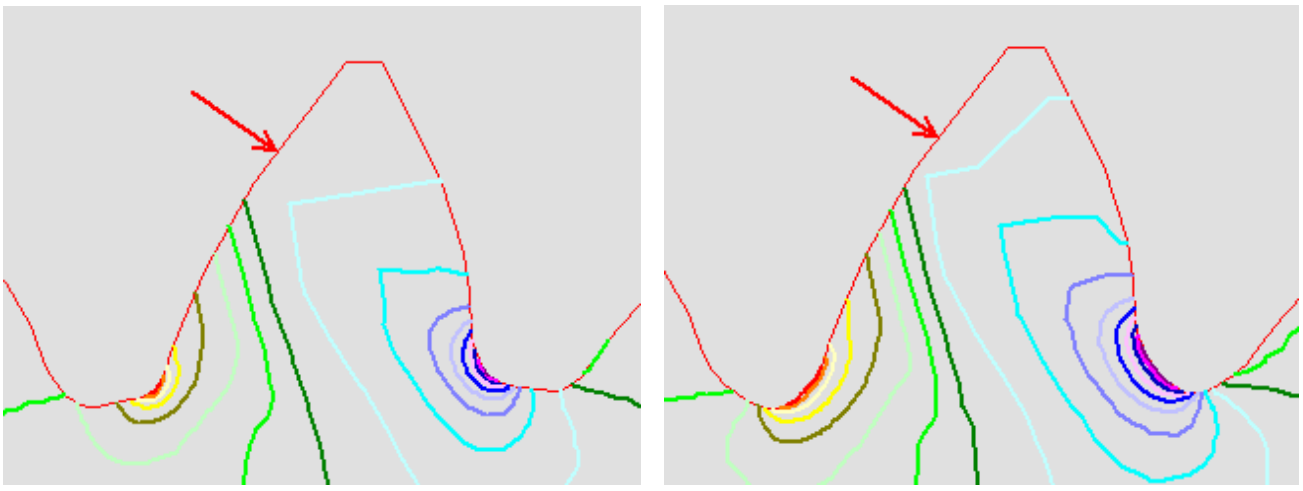


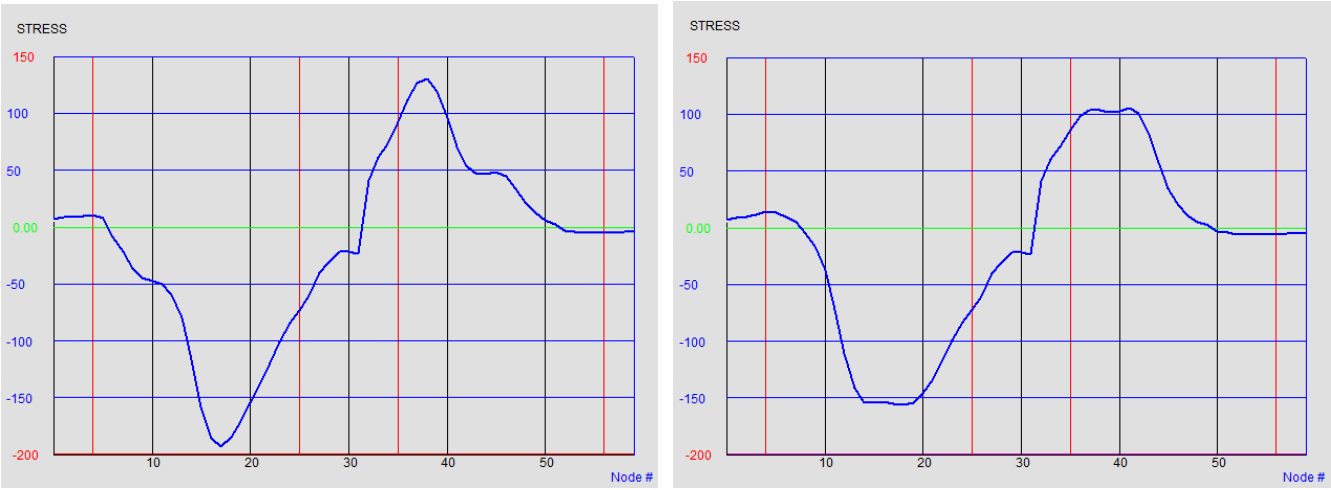
Fig. 15. Root fillet optimization results

The optimized fillet tooth profile and its FE mesh could be reviewed by marking (or unmarking) separately or simultaneously the fooling checkboxes; “Contour”, “Boundary”, “Mesh”, “Force” and using the “SHOW” button (see Table 1). Graphic images of the optimized fillet tooth stresses isograms (or colored areas) and stress chart can be shown on the program interface screen by clicking on the corresponding command buttons (Fig. 10). Comparisons of these images before and after root fillet optimization are shown in the Figs. 16 and 17.



a b

Fig. 16. Tooth stress isograms before (a) and after (b) root fillet optimization



a b

Fig. 17. Tooth stress charts before (a) and after (b) root fillet optimization

The surface maximum and Von Mises stresses of the optimized root fillet tooth are also presented in the generated Stress.txt file as functions of the tooth profile points and their X, Y – coordinates. This file also contains the maximum tooth deflection value, related tooth profile point number and its X and Y – coordinates.
The optimized root fillet tooth profile presented by the X, Y – coordinate points (Fig. 18) is placed in the Optimized.txt file.

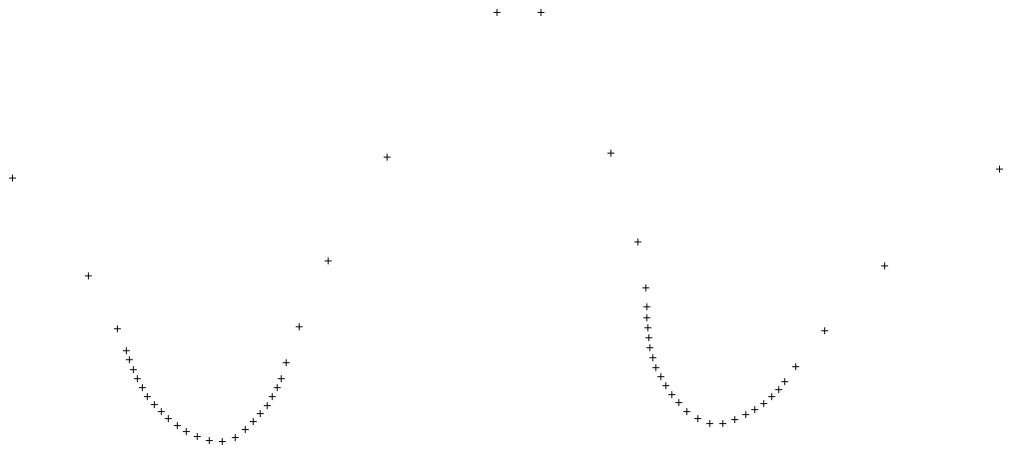


Fig. 18. Optimized root fillet tooth profile X, Y – coordinate points

These optimized tooth profile X, Y – coordinate points could be converted by the B-spline or other interpolation functions available in CAD programs into smooth curves for gear modeling (Fig. 19).

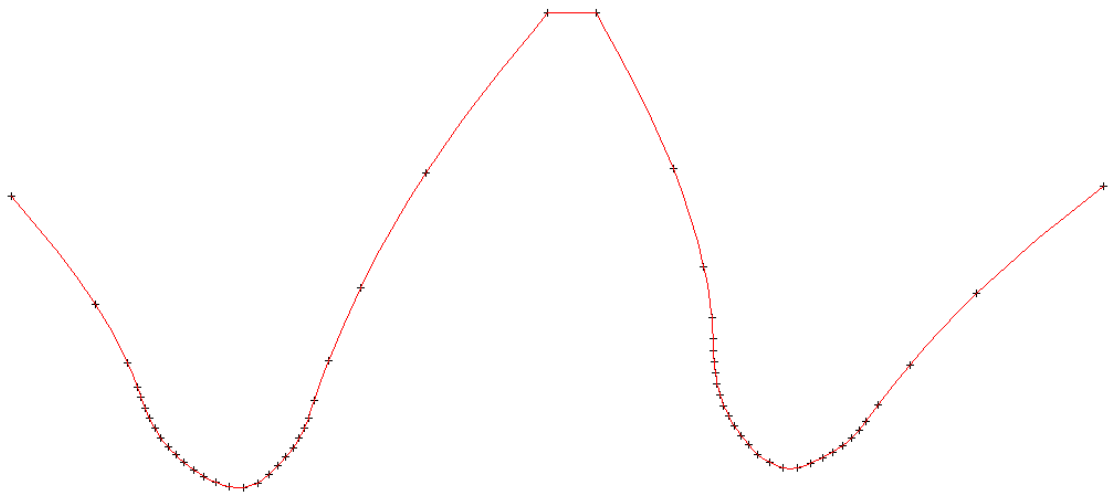


Fig. 19. Tooth profile interpolation for CAD gear modeling.

2.3. Results data

Besides the graphic results shown on the screen, both the Direct FE Analysis and Root Fillet Optimization modes generate the STRESS.txt file with the maximum tooth tip deflection and maximum and Von Mises stresses in the tooth profile points with coordinates X, Y.
The Fillet Optimization mode also generates the Optimized.dat file that contains the tooth profile with the optimized root fillet described in the coordinates points X, Y, and Z.

The results of both calculation modes can be found in My Documents\AKGears\Root Fillet Optimization folder.