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Tutorial Series   Ball Screws - Starter Basics First Results

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1. Foreword

1.1 Aim of the tutorial

This starter tutorial for MESYS Ball Screw Calculation introduces the basic functions of the software and provides an initial overview of its capabilities for ball screw calculation. It covers only those topics and settings required for getting familiar with the product and for the training examples.

For any questions regarding the use of the software, please contact MESYS at any time.

1.2 Software Version

This tutorial was created with MESYS Ball Screw version 12-2024.

1.3. Notes

A blue arrow indicates a request to the reader.
A green arrow indicates a conclusion or effect.

2. MESYS Ball Screws - strengths and possibilities

To get an idea of the possibilities of MESYS Ball Screws, we cordially invite you to visit the MESYS website at the specific address for Ball Screws.

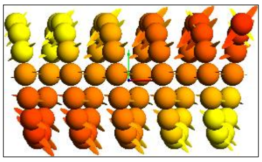
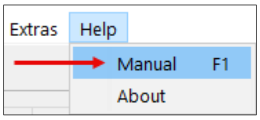


Figure 1

3. Software Manual

3.1 Manual online

Figure 2


The software manual can be accessed from the user interface via the Help menu under Manual - F1.

You can also open the manual at any time with position-specific content directly by pressing the F1 key.

3.2 Manual as PDF

You can also find the Software Manual in PDF format in the main languages in the MESYS installation directory (Figure 3) or directly on the MESYS website under 'Downloads/General downloads'.

4. Calculation of Ball Screws

4.1 General

The MESYS Ball Screw software calculates the load distribution in a ball screw based on axial load, radial load, and tilting moment, as well as the service life according to DIN 26281 derived from the load distribution.

Please Start the MESYS Ball Screws calculation module.

After startup, the software interface is presented with four tabs: 'General', 'Geometry', 'Configuration', and 'Loading'.

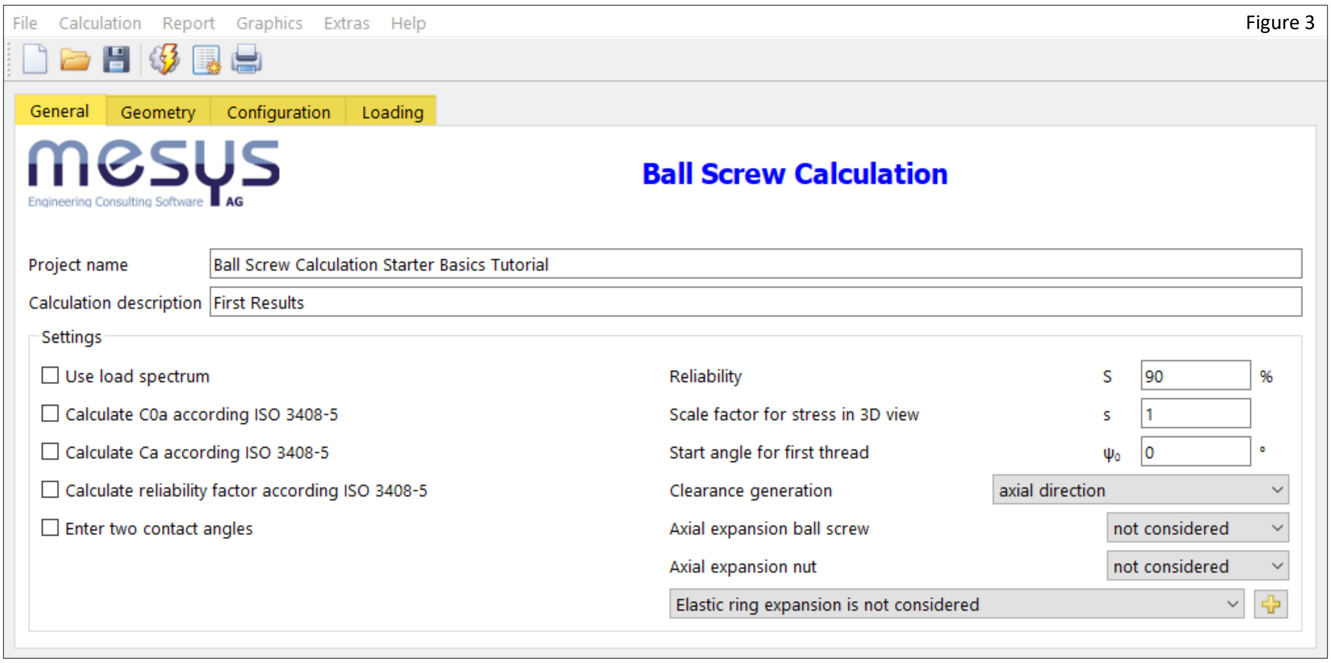


Figure 3

Across the different tabs, a wide range of possible settings is available. Within the scope of this Starter Tutorial, it is not possible to go into detail on all functions of the software due to the potential extent. For the corresponding information, please refer to the online manual in the section Input Parameters and its related subsections.

In the course of this tutorial, we will assign the software several calculation tasks as part of an imaginary project.

➡ According to Figure 3, choose an appropriate name and a description for the project.

Let us use a hypothetical ball screw to take a closer look at settings that are commonly applied in practice. You may assume that the default presets at program start provide a good basis for a step-by-step approach to a typical ball screw calculation, given their broad applicability.

4.2 Menu functions

Not all menus consist of self-explanatory content. This tutorial will guide you through the relevant content and explanations as part of the tasks set and the input process.

Figure 4

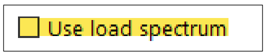
4.3 Settings under 'General'

4.3.1 General

This tutorial provides a simplified overview of the settings listed under the General tab, focusing on those that are either used here or important for understanding. We will concentrate on the essential points, and we kindly ask for your understanding that some functions will only be mentioned at a surface level.

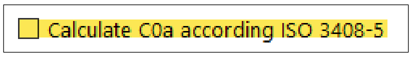
➡ For the time being, leave all settings as they are by default when you start the programme.

4.3.1 Use load spectrum



Another method for analysing application behaviour is to take different conditions or load cases into account. When the checkbox Use load spectrum is activated, the input mask under the Load tab is displayed as an input table. See also Chapter 4.6.2.

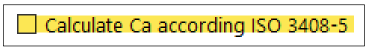
4.3.2 Calculate COa according ISO 3408-5



If this option is activated, the static load rating is calculated according to ISO 3408-5 (2006); material properties such as the modulus of elasticity have no influence.

If the option is deactivated, the calculation is also performed according to ISO 3408-5 (2006), but with the material/pressure factor f_0 from ISO/TR 10657 (2021) instead of the design factor k_0.

4.3.3 Calculate Ca according ISO 3408-5

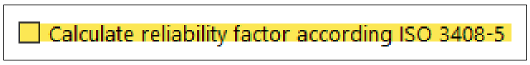


If this option is activated, the dynamic load rating is calculated with the exponent 0.86 according to Equation 8 in ISO 3408-5:2006.

If it is deactivated, the exponent 0.7 is used, as specified in ISO 281:2007, ISO/TR 1281-1:2008, or Lundberg et al. (1947).

4.3.4 Calculate reliability factor according ISO 3408-5

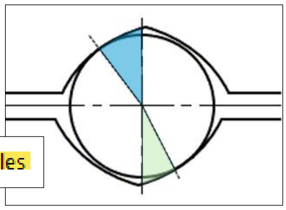
If the option is activated, the reliability factor is calculated using the two-parameter Weibull distribution according to ISO 3408-5:2006.



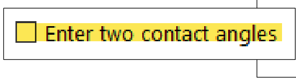
If the option is deactivated, the three-parameter Weibull distribution according to ISO 281:2007 and ISO/TR 1281-1:2008 is used

4.3.5 Enter two contact angles

Figure 5



One or two contact angles can be defined. Different angles may be used for the screw and the nut. The contact angle is determined by the radial contact of the ball with the screw or the nut.



4.3.6 Reliability S

By default, the bearing life is calculated for a reliability of 90%. The desired reliability can be set here between 90% and <100%.

4.3.7 Scale factor s for stress in 3D view

The stress distribution is scaled to s·Dw (ball diameter) for a pressure distribution of 4000 MPa in the 3D view (Figure 6).

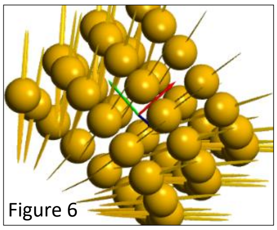
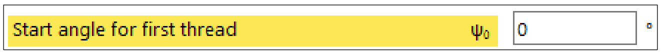


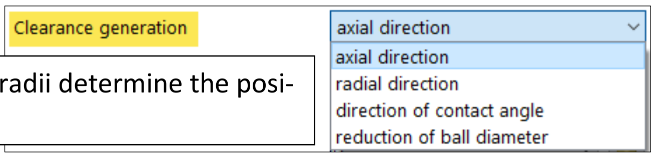
Figure 6

4.3.8 Start angle for first thread Ψ_0

The start angle defines the angular position of the left end of the first thread. At an angle of 0°, the start is located on the y-axis. The angle specifies the position of the center of the gap before the first ball.



4.3.9 Clearance generation



The nominal contact angle, ball diameter, and raceway radii determine the position of the curvature centers at zero clearance.

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Four possibilities for generating clearance are available:

- Axial displacement of the curvature centers (only for gothic profiles with contact angle > 0; limited max. radial clearance).
- Radial displacement of the curvature centers.
- Displacement of the curvature centers in the direction of the pressure angle (not for contact angle = 0).
- Reduction of the ball diameter (slightly decreases the load ratings).

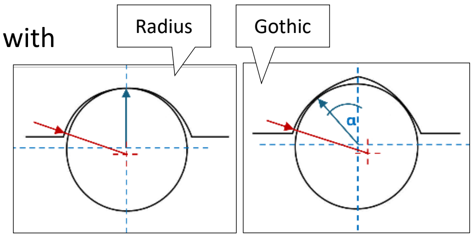
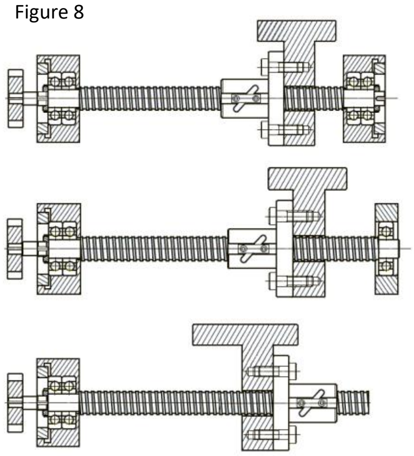


Figure 7

4.3.10 Axial expansion of ball screw and nut

For the axial length change of the ball screw and nut, three options are available: 'not considered', 'fixed left', 'fixed right'. If the load is applied on one side, the screw will either elongate axially or shorten due to axial stresses. Fixed on the left means that the load is applied from the left and the stress decreases toward the right.

Figure 8



Supports

Fixed – Fixed

Axial expansion ball screw	not considered
Axial expansion nut	fixed right

Fixed - Supported

Axial expansion ball screw	fixed left
Axial expansion nut	fixed right

Fixed - Free

Axial expansion ball screw	fixed left
Axial expansion nut	fixed left

4.3.11 Elastic ring expansion

Radial forces can lead to elastic expansion or compression. The calculation is based on the theory of a thick-walled cylinder with constant pressure on the inner or outer surface, using either the minimum or the mean ball contact force. With this option, the state is considered constant over the nut length and is therefore not suitable in the presence of pure tilting moments.

Elastic ring expansion is not considered
Elastic ring expansion based on minimal radial force
Elastic ring expansion based on medium radial force

Figure 9

4.4 Settings under 'Geometry'

4.4.1 General

Under this tab, the geometry of the ball screw is defined.

4.4.2 Input fields

Number of starts / turns

Here, the ball tracks and their length are defined.

Lead Ph / Lead angle phi / Direction

Axial travel of the nut per revolution, alternatively entered via the angle. Direction: right or left.

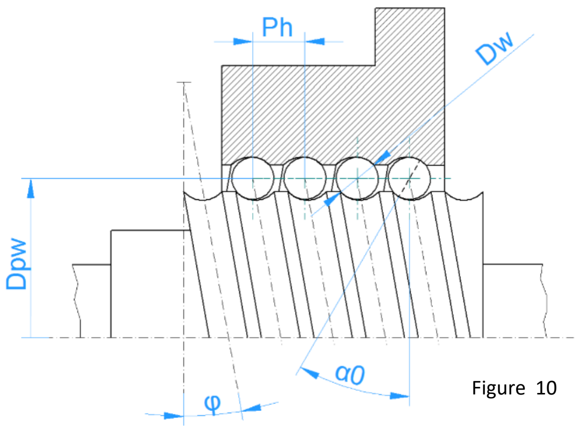


Figure 10

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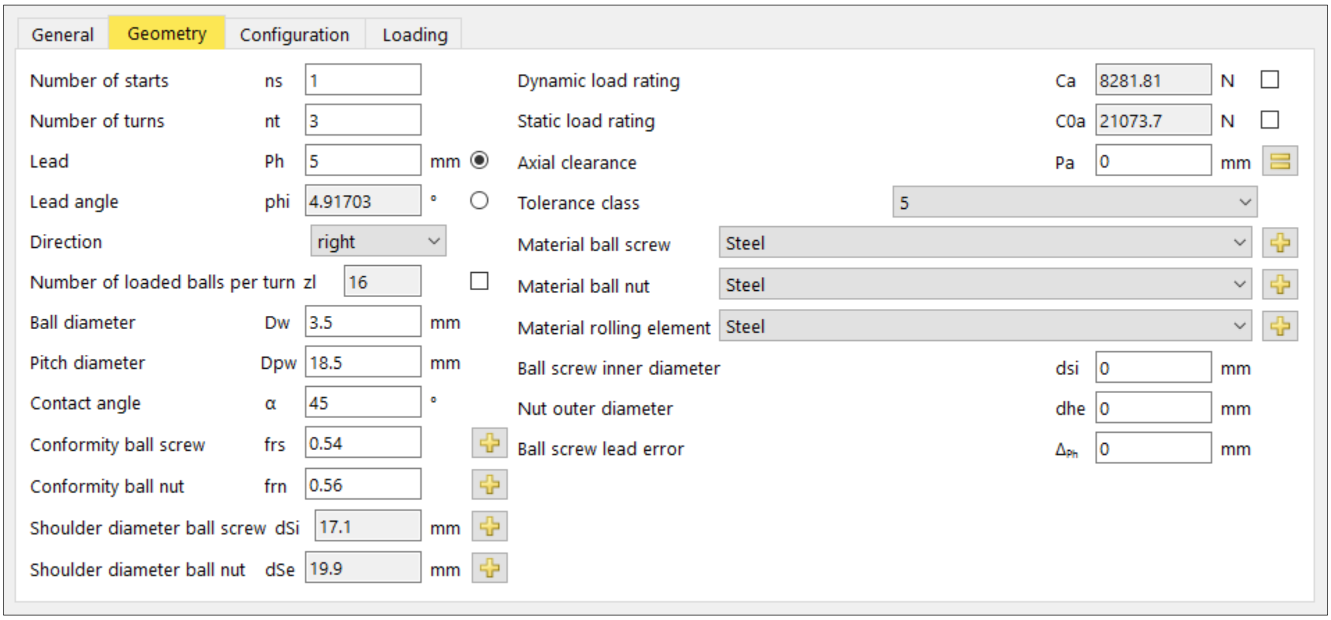
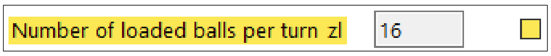


Figure 11

Number of loaded balls per turn

Is usually calculated automatically according to ISO 3408-5:2006, but can be overridden, for example, by using spacer elements.



Ball diameter

Dw, Basic size for load rating and contact stiffness.

Pitch diameter

Rolling element raceway diameter Dpw, basis for pressure angle and geometry (see Figure 10).

Contact angle

Optional inside and outside, with α > 0° gothic profiling, with 0° full radius (right figure).

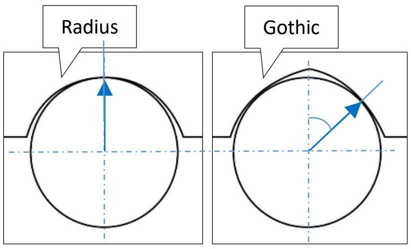
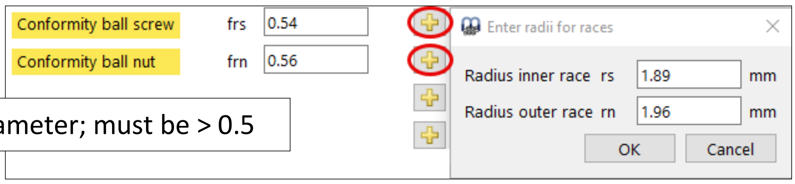


Figure 12

Conformity

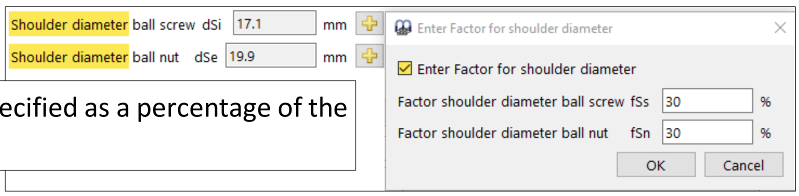


Ratio of raceway curvature radius to ball diameter; must be > 0.5

Figure 13

Shoulder diameter

The shoulder diameter dS determines the lateral support of the raceway.



Alternatively, the shoulder height can be specified as a percentage of the ball diameter (typically 10–40%).

The software checks whether the contact ellipse lies within the shoulder – otherwise the calculated pressures are invalid.

Figure 14

Load ratings

They can be entered manually or calculated by the software. The dynamic load rating for life is according to ISO 3408-5, the static load rating according to ISO 76 / ISO 3408-5.

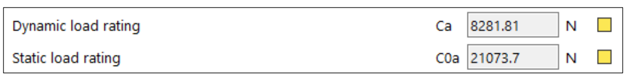


Figure 15

See options in Chapter 4.3.2.

Axial clearance / Preload

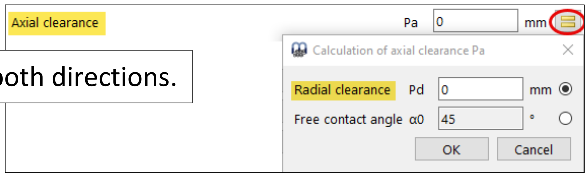


Figure 16

The axial clearance is the difference in axial displacement in both directions.

With a gothic profile, the clearance can also be negative (preload), while with a full-radius profile it must be positive.

➡ A preload is defined by entering a negative value for Pa.

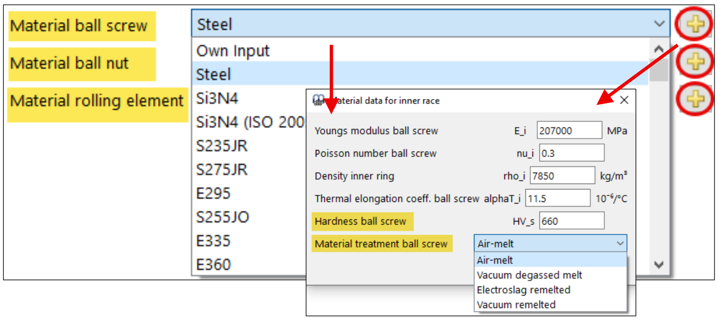
Using the - button (Figure 16), a positive radial clearance can alternatively be entered, or a free contact angle can be applied for full-radius profiles.

Tolerance class

The tolerance classes refer to JIS B 1192-1997, ISO 3408-3:2006 & DIN 69051-3, and are taken into account in the calculation of the load ratings.

Material

Here, the materials for the screw, nut, and balls can be defined. Using the - buttons, hardness and heat treatment can also be specified. The material of the balls only affects the contact stiffness in the load distribution but is not considered in the life calculation.

Figure 17


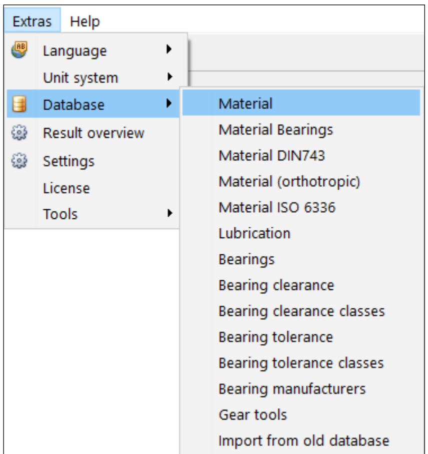
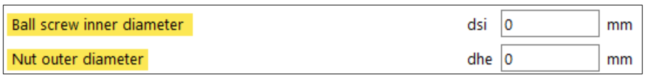


Figure 18

In addition to the links found under the Extras menu, such as to material databases, custom database entries can also be created — for example for materials. It is further possible to import from an existing database or to initiate an encrypted export of data.

Ball screw inner diameter

Is used when an axial or radial expansion has to be taken into account.

Figure 19


Nut outer diameter

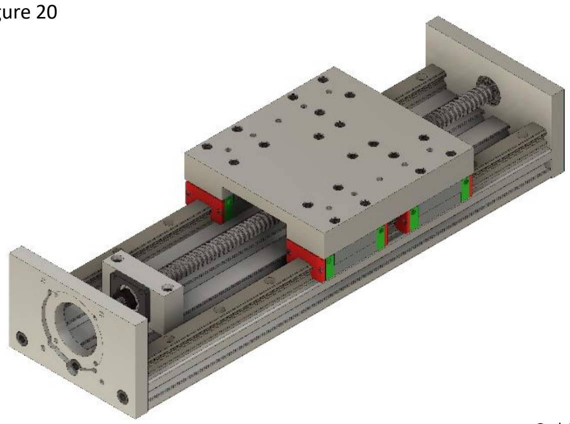
Is used when an axial or radial expansion has to be taken into account. If the input value is 0, a diameter of Dpw + 20·Dw is applied.

Ball screw lead error

Optional input that affects the load distribution.

4.4.3 Input of Geometry

Figure 20



GrabCAD

An imaginary positioning drive for use in machine tools is to be analysed. The following data is available:

Number of starts:	1	
Number of turns:	3	
Lead:	5	mm
Ball diameter:	3.5	mm
Pitch diameter:	18.5	mm
Contact angle:	45	°
Conformity spindle:	0.54	
Conformity nut:	0.56	
Axial clearance:	0	mm

Please enter this data under the 'Geometry' tab accordingly (Figure 11).

4.5 Input of Loading

4.5.1 General

For each coordinate direction, either a force or a displacement can be entered.
Moments are only possible in the Y and Z directions, since the torque around the axis is coupled with the axial force. The rotation angle rx only affects the axial displacement.

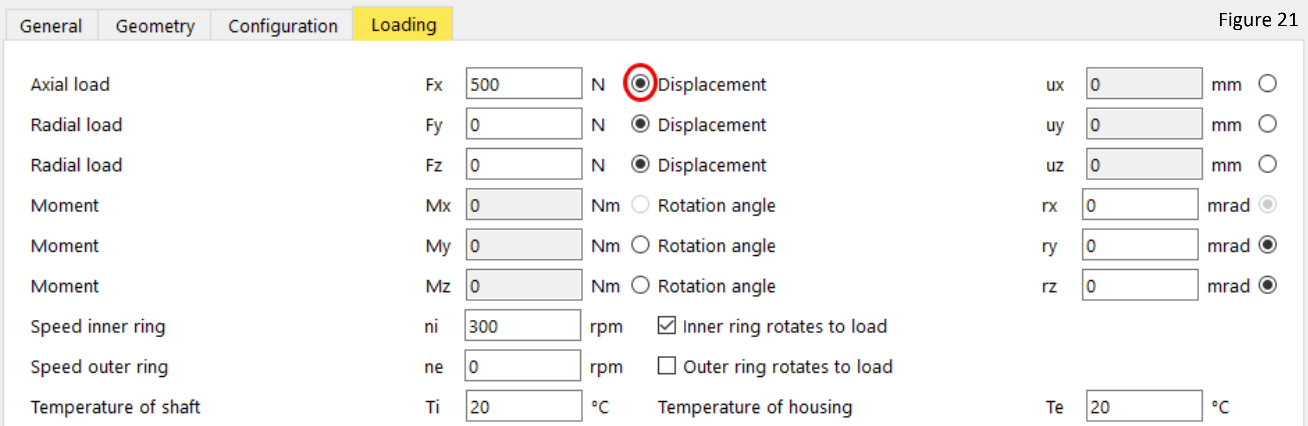


Figure 21

Assign an axial force of 500 N and a speed of 300 rpm as shown in the figure above.

4.5.2 Coordinate system

The x-axis corresponds to the axial direction, the y-axis points upward toward the gap in front of the first ball. The start angle Ψ is positive around the x-axis and starts at zero on the y-axis; the start angle can be changed in the settings.
Moments are positive around their respective axes. Loads act on the inner ring, i.e., a positive load in the y-direction loads the upper rolling elements.

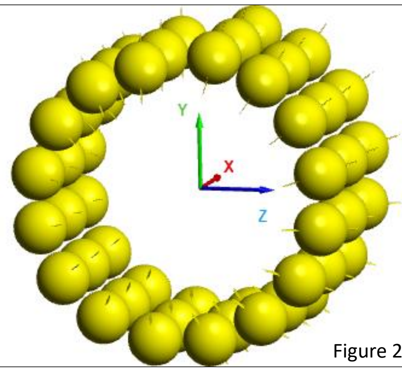


Figure 22

4.6 Calculation

4.6.1 Calculation of a single load case

The calculation step is started via the Calculate command (Figure 23), by pressing F5, or by using the corresponding icon in the ribbon menu.

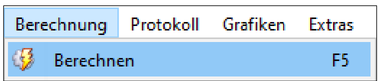


Figure 23

Please activate the calculation process.

As a result of the axial offset of the turns and the current start angle Ψ_0 of 0° for the first start, a tilting moment around the Y-axis is obtained (Figure 24).

Axial load	Fx	500	N	◉ Displacement		ux	0.00307129	mm	○
Radial load	Fy	0	N	◉ Displacement		uy	0	mm	○
Radial load	Fz	0	N	◉ Displacement		uz	0	mm	○
Moment	Mx	-0.397887	Nm	○ Rotation angle	Start angle for first thread	rx	0	mrad	○
Moment	My	0.397026	Nm	○ Rotation angle	Ψ_0 0 °	ry	0	mrad	◉
Moment	Mz	-0.0344511	Nm	○ Rotation angle		rz	0	mrad	◉

Figure 24

Under the 'General' tab, set the start angle for the first start to 90°.

This generates a corresponding tilting moment around the Z-axis:

Axial load	Fx	500	N	◉ Displacement		ux	0.00307129	mm	○
Radial load	Fy	0	N	◉ Displacement		uy	0	mm	○
Radial load	Fz	0	N	◉ Displacement		uz	0	mm	○
Moment	Mx	-0.397887	Nm	○ Rotation angle	Start angle for first thread	rx	0	mrad	○
Moment	My	0.0344511	Nm	○ Rotation angle	Ψ_0 90 °	ry	0	mrad	◉
Moment	Mz	0.397026	Nm	○ Rotation angle		rz	0	mrad	◉

Figure 25

In the 'General' tab, reset the start angle for the first start to 0°

At this point, we would like to enter a first substantial load case and examine it afterwards.

Please enter the following loads:
Fx = 750 N
Fy = -250 N
Mz = 7 Nm

Start the calculation.

Axial load	Fx	750	N	◉ Displacement	ux	0.00395655	mm	○
Radial load	Fy	-250	N	◉ Displacement	uy	0.00217706	mm	○
Radial load	Fz	0	N	◉ Displacement	uz	-8.06379e-05	mm	○
Moment	Mx	-0.596831	Nm	○ Rotation angle	rx	0	mrad	○
Moment	My	0.87243	Nm	○ Rotation angle	ry	0	mrad	◉
Moment	Mz	7	Nm	◉ Rotation angle	rz	0.576454	mrad	○
Speed inner ring	ni	300	rpm	☑ Inner ring rotates to load				

Figure 26

The results are displayed directly in the load input mask.

4.6.2. Calculation of multiple defined conditions – Load spectrum

If the calculation with load spectrum is activated in the General tab (see Chapter 4.3.1), the entire spectrum is calculated instead of a single load case. For each element, load or displacement, speed, and temperature can be entered. Using the context menu (right mouse button), you can choose whether forces/moments or displacements/rotations are used (Figure 27).

Rows can be added with the button or deleted with the button; deletes all entries. Using the import button , a load spectrum can be read from a file (columns and units must match). An export is also possible via the button

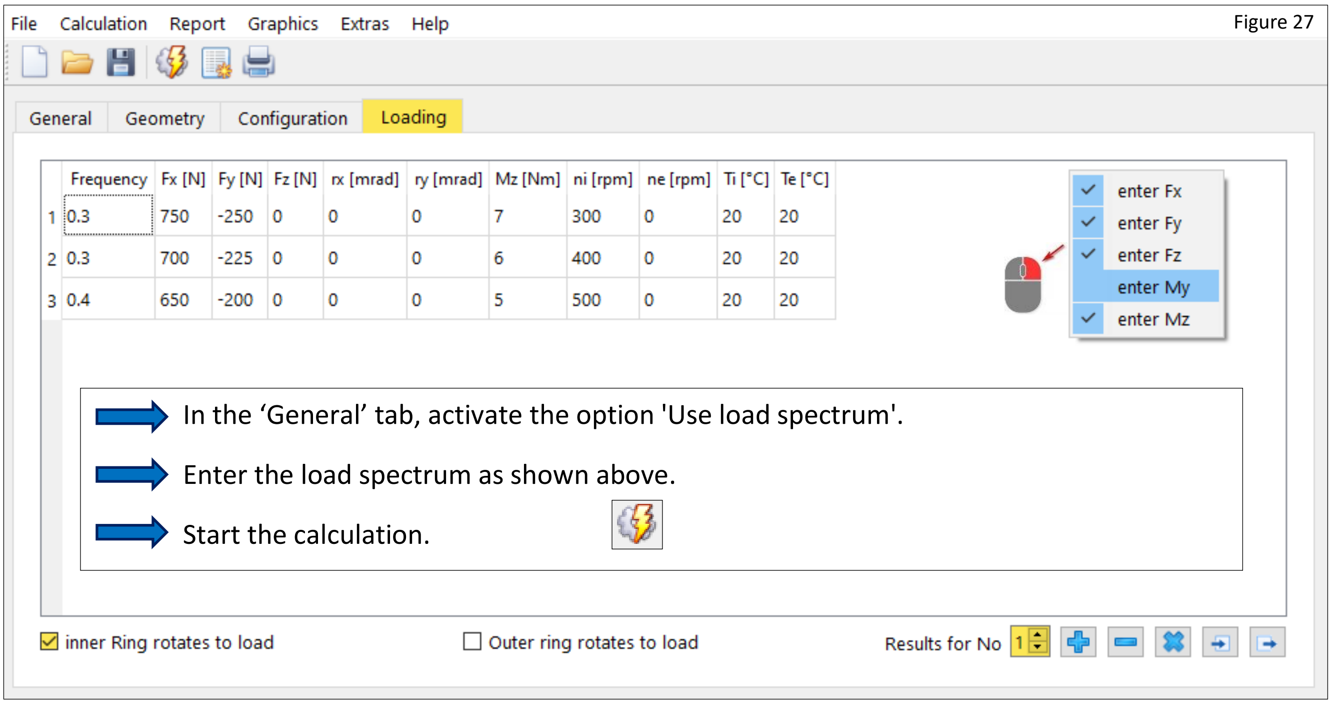


Figure 27

As with the single load case, it can be set whether the ring rotates relative to the load. The load distribution is calculated for each element, and the results show the life of the entire Load spectrum as well as the minimum static safety. Elements from the Graphics menu appear only for the element selected on this page

5. Results

5.1 Current Results overview

5.1.1 General

The contents in the results overview at the bottom of the user interface — still dependent on our example calculation but always up to date — appear as follows after the inputs from Chapter 4.6.2 with load spectrum:

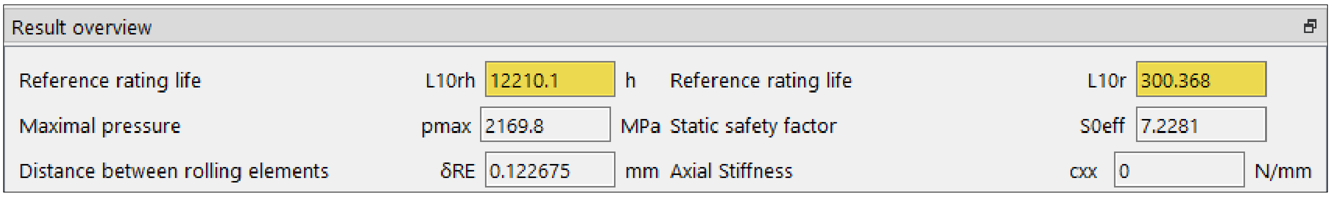


Figure 28

Compare the system life L10rh in the results overview with the single load case calculation from Chapter 4.6.1:

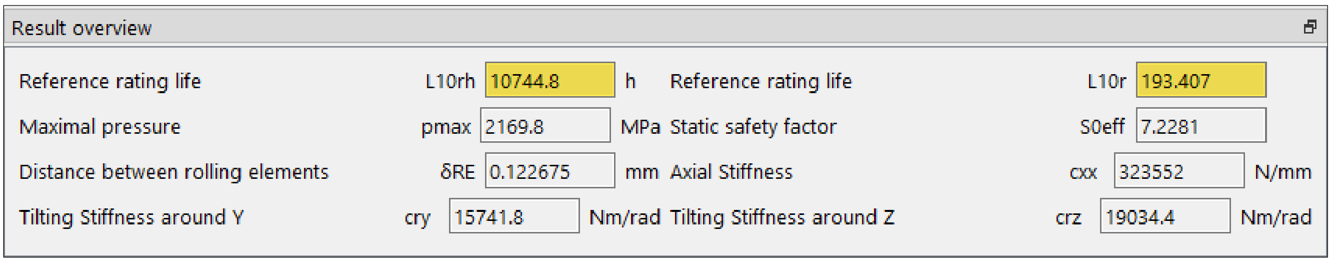


Figure 29

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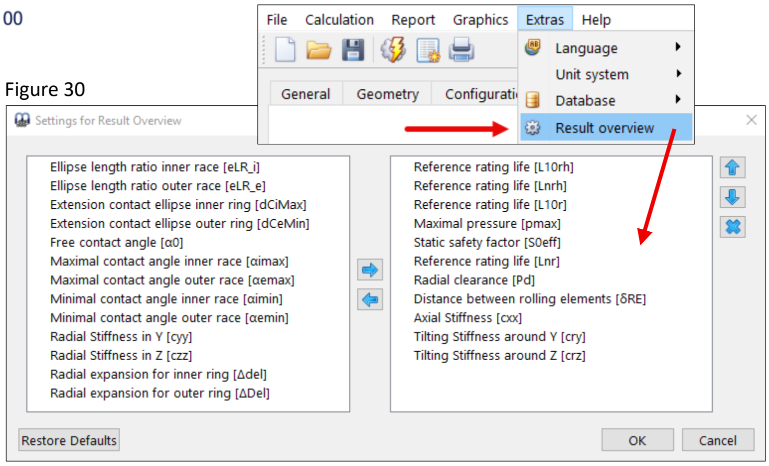
5.1.2 Define contents

Using the menu command Extras / Results overview, the contents of the results window in the user interface can be edited (Figure 30).

Figure 30

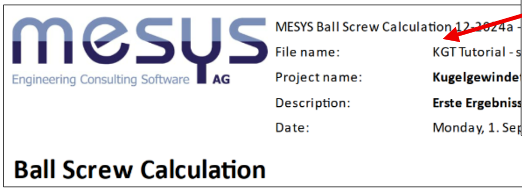


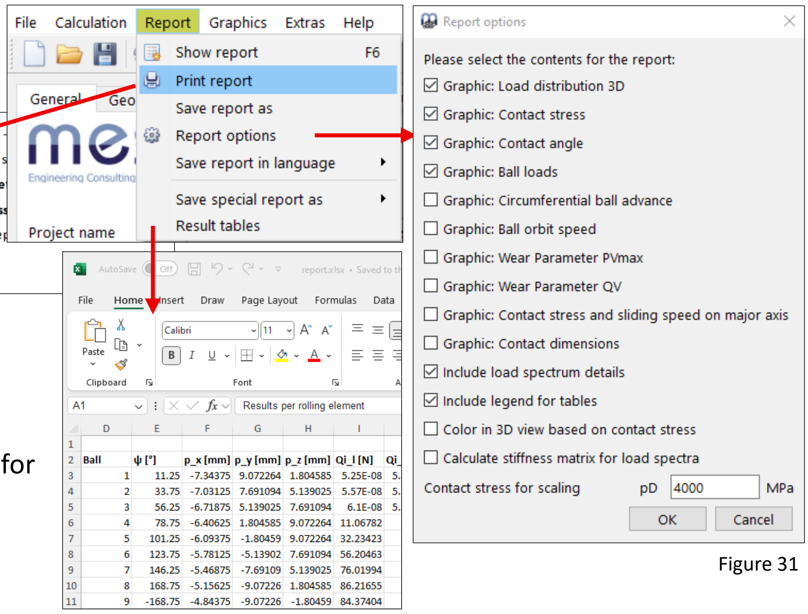
5.2 Reports

5.2.1 Main report

Reports are available in different formats.

A main report as PDF or DOCX with standard content, as well as additional content selectable via 'Report Options', can be accessed through the Report menu.





5.2.2 Result tables

Result tables can be opened in XLSX format for further processing.

Figure 31

5.3 Graphics

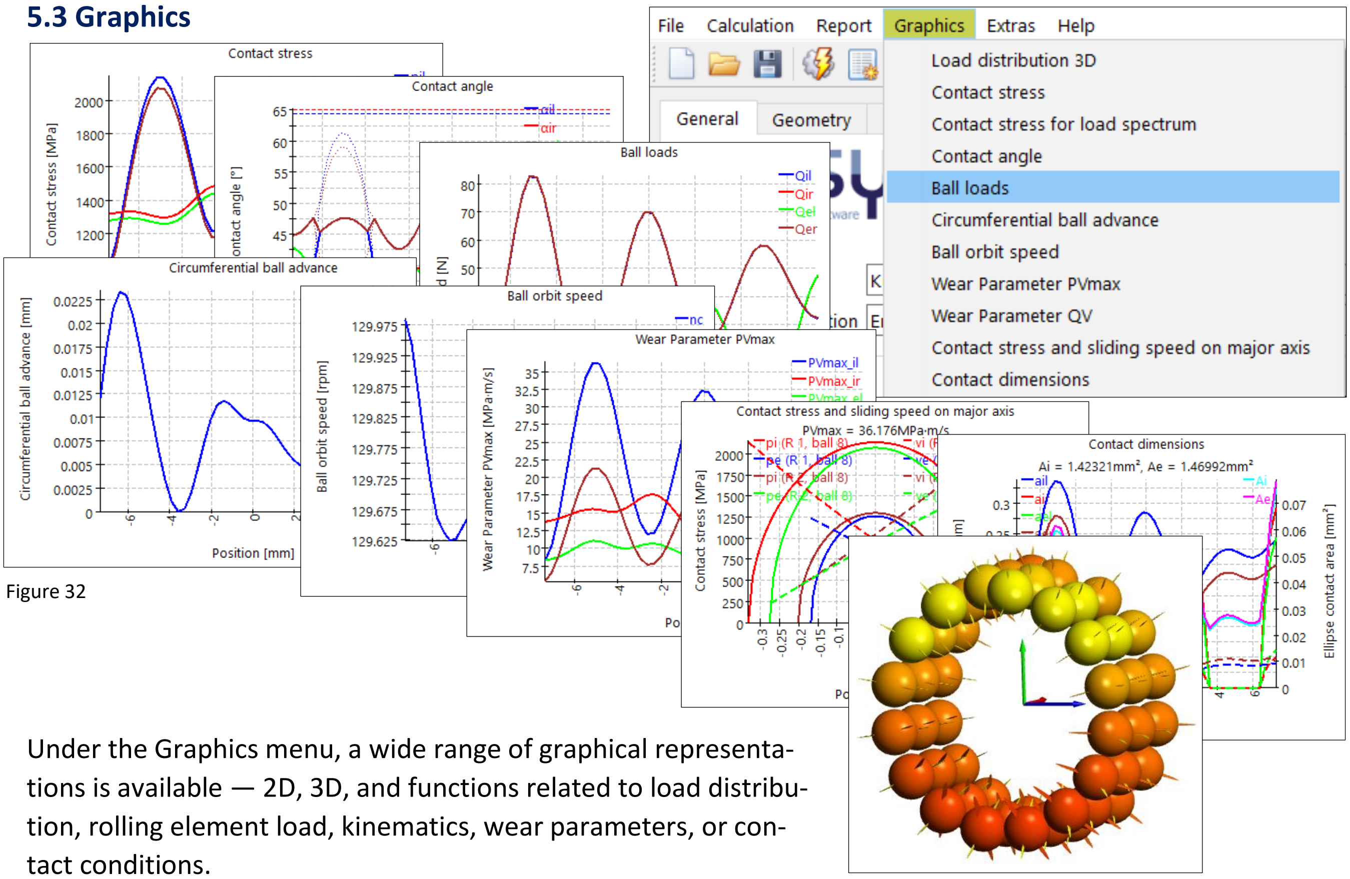


Figure 32

Under the Graphics menu, a wide range of graphical representations is available — 2D, 3D, and functions related to load distribution, rolling element load, kinematics, wear parameters, or contact conditions.

The graphics can be docked to the main program interface with the current outputs and are automatically updated after each calculation.

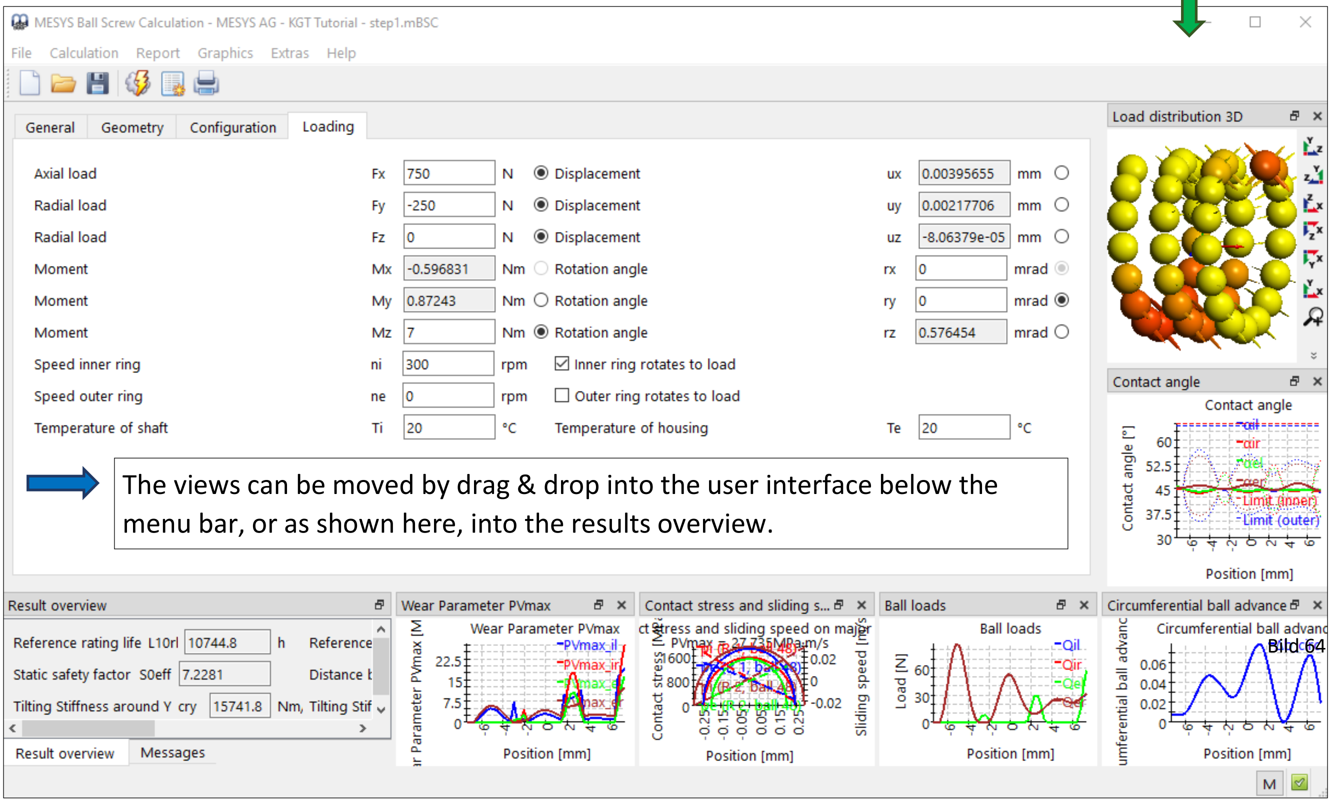


Figure 33

Please edit the report options and print the report.

6. Application design

6.1 Methodology

The successful design of a ball screw follows a proven methodology. The MESYS ball screw calculation provides crucial support in this process and takes over a large part of the required tasks. In the following, we will go through some of the most helpful steps together for the single load case considered in Chapter 4.6.1.

6.2 Contact stress

The Contact stress diagram activated via the Graphics menu shows the contact pressure, which is calculated for each ball and all four possible contact points. In our single load case from Chapter 4.6.1, the inner raceway on the right (pir) and the outer raceway on the left (pel) show sections with 0 MPa (Figure 34). The diagram therefore illustrates, in particular through pir (red) and pel (green), two-point (0 MPa) as well as four-point contact conditions

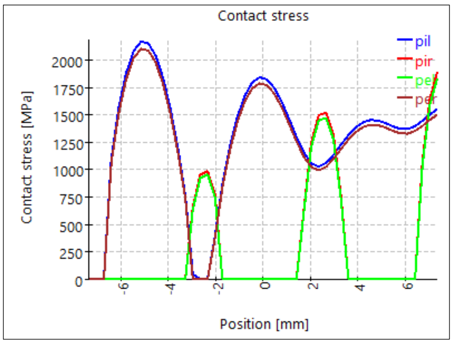


Figure 34

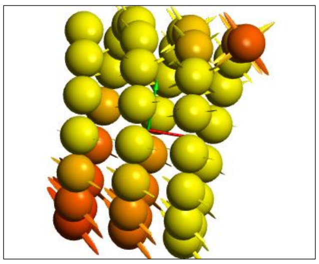


Figure 35: 2-point and 4-point contact condition

6.3 Circumferential ball advance

The diagram for Circumferential ball advance , activated in the Graphics menu, is based on the assumption that the circulation speed of each ball is constant within a section. However, due to different contact angles, the circulation speed varies between the individual rolling elements (Figure 36).

Figure 36

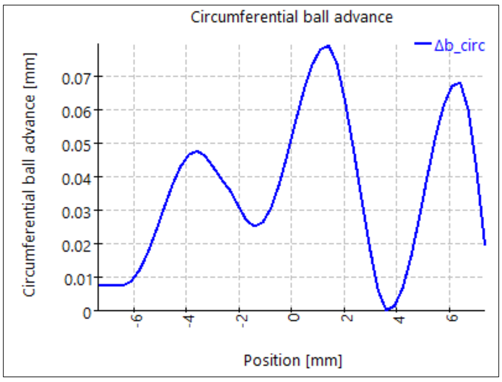
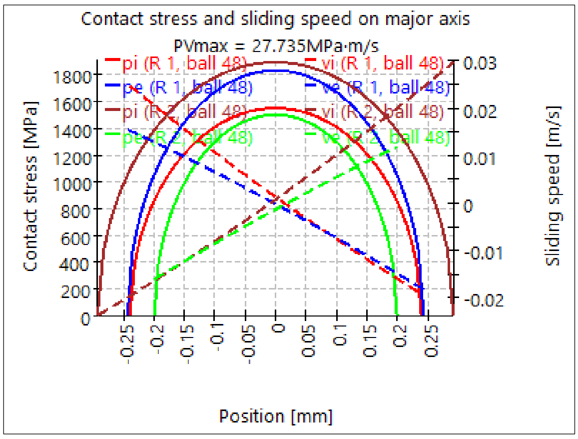


Figure 37



6.4 Contact stress and sliding speed on major axis

This diagram, also activated in the Graphics menu, relates the courses of pressure and sliding velocity by displaying the current values for the selected ball along the major axis of the contact ellipse (Figure 37). Through the graphic options, another ball can be selected, or the one with the currently highest PV value (Figure 38).

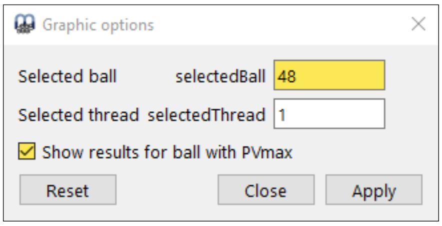


Figure 38

6.5 Contact dimensions

The diagram, which can be activated via the Graphics menu, shows the semi-axes of the pressure ellipses along the position, with the dashed lines indicating the shorter semi-axis.

- The numerical values can be accessed via the results tables (Chapter 5.2.2).
- The dashed lines bi / be correspond to the minor semi-axes.
- The values Ai / Ae below the diagram title correspond to the area sums over nut length.

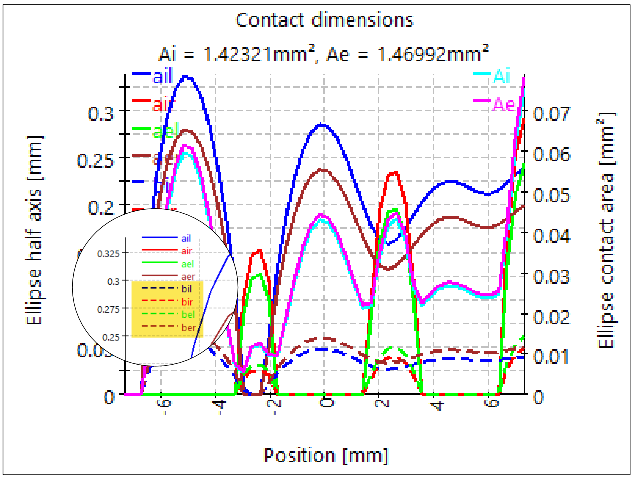


Figure 39

6.6 Optimization

6.6.1 General

In the search for a stiffer system, applying an axial preload could, for example, be a practical approach. To obtain a reference value for a suitable preload, a parameter study is recommended.

6.6.2 Parameter variation

Via the menu Calculation / Parameter variation, a dialog for parameter variations is displayed (Figure 40). It allows the user to perform parameter studies, with the results presented in exportable tables and graphics.

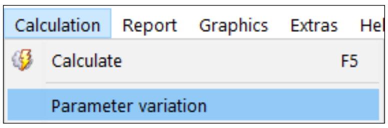


Figure 40

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Optionally, in the parameter variation dialog, an optimization step can be applied under the Optimization tab, respecting defined constraints to maximize or minimize the desired results. For further information on parameter variation, please refer to the corresponding entries in the manual.

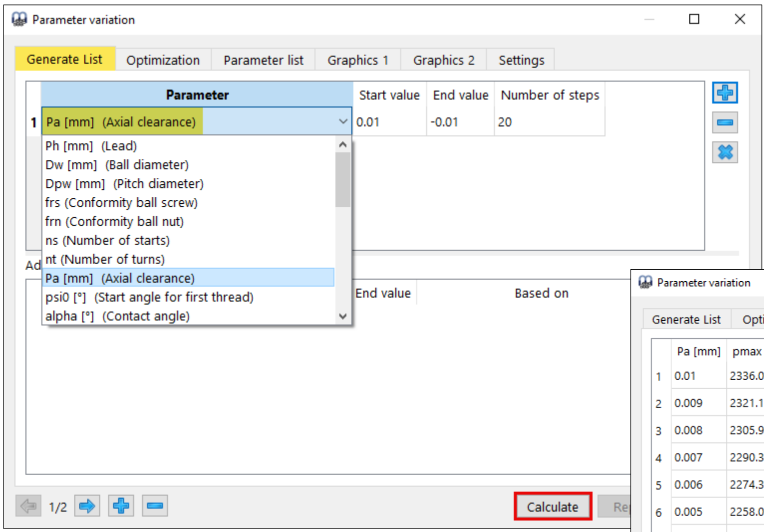
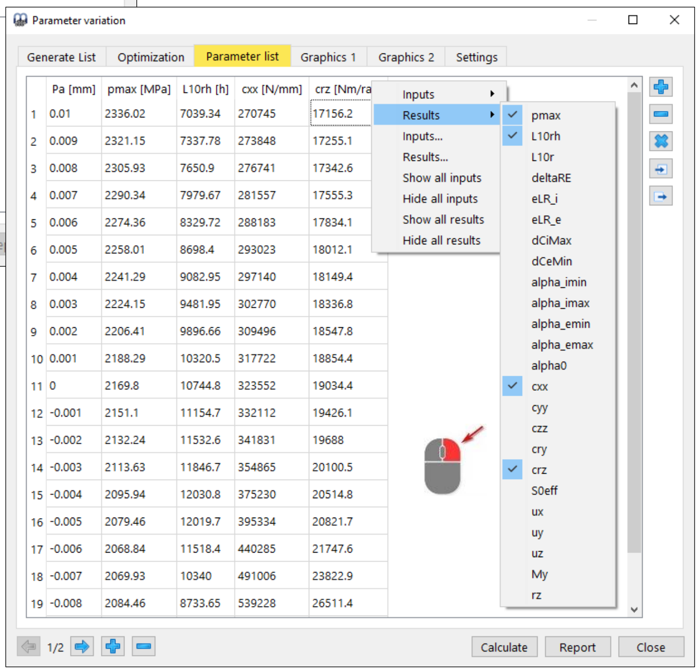


Figure 41

Please assign the value Pa a variation from 0.01 to –0.01 mm in 20 steps, as shown in the figure on the left.

Start the calculation using the designated button.

Figure 42



In the parameter list, activate the desired values via the context menu (Figure 42).

Using Graphics 1 & 2, display the relations of cxx and crz versus axial clearance, as well as pmax and L10rh versus axial clearance (Figure 43 / 44).

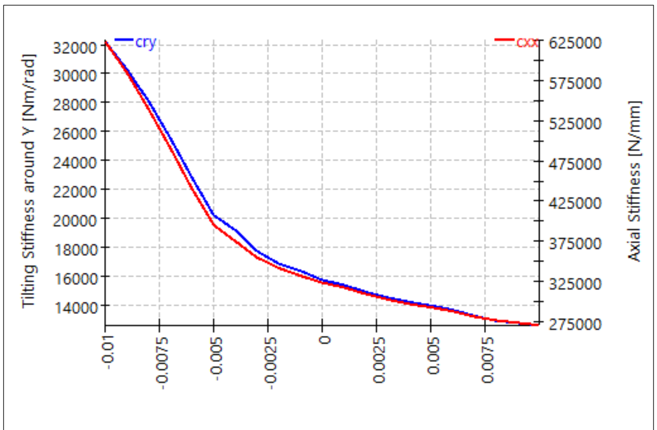


Figure 43

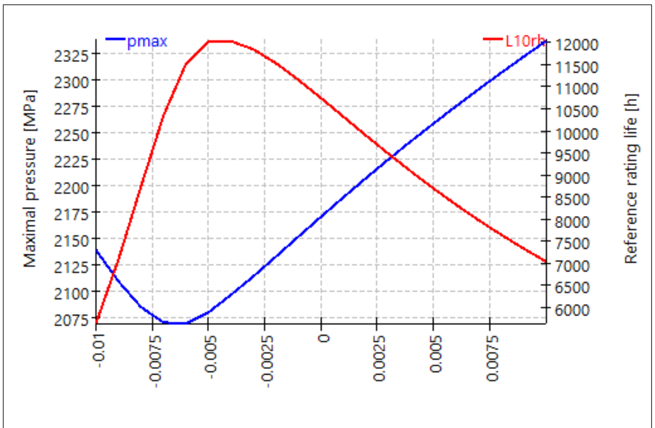


Figure 44

It is evident that an increase in axial preload clearly benefits the stiffness, and that the service life reaches an optimum at 4 µm axial preload.

It should be noted that preload also increases the wear parameters PVmax and QV. Therefore, for high-speed applications, an appropriate balance has to be found.

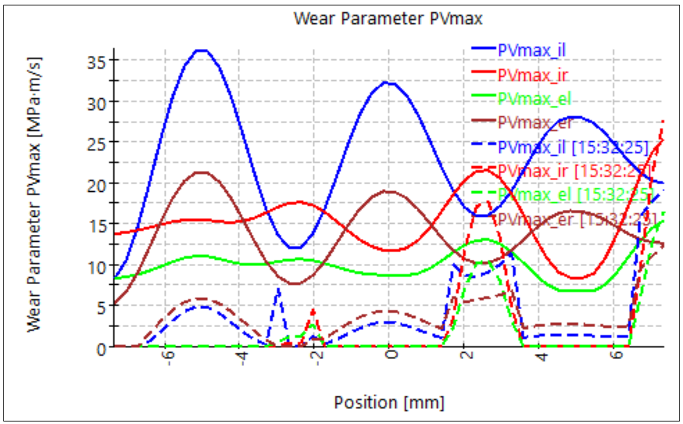


Figure 45: Single load case; PVmax at Pa = – 0.01 mm (preload)
Dashed: without preload

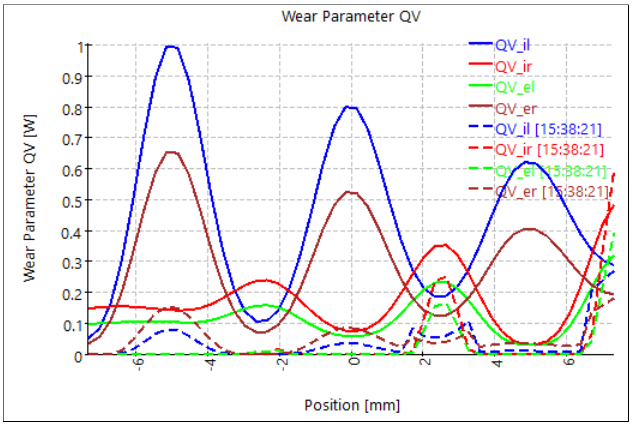


Figure 46: Single load case; QV at Pa = – 0.01 mm (preload)
Dashed: without preload

6.6.3 Definition of the target preload based on an overall evaluation

For a final evaluation, an overall setting for our single load case should be determined based on the given graphical results.

Contact stress (Chapter 6.2):

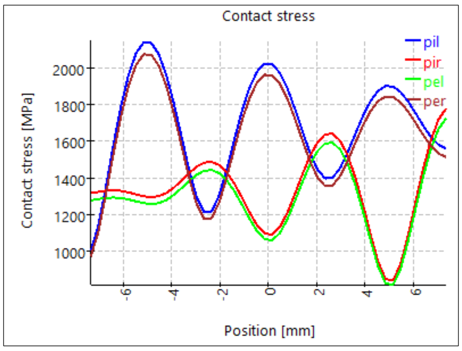
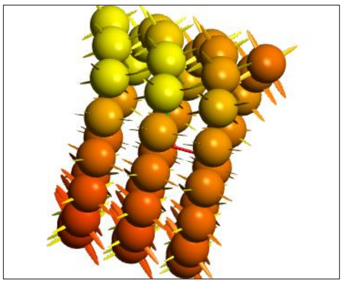


Figure 47

Figure 48: Pure 4-point contact condition

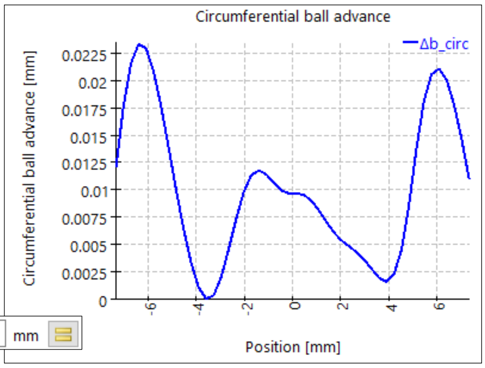


Pa of –0.01 mm generates four-point contact over the entire nut length (Figures 47 / 48).

The corresponding increase in stiffness should be weighed against the wear parameters resulting from the targeted speeds and evaluated accordingly.

Circumferential ball advance (Chapter 6.3):

This kinematic parameter can be reduced from the previous 0.07 mm to 0.0225 mm with a Pa of –0.01 mm.



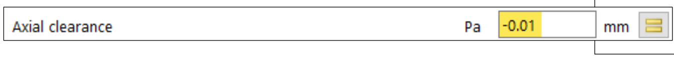
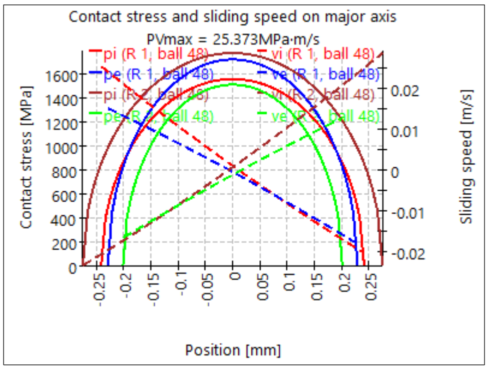


Figure 49

Contact stress and sliding speed on major axis (Chapter 6.4):



PVmax at ball 48 can be reduced to 25.373 MPa·m/s with a Pa of -0.01 mm. This effect, however, clearly does not stand up to an overall evaluation of the application.

Figure 50

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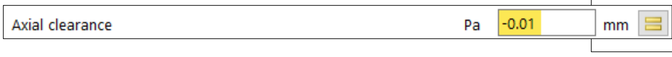
Contact dimensions (Chapter 6.5):

The semi-axes of the contact ellipses, and thus the contact areas, show congruence with the pressure distribution under preload.



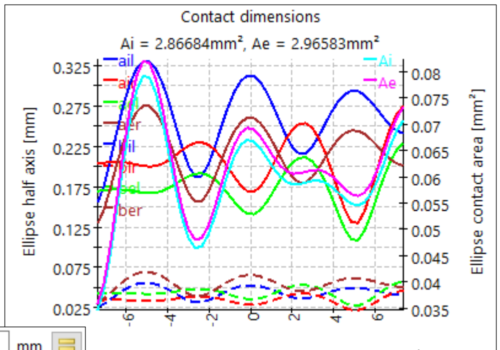


Figure 51

6.6.4 Alternative approach

Using an alternative approach with a preloaded double nut (Figure 53), the tilting stiffness about the Y-axis is to be optimized.

For this purpose, the number of starts per side is to be reduced to a value of 2:

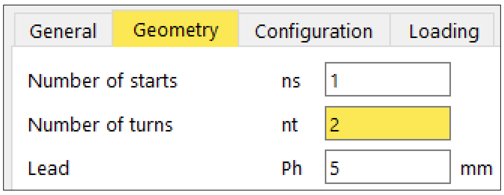


Figure 52

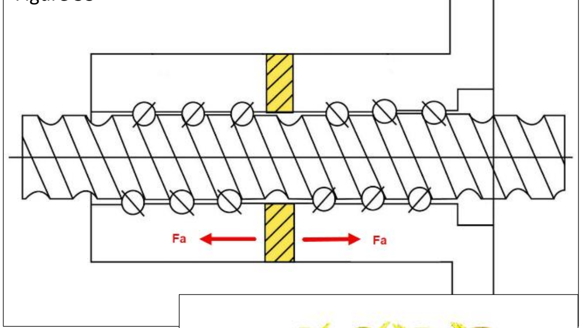


Figure 53

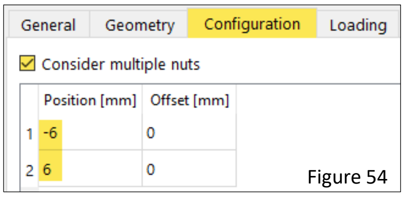


Figure 54

Under the 'Configuration' tab, insert 2 rows using the button and assign each a distance of 6 mm from the coordinate origin (Figure 54).

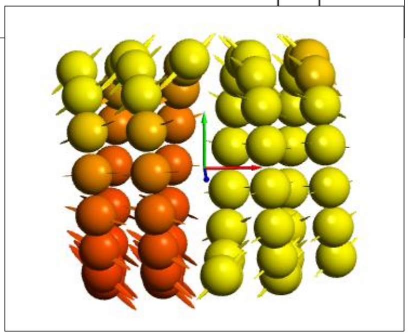


Figure 55

Check the layout via Graphics / Load distribution 3D (Figure 55).

Please start the parameter variation.

With the help of parameter variation, it can be shown that under the same loads as in Chapter 4.6.1 for the single load case, an equivalent tilting stiffness in Y can already be achieved with about 50 % less preload travel (Figures 57 / 58).

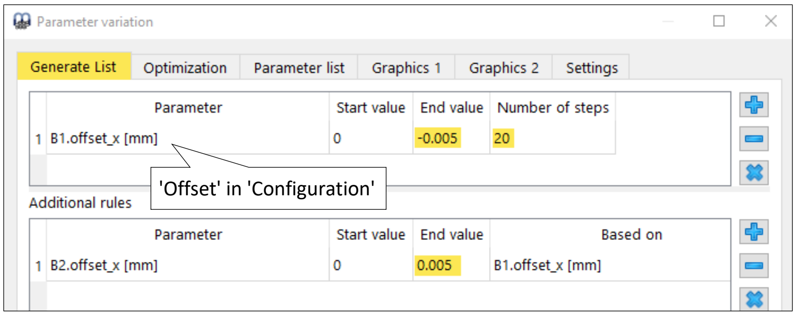


Figure 56

Single nut, 3 turns:

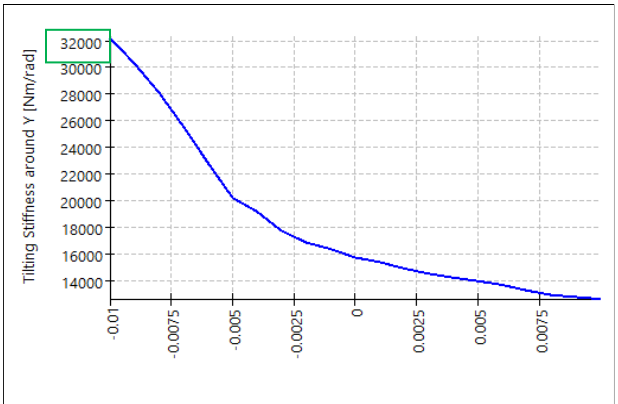


Figure 57

Double nut, 2 turns each:

Figure 58

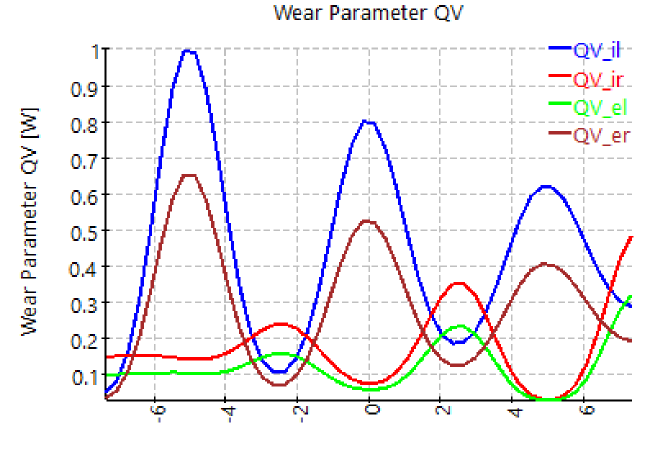


Figure 59

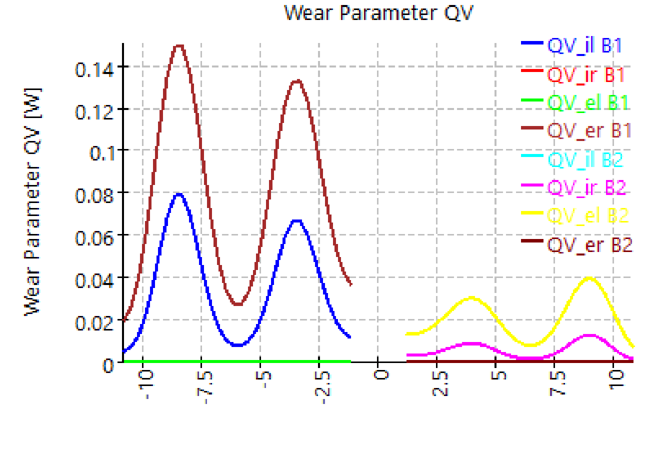


Figure 60

➡ The reduction of the maximum value of the wear parameter QV amounts to 92% for QV_il and 77% for QV_er when using the preloaded double nut compared to the preloaded single nut.

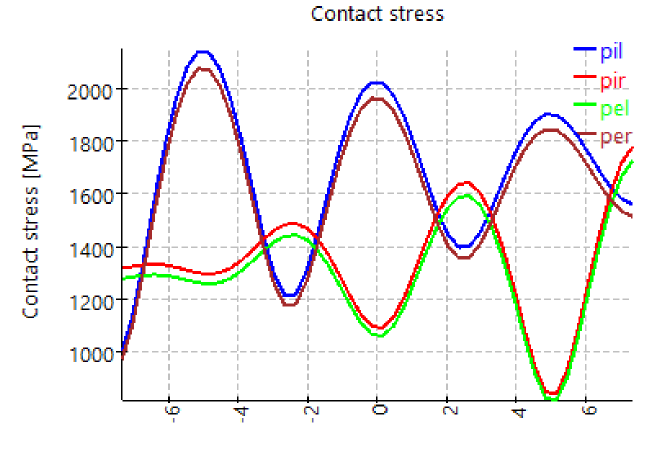


Figure 61

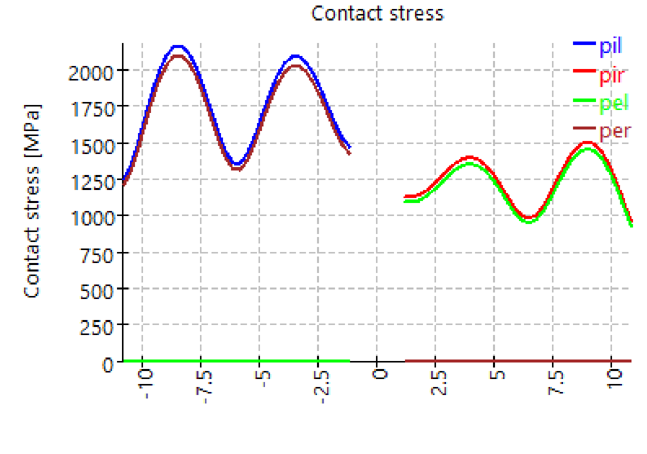


Figure 62

➡ In the case of a preloaded single nut, operation is limited to pure four-point contact (Figure 61). By using a preloaded double nut, however, operation with wear-optimized two-point contact can be achieved over the entire length (Figure 62).

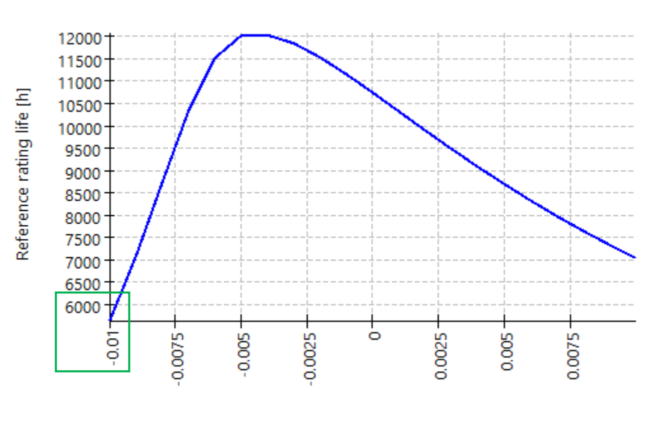


Figure 63

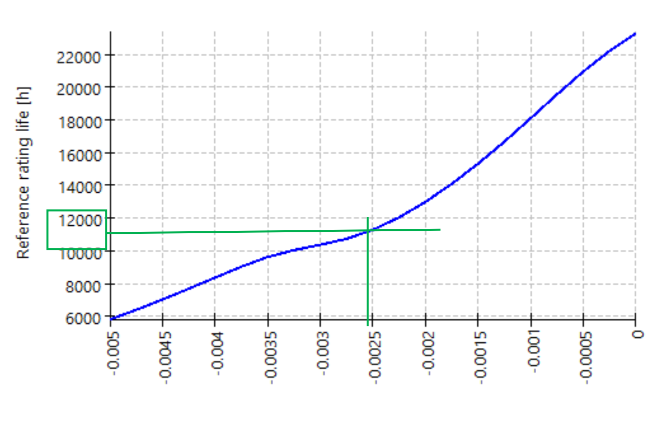


Figure 64

➡ The use of a preloaded double nut shows a potential lifetime gain of up to 100% compared to a purely stiffness-optimized preloaded single nut with the same stiffness (Figures 63 / 64).

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