# MESYS Ball Screws

## Introduction

This Ball Screws calculation (Version 04/2017) calculates the load distribution and the reference rating life according to ISO/TS 16281 (DIN 26281).

The inner geometry of the ball screws must be provided by the user. The operating clearance can be specified. The loading can be specified as force/moment or displacement/rotation independently for each of the five degrees of freedom. Bearing sets can be defined be using a configuration with multiple rows.

The following results can be found in the report:

- Reference rating life according ISO/TS 16281
- Load distribution between rolling elements
- Reaction forces/moments and displacements/rotations
- Contact pressure for each contact
- Static safety factor

In addition to the report the results are shown in several graphics. Report and user interface are both available in metric or US customary units. Supported languages for user interface and report are English, German, French, Spanish, Korean and Chinese.

## Installation

When running the installer the installation directory can be selected. The default location is "\Program Files\MESYS 04-2017". All files are installed into that directory. Also an entry in the start menu is created.

The uninstaller can be called from the start menu. This deletes the installation directory and the entries in the start menu.

Without a license file the software runs as demo version. In the demo version it is not possible to save or load files and a Demo message is shown on each calculation. The demo version may only be used for evaluation of the software.

The license file 'license.dat' has to be placed in the installation directory (in the same directory as MesysBallScrew.exe). The name of the license file may not be changed since it will not be found by the software.

### Configuration with INI-File

Some configuration of the software can be done using 'mesys.ini' in the installation folder.

Currently the settings are used for database access and formatting of the report.

| Section | Value | Description |
|---|---|---|
| General | recentfilenumber | Number of recent files shown in the file menu of the software |
| | floatinglicense | Path to the licensing file for floating license. It will be written by the software but might be copied to other installations.<br>Format: \\\\Server\\Share\\path\license.lic<br>Note: each '\' has to be doubled |
| | floatingtimeout | Time in seconds after a floating license is release if the program is not used. Default is 1800 |
| | fontsize | Fontsize in points, set 0 for default dependent on operating system |
| | style | Either windows, fusion, windowsxp. Select windows or fusion for WinXP |
| | listseparator | Character used as separator for table export. If not set the default setting in operating is used |
| | systemlocale | Set to true for decimal point of operating system or false for '.' as decimal separator |
| | usecalculatethread | If set to true calculation is done in a separate thread, else set to false |
| database | path | The path to the database file can be defined. The database can be copied onto a server, so all software users share the same database. If the filename is given without path, it is opened from the installation directory.<br>For path separators either use '/' or '\\' but not '\'. |
| | iswritable | Set it to true if the database may be changed. If set to false no changes are made to the database by the software. |
| | usecache | If set to true the database is read to memory. This speeds up the program in case the database is on a network drive. Default is false. |
| ballscrew | defaultinputs | Path to a xml-file with default settings<br>For path separators either use '/' or '\\' but not '\'. |
| | calculateonfileload | If set to true the calculation is run when a file is loaded. Default is true. |
| | acceptfiledrop | If set to true a *.xml input file can be loaded by dropping it on the main window |
| | logo | A logo for use on the system page can be defined here. The format had to be PNG. |
| report | format | The outputted report file can have different formats. By default, this value is equal to "INTERNALPDF", but it can be set to "DOCX", "DOC", ODT" or "PDF" (without quotes) |
| | tableformat | The format of the outputted results table can be also set; namely, to "CSV", "XLSX", or "XLS" |
| | topmargin | The top margin for the report in mm |
| | bottommargin | The bottom margin for the report in mm |
| | leftmargin | The left margin for the report in mm |
| | rightmargin | The right margin for the report in mm |
| | papersize | The size of the paper for the report. Available values are A4 and Letter |
| | template | Path to the created template file used for the report creation. Supported file formats: "DOCX", "DOC" or "ODT" |
| | logo | A different logo can be defined, which will be used in the report. The format had to be PNG. |

| report | marginbox1\active | The marginbox is used if set to true, else set it to false |
|---|---|---|
|  | marginbox1\rect | The size of the marginbox is defined with values in mm.The format is @Rect(x1 y1 width height). The parameters x1 and y1 describe the upper left corner of the box. Positive values are measured from the top/left negative velues from the bottom/right.<br>For example @Rect(-35 -20 30 20) is a rectangle at the right bottom. |
|  | marginbox1\text | The text for the margin box. It has to be set in quotations marks (like in "Text"). Either normal text or HTML can be used.<br>Some placeholders are defined: #page, #pageCount, #data, #datetime |
|  | marginbox1\angle | A rotation angle of the margin box can be set in degrees. The orientation of the angle is clockwise if positive. |
|  | marginbox1\isHtml | Either set it to true or false dependent on the type of text. |
|  | marginbox1\drawBox | If set to true a rectangle id drawn indicating the size of the marginbox. Else set it to false. |
|  | marginbox2\... | Like for margin box 1 additional boxes can be defined with increasing numbers. |

Please note that the listed options for margin boxes (marginbox1\...) are only valid if format is equal to "INTERNALPDF".

## Template

As detailed in the table above, a template in (.docx) format can be created so that it is used when generating the software report. For the current version, only the information contained in the header and footer can be edited, in which it is possible to link information to the software such us as 'module license', 'license name', 'date', 'file name', 'project name' or 'description' by means of the text fields option in Microsoft word. Additionally, a company logo can be included, instead of the MESYS logo that it is shown by default at the report:

«moduletitle»-«licensename»

Date:    2/27/2015 11:03:39 AM
File name:    «filename»
Project name:    «projectname»
Description:    «description»

First Page Header

**Field**

Please choose a field

Categories:

(All)

Field names:

Fill-in
GoToButton
GreetingLine
Hyperlink
If
IncludePicture
IncludeText
Index
Info
Keywords
LastSavedBy
Link
ListNum
MacroButton
MergeField
MergeRec
MergeSeq
Next

Description:
    Insert a mail merge field

Field Codes

Field properties

Field name:

description

Format:

(none)
Uppercase
Lowercase
First capital
Title case

Field options

☐ Text to be inserted before:

☐ Text to be inserted after:

☐ Mapped field

☐ Vertical formatting

☑ Preserve formatting during updates

OK    Cancel

## Command line parameters

The software supports a few command line parameters:

- -disableHighDPI disables scaling and tell the operating system to do the scaling. This is currently the default setting.
- -enableHighDPI enables highDPI scaling by the software. This setting still has some problems but it might be useful on some systems.
- -desktopOpenGL tells the software to use hardware OpenGL, which is the default.
- -OpenGLES tells the software to translate OpenGL into DirectX. This can be used if the driver for the graphic card does not work correctly and hardware OpenGL does not work.
- -softwareOpenGL tells the software to use a software driver for 3D graphics. This can be used if the two setting above fail to work.
- -ini=file.ini tells the software to use 'file.ini' for program settings
- -license=license.dat tells the software to use 'license.dat' as license file. This can be used it different license files are available.
- If a *.xml filename is passed as a parameter, the file is opened by the software. This also allows to drop an input file on a program icon on the desktop.

## Update

If the software is updated with a new version the database 'mesys.db' should not be overwritten. Either the new installation is done in a new directory or the database file is copied to a different location.

After the new version is started the database can be updated by choosing menu 'Extras'->'Database'->'Import from old database'. All custom entries will be updated. Changes to default data will be lost as only custom data will be copied.

## Requirements

The rolling bearing calculation is available as 32bit windows program running on Windows Vista, Windows 7, 8 or 10. In addition to the 32bit version which can be used on 32bit or 64bit operating system also a 64bit version is available. The minimum required processor is Intel Pentium 4 or above.

About 100MB of hard disk space is required. All dependencies of the software are available in the installation directory. Therefore, it can just be copied to other machines or started from network or removable disks.

## General usage

To run a calculation first the data on all pages is introduced. Then press the button 🗲 or F5 to run the calculation. After all data is defined the calculation can be run from each tab page. So it is easy to make parameter variations.

There are some special buttons used in the user interface, which are explained in the following table:

| Button | Explanation |
|--------|-------------|
| ✚ | This plus button shows a dialog with additional inputs. Some of these |

| | |
|---|---|
| | inputs need to be defined, some are just optional. |
| ▤ | This conversion button allows the conversion from other types of input. For example the radial clearance can be converted from an axial clearance |
| ★ | This proposal button provides a suggestion for an input by the software |

The unit system for the input and output can be selected on the menu 'Extras->Unit system' either as metric or US units.

Using the context menu for the units of input fields, the current unit can be changed. These setting are not saved in the current version, so the change is only valid for the current session.

Pressing the right mouse button on an input field a window for an input of a formula is shown. This can be used for quick calculations.
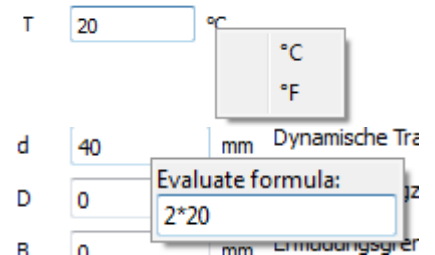
The software is available in English, German, French, Spanish, Chinese and Korean language. The language can be selected in menu 'Extras'.

All graphics can be printed or exported as PNG file using the context menu (right mouse button) in the graphic window. For the export the size of the graphic can be specified.

In the graphic windows of the software, there are different buttons for the view manipulation in 3D, such as the zoom-in, zoom-out and fit-to-window functions and also it is possible to select the point of view from different planes. The 3D model can be dragged with the mouse by holding down SHIFT key as well as zoomed in and out by holding down the CTRL key.
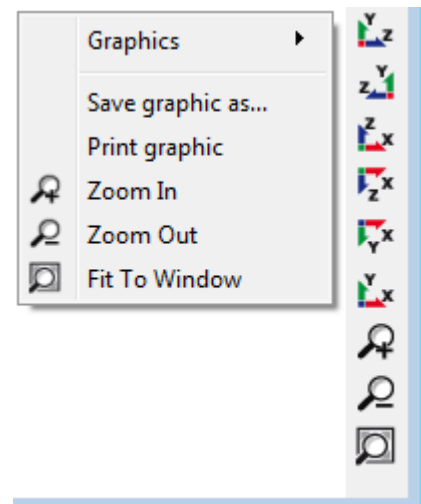
Any diagram of the software can be edited by right clicking on it and selecting the 'Diagram options' at the context menu.

Both the units and bounds for the axes can be set. Moreover, if any of the graphs is of no interest, it can be disabled with the checkboxes. The color and line style of each curve can be changed too.

# Input Parameters

## General

On the first input page in addition to a project name, several settings can be done.



### Project name and calculation description

The project name and the calculation description are just inputs which are shown in the report header. They can be used to enter information about the purpose of the calculation for documentation.

### Use load spectrum

A load spectrum can be used instead of a single load case. This option can be activated here. For each load case a full calculation using all factors is made. The resulting life is calculated using the life of each element (load case). Result graphics are only shown in the report for the selected result element of the load spectrum. However the result graphics corresponding to any element number (case number) of the load spectrum can be shown under the menu 'Graphics'->'Load spectrum' (only until 25 elements), as we can see in this picture.

 All other graphics available under the menu 'Graphics are only valid for the selected element.

Additionally, under 'Graphics'->'Load distribution (Load spectrum)', all the load distribution cases are superimposed on the chart at the same time. This is also possible for the roller graphics.

Please note that more intermediate results are printed in the report if a calculation is done for a single load case.

### Calculate COa according to ISO 3408-5
If this option is selected the static load capacity is calculated according to (ISO 3408-5, 2006). In this case material properties like Youngs modulus have no effect on the static load capacity.

If the option is not selected the static load capacity is calculated according (ISO 3408-5, 2006), but using f0 according ( ISO/TR 10657, 1991) instead of k0. In this case the static load capacity is based on a permissible contact stress of 4200 MPa as for axial ball bearings according (ISO 76, 2006).

### Calculate Ca according to ISO 3408-5
If this option is set the dynamic load capacity is calculated using the exponent 0.86 in equation 8 of (ISO 3408-5, 2006). If the option is not set, the exponent 0.7 is used as in (ISO 281, 2007), ( ISO/TR 1281-1, 2008) or (Lundberg, et al., 1947).

The load capacity is calculated according

$$C_a = f_c \cdot (i \cdot \cos\alpha)^{0.86} \cdot \tan\alpha \cdot z_l^{\frac{2}{3}} \cdot D_w^{1.8} \cdot (\cos\varphi)^{1.3}$$

with either an exponent 0.86 or an exponent of 0.7.

### Calculate reliability factor according to ISO 3408-5
The modification factor for reliability is calculated according to the two parameter Weibull distribution according (ISO 3408-5, 2006) if this option is set. If the option is not selected the three parameter Weibull distribution as in (ISO 281, 2007), ( ISO/TR 1281-1, 2008) is used.

### Enter two contact angles
Either one or two contact angles can be defined. Different contact angles can be used for screw and nut. The contact angle is defined by radial contact of the ball to either screw or nut.

### Reliability S
As default the bearing life is calculated for a reliability of 90%. The required reliability can be changed here with limits 90% and <100%. The life modification factor for reliability fac is calculated according to this input using either the three parameter Weibull relationship as given as formula in (ISO/TR 1281-2, 2008) or the two parameter Weibull relationship used in (ISO 3408-5, 2006).

### Scale factor for stress in 3D view s
The stress distribution is scaled to s*Dw for a contact stress of 4000MPa in the 3D view.

### Start angle for first thread $\Psi_0$
The start angle defines the angular position of the left end of the first thread. With an angle of 0° the start is on the y-axis.

### Clearance generation
The nominal contact angle, ball diameter and radii of races are used to define the positions for centers of curvature in the case of zero clearance.

There are four possibilities to define clearance:

1. Centers of curvature are moved axially. This is only possible for gothic profiles with contact angle larger zero. The maximum clearance that can be achieved is limited.
2. Centers of curvature are moved radially.
3. Centers of curvature are moved in direction of contact angle. This cannot be used in case of contact angle zero.
4. Clearance is generated by reduction of ball diameter. This slightly reduces load capacities as the reduced ball diameter is used for calculation of load capacity.

## Axial expansion of ball screw and nut

The axial expansion of the ball screw and the nut three options are available: "Not considered", "fixed left", fixed right". In case the load is introduced on one side the screw will axially expand or compress because of the axial stresses. "Fixed left" means that the load is introduced on the left of the element and the axial stress will reduce to the right.

## Elastic ring expansion

An elastic expansion/compression because of radial forces can be considered. The calculation is based on thick ring theory with constant pressure at the outside or inside. Either the minimum or the medium contact force of the balls is used to calculate this elastic deformation. The deformation is constant over the whole length of the nut. Therefore, the method is not suited for a pure moment load.

## Ball screw geometry



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Number of starts | ns | 1 | | Dynamic load number | Ca | 0 | kN | ☐ |
| Number of turns | nt | 1 | | Static load number | C0a | 0 | kN | ☐ |
| Lead | Ph | 0 | mm ◉ | Axial clearance | Pa | 0 | mm | ▤ |
| Lead angle | phi | 0 | ° ○ | Tolerance class | | 5 | | ▼ |
| Direction | | right ▼ | | Material ball screw | | Steel ▼ | ✚ |
| Number of loaded balls per turn | zl | 0 | ☐ | Material ball nut | | Steel ▼ | ✚ |
| Ball diameter | Dw | 0 | mm | Material rolling element | | Steel ▼ | ✚ |
| Pitch diameter | Dpw | 0 | mm | Ball screw inner diameter | dsi | 0 | mm |
| Contact angle | α | 0 | ° | Nut outer diameter | dhe | 0 | mm |
| Conformity ball screw | frs | 0.52 | ✚ | Ball screw lead error | $\Delta_{Ph}$ | 0 | mm |
| Conformity ball nut | frn | 0.52 | ✚ | | | | |
| Shoulder diameter ball screw | dSi | 0 | mm ✚ | | | | |
| Shoulder diameter ball nut | dSe | 0 | mm ✚ | | | | |

### Load capacities

The load capacities can be an input or an output. If they are given by the user they will not be changed because of surface hardness of the material. The surface hardness is only considered if the values are calculated by the software.

The load capacity will be calculated using the free contact angle $\alpha_0$, not the nominal contact angle $\alpha$. This mainly makes a difference for nominal contact angle of zero in case of a full radius in races.

### Dynamic load number

The dynamic load number is used for the calculation of bearing life. It is calculated according (ISO 3408-5, 2006) with factor fc according ( ISO/TR 1281-1, 2008). Either 0.86 or 0.7 according (ISO 281, 2007) is used as an exponent.

The dynamic load number can be influenced by a modification factor available at material properties.

### Static load number

The static load number is calculated according (ISO 76, 2006) and ( ISO/TR 10657, 1991) or according (ISO 3408-5, 2006).

### Number of starts

The number of starts defines the number the ratio between lead and pitch or the number of parallel ball tracks.

### Number of turns

Each ball track has this number or turns. It does not have to be an integer value.

### Lead

The lead is the axial travel of the nut for a 360° rotation.

### Lead angle

Instead of the lead, the lead angle can be used as input. The lead is $Ph = D_{pw} * \pi * \tan(\varphi)$

### Direction

The lead can either be right or left handed. The sense of rotation is defined by this input.

### Number of loaded balls per turn

The number of loaded ball per turn us usually calculated according (ISO 3408-5, 2006). It can be overwritten in case spacers are used.

### Ball diameter

The diameter of the balls is specified here.

### Pitch diameter

The pitch diameter is the diameter of the centers of rolling elements when they have the same amount of clearance to both races. The diameters of inner and outer race are calculated by this value, the diameter of rolling element, the contact angle and the clearance.

### Contact angle

Either one or two contact angles can be defined. For contact angle larger zero a gothic profile is used, for contact angle of zero a full radius is used.

If a full radius should be used, the clearance has to be generated either radially or by reduction of ball diameter.

## Conformity of ball screw and ball nut

The conformity is the ratio between radius of curvature of a race and the ball diameter. For geometric reasons the value has to be larger than 0.5. The values used for the calculation of tables in ISO 281 are $f_i=f_e=0.52$ for radial ball bearings and $f_i=f_e=0.535$ for thrust ball bearings as stated in ( ISO/TR 1281-1, 2008).

Using the ✚-button behind the input field, the conformity can be calculated from a given radius. Ensure that you input the correct roller and pitch diameter before.

## Shoulder diameter of inner and outer ring

The shoulder diameter of inner and outer ring can be defined.

The shoulder diameter is compared to the maximum extension of the contact ellipsis. A warning is shown if the ellipsis would extend above the shoulder. The hertzian stress is not valid in that case.

The required shoulder diameter is shown in the report together with a length ratio eLR_i, eLR_e, which is showing a safety of shoulder length. The length ratio is defined as the length from lower end of contact ellipsis to shoulder (the green line the graphics) divided by the length of the contact ellipsis 2a (red line in the graphics). The value should therefore be larger than 1 or 100%.
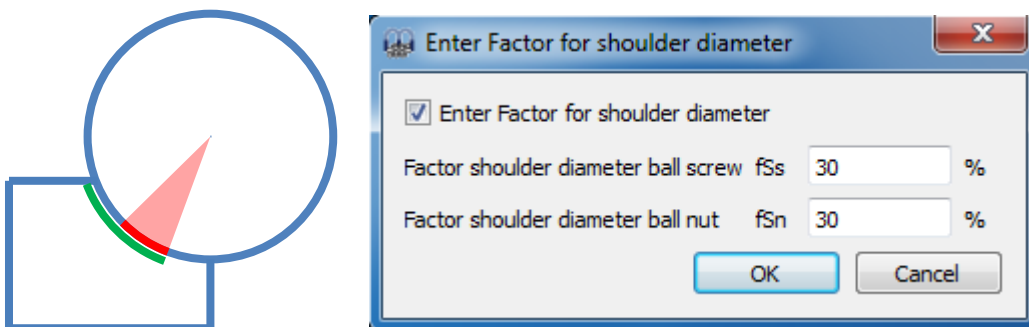


Instead of using an absolute value, the shoulder height can be defined using a percentage of ball diameters. A factor of 50% would be a shoulder up to the pitch diameter, so the factor should be between 10% and 40%. Using this factor allows to have default geometry on changing ball diameter or pitch diameter.

## Axial clearance

The axial clearance is the difference between the possible axial displacement in positive and negative direction. It can be negative for gothic profiles, but it has to be positive for full radius profiles.

A pretension can be entered by using a negative value for the axial clearance Pa. A ▭-button allows the input of radial clearance instead of axial clearance or a free contact angle can be used for full radius profiles.

## Tolerance class

The tolerance class will be considered in calculation of static and dynamic load capacity.

### Material ball screw

The material of the ball screw can be defined here. Using the ✚-button the hardness and material treatment can be defined too.

### Material ball nut

The material of the ball nut can be defined here. Using the ✚-button the hardness and material treatment can be defined too.

### Material rolling element

The material of the ball can be defined here. It does only affect the contact stiffness in calculation of load distribution.

### Ball screw inner diameter

The inner diameter in case of a hollow screw. This input is only used in case axial or radial expansion is considered.

### Nut outer diameter

The outer diameter of the nut. This input is only used in case axial or radial expansion is considered. In case the input value is zero a diameter of Dpw + 20*Dw is used internally.

### Ball screw lead error

An optional lead error for the ball screw. This will affect the load distribution.

## Bearing configuration

A group of nuts can be considered in the calculation. The nuts are assumed to be connected to a rigid shaft and housing. The loads or displacements are given for the origin of the bearing group instead for each single bearing.

A relative position can be entered for each bearing. An axial offset allows the definition of pretension in the system. The offset is an additional movement of the ball nut. The displacements, forces and moments under loading are applied at the reference position 0. So in most cases the positions should be chosen symmetrically around zero.

Additional bearings can be added using the ➕-button. A row can be deleted using the ➖ - and the ✖-button clears all inputs.

With the context menu (right mouse button) in the table several results values can be shown in the table. This allows seeing quickly how load or life is distributed among the nuts.

# Loading

For each coordinate direction you can select if a force or a displacement should be entered.

A moment load can be entered for two directions only, because the torque around the axis is connected to the axial force. The rotation angle rx will affect the axial displacement only.

Use the radio buttons to select the elements you want to enter.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| General | Geometry | Configuration | Loading | | | | | | |
| Axial load | Fx | 0 | N | ◉ Displacement | ux | 0 | µm | ○ |
| Radial load | Fy | 0 | N | ◉ Displacement | uy | 0 | mm | ○ |
| Radial load | Fz | 0 | N | ◉ Displacement | uz | 0 | mm | ○ |
| Moment | Mx | 0 | Nm | ○ Rotation angle | rx | 0 | mrad | ◉ |
| Moment | My | 0 | Nm | ○ Rotation angle | ry | 0 | mrad | ◉ |
| Moment | Mz | 0 | Nm | ○ Rotation angle | rz | 0 | mrad | ◉ |
| Speed inner ring | ni | 0 | rpm | ☑ Inner ring rotates to load | | | | |
| Speed outer ring | ne | 0 | rpm | ☐ Outer ring rotates to load | | | | |
| Temperature of shaft | Ti | 20 | °C | Temperature of housing | Te | 20 | °C | |

## Coordinate system

The coordinate system is defined with x as the axial direction. The y-axis points up to the first rolling element and the angle ψ is positive around the x-axis or clockwise in the diagram on the right (looking in the direction of the x-axis). The angle starts with zero at the first rolling element on the y-axis as default; it can be changed under settings. Moments are positive if acting around the corresponding axis.

The load is acting on the inner ring, so a positive load in y-direction leads to a loading of the rolling elements on the top as shown in the graphics on the right.
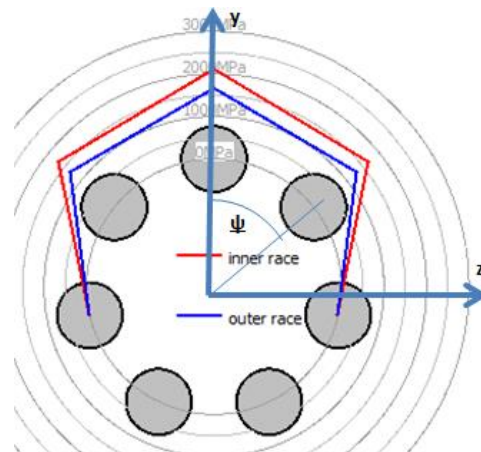
## Inner ring rotates to load

The resulting life is slightly different if the load distribution on a race is stationary or rotating. For many bearings the inner ring rotates relative to the load. This is the case if the inner ring is connected to a rotating shaft and the load is stationary in space.

What is the correct input, if only an axial load occurs? In this case the input doesn't matter since the results are the same for both settings if all the rollers have the same loading.

## Outer ring rotates to load

For the outer ring the same is valid as for the inner ring. In many applications the outer ring is stationary to the load.

## Temperature of screw and nut

The temperatures of the shaft and the nut are considered in axial elongation of the screw and the nut and they will affect the radial clearance due to radial thermal expansion.

# Load spectrum

If at the tab-page 'General' the flag for the calculation with load spectrum is set, instead of for a single load case, the calculation will be done for a load spectrum. The load or displacement, the rotation speed and the temperatures can be specified for each element.

| | Frequency | Fx [N] | Fy [N] | Fz [N] | rx [mrad] | ry [mrad] | rz [mrad] | ni [rpm] | ne [rpm] | Ti [°C] | Te [°C] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.45 | 8000 | 0 | 0 | 0 | 0 | 0 | 1000 | 0 | 20 | 20 |
| 2 | 0.35 | 5000 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 20 | 20 |
| 3 | 0.1 | 2000 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 20 | 20 |

☑ inner Ring rotates to load   ☐ Outer ring rotates to load   Results for No  1

Using the context menu that opens clicking the right mouse button you can select which forces or moments should be used as input values. If a value is not selected the corresponding displacement/rotation can be entered.

Rows can be added using the ➕-button or a selected row can be deleted using the ➖-button. The ✖-button clears all the inputs.

Using the ➡-button the load spectrum is read from a file. The columns that are currently shown with its units have to be used for the input file. As the data from the file is added to the inputs, you must clear the inputs first to define a full load spectrum. Likewise, a created load spectrum table can be exported with the corresponding ➡-button.

As for the single load case a selection is available if the ring is rotating relative to the load or not. A ring not rotating to the load would be on the safe side.

The load distribution is calculated for each load case. The resulting life for the whole load spectrum is shown as result and the minimum static safety of all elements. The result graphics are only shown for the element of the load spectrum that is chosen as results on this page.

# Parameter variations

Using the menu point "Calculation"->"Parameter variation" a dialog for parameter variations is shown. It allows the user to do parameter studies with results provided in tables and graphics. Typical applications are, for example, visualizing life over clearance or displacement over load.
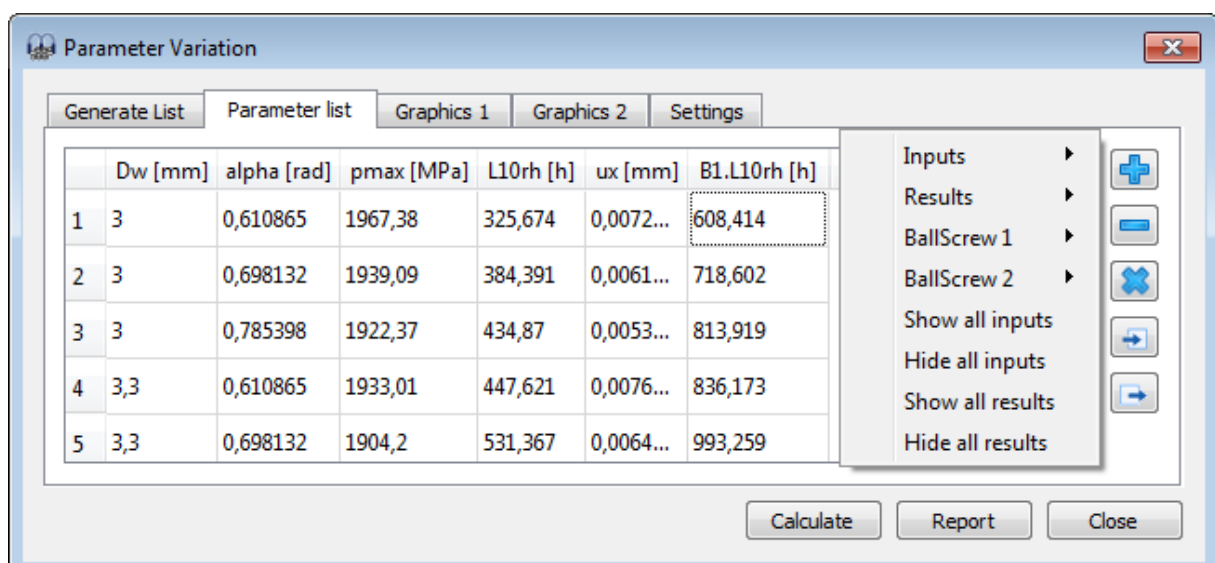
## Generate list

Several input parameters can be added to the table "Generate list" and ranges (Start/End values) can be defined for them. Dependent on the bearing type the calculation can take up to 0.1sec for a single calculation, using load spectra and defining many steps can lead to long calculation times.
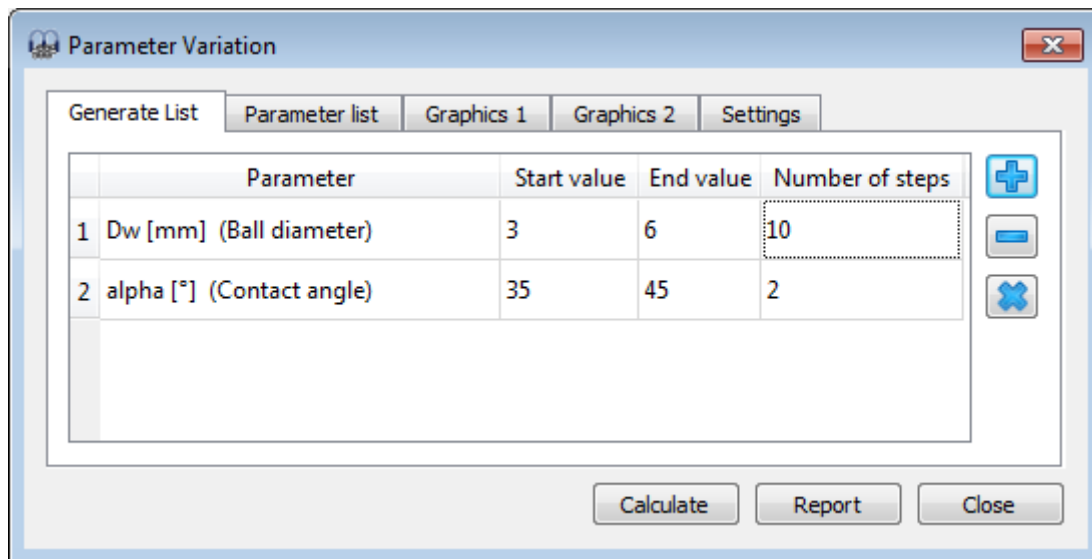


## Parameter list

Before we generate a list, it is necessary to define first those outputs or variables we are interested in at the tab window 'Parameter list'.

As shown in the picture, by doing a right mouse-click on the tab window 'Parameter list', a context menu will enable us to add the columns corresponding to the outputs or results we are interested in. The rows will contain the variable values according to the bounds and number of steps.

By clicking on 'Calculate' while the "Generate list" tab window is active, a list of all parameter combinations will be generated at the corresponding tab window 'Parameter list' and the analysis will be run. Depending on the chosen number of parameters and steps, the analysis can lead to long calculation times.

A second way to create a table (parameter list) is possible by adding rows and entering values manually with the ✚-button. Moreover, a whole table can be imported from a csv-file using the ➡-button or exported into a file using the ➡-button. Then, in order to run the analysis, we just have to click on "Calculate" while this page is active. Please note that the any parameter list is not saved if the dialog is closed.

## Graphics

On the pages "Graphics1" and "Graphics2" the results can be shown as graphic.

If the parameter list was generated by "Generate list" and no more than two input parameters are used, lines are used for the diagram. For more parameters or other sources just points are shown.

The line charts of the chosen outputs can be overlapped so that the user can easily perform any comparisons. The graphic area consists of two different y-axis, thus being possible to compare different types of output results (units) at a time. Furthermore, although the basic combined life (L10rh) for a ball screw with two nuts is being primarily analyzed in the graphic, by doing a click on the ✚-button, it could also be possible to add any other analyzed outputs with the same units of one of the two available y-axis; like the L10rh for any of the nuts, shown in the example of the picture above.

## Report

You have to activate the checkbox "Include in report" if the graphic should be added to the report. Moreover, under the tab-page 'Settings' another checkbox is available for including the parameter list in the report.
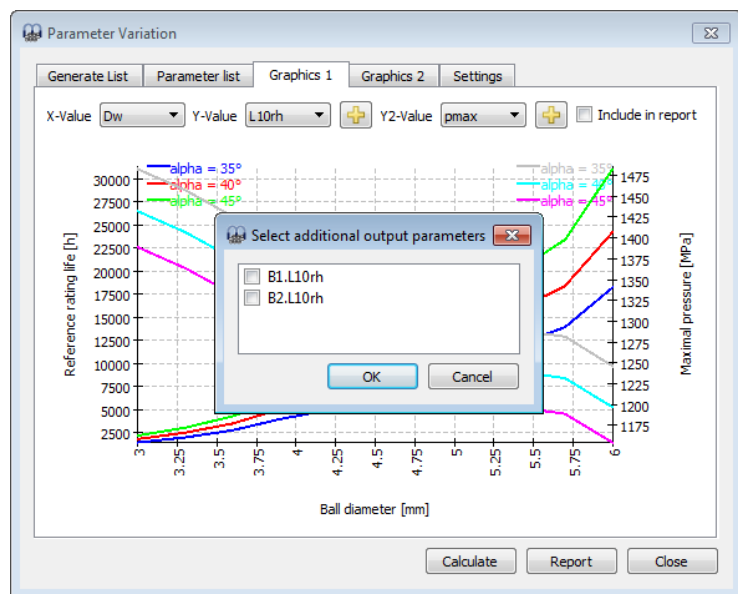
# Statistical parameter variations

Using the menu point "Calculation"->"Parameter variation (statistical)" an analogous tool to the default parameter variation is available. The main difference between them lies in the fact that this tool supports statistical evaluations when doing parameter variations.

The default version of parameter variation is helpful to visualize the influence of one parameter on one or multiple results. The statistical version can be used if the influence of multiple uncertainties should be evaluated. Instead of manually checking multiple parameters an automatic calculation of the whole ranges can be done. In order to understand the reasons behind the results it will still be necessary to carry out additional evaluations, but the software shows the ranges of results that have to be expected.

## Generate list

As in the normal parameter variation, several input parameters can be added to the table "Generate list" and ranges (Start/End values) can be defined for them. No calculations steps are required for the ranges. However, a limitation on the number of statistical calculations can be set under the tab-page 'Settings'.

Different types of probability distributions can be chosen from a drop-down list which is shown when double-clicking on a cell under the 'Distribution' column for any of the parameters:
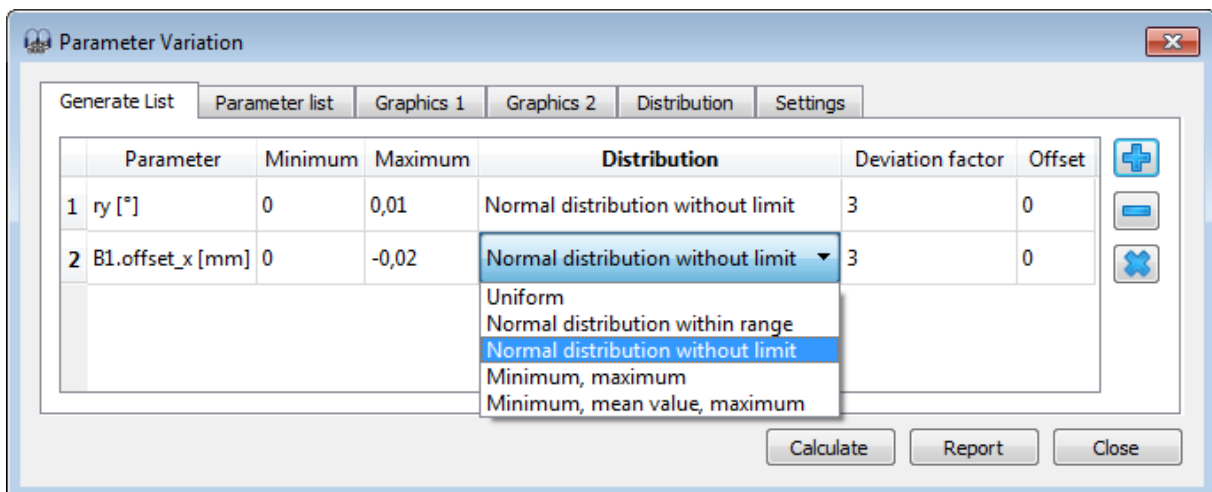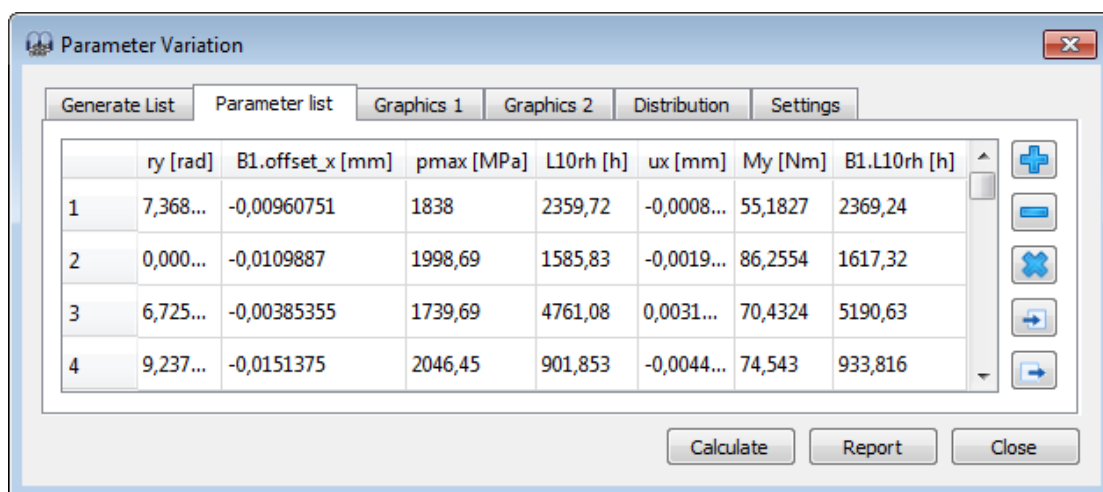


- Uniform: The probability is equally distributed for a set of values between the maximum and minimum value of the parameter.
- Normal distribution within range: The probability is calculated for a set of values ranging from the minimum to maximum by using a normal distribution.
- Normal distribution without limit: The probability is calculated for a set of values theoretically in the range of $(-\infty, +\infty)$ by using a normal distribution.
- Minimum, maximum: The probability is equally distributed between the maximum and minimum values of the parameter.
- Minimum, mean value, maximum: The probability is equally distributed between the maximum, mean and minimum values of the parameter.

Additionally, a factor can be set for the deviation and an offset value between -1 and 1 can be used to shift horizontally the 'bell curve' in either direction.

## Parameter list

The generation of the parameter list is performed as explained for the non-statistical parameter variation. By clicking on 'Calculate' while the "Generate list" tab window is active, a list of all parameter combinations will be generated at the corresponding tab window 'Parameter list' and the statistical analysis will be run. Depending on the chosen number of parameters and the specified number of calculations, the analysis can lead to long calculation times.

A second way to create a table (parameter list) is possible by adding rows and entering values manually with the ✚-button. Moreover, a whole table can be imported from a csv-file using the ➡-button or exported into a file using the ➡-button. Then, in order to run the analysis, we just have to click on "Calculate" while this page is active. Please note that the any parameter list is not saved if the dialog is closed.



## Distribution

The probability distribution is graphically represented at the tab-page 'Distribution'. The larger number of calculations, the smoother the bell curve will be. A first insight is already possible with a smaller number of calculations, but for nice-looking curves several thousand calculations are needed.
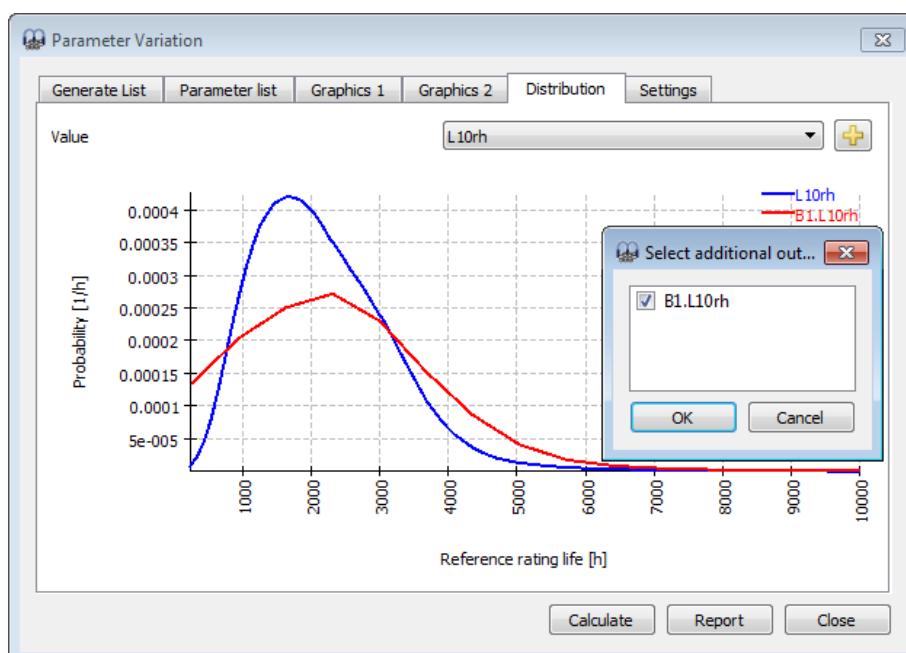
# Graphics

On the tab-pages 'Graphics' any variable combination can be visualized in the form of point clouds, where the some trends for the relationship between the parameters might be recognized, as shown in the picture below.
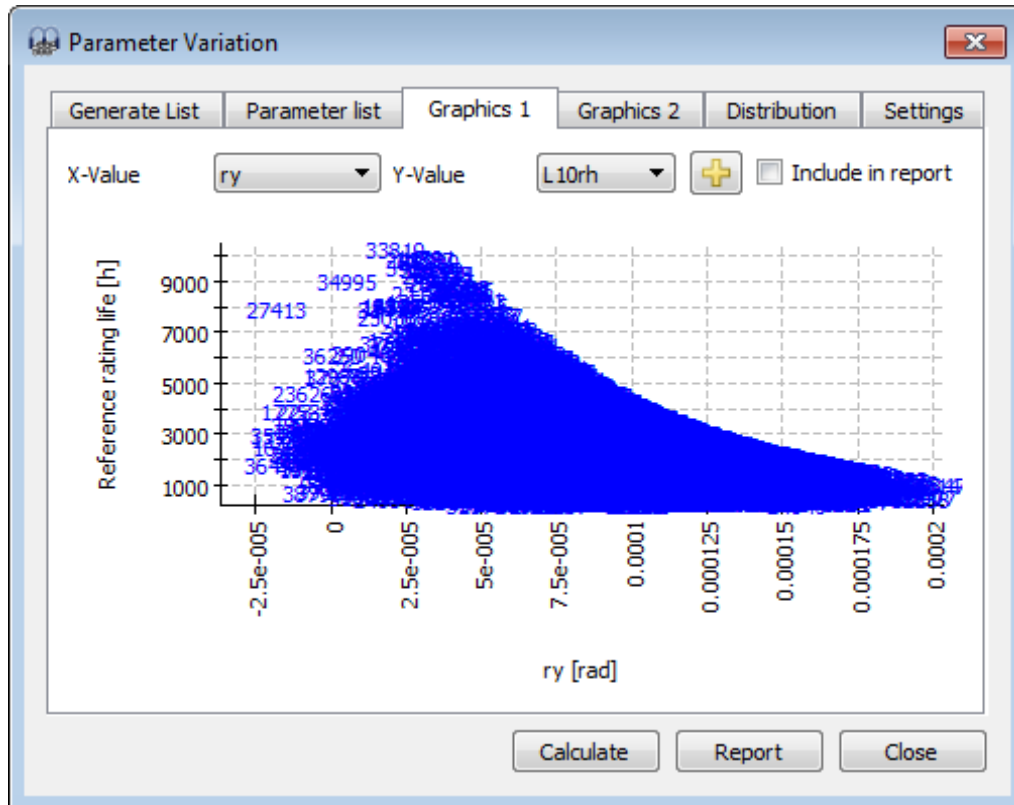


# Report

You have to activate the checkbox "Include in report" if the graphic should be added to the report. The report will also show minimum, maximum, mean value and standard deviation for each selected result.

# Database

As database a SQLite database is used. In addition to the possibilities of the software also standard tools could be used to change the database. Please only add datasets with id > 100000 and don't modify datasets with id < 0 since they are used internally. On future versions datasets with id< 100000 might be changed or added.

In the current version there are database tables for Bearings, Bearing Clearance, Bearing Tolerance, Material, Material Bearings and Lubrication. They can be added using the Menu 'Database' under 'Extras'.
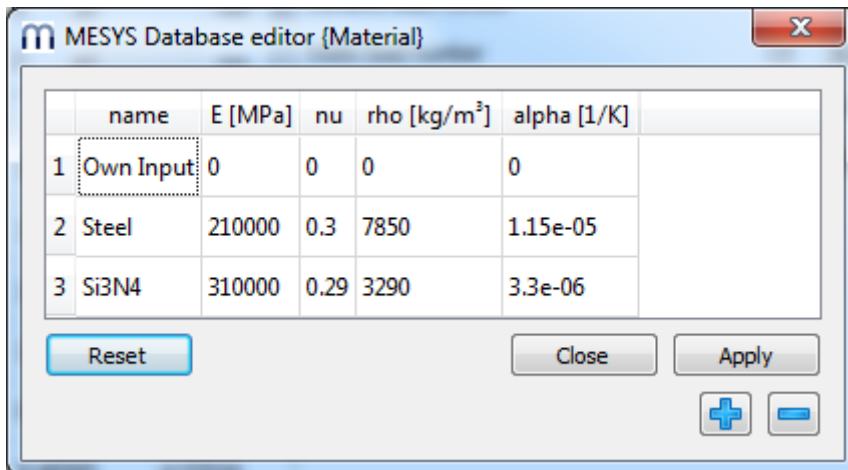


Data is written into the database only when clicking the Apply-Button, changes can be removed by selecting 'Reset' before 'Apply' is clicked.

Rows can be added using the ➕-button or a selected row can be deleted using the ➖-button.

## Changing names in the database

When a calculation file is loaded, the software searches the database for combinations of id and name of a dataset. If the item is not found the inputs are changed to 'own input'.

Therefore, calculations files that are opened by other installations of the software with a different database, will show 'own input' and give the correct results.

If you change the name of entries in the database the same will happen. You will see 'own input' in old files that used this entry and they will use the original data.
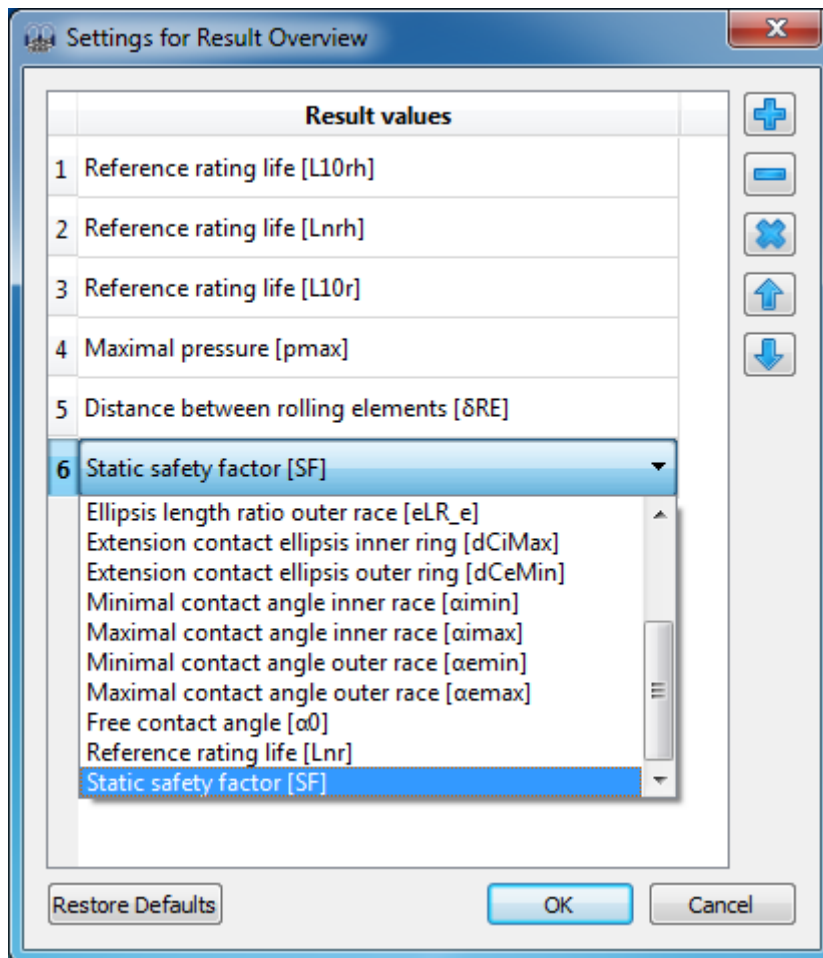
# Results

Results are provided as a small result overview directly in the software, a main PDF text report, a tolerances report and separate graphics windows. Graphic windows can be docked onto the main program interface and are automatically updated on each calculation.
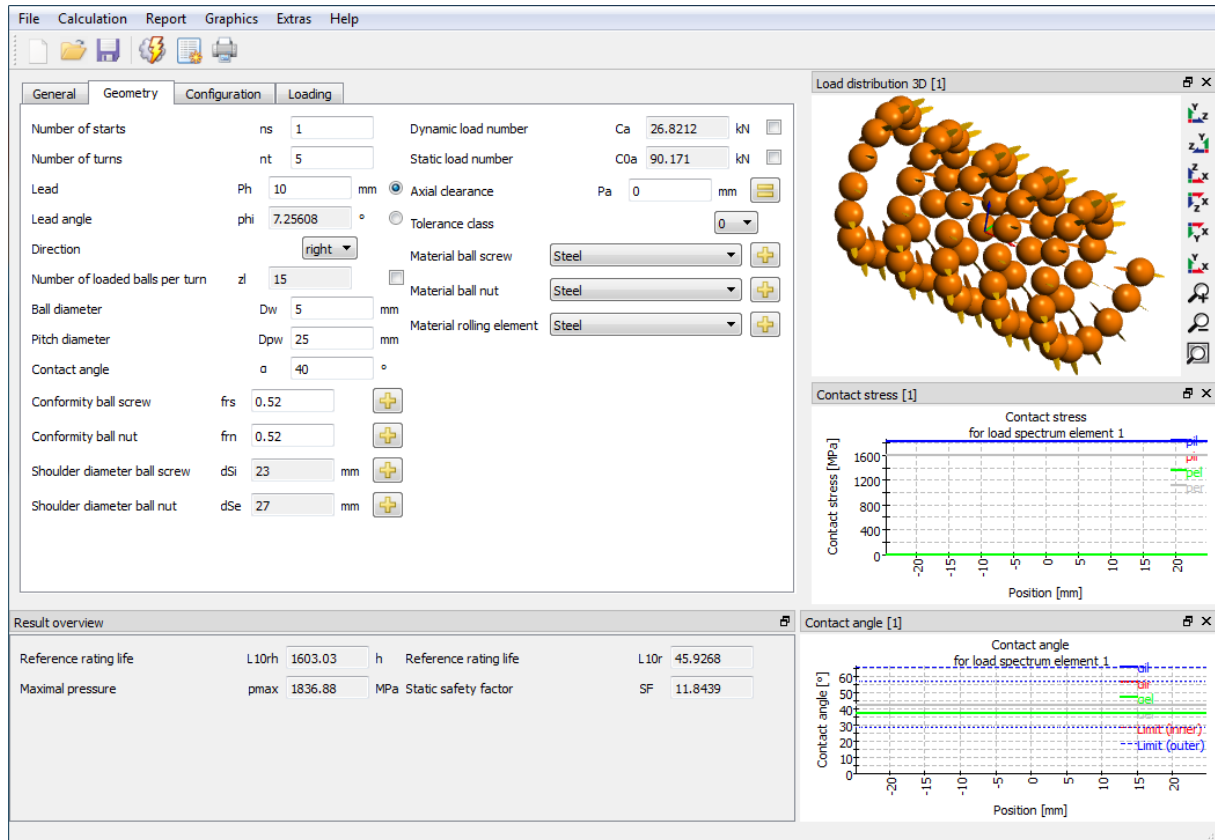


## Result Overview

The result overview shows the reference life $L_{10r}$ in $10^6$ rotations and the reference life $L_{10rh}$ in hours. The modified reference life $L_{nmr}$ considering reliability and lubrication is also shown in $10^6$ rotations and in hours.

The maximum pressure and the static safety provide information about the maximum loading.

The result overview can be customized using "Extras->Result overview". The items shown in the overview can be selected and additional items can be added using the ➕-button or the context menu with the right mouse button. Note that only values are actually shown in the result overview that are valid. So you will see fewer values than selected in the settings.

The settings for the result overview are saved in the windows user profile not in the calculation file. So they will be the same for different calculations.

## Main Result Report

The text report is provided in PDF format.

In the menu Report->Options the contents of the report can be configured. The graphics to be included can be selected and some sections of the report could be discarded if not of interest. The legend for all the table parameters can be shown in the report.

### Saving main report

The main report can be saved using the menu "Report->Save Report As" in different formats. It can be saved as PDF, DOC, DOCX or ODT (Open Office) format.

## Customizing report logo

As default a MESYS logo is shown on top of the report. This can be customized by placing a 'logo.png' into the installation directory. The logo should be created using a size, so that it fits into the header table. The DPI setting in the logo is considered, so that a high-resolution image could also be used. Additionally, it also exists the possibility to create an own template of the supported file formats (DOC, DOCX and ODT) and generate the report from it, thus having the chance to customize the logo.

## Customizing report logo

# Result Graphics

Several results can be shown as graphics.

All graphics are also appended to the report, so that a full documentation is provided in one document.

Using the context menu (right mouse button) in a graphics window the graphic can be exported as file or be printed.

## Load distribution 3D

Here the contact stress of an angular contact bearing with radial and axial load and relatively high speed is shown. The contact stress is larger on the inner race (red) in the load zone but slightly larger on the outer race on the opposite side because of centrifugal loads.
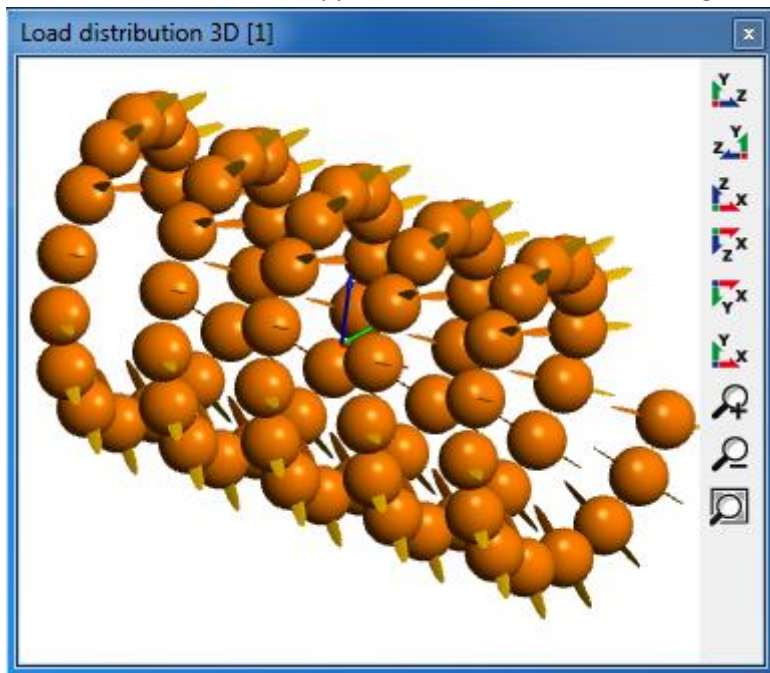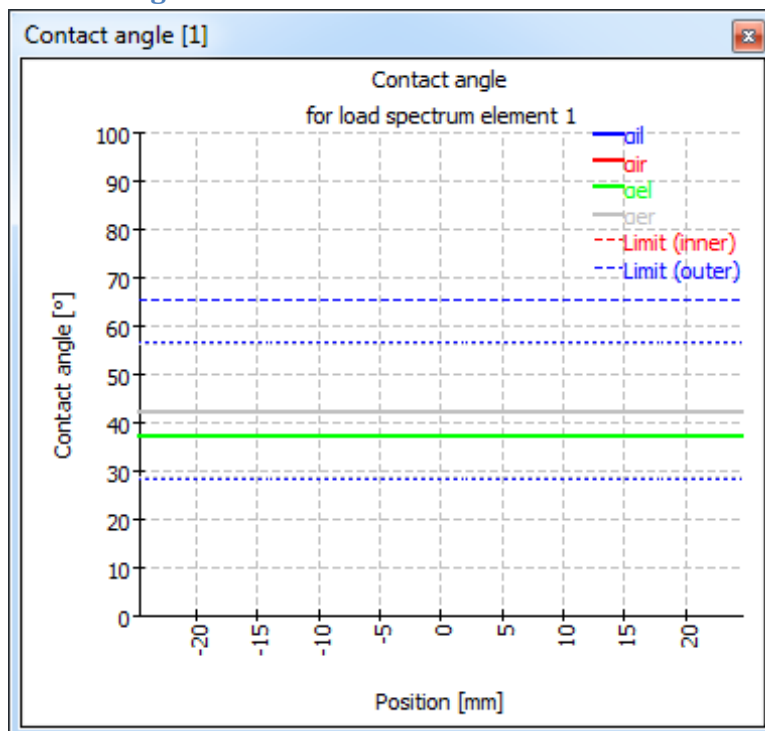


With this chart, it can be noticed the contact stress by means of color-based representation of the contact stress levels on each rolling element and the corresponding contact ellipse on them. The visualization can be accurately rendered in any perspective.

## Contact stress
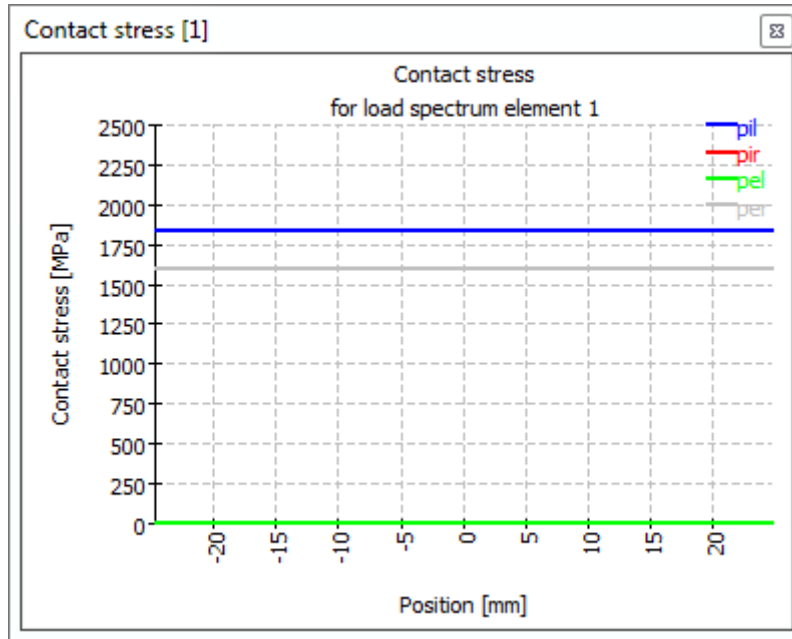


## Contact angle



The contact angle is shown for a nominal contact angle of 40°. As for typical axially loaded ball screws, both the load level for all balls and the contact angles of inner and outer race are almost equal along the axial position.

The extension of the contact ellipsis is shown with the dotted lines. The contact angle corresponding to the shoulder is shown as dashed straight line at the top, so the shoulder is high enough in this case.

## Ball loads
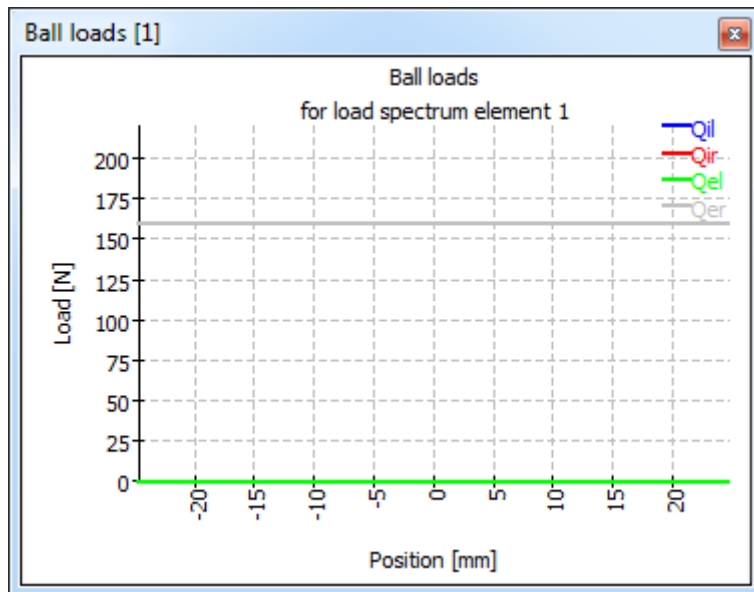
# Bibliography

**ISO/TR 10657. 1991.** *Explanatory notes on ISO 76.* s.l. : ISO, 1991.

**ISO/TR 1281-1. 2008.** *Rolling bearings - Explanatory notes on ISO 281 - Part 1: Basic dynamic load rating and basic rating life.* s.l. : ISO, 2008.

**AGMA 925. 2003.** *Effect of Lubrication on Gear Surface Distress.* 2003.

**Baalmann, K. 1994.** Gleichung für die Sollviskosität nach DIN ISO 281. *Tribologie und Schmierungstechnik.* 1994.

**Barnsby, Roger. 2003.** *Life ratings for modern rolling bearings.* NewYork : ASME International, 2003.

**Boresi, Arthur P. and Schmidt, Richard J. 2005.** *Advanced Mechanics of materials.* s.l. : John Wiley&Sons, 2005.

**de Mul, J. M., Kalker, J. J. and Fredrikson, B. 1986.** The ContactBetween Arbitrary Curved Bodies of Finite Dimensions. *Journal of Tribology.* 1986, Vol. 108.

**DIN 7190. 2001.** *Pressverbände - Berechnungsgrundlagen und Gestaltungsregeln.* 2001.

**DIN 732. 2010.** *Wälzlager - Thermisch zulässige Betriebsdrehzahl - Berechnung und Beiwerte.* s.l. : DIN, 2010.

**Fujiwara, Hiroki and Yamauchi, Kazuto. 2010.** Tolerance Design of Logarithmic Roller Profiles in Cylindrical Roller Bearings. *Journal of Advanced Mechanical Design, Systems, and Manufacturing.* 4, 2010, Vol. 4.

**Harnoy, Avraham. 2003.** *Bearing Design in Machinery.* New York, Basel : Marcel Dekker, 2003.

**Harris, T., Rumbarger, J. H. and Butterfield, C. P. 2009.** *Wind Turbine Dsign Guideline DG03: Yaw and Pitch Rolling Bearing Life.* Golden, Colorado : National Renewable Energy Laboratory, 2009.

**Harris, Tedric A. and Kotzalas, Michael N. 2007.** *Rolling Bearing Analysis: Advanced Concepts of Bearing Technology.* s.l. : CRC Press, 2007.

**Harris, Tedric A. and Kotzalas, Michael N. 2007.** *Rolling Bearing Analysis: Essential Concepts of Bearing Technology.* CRC Press : s.n., 2007.

**Heemskerk, R. 1980.** EHD lubrication in rolling bearings, review of theory and influence on fatigue life. *TRIBOLOGIA E LUBRICATIONE.* 1980.

**Houpert, L. 1999.** Bearing Life Calculation in Oscillatory Applications. *Tribology Transactions.* 1999, Bd. 42.

**ISO 15312. 2003.** *Rolling bearings - Thermal speed rating - Calculation and coefficients.* 2003.

**ISO 281. 2007.** *Rolling bearings - Dynamic load ratings and rating life.* 2007.

**ISO 286-1. 2010.** *ISO code sytem for tolerances of linear sizes - Basis of tolerances, deviations and fits.* 2010.

**ISO 3408-5. 2006.** *Static and dynamic axial load ratings and operational life.* s.l. : ISO, 2006.

**ISO 5753. 2009.** *Rolling bearings - Internal clearance - Part 1: Radial internal clearance for radial bearings .* 2009.

**ISO 76. 2006.** *Rolling bearings - Static load ratings.* s.l. : ISO, 2006.

**ISO/TR 1281-2. 2008.** *Rolling bearings - Explanatory notes on ISO 281 - Part 2: Modified rating life calculation, based on a systems approach to fatigue stresses.* s.l. : ISO, 2008.

**ISO/TS 16281. 2008.** *Rolling Bearings - Methods for calculating the modified reference rating life for universally loaded bearings.* s.l. : ISO, 2008.

**Nakajima, Katsuhiko. 1995.** Thermal Contact Resistance Between Balls and Rings of a Bearing Under Axial, Radial, and Combined Loads. *Journal of Thermophysics and Hear Transfer.* 9, 1995, Bd. 1.

**Niemann, G. und Winter, H. 2003.** *Maschinenelemente Band 2: Getriebe allgemein, Zahnradgetriebe - Grundlagen, Stirnradgetriebe.* Heidelberg : Springer, 2003.

**—. 2004.** *Maschinenelemente Band 3: Schraubrad-, Kegelrad-, Schnecken-, Ketten-, Riemen-, Reibradgetriebe, Kupplungen, Bremsen, Freiläufe.* Heidelberg : Springer, 2004.

**Niemann, G., Winter, H. und Höhn, B.-R. 2005.** *Maschinenelemente Band 1: Konstruktion und Berechnung von Verbindungen, Lagern, Wellen.* Heidelberg : Springer, 2005.

**Paland, E.-G. 1968.** Die Lastverteilung in einem auf der Ebene abgestützten Zylinderrollenlager. *Maschinenbautechnik (Schmierungstechnik).* 17, 1968, Bd. 8.

**Schlecht, Berthold. 2007.** *Maschinenelemente 1.* München : Pearson Studium, 2007.

**—. 2010.** *Maschinenelemente 2.* München : Pearson Studium, 2010.

**Teutsch, Roman and Sauer, Bernd. 2004.** An Alternative Slicing Technique to Consider Pressure Concentrations in Non-Hertzian Line Contacts. *Journal of Tribology.* 2004, Vol. 126.