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MESYS Rolling Bearing Calculation

Introduction

This rolling bearing calculation (Version 04/2017, File version 3.0) calculates the load distribution, the reference life and the modified reference life according ISO/TS 16281 (DIN 26281) for the following types of bearings:

- Deep groove radial ball bearings
- Double row deep groove ball bearings
- Axial deep groove ball bearings
- Radial angular contact bearings
- Axial angular contact bearings
- Double row radial angular contact bearings
- Double row axial angular contact bearings
- Single row spherical ball bearings
- Double row spherical ball bearings
- Four-point ball bearings considered as radial bearings
- Four-point ball bearings considered as axial bearings
- Duplex ball bearings
- Radial cylindrical roller bearings
- Double row radial cylindrical roller bearings
- Axial cylindrical roller bearings
- Barrel roller bearings
- Needle bearings
- Tapered roller bearings
- Double row tapered roller bearings
- Axial tapered roller bearings
- Radial spherical roller bearings
- Axial spherical roller bearings
- Cross roller bearings considered as radial bearings
- Cross roller bearings considered as axial bearings
- Angular roller bearings considered as radial bearings
- Angular roller bearings considered as axial bearings

Additional bearing types will be added in the future.

The inner geometry of the bearings can be approximated by the software or provided by the user. The operating clearance can be specified. The influence of interference fits, temperature and centrifugal load on the clearance can be taken into account. Centrifugal loads and gyroscopic moments on the rolling elements can be considered for ball bearings only.

In extension of ISO/TS 16281 the influence of reduced material hardness can be considered according NREL guideline DG03. This includes a check of the case core interface.

The lubricant film thickness can be calculated by the software. This is done according to Harris: Rolling bearing elements.

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. This can be used for spindles or multiple row cylindrical roller bearings.

The following results can be found in the report:

- Reference life according ISO/TS 16281
- Modified reference life according ISO/TS 16281
- Basis life and modified life according ISO 281 for comparison
- Load distribution between rolling elements
- Reaction forces/moments and displacements/rotations
- Contact pressure for each contact
- Required shoulder height for contact ellipsis in ball bearings
- Static safety factor
- Maximum subsurface shear stress and stress at case core interface
- Load dependent friction torque for ball bearings based on coulomb friction
- Change to clearance because of interference fit and temperature
- Wear parameters like PV and QV for ball bearings

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, Chinese and Korean.

Parameter variations can be made using ranges for several parameters. The results of parameter variations are given as tables or graphics. Proposals are provided for several inputs and conversions like axial clearance in radial clearance are possible.

Elastic deformations of the outer ring can be considered with an extension of the base software. The loading can be specified on several points in radial, axial or tangential direction and the life and load distribution are calculated with a deformed outer ring. The main use of this feature is for track rollers but also deformations in a planetary gear as outer ring can be considered. The elastic outer ring can be considered with following bearing types: Deep groove ball bearing, radial angular contact bearing, four-point ball bearing and radial cylindrical roller bearings. Multi row bearings can be considered using bearing configurations.

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 MesysRBC.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.

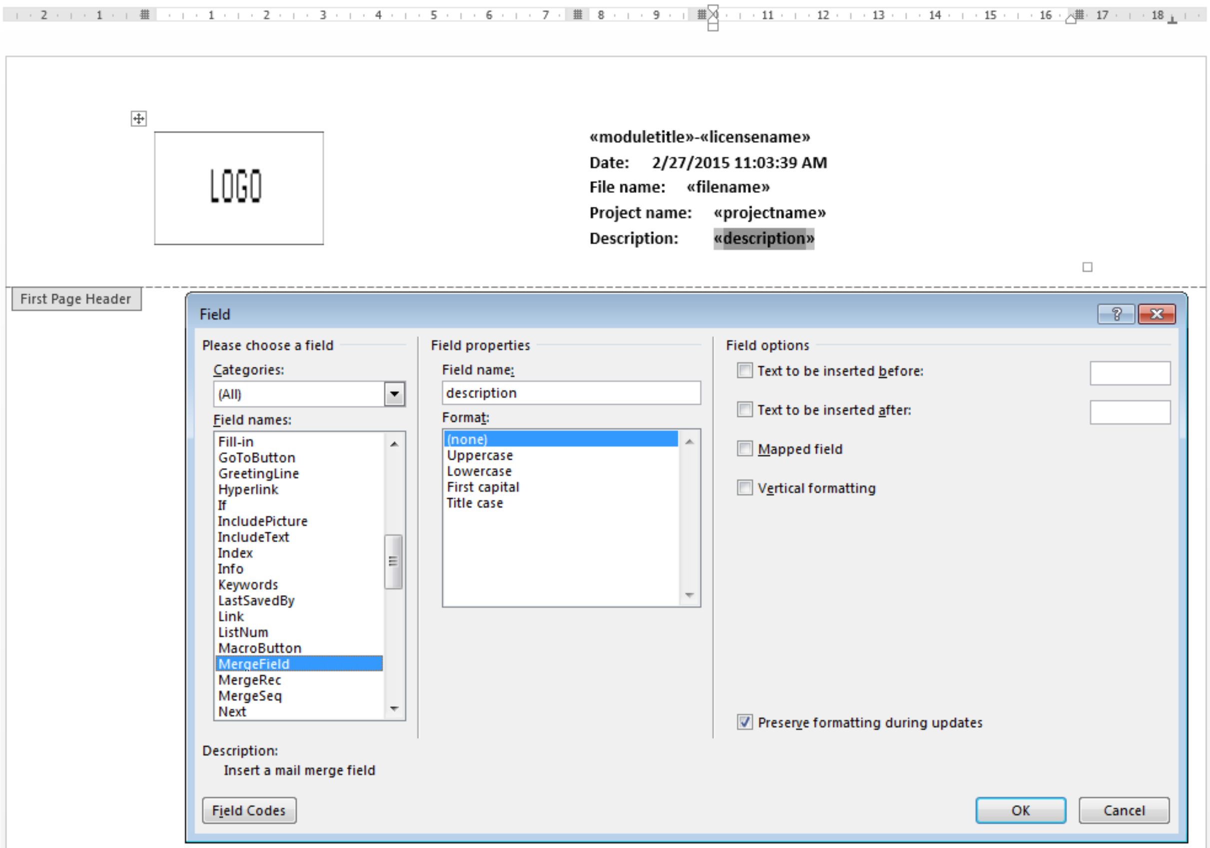
Section	Value	Description
General	recentfilenumber	Number of recent files shown in the file menu of the software
	floatinglicense	Path to the licensing file for floating license. It will be written by the software but might be copied to other installations. Format: \\\\Server\\Share\\path\\license.lic 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.
	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. 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.
Importdatabases	path_1	A path to additional databases can be defined. These additional databases are read only and optionally encrypted. If the filename is given without path, it is opened from the installation directory. For path separators either use '/' or '\\' but not '\'.

	password_1	The password for the encrypted database
rbc	defaultinputs	Path to a xml-file with default settings 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 output 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. 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. 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:



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 150MB 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

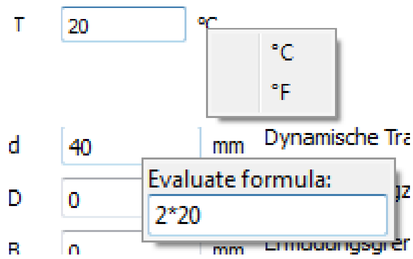
To run a calculation, first the data on all pages is introduced. Then press the button  or F5 to run the calculation. After all data is defined the calculation can be run from each tab page. So it is easy to make parameter variations.

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

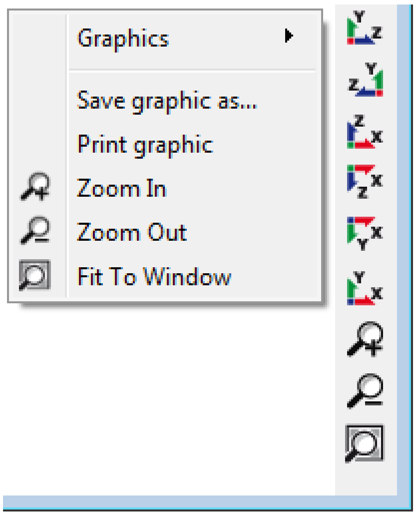
The unit system for the input and output can be selected on the menu ‘Extras->Unit system’ either as metric or US units.



Using the context menu for the units of input fields, the current unit can be changed. These settings are saved for the current user.

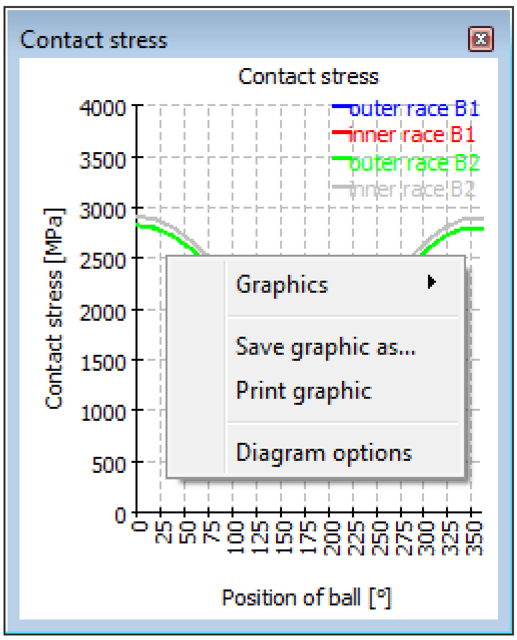
Pressing the right mouse button on an input field a window for an input of a formula is shown. This can be used for quick calculations.

The software is available in English, German, French, Spanish, Korean and Chinese language. The language can be selected in menu ‘Extras’.



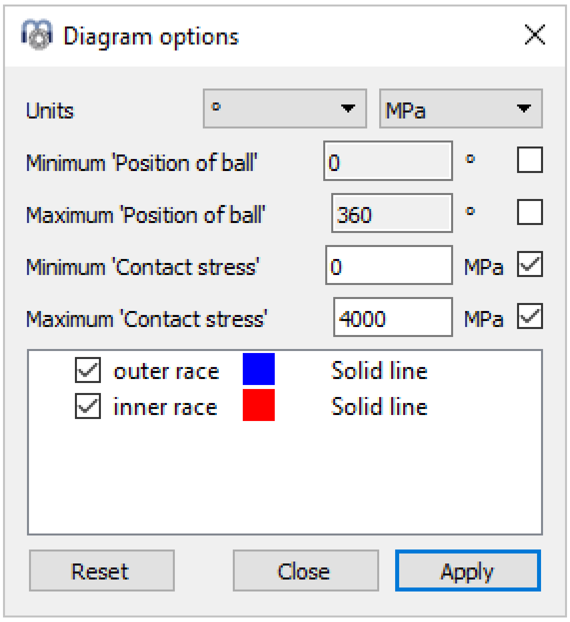
All graphics can be printed or exported as PNG file using the context menu (right mouse button) in the graphic window. For the export the size of the graphic can be specified.

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.



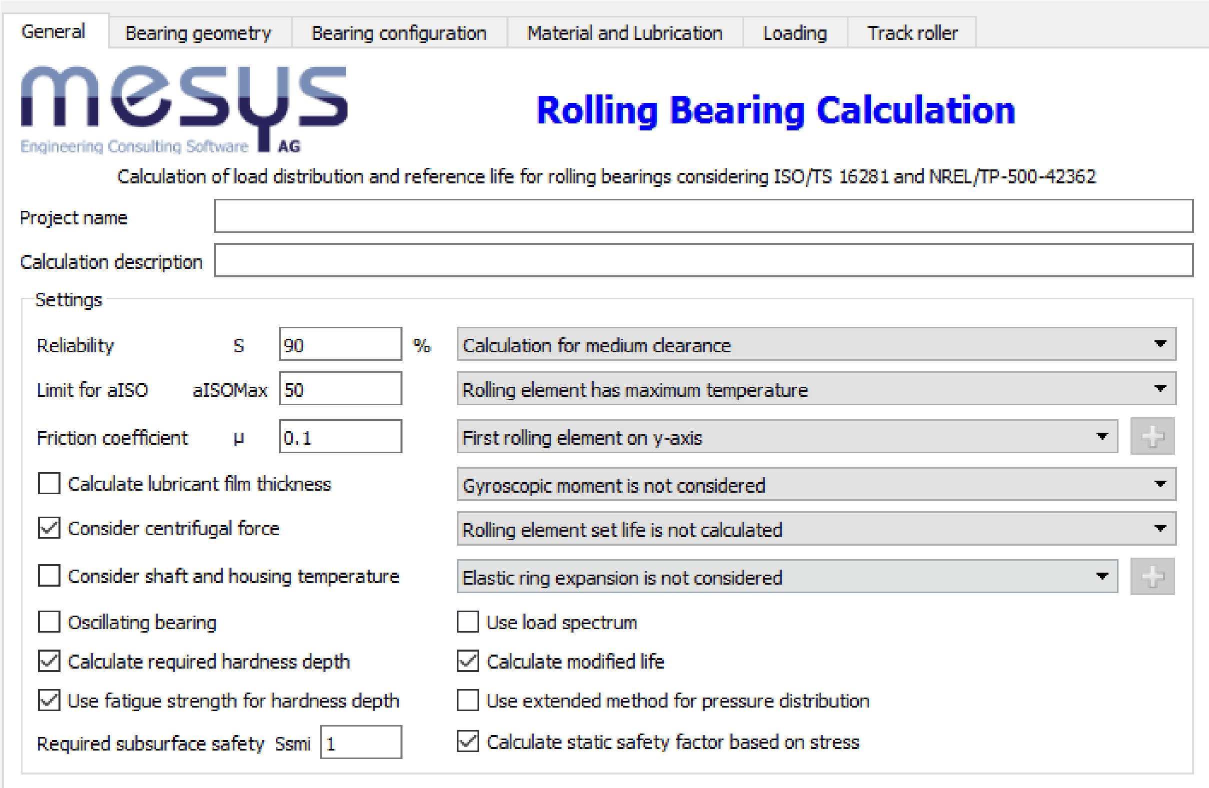
Units and precision of numbers in tables can be changed by right click on the header of a column.

Input Parameters

The input parameters are shown on five tab pages.

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.

Reliability

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 a_1 is calculated according to this input using the three parameter Weibull relationship as given as formula in (ISO/TR 1281-2, 2008). The table in ISO 281 (2007) is also calculated according to this formula and has changed to previous versions of the standard.

Limit for a_{ISO}

The life modification factor for systems approach a_{ISO} takes into account lubrication properties and fatigue limit of the bearing and it is multiplied to the L10r life to get the modified reference life. According to ISO 281 this factor is limited to a maximum value of 50. In some cases, for example in wind turbines a smaller maximum limit of 3.8 is required.

The maximum limit for the a_{ISO} factor can be specified here. The input is only an upper limit for the a_{ISO} factor which is calculated according to (ISO 281, 2007).

Friction coefficient

The friction coefficient is used to calculate the friction moment of the bearing assuming coulomb friction in the contacts. In the actual version, this is only available for ball bearings. The friction moment is only considering the load dependent part of the friction; the no load part is not considered.

A proposal by (Harris, et al., 2007) is a value of 0.1 for the friction coefficient.

Calculate lubricant film thickness

The calculation of modified reference life requires a viscosity ratio κ. This ratio is calculated by the lubricant viscosity and a reference viscosity ν_1 or it can be calculated from the lubricant film parameter Λ as $\kappa = \Lambda^{1.3}$ according (ISO 281, 2007) and (ISO/TR 1281-2, 2008).

Since the viscosity ratio is calculated using standard settings for surface roughness, loading, pressure viscosity coefficient of the oil and geometric properties, the usage of lubricant film thickness takes into account more parameters of the actual bearing. For the definition of the reference viscosity ν_1 see the derivation in (Baalmann, 1994) or (Heemskerk, 1980).

If this setting is activated the lubricant film thickness is calculated according (Harris, et al., 2007). For ball bearings the minimal film thickness is calculated using equation 4.60 (Harris, et al., 2007) by Hamrock and Dowson. For roller bearings equation 4.57 (Harris, et al., 2007) according Dowson and Higginson is used. The same formulas are used for the calculation of Λ in (ISO/TR 1281-2, 2008). The software uses the minimal film thickness for the calculation of Λ, in contrast to (Heemskerk, 1980) who is using the central film thickness.

In addition, a thermal correction is applied from version 08-2016 on. The thermal correction factor is calculated according to (Koch, 1996) using the formula 4.62 from Wilson and Murch. Different literature provides different correction factors, see (Baly, 2005) or (Gohar, 2001). As temperature the input for the lubricant temperature is used. For high speed the thermal correction factor reduces the film thickness.

This calculation requires the input of surface roughness, oil density and oil pressure viscosity coefficient. The minimal film thickness for all contacts is then used for ball bearings. For roller bearings the minimal film thickness for each section is calculated and used for the calculation of life modification factor for systems approach a_{ISO} for this section.

Consider centrifugal force

The centrifugal force can be considered for ball bearings and radial cylindrical roller bearings in this version of the software. It will also be added for other roller bearings in the future.

Centrifugal forces will increase the pressure at the outer race, but decrease the pressure at the inner race. It will lead to different contact angles on inner and outer race and an increased spin to roll ratio.

Consider shaft and housing temperature

If this option is activated the shaft and housing temperatures are available as inputs in addition to inner and outer ring temperatures.

Oscillating bearing

Some bearings are not fully rotating but they are just oscillating. In this case, the effective number of load cycles is smaller than for a rotating bearing which can be considered by the software. The calculation is done according (Harris, et al., 2009) which is based on (Harris, et al., 2007).

An oscillating angle and an oscillating speed (oscillations per minute) have to be provided in this case. The oscillation angle is defined as the angle between the two and points of oscillation, so it is twice the amplitude.

The rotation speeds n_i and n_e are used for the calculation of centrifugal forces and lubrication film thickness, oscillation speed f_{osc} is used for the calculation of life in h. For the speed used to calculate the lubrication factor (Houpert, 1999) proposes $n = \Theta_{osc}/180°*f_{osc}$. The speed has to be entered by the user.

In case of $\Theta_{osc} < \Theta_{crit}/2$ fretting corrosion can occur; the bearing should be rotated by a larger angle from time to time to redistribute the lubricant. A warning is shown in this case.

Calculate required hardness depth

The hardness depth is an input for material parameters. If it should be calculated by the software or if it is of no interest for through hardened bearings for example, then set this flag.

If the flag is not set a check is made if the hardness depth is large enough.

Use fatigue strength for hardness depth

If this flag is set the hardness depth is calculated using the fatigue strength of the core. If it is not set the yield point is used.

If the calculation is done using a maximal load the yield point can be used. If it is done using the equivalent load the fatigue strength is recommended.

Required subsurface safety

A required safety factor for the subsurface stresses against the yield point can be defined. It will be used for the calculation of the required hardness depth.

Selection for clearance

You can select which clearance is taken into account for the calculation. For interference fit and clearance a range of tolerances is given. The calculation can either use the minimum, medium or maximum value of the clearance. For other needs the operating clearance can be specified directly as a number.

Rolling element temperature

As default the temperature of the rolling element for calculation of operating clearance is set to the maximum temperature of inner and outer ring. This default setting can be changed to either the inner or outer ring temperature or a user input can be selected, which will be shown on page "Loading" together with the inner and outer ring temperatures.

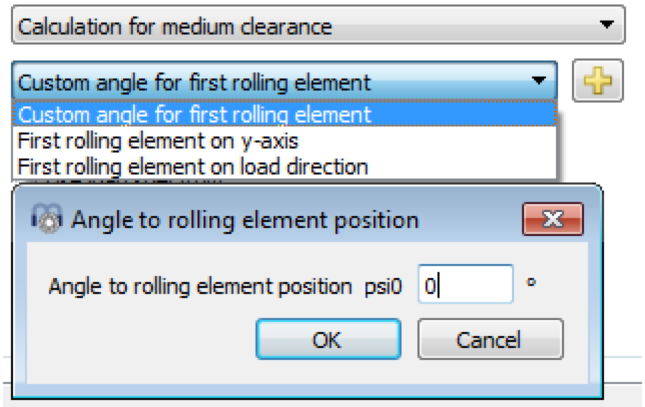
If the heat is generated by the bearing the maximum temperature is a reasonable selection. If the heat is generated by other heat sources, the mean temperature could be a better choice.

Position of first rolling element

As the circumferential position of the rolling elements within the bearing may affect to the results, an option to define the position of the first rolling element by means of the angle is available. If a custom angle is desired, it can be entered by using the -button.

The selection "First rolling element on load direction" uses the radial displacement for definition of the angle. For pure moment load the angle is set to zero.

The option is not yet available for track roller calculation with elastic outer ring.



Options for gyroscopic moment

In case of different directions of forces on inner and outer ring contact, the gyroscopic moment on the ball will affect the load distribution. For high speed ball bearings often "outer race control" is assumed, which means that spinning speed at outer race contact is zero. The available options are:

- "Gyroscopic moment is not considered": This is the same behavior than older versions of the software. No gyroscopic moment is considered and spinning speeds are calculation by Coulomb friction.
- "Gyroscopic moment based on outer race control": The ball rotation vector is calculated assuming no spinning at outer race contact. The gyroscopic moment is only causing a friction force at outer race contact.
- "Gyroscopic moment based on outer race control, distributed force": The ball rotation vector is calculated assuming no spinning at outer race contact. The gyroscopic moment is causing a friction force at inner and outer race contact. The friction forces at each contact are proportional to normal force.
- "Gyroscopic moment based on inner race control": The ball rotation vector is calculated assuming no spinning at inner race contact. The gyroscopic moment is only causing a friction force at inner race contact.
- "Gyroscopic moment based on inner race control, distributed force": The ball rotation vector is calculated assuming no spinning at inner race contact. The gyroscopic moment is causing a friction force at inner and outer race contact. The friction forces at each contact are proportional to normal force.
- "Gyroscopic moment based on friction": On each iteration for ball equilibrium the frictional forces based on Coulomb friction are calculated in the contact ellipses. The ball rotation vector is based on this calculation. The resulting gyroscopic moments is distributed on both contacts proportionally to the normal loads. This options leads to much longer calculation time and it can lead to convergence problems if not all balls are loaded.

For high speed ball bearing usually "outer race control" is assumed, this limits the selection to two options only. For low speed the gyroscopic has usually only very little influence and can be ignored.

The gyroscopic moment cannot yet be taken into account for four-point bearings.

Life for rolling elements

The bearing life calculation usually only takes into account fatigue life of the bearing races.

Life for rolling elements can optionally be calculated. The rolling element life is calculated analogous to (ISO/TS 16281, 2008) like described by (Correns, 2015). For the combination of life for single rolling elements to the life of the rolling element set, two options for the Weibull exponent can be considered, either e=10/9 for ball bearings and e=9/8 for roller bearings as in (ISO/TS 16281, 2008) and (ISO/TR 1281-1, 2008), or e=1.5 as in (ISO/TR 1281-2, 2008) section 4.2.1 for the reliability factor a_1. This is different to (Correns, 2015) where an exponent of e=10/3 for ball bearings and e=9/2 for roller bearings is used without giving a reason for these exponents.

If this option is activated, the usual bearing life is not changed just the life of the rolling element set L10r_RESet is calculated in addition.

Elastic ring expansion

As default only the elasticity of the contact between rolling element and race is considered. If for example an angular contact bearing with clearance between outer ring and housing is under axial pretension, the outer ring can expand radially. This will reduce the pretension.

In the current version two options for consideration of elastic expansion of bearing rings are available. Both options are based on the assumption of a thick-walled ring as in the calculation of interference fits.

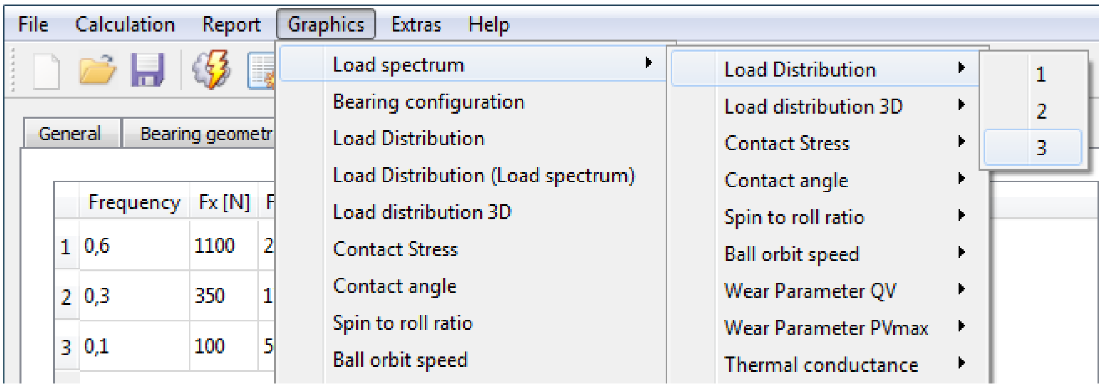
Either the minimal or the mean radial force in the load distribution is converted into a constant radial pressure which is then taken into account as in a calculation for interference fits. When the gap between ring and shaft/housing is closed there will be no further effect. This calculation approach is only valid if the variation of radial forces is small. So the axial load should normally be larger than the radial load.

The ring diameter is taken as Dpw±Dw, so a stiffening effect of shoulders is not taken into account. An additional factor for the ring stiffness can be defined using the -button behind the selection box.

The remaining gap widths is shown in the report.

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. 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 (load case) 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 modified life

If this flag is set the modified reference life L_{nmrh} will be calculated. You can clear the flag if no information about lubrication is known or lubrication should not be considered in the calculation.

Use extended method for pressure distribution

In (ISO/TS 16281, 2008) a simplified approach to calculate edge stresses in roller bearings is used and extended method according other literature are recommended. If this option is set the pressure distribution is calculated according to (de Mul, et al., 1986), which is the newest literature in the proposals of the standard.

This extended method is available for radial and axial cylindrical roller bearings, taper roller bearings and spherical roller bearings.

Calculate static safety factor based on stress

If this options is set the static safety is calculated based on maximal contact stress. For ball bearings $SF = \left(\frac{p_{perm}}{p_{max}}\right)^3$ is used, for roller bearings $SF = \left(\frac{p_{perm}}{p_{max}}\right)^2$ is used, so that the safety factor is proportional to the load. The permissible stress is based on (ISO 76, 2006).

If the option is not set, the static safety factor is calculated based on maximum rolling element load and Q_{max} in (ISO/TR 10657, 1991).

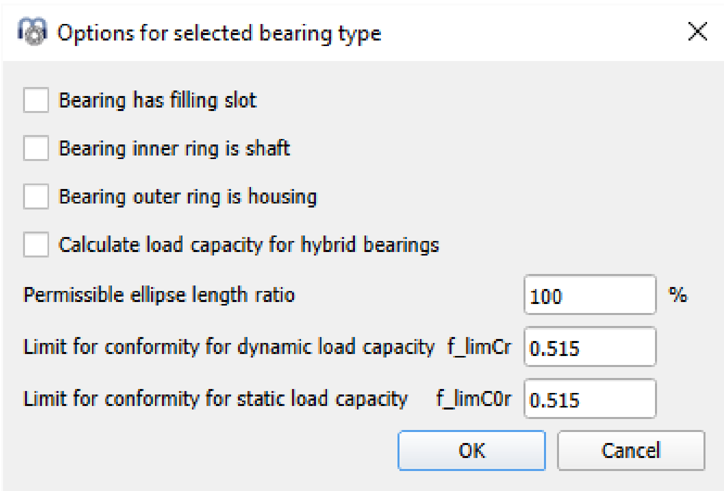
For ball bearings both options usually show the same results, but for roller bearings edge stresses are only considered if the static safety factor is based on stresses.

Bearing geometry

Bearing types

Different types of ball and roller bearings can be calculated using the software. In addition to the calculation of a single bearing, a configuration of several rows can be defined using “Bearing configuration”.

By using the -button behind the bearing type, some options for the selected bearing type can be defined. For all bearings, it can be selected that inner ring and shaft or outer ring and housing are identical. This affects the material input and the input of tolerances.



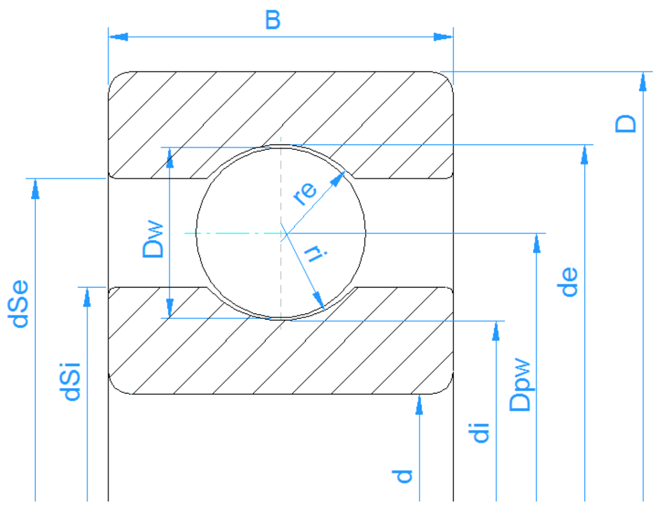
The option “Calculate load capacity for hybrid bearings” will use (ISO/DIS 20056-1, 2016) and (ISO/DIS 20056-2, 2017) for the calculation of load capacities, which leads to increased static load capacity.

For ball bearings a limit for the conformity used in calculation of load capacity can be defined. The load capacity is calculated by the maximum value of the given limit and the actual geometry input.

In the current version the following bearing types are supported:

Deep groove radial ball bearing

Deep groove radial ball bearings are cheap standard bearings. Both radial and axial loads can be transmitted. The nominal contact angle is 0°, which will increase under axial load depending on the radial clearance in the bearing. The free contact angle $\alpha 0$ is shown in report and result overview.



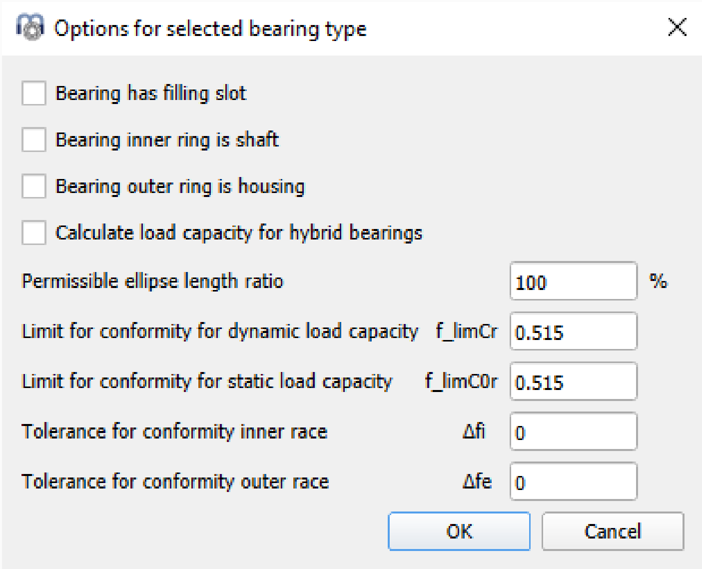
The geometry is described with number and diameter of balls, pitch diameter, conformity of inner and outer race and the diametral clearance. The number of balls in the bearing is restricted, to be able to assemble the bearing.

The conformity is the input parameter defining the radius of the races. ($ri = fi \cdot Dw, re = fe \cdot Dw$)

Usually the conformity is $fi = fe = 0.52$ for deep groove radial ball bearings.

The diametral clearance is defined as $Pd = de - di - 2Dw$.

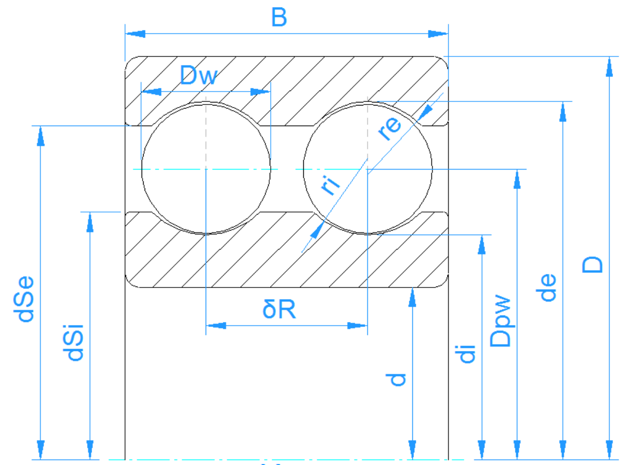
The -button behind the bearing selection, also offers some other settings depending on the bearing type. For deep groove radial ball bearings, it can be selected if a “filling slot” bearings is used, which influences the calculation of the load capacity with factor bm in (ISO 281, 2007).



The permissible ellipsis length ratio controls the warning about cut off of contact ellipsis. A value below 100% would allow some amount of cut off, a value larger 100% adds an additional distance. This permissible value is used for the calculation of permissible axial load limit given in the report too.

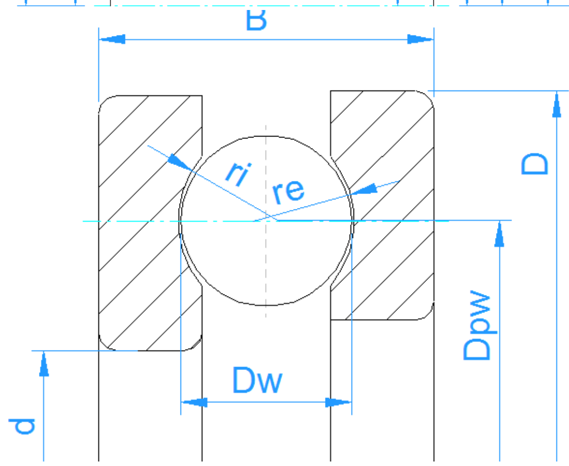
Double row deep groove ball bearing

For double row deep groove ball bearings, a distance between rows ‘δR' has to be defined in addition to the parameters of the single row deep groove ball bearing.

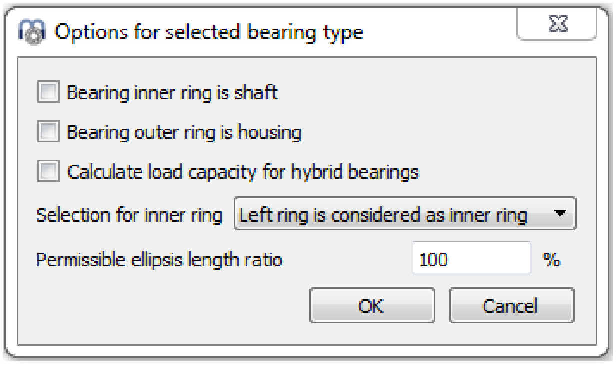


Axial deep groove ball bearings

For axial deep groove ball bearings, the nominal contact angle is 90°. The default conformity is fi = fe = 0.535.



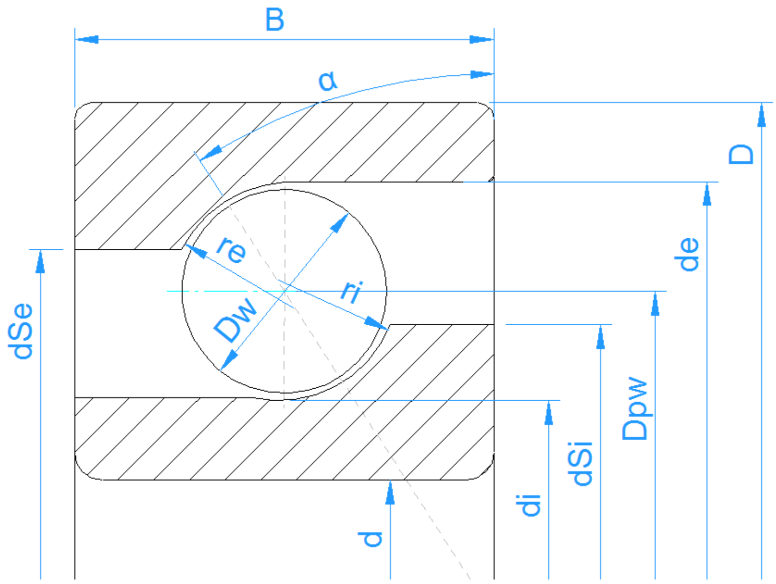
In the bearing type options dialog, it can be defined if the left or the right ring shall be considered as inner ring. This also changes the sign of the axial force, which is given for the inner ring.



No tolerances are considered for axial deep groove ball bearings.

Radial angular contact bearing

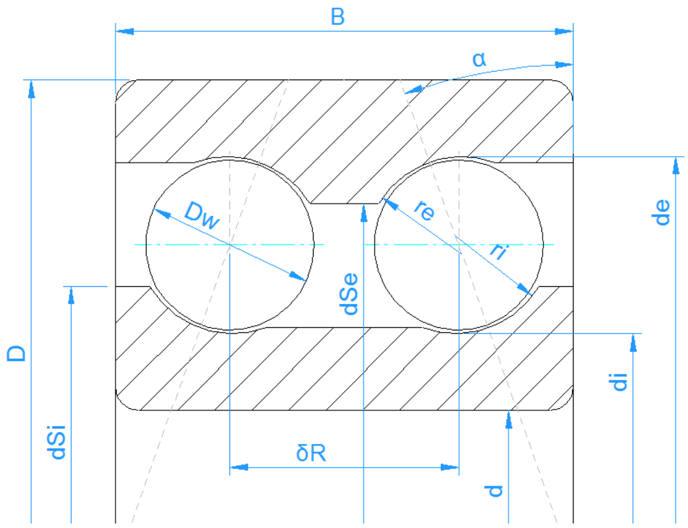
The angular contact bearing is similar to the deep groove ball bearing, but the contact angle is larger. Standard bearings have contact angle of 15°, 25° or 40°.



Double row angular contact bearings can be either defined using a single row bearing and a configuration of two bearings or a double row angular contact bearings can be defined directly. This allows the input of radial clearance of the two row bearing. In both cases life modification factor a_{ISO} is calculated for both rows separately.

The direction of contact angle can be defined using the -button behind the contact angle. Additionally, the input of direction of contact is available in the bearing type options.

The -button for axial clearance allows to calculate the axial clearance for given pretension or for given radial clearance in case of double row angular contact bearing.

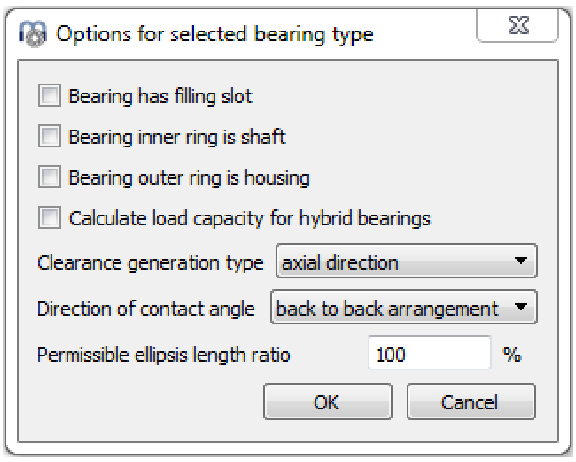


Double row radial angular contact bearing

For double row angular contact bearings the configuration of contact angles can be defined in the options dialog.

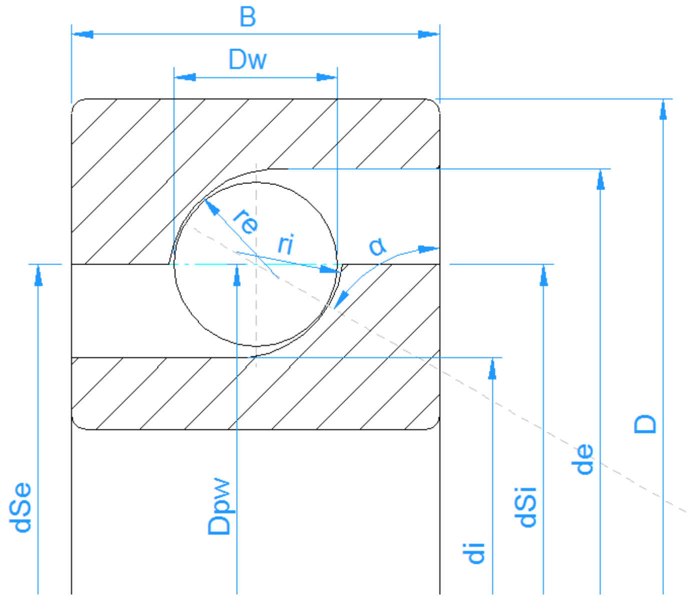
The clearance can be generated in three different ways. See at four point bearing below.

In addition to the inputs for the single row angular contact bearing the distance between rows has to be entered.



Axial angular contact bearing

The description of geometry for axial angular contact bearings is the same as for radial angular contact bearings. The only difference in geometry is a value of 0.535 for the conformity, instead of the 0.52 used for radial bearings.

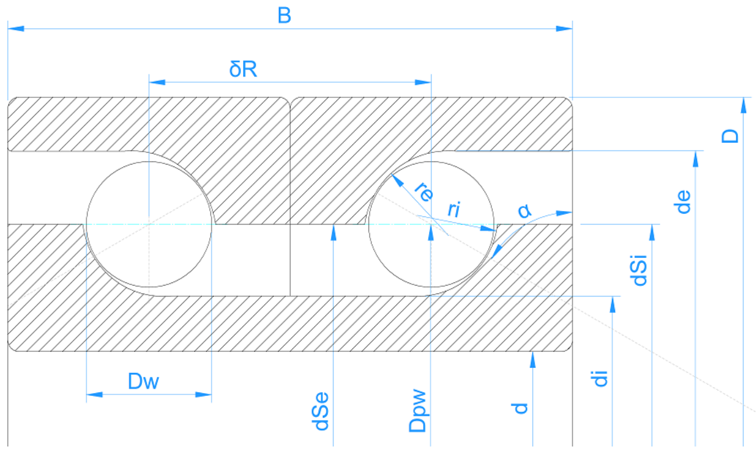


The results for load distribution are the same for the selection of axial or radial angular contact bearings, but for axial bearings additional reduction factors are considered in the calculation of load capacity. Therefore, the resulting life is smaller if the bearing is calculated as axial bearing.

Standard axial angular contact bearings have a contact angle of 60°.

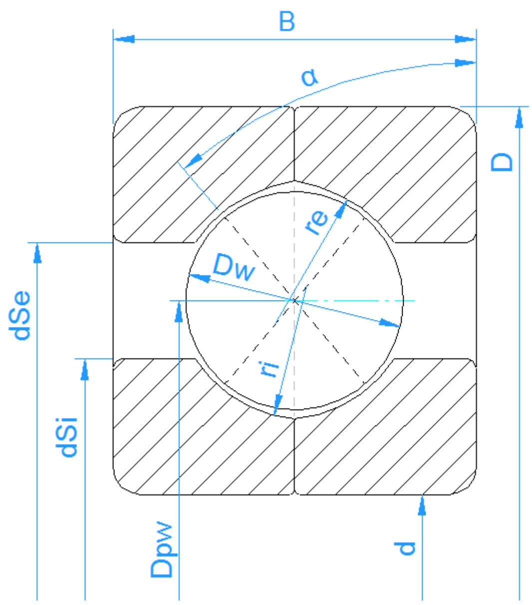
Double row axial angular contact bearing

Just as for the radial case, double row axial angular contact bearings can be either defined using a single row bearing and a configuration of two bearings or a double row angular contact bearings can be defined directly.



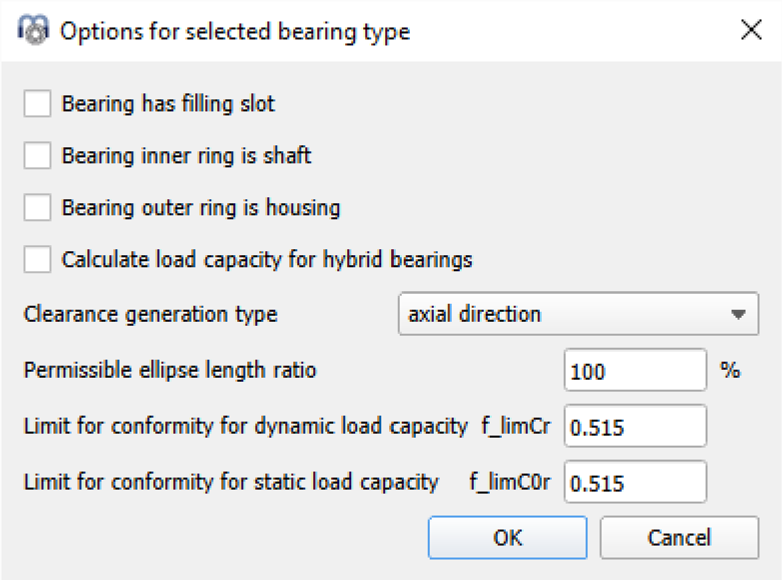
Four-point bearing considered as radial bearing

This can be used for standard QJ bearings with 35° contact angle. Load capacity for a four-point bearing is calculated as a double row bearing, as usually done in bearing catalogues. The results are reported for both rows. In case of two contact points, there is one contact on the inner ring of one row and on the outer ring of the other row. All possible four contacts are considered in life calculation.



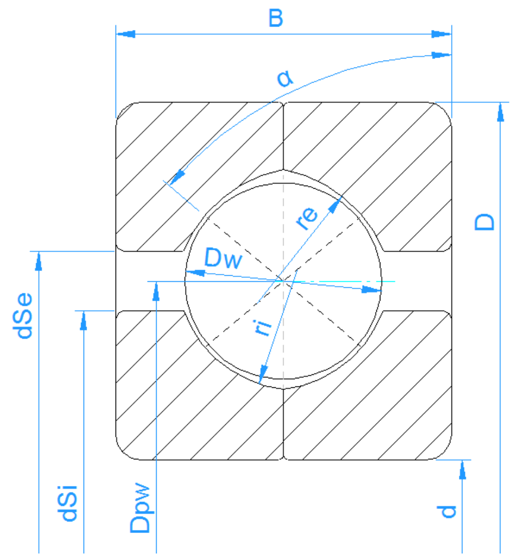
Using the ✚-button behind the bearing type a “filling slot” can be defined and the method clearance is generated for the bearing. There are three ways to generate clearance in the software:

1. Centers of curvature are moved in axial direction. This leads to a decreased contact angle for radial load. It corresponds to a four point considered as angular contact bearing.
2. Centers of curvature are moved in radial direction. This leads to an increased contact angle for axial load.
3. Centers of curvature are moved along the nominal contact angle.



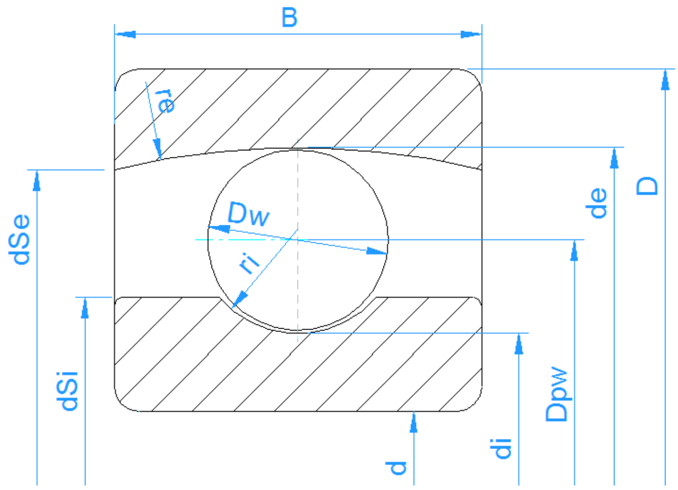
Four point bearings considered as axial bearing

This selection can be used for slewing rings as done in (Harris, et al., 2009). Because of additional reduction factors for axial ball bearings the calculated life will be smaller than considered as a radial bearing. The load distribution is the same as for the four-point bearing considered as radial bearing.



Self-aligning ball bearing

Spherical ball bearings can be selected as single or double row bearings. A single row bearing has a contact angle of zero.



Self-aligning ball bearing (double row)

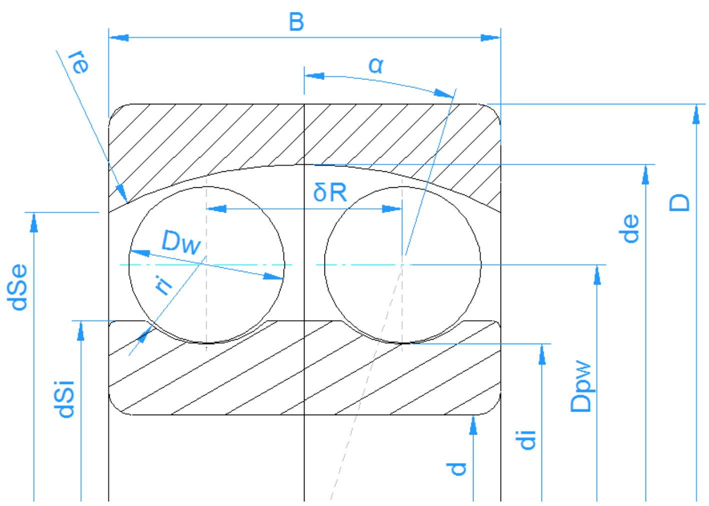
For double row bearings the distance of rows is defined by the contact angle. The distance between rows is then

$$\delta_R = D_{pw} \cdot \tan\alpha$$

For spherical ball bearings the conformity of outer race is defined as

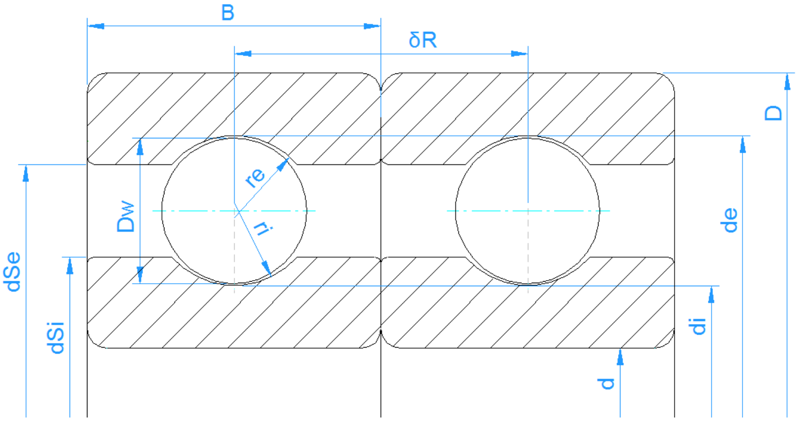
$$f_e = \frac{r_e}{D_{pw}/\cos\alpha + D_w}$$

So it is the ratio of radius and outer race diameter, which is 0.5 as standard.



The shoulder diameter of the outer ring is automatically limited by the width and the radius of the outer race. Still a larger value as the limit could be entered by the user. The life modification factor a_{ISO} is calculated for both rows separately.

Duplex bearings



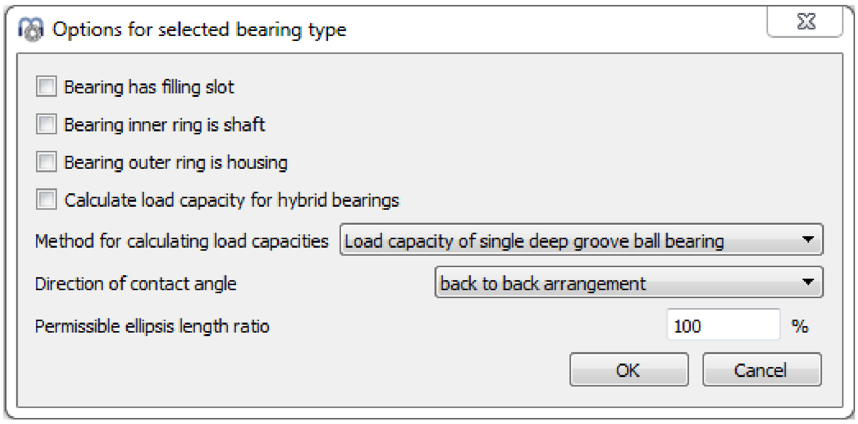
Two deep groove ball bearings can be calculated as a set by selecting “Duplex bearings”. The same could be done by using a single deep groove ball bearing and a configuration of two bearings but the input is more flexible using “Duplex bearings”.

The geometry data is defined for a single deep groove ball bearing, additionally the distance between the two rows is an input value. The input of the diametral clearance is for the single bearing only.

The clearance of the configuration can then be changed by an axial offset δ_{CC} between inner and outer ring of each bearing. Using the -button it can be calculated from a given axial clearance, radial clearance or pretension force for the bearing configuration.

The free contact angle of the bearing α_0 and α_{0eff} are shown in the report and in the results overview.

Options for the bearing allow selecting of face-to-face or back-to-back configuration. This has an influence of the load distribution on moment loads or a tilted bearing.



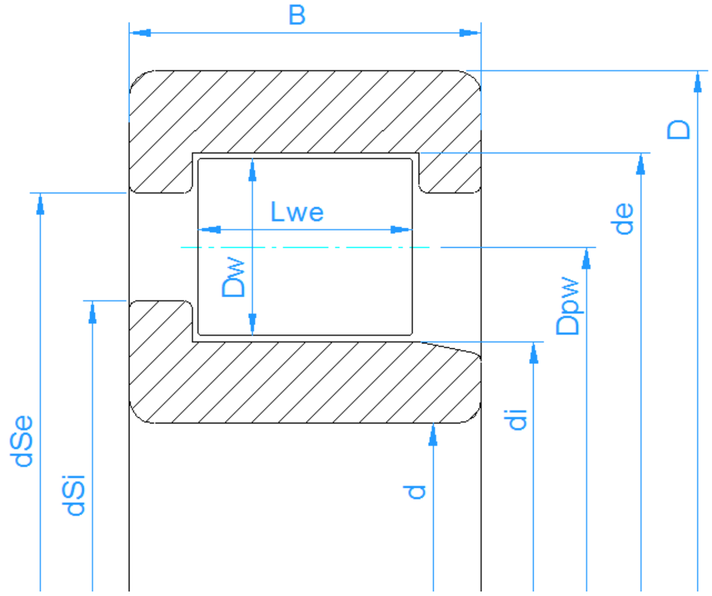
For the calculation of load capacities there are four options:

1. *Load capacity of single deep groove ball bearing*: The input values are for a single bearing only. These are the values which are given in the documentation of the single bearing. In this case the load capacities of the pair are shown as C_{sys} in the report.
2. *Load capacity of paired deep groove ball bearings*: Here the calculation is done using load capacities for two paired deep groove ball bearings using factors of $2^{0.7}$ for dynamic and 2 for static load capacity.
3. *Load capacity of double row deep groove ball bearing*: Here the load capacities are calculated using the factors for a double row bearing. The dynamic load capacity is smaller than for the second case.
4. *Load capacity of double row angular contact ball bearing*: Here the load capacity is calculated using the free contact angle of the bearings.

If thermal effects are considered, the axial offset δ_{CC} will be modified during the calculation to take the different axial elongation of inner and outer ring into account. The results are the same as if using a single radial deep groove ball bearing with a configuration of two bearings.

Radial cylindrical roller bearings

The radial cylindrical roller bearing is a bearing providing a high load capacity for radial loads but it does not support high axial loads or misalignment of inner and outer ring.

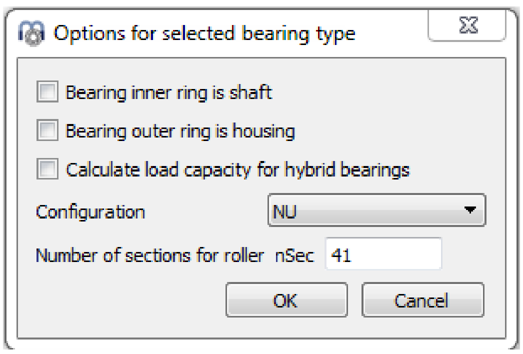


In addition to the parameters used for ball bearings the effective length of the roller L_{we} is a required input parameter. The effective length is a little smaller than the length of the roller because of radii at the end of the roller. The contact angle is always zero for cylindrical roller bearings.

The roller profile is considered as defined by ISO/TS 16281 as default. If the extended calculation for pressure distribution is selected an input of profile for races and roller is possible using the ✚-button behind the roller effective length. Several options are available including reading the profile from a file.

The axial load is considered as shown by (Harris, et al., 2007). The axial load brings a tilting moment to the roller and an unsymmetrical load distribution on the races occurs. The axial forces are considered at the half height of the shoulders. If 20% is entered for the height of the shoulder the axial force is acting at 10% of roller diameter.

The type of cylindrical roller bearing NU, NJ, NUP … can be selected in the options dialog of the bearing.



For cylindrical roller bearings which support axial loads a radial and axial clearance can be specified. It is important to enter a value for axial clearance if tilting occurs. For NUP type the axial clearance has influence on the reaction moment.

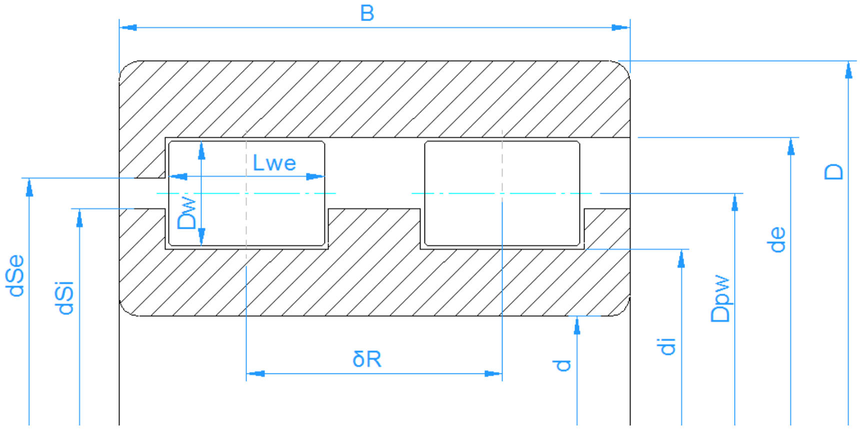
For NUP type the axial clearance is measured between left and right positions of the rings like for deep groove ball bearings. For directional bearings like NJ the axial clearance is between reference position and one side like for angular contact ball bearings or taper roller bearings.

For types which do not support axial loads like 'NU' the axial displacement 'ux' has to be selected as input instead of 'Fx'.

The number of sections for the calculation of load distribution can be changed in bearing options too. The minimum is 31 sections. A larger value reduces the edge stresses by the approximation function in ISO/TS 16281, if the extended method for pressure distribution is not active.

Radial cylindrical roller bearings (double row)

In addition to the inputs for a single row bearing, the distance between the row centers has to be defined. Generally, the same results are obtained as if using a single row bearing with a bearing configuration of two rows; however, the results will differ if the configuration shows different positions of shoulders under axial load. An additional difference is the load capacity, which is shown for the double row bearing.

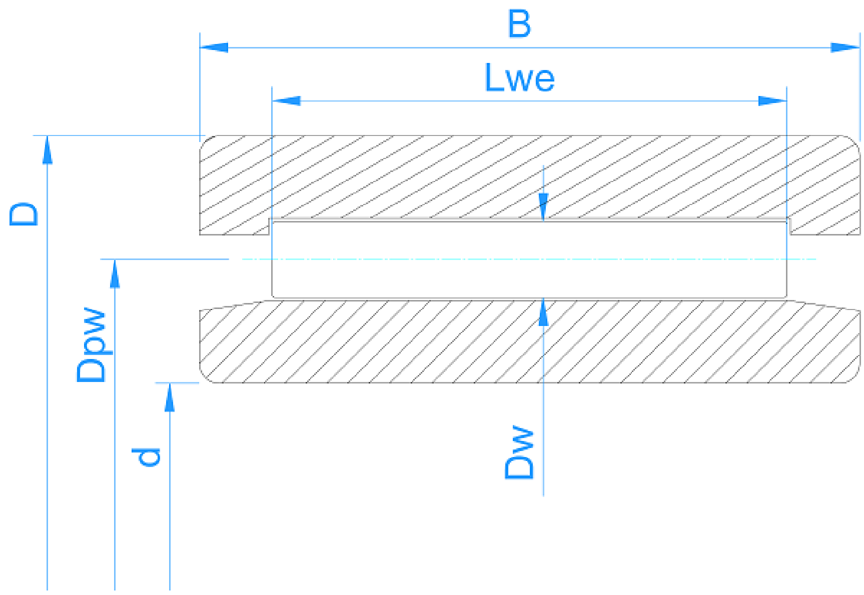


The different bearing types can be selected in the options dialog as well.

Needle bearings

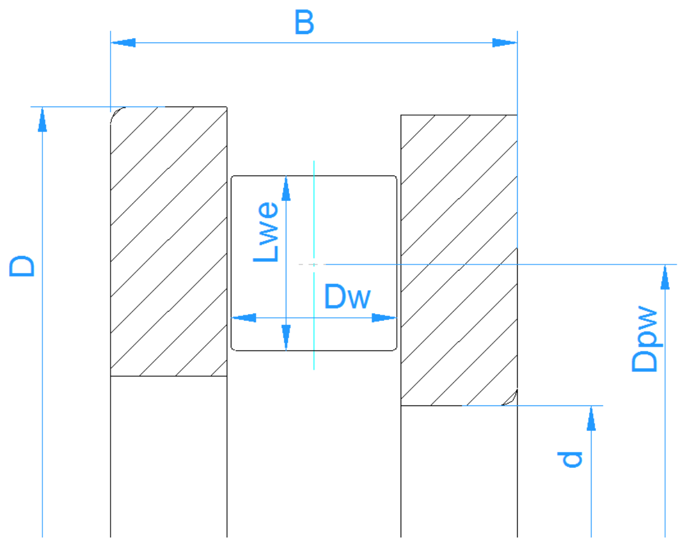
Needle bearings can be calculated using the selection 'Cylindrical roller bearing' too. The type 'needle bearing' was only added so the types can be separated in the database.

Needle bearings do not support axial forces. Therefore 'ux' has to be selected as input instead of 'Fx'. The axial clearance is not available as an input.



Axial cylindrical roller bearings

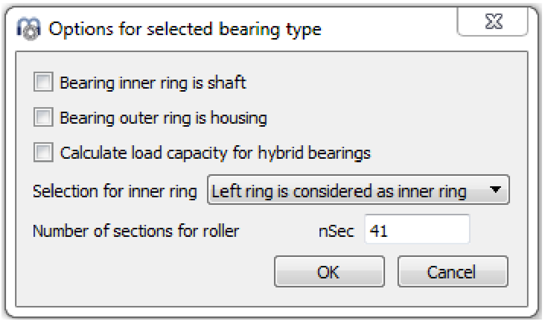
Axial cylindrical roller bearings have a contact angle of 90°. They only allow axial forces and bending moments. No radial forces can be used. Therefore, uy, uz have to be entered instead of Fy, Fz.



The options dialog (-button behind bearing type) allows to specify if the left or the right ring shall be considered the "inner ring" on which loading applies. The default setting "Left ring is considered as inner ring" results in a positive axial load to be entered.

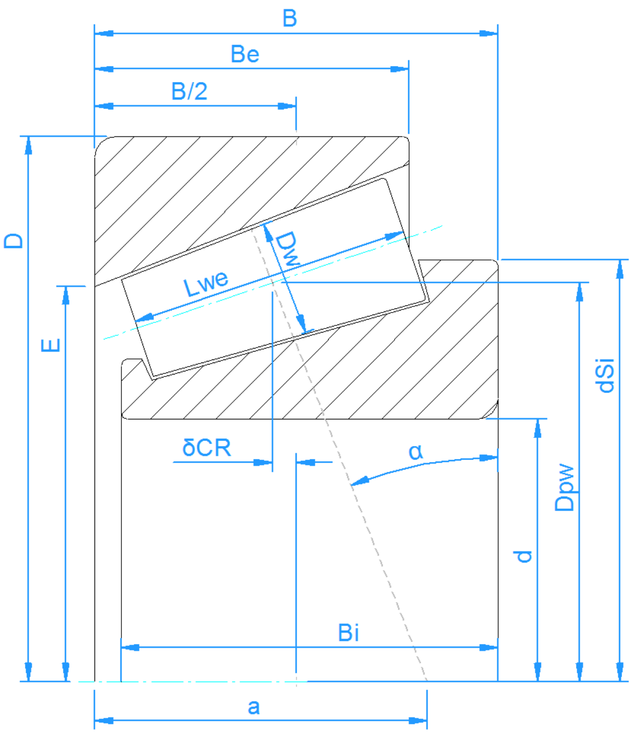
An axial clearance can be entered; its only influence is an offset to the axial displacement.

No tolerances are considered for axial cylindrical roller bearings.



Radial tapered roller bearings

Tapered roller bearings use a conical roller instead of a cylindrical roller. The input roller diameter is given for the middle of the roller and also the pitch diameter D_{pw} is defined for the middle of the rollers. The clearance is defined as axial clearance.



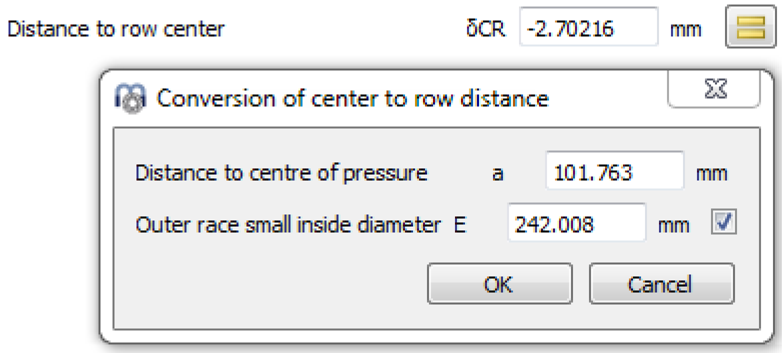
The contact angle should be the direction of the load. Therefore, the angle of the outer ring, the cup, has to be specified for the contact angle. The angles for the roller and the cone are then calculated so that all cones intersect on no load condition.

If the axial force is too small a calculation error can occur since the bearing will fall apart. You have to enter an axial force large enough or to specify an axial displacement instead.

The direction of contact angle can be defined using the -button behind contact angle or bearing type.

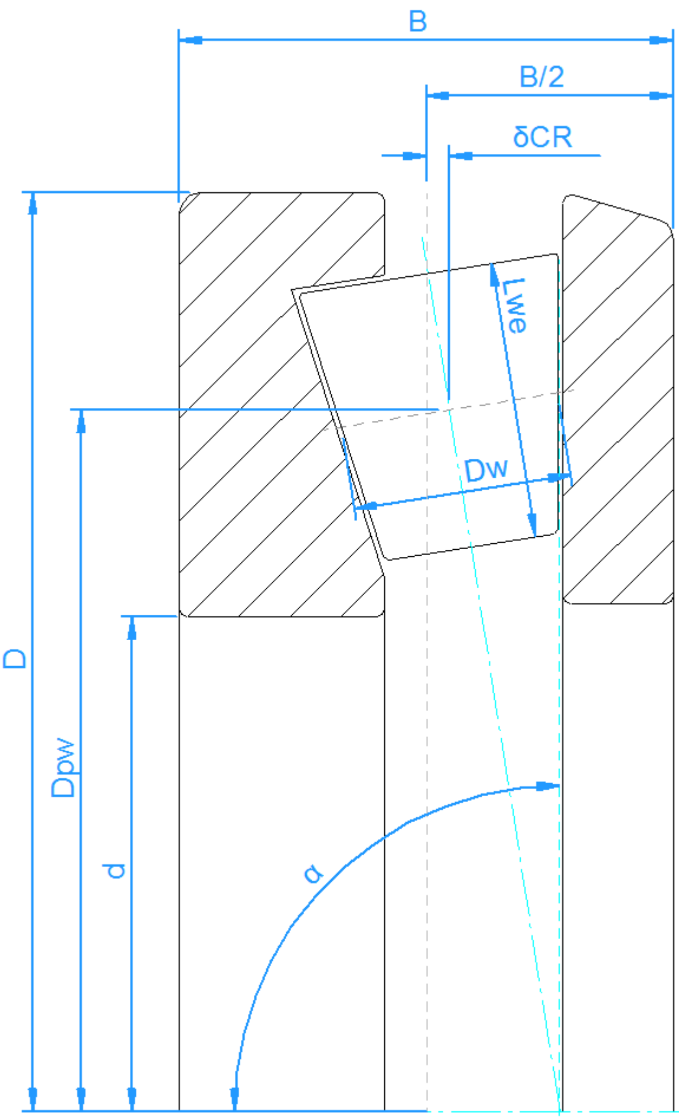
The diameter of the shoulder of the inner ring can be defined. The force is assumed to be at the medium height of the shoulder.

The distance between center of bearing and center of roller ‘δCR’ can be defined in two different ways by using the -button. It can be converted either from the distance to the center of pressure ‘a’, or from the outer race small inside diameter ‘E’ by setting the corresponding flag. Note that changing ‘E’ will in turn modify ‘Dpw’ according to their geometric relations.



Axial tapered roller bearing

The inputs which define a tapered roller thrust bearing are a bit simpler than for the radial case of tapered roller bearings, since the distance between center of bearing and center of roller ‘δCR’ is directly entered by the user. The clearance is also defined as axial clearance.



As shown in the picture, a contact angle ranging from 90° to 0° can be set, but it should always be between 90° and 45° in order to suit its axial load-carrying design.

No radial forces can be accommodated, so the radial displacements ‘uy’ and ‘uz’ under loading have to be set to zero.

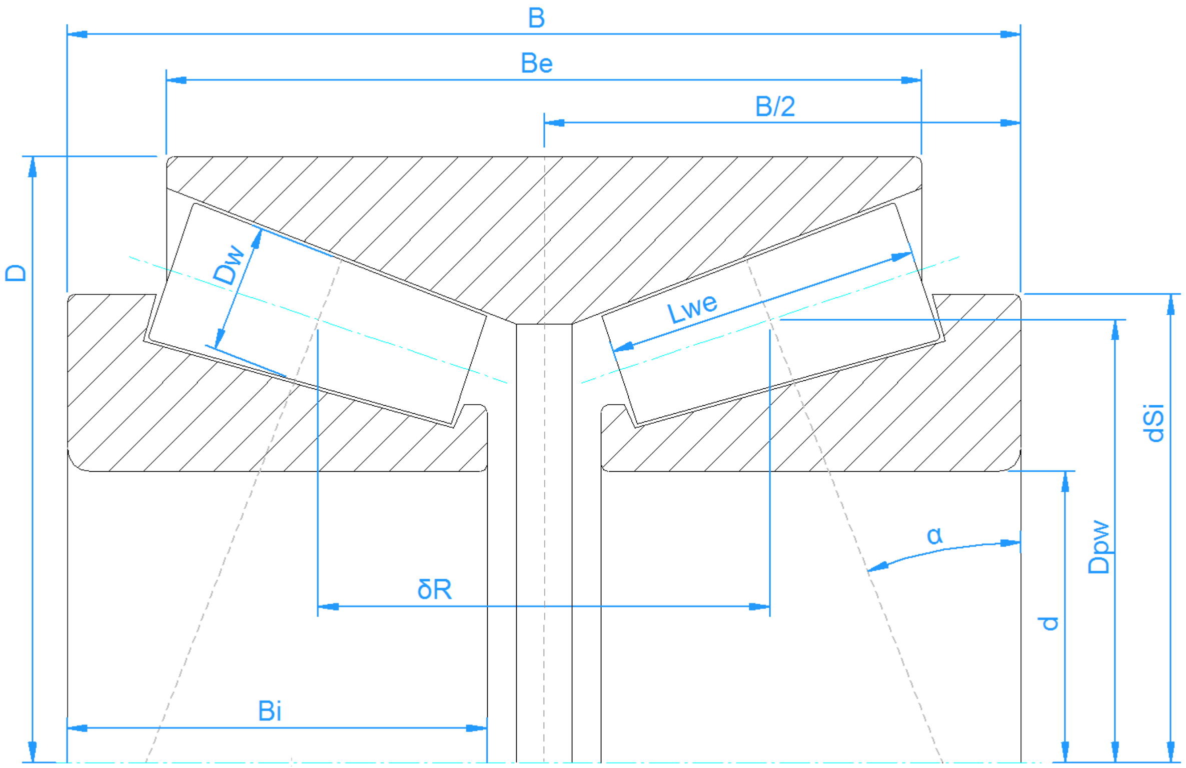
The direction of contact angle can be defined using the -button behind contact angle or bearing type.

The height of the shoulder of the inner diameter can be defined through the factor ‘fSi’ (%) in terms of percentage of the roller diameter. The force is assumed to be located at the medium height of the shoulder.

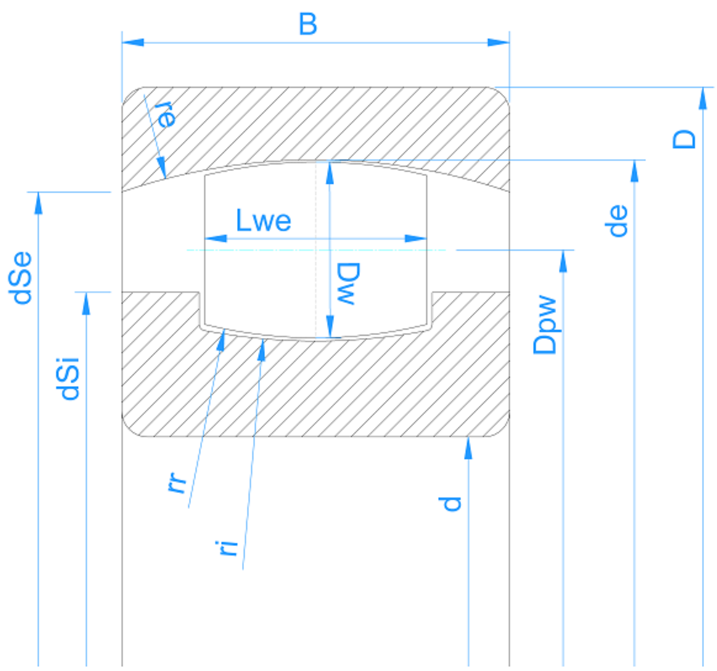
No tolerances are considered for axial tapered roller bearings.

Radial tapered roller bearing (double row)

As for other double row bearings types the arrangement of contact angles can be defined in the options dialog. Unlike the single row radial tapered roller bearing the distance between rows measured from the center of the corresponding rollers has to be entered. The same results are calculated as if using a single row bearing with a bearing configuration of two rows. The only difference is the load capacity, which is shown for the double row bearing. As in the other bearing types, the clearance can be also defined as radial clearance.



Barrel roller bearings



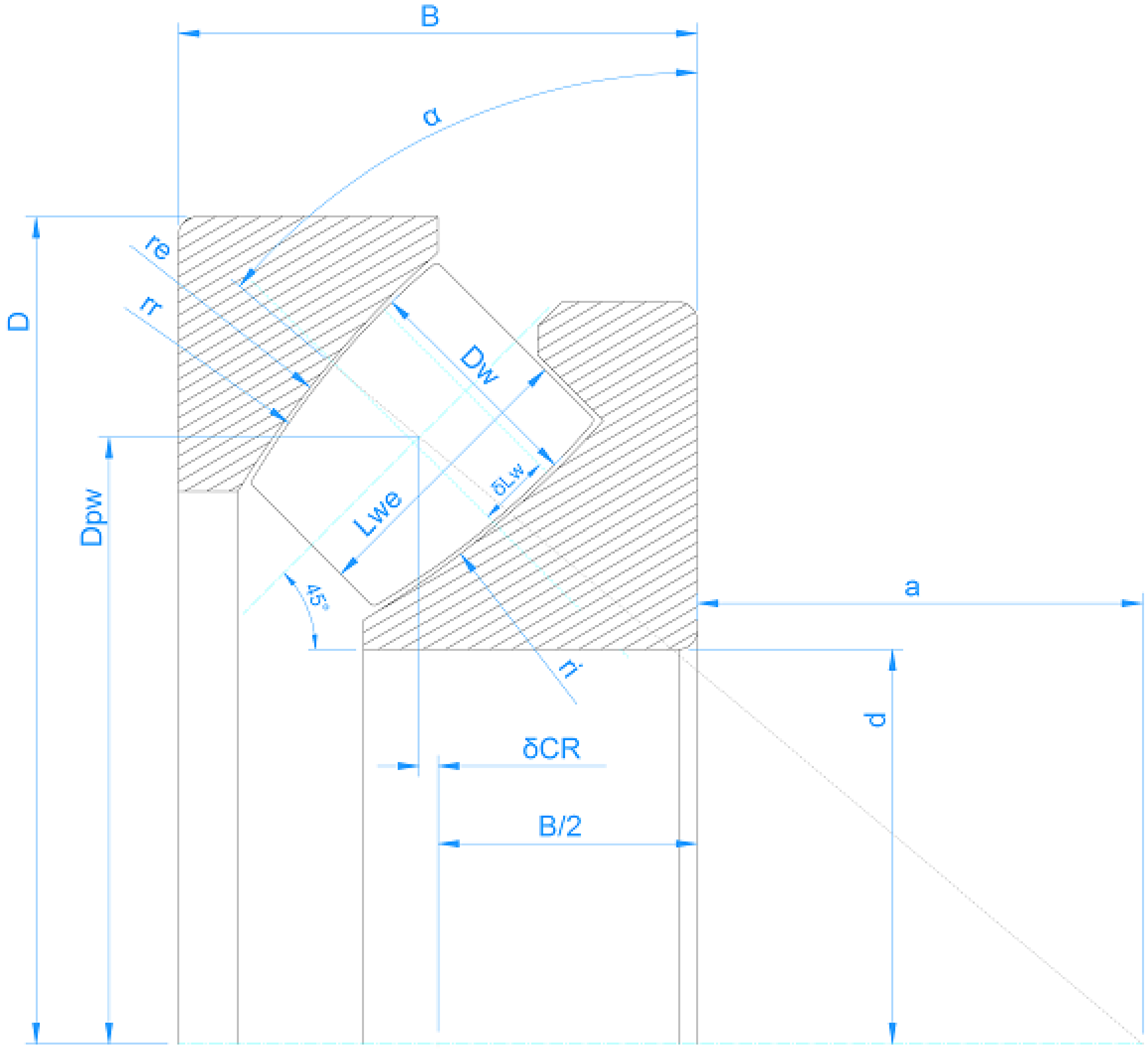
Barrel roller bearing are single row spherical roller bearings. As for double row spherical roller bearings the outer race is a sphere and the bearing does not support moment loads. Therefore, the tilting angle has to be defined instead of moment load.

The radius of inner race, outer race and roller can be specified as ratio to the nominal diameter of the outer race: $d_e = D_{pw} + D_w$. Default parameters are: $f_e = 0.5$; $f_i = 0.5$; $f_r = 0.485$. If the radius for the outer race is chosen differently, the bearing cannot rotate freely any more.

The load capacity is calculated using bm=1 as this seems to be the case in catalog data of major manufacturers.

Axial spherical roller bearing

The pitch diameter D_{pw} is defined as intersection of contact angle α and axis of roller. Usual values for contact angle are 45° to 50°.



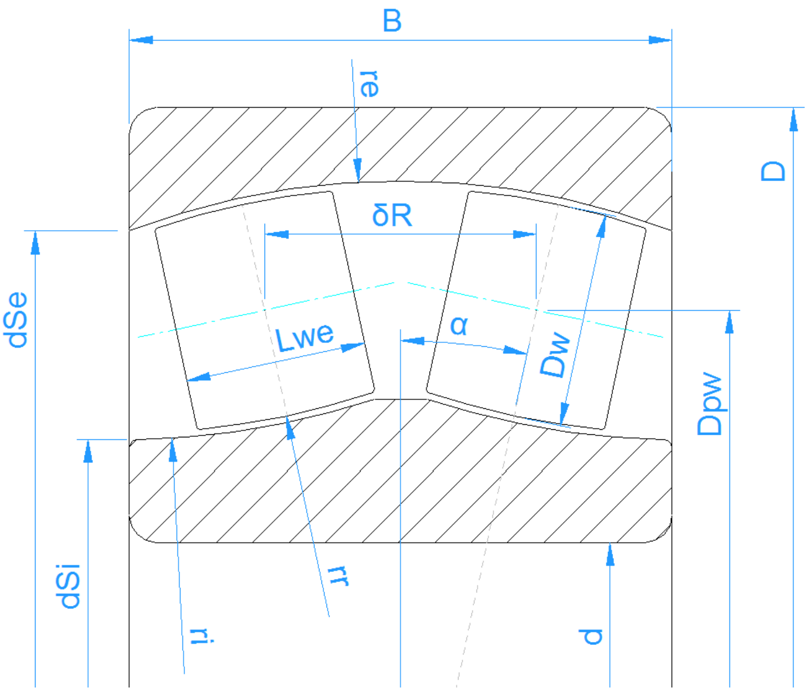
Radii of inner race and roller are defined by factors f_i and f_r like for the radial spherical roller bearings. They are defined as $r_i = f_i*(2*r_e)$ and $r_r=f_r*(2*r_e)$. Default values are $f_i = 0.5$ and $f_r = 0.485$. If the three radii r_i, r_e, r_r are entered using the -button behind f_i, f_r, the factors f_i, f_r and the pitch diameter D_{pw} are calculated.

The unsymmetry of the roller is defined by δL as offset between center of roller and position of maximum roller diameter D_w. A sizing button is available to calculate δL so that the contact point is at the center of the roller.

The load capacities are calculated using the roller diameter D_{we} at the contact point.

Spherical roller bearing

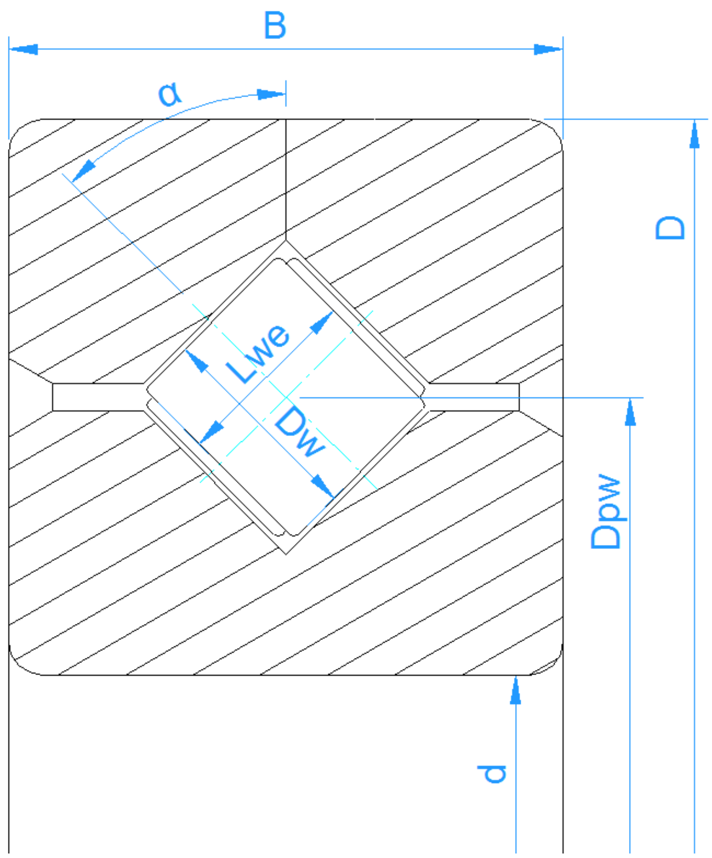
The distance between both rows is determined the contact angle and the pitch diameter. In contrast to the other bearing types the nominal diametral clearance is only applied to the inner race.



The radius of inner race, outer race and roller can be specified as ratio to the nominal diameter of the outer race: $d_e = \frac{D_{pw}}{\cos(\alpha)} + D_w$. Default parameters are: $f_e = 0.5; f_i = 0.5; f_r = 0.485$. If the radius for the outer race is chosen differently, the bearing cannot rotate freely any more.

Cross roller bearings

Cross roller bearings have a contact angle of 45°. They can be selected as radial or axial bearings. Differences are the calculation of load capacity and the input of clearance as radial or axial clearance.



The number of rollers has to be entered for one row; so it is half of the total number of rollers. The length of the roller has to be smaller than its diameter.

Angular roller bearings

Angular roller bearings are similar to cross roller bearings, but all rollers are mounted in one direction. Therefore, the restriction on roller length does not apply anymore and the contact angle is available as input.

Approximation of bearing geometry

If the inner bearing geometry is not available, it can be approximated by the software. Four possibilities are available:

Enter outside geometry only

In this case only the outside geometry of the bearing is defined with inner diameter d, outer diameter D and width B. Additionally the contact angle and the clearance have to be defined.

The number and size of rolling elements are approximated by the software. The load capacities are then calculated using this inner geometry. This does not lead to accurate results, because the real bearing geometry is not used. But still influences of moment loads and other parameters could be seen.

Enter outside geometry and load capacities

In this case the inner geometry is approximated as before, but the load capacities are provided by the user. The load capacities are usually available in bearing catalogues.

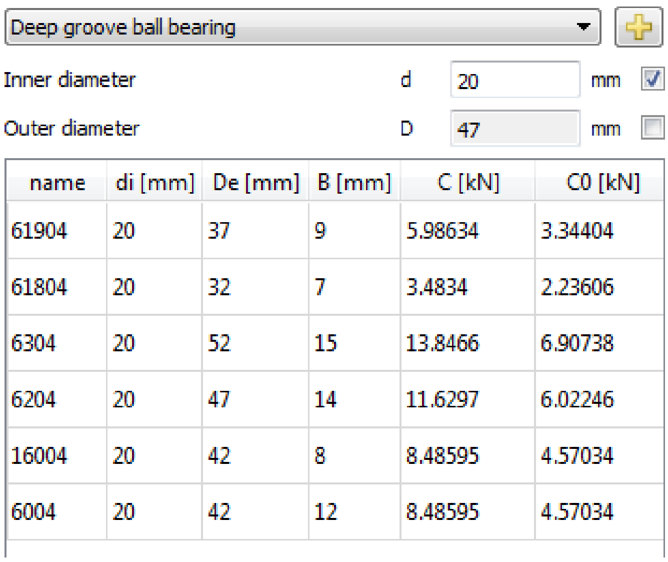
Enter inner geometry

Using this selection, you have to enter all the dimensions for inner geometry. The load capacities are calculated according to the standards.

Enter inner geometry and load capacities

Since bearing manufacturers often use load capacities larger than calculated according to standards, it is possible to enter both: the inner geometry and the load capacities. The load capacities are then used for the calculation of life.

Select bearing from database



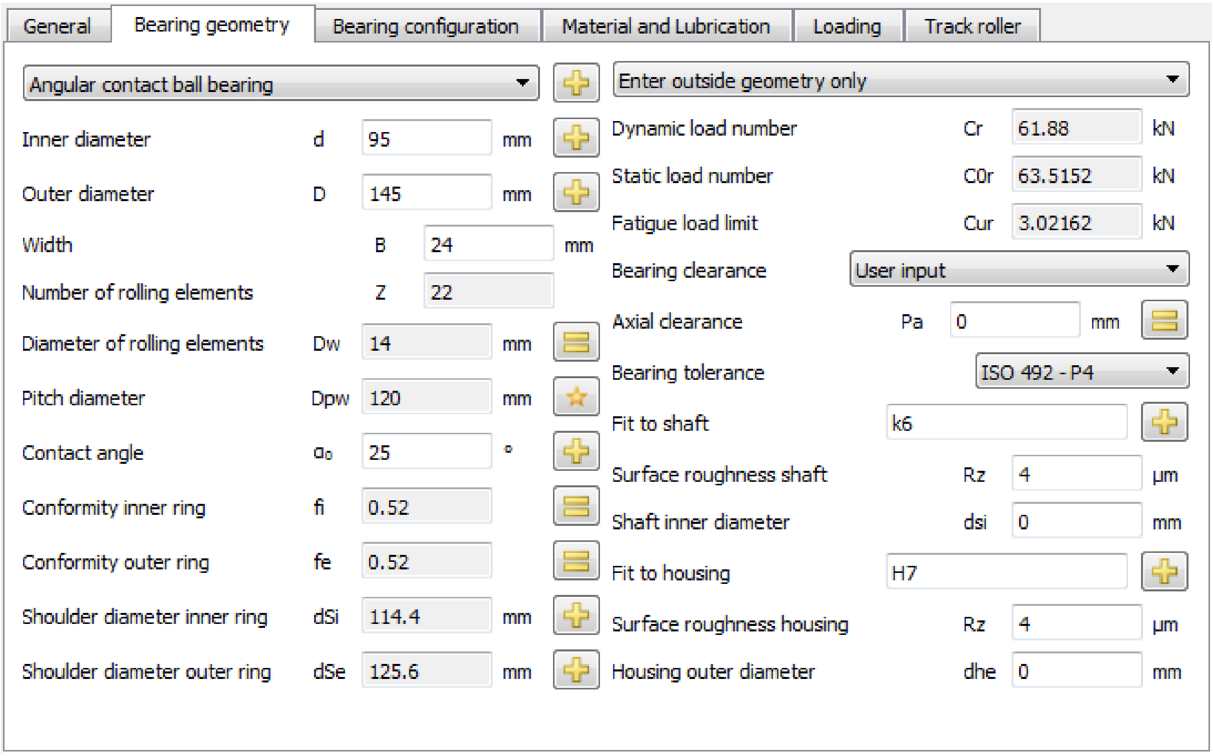
name	di [mm]	De [mm]	B [mm]	C [kN]	C0 [kN]
61904	20	37	9	5.98634	3.34404
61804	20	32	7	3.4834	2.23606
6304	20	52	15	13.8466	6.90738
6204	20	47	14	11.6297	6.02246
16004	20	42	8	8.48595	4.57034
6004	20	42	12	8.48595	4.57034

Instead of entering bearing geometry by the user, it can be selected from a database.

Inner and outer diameter can be defined optionally. This restricts the number of bearings shown in the list. By clicking on the titles of the columns the data can be selected according to this column.

Double clicking of a row reads in the bearing data and updates the values which are read from the database.

The data of inner geometry of the bearings provided with the database are approximated from outer dimensions. Additional databases from bearing manufacturers are available. Catalog data with approximated inner geometry is available from SKF and included in the installation. Encrypted bearing databases including inner geometry are available from GMN and IBC, please contact the bearing manufacturer for these databases.



Load capacities

Dependent on the setting for the approximation of bearing geometry, 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.

Dynamic load number

The dynamic load number is used for the calculation of bearing life. It is calculated according (ISO 281, 2007) with factor fc according (ISO/TR 1281-1, 2008). The factor b_m can be influenced for filling slot bearings using the options dialog for the bearing type (-button behind bearing type). If the option for hybrid bearing is selected in the options dialog, the dynamic load capacity is calculated according to (ISO/DIS 20056-1, 2016), leading to larger bm and smaller fc, but unchanged load capacity compared to steel bearings.

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). It is only for documentation and only used in the calculation of static safety factor if the static safety is not calculated based on stresses (see settings “Calculate static safety factor based on stresses”). It is also used in one case for track roller calculation, see that section for details.

If the option for hybrid bearing is selected in the bearing options dialog, the static load capacity is calculated according to (ISO/DIS 20056-2, 2017), leading to larger static load capacities. Note that (ISO/DIS 20056-2, 2017) also uses higher values for recommendations of static safety factors.

The static load number is based on a permissible stress which can be changed at inputs for material data.

For bearings with low speed higher loads are permitted sometimes. For example, (ISO 1002, 1983) allows a radial force of over five times the static load capacity for nonrotating ball bearings.

Fatigue load limit

The fatigue load limit is calculated according (ISO 281, 2007) section B.3.2.1.2 for ball bearings and according section B.3.2.1.3 for roller bearings. For roller bearings, the standard calculation according ISO/TS 16281 is used, not the extended method for pressure distribution.

The fatigue load limit is based on fatigue strength of 1500MPa and it is used for the calculation of modified life. The fatigue strength can be modified using inputs for material data.

Inner, outer diameter and width

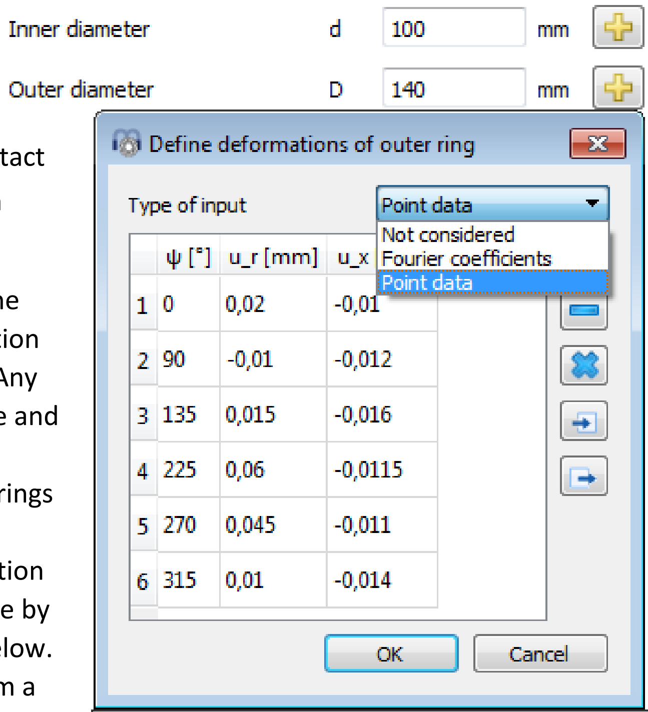
The inner diameter, outer diameter and width are only needed for documentation and for the approximation of inner geometry. They are not used in the calculation itself.

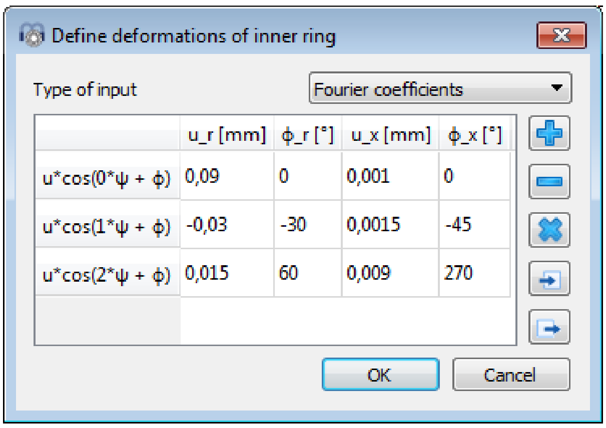
If the inner geometry is provided these values could be set to zero.

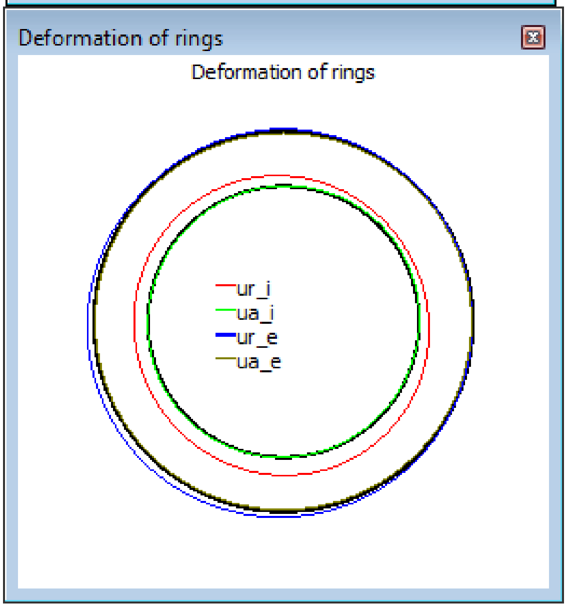
Deformations of rings

If deformations of outer and inner ring are, for instance, known by means of FE analyses, they can be entered into the software to evaluate their influence on bearing life and contact stress by clicking on the -button behind both diameter input fields.

They are two possibilities. On one hand, with the option 'Point data', as many points of deformation as needed can be added to the the data table. Any point is positioned circumferentially by its angle and both the axial and radial deformation can be defined. Note that the deformations along the rings between any defined points will be linearly interpolated. On the other hand, there is an option to define the an approximate deformation curve by 'Fourier coefficients' as shown in the picture below. Addtionally, a whole table can be imported from a csv-file using the -button and any created table can be exported into a file using the -button.







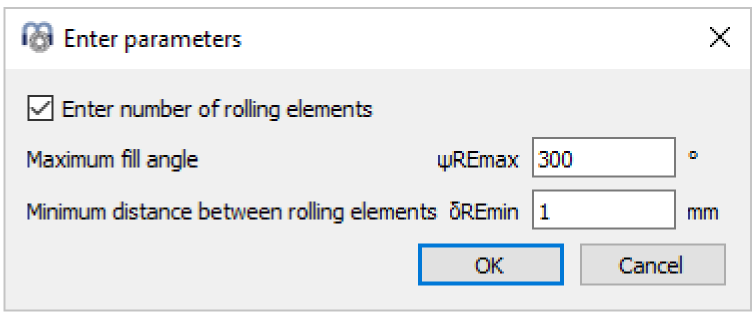
In the current version, the definition of deformation cannot be used together with track roller calculation with elastic outer ring.

Number of rolling elements

The number of rolling elements has to be specified. A minimum number is three; the maximum number depends on the bearing pitch diameter. A warning is shown if the rolling elements overlap, the distance between rolling elements is available in the results overview and report.

For cross roller bearings, this is the number of rollers for one row.

Using the -button the number of rolling elements can be calculated automatically



based on a maximum fill angle and a minimum distance between the rolling elements. For deep groove ball bearing the fill angle would be 180-200°, the minimum distance can be based on requirements for the cage.

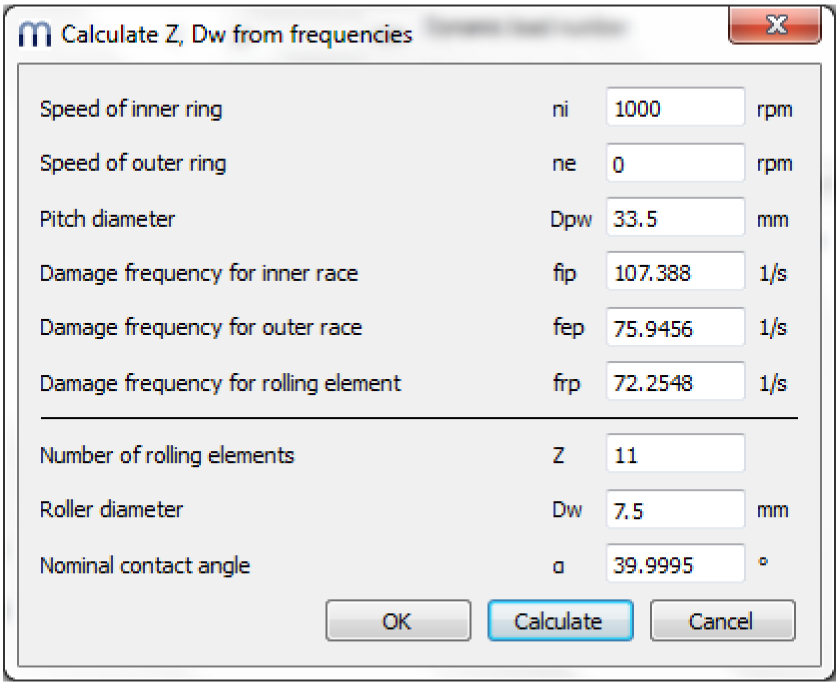
This option is mainly thought to allow the variation of the rolling element diameter in the parameter variation with an automatic setting of the number of rolling elements.

Diameter of rolling elements

The diameter of the rolling elements is specified here. For taper roller bearings, the diameter in the middle of the roller is used.

Calculation of basic geometry from damage frequencies

Using the -button the number of rolling elements, roller diameter and contact angle can be calculated from given damage frequencies. This can be used if damage frequencies for a bearing are given and geometry data is missing.



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.

Usually the mean value of inner and outer diameter of the bearing is taken, but it can be different. For example, it is not valid for a needle bearing without inner ring. The mean value can be selected using the -button behind the input.

Contact angle

The contact angle has to be provided for angular contact bearings, four-point ball bearings, spherical ball bearings, taper roller bearings ad spherical roller bearings. For taper roller bearings, the cup angle is used since this is the direction of the force. Using the -button the direction of contact angle can be selected.

For double row angular contact bearings, the back-to-back arrangement has the larger width between the centers of pressure and it is also called O-configuration, while the face-to-face arrangement is the same as the X-configuration.

Conformity of inner and outer ring

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).

According to (ISO/TS 16281, 2008) usual values are f_i=0.52 and f_e=0.53 for radial ball bearings and f_i=f_e=0.54 for thrust ball bearings. (ISO 76, 2006) also uses f_i=f_e=0.54 for thrust ball bearings.

For spherical or barrel roller bearings values of f_i= f_e=0.5 should be used. Here the diameter of the outer race d_e is used as reference.

According to (ISO 281, 2007) and (ISO 76, 2006) a larger conformity reduces the load capacity and therefore a reduction of fc is required, but a smaller conformity does “not necessarily increase the load-carrying ability”. Therefore, the software allows to enter a limit for the conformity used for the calculation of load capacity. See the -button behind the bearing type for ball bearings.

For spherical ball bearings, the diameter of outer race d_e is used as reference for f_e. So f_e=0.5 should be used as default.

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.

Conformity of roller

For spherical or barrel roller bearings, the conformity of the roller has a usual value of f_r=0.485. The diameter of the outer race d_e is used as reference, so r = f_r*d_e.

Distance between rows

For double row bearings, the distance between rows is shown in the user interface. It is the axial distance between the centers of balls. For double row angular contact bearings, it is an input, for the other bearing types it is an output since the distance is calculated by pitch diameter and contact angle. The distance between rows is

$$\delta_R = D_{pw} \cdot \tan \alpha$$

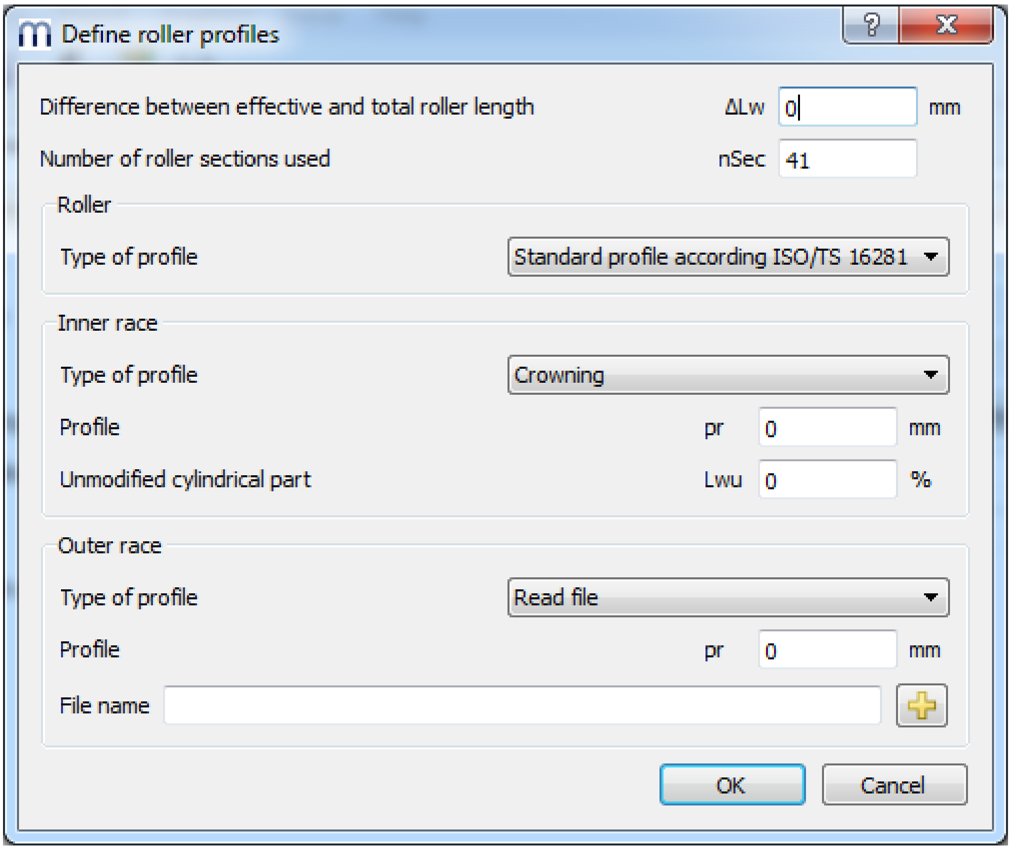
Effective length of roller

The effective length of the roller is the length that can be loaded. A radius at the end of the roller has to be subtracted to get the effective length.

If the extended method pressure calculation for pressure distribution is selected on page ‘General’ the roller profile can be defined using the -button.

Defining roller profiles

Profiles can be defined for inner race, outer race and roller.



As general inputs the difference between effective and total roller length can be defined. As it increases the stiffness of the roller it has an influence on the calculation.

The number of sections for the calculation has to be larger 30 and has to be an odd number. The calculation accuracy and the calculation time increase with a larger number of sections.

Four options are available for the profiles:

1. Standard profile according ISO/TS 16281:
   This is using the defaults of the standard, which is logarithmic profile of the roller and no profile on the races.
2. Logarithmic profile:
   The amount of relief can be defined and a cylindrical part that should not be modified. The following formula is used:

$$P(x) = Pr \cdot ln\left(\frac{1}{1 - \left\{\frac{2|x| - L_{wu}}{L_{we} - L_{wu}}\right\}^2}\right)$$

   For the roller a sizing button provides the default relief according ISO/TS 16281. The default relief of 0.00035*Dw for short cylindrical roller bearings corresponds to a contact stress of 3000MPa.
3. Modified logarithmic profile:
   The amount of relief is calculated according following formula derived from (Fujiwara, et al., 2010):

$$P(x) = A \cdot ln\left(\frac{1}{1-\left\{1-e^{-\frac{Pr}{A}}\right\}\left(\frac{2|x|-L_{wu}}{L_{we}-L_{wu}}\right)^2}\right)$$

using

$$A = 2D_w \cdot \left(\frac{p\cdot(1-\nu^2)}{E}\right)^2$$

The maximum relief is not infinity at the edge of the roller like in the logarithmic profile according ISO/TS 16281 but limited to the maximum value of pr.

Using p =3000MPa and pr=Infinity the results are the same as for the logarithmic profile according ISO/TS 16281 above.

The material data for this profile is always taken from the contact roller/inner race.

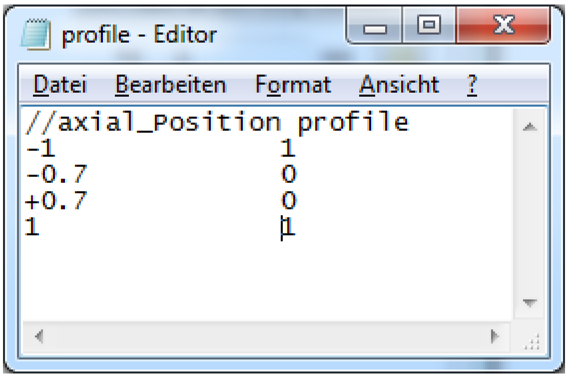
4. Crowning:

   A circular arc tangential to the cylinder is used to generate the profile. The amount of relief and a percentage of unmodified cylinder length can be defined.

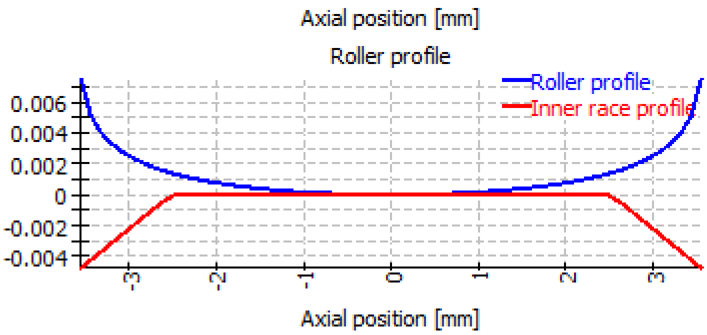
5. Read file:

   The profile can be read from a file. The data has to be specified with two values on each line, an axial position and the profile relief. The axial position is scaled with the roller length and the relief is scaled with the input for the profile relief. So a range from -1 to +1 can be used for the axial position and 0 to 1 for the relief.

   A very simple file is shown here. It was selected for the inner race profile on the right:



```
//axial_Position profile
-1              1
-0.7            0
+0.7            0
1               1
```

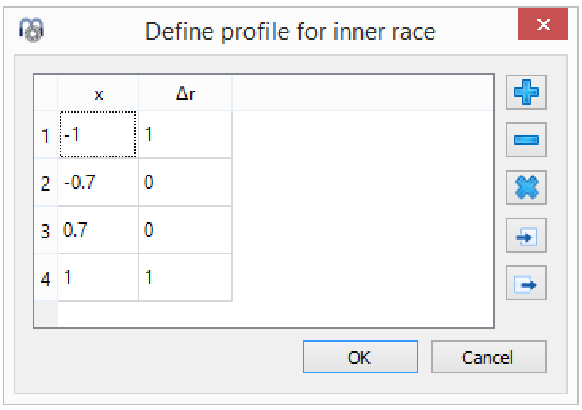


   The unsymmetrical profile is used from left to right for most bearings. For taper roller bearings and axial spherical roller bearings the profiles is used from left to right if direction of contact angle is left. For contact angle to the right the profile is mirrored. So mounting conditions do not influence the profile.

6. User input:

   Instead of defining a file name the points for the profile can be defined in a table. Again as above use a range of -1 to +1 for the axial position and a value between 0 and 1 for the profile relief.

   The table in the diagram on the right shows the same data as the file above.



	x	Δr
1	-1	1
2	-0.7	0
3	0.7	0
4	1	1

The profiles can be shown in the graphics for roller profile.

Offset for roller center

For axial spherical roller bearings, an offset for the roller center δL can be defined. It is the distance between the center of the roller and the position of the maximum diameter D_w.

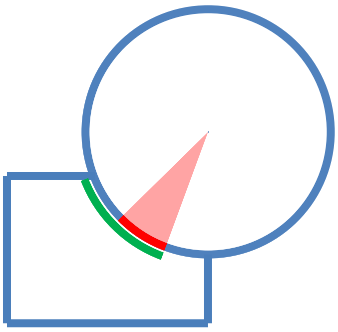
Shoulder diameter of inner and outer ring

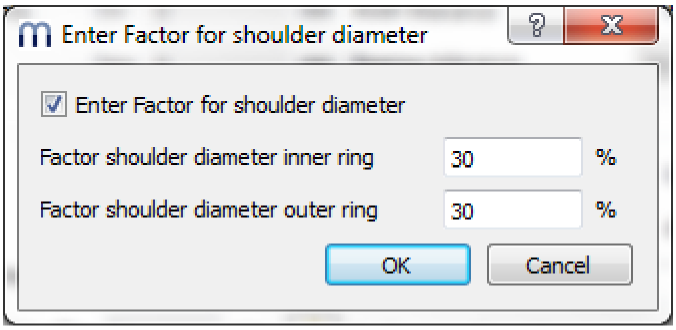
For ball bearings and radial cylindrical roller bearings the shoulder diameter of inner and outer ring can be defined. For tapered roller bearings, the shoulder for the inner race can be defined. If an input of zero is given it will not be considered.

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%.

For spherical ball bearings, the shoulder diameter of the outer race is limited by the radius of outer race and bearing width automatically, if the bearing width is entered.





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.

For radial cylindrical roller bearings and tapered roller bearings it is assumed that the axial force is acting at half the height of the shoulder.

Distance to row center

This input is only available for taper roller bearings and axial spherical roller bearings. It is the distance between center or roller and center of bearing. It can be calculated from the distance to center of pressure ‘a’ provided in bearing catalogs.

Bearing clearance

The bearing clearance can be set automatically according (ISO 5753, 2009) (C2…C5) for deep groove ball bearings, four point bearings, self-aligning ball bearings, spherical and cylindrical roller bearings.

In addition, there are the settings ‘from database’, ‘own input as operating clearance’ and ‘own input’.

From database
If 'From database' is selected the minimal and maximal values for the bearing clearance are taken from the bearing database. An error message is shown if the bearing data is not selected from database.

If is not necessary to use the clearance from database also the other options for clearance can be selected.

User input as operating clearance
Selection 'user input as operating clearance' means that no modification to the clearance will be done by the software. No interference fit or temperature is taken into account. This is the recommended setting if you know the clearance you want to consider.

User input
Selecting 'user input' allows entering the clearance of the bearing before mounting. Influence of temperature or interference fits will be considered additionally.

User input as range
Selecting 'user input as range' allows entering the clearance of the bearing before mounting as a range using the -button. Influence of temperature or interference fits will be considered additionally. The load distribution will be calculated using the clearance according to the setting as minimum, medium or maximum value of the range.

Diametral clearance
The diametral clearance P_d is shown for deep groove radial ball bearings, spherical ball bearings, cylindrical roller bearings and spherical roller bearings. In is the distance between the upper and the lower position the inner ring can have without load in a fixed outer ring. It can be calculated as

$$P_d = d_e - d_i - 2 \cdot D_w$$

For pretension, a negative clearance can be entered.

The same value is sometimes described as radial clearance (in contrast to axial clearance), but the measurement is still a difference of diameters.

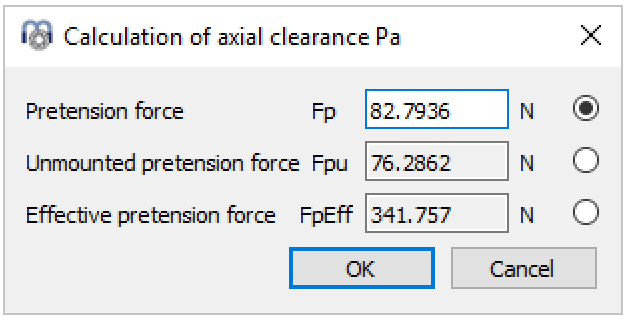
A -button allows the input of axial clearance instead of diametral clearance. For deep groove ball bearings the clearance can also be calculated for given free contact angle.

Axial clearance
The axial clearance P_a is shown for angular contact bearings, four point bearings, cylindrical roller bearings and all axial bearings. The axial clearance is the difference between the possible axial displacement in positive and negative direction for four point bearings and cylindrical roller bearings.

For single row angular contact bearings or tapered roller bearings it is the axial distance between inner and outer ring when the bearing rings are moved together with a very small axial load. So in this case the clearance is between center and one direction and for double row angular contact bearings, four point bearings and cylindrical roller bearings it is the maximum distance between left and right movement.

For cylindrical roller bearings, a value larger than zero should be entered for the axial clearance, since the bearing usually has axial clearance. If the calculation is done with clearance zero you will get some axial loads on the rollers if there is a tilting angle of the bearing. This should be the case for a locating cylindrical roller bearing, but not for a non-locating bearing. So the correct clearance should be entered in both cases.

A pretension can be entered by using a negative value for the axial clearance Pa. A -button allows the input of diametral clearance instead of axial clearance. For angular contact bearings or tapered roller bearings the axial clearance can also be calculated for a given pretension force.



For roller bearings, the calculation of axial clearance from pretension force does not yet take into account the extended pressure calculation or changes of profiles.

Dependent on the bearing type several options for the pretension force are available. The calculation with “Fp” is using nominal dimensions for the bearings, the calculation using “Fpu” is using nominal dimensions together with a radial elastic expansion without limit; this option can be used for the case of loading an unmounted bearing axially during manufacturing. The effective pretension force “FpEff” is calculated using the dimensions after fitting.

Bearing tolerance

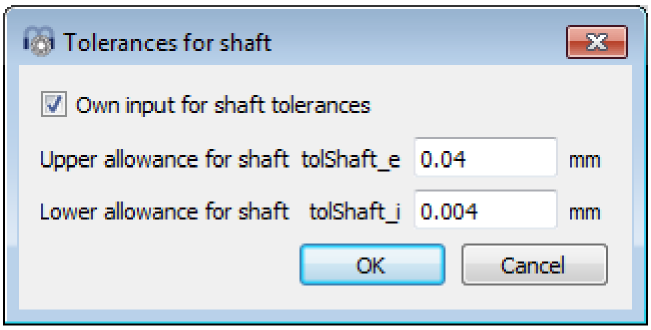
The bearing tolerance can be considered according ISO 492 (P0...P2). If selecting ‘Not considered’ the interference fit is not considered for operating clearance. If selecting ‘Nominal dimensions’, the tolerances of the bearing are considered zero. Then the interference fit can be defined with the inputs for the shaft only.

Selecting ‘User input’ allows the definition of custom tolerances.

Fit to shaft/housing

The fit between inner ring and shaft can be defined as a tolerance according (ISO 286-1, 2010). For example, it can be specified as ‘k6’. The same is possible for the fit between outer ring and housing.

A numerical value can be specified directly using the -button next to the input field. Selecting “own input” allows the input of arbitrary tolerances:



Shaft inner diameter/Housing outer diameter

The inner diameter of the shaft can be specified for a hollow shaft. This has an effect on the interference fit.

For the housing the outer diameter can be specified. If zero is entered a value of $2 \cdot D$ will be used in the calculation.

Surface roughness shaft and housing

The surface roughness of the shaft and the housing is only used for the calculation of the interference fit. The effective interference of the parts is reduced by $0.4 \cdot Rz$ according (DIN 7190-1, 2017). In previous versions, a reduction of $0.8 \cdot Rz$ was used as in the previous version of the standard.

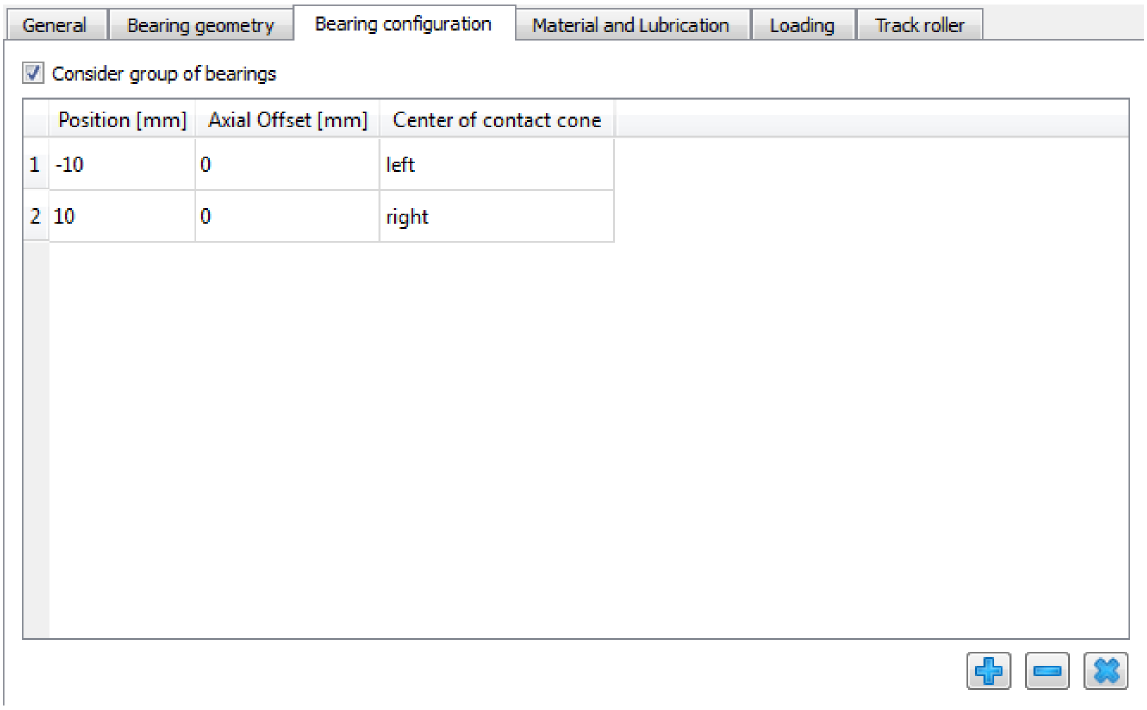
The surface roughness of shaft and housing is only used for the calculation of the interference fit.

Bearing configuration

A group of bearings can be considered in the calculation. The bearings 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 outer ring of a bearing. 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.

For bearings with a contact angle the position of the cone center can be specifies. In the picture an O-configuration (or back-to-back configuration) is defined.



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

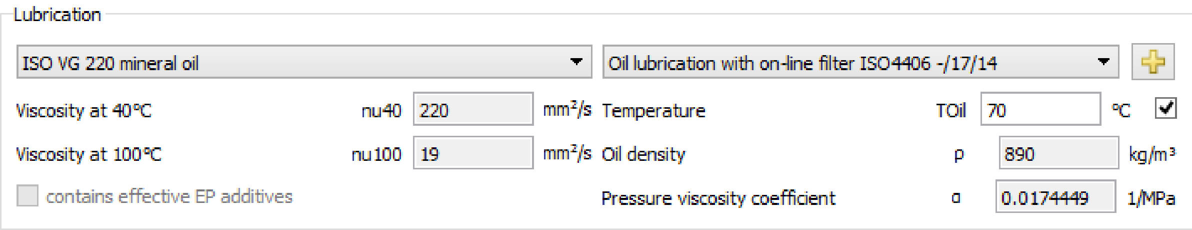
The possibility of bearings groups allows the calculation of 8-point ball bearings as two rows of four point bearings; it allows sets of angular contact bearings, paired taper rollers or sets of cylindrical roller bearings which could be used in a planetary gear.

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 bearing rows.

Lubrication

The lubrication has an effect on the modified life rating. A large oil film thickness prevents direct contact between rolling element and races and therefore can increase the life.

Some lubricants can directly be selected from the list. Mineral oils and PAG-based synthetic oils are provided. For other types of oil, 'own input' can be selected.



Contamination factor

The contamination factor is used for the calculation of life modification factor a_{ISO}. It is considering the cleanness of the lubricant and can be calculated with the viscosity ratio, the bearing size and a selection of oil cleanness according ISO 4406. The selection according ISO 4406 defines how many particles of certain size may exist.

Also an own input of the contamination factor can be selected and the factor can be entered using the -button. The contamination factor is in the range from 0.1 to 1 and guide values can be selected according (ISO 281, 2007):

Contamination level	e_C	
	$D_{pw} < 100mm$	$D_{pw} \geq 100mm$
Extreme cleanliness Particle size of order of lubricant film thickness, laboratory conditions	1	1
High cleanliness Oil filtered through extremely fine filter; conditions typical for bearings greased for life and sealed	0.8.to 0.6	0.9 to 0.8
Normal cleanliness Oil filtered through fine filter; conditions typical for bearings greased for life and shielded	0.6 to 0.5	0.8 to 0.6
Slight contamination	0.5 to 0.3	0.6 to 0.4
Typical contamination Conditions typical of bearings without seals; course filtering; wear particles from surroundings	0.3 to 0.1	0.4 to 0.2
Severe contamination Bearing environment heavily contaminated and bearing arrangement with inadequate sealing	0.1 to 0	0.1 to 0
Very severe contamination	0	0

Note that for small bearings the values for eC calculated from oil cleanliness can be much lower than in the table.

Kinematic viscosity

The kinematic viscosity has to be given for two temperatures: ν_{40} at 40°C and ν_{100} at 100°C. The actual viscosity at the given temperature will then be interpolated using these values.

If a single kinematic viscosity at operating temperature is given, it can just be entered in both inputs and therefore will be used in the calculation.

A high viscosity results in a larger lubricant film, but efficiency will be reduced if it is too large.

Oil temperature

The oil temperature is only used for the calculation of lubricant properties like operating viscosity. It has no influence on clearance. If the oil temperature is not selected as input, it will be set to the temperature of the rolling elements as calculated from the temperatures of the rings dependent on the settings or as given on page "Loading".

Oil density

The oil density is used for the calculation of dynamic viscosity. If a lubricant from the list is selected the density is modified according to the oil temperature according (Niemann, et al., 2005). If 'own input' is selected, the input value is directly used for the calculation.

Pressure viscosity coefficient

The pressure viscosity coefficient α is used for the calculation of lubricant film thickness. If the film thickness should not be calculated, you can just enter zero.

According (ISO/TR 1281-2, 2008) pressure viscosity coefficient α can be calculated by the kinematic viscosity ν_0 in cm²/s as

$$\alpha = 0.1122 \cdot \left(\frac{\nu_0}{10^4}\right)^{0.163}$$

To calculate the reference viscosity ν_1 a value of $\alpha = 0.0077 \cdot \nu^{0.204}$ using ν in mm²/s and α in mm²/N is used according (Baalmann, 1994).

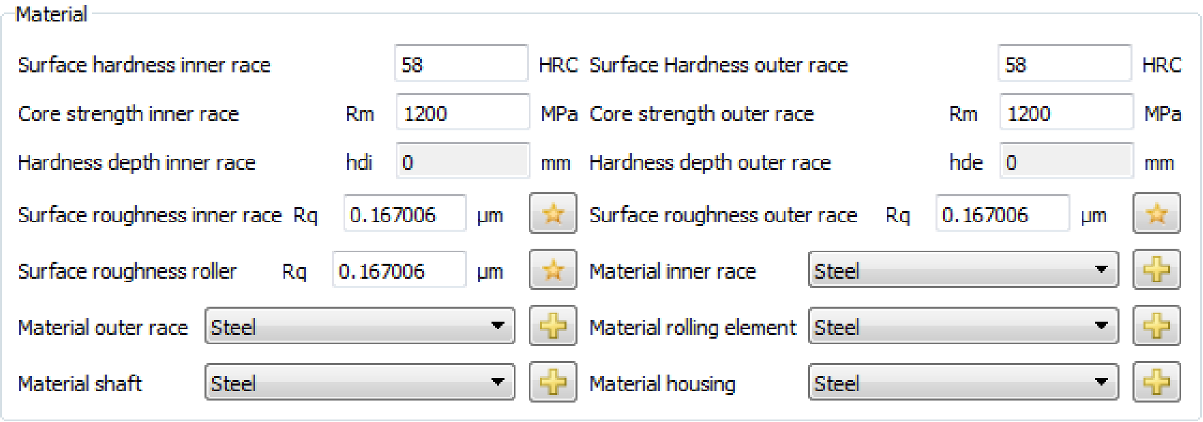
In the software, the proposal according (AGMA 925, 2003) is used, because different oil types are considered. The pressure viscosity coefficient is calculated as $\alpha = k \cdot \eta_M^s$, where η_M is the dynamic viscosity at operating temperature. The factors k and s are given for different lubricant types as shown in the following table:

Oil type	**k**	**s**
Mineral oil	0.010471	0.1348
PAO based synthetic non-VI improved oil	0.010326	0.0507
PAG based synthetic	0.0047	0.1572

This formula is used if a lubricant from the list is selected. If 'own input' is selected, either the formula according to (ISO/TR 1281-2, 2008) 11.8 or according to (AGMA 925, 2003) or a direct input can be selected using the -button next to the input field.

Material

Material properties for rolling element, inner and outer ring, shaft and housing can be defined. This data is used for the calculation of load distribution and interference fit between bearing and shaft/housing. Also hardness and surface roughness can be specified.



Surface hardness

The surface hardness is given as Rockwell hardness HRC. If the surface hardness is smaller than 58HRC a reduction in dynamic and static load capacity is taken into account according (Harris, et al., 2009). This reduction is only considered as long as the load capacity is calculated by the software. The reduction factor for dynamic load capacity is:

$$C' = C\left(\frac{HRC}{58}\right)^{3.6}$$

An input value for load capacity is not modified because of the hardness value. If a modification factor for dynamic load capacity or the permissible stress for static capacity is defined in material data, a reduction because of hardness is not considered.

The static safety factor is also affected by a reduced hardness. This is also done according (Harris, et al., 2009) using the factor fs:

$f_s = 1.5\left(\frac{HV}{800}\right)^2$ (Ball bearings) or $f_s = 2\left(\frac{HV}{800}\right)^2$ (roller bearings), with $f_s \le 1$

For this formula HV is calculated as HV = (223 * HRC + 14500) / (100 - HRC) according (Schlecht, 2010).

Core strength of inner and outer race

The ultimate strength of the inner and outer ring core and the corresponding hardness depth are used for a check of case core interface. The actual shear stress at hardness depth is compared with the shear yield stress τ_{yield} and the shear fatigue strength τ_a which are calculated according (Harris, et al., 2009) from the input value of ultimate strength:

$$\tau_{yield} = 0.425 \cdot Rm;\ \tau_a = 0.6 \cdot \tau_{yield}$$

If the material is though hardened, the software can be set to calculate the hardness depth automatically. Then no warnings will occur, just a larger hardness depth is calculated on load increase.

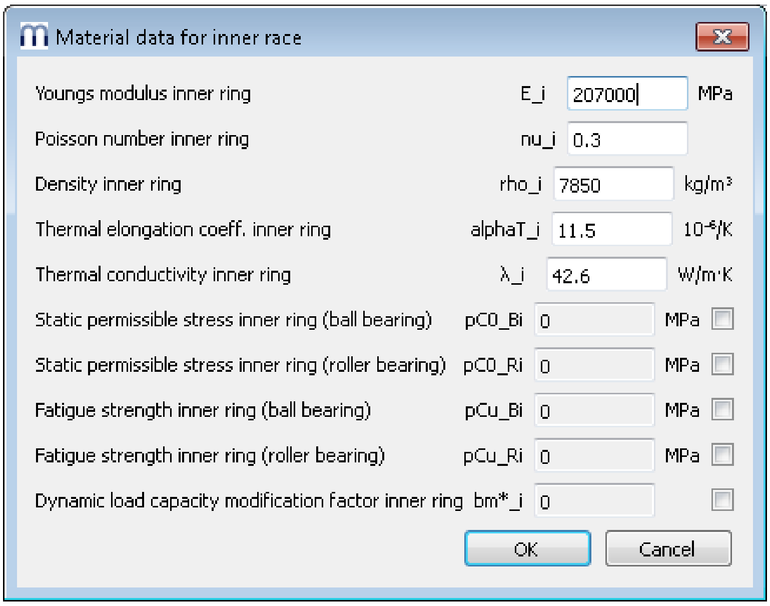
Surface roughness

The surface roughness R_q is used for the calculation of the specific lubricant film thickness Λ. It is a root mean square roughness R_q or R_{RMS}. According (Niemann, et al., 2005) an approximation is given as $R_q \approx 1.25 \cdot R_a$.

According to (Baalmann, 1994) an estimate for a usual composite roughness is given by $R_q = 1.2 \cdot 10^{-5} \cdot D_{pw}^{0.55}$. This formula according Baalmann is used when the sizing button next to the input field is clicked.

Material for races, rolling element, shaft and housing

The material of the races, the rolling element, shaft and housing can be selected to be steel or Si3N4. The list is taken from the database therefore it can be extended by the user. Also 'own input' is available and the material data can be defined using the -button.



For material data the Young's modulus, the Poisson number, the density, the thermal elongation coefficient and the thermal conductivity can be defined. This data is used to calculate the operating clearance and the load distribution within the bearing. The thermal conductivity is used to calculate the thermal resistance for ball bearings according (Nakajima, 1995).

Optionally a static permissible stress can be defined which is used for the calculation of static load capacity and static safety factor. The default value is 4000MPa for roller bearings and 4200MPa for ball bearings. For spherical ball bearings the permissible stress is multiplied by 4600/4200 for the outer ring internally by the software.

The fatigue strength is used for the calculation of the fatigue load limit Cu. The default value is 1500MPa, it can be overwritten by the user.

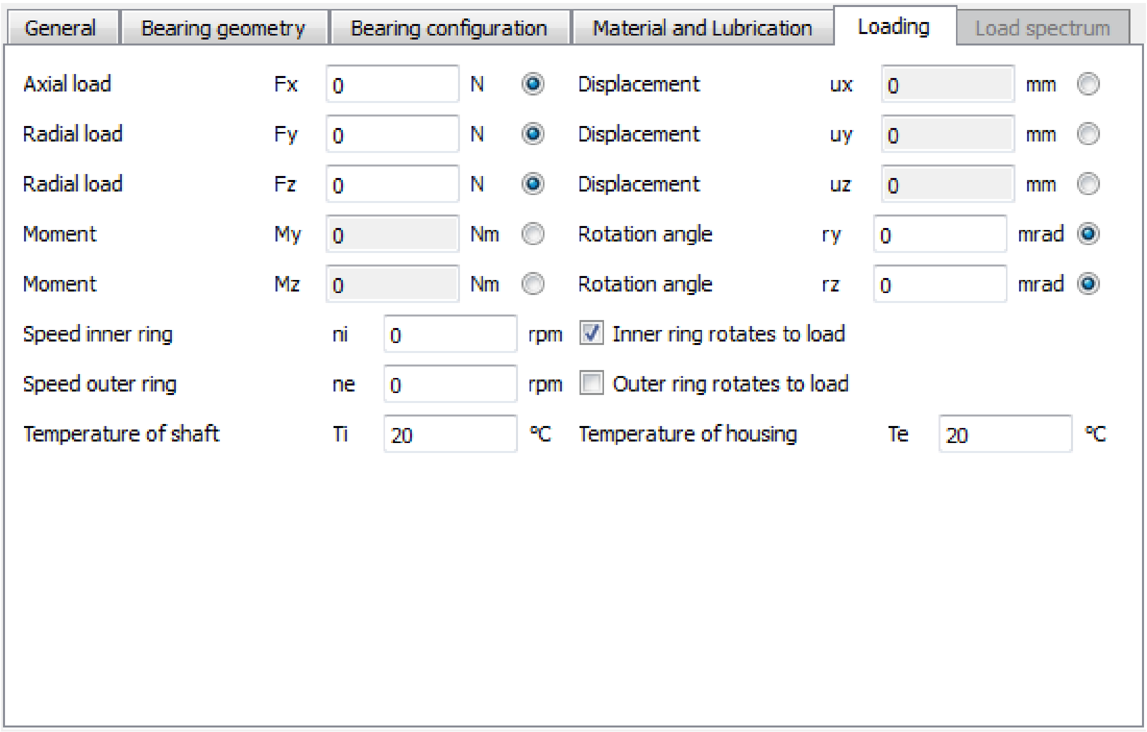
The dynamic load capacity can be modified dependent on the material selection, too. The bm*-factor is multiplied to the dynamic load capacity according ISO 281. This allows to consider a material influence on dynamic load capacity. A different value can be used for inner and outer race. The value of bm*-factor for the rolling element is only used for the calculation of rolling element set life, it does not affect the dynamic load capacity of the bearing.

Loading

For each coordinate direction, you can select if a force or a displacement should be entered. For example, if a calculation of a tapered roller bearing should be done considering only radial load, the displacement in axial direction can be fixed to zero and the reaction force in axial direction will be calculated.

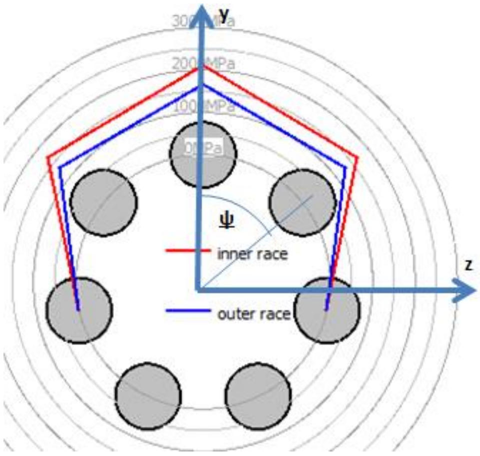
A moment load or a rotation (misalignment) can be entered for two directions only, because the rotation around the bearing axis is not constrained.

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



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. Moments are positive if acting around the corresponding axis.



The load is acting on the inner ring (different for track rollers with elastic outer 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 inner ring

The temperature of the inner ring is used for the calculation of the interference fit between shaft and inner ring only. It affects the operating clearance. Optionally the temperature of the shaft can be entered too.

Temperature of outer ring

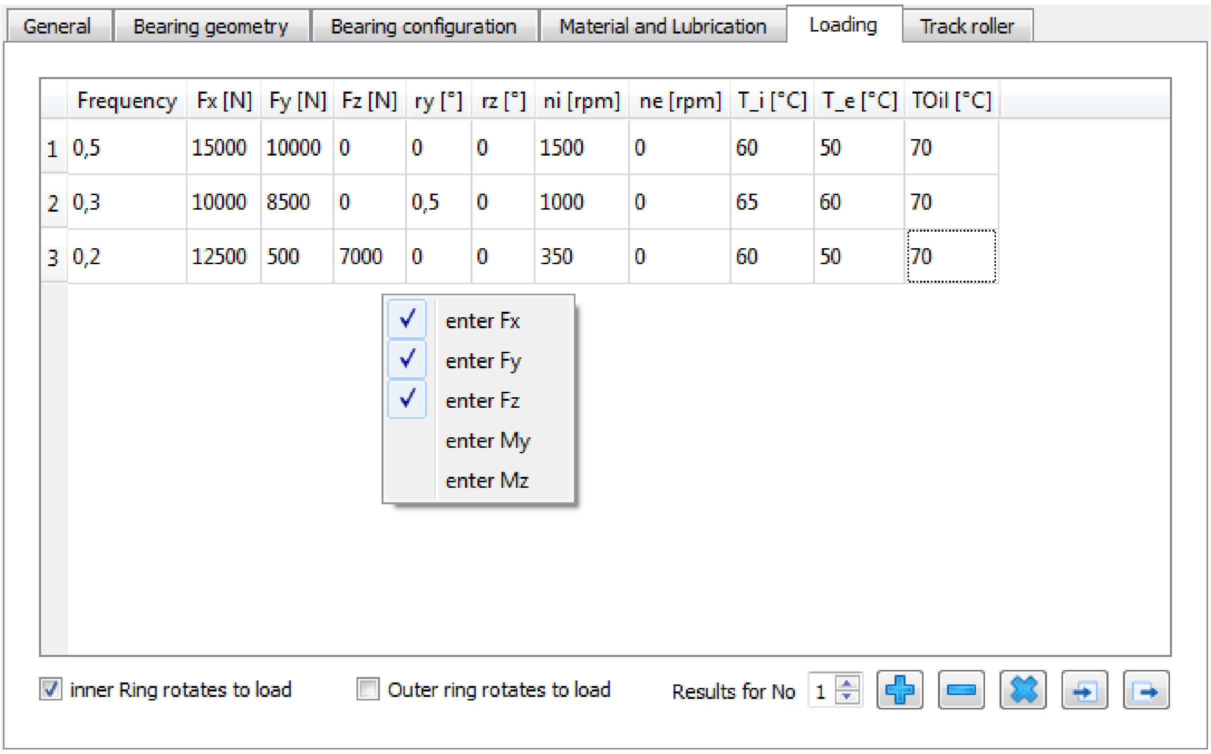
The temperature of the outer ring also affects the operating clearance. Optionally the temperature of the housing can be entered too.

Temperature of rolling element

The temperature of the rolling element is assumed to be the maximum value of shaft and housing as default. This can be changed under settings and a manual input of the rolling element temperature is available optionally too.

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.



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.

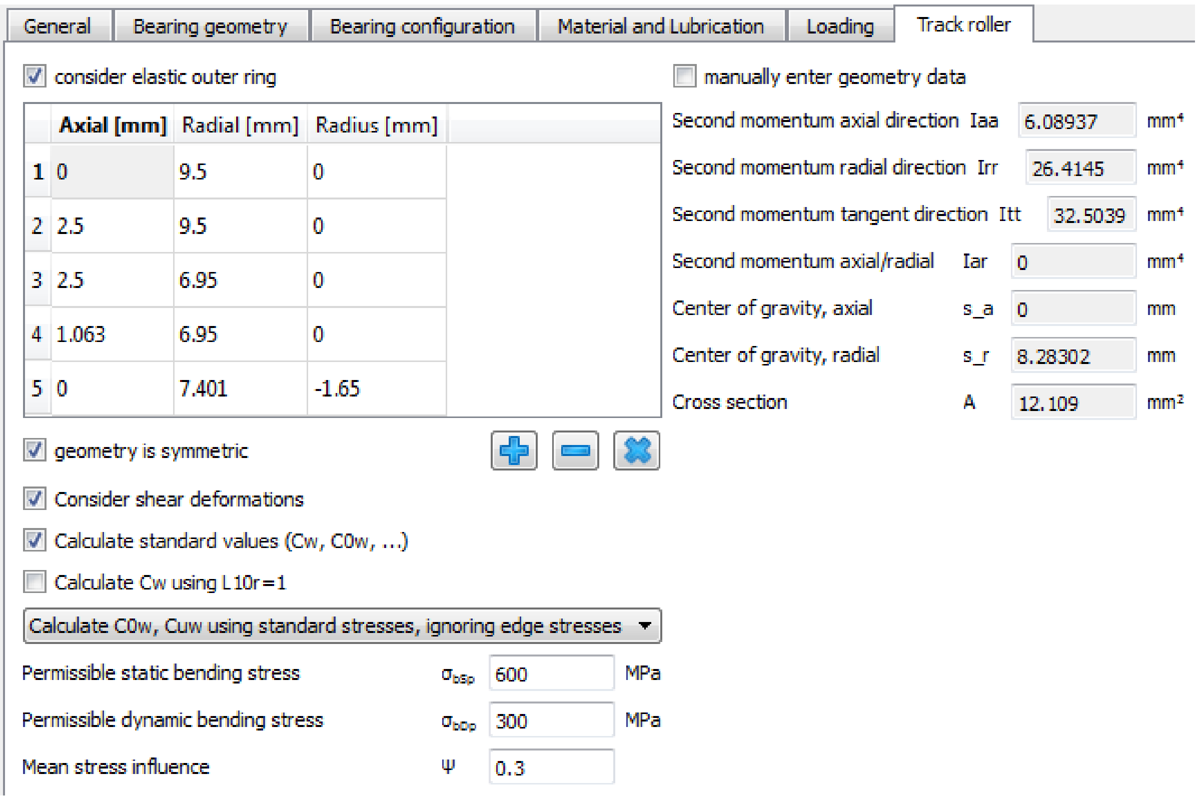
As for the single load case a selection is available if the ring is rotating relative to the load or not. A ring not rotating to the load would be on the safe side.

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.

Track rollers

Elastic deformations of the outer ring can be optionally enabled. This is an extension to the base bearing software.

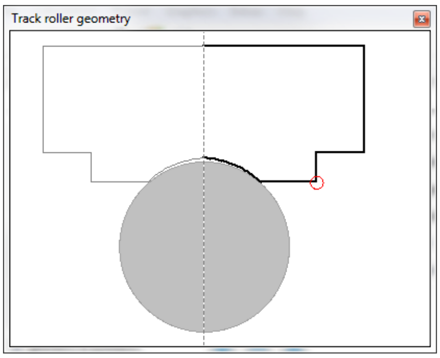
The outer ring of the bearing is modeled by a Timoshenko beam element. So bending, axial deformations and shear deformations are considered. The shear correction factor is fixed to 1. The calculation should only be used if the approximation as beam seems to be appropriate. The beam does not consider deformations within the cross section for example in axial direction for multi row bearings.



Supported bearing types

The calculation with elastic outer ring is only available for several bearing types. The calculation is possible for:

- Deep groove ball bearing
- Radial angular contact bearing
- Double row radial angular contact bearing
- Radial four point ball bearing
- Radial cylindrical roller bearing
- Double row cylindrical roller bearings
- Double row tapered roller bearings



Multi-row bearings can be considered using the “bearing configuration”.

Track roller geometry

The track roller geometry can be defined using several points. The contour starts at axial position zero on the outside of the bearing and is then defined in clockwise direction.

A radius can be defined in the third column. An arc from the last point to the new point will be generated. For a convex contour use a positive value, for a concave contour use a negative value. A clockwise arc has a positive radius, a counterclockwise arc a negative radius.

Either a full geometry is defined back to the start point or only half the geometry is defined for a symmetric outer ring. In the graphic for the symmetric track roller geometry the mirrored part is shown in grey.

Symmetric geometry

A symmetric geometry starts at axial position zero on the outside diameter and ands on axial position zero on the inner diameter.

An unsymmetrical geometry should end with its start point.

Consider shear deformations

As default shear deformations in the elastic outer ring should be considered. Since other software and old literature, see (Paland, 1968), is only considering deformations because of bending, the influence of shear deformations can be ignored by clearing this setting. The effective load capacities will be higher because the deformation of the outer ring is reduced.

Calculate standard values

Some standard values for track rollers can be calculated automatically using a pure radial load at axial position zero.

Because of elastic deformations of the outer ring track rollers show a different load distribution than rigid bearings. This leads to a decrease of life which is taken into account be giving reduced effective load capacities in bearing catalogs.

The effective dynamic load capacity C_w is given in bearing catalogs for track rollers. There are two options to calculate this value. See option 'Calculate C_w using L_{10r} = 1' below. Also for effective static load capacity there are two options. See section 'Calculation options for C_{0w} and C_{uw}' below.

The load capacities are calculated using a radial load on the angle of zero, so it is acting directly on a rolling element.

The static and dynamic permissible radial loads are the loads were the permissible bending stress is reached. See below. The permissible static and dynamic loads are calculated using a radial load which is acting between two rolling elements. This is the critical case.

If a bearing configuration is used effective load capacities and permissible radial loads are calculated for the whole bearing.

Calculate C_w using $L_{10r} = 1$

As the dynamic load capacity is defined in (ISO 281, 2007) a radial bearing loaded with $F_r = C$ should have a life $L_{10} = 1$ (One million load cycles). This definition is used for the definition of the effective dynamic load capacity if the option 'Calculate C_w using L_{10r} = 1' is set. The software iterates for a radial load which leads to L_{10r} = 1 and this is shown as effective dynamic load capacity C_w.

For bearings with a small number of rolling elements the life L_{10r} = 1 is not reached for the rigid bearing loaded with F_r = C. The reason is that (ISO 281, 2007) assumes a load zone of 180° which cannot be reached if only six rolling elements are used for example. Therefore a different definition for C_w is available if the option is not set. In this case C_w is defined to the radial load which leads to the same life as a rigid bearing with F_r = C.

This option will only have an influence for a small number of rolling elements. If the option is not set, C_w will lead to the same life for the elastic bearing as C for the rigid bearing.

Calculation options for C_{0w} and C_{uw}

Several options for the calculation of effective static load capacity are available.

Calculate C_{0w}, C_{uw} using standard stresses

If the option 'Calculate C_{0w}, C_{uw} using standard stresses' is set the effective static load capacity C_{0w} is defined as the radial load which leads to p_{max} = 4200 MPa (or 4000 MPa for roller bearings). The effective fatigue limit is defined similar, but with a stress of 1500 MPa in this case.

Calculate C_{0w}, C_{uw} using standard stresses, ignoring edge stress

For roller bearings edge stresses can occur on high loading leading to different results than usually found in bearing catalogues. Therefor a second option exists for the calculation of effective static load capacity C_{0w}.

If this option is selected the stress in the center of the roller is compared with the permissible stress as above. So edge stresses are not taken into account.

For ball bearings, this option does not affect the results, it only makes a difference for roller bearings.

Calculate C_{0w}, C_{uw} using roller load

If the option is set C0w is defined as the radial load which leads to the same maximum roller load than a rigid bearing loaded with F_r = C_0. Also for the calculation of C_{uw} the comparison of roller loading instead of stress is made.

If this option is selected the resulting C_{0w} has the same meaning than C_0 for the rigid bearing. It can be useful if own input is used for the static load capacity.

Permissible static bending stress

The permissible static bending stress is used to calculate the permissible static radial load and a safety factor for the bending stresses in the outer ring. The stress is calculated as maximal value of bending stress plus tension in the outer ring.

$$\sigma_{max} = \sigma_{b,max} + F_t/A$$

If not defined manually the software automatically selects the point of input geometry which leads to the highest stress. Only points in the geometry list are considered, no intermediate values. This could make a difference for convex radii.

Permissible dynamic bending stress

The permissible dynamic bending stress is used to calculate the permissible dynamic radial load and a safety factor for the bending stress amplitude. The stress is considered at the point where the maximal stress occurs.

$$\sigma_{max} = \sigma_{b,max} + F_t/A$$

$$\sigma_{min} = \sigma_{b,min} + F_t/A$$

$$\sigma_m = (\sigma_{max} + \sigma_{\text{min}})/2$$

$$\sigma_a = (\sigma_{max} - \sigma_{\text{min}})/2$$

The input value is a permissible alternating stress with is reduced by the mean stress influence coefficient ψ. The safety factor is calculated as

$$S_{dyn} = \frac{\sigma_{bDperm} - \Psi \cdot \sigma_m}{\sigma_a}$$

The permissible dynamic radial load is calculated so that a safety factor of 1 is reached.

Mean stress influence

The mean stress influence is considering the mean stress for calculating permissible amplitude of bending stress.

The mean stress influence coefficient can be calculated as $\Psi = \sigma_{bDperm}/(2 \cdot R_m - \sigma_{bDperm})$ using the definition according DIN 743.

Axial position for the load

If an asymmetric geometry is defined an axial position for the load can be defined. It is used for the calculation of standard values like Cw, C0w …

For symmetric geometry the load is applied at position zero.

Manually enter geometry data

It is not mandatory to enter the cross section using point data. Also cross section data can be introduced directly after calculating them by a CAD system for example.

If the cross section data is entered manually, also the critical point for calculating bending stresses has to be defined manually. Unfortunately, this point is load dependent. If you just have a radial load on a symmetric cross section this is not a problem, but you have to be careful in other cases.

Second momentums

The second momentums are given on polar coordinates for the cross section. They are given relative for the center of gravity, not for the origin of the coordinate system.

The second momentum in axial direction I_{aa} and in radial direction I_{rr} are usually available. For the tangent direction the torsional moment should be given, but since this is not usually known the polar moment $I_{tt} = I_{aa} + I_{rr}$ can be used as replacement. This is only exact for a circular cross section, but the torsion load is not the main loading to the outer ring, so it could be acceptable.

The deviatory momentum is defined as $I_{ar} = +\iint a \cdot r \, dA$. Depending on the literature also definitions with a negative sign are usual. The deviatory momentum is zero for symmetric cross sections.

Center of gravity

The center of gravity is defined using its axial and radial coordinate. For symmetric cross sections the axial position is zero.

Cross section

The cross section of the outer ring has to be entered here. Since the calculation is considering tension and shear deformations it has an influence on the load distribution.

Critical point

The critical point for the calculation of bending stress has to be entered if the geometry data is entered manually. The bending stress is calculated using this point.

Be sure to enter the correct value for the given load conditions. The critical point is marked with a red circle in the graphics of track roller geometry.

Track roller loading

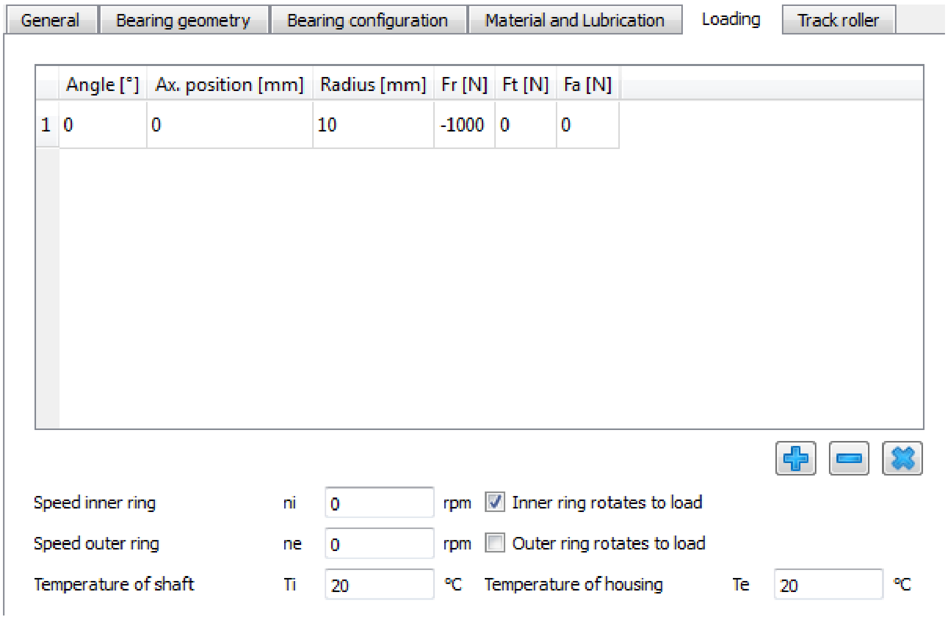
In the case of elastic outer ring the input of loading is changed. Instead of the load onto the inner ring, the load on the outer ring can be defined on several points. It is not possible to define displacements or rotations directly.

An angle, axial and radial positions define the point where the load is acting. The load can be defined in axial, radial and tangential direction. Since the overall torque has to be zero an input of tangential load can only be used if several loads are defined.

The coordinate system is standard a cylindrical coordinate system with r-direction pointing to the outside. Therefore, Fr should usually be entered as negative value for pressure.

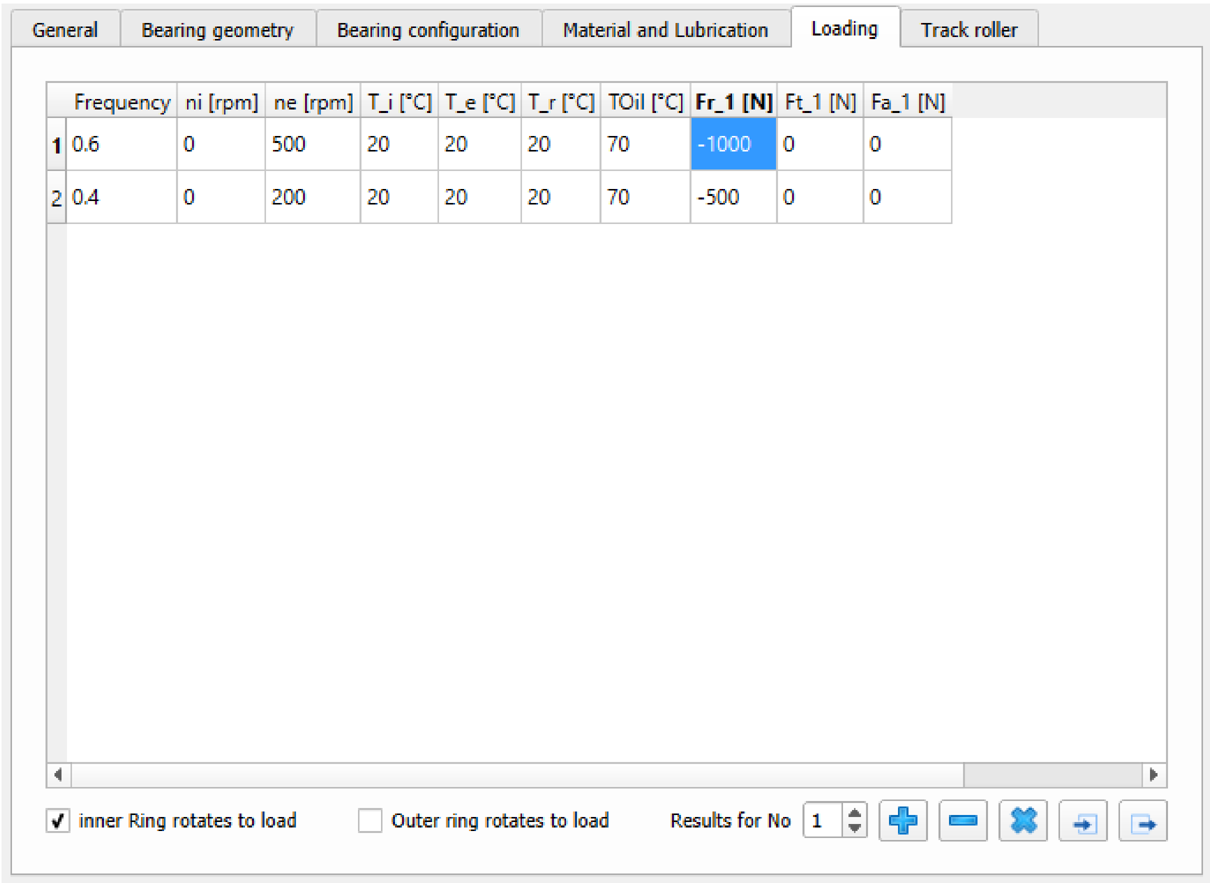
The axial position can be used if you assume that the radial load is not centric. An eccentrical load leads to torsion of the outer ring.

The first rolling element on the y-axis is at an angle of zero. The results will be different if the load is applied on the position of a rolling element or between them. Both cases should be considered in doubt.



Load spectra for track rollers

If load spectra are used for track rollers as a first step the location of forces has to be defined in the loading page without activating load spectra. If the load spectra are activated afterwards a column for each force is available as input.

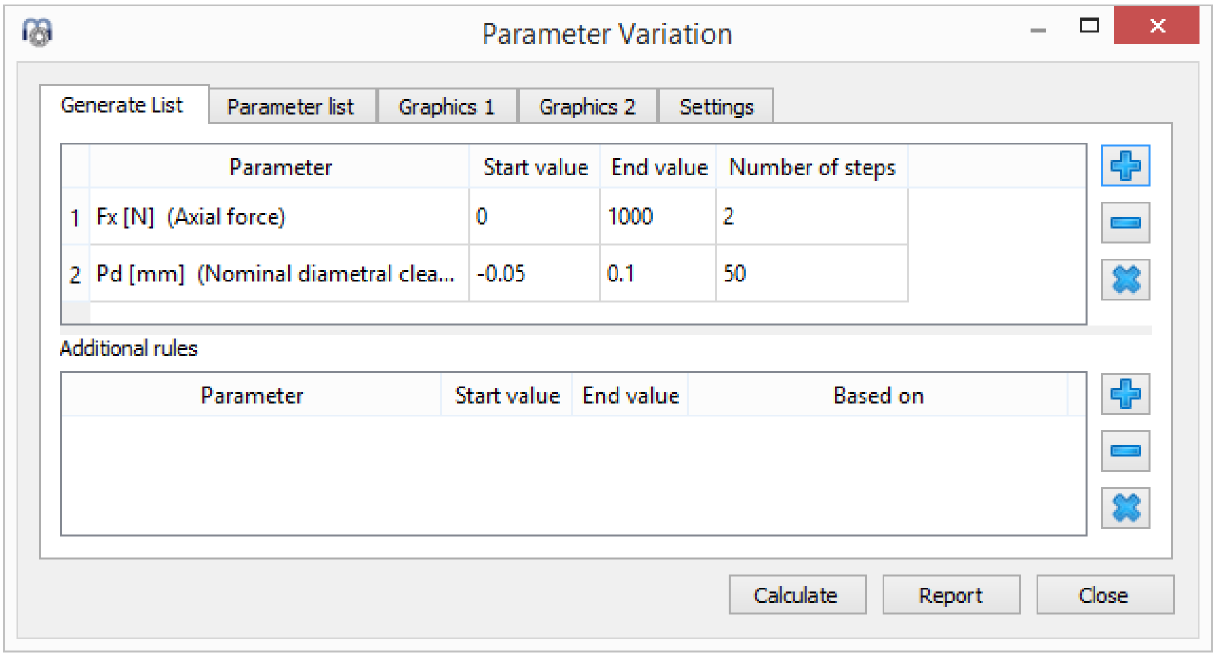


Parameter variations

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.



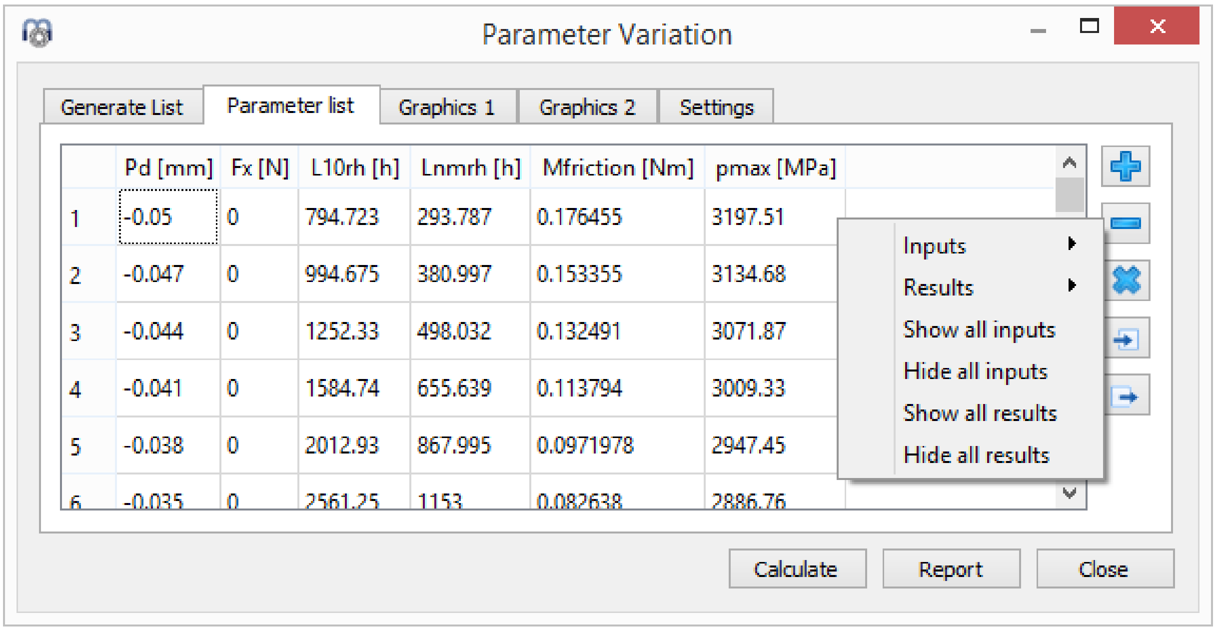
Additional rules can be used to set additional input parameters dependent on parameters on the first list. The additional parameter is interpolated between a start and end value based on another parameter. For example additional parameter y between y1 and y2 based on parameter x in range x1 to x2:

$$y = y_1 + \frac{y_2 - y_1}{x_2 - x_1}(x - x_1)$$

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.



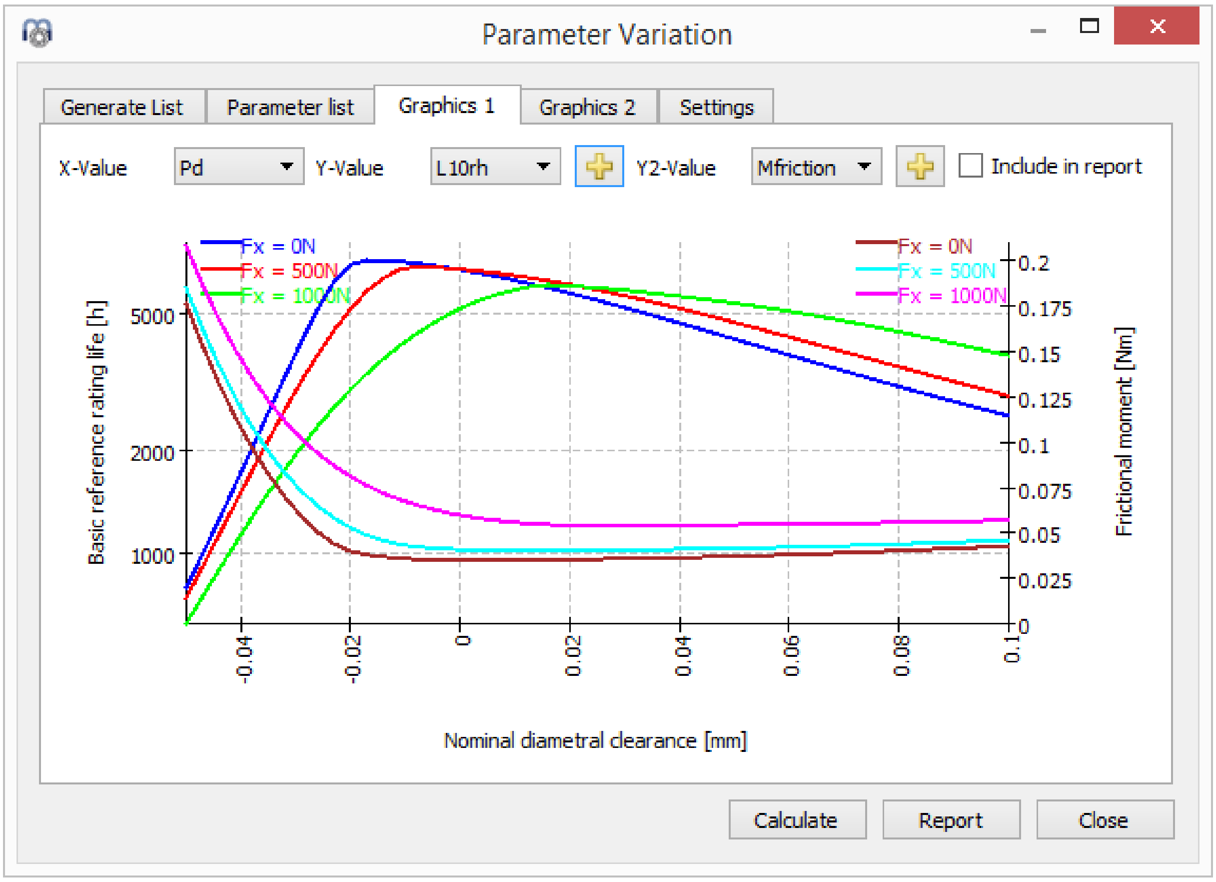
By clicking on 'Calculate' while the "Generate list" tab window is active, a list of all parameter combinations will be generated at the corresponding tab window 'Parameter list' and the analysis will be run. Depending on the chosen number of parameters and steps, the analysis can lead to long calculation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



In case only one input parameter is selected, 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 life (L10rh) 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 'Lnmrh' shown in 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

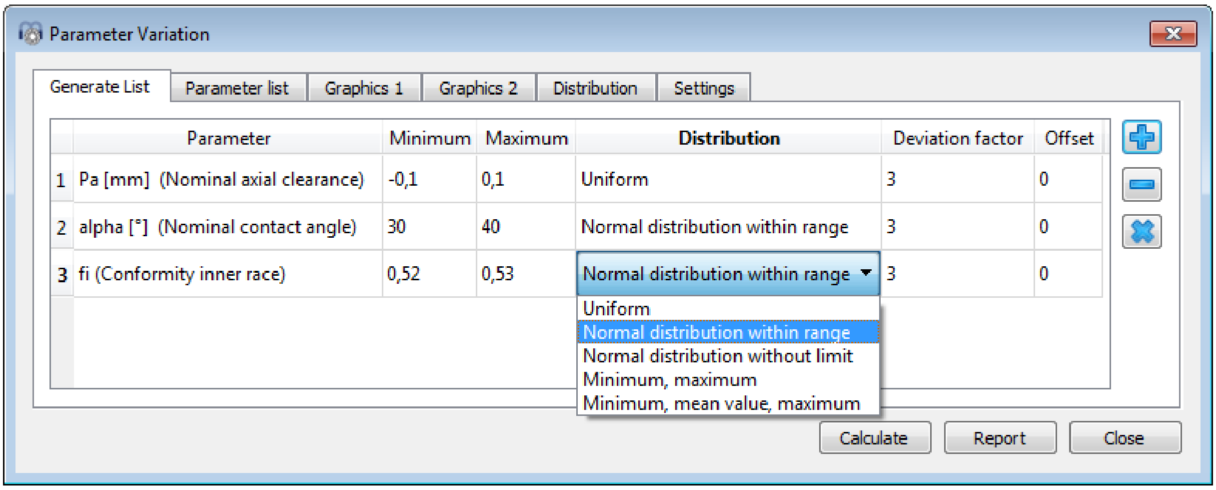
Using the menu point "Calculation"->"Parameter variation (statistical)" an analogous tool to the default parameter variation is available. The main difference between them lies in the fact that this tool supports statistical evaluations when doing parameter variations.

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:



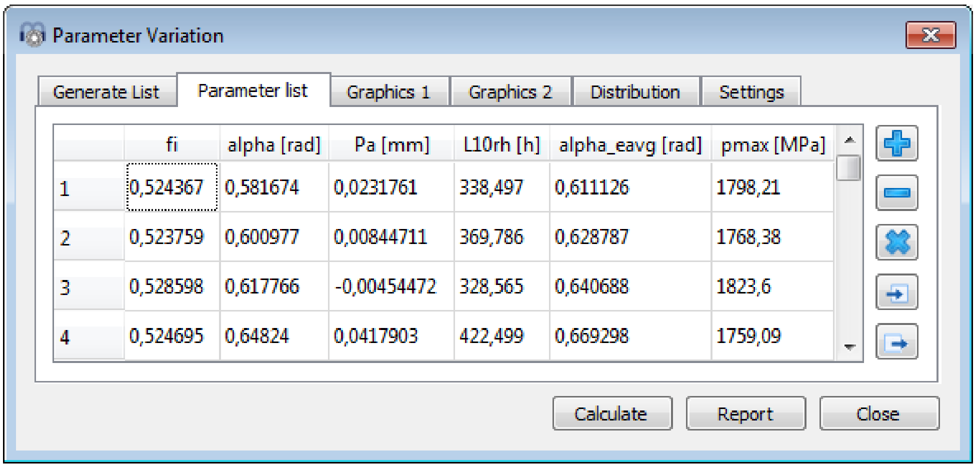
- Uniform: The probability is equally distributed for a set of values between the maximum and minimum value of the parameter.
- Normal distribution within range: The probability is calculated for a set of values ranging from the minimum to maximum by using a normal distribution.
- Normal distribution 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

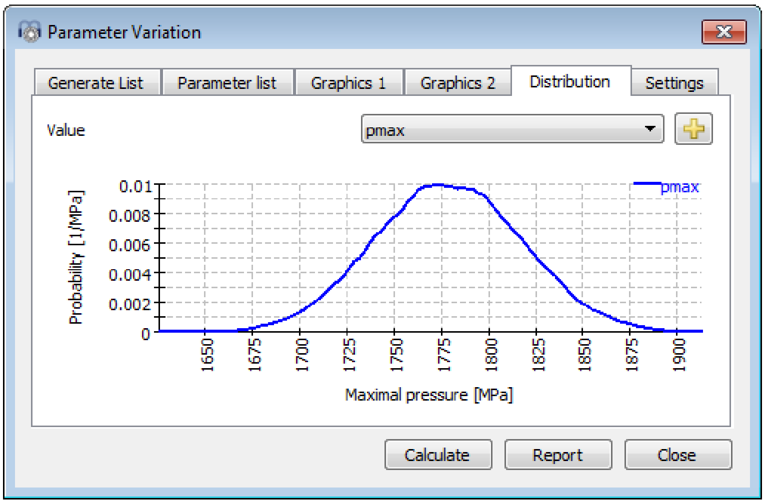
The generation of the parameter list is performed as explained for the non-statistical parameter variation. By clicking on ‘Calculate’ while the “Generate list” tab window is active, a list of all parameter combinations will be generated at the corresponding tab window ‘Parameter list’ and the statistical 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.



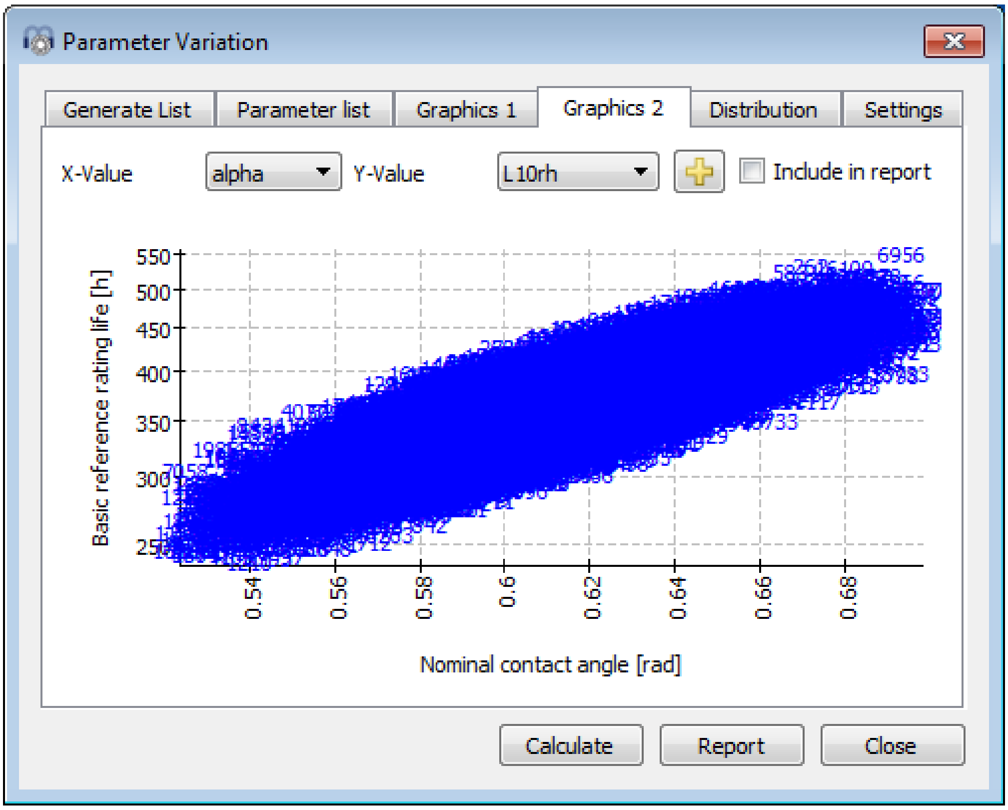
Distribution

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 some trends for the relationship between the parameters might be recognized, as shown in the picture below.

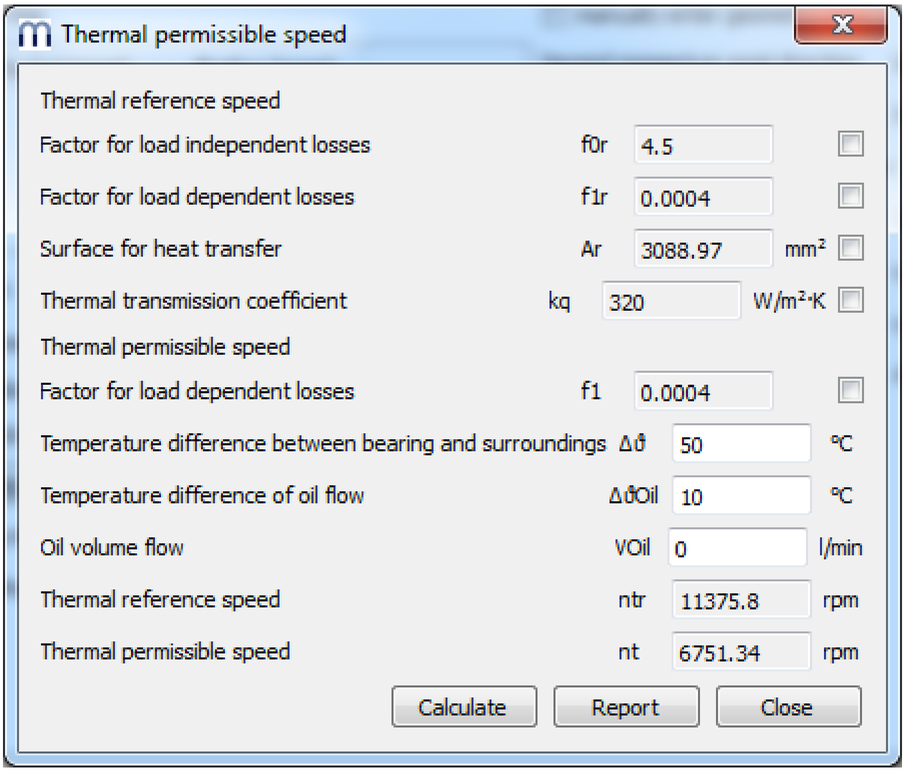


Report

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.

Thermal permissible speed

The thermal reference speed according (ISO 15312, 2003) and the thermal permissible speed according (DIN 732, 2010) are calculated by the software. The calculation can be run separately under menu ‘Calculation’->’Thermal permissible speed’.



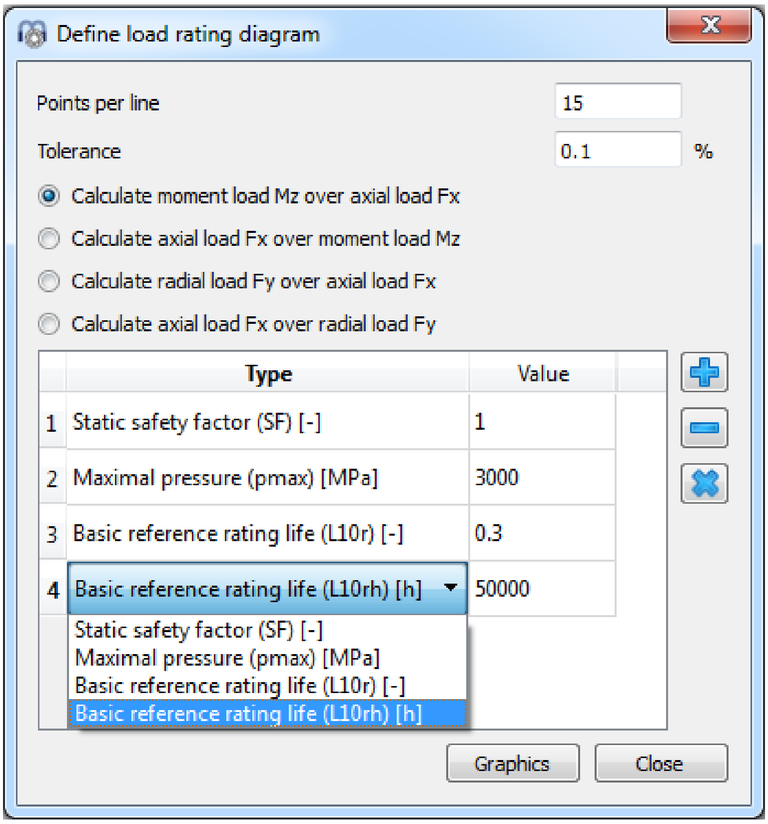
Most of the parameters can be overwritten by the user. Note that the calculation is just according to the standard. The equivalent load is calculated by axial and radial load, moment load is not considered. Also clearance is not considered.

If a bearing geometry is not considered in the standard, the input values for f0r, f1t and f1 can be entered by the user and the calculation can be run.

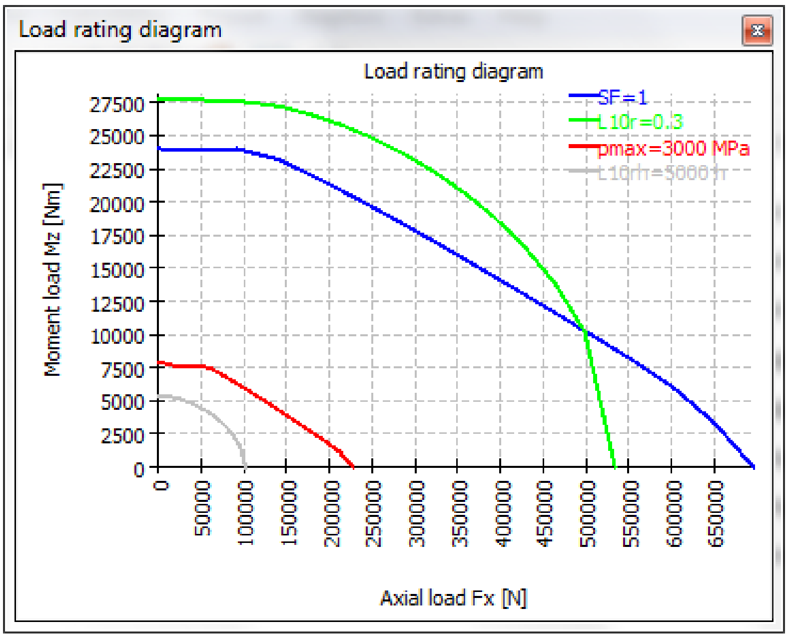
The results for thermal reference speed and for thermal permissible speed are also shown in the main report.

Load rating diagram

A load rating diagram can be configured at menu 'Calculation'->'Load rating diagram'. It allow us to show four possible line charts, where the variables of the XY axes are compared against each other (Mz-Fx, Fx-Mz, Fy-Fx, Fx-Fy) while maintaining constant four types of values predefined by the user (see the picture). These diagrams are often used for slewing rings.



In the following picture it is shown a graphic example of the load rating diagram by which tilting moment (Mz) is compared against axial load (Fx) for a security factor of 1, Maximal pressure of 3000 Mpa, 300,000 cycles and 50000 h.

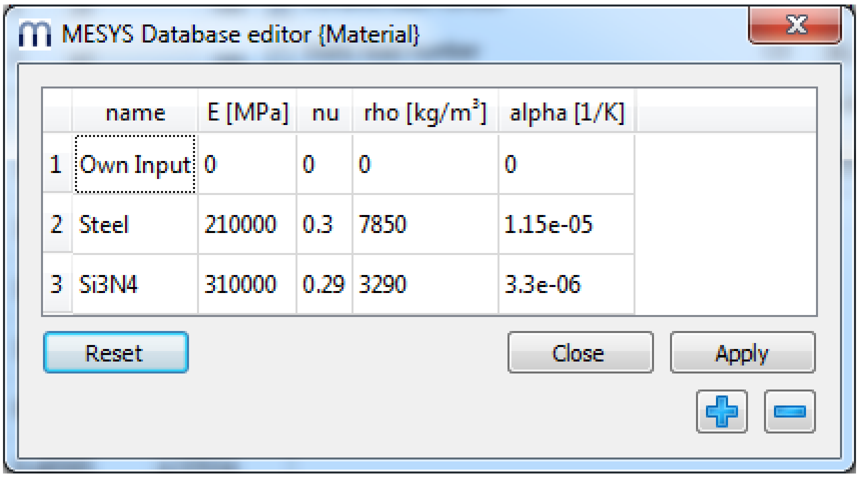


For each axial load the tilting moment is increased until the selected criteria are reached. The number of points used for one line and a tolerance for the calculation can be defined.

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

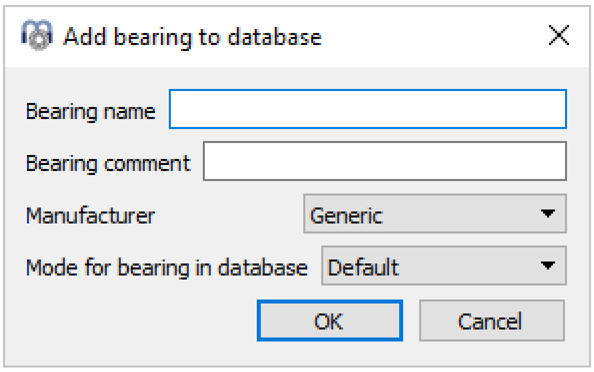
When a calculation file is loaded, the software searches the database for combinations of id and name of a dataset. If the item is not found the inputs are changed to 'own input'.

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.

Add bearings to database

For adding bearings to the database please enter the geometry data into the calculation windows, run the calculation and then select 'Extras->Database->Add bearing to database'. You will be prompted for bearing name, comment, manufacturer and a database mode.



If the combination of name and manufacturer is already found in the database you will be asked if the dataset should be overwritten.

The mode can be

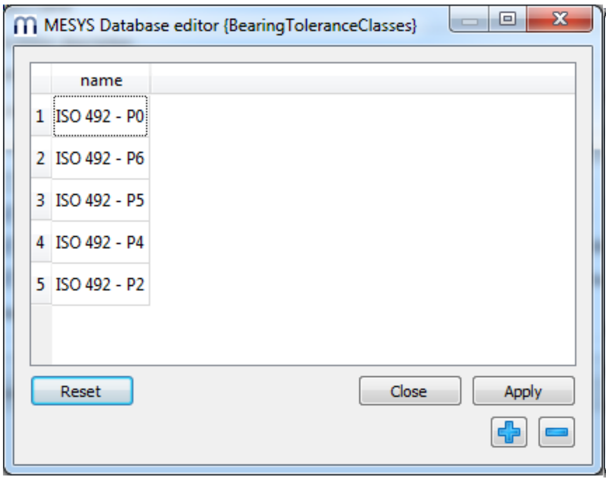
- “Default”: Default behavior
- “Approximated”: A comment about approximated inner geometry will be shown in the report and damage frequencies will not be shown
- “Hide inner geometry”: Inner geometry will not be available in the report and in input data. This option is for additional encrypted databases.

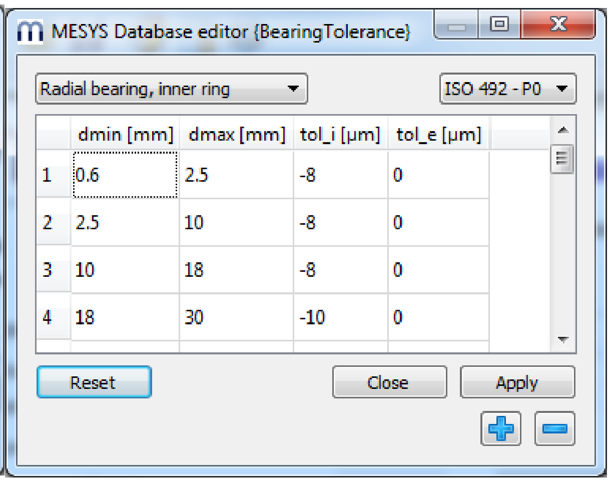
Database Tables

For some database tables more information about usage is given in the following sections.

Bearing Clearance and Bearing Tolerance

For clearance and tolerance definitions two tables have to be used. In Table ‘BearingClearanceClasses’ or ‘BearingToleranceClasses’ the available names are defined.





In table ‘BearingClearance’ and ‘BearingTolerance’ then the actual values are defined dependent on the diameter.

Bearing Materials

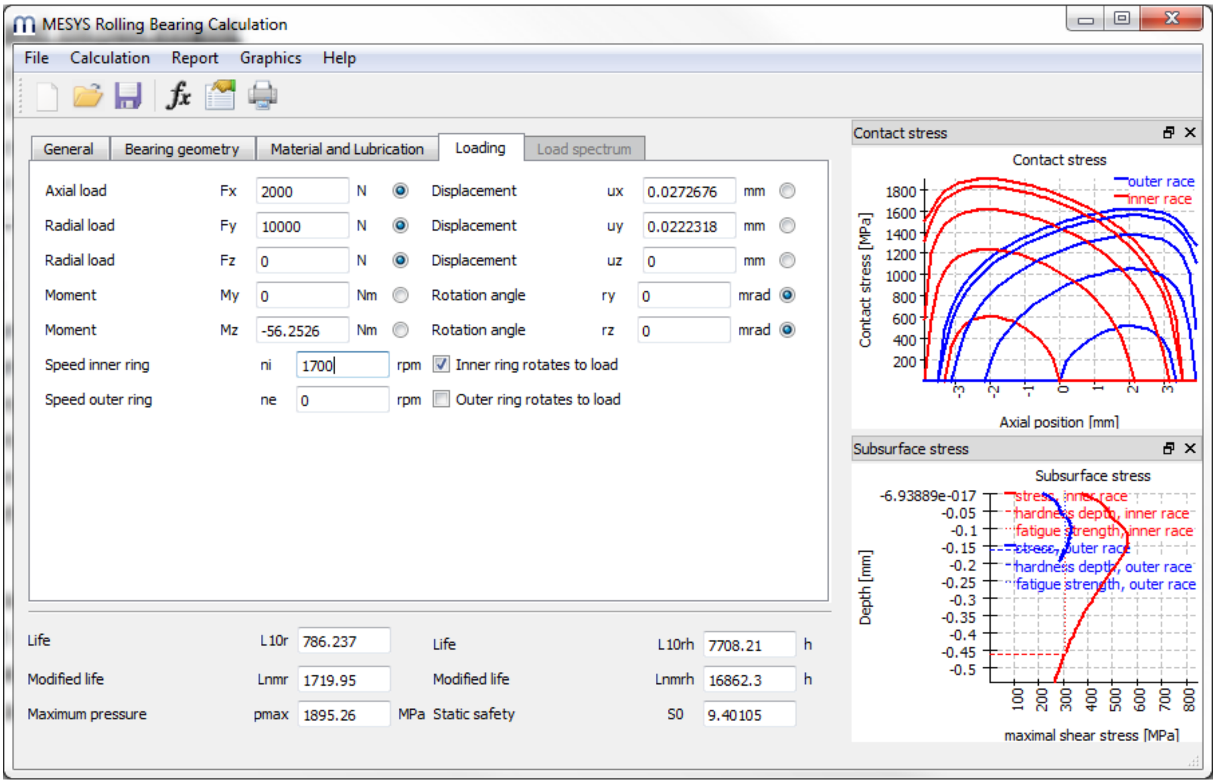
The table ‘Material Bearings’ allows to set additional information about permissible stresses for bearing calculations.

Bearing Manufacturers

The tables ‘Bearing Manufacturers’ allows to set additional names for bearing manufacturers.

Results

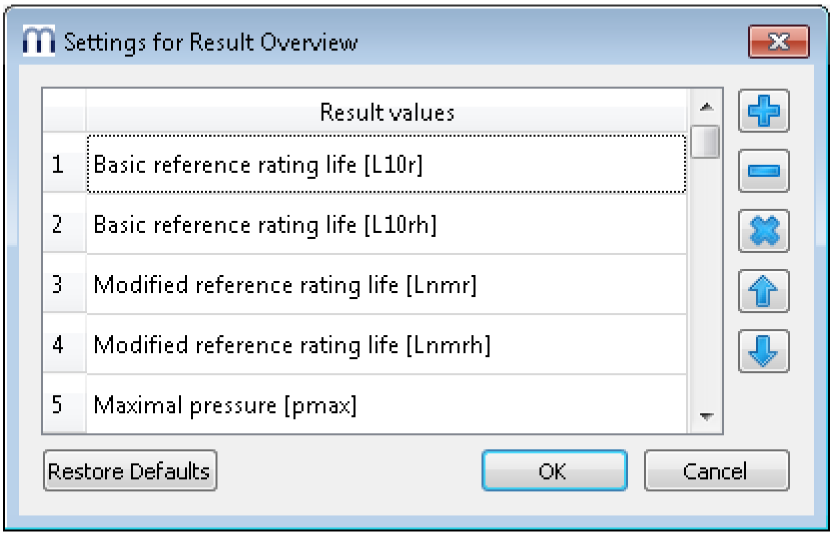
Results are provided as a small result overview directly in the software, a main PDF text report, a tolerance report and separate graphics windows. Graphic windows can be docked onto the main program interface and are automatically updated on each calculation.



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.

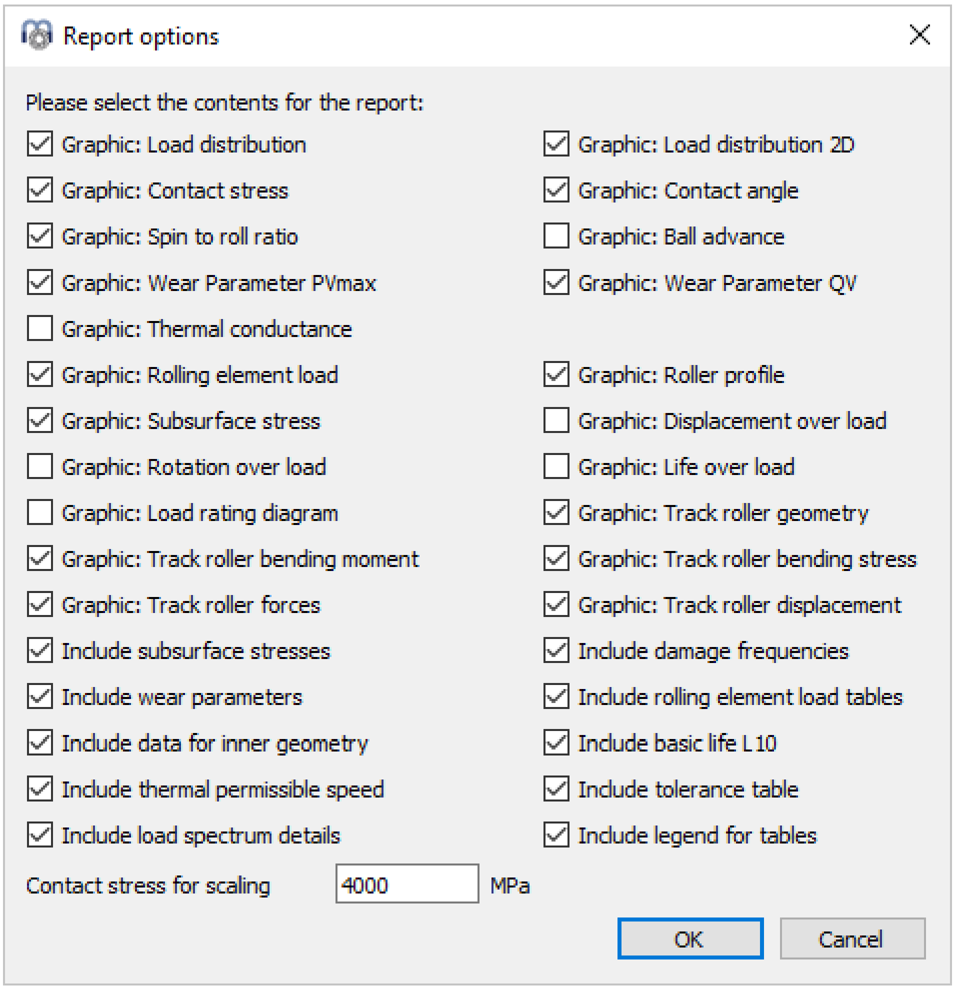


The result overview can be customized using "Extras->Result overview". The items shown in the overview can be selected and additional items can be added using the -button or the context menu with the right mouse button. Note that only values are actually shown in the result overview that are valid. So 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. An example report is available as separate document. The results are provided in sections 'Bearing inner geometry', 'Forces and displacement', 'Life', 'Subsurface stresses' and 'Damage frequencies'.



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 defining a logo in the “mesys.ini” file. 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.

Result tables

In the menu Report->Result tables, it is possible to output the result data by means of tables, which can be generated in different file formats as explained before at “Configuration with INI-File” (p.3).

Tolerances Report

In the menu Report->Tolerance report a special report for tolerances can be generated. While the tolerances for the selected calculation case are included in the main report, the additional report shows tolerances and pressure for maximum, medium and minimum clearance.

Custom Report Templates

Custom report templates can be added in subdirectory “templates/rbc”. Reports based on these templates can be generated by selecting the report template under Report->Report templates.

The report templates are word files with DOCVARIABLE fields. These fields are filled on generation of the report.

Possible fields are:

- DOCVARIABLE VAR name [unit]: the variable with the name ‘name’ is printed. Optionally a unit can be provided in brackets, for example [mm]. Additionally, a format could be added like %6.3g or %6.3f, where ‘f’ always generates a fixed point output and ‘g’ generates an exponential output for large numbers.
- DOCVARIABLE VARU name [unit]: the variable with the name ‘name’ plus the unit are printed. Optionally a unit can be provided in brackets, for example [mm]
- DOCVARIABLE TABLE tablename: A table is inserted
- DOCVARIABLE GRAPHIC graphicName width=130 height=70: A graphic is inserted. Optionally height and width can be given in millimeters.

Regarding details for variable names, table names and graphic names please ask support@mesys.ch for additional documentation.

Result Graphics

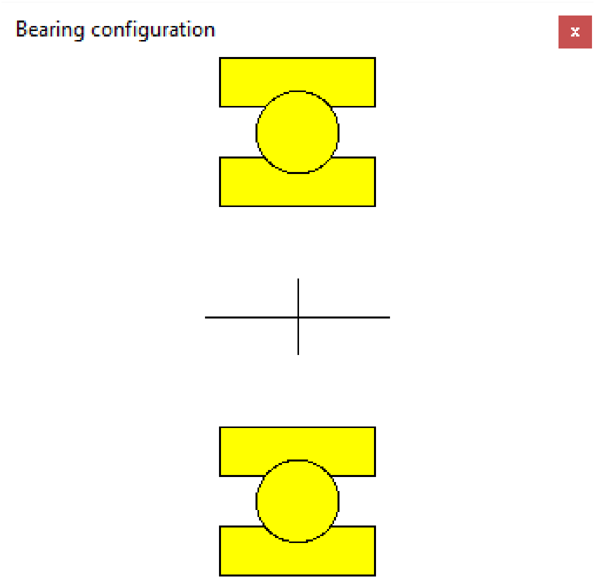
Several results can be shown as graphics.

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.

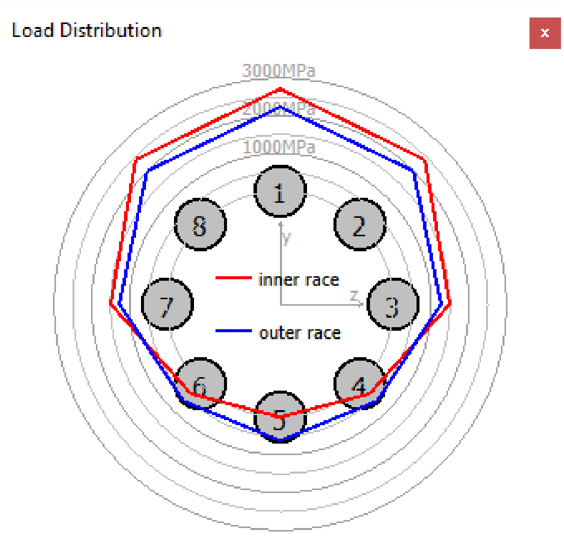
Bearing configuration

The bearing configuration shows the bearing rows and their position. It is mainly used together with the bearing configuration. Bearing inner and outer diameter has to be defined for generating this image.



Load distribution

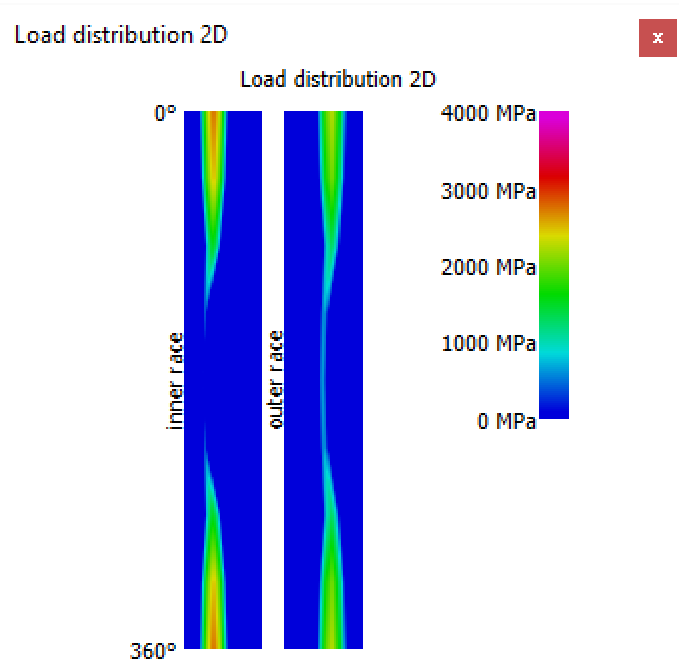
Here the contact stress of an angular contact bearing with radial and axial load and relatively high speed is shown. The contact stress is larger on the inner race (red) in the load zone but slightly larger on the outer race on the opposite side because of centrifugal loads.



Load distribution 2D

The 2D load distribution shows the pressure distribution on inner and outer race as color strip. The maximum stress for the scale can be defined under report options. The graphic is available for a single load case and for the whole load spectrum.

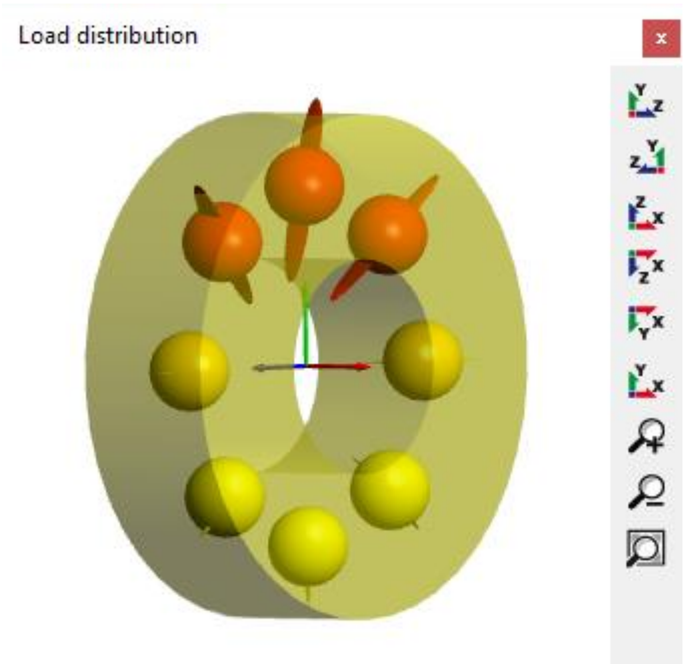
This diagram also gives an impression of contact angle variation.



Load distribution 3D

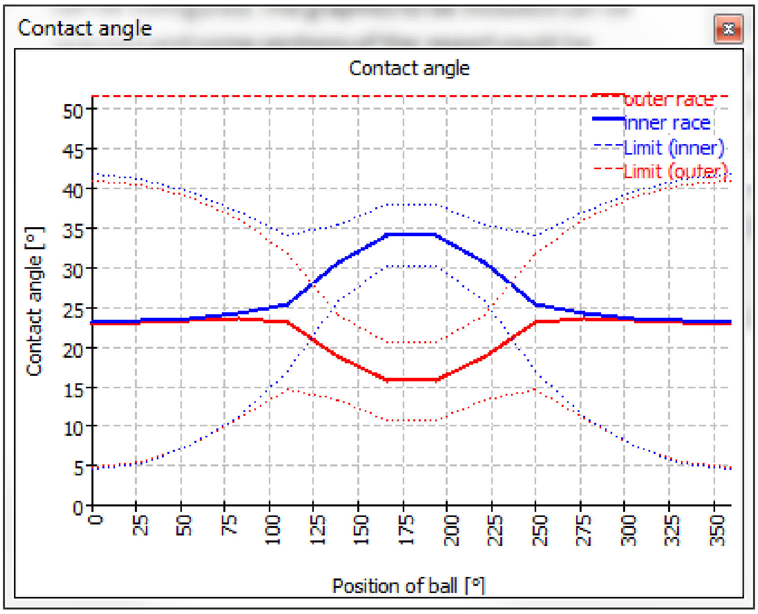
This diagram shows the load distribution on a 3D visualization of the bearing. The stress level is indicated by the color of the rolling element and the contact ellipse. The visualization can be accurately rendered in any perspective.

The 3D views can be rotated with the left mouse button. Panning is activated by pressing “Shift”, zooming by pressing “Ctrl”.



Contact angle

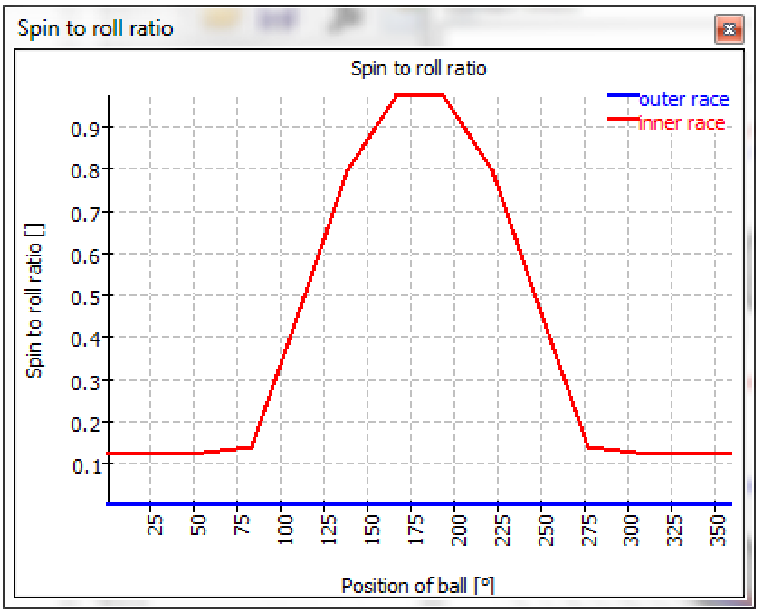
The contact angle is shown for an angular contact bearing with nominal contact angle of 20°. In the load zone the contact angles of inner and outer race are almost equal, but there is a big difference opposite to the load zone because of the centrifugal load.



The extension of the contact ellipsis is shown with the dotted lines, so we have a wide contact ellipsis at 0° and a smaller one at 180°. 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.

Spin to roll ratio

The spin to roll ratio can be shown also. The calculation assumes 'outer race control' if either relative speed or friction coefficient is zero so there is no spinning at the outer race and all the spin occurs at inner race.
If speed and friction coefficient are not zero, spinning and rolling speed are calculated considering Coulomb friction.

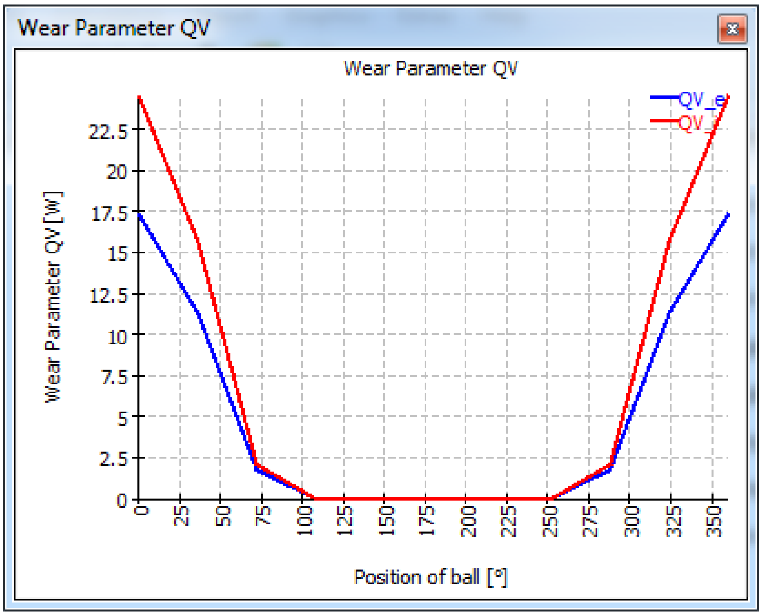


Wear parameter QV

For ball bearings spinning and rolling speed are calculated in the contact ellipsis.

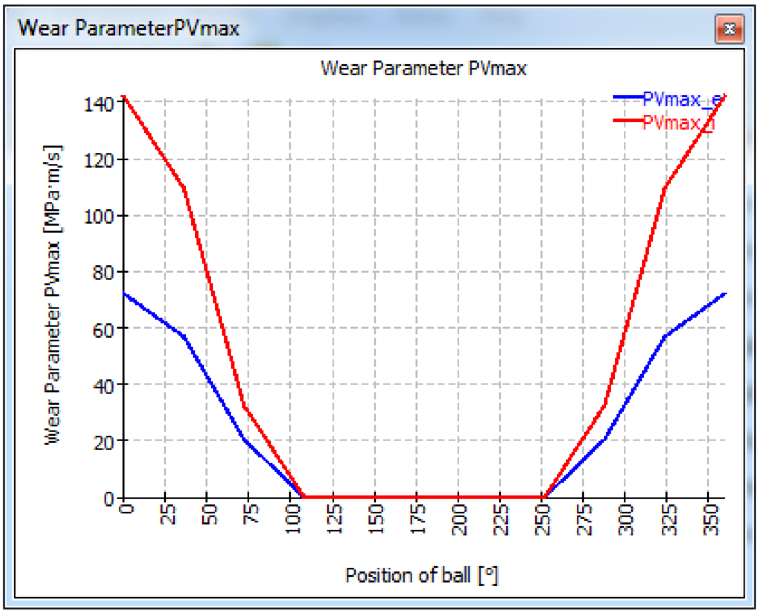
The wear parameter QV is calculated for each contact zone as

$$QV = \int p \cdot v \, dA$$



Wear Parameter PVmax

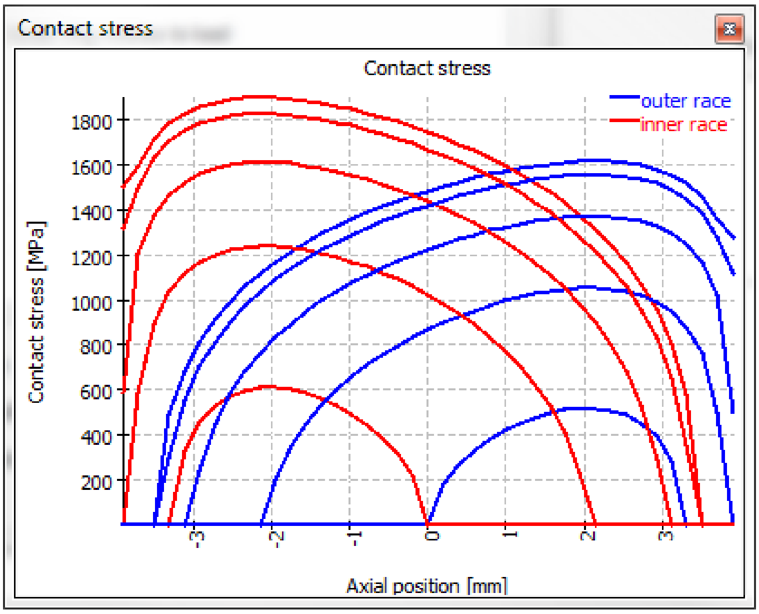
The wear parameter PVmax is the maximum value of the product pressure times sliding velocity in the contact ellipsis.



Contact stress for roller bearings

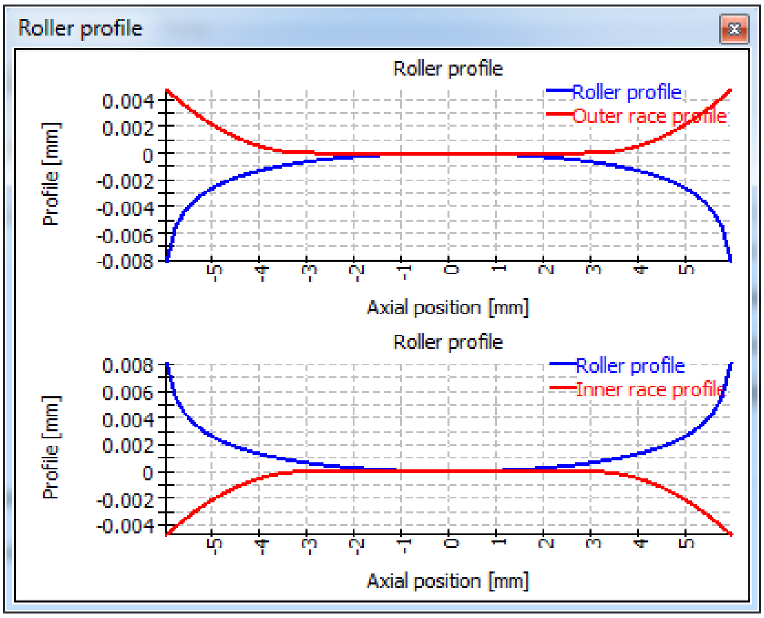
The contact stress for roller bearings is shown over the axial position or the length of the roller. This example is for a cylindrical roller bearing under radial and axial load and without misalignment between inner and outer race.

Because of the tilting of rollers under axial load the radial load is not distributed equally over the length of the roller.



Roller profile

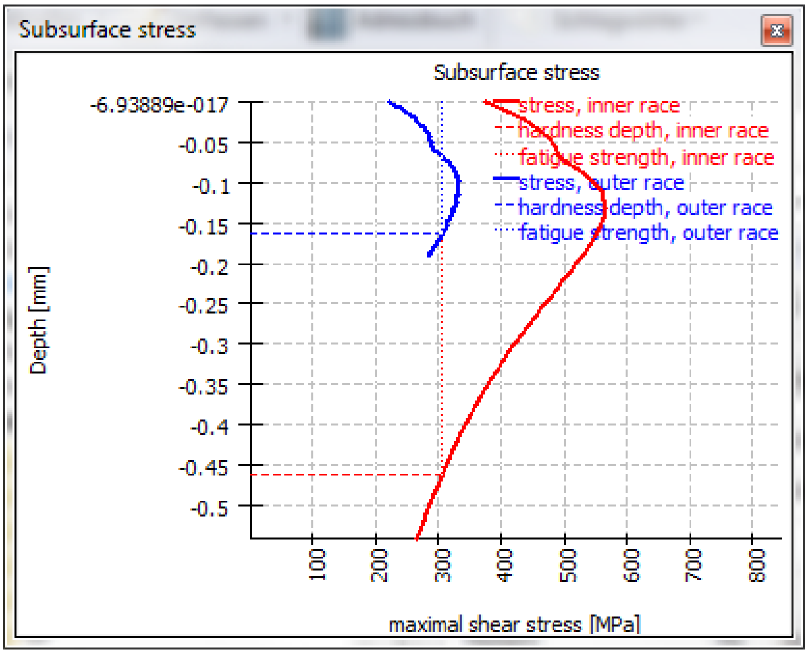
The roller profile and the profile of the races can be shown graphically. The profile can only be user defined if the extended method for pressure distribution is activated



Subsurface stress

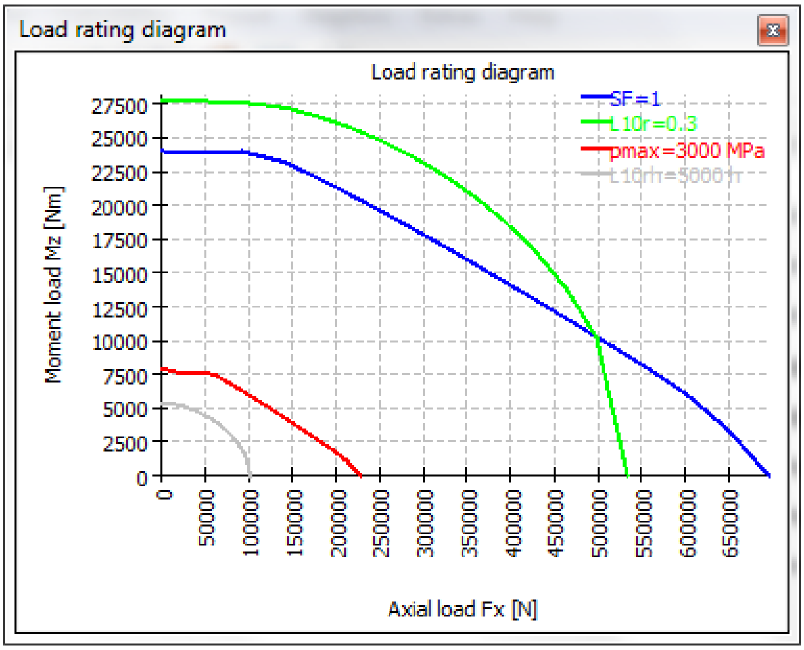
The subsurface shear stress is shown for the contact with the highest surface pressure. The required hardness depth is shown in the diagram dependent on the fatigue strength of inner and outer race.

The red curve is for the shear stress of the inner race, the blue curve for the outer race.



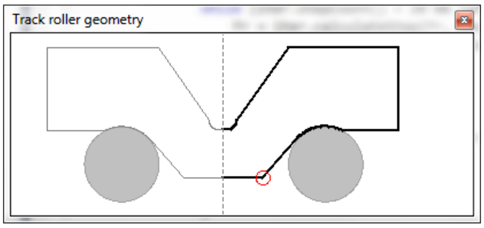
Load rating diagram

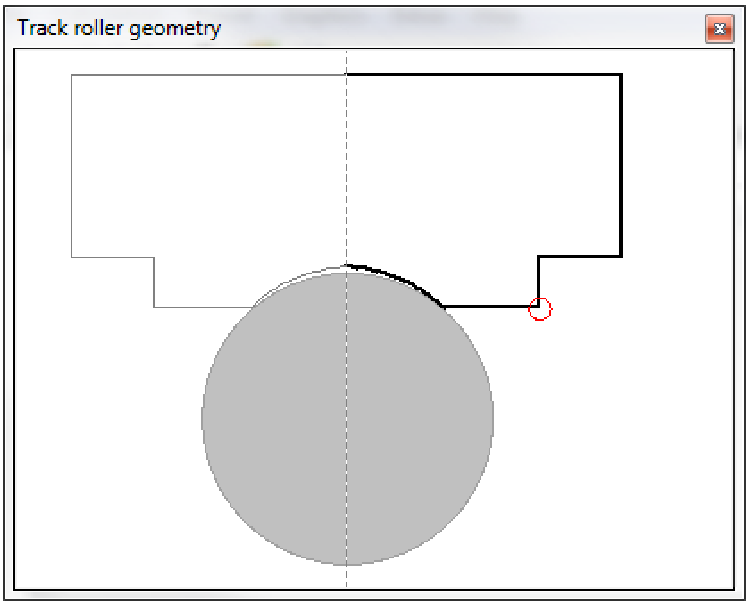
The load rating diagram shows the permissible range for tilting moment and axial load for different criteria which can be configured under 'Calculation'->'Load rating diagram'.



Track roller geometry

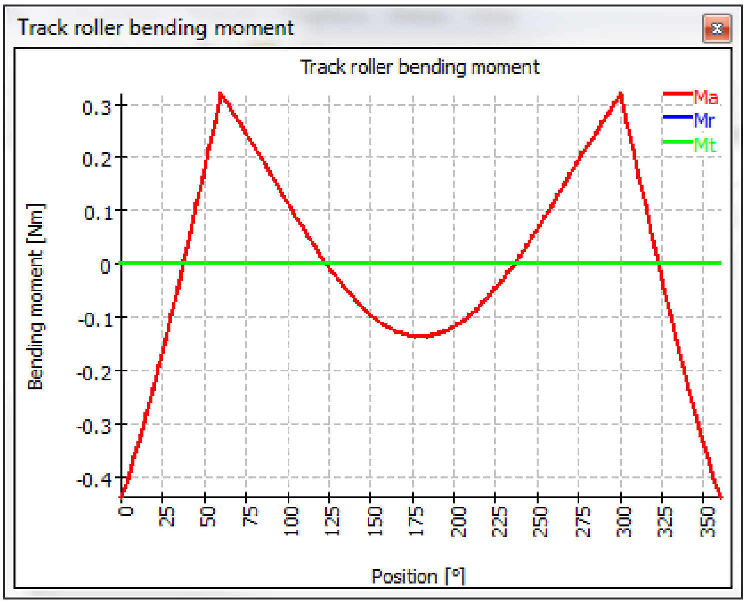
The track roller geometry is shown if defined using point data. For symmetric cross sections the mirrored is shown in grey and the critical point for bending is marked by a red circle.





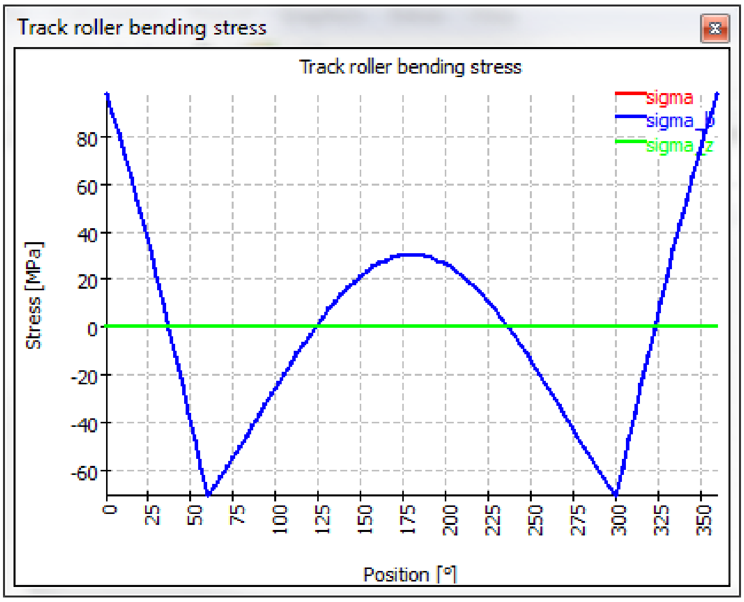
Track roller bending moment

The track roller bending moment is shown using the local coordinate system. For a pure radial load on a symmetric cross section only the Moment around the bearing axis M_a occurs. The moment M_r is a tilting around a radial axis and the moment M_t is a torsional moment in the beam describing the outer ring.



Track roller bending stress

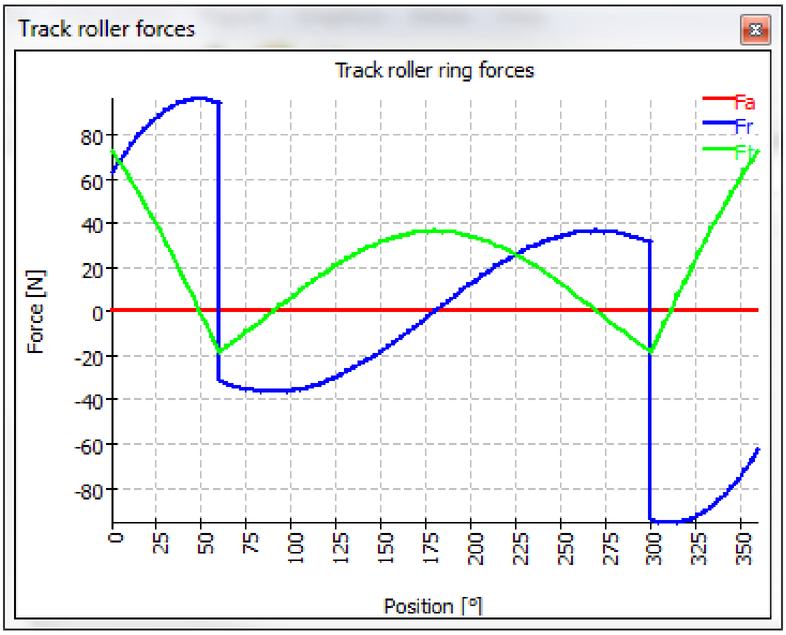
The bending stress and the stress due to tension are shown in the diagram. The bending is calculated for a critical point either defined manually or automatically by the software. These stresses are used to calculate a static and dynamic safety factor for the outer ring.



Track roller forces

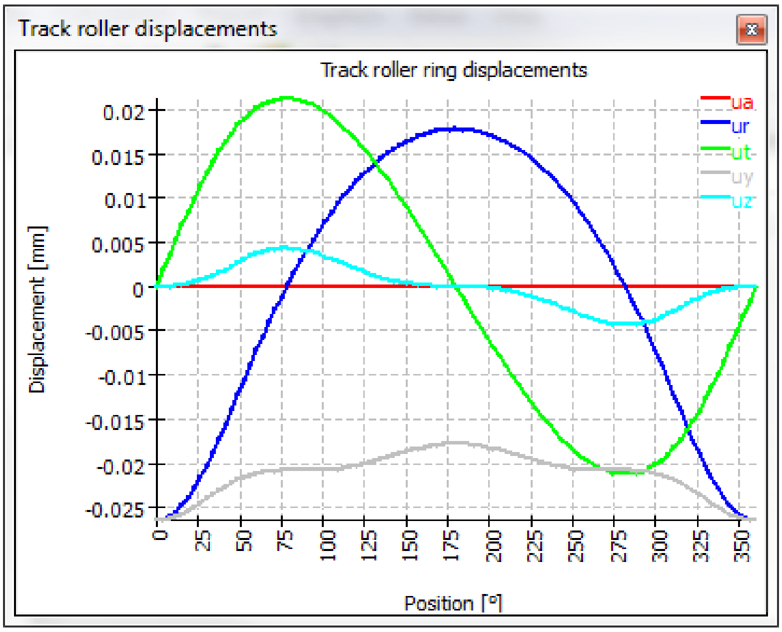
The forces in the beam modeling the outer ring are shown. The force F_a is in the direction of be bearing axis, therefore it is a shear force in the beam. The force F_r is a shear force in radial direction and F_t is the tangential force so it is tension (positive) or pressure (negative) in the beam.

We can also see that loads are only introduced at 0°, 60° and 300°, so only three rolling elements are under load.



Track roller displacements

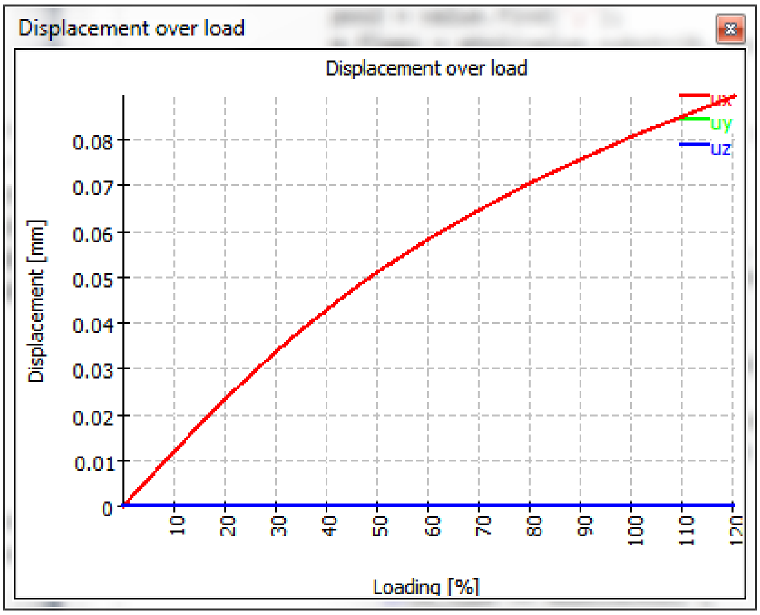
The displacements are shown in local coordinates and in global coordinated. The global coordinates allow seeing quickly that this example makes mainly a rigid body movement of the outer ring in negative y-direction. In other examples the deformations of the ring might be different, so the values in local coordinates are more important.



Displacement over load

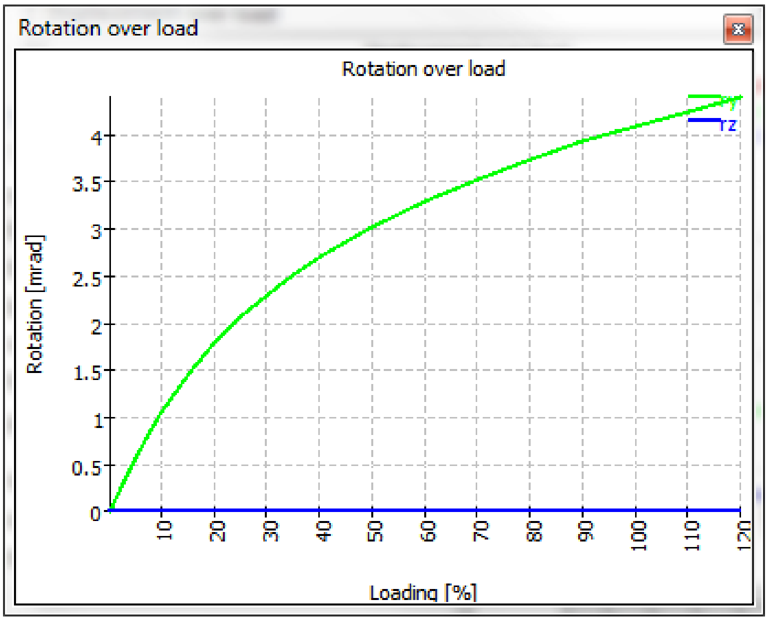
The displacement over load can be shown as graphics. All load components are multiplied with a load factor and the displacements are shown. Only loads are multiplied with the load factor, displacements or rotations entered are not modified.

This diagram can be used as information about stiffness. Dependent on the type of loading (axial or radial) different stiffness can be calculated.



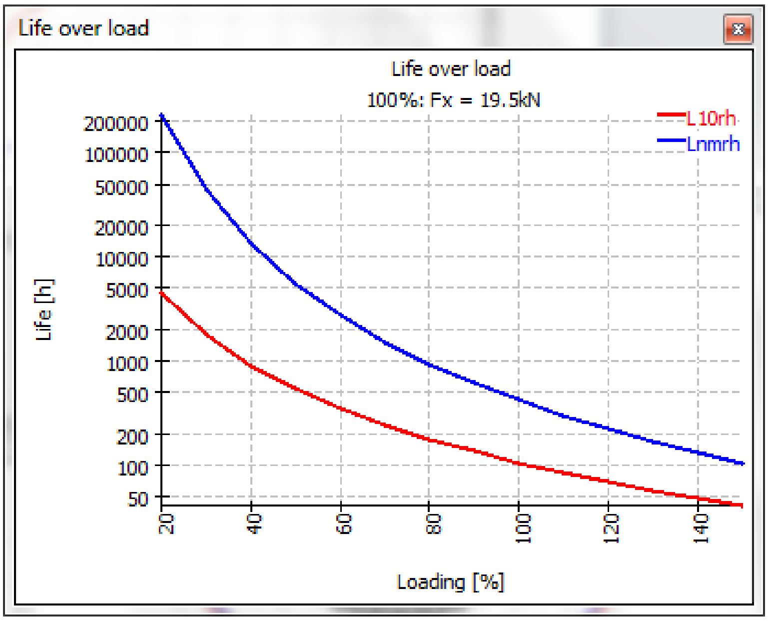
Rotation over load

Like in the graphics before the rotations are shown dependent on a load factor. This graphic can only be shown if the moment is an input not for the tilting angle as an input. All loads are multiplied with the load factor.



Life over load

The life over a load factor can be shown as a diagram. All loads and moments are multiplied by a load factor; all inputs for displacements/rotations stay constant. As reference the loading is shown on top of the diagram.



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