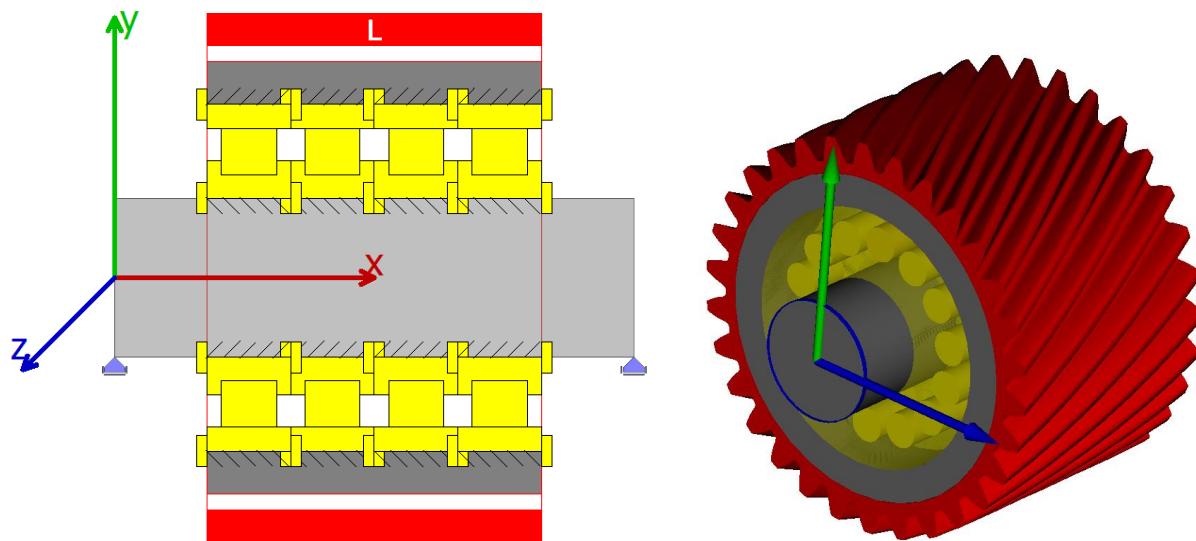


Tutorial: Calculation of a planet support with cylindrical roller bearings

A helical planet is supported by four cylindrical roller bearings. Because of the helical gear a radial load and a moment load has to be supported by the bearings.

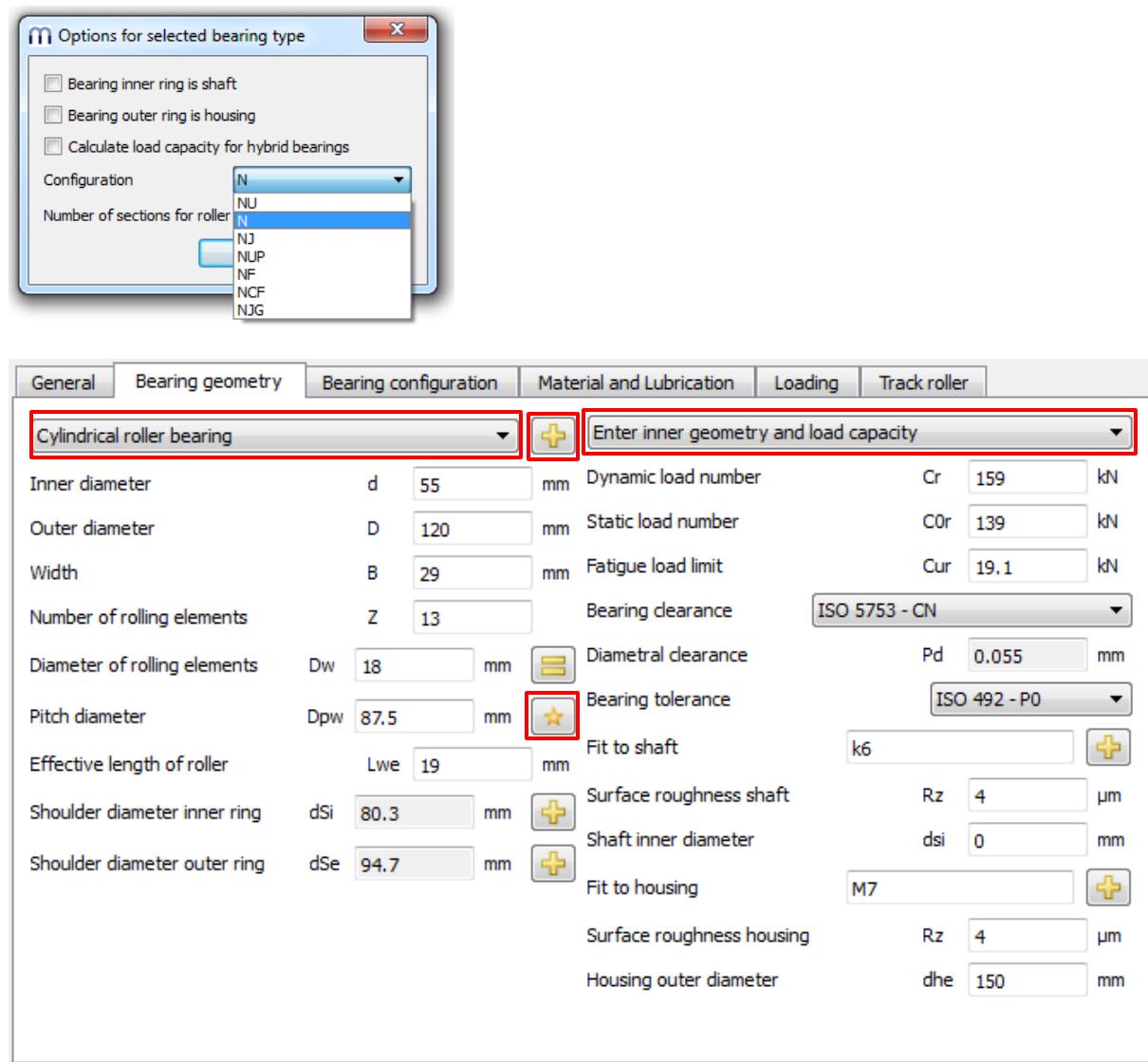


Bearing geometry

The bearing geometry for a cylindrical roller bearing N311 is provided in the following table:

Item	Formula	Value	Unit
Inner diameter	d	55	mm
Outer diameter	D	120	mm
Width	B	29	mm
Number of rollers	Z	13	
Roller diameter	Dw	18	mm
Length of roller	Lwe	19	mm
Pitch diameter	Dpw	87.5	mm
Dynamic load capacity	C	159	kN
Static load capacity	C0	139	kN
Fatigue limit	Cu	19.1	kN
Bearing clearance		CN	
Bearing tolerance		P0	
Shaft tolerance		k6	
Housing tolerance		M7	
Pitch diameter gear	dhe	150	mm

By selecting the tab corresponding to the page “Bearing geometry”, the geometrical input will be entered. Now click on the drop-down list on the left in order to choose the desired type of bearing, for this case “Cylindrical roller bearing”. Using the **+**-button behind the bearing selection, we can choose the type of “Configuration” from the drop-down list. Click on “N” and press OK. To proceed with the required input data, “Enter inner geometry and load capacity” must be selected from the drop-down list on the upper right side of the page.



The user can either automatically obtain the Pitch diameter, Dpw ($Dpw = (50+80)/2 = 65\text{mm}$), when clicking the button **★**, or enter it manually.

The pitch diameter of the gear is used for the outer diameter of the housing. Now all the geometry of the bearing is given and both the “Shoulder diameter inner ring dSi” and “Shoulder diameter inner ring dSe”, as well as the “Diametral clearance Pd” will be shown after running the software.

Bearing Configuration

As we have four bearings, we enter their positions on the tab page “Bearing configuration”. The amount of bearings can be added using the -button on the bottom right corner. We want to set the configuration’s origin in the middle of the four bearings, so the distance of the two first bearings from the origin is half of the bearing width, i.e. $B/2=\pm 14.5\text{mm}$, and the one of the outer bearings, $B+B/2=\pm 43.5\text{mm}$.

	Position [mm]	Axial Offset [mm]
1	-43.5	0
2	-14.5	0
3	14.5	0
4	43.5	0

Consider group of bearings

Loading

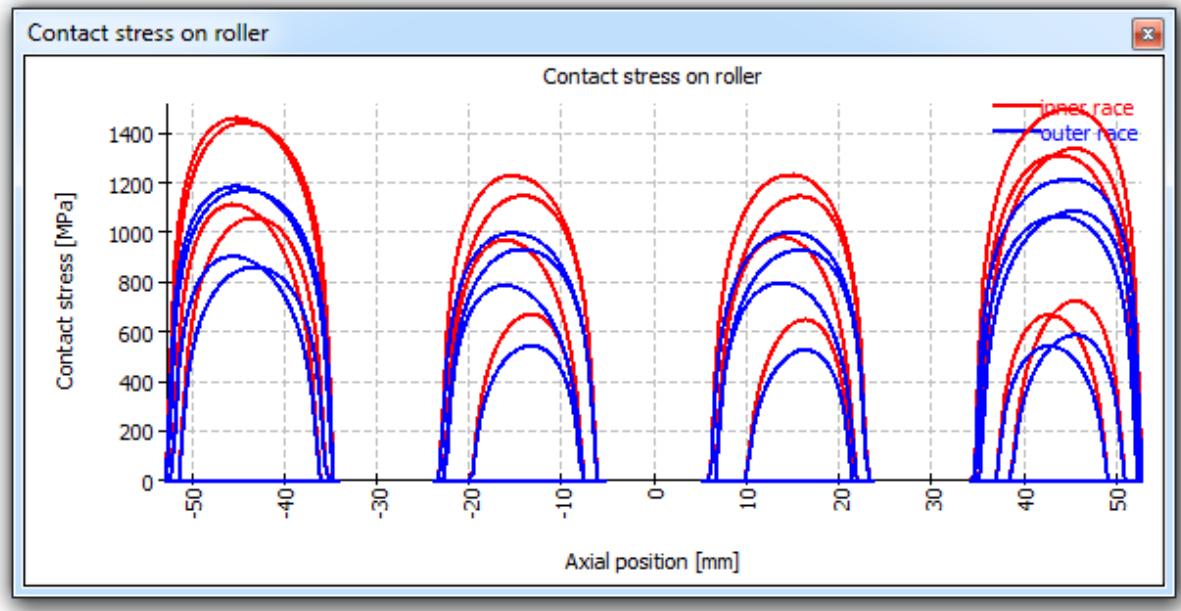
The loading is imposed by the gear. We have a radial force of $F_z = 40\text{kN}$ and a bending moment of $M_z = 800 \text{ Nm}$. Note that a pair of forces in axial direction are responsible for the moment, not the given radial force. The speed of the inner race is the speed of the planet carrier. This speed should be $n_i = 500\text{rpm}$. The outer race rotates with the planet. So $n_e = -1000\text{rpm}$ which results in a relative speed of 1500rpm . So press now on the tab “Loading” and enter the data as shown:

General	Bearing geometry	Bearing configuration	Material and Lubrication	Loading	Track roller
Axial load	F_x	0 N	<input type="radio"/> Displacement	ux	0 mm <input checked="" type="radio"/>
Radial load	F_y	0 N	<input checked="" type="radio"/> Displacement	uy	-8.57967e-05 mm <input type="radio"/>
Radial load	F_z	40000 N	<input checked="" type="radio"/> Displacement	uz	0.0364159 mm <input type="radio"/>
Moment	M_y	0 Nm	<input checked="" type="radio"/> Rotation angle	ry	-0.00297589 mrad <input type="radio"/>
Moment	M_z	800 Nm	<input checked="" type="radio"/> Rotation angle	rz	0.58841 mrad <input type="radio"/>
Speed inner ring	n_i	500 rpm	<input type="checkbox"/> Inner ring rotates to load		
Speed outer ring	n_e	-1000 rpm	<input checked="" type="checkbox"/> Outer ring rotates to load		
Temperature of shaft	T_i	20 °C	Temperature of housing	T_e	20 °C

Result overview					
Basic reference rating life	L_{10r}	2854.51	Basic reference rating life	L_{10rh}	31716.7 h
Modified reference rating life	L_{nmr}	17615.4	Modified reference rating life	L_{nmrh}	195726 h
Maximal pressure	p_{max}	1497 MPa	Static safety factor	SF	7.13964

Entering these values and running the calculation we will get a resulting life $L_{10rh} = 31716\text{h}$.

After running the software (press on the  -button), we will realize that the bearings on the left and the right will take a larger load than the center bearings, as can be seen either in the chart at “Graphics”->“Contact stress on roller” or in the report, by pressing on the  -button.



Number	Fx [kN]	ux [mm]	Fy [kN]	uy [mm]	Fz [kN]	uz [mm]	My [Nm]	ry [mrad]	Mz [Nm]	rz [mrad]	pmax [MPa]	SF
1	0	0.0000	-8.37163	-0.0257	11.8121	0.0363	4.13	-0.00	6.07	0.59	1459.64	7.51
2	0	0.0000	-1.92951	-0.0086	8.18601	0.0364	1.47	-0.00	2.22	0.59	1228.60	10.60
3	0	0.0000	1.96474	0.0084	8.19436	0.0365	-1.59	-0.00	2.22	0.59	1231.08	10.56
4	0	0.0000	8.33641	0.0255	11.8076	0.0365	-4.08	-0.00	6.23	0.59	1497.00	7.14

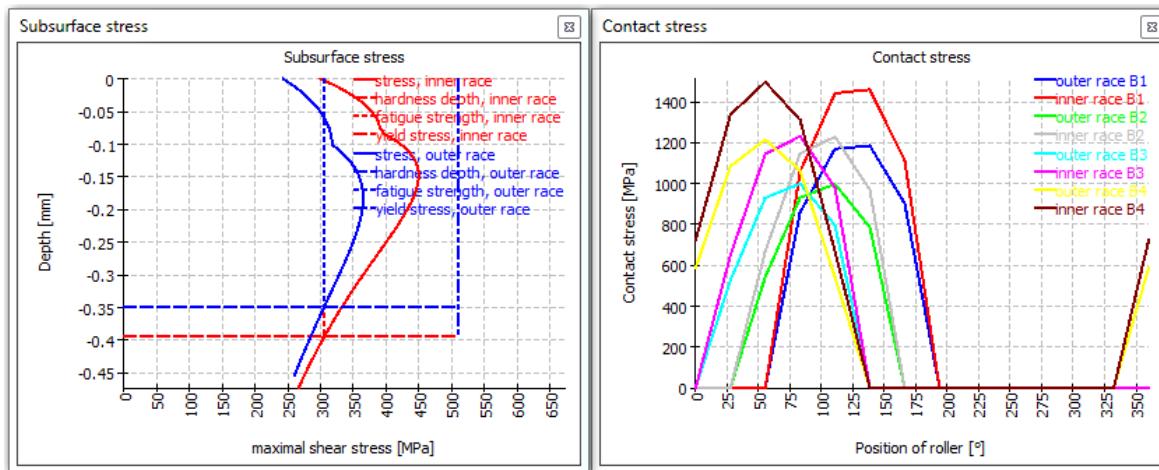
Note that this calculation assumes a rigid shaft and housing, so the real loading on the outside bearings should be a little different.

In the report we also find the pressure between shaft, bearing and housing:

Pressure between inner ring and shaft	pFitShaft	11.114 MPa
Pressure between outer ring and housing	pFitHousing	0.9324 MPa

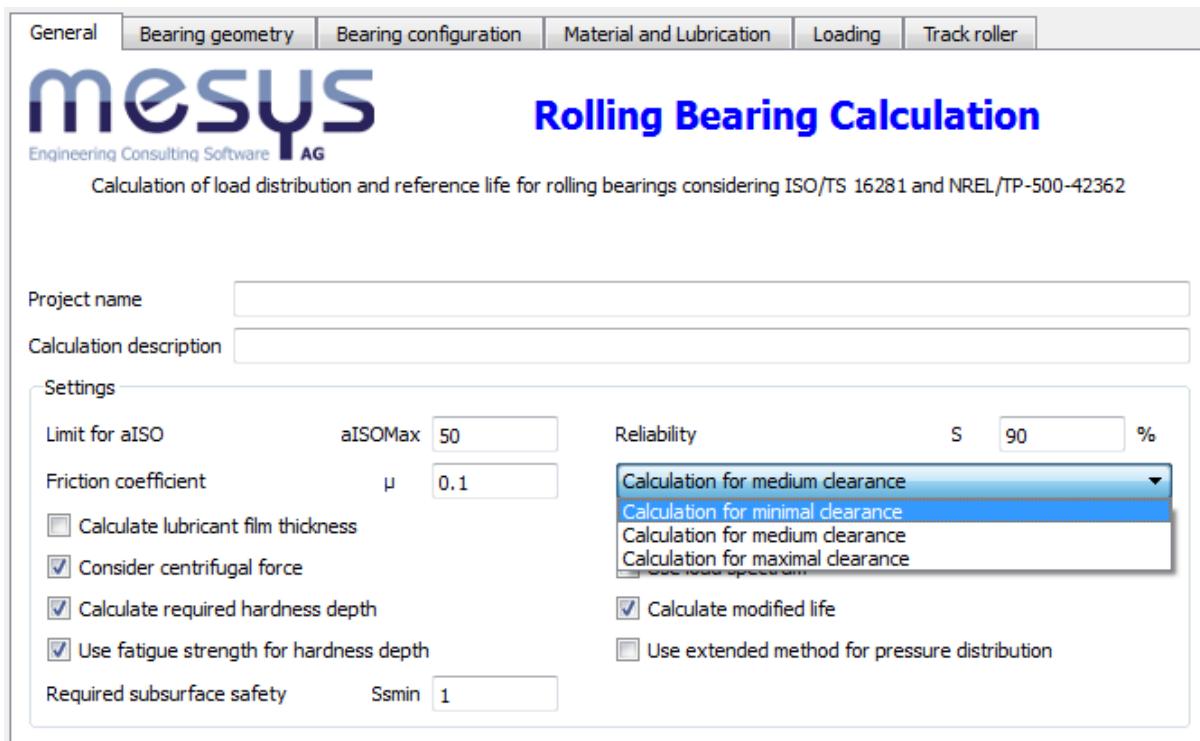
Since the outer ring is rotating to the load it should have a stronger fit than the inner ring. The interference of the outer ring should be increased; the interference of the inner ring should be decreased.

Since the loading is quite small, the subsurface stresses should be no problem. We can see in the graphics that a hardness depth of 0.4mm would be enough for the highest loaded contact.

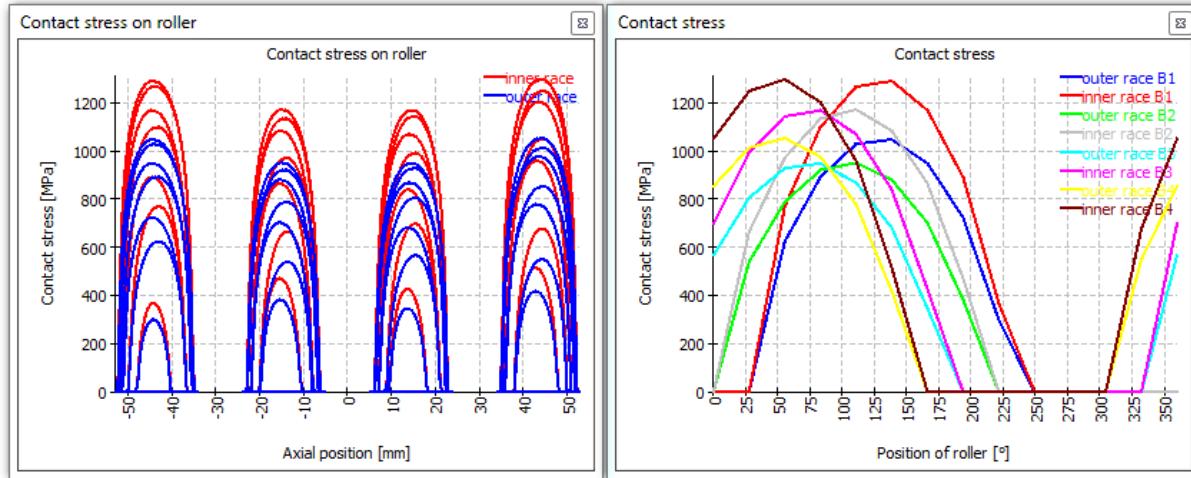


The load zone for the bearings is relatively small. It is only about 140°.

Selecting “minimal clearance” on the tab page “General” and running the software, the load zone increases to 200° and the life L10rh to 64000h.



General						Bearing geometry	Bearing configuration	Material and Lubrication	Loading	Track roller
mesys Engineering Consulting Software AG						Rolling Bearing Calculation				
Calculation of load distribution and reference life for rolling bearings considering ISO/TS 16281 and NREL/TP-500-42362										
Project name										
Calculation description										
Settings										
Limit for aISO		aISOMax		50		Reliability		S 90 %		
Friction coefficient		μ		0.1		<input type="button" value="Calculation for medium clearance"/> <input type="button" value="Calculation for minimal clearance"/> <input type="button" value="Calculation for medium clearance"/> <input type="button" value="Calculation for maximal clearance"/>		<input checked="" type="checkbox"/> Calculate modified life <input type="checkbox"/> Use extended method for pressure distribution		
<input type="checkbox"/> Calculate lubricant film thickness										
<input checked="" type="checkbox"/> Consider centrifugal force										
<input checked="" type="checkbox"/> Calculate required hardness depth										
<input checked="" type="checkbox"/> Use fatigue strength for hardness depth										
Required subsurface safety		Smin		1						



Therefore further reducing the clearance could improve the life, but this has to be done under consideration of temperatures which also influence the clearance.

The change from medium clearance to minimum clearance reduces the angle rz from 0.59mrad to 0.24mrad. This can affect the contact pattern between the gears and therefore is important for the lead modifications of the gear.

For maximal clearance life reduces to 21901h and the angle increases to $rz = 0.8\text{mrad}$. So just the position in the tolerance field influences both the life and the tilting angle by a factor of three or more.

Comparison with MESYS Shaft Calculation

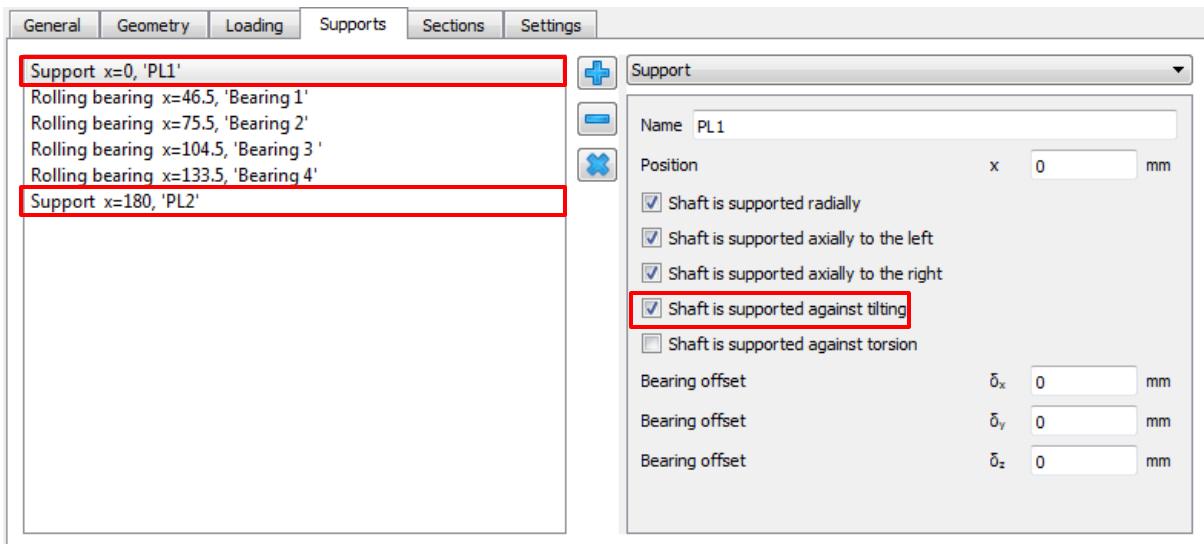
It is noteworthy to compare this example with the output from the *MESYS Shaft calculation* in order to take into account non-rigid conditions for both the pin and the bearing's inner ring.

Here is the output for the bearing calculation:

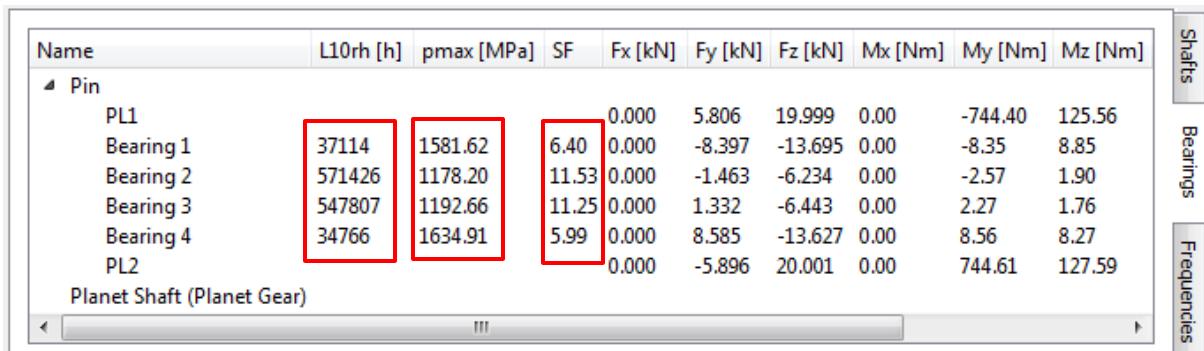
Number	Fx [kN]	ux [mm]	Fy [kN]	uy [mm]	Fz [kN]	uz [mm]	My [Nm]	ry [mrad]	Mz [Nm]	rz [mrad]	pmax [MPa]	SF
1	0	0.0000	-8.37163	-0.0257	11.8121	0.0363	4.13	-0.00	6.07	0.59	1459.64	7.51
2	0	0.0000	-1.92951	-0.0086	8.18601	0.0364	1.47	-0.00	2.22	0.59	1228.60	10.60
3	0	0.0000	1.96474	0.0084	8.19436	0.0365	-1.59	-0.00	2.22	0.59	1231.08	10.56
4	0	0.0000	8.33641	0.0255	11.8076	0.0365	-4.08	-0.00	6.23	0.59	1497.00	7.14

Number	x	eC	aISO	Pref [kN]	L10r	Lnmr	L10rh [h]	Lnmrh [h]
1	4.17	0.55	5.74	11.66	6061.62	34821.7	67351.3	386908
2	4.17	0.55	14.16	7.05	32386.2	458693	359846	5.09659e+006
3	4.17	0.55	14.05	7.08	31978.7	449386	355318	4.99318e+006
4	4.17	0.55	5.68	11.74	5917.88	33592.4	65754.3	373248

We will compare it in turn with two possible conditions in the *MESYS Shaft Calculation*, on one hand we suppose that the shaft is supported against tilting:

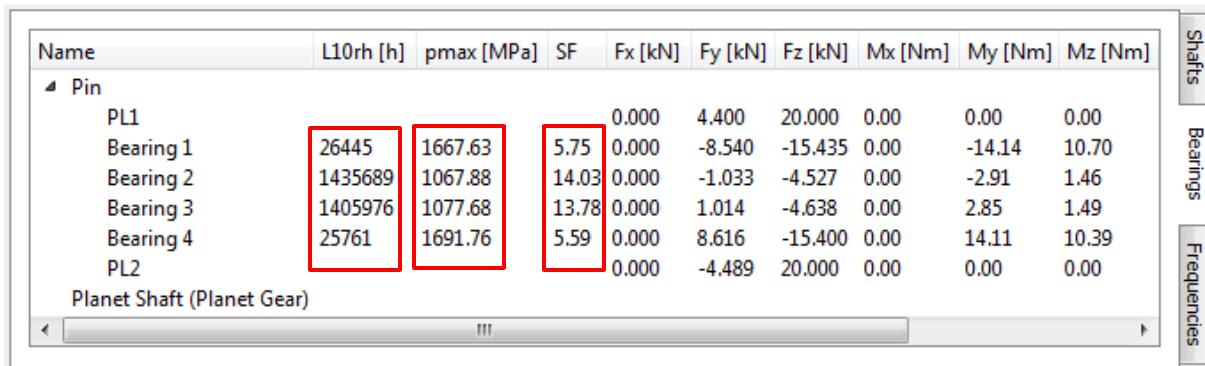


The screenshot shows the 'Supports' tab of the MESYS Shaft Calculation software. On the left, a list of supports is shown with some entries highlighted by red boxes: 'Support x=0, 'PL1'' and 'Support x=180, 'PL2''. On the right, a detailed configuration dialog for 'Support PL1' is open. It includes fields for 'Name' (PL1), 'Position' (x: 0 mm), and several checkboxes for shaft support conditions. The checkbox 'Shaft is supported against tilting' is checked and highlighted with a red box. Other checkboxes include 'Shaft is supported radially', 'Shaft is supported axially to the left', 'Shaft is supported axially to the right', and 'Shaft is supported against torsion'. Below these are fields for 'Bearing offset' (δ_x, δ_y, δ_z) with values set to 0 mm.



The screenshot shows the 'Bearings' tab of the MESYS Shaft Calculation software. It displays a table of bearing data for a planet gear assembly. The columns include Name, L10rh [h], pmax [MPa], SF, Fx [kN], Fy [kN], Fz [kN], Mx [Nm], My [Nm], and Mz [Nm]. The table lists four bearings (Bearing 1-4) and a pin (PL1). Some data values are highlighted with red boxes: L10rh values for Bearing 1 (37114), Bearing 2 (571426), Bearing 3 (547807), and Bearing 4 (34766); pmax values for Bearing 1 (1581.62), Bearing 2 (1178.20), Bearing 3 (1192.66), and Bearing 4 (1634.91); and SF values for Bearing 1 (6.40), Bearing 2 (11.53), Bearing 3 (11.25), and Bearing 4 (5.99). The table also includes data for the planet shaft and gear.

And on the other hand, we suppose that it is not:

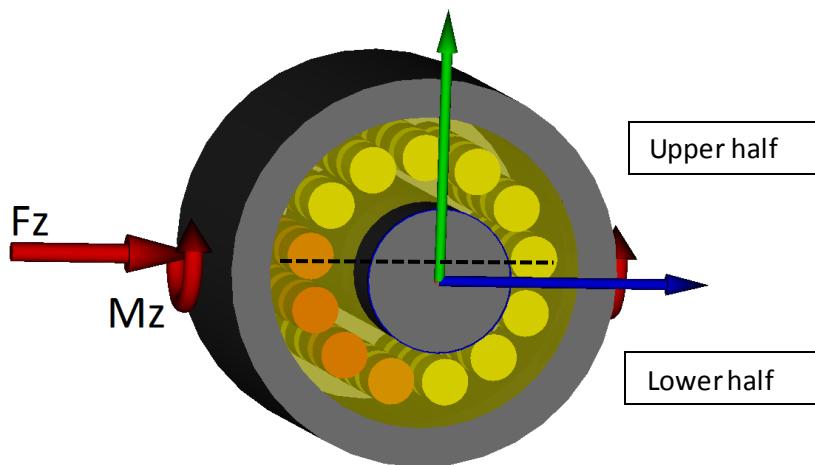


Name	L10rh [h]	pmax [MPa]	SF	Fx [kN]	Fy [kN]	Fz [kN]	Mx [Nm]	My [Nm]	Mz [Nm]
Pin									
PL1				0.000	4.400	20.000	0.00	0.00	0.00
Bearing 1	26445	1667.63	5.75	0.000	-8.540	-15.435	0.00	-14.14	10.70
Bearing 2	1435689	1067.88	14.03	0.000	-1.033	-4.527	0.00	-2.91	1.46
Bearing 3	1405976	1077.68	13.78	0.000	1.014	-4.638	0.00	2.85	1.49
Bearing 4	25761	1691.76	5.59	0.000	8.616	-15.400	0.00	14.11	10.39
PL2				0.000	-4.489	20.000	0.00	0.00	0.00
Planet Shaft (Planet Gear)									

Having a glance at these highlighted results, the user quickly realizes how important this fact is for the bearing's dimensioning.

It is also worth mentioning that the asymmetric “ p_{max} [MPa]” distribution between the four bearings has to do with the roller’s position in the different bearings. Since we have bearings with an odd number of rollers, i.e. $z=13$, subject to a M_z loading, the resultant force distribution on the rollers at the first bearing will be a bit smaller than at the fourth bearing. As we can see in the figures, the rollers with more pressure of the fourth bearing are located at the upper half, which is coincident with the part with less number of rollers, so this way, the maximum pressure reached in the roller is a little bit higher. At the first bearing, the situation is just the opposite.

View from the first bearing location:



View from the fourth bearing location:

