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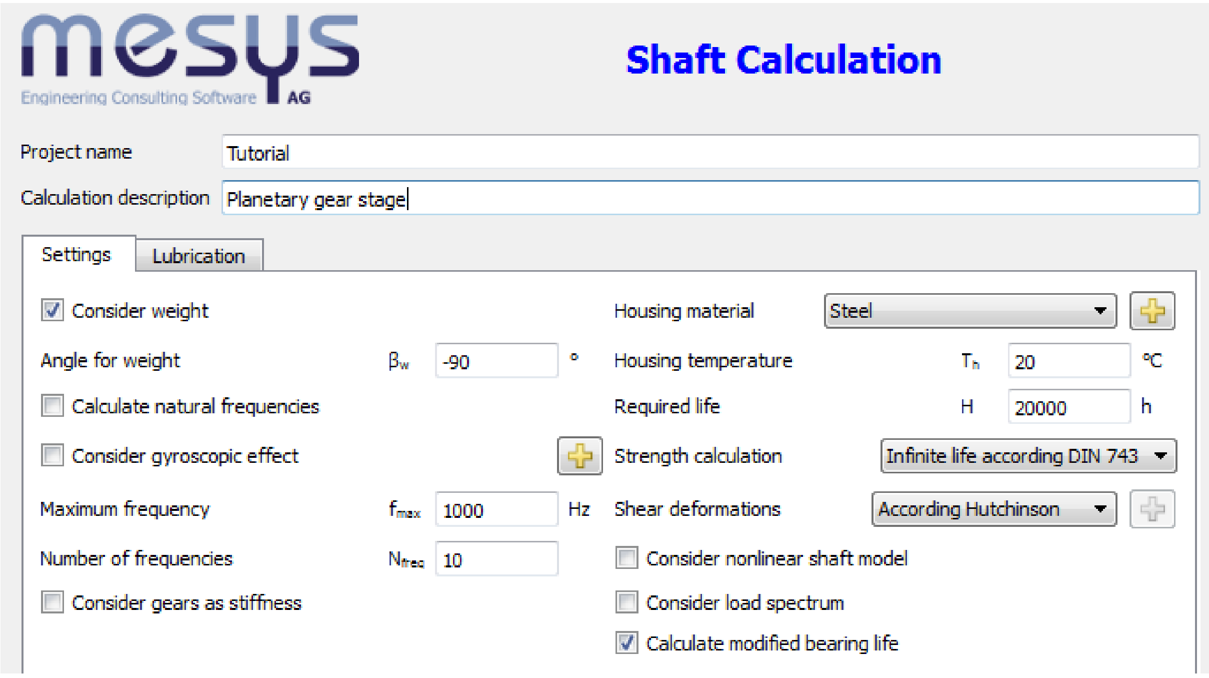
Tutorial: Calculation of a planetary gear train

This tutorial shows the usage of MESYS shaft calculation with shaft systems. A two-stage planetary gear stage is defined using the program. Please start with the tutorial for shaft calculation to see how to introduce geometry and supports for single shafts.

The model is built in two steps. In the first step, only one planetary stage is build, in the second step the second planetary stage is added. As this tutorial should be easy to use, shaft geometry and gear data is kept as simple as possible.

System Data



We do not need to change anything on the first page for system data.

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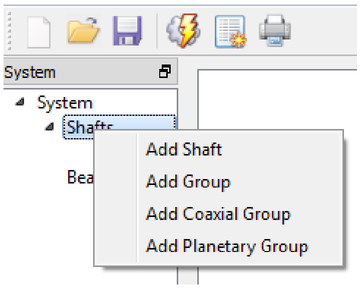
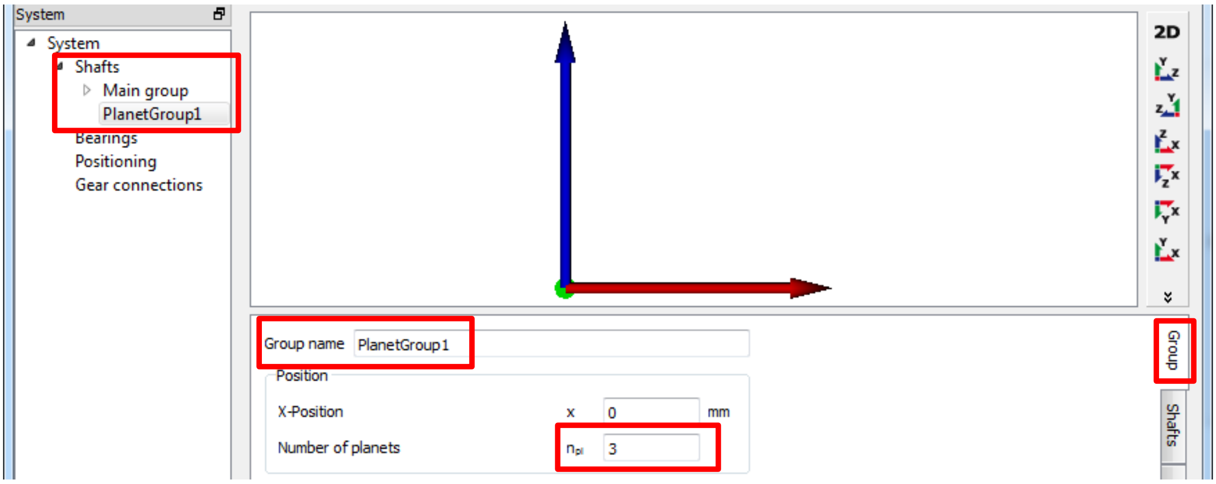
Defining Shafts



For a planetary gear stage we need at least two shaft groups. With a right mouse click on ‘Shafts’ in the system add a ‘Group’ and a ‘Planetary group’.

The groups can be given a name on the page for the group, the number of planets is defined to 3 for the ‘PlanetGroup1’:



For the ‘Main group’ we add three shafts named ‘Sun shaft1’, ‘Ring shaft’ and ‘Carrier shaft1’. For the PlanetGroup1 we add two shafts named ‘Pin1’ and ‘Planet shaft1’.

The shaft geometry is assumed to be

Shaft	Outer diameter	Inner diameter	Length	Position
Sun shaft1	20	0	50	0
Ring shaft	100	80	15	38
Carrier shaft1	55	45	50	22.5
Pin1	10	0	20	0
Planet shaft1	23	19	10	5

The position is only entered for better visibility of the shafts, it will be considered later on again.

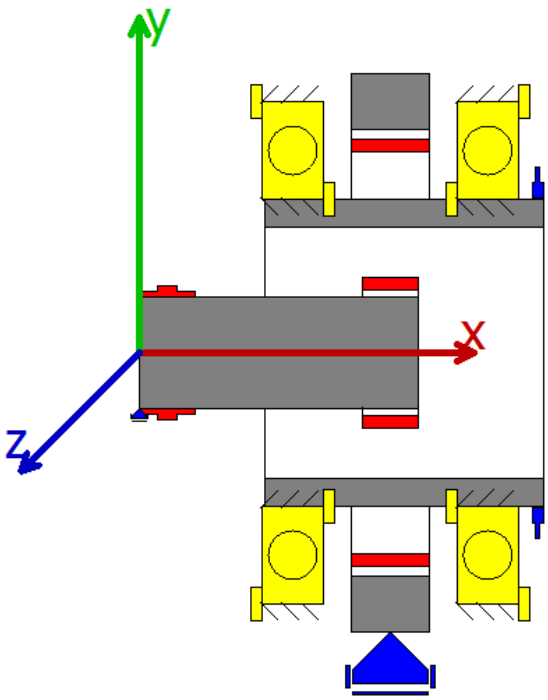
For the shafts, we add the following elements:

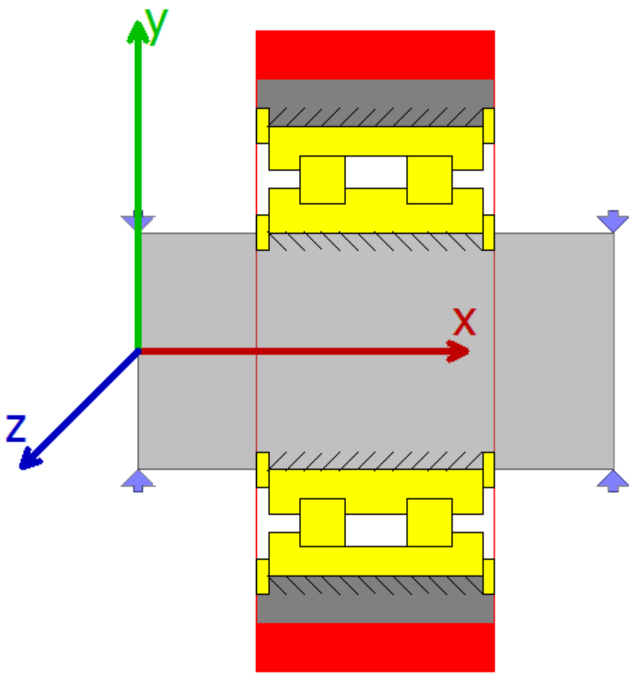
Shaft	Element	Name	Position	Parameters
Sun shaft1	Coupling	Input	5	T = 20Nm
	Cyl. Gear	Sun1	45	mn=1, α=20, b=10, z=25
	Support	SupportMotor	5	Axially and radially fixed
Ring shaft	Gear	Ring	7	mn=1, α=20, b=14, z=-74
	Support	Support	7	Everything fixed
Carrier shaft1	Rolling bearing	B1	5	Deep groove ball bearing 16011 Radially and axially supported to left
	Rolling bearing	B2	40	Deep groove ball bearing 16011 Radially and axially supported to right
	Reaction coupling	Output	49	b=2

Pin1	Planetary support	PL1	0	Everything is fixed
	Planetary support	PL1	20	Everything is fixed
Planet shaft1	Cyl. Gear	Planet1	5	mn=1, α=20, b=10, z=25
	Rolling bearing	B3	5	Cylindrical roller (double row) NNC4800 Radially and axially fixed

The planetary supports with everything set to fixed can be used for a pin that is pressed into a carrier. The carrier geometry is only an approximation of the real more complex geometry, this is a restriction of the beam models used.

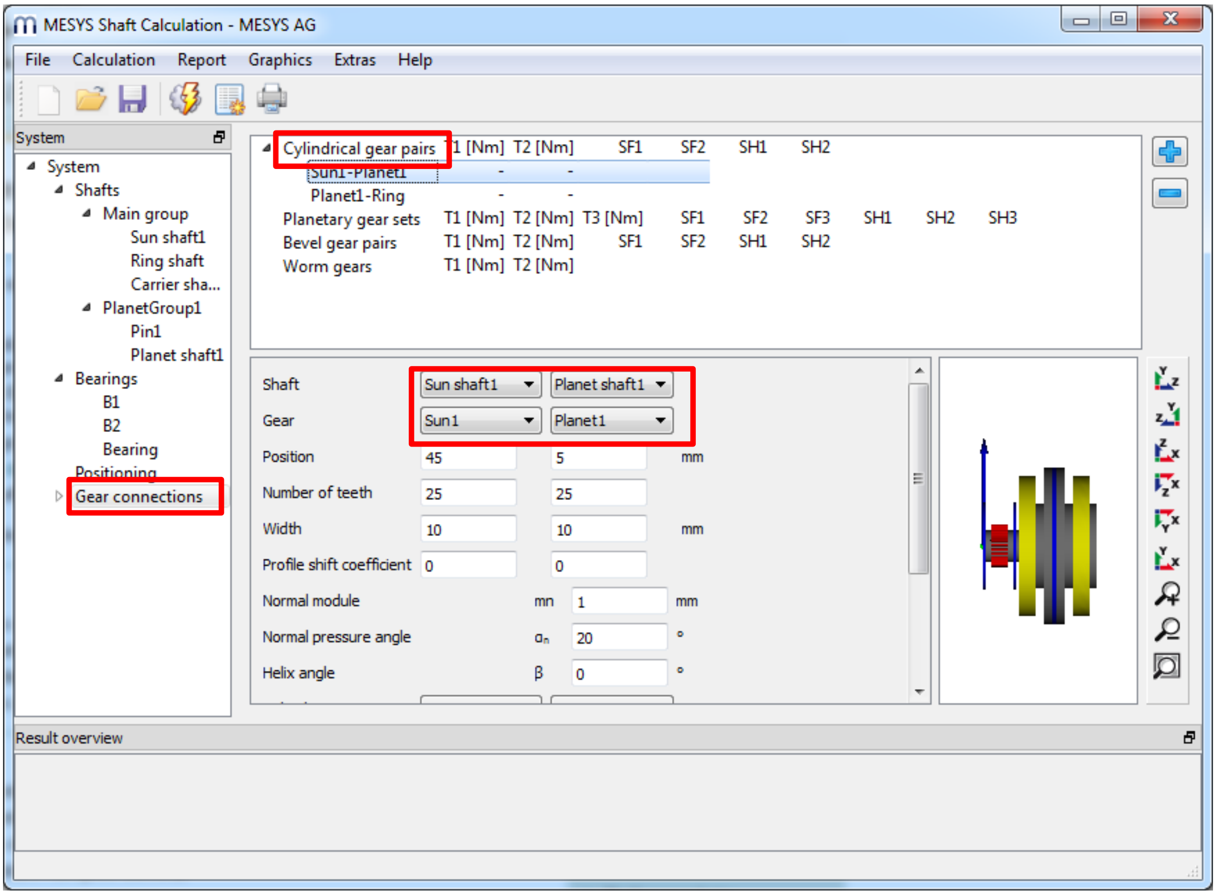
Now the groups should look like the following images:





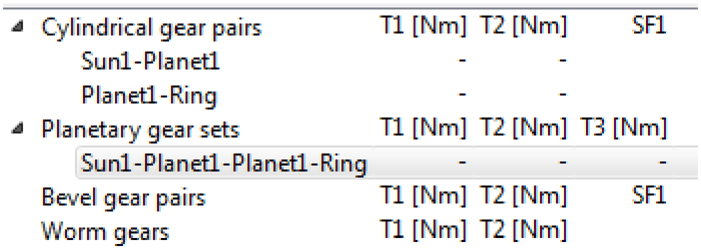
Defining gear connections

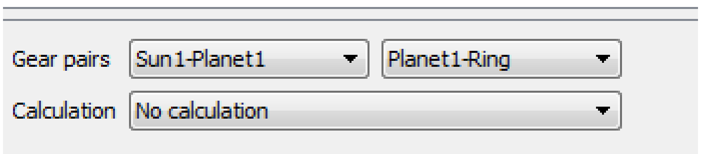
As the next step connections are defined between the gears. For this select ‘Gear connections’ in the system tree, click on ‘Cylindrical gear pairs’ and add a connection using the -button on the right.



Now select the shafts and gears, which should be connected. Connect Sun1-Planet1 for the first pair, then add a second pair and connect Planet1-Ring. Circumferential backlash and gear mesh stiffness can be changed here. It is not needed to enter the center distance as it will be calculated later. The calculation program for the gear strength calculation can be selected if available.

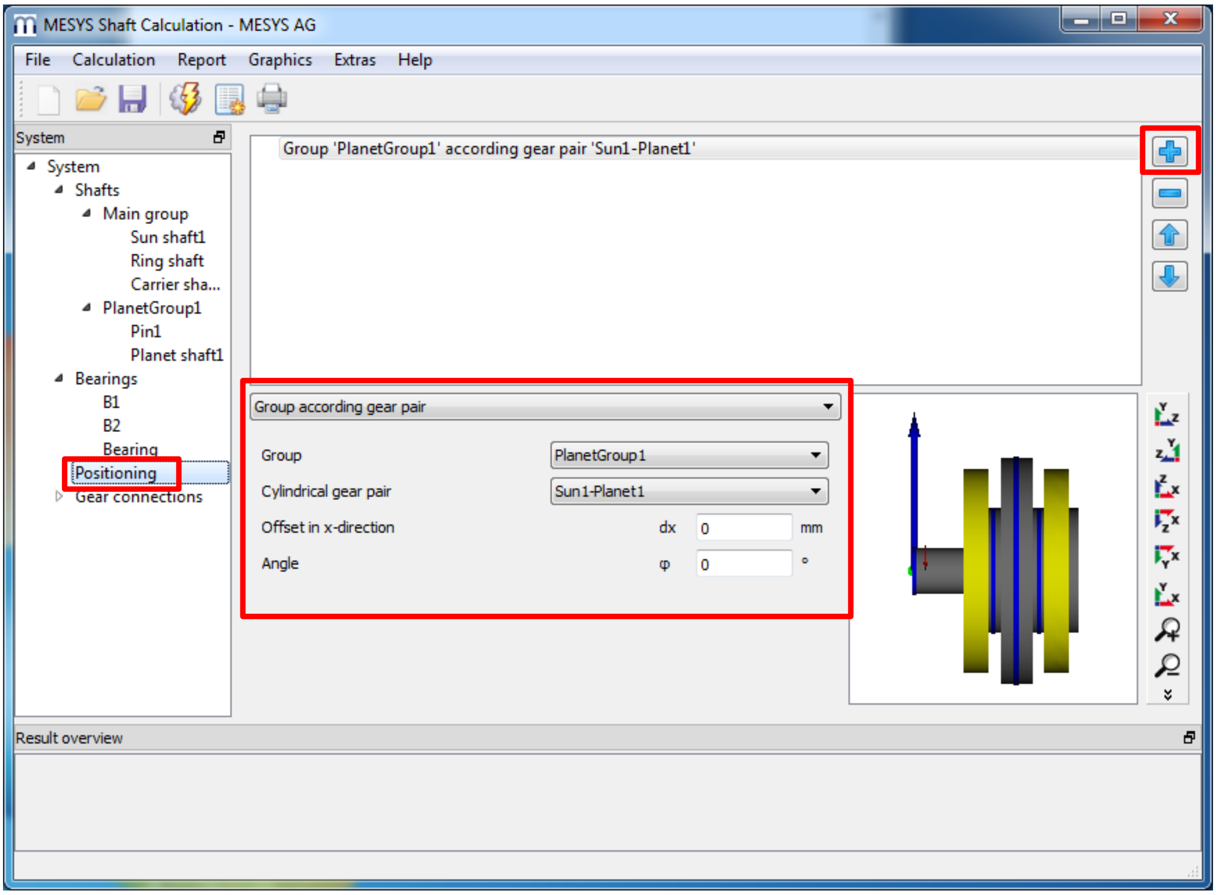
The connections for the pair have to be defined. In addition, a planetary gear set can be added to call a gear calculation for the planet gear set, instead of just calculations for gear pairs.





Define positioning

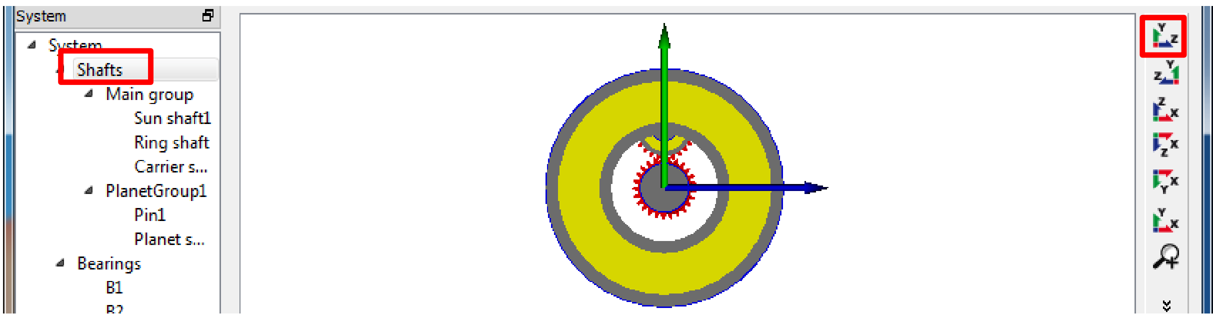
The next step is to define the positioning of the planetary group. For this select 'Positioning' in the system tree.



Add a constraint using the -button on the right. Several options for positioning are available. Select 'Group according gear pair' and position 'PlanetGroup1 with pair 'Sun1-Planet1'. The angle could be changed, we just leave it to 0° for this example.

In addition the ring gear could be axially positioned according to the gear pair, but we just leave the manual position defined before.

Now click on 'Shafts' in the system tree and choose the y-z-plane for the view:



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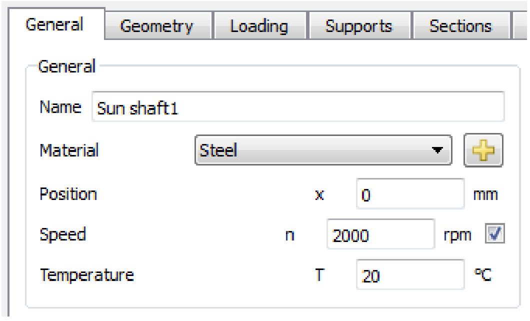
Running the calculation



Before running the calculation we have to define the speed for the system. Enter a speed of 2000rpm for 'Sun1'.

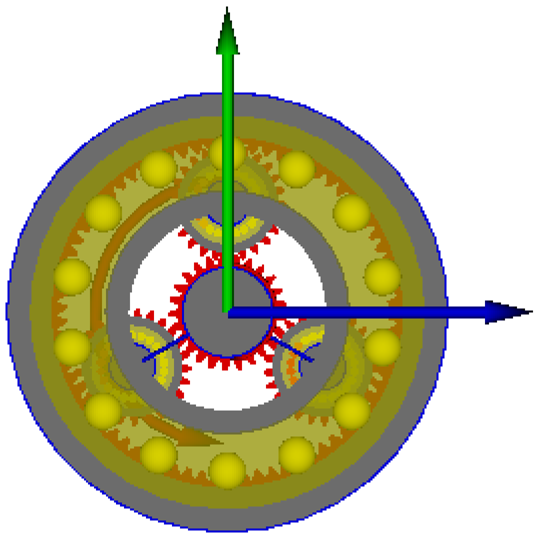
For all other shafts the flag behind the input of speed should not be set as the speed is calculated by the program. A speed for the ring could be set, if it is not equal zero.

After running the calculation the results overview should look similar to the following:

Result overview

Minimal bearing reference life	minL10rh	3207.88	h	Minimal bearing modified reference life	minLnmrh	811.542	h
Minimal bearing basic life	minL10h	3591.63	h	Minimal bearing modified life	minLnmh	1073.05	h
Maximal bearing stress	pmax	2149.69	MPa	Minimal static safety for bearings	minSF	3.46231	
Minimal root safety for gears	minGearSF	1.856		Minimal flank safety for gears	minGearSH	1.101	
Maximal displacement in x	maxUx	0	mm	Maximal displacement in y	maxUy	0.0283372	mm
Maximal displacement in z	maxUz	0.0240493	mm	Maximal displacement in radial direction	maxUr	0.0312621	mm
Maximal equivalent stress	maxSigV	34.2776	MPa				

The safety factors for the gears depend on the selected program for gear calculations. We also did not enter any details for the gear calculations. Minimum bearing life is 3200h, static bearing safety is 3.4. Therefore bearings could be ok, dependent on the needs for life. Minimum gear safety is 1.10 for the flank and 1.8 for the root stresses, so gears should also be ok.

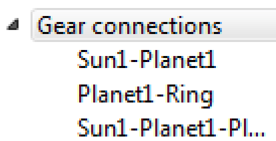


After running the calculation also all three planets are shown.

This can now be used to detail the shaft geometry and optimize the gears.

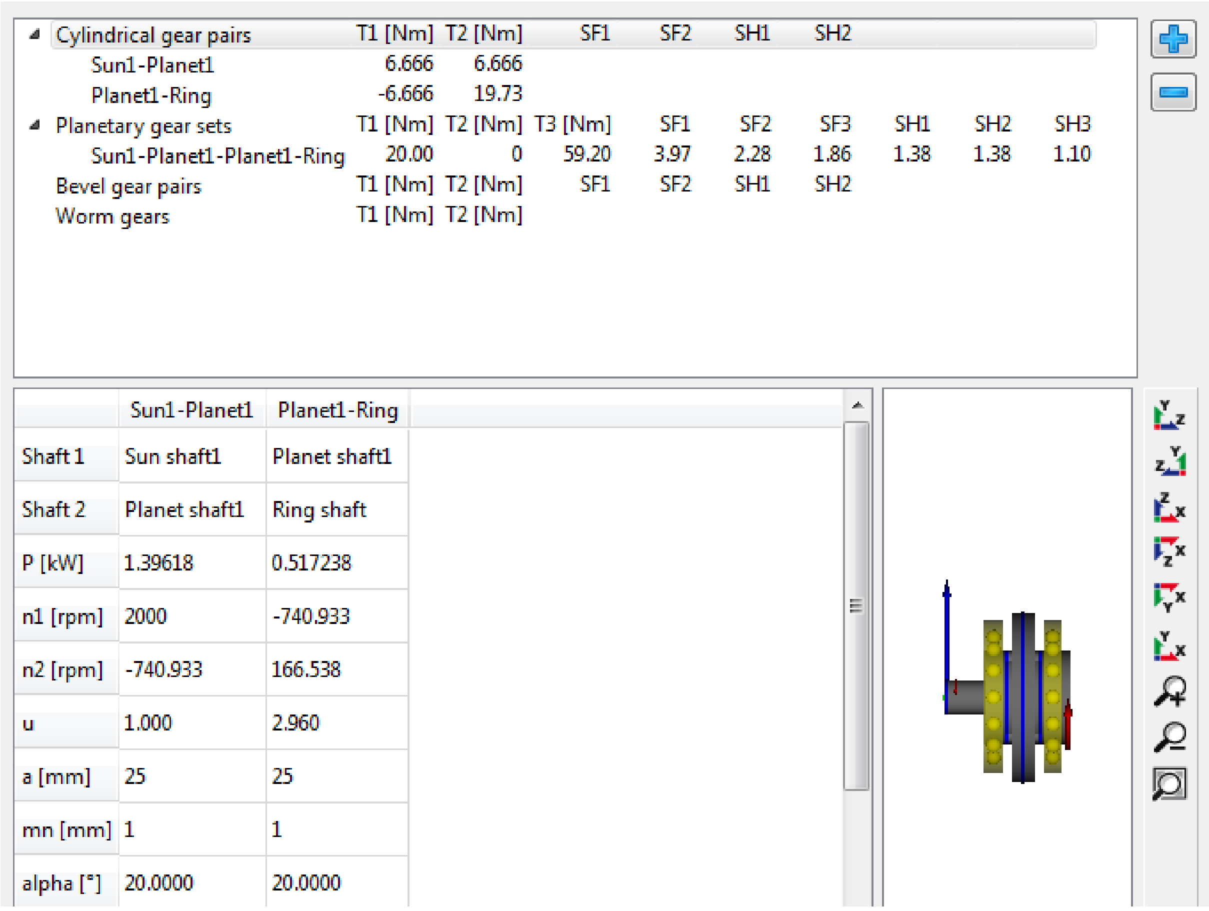
Gear calculations

For gear calculations the 'Required Life' on page 'System' should be defined. Also either 'Consider gears as stiffness' should be set which results in an automatic increase of shaft diameter according to the gears, or you should consider the gear stiffness in the shaft geometry yourself.



The gear calculation can be opened by selecting the gear pair in the system tree. Dependent on the gear calculation program it is opened within the shaft calculation program or as an extra window. Gear parameters can be changed and are read back on closing the gear calculation. Here we have three entries for calculations. Two gear pair calculations and one planet gear calculation.

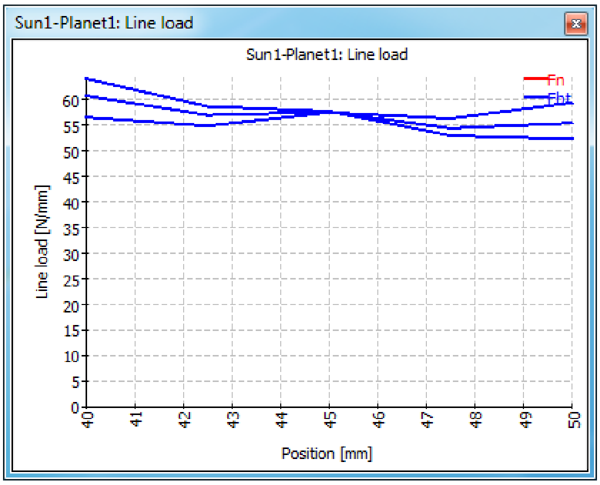
On the page ‘Gear connections’ the torque for each gear is shown and its safety factors. Selecting ‘Cylindrical gear pairs’ an overview for gear pair data is shown in a table.

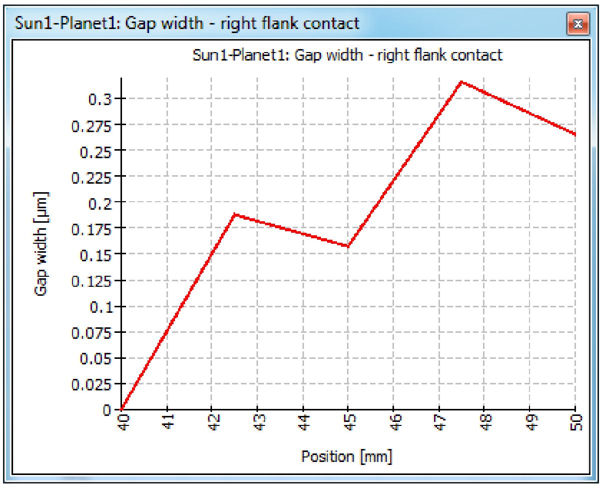


Here only safety factors are shown for the planetary gear stage as no calculation program is selected for the pairs. Note that for the gear pairs the torque is shown for one contact, the sum of all contacts is used for the planetary gear sets.

Graphics for gear pairs

Two graphics for gear pairs are available so far. The line load and the gap width.





The line load showns the loading of all three contacts. The small difference is because of the weight of the shafts. The gap width shows the gap between the flank if the contact would be just on one point. So in this case a flank line correction of 0.3µm could be made, but this small value can be ignored. Gear mesh stiffness, shaft and bearing stiffness have an influence to these diagrams. But also manufacturing errors and housing stiffness have an influence on the real gearbox.

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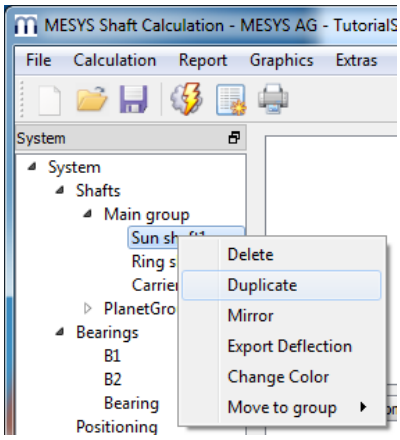
Adding a second stage



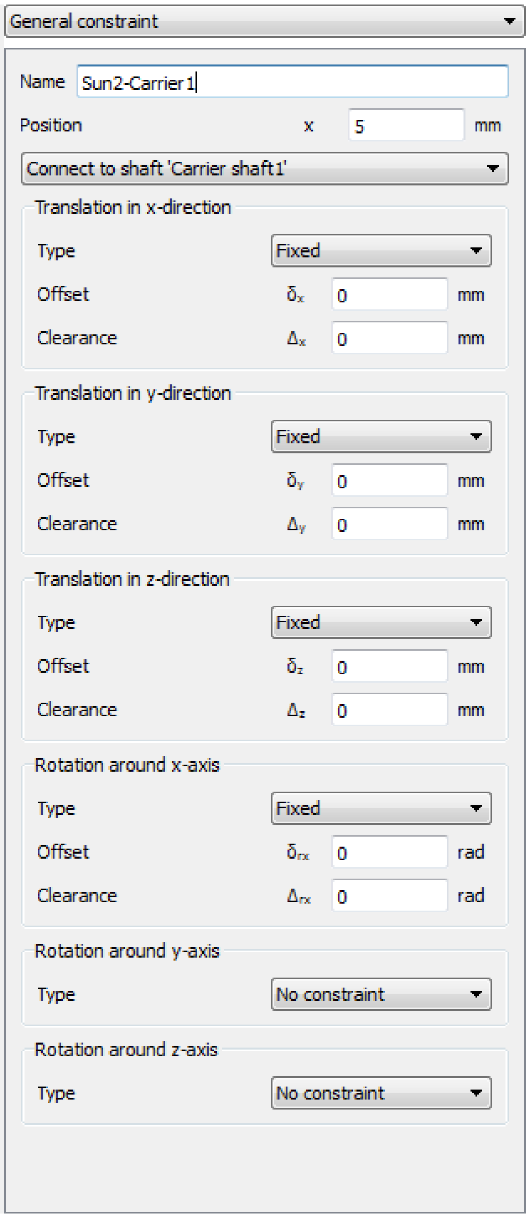
For the second stage, a copy is made for sun shaft and carrier shaft first. Click on the shaft using the right mouse button and select 'Duplicate'. Then rename the shafts 'Sun shaft2' and 'Carrier shaft2' and move them to positions 60 and 82.5.

Replace the support of 'Sun shaft2' with a general constraint to couple it with carrier1 and remove the coupling 'Input'.

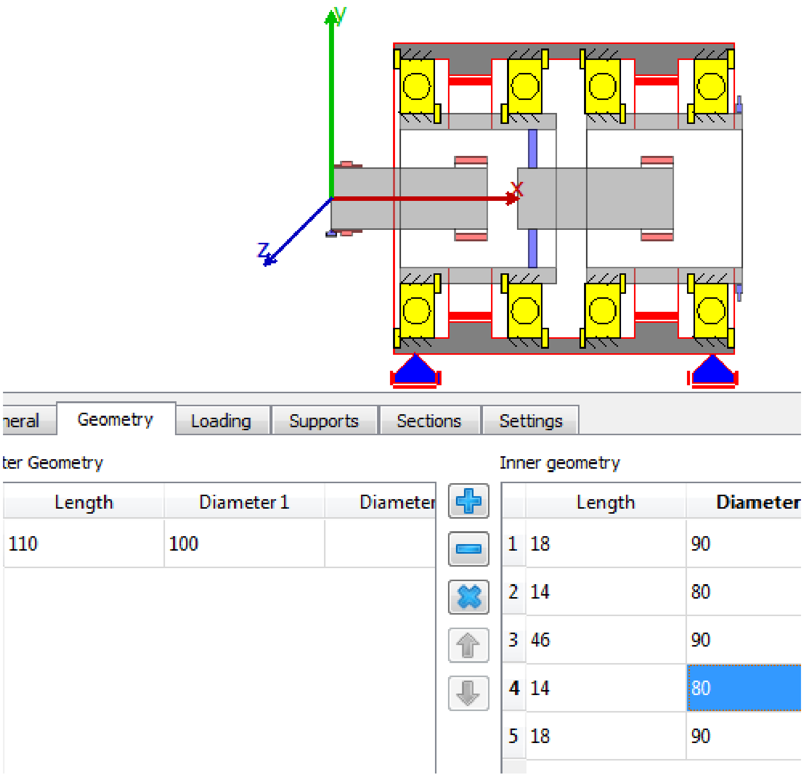
Rename 'Sun1' to 'Sun2' and clear the flag for input of speed.

For 'Carrier1' remove the coupling for reaction moment.

For 'Carrier2' rename the bearings to 'B4' and 'B5'.



We change the geometry of the ring shaft using a start position of 20 and add a second ring gear to it with same geometry:



Instead of one support we use two supports on the ring gear to avoid deformations.

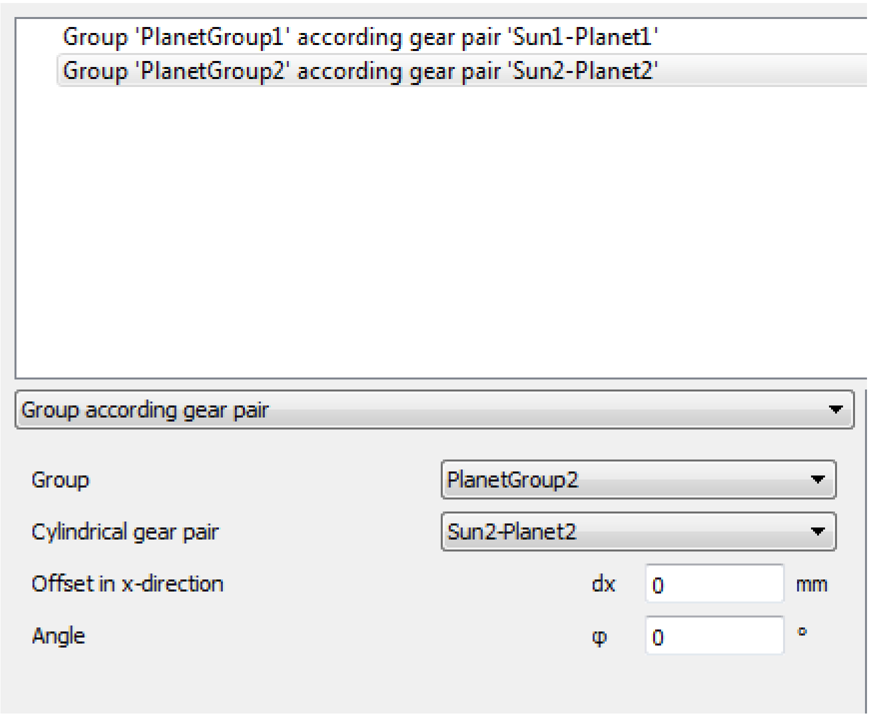
Then we add a new planetary group named 'PlanetGroup2'. We duplicate the shafts 'Pin1' and 'PlanetShaft2' and move the copies to the new group clicking with the right mouse button and choosing 'Move to group'.

Then we rename the force and support elements in the new group and connect the pin2 to 'Carrier shaft2' under 'Supports'. The bearing for the planet had to be connected with 'Pin2' for the outer ring.

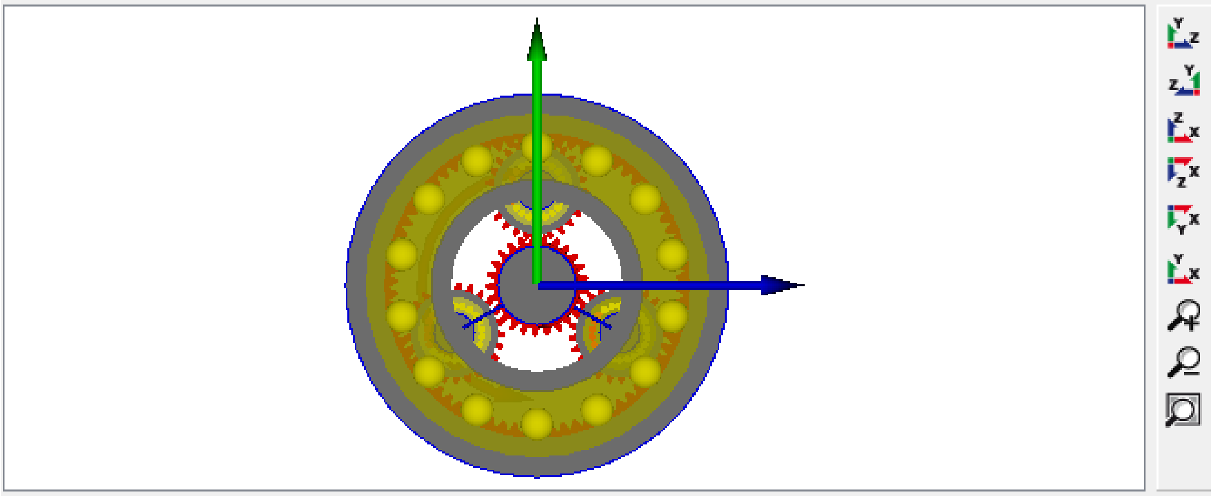
Now we go to 'Gear connections' and add the connections for the new planetary stage:

Cylindrical gear pairs	T1 [Nm]	T2 [Nm]	
Sun1-Planet1	6.666	6.666	
Planet1-Ring	-6.666	19.73	
Sun2-Planet2	-	-	
Planet2-Ring2	-	-	
Planetary gear sets	T1 [Nm]	T2 [Nm]	T3 [
Sun1-Planet1-Planet1-Ring	20.00	0	5
Sun2-Planet2-Planet2-Ring2	-	-	
Bevel gear pairs	T1 [Nm]	T2 [Nm]	
Worm gears	T1 [Nm]	T2 [Nm]	

On page 'Positioning' we add the constraint for the second planetary group:



After running the calculation we have a look at the results overview on page 'Shafts':



Name	n [rpm]	∑T [Nm]	∑P [kW]	minL10rh [h]	minLnmrh [h]	pmax [MPa]	minSF	maxSigV [MP
Sun shaft1	2000.00	20	4.18879	-	-	-	-	22.07
Ring shaft	0.00	293.626	2.18306e-31	-	-	-	-	5.22
Carrier shaft1	505.05	79.1981	4.18869	∞	∞	328.09	99.00	7.62
Pin1	505.05	0.0714639	0.00377964	-	-	-	-	34.18
Planet shaft1	-989.90	6.6635	0.690751	2987	773	2160.50	3.43	5.73
Sun shaft2	505.05	79.1981	4.18869	-	-	-	-	87.34
Carrier shaft2	127.54	313.626	4.18871	∞	∞	130.69	99.00	30.13
Pin2	127.54	0.282965	0.00377921	-	-	-	-	135.48
Planet shaft2	-249.97	26.399	0.691053	101	12.83	4422.07	0.82	23.10

The output speed on Carrier2 is now 127.5 rpm, the output torque is 314Nm. The bearing life L10rh is only 101h for planet shaft 2, which needs to be improved.

The safety factor for the gears on the second stage are also too small, because the size of the gears was not increased:

Cylindrical gear pairs	T1 [Nm]	T2 [Nm]	SF1	SF2	SH1	SH2			
Sun1-Planet1	6.663	6.663							
Planet1-Ring1	-6.663	19.72							
Sun2-Planet2	26.40	26.40							
Planet2-Ring2	-26.40	78.14							
Planetary gear sets	T1 [Nm]	T2 [Nm]	T3 [Nm]	SF1	SF2	SF3	SH1	SH2	SH3
Sun1-Planet1-Ring	19.99	0	59.17	3.96	2.28	1.85	1.38	1.38	1.10
Sun2-Planet2-Planet2-Ring2	79.20	0	234.42	0.68	0.44	0.63	0.35	0.31	0.54
Bevel gear pairs	T1 [Nm]	T2 [Nm]	SF1	SF2	SH1	SH2			
Worm gears	T1 [Nm]	T2 [Nm]							

So the next step is the resizing of the second planetary stage.