

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 | ystem Data | | | | | | | | | | |
|--|--------------------------------|-------------------|------|----|------------------------|--------------------------------|-----------------------------------|------|----------|----|--|
| | | Shaft Calculation | | | | | | | | | |
| Project name | Tutorial | | | | | | | | | | |
| Calculation description Planetary gear stage | | | | | | | | | | | |
| Settings Lubricat | ion | | | | | | | | | | |
| Consider weight | | | | | Housing material | Steel | | | | • | |
| Angle for weight | | βw | -90 | • | Housing temperature | | | Th | 20 | °C | |
| Calculate natural | frequencies | | | | Required life | | | н | 20000 | h | |
| Consider gyrosco | pic effect | | | ÷ | Strength calculation | | Infinite life according DIN 743 🔹 | | | | |
| Maximum frequency | | f _{max} | 1000 | Hz | Shear deformations | | According | Huto | hinson 🔹 | - | |
| Number of frequencie | Number of frequencies Nfreq 10 | | | | | Consider nonlinear shaft model | | | | | |
| Consider gears as stiffness | | | | | Consider load spectrum | | | | | | |
| | | | | | | | Calculate modified bearing life | | | | |

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



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 | Rolling bearing | B1 | 5 | Deep groove ball bearing 16011 |
| shaft1 | | | | 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 | PL1 | 0 | Everything is fixed |
|--------|-----------------|---------|----|---|
| | support | | | |
| | Planetary | PL1 | 20 | Everything is fixed |
| | support | | | |
| Planet | Cyl. Gear | Planet1 | 5 | mn=1, α=20, b=10, z=25 |
| shaft1 | 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.



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| MESYS Shaft Calculation - M | IESYS AG | | | | | | | | | |
|---|--|--|--------------------------------------|--|-------------------|-------------------|-------------------|---------|-----|---------------|
| File Calculation Report | Graphics Extras He | lp | | | | | | | | |
| 📄 📂 🖬 🚳 📑 | a | | | | | | | | | |
| System System Sustem Main group Sun shaft1 Ring shaft Carrier sha PlanetGroup1 Pin1 | Cylindrical gear par Sun1-Planet1 Planet1-Ring Planetary gear set Bevel gear pairs Worm gears | irs 1 [Nm] T - 5 T1 [Nm] T T1 [Nm] T T1 [Nm] T | "2 [Nm "2 [Nm "2 [Nm "2 [Nm |] SF1 - -] T3 [Nm]] SF1] | SF2 SF1 SF2 | SH1 SF2 SH1 | SH2 SF3 SH2 | SH1 SH2 | SH3 | |
| Planet shaft1 Bearings B1 | Shaft | Sun shaft1 | ▼ PI | anet shaft 1 🔻 | | | | | | Ľz v |
| B2 | Gear | Sun1 | • P | anet1 🔻 | | | | | | Z |
| Positioning | Position | 45 | 5 | | mm | | | | 1 - | ⊑ × |
| Gear connections | Number of teeth | 25 | 2 | 5 | | | | = | | zx |
| | Width | 10 | 1 |) | mm | | | | | I∏ x |
| | Profile chift coefficient | 0 | | | | | | | | Y.x |
| | Profile shirt coefficient | U | U | | | | | | | |
| | Normal module | | mn | 1 | mm | | | | | ~ |
| | Normal pressure angle | | an | 20 | • | | | | _ | \mathcal{P} |
| | Helix angle | | β | 0 | • | | | | | |
| | | r | | | | | | + | | |
| Result overview | | | | | | | | | | Ð |
| | | | | | | | | | | |
| | | | | | | | | | | |
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| | | | | | | | | | | |

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.

| ⊿ | Cylindri | cal gear pairs | T1 [Nm] | T2 [Nm] | SF1 |
|----|------------|------------------------|----------|---------|---------|
| | Sun1 | L-Planet1 | - | - | |
| | Plan | et1-Ring | - | - | |
| 4 | Planetar | y gear sets | T1 [Nm] | T2 [Nm] | T3 [Nm] |
| | Sun1 | L-Planet1-Planet1-Ring | - | - | - |
| | Bevel ge | ar pairs | T1 [Nm] | T2 [Nm] | SF1 |
| | Worm g | ears | T1 [Nm] | T2 [Nm] | |
| | | | | | |
| | | | | | |
| Ge | ear pairs | Sun 1-Planet 1 🔹 | Planet1- | Ring | • |
| Ca | alculation | No calculation | | | - |



Define positioning

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

| MESYS Shaft Calculation - | MESYS AG | 1 | |
|---|---|--|----------|
| File Calculation Report | Graphics Extras Help | | |
| 🗋 📂 🗔 🚳 🌉 | _ | | |
| System 🗗 | Group 'PlanetGroup1' according gea | ar pair 'Sun1-Planet1' | 5 |
| System Shafts Main group Sun shaft1 Ring shaft Carrier sha PlanetGroup1 | , | | |
| Pin1 Planet shaft1 | | | |
| Bearings B1 B2 Bearing Positioning Gear connections | Group according gear pair Group Cylindrical gear pair Offset in x-direction Angle | PlanetGroup1 ▼ Sun1-Planet1 ▼ dx 0 φ 0 | |
| Result overview | | | P |

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:





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 | | | | | | | 5 |
|--------------------------------|-----------|-----------|-----|--|-----------|-----------|----|
| Minimal bearing reference life | minL 10rh | 3207.88 | h | Minimal bearing modified reference life | minLnmrh | 811.542 | h |
| Minimal bearing basic life | minL 10h | 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 | i | | | |

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

Gear connections
 Sun1-Planet1
 Planet1-Ring
 Sun1-Planet1-Pl...

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.

| ▲ Cylind | rical gear pairs | T1 [Nn | n] T2 [Nm] | SF1 | SF2 | SH1 | SH2 | | | | |
|-----------------|----------------------------------|-----------------|----------------------|---------|------|------|------------|------|------|------------|-----|
| Su | n1-Planet1 | 6.60 | 6.666 | | | | | | | | |
| Pla A Dispet | net1-Ring | -6.60 T1 [Ne | 6 19.73 1 T2 [Nm] | T2 [Nm] | SE1 | SE3 | CE2 | CL1 | CL12 | CH2 | |
| Planet | ary gear sets n1-Planet1-Plar | net1-Ring 20.0 |)0 0 | 59.20 | 3.97 | 2.28 | 1.86 | 1.38 | 1.38 | 1.10 | |
| Bevel | gear pairs | T1 [Nn | n] T2 [Nm] | SF1 | SF2 | SH1 | SH2 | | | | |
| Worm | gears | T1 [Nn | n] T2 [Nm] | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | Sun1-Planet1 | Planet1-Ring | | | | | ^ | | | | ¥_z |
| Shaft 1 | Sun shaft1 | Planet shaft1 | | | | | | | | | z,Y |
| Shaft 2 | Planet shaft1 | Ring shaft | | | | | | | | | Ľ |
| P [kW] | 1.39618 | 0.517238 | | | | | | | ı | | z× |
| n1 [rpm] | 2000 | -740.933 | | | | | = | | | | , ¥ |
| n2 [rpm] | -740.933 | 166.538 | | | | | | | T | 1 | |
| u | 1.000 | 2.960 | | | | | | 1 | | <u>i</u> | 2 |
| a [mm] | 25 | 25 | | | | | | | 8 | 8 | D |
| mn [mm] | 1 | 1 | | | | | | | | | |
| alpha [°] | 20.0000 | 20.0000 | | | | | | | | | |

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.



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:



| neral | Geometry | Loading | Supports | Sectio | ns | Se | ttings | | |
|----------|----------|---------|----------|---------|----|-----|---------|--------|----------|
| ter Geor | netry | | | | | Inr | ner geo | metry | |
| L | ength | Diamete | r1 D | iameter | ÷ | | | Length | Diameter |
| 110 | | 100 | | | | 1 | 18 | | 90 |
| | | | | | * | 2 | 14 | | 80 |
| | | | | | | 3 | 46 | | 90 |
| | | | | | | 4 | 14 | | 80 |
| | | | | | | 5 | 18 | | 90 |
| | | | | | | | | | |

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'.



| ame Sun2-Carrier 1 | | | |
|-------------------------------|-------------------|----------|-----|
| osition | x | 5 | mm |
| Connect to shaft 'Carrier sha | aft1' | - | • |
| Translation in x-direction | | | |
| Type | Fixed | | • |
| Offset | δ, | 0 | mm |
| Clearance | ۸., | 0 | mm |
| | | | |
| Translation in y-direction | | | |
| Туре | Fixed | | - |
| Offset | δν | 0 | mm |
| Clearance | Δ_{γ} | 0 | mm |
| Translation in z-direction | | | |
| Туре | Fixed | | • |
| Offset | δz | 0 | mm |
| Clearance | Δz | 0 | mm |
| Rotation around x-axis | | | |
| Туре | Fixed | | • |
| Offset | δ _{rx} | 0 | rad |
| Clearance | Δ_{rx} | 0 | rad |
| Rotation around y-axis | | | |
| Туре | No co | nstraint | • |
| Rotation around z-axis | | | |
| Type | No co | nstraint | - |



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:

| 4 | Cylindrical gear pairs | T1 [Nm] | T2 [Nm] | |
|---|----------------------------|---------|---------|------|
| | Sun1-Planet1 | 6.666 | 6.666 | |
| | Planet1-Ring | -6.666 | 19.73 | |
| | Sun2-Planet2 | - | - | |
| | Planet2-Ring2 | - | - | |
| 4 | 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:

| Group 'PlanetGroup1' acc | ording gear pair 'Sun1-Planet1' | | | | | | | | |
|--|---|--|--|--|--|--|--|--|--|
| Group 'PlanetGroup2' according gear pair 'Sun2-Planet2' | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
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| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| Group according gear pair | • | | | | | | | | |
| | | | | | | | | | |
| C | | | | | | | | | |
| Group | PlanetGroup2 | | | | | | | | |
| Group | PlanetGroup2 | | | | | | | | |
| Group Cylindrical gear pair | Sun2-Planet2 | | | | | | | | |
| Group Cylindrical gear pair | PlanetGroup2 Sun2-Planet2 dx mm | | | | | | | | |
| Group Cylindrical gear pair Offset in x-direction | PlanetGroup2 Sun2-Planet2 dx 0 mm | | | | | | | | |
| Group Cylindrical gear pair Offset in x-direction Angle | PlanetGroup2 Sun2-Planet2 dx 0 mm φ 0 ο | | | | | | | | |
| Group Cylindrical gear pair Offset in x-direction Angle | PlanetGroup2 ▼ Sun2-Planet2 ▼ dx 0 mm φ 0 ° | | | | | | | | |

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



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¥ z z Y ^zx zx γx Y_x R P Ø Shafts Name n [rpm] ΣT [Nm] ΣP [kW] minL10rh [h] minLnmrh [h] pmax [MPa] minSF maxSigV [MP Sun shaft1 2000.00 20 4.18879 22.07 ---0.00 293.626 5.22 Ring shaft 2.18306e-31 ---Bearings Carrier shaft1 505.05 79.1981 4.18869 328.09 99.00 7.62 8 8 505.05 0.0714639 0.00377964 -34.18 Pin1 ---Planet shaft1 -989.90 6.6635 0.690751 2160.50 5.73 2987 773 3.43 Sun shaft2 505.05 79.1981 4.18869 ----87.34 Frequencies Carrier shaft2 127.54 313.626 4.18871 130.69 99.00 30.13 œ œ 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-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.

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