Finite Element Model data sheet for TP+/TP+ High Precision Series Planetary Gearboxes of Wittenstein AG.

Geometry

Since the exact inner geometry of the gear is not taken into account, the geometry of the planetary gear (PG) model is rather a dummy body that supports the input and output shaft through two simplified bearings. The input shaft is a hollow cylinder. Another couple of solid cylinders approximate the output shaft and the pinion.
Figure 1 shows the FE model parameters. Note that the catalog provides some of the dimensions in a range of minimum and maximum values. The FE model uses the minimum values of these geometries. As the pinion teeth are not modeled, a thin rectangular block (not pictured in Figure 1) emulates the connection interface between the pinion and the toothed rack.

FEM Geometry

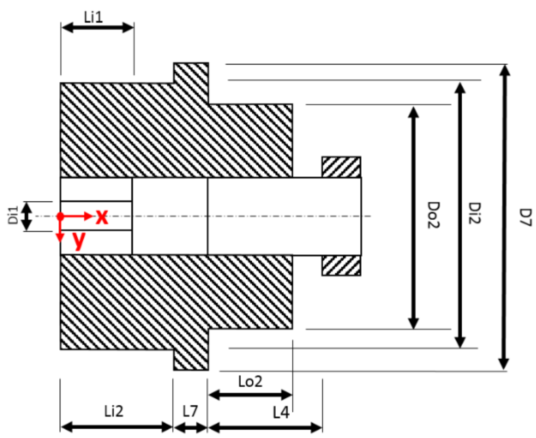

Figure 1: FE geometry derivation

Units

The FE model is in SI units, unless otherwise stated.

Mass

The mass $Mass$ and the rotational inertia J_{xx} of the gearbox for each planetary gear variant are provided in the catalog.
An equivalent density ρ_{eq} is computed for the casing of the gearbox, so that the total mass of the gear is distributed only on the gear casing.

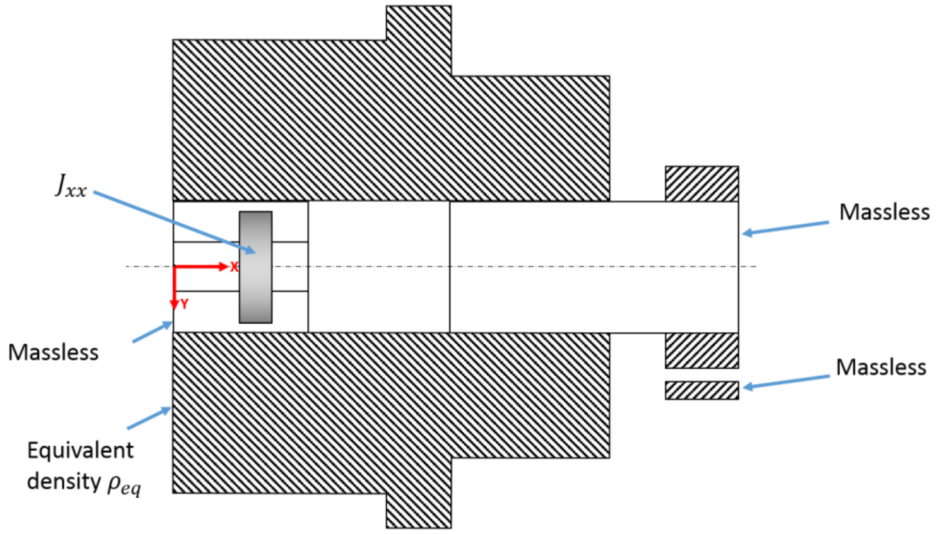

Figure 2: Mass

The shafts and pinon of the FE model have zero density, and do not contribute to the overall weigh of the gearbox.
The rotational inertia is modelled as a point mass in the input shaft.

Stiffness

The material of the real gear casing is steel. The inner geometry of the PG is strongly simplified for efficient computation. Under these circumstances, exact modeling of the elastic behavior of the casing is not possible.
Instead, a sufficient estimation is applied to the elasticity modulus of the casing E_{eq} based on the equivalent density ρ_{eq}.
This estimation is based on the assumption that the FE model probably contains more material than in reality if the equivalent density is slightly lower than steel ($\rho_{steel} = 7850\ kg/m^3$). Thus, the equivalent elasticity modulus should be lower than that of steel ($E_{steel} = 210\ GPa$). This way, we compensate for abundant material. The equivalent elasticity modulus is computed using this formula:

$$E_{eq} = \frac{\rho_{eq}}{\rho_{steel}} E_{steel}$$

The product catalog provides the linearized torsional stiffness k_t of the output shaft in the rotational degree of freedom (DOF) about X direction (RX). The stiffness of the remaining DOF is initialized to a very high value of $1e12\ N/m$.
The torsional stiffness is placed between the input and output shaft.

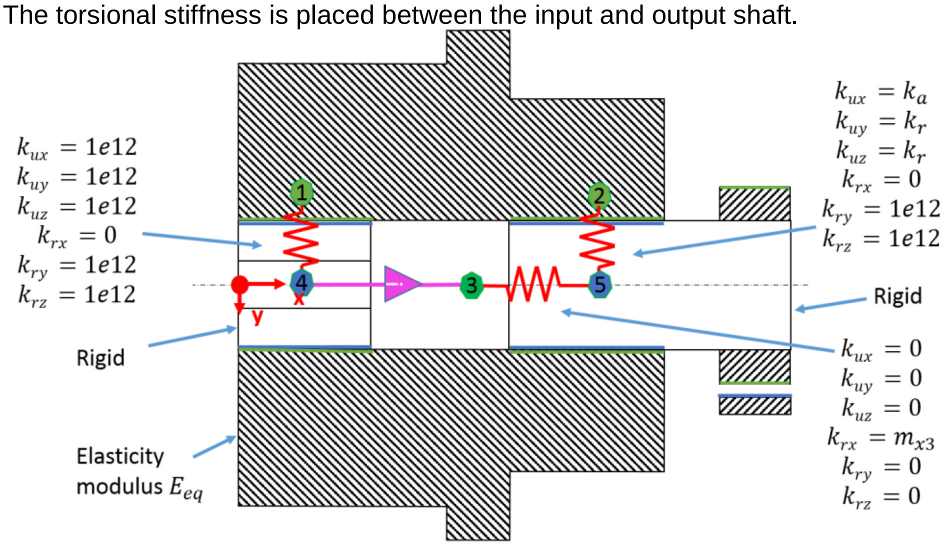

Figure 3: Stiffness

Damping

Information on damping of the planetary gearbox is not provided in the manufacturer's catalogue. Therefore, provision was set in the FE model for manual input from the user.
The material damping of the casing and shafts are not taken into account, since all these parts are made of steel. The damping of steel can be ignored when compared with other damping sources like bearings, sealing etc.
The rotational damping $BDamp$ of the angular gearbox measured between output shaft and casing is a free model parameter.
The torsional damping $GDamp$ of the angular gearbox measured between input and output shaft is a free model parameter.

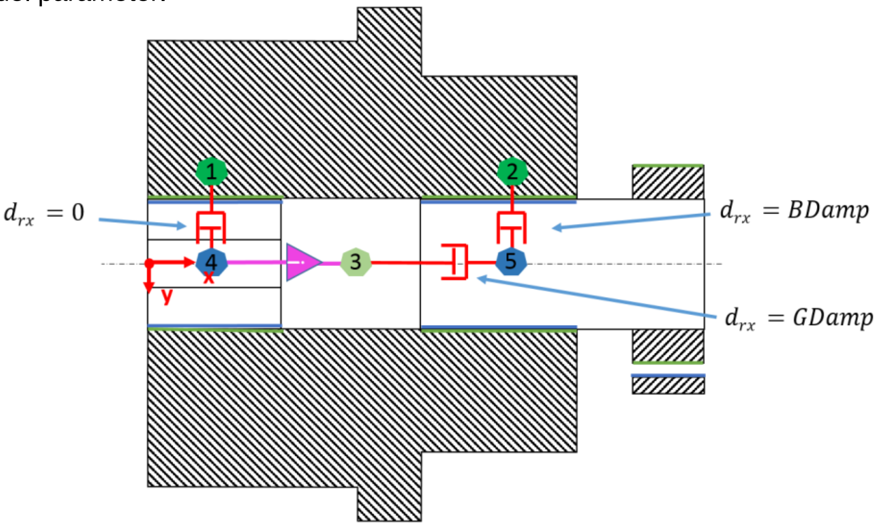

Figure 4: Damping

Kinematic

The transmission ratio of the PG is provided in the catalog. In the FE model, this kinematic transformation is modeled through a constraint equation between the inner end surface of the input shaft and the inner end surface of the output shaft.
A thin rectangular block, in its dimensions approximated to the circumference of the pinion, helps modelling the kinematic relation between the pinion head and the rack teeth. A constraint equation relates the rotating motion of the pinion to the linear motion of this block.

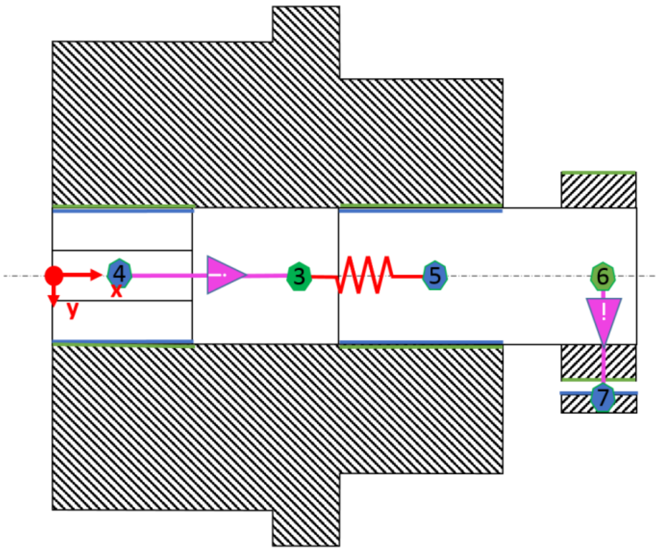

Figure 5: Kinematic constrains

Thermal

At the current stage of development, the linear thermal expansion coefficient of steel (12e-6 1/K) is defined in the FE model and assigned to both the casing and the shafts. In the future, other thermal properties such as thermal conductivity will be added to the model.

Finite Element Mesh

The whole volume was meshed with hexagonal volume elements. The elements can have linear or quadratic interpolation (see ANSYS SOLID185 or SOLID186 elements).

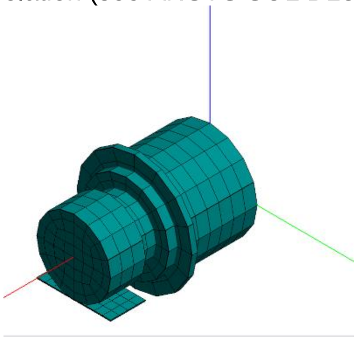

Figure 6: Finite element mesh

The rotational inertia is modeled through one discrete point mass element (see ANSYS MASS27 element) in the middle of the input shaft.
The stiffness and damping of the bearings are modeled through linear spring elements (see ANSYS MATRIX27 element).

Model interfaces

Model interfaces provide a way to connect different models to a robust assembly. Interfaces can also be used as a reference for positioning.

Input side

- ShaftIn_1 (cylindrical surface on the inner of the input shaft)
- ToMotor_1 (plane to connect with the motor adapter)

Output side

- ToRack_1 (plane surface to connect with the rack)

Mounting and fixing

- FlangeSeat_1 (plane on the flange facing the motor side)
- FlangeFront_1 (plane on the flange facing the output side)
- FlangePeri_1 (cylindrical surface of the flange)

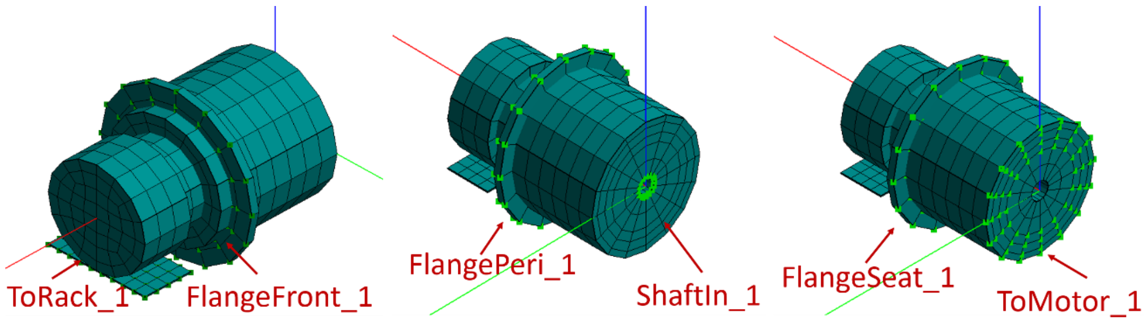

Figure 7: Model interfaces or Nodal sets

Furthermore, the reference coordinate system (Origin), the reference planes (XY, YZ, ZX) and reference axes (X, Y, Z) are recommended for positioning parts.

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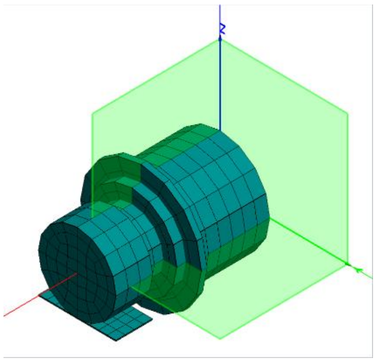

Figure 8: FE reference planes, axes and origin

Model validation – Eigenvalue and Mass

The models eigenvalues can be predicted in an analytical way. We compare the results from the numerical eigenvalue analysis (computed with ANSYS) with the analytical results. This way we perform an analytical model validation, which ensures that no modeling errors have slipped in.
The flange and rack teeth of the model was constrained, while a modal analysis was conducted. The Eigen frequencies of the model was found that way. In the following tables, you can see the results for the first eigenvalue for the model variants compared with the analytical result.

Table 1: Results for PlanetaryGear_TP_110_S_MF2_i100_0_48_1_TP_110_4_38_100_100_1.0_0.cdb, Solid185 elements w/o midside nodes

	Numerical (Ansys)	Analytical	Ratio (numerical/analytical)
Mode No 1 (Hz)	37.4448975	37.6229187	0.995268279
Mass (Kg)	**33.132841**	**34**	**0.974495323**

Table 2: Results for PlanetaryGear_TP_110_S_MF2_i100_0_48_1_TP_110_4_38_100_100_1.0_1.cdb, Solid186 elements with midside nodes

	Numerical (Ansys)	Analytical	Ratio (numerical/analytical)
Mode No 1 (Hz)	37.4190585	37.6229187	0.994581489
Mass (Kg)	**33.998322**	**34**	**0.999950646**

These results are representative for all available model variants. In general, the accuracy is very high and enhanced when elements with quadratic interpolation are used.

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