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DoE analysis of the spherical joint friction torque

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1. Introduction

The article deals with numerical modeling of friction properties of a spherical joint. The goal was to predict the key dimensions of the four spherical joint components in order to reach the target value of the friction torque. The Design of Experiment (DoE) method implemented in Ansys Design Explorer software was used to investigate the relationship between a set of four input parameters (contact overclosure values) and one output parameter (friction torque). The individual design points defined by the DoE method were solved using the FE method in Ansys Mechanical. The approximated response surface allows to predict the continuous values of the friction torque in the interval of interest. The workflow described in the article was used to find out the best combination of the part dimensions.

Friction torque describes the ability of the spherical joint to allow rotational movement thus the essential property of the joint. Very low torque values mean free play of the joint and result in fast wear while very high torque values mean unwanted resistance to rotational motion.

The friction torque is measured in two direction:

- rotation (about the pin axis) and
- tilting.

The friction torque is measured in two different conditions:

- static conditions (break-away torque): the torque is measured after a long period without movement
- dynamic conditions (running torque): the joint is moved over the entire range of motion just before the measurement.

The torque values in dynamic conditions and rotational direction are described in this article. The torque is calculated as a product of the friction force and the lever arm. The friction force is evaluated according to the simple Coulomb’s law as a product of the normal force and the friction coefficient.

2. Input data and FE model description

The geometry of the spherical joint was simplified, small features were ignored and only a segment representing 1/16 of the full circle (i.e. 22.5°) was modeled. The simplified geometry was meshed with hexahedral elements (Fig. 1).

A linear elastic material model was used for the metal components of the spherical joint: steel pin, steel closing ring and aluminum body. Consequently, the stress values were checked and it was proved that they do not exceed the yield stress limit. The bearing is made of polyoxymethylen. An elastic-plastic material model based on measured curves was defined. Creep properties of the bearing were neglected.

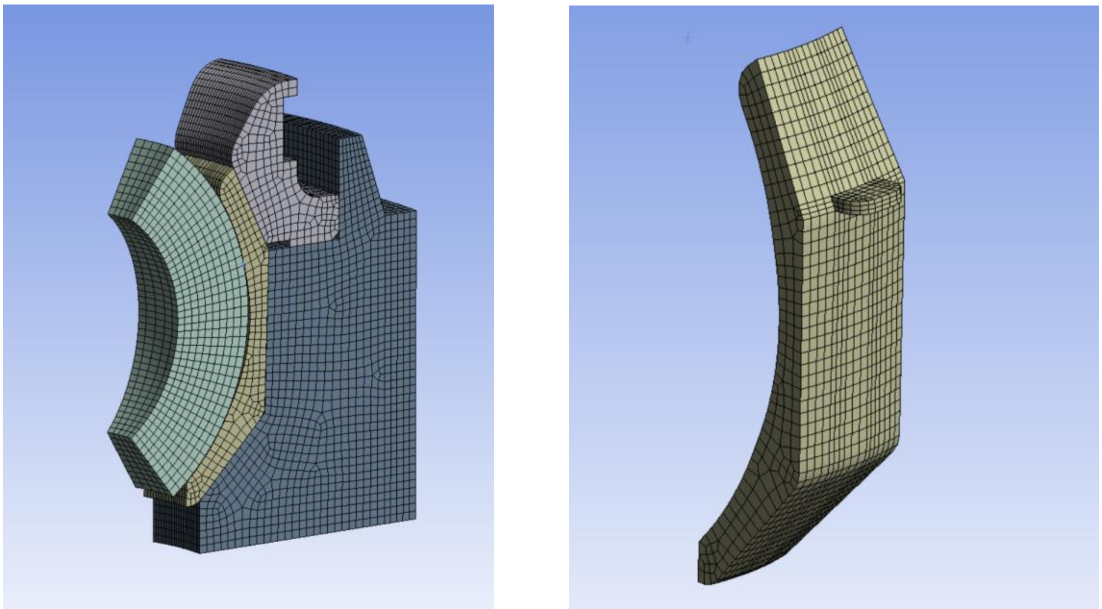

Fig. 1. Hexahedral mesh of the spherical join

There are four essential contact pairs defined between the spherical joint components:

1. pin – bearing (spherical shape)
2. bearing – closing ring (conical shape)
3. bearing – body I (cylindrical shape)
4. bearing – body II (conical shape)

Ansys Mechanical allows to define initial overclosure (penetration) of each contact pair as a parameter called offset [1].

The center of the pin was constrained in all direction in order to fix the structure. Symmetrical boundary conditions were defined on the trimmed faces of the joint segment. No external forces were applied to the structure. The assembly was loaded with internal forces coming out of the initial overclosure – the overclosure values of the four above listed contact pairs were four input parameters of the DoE analysis.

The main output of the FE analysis was friction torque in rotation. The torque was calculated as a product of the normal force, the friction coefficient [2] and the lever arm in each individual contact element of the contact pair "pin – bearing". Consequently the torque value of all elements was summed up.

3. DoE Analysis

The Design of Experiment (DoE) method implemented in Ansys Design Explorer software was used to investigate the relationship between the set of four input parameters (contact initial overclosure values) and one output parameter (friction torque of the contact pair "pin – bearing"). The combinations of input parameters (design points) were automatically created by Design Explorer in the user defined range using the central composite method. The approximated response surface allows to predict the values of the friction torque in the analyzed interval of interest.

4. Results

The first important result of the DoE analysis is the sensitivity chart (Fig. 2) describing the sensitivity of the output parameter (torque) on the four input parameters (contact pair offset).

The chart clearly shows that the first parameter (offset of the contact pair "pin – bearing") is the most important of all four input parameters.

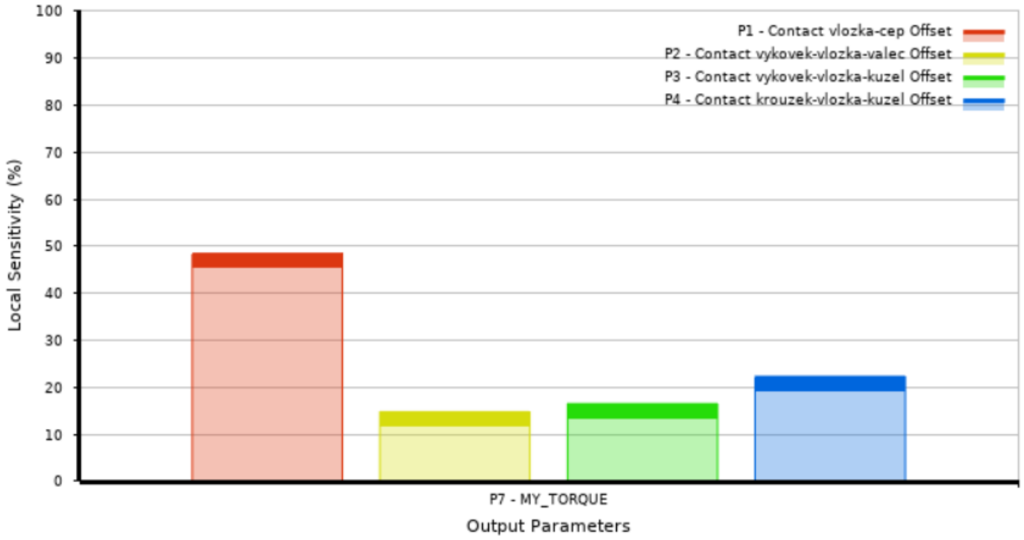

Fig. 2. Local sensitivity of the four input parameters (contact pair offset values)

The second useful result of the DoE analysis is the predicted torque value for any combination of the four input parameters in the analyzed interval. The approximated response surface is created based on the results of analyzed design points. The Design Explorer software is also able to find out combinations of input parameter values for a known target value of the output parameter.

5. Conclusion

The described workflow was used to identify the parameters with the highest sensitivity and to find out the best combination of the part dimensions needed to achieve the target value of the friction torque. The parameters with higher sensitivity represent dimensions which have stronger influence on the resulting torque therefore they request tighter manufacturing tolerances and stricter quality control in general.

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[1] Ansys Product Help, online documentation, revision 2020 R2.
[2] Pomp, N., Palasovics, N., Měření koeficientu tření kulového čepu, VÚTS, a.s., Liberec, 2020. (in Czech)