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Design of the levers at the development of new self-equalizing thrust bearings

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Abstract

Plain bearings are undoubtedly one of the main parts of the power machines (such as a turbine or compressor). However, there are many cases when in large power equipment is occurring asymmetrically loading on bearings due to thermal deformations, production inaccuracies, or simple deflection of the shaft. Presented research deals with the numerical analysis of levers being as the first step at the design of a new self-equalizing thrust bearing with the goal to find out its behaviour and base on that to make the improvements. The numerical analysis was done for the bearing with 12 segments using the software ANSYS. The boundary conditions were applied so to prevent the movement (collapse) of the system and at the same time use them to influence the stress distribution in the levers as little as possible. The steel 34CrNiMo6 has been used for the levers in a refined state. The achieved results confirmed the design of the levers, its sufficient stiffness, good functionality, and reliability.

Keywords: lever; design; trust bearing; numerical analysis;

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1. Introduction

Bearings are probably the most common type of engineering components used in all types of machines. According to Carlson et al. (2002), the load acting on a bearing determines its dimensions and consequently the size of the relevant mechanical components, such as bushings, shafts, and others. To be possible produce smaller, more efficient, and cheaper assemblies, there is a constant trend of increasing the allowable bearing load.

Customers are encouraged by bearing manufacturers to provide bearings that survive lubrication contaminated with debris or withstand damage to debris without severely reducing service life. This challenge has led to a considerable amount of research into the most efficient and economical methods of modifying bearings so that they are resistant to damage. (Adishesha, 2002)

One of the key components on a powerful rotating machine is plain bearings. Plain bearings significantly contribute to the total power loss of the machine, and therefore the manufacturers of such rotating machines place the highest demands on the bearings (or their manufacturers). To absorb axial forces in applications where the use of rolling bearings is unsuitable in terms of dimensional limits, service life, high loads, or difficult access during assembly, hydrodynamic thrust bearings are used. (Ferroudji, 2019) The principle of hydrodynamic lubrication of the bearing consists in the fact that the action of hydrodynamic forces in the oil film tilts the segments and thus the formation of an oil film which has the shape of a wedge in the direction of rotation of the bearing. The pressure in this wedge is caused by the adhesion of the flowing oil to the rotating collar. The pressure field transmits the load of the support disk acting on the rotor and distributes it to the individual bearing segments. The pressure in the oil wedge, and thus the load on the individual segments, is inversely proportional to the thickness of this oil wedge. In terms of evenly distributed load of individual segments and thus the maximum bearing capacity of the entire bearing, it is necessary to maintain the same oil wedge thickness for all segments. (Mikula, 1985; Rølvåg, 2020)

In large rotary machines such as a turbine, turbocharger or generator, axial plain bearings with tilting segments are almost always used. The design of the new trust pad bearing with self-equalizing function is a long-term research of the authors in cooperation with GTW company (Czech Republic), while the goal of the research described in this paper is to analyse the preliminary designed self-equalizing trust bearing employing the numerical analysis to evaluate whether the design is worthy further investigation, and production for experimental testing.

2. Design of a bearing

In the case of large rotary machines, due to the deflections of the stator (but also the rotor) components, the required parallelism of the active surface of the segments with the active surface of the rotor collar is not guaranteed. This deflection is caused by many factors (thermal expansion, shaft deflection, "inaccuracy" in production, etc.) and it can result in a reduction in bearing capacity. Long-term "overheating" of the bearing under its dynamic stress causes also so-called fatigue cracking (Pantazopoulos, 2019) that is show in Fig. 1.

Fig. 1. Fatigue cracking caused by dynamic load.

The magnitude of the permissible deviation from the parallelism of the bearing axis with the shaft axis depends on the circumferential speed and the magnitude of the load, and if the deviation is greater than the permissible, steps must be taken to adjust the overall solution or use a special bearing that is able to accommodate this deviation. (Gomez, 2020) Currently, the only solution that can capture the deviation from the parallelism of the bearing axis with the shaft axis is a system of levers at so called self-equalizing bearing. (Martsinkovsky et al., 2012; Woo and O'Neal, 2019)

An example of self-equalizing trust bearing is in Figure 2 at which the axial segments are attached using nozzles and the axial load is transferred to the levers through the pressure distribution element.

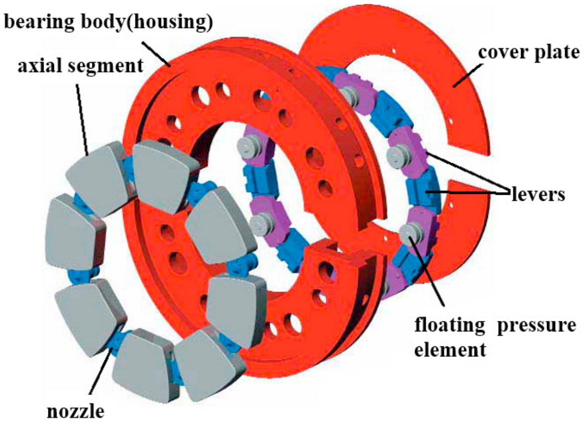

Fig. 2. Basic parts of self-equalizing trust bearing.

In an axial self-equalizing bearing, the alignment element (lever) is the most important part of the assembly. The task of the set of levers is to distribute the load evenly over the entire circumference of the bearing that is then transferred to the bearing housing and subsequently to the machine frame.

Despite of using oil film, the bearing is subject to high material and dimensional requirements. Depending on the size difference between the small and large diameters of the intermediate ring of the active surface of the collar, the number of levers in the set ranges between 12 to 44 levers as standard (from 6 to 22 for the lower levers, and the same number for upper levers).To design a new type of self-equalizing bearing, the lever has to meet the following requirements

- to use as simplest designing features as possible,
- to use the shape of the levers in such a way that the levers roll over each other.

The requirements for the material resistance to all types of loads caused that for the design of levers, the 34CrNiMo6 steel has been used in a refined state with a limit of strength of 1300 MPa and a yield strength of 900 MPa. This type of steel is the most often used material used for the bearings of the turbines and compressors. (Zaidi et al., 2020; Wittke et al., 2019) To improve the properties of the based material, the surface treatment has been one of the goals of long-term research, while several types of surface treatment were tested. It was shown that the best tribological properties has the surfaces hardened by electroless nickel plating.

2.1. Numerical simulation

To have a start point of the designing of a new self-equalizing bearing, the numerical analyses of the levers were carried out.

The presented numerical analysis was done for the bearing with 12 segments and sizes external diameter of segments 345.4 mm and internal diameter of segments 231 mm using the software ANSYS. The numerical model has been defined of the non-linear type considering big deformations with contact elements defined in joins. A load of bearing was set-up based on the real values provided by GTW company (Czech Republic) that was measured in real practice at one of the industrial stream turbines and from which result that the bearing can be standardly loaded with an axial force of 128 kN. The basic dimensions of a lever have been considered according to Fig. 3a, they are l = 4.4343 mm; b = 29.0017 mm and h = 6.533 mm.

The model of the axial bearing self-balancing system is cyclically symmetric. Minor asymmetries caused by the dividing plane of the bearing do not affect the balancing function and could be neglected in the model. Thus, two whole levers can be included in one symmetrical segment. (Camagic et al., 2019) A solution was chosen where the symmetrical segment contains the entire lower lever arm and two halves of the upper lever arm as it is shown in Fig. 3b.

The boundary conditions were applied so to prevent the movement (collapse) of the system and at the same time use them to influence the stress distribution in the levers as little as possible. Therefore, circumferential movement (in the direction of the bearing circumference) was forbidden in the entire section plane of the upper lever. (Iacoviello, 2017) For numerical stability of the calculation, one point of the upper lever in the radial direction, two points on the lower lever in the radial direction and one in the circumferential direction were also limited. (Katinic et al., 2019; Vazdirvanidis et al., 2009) These conditions prevented radial displacements of the entire levers and their rotation around the "z" axis (axial direction). (Sepe et al., 2019)

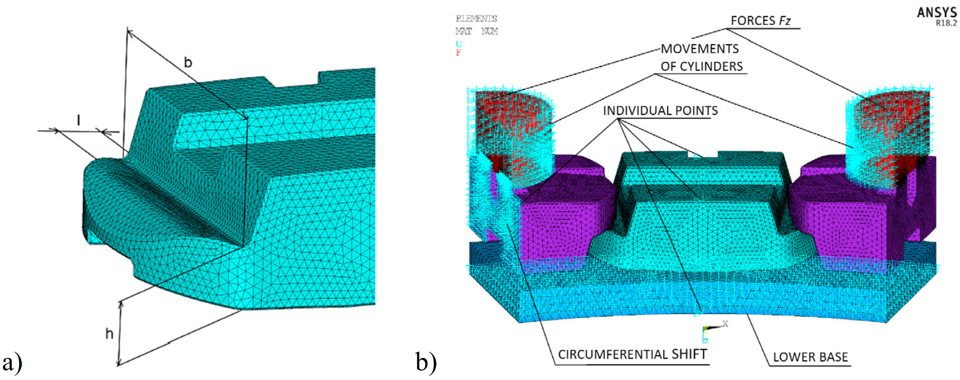

Fig. 3 Basic sizes of a lever and the numerical model.

Steel 34CrNiMo6 has been used for the analysis. The material is elastic, modulus of elasticity $E = 2.1e^5$ MPa, Poisson's ratio $\mu = 0.3$. Finite elements were chosen of type Solid185. It is an eight-node 3D element for modelling solid structures. It supports many different load models, including large deformations. (Baragetti, 2020) The nodes have 3 degrees of freedom (x, y and z offset). The shape of the element can be reduced in various ways by merging nodes. In these calculations, the shape of a tetrahedron is used, which best discretizes even geometrically very complex shapes. FEM model of this bearing has been created by 75,280 nodes and 369,446 finite elements, mostly four-wall elements. There are 2D triangles only in the contacts.

2.2. Results and discussions

The maximum value of the vertical displacement reached 0.053 mm. A small inclination of the levers towards the outer circumference of the bearing is also observable here.

The maxima of the dominant vertical stress in the inner corners of the lever arms reach the values σ_z = 134 MPa in tension. Only the pressure values σ_z in a close area of the lever arm contacts were higher. The reduced stress according to the Huber-Mises-Hencky (HMH) strength theory reaches a maximum value of approx. σ_{HMH} = 180 MPa in the corners of the lever arms. (Fig. 4) Again, only the values in the local area of the lever arm contacts were higher.

On the upper surface of the lower lever arm between the groove for the pin limiting the radial movement of the lever arm and the longitudinal oil groove on the lever arm, the stress is approx. σ_{HMH} = 130 MPa mainly due to the tensile stress in the "*x*" direction. At the edge of the groove for the pin, it is locally approximately σ_{HMH} = 190 MPa.

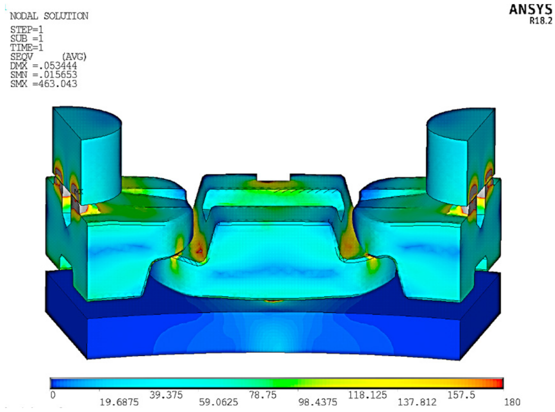

Fig. 4 Reduced stress distribution (σHMH) on a bearing equalizing system.

It is worth mentioning the relatively high value of stress in the area between the recess for the pin and the oil channel at the upper levers. Here the stress is highest at the medium size of the levers. This stress is given mainly by the tensile stress of the surface from the bending of the levers. To local stress tip then occurs at the edge of the pin grooves. From this resulted that it would be advisable to slightly move or narrow the oil channel and round or chamfer the edge at the pin.

34CrNiMo6 steel has been used for the levers in a refined state with a yield strength of 900 MPa. Due to this, the stress values of the levers can be considered safe.

3. Conclusions

To avoid a misalignment in rotary machines such are turbines or compressors, the trust bearings are used. Nowadays, old-style elliptical or four-lobed bearings are replaced by a tilting pad bearing for adjustment facilities of shaft positions. The advantages of tilting pad bearings are, for example, total avoidance of oil whirl and dynamic instability, lesser amplitude of shaft vibration, increased safety and operability, and easier thermo element placement. (Basu and Debnath, 2019; Majidi et al., 2019; Papadopoulous et al., 2019)

The numerical analysis of the newly developed self-equalizing trust bearings presented in the article was done to evaluate of a geometry design to be suitable for the next production and further testing. The most important part of the bearing are levers produced from steel 34CrNiMo6. The numerical analysis was done for the bearing with 12 segments using the software ANSYS. The boundary conditions were applied so to prevent the movement (collapse) of the system and at the same time use them to influence the stress distribution in the levers as little as possible. The load was set up based on the real values for this type and size of bearings. The results has shown that the design is enough rigid, and the lever can be considered safe.

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