Modelling and Simulation of Rolling bearings using advance Software Tools

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Abstract. This paper presents an approach in modelling, simulation and analysis of rolling bearings using new developed mathematical model and software CATIA V5 as a tool. Rolling bearing represents an assembly that is typical and common in lot of engineering applications and it consists of a few components. Because of load transfer from a ring to another one, through rolling elements; they are not equally engaged in load distribution. Degree of inequality of the load distribution between rolling elements and rings depends on external load, stiffness of bearing parts, number and form of rolling elements. Comparative analysis of the load distribution in journal loaded ball and roller bearings will be carried out in this paper. Influence of bearing internal geometry on the load distribution is analyzed by new mathematical model of load distribution in rolling bearing. Results of carried out analyses are using for development of rolling bearing design providing better performances (static and dynamic load ratings, operating life etc.). Analysis part of the paper consists of FEM analysis of the rolling bearing model, conducted by software tool in aim to compare calculations with simulation results.

1 Introduction

Rolling bearing is an assembly that is very important in most of mechanical systems and machines in every branch of Engineering. Concerning distinct parts of a bearing assembly, such as inner ring, outer ring and rolling elements, it represents a system that is not so easy, but it was and still is very interesting for modelling and simulations of any kind. In aim to increase rolling bearings quality and reliability, it is necessary to improve an estimation, construction and technology of rolling bearing manufacturing process. This kind of an approach in modelling is very important, because starting from a mathematical model of load distribution in a mechanical system, we attend to achieve particular objective in Engineering practice and application.

2 Bearing load distribution

The especially important place in rolling bearings estimation and optimization is taking a problem of load distribution between rolling elements. The carrying capacity, service life, stiffness, noise, vibrations and other operational performances of the bearing have significant influence on the load distribution. The internal bearing geometry has may be the major influence on the load distribution between elements in bearing assembly. For this reason, the load distribution for two the most used types of rolling bearing (deep groove ball bearing and cylindrical roller bearing) is analyzed in this paper 'Figure 1'. In the further considerations, the following is supposed:

- the bearing is loaded with constant radial external load F_R;
- the other parts of rolling bearing assembly are rigid;
- form of rolling bearing parts is absolutely accurate;
- in the non-loaded condition, at concentric position of rings the rolling elements and outer ring adjoin, and there is a clearance between rolling elements and internal ring equalling to half of a total internal radial clearance.
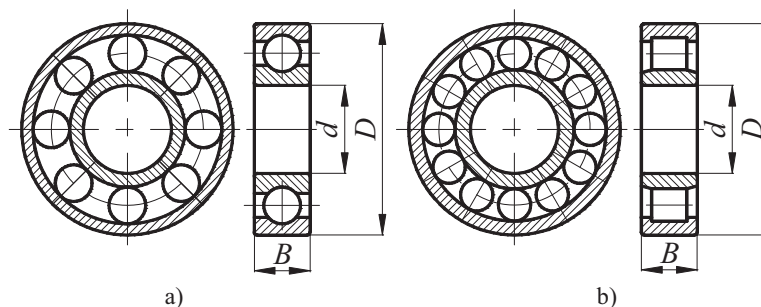
Figure 1. External geometry of rolling bearing: a) ball bearing; b) roller bearing

External load of rolling bearing is transferred from one ring to other one through the rolling elements. In radial loaded bearing, not all rolling elements are simultaneously active. The rolling elements participating in transfer of external load are in loaded zone 'Figure 2'. Load distribution in the loaded zone is unequal.
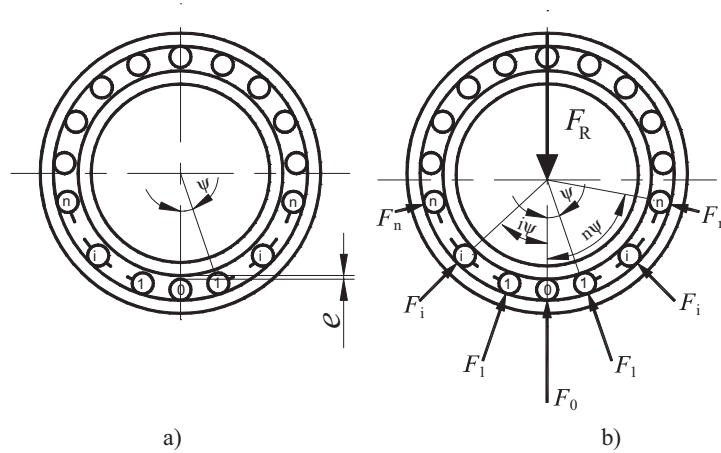

a)   b)

Figure 2. Radial bearing with internal clearance: a) non-loaded; b) loaded with radial external load

Several factors influence on the number of rolling elements participating in transfer of external load, as well as degree of their engagement in load distribution: design (type) of the bearing, external load, volumetric and contact stiffness of rolling bearing parts, internal geometry (number of rolling elements, clearance or interference, accuracy). Because of large number of the influence factors and complexity of their influence on load distribution, the load distribution factor used to be involved into the mathematical model. This factor represents the ratio of rolling element load and external load. When the load is directed to one of rolling elements, conditionally signed with "0" (most loaded rolling element), expression of the load distribution factor K_{ri} can be written:

$$K_{ri} = \frac{F_i \cos(i\psi)}{F_R} = \frac{\left(\cos(i\psi) + \dfrac{e}{2\delta_0}(\cos((i\psi)) - 1)\right)^\beta \cos(i\psi)}{1 + 2\sum_{j=1}^{n}\left(\cos(j\psi) + \dfrac{e}{2\delta_0}(\cos((j\psi)) - 1)\right)^\beta \cos(j\psi)}, \quad i = 0,1,\ldots,n \qquad (1)$$

where are:
- F_i – load of "i"-rolling element 'Figure 2b';
- F_R – external load of bearing 'Figure 2b';
- $\beta = \begin{cases} \dfrac{3}{2} - \text{ball bearing} \\[2mm] \dfrac{10}{9} - \text{roller bearing} \end{cases}$ – exponent of rolling element shape;
- $\psi = 2\pi/z$– angular distance between rolling elements 'Figure 2a';
- z – total number of rolling elements in bearing;
- $n = (z_s-1)/2$ – auxiliary parameter 'Figure 2a';
- z_s – number of rolling elements simultaneously participating in load transfer;
- e – internal radial clearance 'Figure 2a';
- δ_0 – total deformation on the contact between "0"- rolling element and raceway 'Figure 2b'.

Based on Formula (1) it is possible to make conclusion that the load distribution factor being the quantitative characteristic of load distribution between rolling elements, depends on total number of rolling elements, internal radial clearance, as well as on total contact deformation on the place of the most loaded "0"- rolling element caused by acting of external load. Based on the analysis of change of this factor it is possible to explain character of load distribution between rolling elements depending on the various influence factors. The diagrams of the load distribution between rolling elements in ball and roller bearing with zero clearance are drawn based on Formula (1) and shown in 'Figure 3'. The inequality of the load distribution is decreased with number of rolling elements. The load distribution in roller bearing is less unequal. It is caused by favourable contact conditions due to initial linear contact between rollers and raceways. As shown on the diagrams in 'Figure 3', the load distribution factors of appropriate rolling elements (0, 1,…,4,…) vary in amount. The relation between load of roller and load of appropriate ball in zero-clearance bearing can be determined with Formula (2).
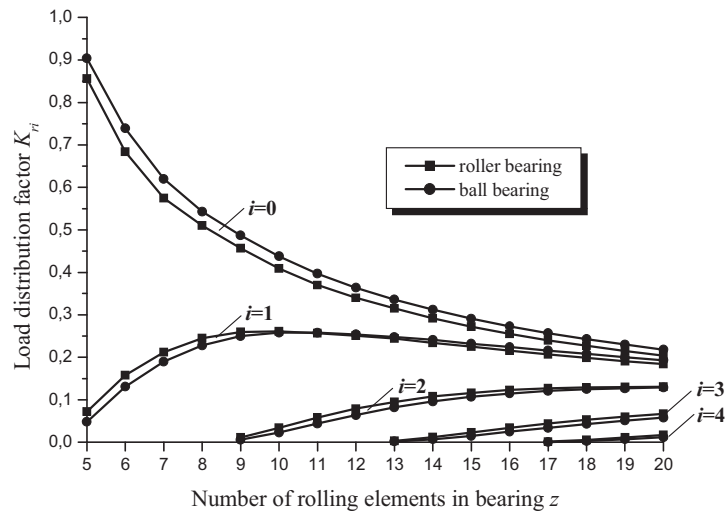
Figure 3. The load distribution versus number of rolling elements in bearing

$$\left(\frac{F_{i,\text{roller}}}{F_{i,\text{ball}}}\right)_{e=0} = \left(\frac{K_{ri,\text{roller}}}{K_{ri,\text{ball}}}\right)_{e=0} = \cos^{-\frac{7}{18}}(i\psi)\frac{1+2\sum_{j=1}^{n}\cos^{\frac{5}{2}}(i\psi)}{1+2\sum_{j=1}^{n}\cos^{\frac{19}{9}}(i\psi)}, \quad i=0,1,\ldots,n \qquad (2)$$

Diagrams given in 'Figure 4' are obtained on the basis of Formula (1) for the most loaded rolling element ($i = 0$). These functions show how load of the "0"-rolling element, as well as load distribution in a bearing, depends on internal radial clearance and shape of rolling elements. Inequality of load distribution is increased with increasing clearance and the load of the most loaded rolling element therewith can be heavier even more than 80%. Ball bearing is more sensitive to radial clearance than roller bearing. This is caused by adverse initial point contact between balls and raceways in comparison to linear contact between rollers and raceways.
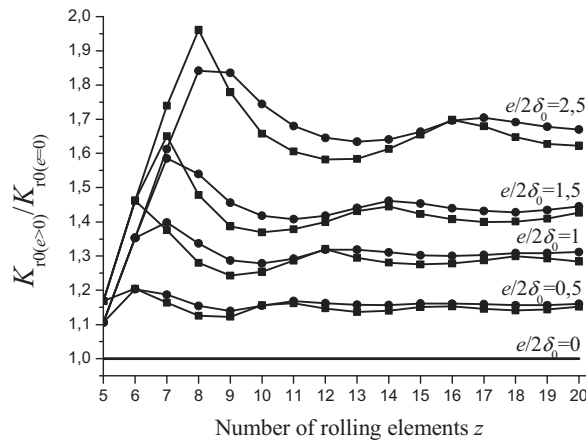

Figure 4. Influence of internal radial clearance on load distribution in rolling bearing

The carried out analyze can be used for more precise determination of load carrying capacity, stiffness, service life and other performances of rolling bearings, such as an excellent base for bearing modelling and simulation.

3 Modelling and simulations

Based on mathematical model and results of bearing load distribution analysis, corresponding models of rolling bearings are performed using software CATIA V5, as a modern and advanced engineering software tool. Modelling process is conducted In "Part design module" of this software, where bearing models are made in their original size and with standard performances. Using main bearing parameters, with some correlations and formulas between them, it is possible to make series of bearings by parametric modelling method in aim to find the best solution for demanding conditions. For above mentioned bearing models, CATIA V5 as an advance soft-

ware tool gives an opportunity to make several simulations. The first is the simulation of kinematics, which means motion simulation of bearing elements in work, which is possible to make in CATIA V5 module for DMU Kinematics. Besides this kinematics simulation, it is very importance to make a simulation of the bearing assembly that works under the real load conditions. It could allow us to analyze the unequal load distribution of the bearing, stress values such as displacements of every part in bearing assembly.

Problem definition phase. The simulation is made based on FEM method where in pre-processing or problem definition phase for relevant finite element of the bearing is selected to be linear elastic tetrahedron. In this simplified case same steel is chosen for all parts of bearing assembly with corresponding mechanical and other properties.

Calculation phase. In aim to calculate correct stress values in all nodes of the bearing assembly, elastic balance equations are to be defined. Equations that connect stress and external load values in a model node (x, y, z); can be written in the matrix form:

$$[B]^T \{\sigma\} + \{F\} = 0, \tag{3}$$

where $[B]^T$ is transponded matrix of differential operators. Partial differentiation of stress vector $\{\sigma\}$ gives equations system that is to be solved. Calculation of this problem is done using structure analysis modulus of advance software CATIA V5 tool. In this case of complex bearing load, but relative low number of tetrahedrons as finite elements, the calculation process measured in a few dozens of minutes.

Post processing or result analysis phase. The stress values calculation in most of FEM software is based on using Huber, Misses and Hencky hypothesis about potential energy of deformations based on formula:

$$\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - (\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) \leq [\sigma]^2 \tag{4}$$

As an example 'Figure 5' shows the Von Misses stress values of a loaded roller bearing assembly caused by unequal load distribution that fits to the nonuniform load distribution from the mathematical model.
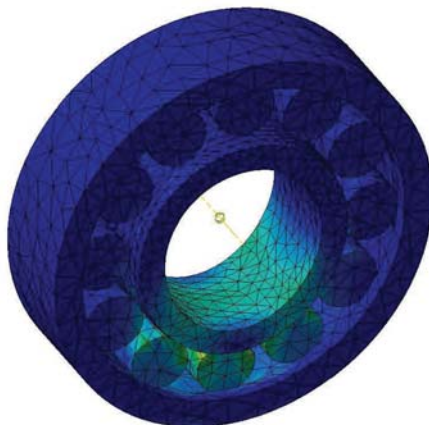

Figure 5. Von Misses stress distribution on roller bearing assembly.

As an approach in a simulation of the bearing dynamic behaviour is to analyze the frequency content of the simulated system. This kind of simulation problems is also possible to conduct in CATIA V5 structure analyzes module with set of dominant self frequencies as a result. Based on presented simulation results, this advance software tool allow us to solve also some optimization problems, but this aspect of analyzes exceed simulation topic and it is not presented in this paper.

4 References

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