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INVESTIGATIONS ON CAGE DYNAMICS IN ROLLING BEARINGS BY TEST AND SIMULATION

TRACK OR CATEGORY

Rolling Element Bearings III (7A)

AUTHORS AND INSTITUTIONS

Sebastian Schwarz, M.Sc.[1], Dr. rer. nat. Hannes Grillenberger[2], Dr.-Ing. Stephan Tremmel[1]
[1] Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Engineering Design (KTmfk), Erlangen, Germany
[2] Bearing Fundamentals, Schaeffler Technologies AG & Co. KG, Herzogenaurach, Germany

INTRODUCTION

Demands on the performance of rolling bearings are constantly increasing. For example, in the process of electrification in the automotive industry and in the bearing assembly of main spindle of machine tools, a guidance system that is as low in vibration as possible is required. A potential cause of vibrations in rolling bearings can be the cage, which under certain operating conditions performs a very high frequency movement, which can be accompanied by strong elastic deformation, that can limit the performance of the bearing.

The calculation of the elastic deformation of the cage during an unstable movement represents a challenge, that has not or only approximately been considered, in previous publications on the subject of cage instability. GRILLENBERGER presents a first extension to rigid cage modelling, in which several cage segments allow macro elastic deformation of the cage by spring-damper elements [1]. A more detailed modelling of the elasticity of rolling bearing cages is described by HAHN [2]: a reduction of the cage FE-model according to CRAIG and BAMPTON [3] allows a precise calculation of the cage deformation. The multibody simulation software CABA3D (*Computer Aided Bearing Analyzer 3 Dimensional*) used for this purpose is also used in this paper to investigate the cage dynamics in a cylindrical roller bearing with respect to different load cases and speeds.

TEST AND SIMULATION CONDITIONS

A very detailed illustration of the individual contacts and the deformation behavior of the cage is crucial for the quality of dynamic simulations of rolling bearings, since the cage movement can change considerably with respect to small changes in the initial and boundary conditions. CABA3D from SCHAEFFLER is a program that enables such special and demanding investigations of cages, for example by implementation of a reduced FE-model of the cage and precise contact calculation. In order to calculate the cage movement with respect to various boundary conditions, the load in axial and radial direction, the speed of the inner ring and the coefficient of friction in the contact between cage and rolling elements are varied for an axially loadable cylindrical roller bearing. The cage of the roller bearing is made of glass fibre reinforced polyamide and is guided on the outer ring. Optical measurements of the motion of the rolling bearing cage are used to compare simulation and real cage dynamics. In order to measure the cage motion in the experiment, reference markers are placed on the front face of the cage, shaft and housing, see Figure 1. The reference markers on the housing provide the basis for the definition of the fixed coordinate system for capturing the cage motion, so

Figure 1: Cylindrical roller bearing with reference markers used to measure cage kinematics.

that the cage kinematics and the vibrations of the test rig are not superimposed. For the comparison between the simulation results and the optical measurement, the rotations, the displacements of the cage center of mass and the deformation of the cage at the reference points are used. The axially loadable cylindrical roller bearing with an inner diameter of d_i = 60 mm is operated in the experiment without lubricant. The cage movement is measured with a bearing load of F_r = 6 500 N and F_a = 2 300 N in radial and axial direction and an inner ring speed of n_i = 2 100 rpm by a high-speed camera system with a measuring frequency of 8 000 Hz.

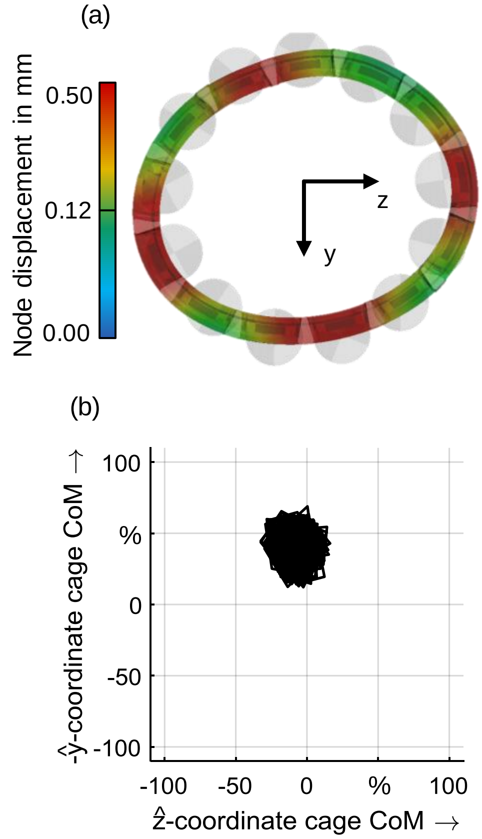

Figure 2: (a) Calculated elastic deformation (enlarged 10-times) and (b) motion of the center of mass (normalized to the guidance clearance) of a glass fibre reinforced plastic cage during an unstable cage movement for a time range of one cage revolution.

CALCULATION OF CAGE DYNAMICS

Depending on the initial conditions and boundary conditions, the rolling bearing cage exhibits diverse motion behavior, for which certain properties such as vibration and noise behavior are characteristic. In particular, the unstable cage movement is characterized by a very high dynamic in the form of a high-frequency movement of the cage center of mass, which is often accompanied by a strong elastic deformation, see Figure 2. The shape of the trajectory of the cage center of mass is circular and uses approximately 25 % of the guidance clearance. The frequency of the cage deformation in the present case is about 1800 Hz, which can lead to a strong noise generation.

These cage dynamics also influence the kinematics of the rolling elements and the shaft. This is particularly evident by a large deviation in the rolling element speed and rolling element complement speed. In addition, the vibrations of the cage are transmitted directly to the shaft via the rolling elements and the bearing rings, which can lead to shaft vibrations, especially in the case of non-centering bearings.

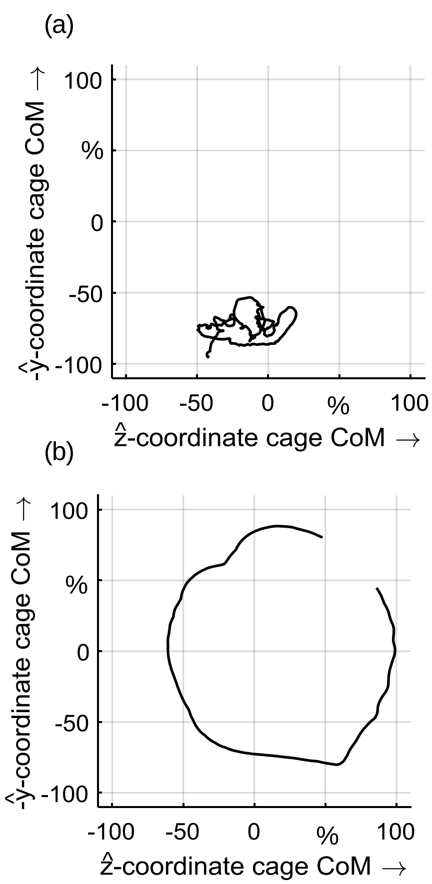

Figure 3: Trajectory of the cage center of mass of cylindrical roller bearing for a stable (a) and circling (b) cage motion normalized to the cage guidance clearance for a time range of one cage revolution.

CLASSIFICATON OF CAGE DYNAMICS

The results of a large number of simulations lead to the conclusion that cage movements can be classified into three types of movement – stable, unstable and circling. These three motion types have specific properties that allow any cage motion to be classified into these three motion types.

A very important characteristic for distinguishing the cage movements is the trajectory of the cage center of mass, see Figure 3. The trajectory of stable cage movement shows that the cage center of mass moves slightly during the period of one cage revolution, while the circling cage movement has a circular shaped motion. Finally, a high frequency oscillation of the cage center of mass can be observed in the unstable motion pattern in Figure 2. The standard deviation of these normalized coordinates for the period of one cage revolution is used as an indicator for classification.

In addition to the coordinates of the cage center of mass, its speed also indicates that it belongs to one of the movement types. The whirl ratio according to GUPTA is defined as the ratio of the rotational speed of the cage center of mass to the rotational speed of the rolling element complement [4]. The arithmetic mean and the standard deviation for the time range of one cage revolution are determined as scalar properties for classification.

The deformation of the cage and the deviation of the cage speed from its average are also defined as additional indicators for the classification of the cage movement. The fluctuation of these two kinematic parameters is evaluated statistically on the basis of their standard deviation. Together with the features already mentioned,

those characteristics form the CDI (*<u>C</u>age <u>D</u>ynamics <u>I</u>ndicator*), which can be used to determine the dynamic behaviour of the cage. [5]
In order to determine the behavior of different cages for each of the movement types, a total of 4788 training data were carried out, for each of which the CDI was calculated for every cage revolution. On the basis of these data, quadratic discriminant analysis was trained to classify cage movement and reached a prediction accuracy of 93.3 % after five-fold cross-validation.

COMPARISION TO EXPERIMENTAL RESULTS

During the experimental tests movement and deformation of the cage was determined with the help of the optical measuring system.
As previously calculated in the simulation, an unstable cage movement could be observed for the mentioned boundary conditions. The comparison between the calculated and measured cage deformation is shown in Figure 3. The amplitudes of both signals are very similar, only the frequency of the vibration is higher for the calculated cage motion. This may be due to the isotropic modelling of the cage material and assumptions in the friction calculation.

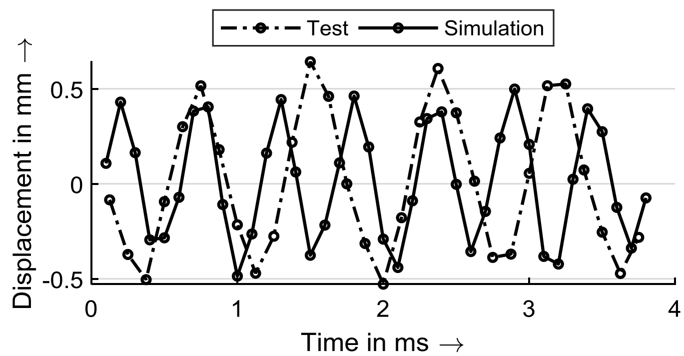

Figure 4: Measured and calculated displacement of a PA66 fibre reinforced cage under combinded load in a dry contact situation.

SUMMARY AND CONCLUSIONS

Using the multi-body simulation tool Caba3D, it has been shown that the dynamics of a rolling bearing cage can be calculated for different cage motion types. To distinguish these classes, important characteristics are developed which form the CDI (*<u>C</u>age <u>D</u>ynamics <u>I</u>ndicator*). With the help of quadratic discriminant analysis the cage movements can be automatically classified into the movement types unstable, stable and circling. On the basis of 4788 training data, a prediction accuracy of 93.3 % could be achieved after five-fold cross-validation, which can be considered reliable for practical application.
Finally, the cage movement for a cylindrical roller bearing calculated in the simulation and measured in the experiment was compared. As predicted in the simulation, cage instability could be observed in the experiment. Only quantitative discrepancies in the frequency of the deformation can be observed, in general the results show a high qualitative agreement.

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KEYWORDS

Rolling Bearings: Rolling Element Bearings, general.