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NEW APPROACH IN THE RESEARCH OF DYNAMIC BEHAVIOR OF ROLLING ELEMENT BEARING

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Abstract: Rolling element bearings are among the most common components to be found in rotating machinery. Their dynamic performance is often the limiting factor in the performance of the machines that use them. Specific functional principle and design of rolling bearings are one of the most important causes for generation of noise and vibrations in mechanical systems. This paper presents results of research the author in the field of mathematical modeling and experimental testing of the impact construction bearings for their dynamic behavior.
Keywords: rolling element bearing, rotor vibrations, ball passage frequency

1. INTRODUCTION

The analysis of rotating machine elements motion is one of the most important fields of research in engineering practice. The research of rotor dynamics finds its application in a wide range of machinery, from large machines that produce energy to those very small used in medicine. The rotor support characteristics have a great influence on rigid rotor dynamics. Rolling element bearings are mostly used as rotor supports in rotating machinery. Specific construction of rolling element bearings and its functional principle have significant influence on inducement of noise and vibrations in mechanical systems[1].

A large number of researches in the field of rolling element bearings are directed toward analysis of dynamic behaviour of system rotor-rolling element bearing, as well as investigation of the influence on bearing design parameters on its dynamic behaviour [2,3,4,5,6]. All the above-mentioned papers present very complicated models, which encompass systems of differential equations, which describe the complex movement of the rigid rotor in rolling element bearing, including the problem of non linear elasto-hydrodynamic contact between rolling elements and bearing races. For solving of systems of differential equitation's, most authors use Newton-Raphson method, while to obtain a vibration spectrum the fast Fourier's transformation (FFT). Due to their complexity, these models are practically useless for any parametric analysis. So, it can be tell that today it doesn't exist an effective mathematical model for predicting the rigid rotor dynamic behaviour leaned on rolling element bearings [1].

In this paper, a new dynamics model for the analysis of dynamic behaviour of rigid rotor supported on the rolling element bearings has been proposed, which is much simpler and as such more appropriate for the analysis of the impact of structural and operating characteristics of rolling element bearings to its dynamic behaviour and state of the operating accuracy. Model considers an ideally manufactured rolling bearing with radial contact and internal radial clearance.

2. MECHANISMS FOR GENERATION VIBRATIONS IN ROLLING BEARINGS

Reasons for generation of disturbance forces that cause vibratory movement and affect the dynamic behaviour of rigid rotor in rolling element bearings, in general can be classified into four categories [7]:

» specific construction and operating profile of rolling element bearing (primary bearing induced vibration - structural vibrations),
» micro and macro geometry errors of bearing elements (vibrations with technological origin),
» damage of bearing elements (vibrations due to damage of bearings elements),
» negative environmental impact (vibration due to the environmental effects).

The first sort of distraction forces generation is a direct consequence of discrete structures of rolling element bearings, which causes that the mutual position of elements and distribution of bearing load is cyclically changed during operation. Generation of oscillations is a direct consequence of specific functional principle and design of bearings and cannot be avoided, even in ideally manufactured rolling element bearings. These vibrations are also known as structural vibrations.

In other three cases, disturbance forces occur due to various geometric imperfections of working surfaces, originated in manufacturing and assembly phase i.e. before the exploitation phase or in exploitation phase by wearing of working surfaces or negative influence of environment. As the vibration generation is a consequence

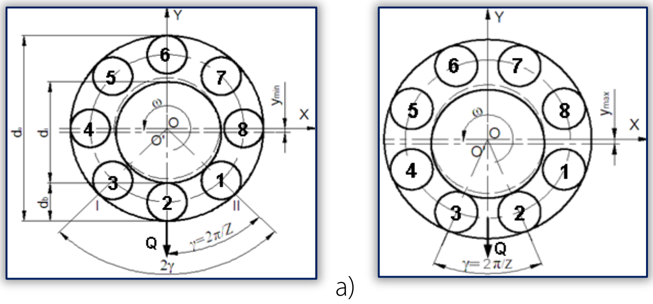
of imperfection in manufacturing and exploitation, they often can be reduced and even missed.
Bearing construction has influence on the vibration generation in all noted cases. However, only in the first case the specific bearing construction directly causes vibrations, while in other cases the vibrations are caused by technological errors and damage of bearing elements as well as the disturbance forces generated in bearing vicinity.

3. STRUCTURAL VIBRATIONS

In principle structural vibrations, caused by specific construction of rolling bearings, appear in two ways [8]:

- » because of influence of internal radial clearance and discrete structure of rolling element bearings,
- » because of periodical changes in stiffness of rolling element bearings due to contact deformations.

Generation structural vibration in rolling element bearings is consequence of discrete structure and kinematics of bearing. Namely, load distribution from inner to outer bearing race occurs across definite number of discrete, cage separated rolling elements, whose angular position, in relation to direction of outside load, is constantly changing during bearing operation. This simple change in rolling elements position causes the constant change of internal and outer race mutual position, which occurs periodically with the cage rotation. Accordingly, axis of internal race, in relation to outside, is constantly oscillating during the bearing operation. Internal radial clearance, which is planned in bearings to avoid negative influence of errors in micro and macro geometry, temperature dilatation and deformations occurred during installation and caused by external load, is the basic reason of these oscillations.



a) b)

Figure 1. The extreme rotor positions in the rolling element bearing [10]

Figure 1. shows rolling element bearing with eight rolling elements in two extreme positions In the Fig 1.a) load is transferred trough rolling elements 1, 2 and 3, while the rolling element number 2 is exactly on the direction of external radial load. In the Figure 1.b) rolling elements 1, 2, 3 and 4 participate in the transfer of external load and are symmetrically distributed in relation to the direction of external radial load.
From the image it is obvious that the radial distance between the bearing races is different. Position in the Figure 1.a) has the minimum radial distance between the bearing races. By rotation of rolling elements set, together with the separator, the radial distance between the races is increased until the set of rolling bodies doesn't come to symmetrical position in relation to the direction of external load, which is shown in the Figure 1.b). In this case, the radial distance between the bearing races is largest. By further rotation of the elements set, they will be returned to their original position, when the rolling element designated as number 3 is in the direction of external radial load.
These changes of relative distance between the races of bearings occur periodically with the rotation of rolling elements set and separator and the frequency of vibration will be equal to the frequency of rotating separator (f_c) multiplied with total number of rolling elements in the bearing (z). This frequency is known as the ball passage frequency (f_{bp}). According to [9]:

$$f_{bp} = z \cdot f_c = \frac{z}{2} \cdot \omega \cdot \left(1 - \frac{d_b}{d_c} \cdot \cos\alpha\right) \qquad (1)$$

where ω is the shaft frequency, d_b the diameter of rolling elements, d_c cage pitch diameter, α the bearing contact angle.
The ball passage frequency (BPF) represents the speed with which rolling elements come over a fixed point on the outer race of bearing [12]. BPF is a very important feature for diagnosis of the rolling element bearing working state. During the analysis of vibration, a specific vibration frequency of rolling bearing is used during the vibration spectre analysis for the detection of damage locations and various irregularities on bearing elements.

4. EXPERIMENTAL ANALYSIS

In order to verify the proposed mathematical model, the experimental analysis of bearing vibrations was performed, as well as vibration frequency spectrum analysis. Vibrations measurement is done using the device for rolling bearings dynamic research, which is developed at the Faculty of Mechanical Engineering in Podgorica. The layout of device is showed at the picture Figure 2. Bearings used in experimental analysis were specially selected and assembled for specific experiments during research.

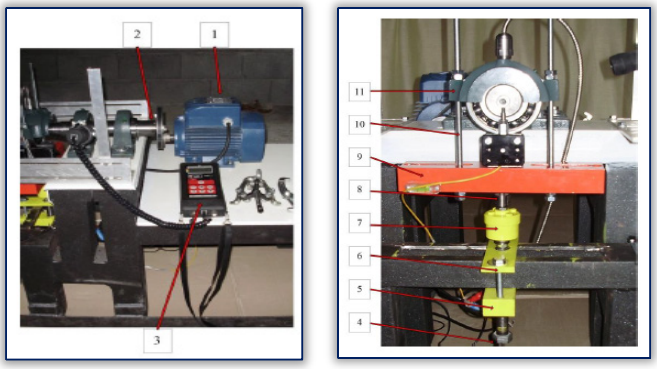


Figure 2. Device for rolling bearings dynamic research

5. EXPERIMENTAL APPARATUS

The basic element of the test bench was a shaft, whose frequency could be changed, supported by two rolling element bearings and driven by a 1.5 kW electromotor (Figure 2). Investigated bearings were located on the front side of the shaft. During experimental analysis shaft frequency was n=1476 min-1, which correspond to ω = 154,5 s-1. The shaft frequency was determined by a stroboscopic lamp. The test bench enables the measurement of relative vibrations (movement) between bearing outer race and rotor, as well as the absolute vibrations of bearing outer race. Relative vibrations were measured by a non-contact sensor which operates on eddy currents principle. The sensor was mounted onto a housing which enables precise change of distance between the sensor and shaft surface. The sensor output, after appropriate filtration to eliminate unwanted noise and static voltage, was fed to a 16 bit, 12 channel, 200 kHz data acquisition board. The measuring system enables measurement of vibration movement in a range of ±125 μm and in frequency range of 5-8000 Hz. The data acquisition was performed in Lab VIEW.

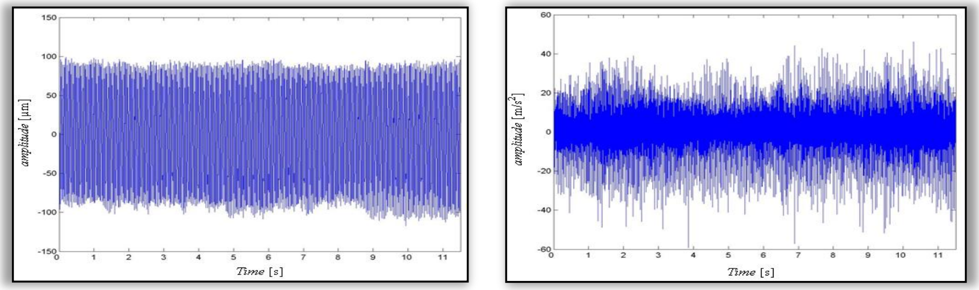


Figure 3. Time record of bearing vibrations: a) relative; b) absolute [10]

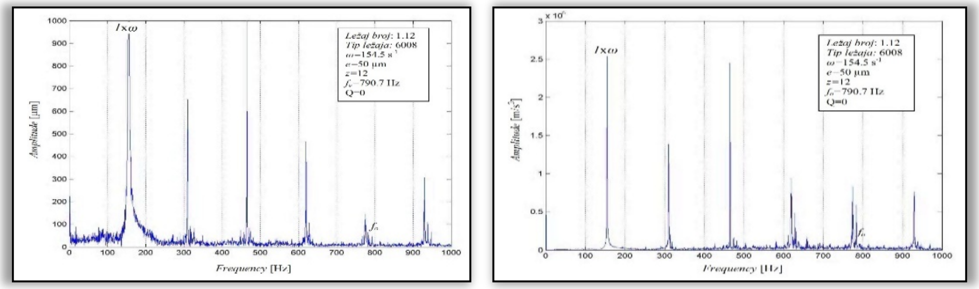


Figure 4. Time record of bearing vibrations: a) relative; b) absolute [10]

6. EXPERIMENTAL PROCEDURE

As the result of every experimental analysis on the bearings, the time record of vibrations was obtained. The representation of the time record is given on Figure 3. a) and b). The Nyquist sampling principle was employed in order to eliminate any chance of aliasing, leading to the generation of false frequency contribution in the frequency spectrum. Note that the sampling frequency should be at least twice that of the measured (maximum frequency of interest). However, it is recommended that the sampling frequency is ten times greater than maximum frequency of interest. As the maximal calculated value of ball passage frequency of investigated bearings was up to 1500 Hz, the sampling frequency of 20 kHz was chosen for experimental analysis in line with noted recommendations. The level of vibration was recorded during time period of 15 seconds on each of the bearings used in experimental analysis, which produced a record containing 300000 data points. The results over time were processed by FFT analysis using the MATLAB functions for digital signal processing - Signal Processing Toolbox. The frequency spectrum is shown on Figure 4 a) and b), where f_{bp} represent the first harmonic of the BPF, while 1xω is the angular frequency of shaft rotation. Vibration spectrum contains peaks even at higher harmonics of ball passage frequency. However, during the parametric analysis only amplitude on primary frequencies were considered, that are in most cases significant for assessment of vibration behaviour of mechanical systems. Sixteen vibration spectrums were recorded for each investigated bearing and the analysis was performed with mean values.

On the frequency diagram high values of vibratins amplitude on shaft frequency and its harmonics could be recognized, as well as on BPF. High level of vibrations of shaft frequency is consequence of residuary imbalance in system, while vibrations on the BPF are consequence of specific construction and rolling bearing working manner. These vibrations are called structural vibrations of rolling bearing. It couldn`t be evaded, and are present at every rolling bearing, even at the ideal construction.

7. CONCLUSION

Rolling element bearings are one of the main noise and vibrations generator at mechanical constructions. Reasons for generation noise and vibrations in rolling bearings in general can be classified into four categories: specific construction and operating profile of rolling element bearing (structural vibrations), vibrations with technological origin, damage of bearing elements, negative environmental impact. Bearing construction has influence on the vibration generation in all noted cases.

However, only in the first case the specific bearing construction directly causes vibrations, while in other cases the vibrations are caused by technological errors and damage of bearing elements as well as the disturbance forces generated in bearing vicinity.

In the shaft bearing assembly supported by perfect ball bearings, the vibrations at the shaft frequency and the ball passage frequency (BPF) dominate the vibration spectrum. The vibrations at the latter frequency are called ball passage vibrations (BPV).

Note

This paper is based on the paper presented at 13th International Conference on Accomplishments in Mechanical and Industrial Engineering – DEMI 2017, organized by University of Banja Luka, Faculty of Mechanical Engineering, in Banja Luka, BOSNIA & HERZEGOVINA, 26 - 27 May 2017.

References

[1] Harris T.A., Kotzalas M.N., (2007), Rolling Bearing Analysis, Taylor & Francis, USA,
[2] Крючков Ю. С. (1959), Влияние зазора на вибрацию и шум подшипников качения, Вестник машиностроения, No 8, pp. 30-33.
[3] Harsha S. P., (2005), Non-linear dynamic response of a balanced rotor supported on rolling element bearings, Mechanical Systems and Signal Processing, Volume, Vol. 19, No 3, pp. 551-578
[4] Tomović R., Miltenović V., Bulatović R., (2006), Dynamic model of rolling bearing, Proceedings of 2nd International Conference "Power Transmissions 2006", Novi Sad, pp. 215-220
[5] Gupta P.K., (1984), Advanced dynamics of rolling element bearings, Springer Verlag
[6] Jang G.H., Jeong S.W., (2002), Nonlinear excitation model of ball bearing waviness in a rigid rotor supported by two or more ball bearings considering five degrees of freedom, Journal of Tribology, Vol. 124, No. 1., pp. 82-90
[7] Tomović R., (2010), Istraživanje uticaja konstrukcionih parametara kotrljajnih ležaja na stanje njihove radne ispravnosti, doktorska disertacija, Mašinski fakultet Niš,.
[8] Tomović R., Miltenović V., Banić M., Miltenović A., (2010), Vibration response of rigid rotor in unloaded rolling element bearing, International Journal of Mechanical Science, Vol. 52, No. 9, pp. 1176-1185;
[9] Tomović R., (2006), Kinematički model kotrljajnog ležaja, International Conference "Konstruisanje, oblikovanje, dizajn" KOD2006, Palić, pp. 101-104

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