

# Dynamics of Ball Bearings with Damages at Outer Raceway Surface -Vibration Response under Different Loads

Ivana Atanasovska\* and Natasa Soldat\*\*

\* *Mathematical institute of SASA, Belgrade, Serbia*

\*\* *University of Belgrade-Faculty of Mechanical Engineering, Serbia*

**Summary.** This paper presents the new approach in analyzing the vibration response of rolling ball bearings. The simplified methodology for vibration calculation is developed in order to become a tool for analyzing the wide range of different ball bearing types with different defects and under various working conditions. The methodology is verified by compare with available experimental results. For a particular ball bearing type and a particular damage shape and size, all of steps in the developed procedure are performed and results are presented. The conclusions about the dynamics of ball bearing with damage are obtained in accordance with graphical presentation of the results.

## Introduction

The operation characteristics which are required from rolling bearings become very rigorous in last few decades. This condition is result of the fact that rolling bearings are the part of almost all contemporary transmission systems including systems in generators of renewable energy. Consequently, the energy savings, longer working life and noise and vibration reducing have become an integral part of all ball bearing studies. In that sense, the rolling bearings as well know and widely used standard machine elements, have been entered into the focus of contemporary research of many group of mechanics scientists. Almost of all them are studying the dynamic behavior of rolling bearings as the most important bearing characteristics which reflect almost all characteristics of design, production, assembly and bearing operation and maintenance.

But, the unique methodology for analyzing the dynamic behavior of rolling bearings still doesn't exist. The results presents in this paper is a step forward in developing such a methodology, which will be in same time with satisfactory accuracy and simplified enough for widely usage, with emphasis on qualitative and comparative analyses. The special attention is paid to developed procedure with possibilities to studying the different ball bearing defects with failure prediction possibilities, in order to make a tool for reversible maintenance.

## Simplified methodology for analyzing the dynamics of radial ball bearings

Ball bearing assembly has been analyzed as a system of elastic related masses, with fixed outer ring in housing, and rigidly bounded inner ring to the shaft. Contact between balls and races can be modeled as non-linear springs, which operate only in compression, simulating contact deformations and resulting forces. System of differential equations describing the vibrations of the bearing assembly can be expressed as, [1]:

$$[M]\{\ddot{q}(t)\} + [D]\{\dot{q}(t)\} + [C]\{q(t)\} = \{F(t)\} \quad (1)$$

where:  $[M]$  – mass matrix;  $[D]$  – damping matrix;  $[C]$  – stiffness matrix;  $\{q(t)\}$  and  $\{F(t)\}$  are vectors of generalized movements and external forces.

The main postulates of the mathematical phenomenological mapping has been used for simplifying the system of equations (1) in the case of radial ball bearing, [1], to a single degree of freedom system with reduced mass of shaft and housing and with time-dependence radial stiffness of ball bearing of whole assembly.

The time-dependence stiffness has been calculated by Finite Element Analysis, [2]. In figure 1 the developed Finite Element Model of a particular radial ball bearing type 6206 with defect (with width of 0,3mm and depth of 50 $\mu$ m) is shown. The modeled defect shape often exists under fatigue or other damaging phenomena, [3, 4]. Figure 2 shows obtained radial stiffness for different external loads.

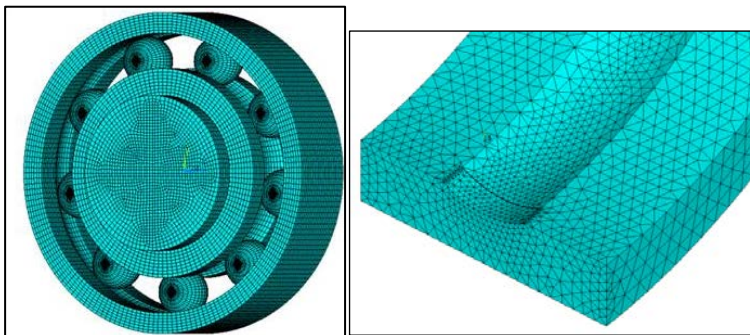


Figure 1. Finite Element Model for stress-strain analysis (with damage detail)

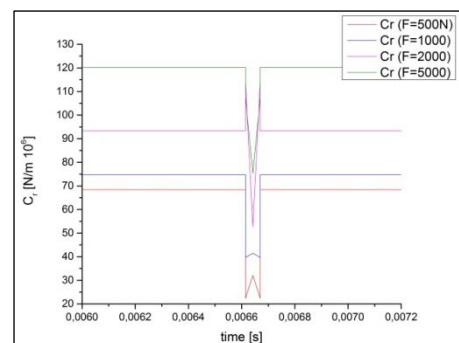


Figure 2. Variable radial stiffness for ball bearing with damage - zoom in detail

## Results and conclusions

The obtained functions of radial stiffness are incorporated in the appropriate equations for calculation the radial ball bearing vibrations, [1]. The Runge-Kutta method by MathLab software has been used for differential equations solving. The obtained results give the vibration response of modeled ball bearing type in both of the cases: with and without damages and for different external loads. For new methodology verification the available experimental results for the same type of ball bearing vibrations in the case without damages are used, [5].

The obtained results are presented by set of comparative diagrams. Two of the comparative diagrams for discussing the influence of damages on 6206 bearings vibrations are shown in Fig. 3. Similar diagrams are created for other external forces in range of ball bearing load capacity. It is easy to conclude that the effects of damages on other raceway surface have different character for different external loads. The no predictable qualitative vibration response of rolling bearings with damages could be expected. Therefore, the one more quality of presented methodology could be the analysis of optimal external load range in cases of rolling bearings for which operation the monitoring systems shows the responses characteristic for existing damages. For these purposes the velocity-displacement diagrams, Fig.4, could be created and analyzed.

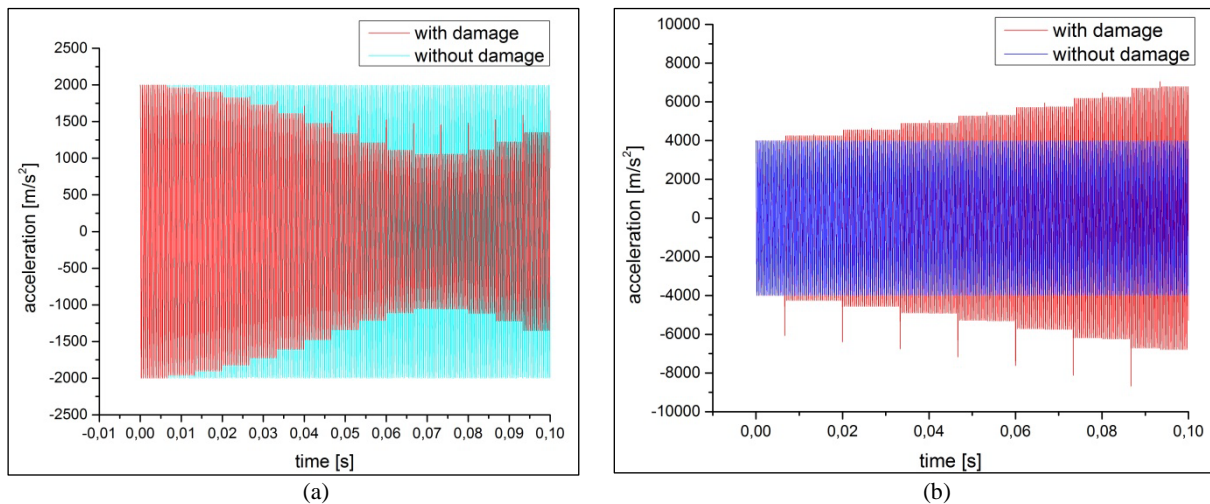


Figure 3. Comparative diagrams for vibration responses of ball bearing with and without damage: (a) external load 1000 N; (b) external load 2000 N

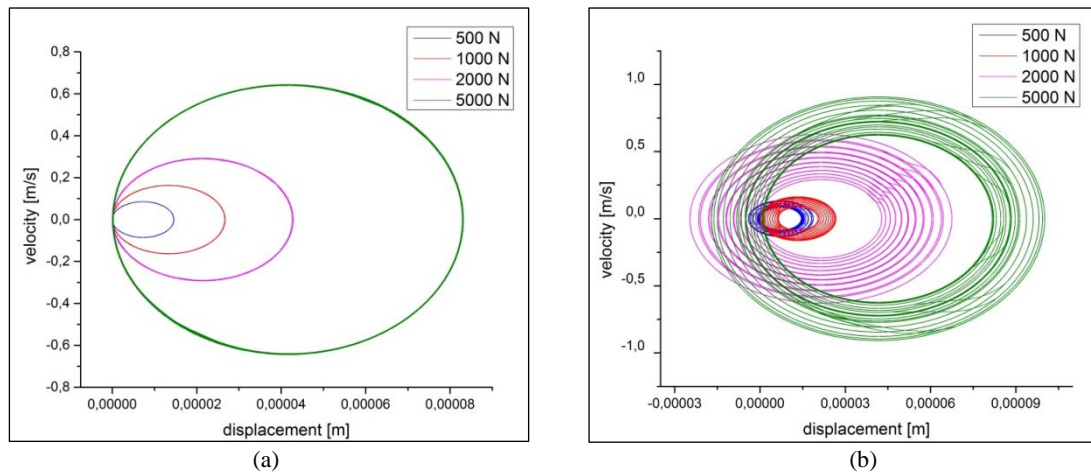


Figure 4. Velocity-displacement diagrams: (a) ball bearing without damage; (b) ball bearing with damage

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