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An analytical model of Rolling Bearing System for Outer Race Fault Prediction

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Abstract
In the present technological enhancement and advancement, rolling element bearings are used to handle vibrations of mechanical and electrical systems such as shafts, rotors for mechanical, electrical, medical, biomedical, biomedical instrumentation and other activity in manufaturing, mechanical systems and industrial applications. The present work is focused on the modeling of roller bearings in a way that the fault on any of its component can be identified for further diagnosis. For the purpose a 6002 Deep Groove Rolling Bearing was considered for analyzing displacement data obtained due to vibration over the faulty element.
Keywords: *Rolling Bearing System, Outer race defect, 6002 Deep Groove Rolling Bearing, displacement*

1. Introduction

Ball bearings and roller bearings can both be classified as "rolling bearings". All forms of bearings utilize the rolling action of balls and/or rollers to minimize friction and to constrain motion of one body relative to another. Even though there are many different type of rolling bearings, they all consist of the same general components.

1. A complement of balls and/or rollers which maintain the shaft and a usually stationary structure in a radially spaced relationship
2. Two usually steel rings each of which has a hardened raceway on which hardened steel balls or rollers roll
3. A cage or separator (retainer) which holds rolling elements in an angularly spaced relationship

Rolling bearings are bearings with two components that move in opposite directions. These parts are the inner and outer ring, and they are separated by rolling elements. The rolling elements roll between the two rings during operation. This occurs on hardened steel surfaces called raceways. The friction generated here is significantly lower compared to plain bearings. Faults mainly occur in following components of a rolling bearing

1. outer race
2. inner race
3. rolling element

In this paper a model of rolling element bearing is presented in order to govern faults in outer race of the bearing.

2. Modelling of Rolling Bearing System

Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

2.1 Modelling assumptions

1. For small displacements (less than 0.4mm) of the roller with respect to the defect at outer race, the bearing is not considered as faulty

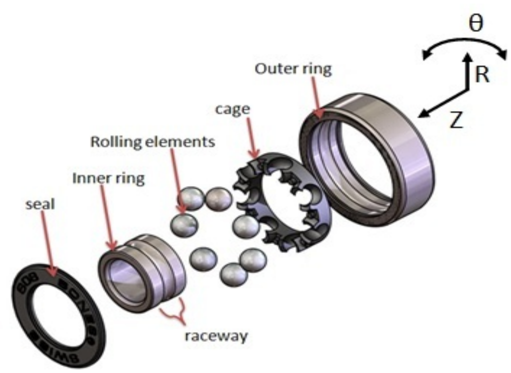

Fig.1. components of rolling element bearing

2. The outer race remains stationary and that the inner race rotates at the shaft speed
3. The deflection pattern of the bearing rings is the sine waves around the rings
4. The bearing rings are assumed to be isolated continuous systems

2.2 Governing equation of motion

$$\ddot{q}_i + \omega^2{}_i q_i = \frac{Q_i}{M_i}$$

Where

q_i is the generalized displacement co-ordinate for the i^{th} sine mode. Q_i is the generalized force for the i^{th} mode and M_i and ω_i are the generalized mass and natural frequency for the i^{th} mode

$$M_i = 2\pi\rho a$$

The natural frequency for the i^{th} mode of flexural vibration of the races is

$$\omega_i = \frac{i(i^2-1)}{\sqrt{1+i^2}}\sqrt{\frac{EI}{\rho a^4}}$$

Where

i is the number of sine waves around the circumference (=2,3,4…..) a is the radius of neutral axis I is the moment of inertia of the cross-section E is the modulus of elasticity and ρ is the mass per unit length

2.3 Generalised force

$$Q_i = \int_0^{2\pi} P(\emptyset, t) X_i\,(\emptyset) d\emptyset$$

Where

X_i is the mode shape and $P(\emptyset, t)$ is the excitation force which is the product of load on the rolling element P and the pulse shape F

$$X_i(\phi) = \sin i\phi + \cos i\phi$$

2.4 The rolling element load

The load on the rolling element at any angle Ø (=$\omega_c t$) is given as

$$P(\emptyset) = P_{max}[1 - \frac{1}{2\,\epsilon}(1 - COS\emptyset)]^n \qquad -\emptyset_1 < \emptyset < \emptyset_1$$

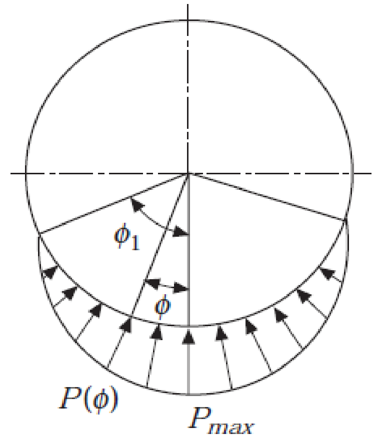

Fig.2. Load on rolling element bearing

3. Bearing parameters and load analysis

For analysis, following assumptions were made for a 6002 deep groove rolling element bearing.

Table 1: Terminology and parameters

S.N.	***Terminology***	Dimension
1	Bore	15 mm
2	Outside diameter	32 mm
3	Width	9 mm
4	Rolling element diameter	4.76 mm
5	Pitch diameter	23.5 mm
6	Groove radius inner race	2.43 mm
7	Groove radius outer race	2.57 mm
8	No. of rolling elements	9
9	Nominal contact angle	0° (assumed)
10	Spindle speed	1500 rpm
11	Material	SAE52100 chrome
12	Weight	30 gm
13	Modulus of elasticity	200 MPa
14	Moment of inertia	5.15×10^4 mm^4
15	Mass per unit length	0.03 kg

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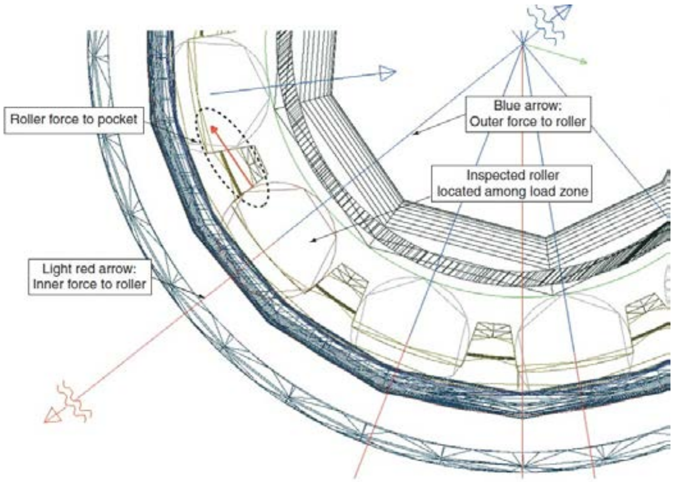

Fig.3. loads on outer race

3.1 Mathematical Equations

P_{max} *is* the maximum load in the direction of the radial load $\in$ is the load distribution factor and $\pm\emptyset_1$ is the extent of load zone and $n = \frac{3}{2}$ for ball bearings and $\frac{10}{9}$ for roller bearings.

Since the load is periodic in nature having a frequency equal to the cage frequency and the load is evenly distributed about the point of maximum deflection the roller load can be expanded in Fourier series for even functions. Therefore, a pure radial load

$$P(\omega_c t) = P_o + \sum_r P_r \cos r\omega_c t$$

The Fourier coefficients P_o and P_r can be determined by the following method.

Therefore,

$$P_0 = \frac{1}{T_c}\int_{-T_c/2}^{T_c/2} P(\omega_c t)\, dt$$

Where T_c is the time period for cage motion = $2\pi/\omega_c$

$$P_0 = \frac{P_{max}}{\pi}\,[A_o\phi_1 + A_1 \sin\phi_1 + A_2/2\sin 2\phi_1 + A_3/$$

$$P_r = \frac{2}{T_c}\int_{-T_c/2}^{T_c/2} P(\omega_c t)\cos r\omega_c t\, dt$$

$$= \frac{P_{max}}{\pi}\left[\frac{2A_0}{r}\sin r\phi_1 + \sum_{l=1}^{3} A_1\left\{\frac{\sin(r+l)\phi_1}{(r+l)} + \frac{\sin(r-l)\phi_1}{(r-l)}\right\}\right]$$

3.2 Outer race defect

Since the outer race is assumed to be stationary, the rolling element load is a function of the angular position of the defect, which remains constant

$$y_k = \left(\sum_i \frac{P(\xi)X_i(\xi)}{M_i{\omega_i}^2}\right)\sum_s F_s \cos s\,(\omega_c t - \theta_k)$$

4. Results

After analyzing three different data set of displacement vs frequency for vibration due to outer race fault, following curve was obtained. As per the assumption, data set 2 was considered as faulty. Same procedure was repeated for different rpm and loading conditions, for which the bearing was supposed to be operating in normal condition.

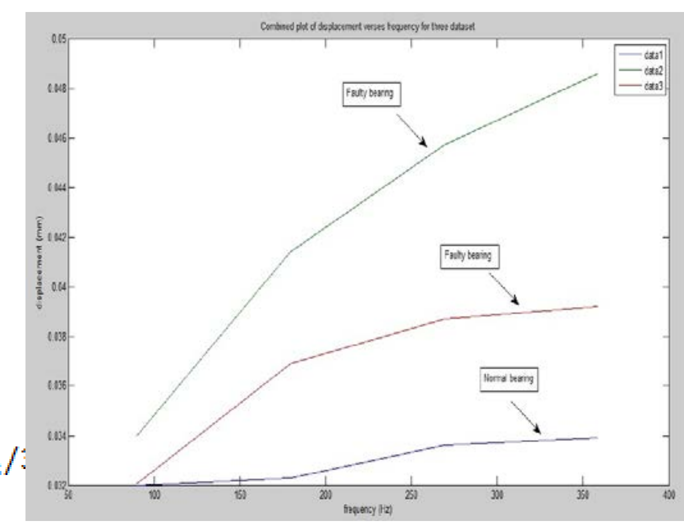

Fig.4. displacement vs frequency plot

5. Conclusion

Rolling element bearing require multiple parameters to be monitored and analyzed to effectively access the bearing condition, in order to take corrective actions before the fault occurs. The present work demonstrate clearly the fault position in outer race by means of dispalcement and frequency data obtained for a set of operation. These data can be processed by using a suitable spectrum analysis technique in order to have spectrum for outer race faults. The inner race defects and the rolling element defects can also be analysed using other diagnosis techniques.

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Vivek Khare is a Doctoral Research Scholar in the department of Aerospace Engineering at IIT Kanpur. He obtained his Master's Degree in DESIGN specialization in Mechanical Engineering from MNNIT Allahabad in 2014 and Bachelor's Degree in Mechanical Engineering from UPTU Lucknow in 2010. He has a vast teaching experience of about 5 years of undergraduate courses related to mechanics and machine design. His current research interest lies broadly in Fracture testing and Structure analysis of composite materials and smart materials.