Investigation on Influence of Local Defect on Vibration Response of Cylindrical Roller Bearing

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Abstract*—Rolling element bearings are commonly used components in machinery for a wide range of applications. A cylindrical roller bearing consists of relatively short rollers that are positioned or guided by cage. Creation of artificial defect of different sizes at various location of the bearing and analyzing its signals is best approach to study the failure analysis of cylindrical roller bearing.From literature survey it is observed that less work was carried out on NJ type cylindrical bearing. There is scope for analysis of faulty cylindrical bearing at various speed and different radial loads was applied on various lateral defect sizes ranging from 0.5mm to 1.5mm on outer race for this study.The actual measurements of vibration signals for healthy, defective bearing has been carried out by using FFT analyzer and time domain signal analysis has been done in comparative manner.

***Keywords*— Cylindrical Bearing,Outer race defects,lateral defect,FFT analysis.**

Introduction

A cylindrical roller bearing is having very high radial load carrying capacity due to line contact between roller and outer race. Cylindrical roller bearing is more rigid than ball bearing. NJ204 bearings have been applying to the auto accessories, precision machinery components relying on the advantage of precision manufacture technology, thus it gets consistent approval in the electronic application field. Various vibration measurement techniques, signal processing technique are available for condition monitoring of defective Cylindrical bearing system such as Time Domain Technique, Frequency Domain Technique. The comparative study of the healthy and defective bearing will helps in condition monitoring of the bearing and with help of this we can predict the probable life of bearing. As we predict the life of the bearing the defective bearing will be replaced before it completely fails and we reduces the breakdown time of the machinery.

The FFT can be effectively used to differentiate between vibration signatures of two defects of different sizes. [1] A Finite element model simulation for analyzing vibration response of a bearing has been developed. A dynamic loading model simulates the distribution load in the outer race due to transfer load from the ball. Moreover, the model to simulate the impulse force due to impact between the ball and the defect located in the outer race is proposed. Time domain analysis is performed to evaluate the output result of vibration analysis from the finite element software[4] Numerical model of a cylindrical roller bearing has been validated through the optimum analytical model proposed by Harris-Jones without major differences. The numerical model presented phenomena of an experimental model; these phenomena are due to the dynamics of the system, where you can explore different events as chaotic behaviour of the rolling elements, falls, blows, slipping between the races and rollers, among others. Numerical model generates the geometry of the load zones adapted to the dynamics of the bearing elements in contact with geometry it may predict behaviour, failure, location of critical areas among others. [5] Experiments were conducted to validate the simulation results of the software. Vibration analysis is a powerful method for bearing defect detection. With this method, it is possible to predict the condition of a bearing.

The roller bearing is tested at constant speed of rpm with Cylindrical roller bearing. Experimental tests were carried out on two sets of bearings. Initially healthy was fixed in the test rig and signals were recorded using. The healthy bearing was replaced by defective bearing and signals were recorded for each one of the case separately under the same standard condition.The paper conclude that distinct and different behaviour of vibration signals from bearings with inner race defect and outer race defect helps in identifying the defects in roller bearings.[9] Some researchers [10] have also prepared model for prediction of local defects. Prediction of amplitude becomes difficult because of the complex nature of system resulting from assembly of bearing elements and mounting of the same on the shaft and housing. Root cause failure analysis of outer ring fracture of four-row cylindrical roller bearing was carried out by H. Hirani [11]. In his study, a visual examination of failed rolling surfaces was emphasized.The effect of radial clearance, number of rollers and viscosity on the bearing noise was examined by Byoung-Hoo Rho et al [12]. It was concluded from their study that the fundamental frequency of the noise components of the cylindrical roller bearing corresponds to the multiplication of the number of rollers and the whirling frequency of the roller centre.

From the exhaustive literature survey it is observed that many researchers done the work on cylindrical bearing of different type but very less work was done on NJ type bearing. most of the work was carried out for the Ball bearing, multi row cylindrical bearing. The previous work was focused on the variety of cylindrical bearing but not on NJ type cylindrical bearing. The FFT analysis is done with various software by researchers.The signal analysis done by most researchers is time domain and frequency domain as per requirement of the research. These authors describe the possibility of identification of the defected element of various bearing by studying rolling element vibrations using the simulation model.

The present work is concentrated on development of mathematical model for Cylindrical bearing with simply supported arrangement for loading on test bearing. The efforts have been carried out by measurement of amplitudes of vibration of test bearing by FFT

Further the work is also focused on measurement of amplitudes of vibration of test bearings experimentally with operational speed range 0-1500 rpm with the defect size ranging from 0.5 mm to 1.5 mm at the outer race. The present research work involves experimental approach to study the effect of defect size as well as speed of rotation on amplitudes of vibration and defect frequencies. The author has done vibration signal analysis in time domain with FFT analyzer. Harmonic and statistical analysis is carried out to for the collected signals by the FFT analyzer. The statistical analysis method utilizing parameters such as RMS value, Peak value Crest factor and kurtosis to detect the presence of defects in a rolling element bearing applying vibration signals. The statistical analysis method is proposed because of its simplicity and quick computation. A statistical analysis method is most suitable with stochastic (or random) signals.

2.0 Design and Development of Experimental Test Rig

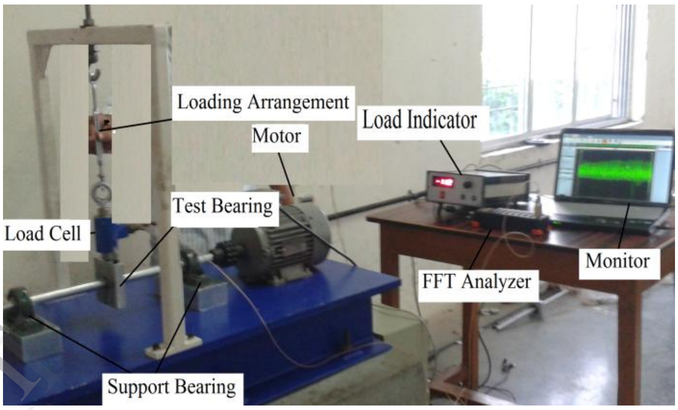
Hertz's analysis applied only to surface stresses caused by a concentrated force applied perpendicular to the surface.Elastic deformation between raceways and rolling elements produces a non-linear phenomenon between force and deformation, which is obtained by the Hertzian theory.

$$F = Kd_r^n$$

The real bearing experiment is performed to validate the model used in simulation study as shown in fig.2.1. It consists of a D.C motor, chain coupling, cylindrical bearings and two healthy support bearing with pedestal . The rotor shaft has a length of 450 mm with a bearing span of 380mm.The almost care is taken to avoid angular misalignment of shaft and bearing..The rotor shaft driven by 0.75 HP d.c motor. A d.c/a.c voltage controller is used to vary the voltage and to adjust motor power supply and due to this, the motor speed can be continuously increased or decreased in the range of 0 to 1500 rpm. NJ204 type of bearing is studied in this work and specifications of the bearings are. Number of Cylinder = 9, Cylinder diameter (db) =7mm, Radial clearance (Cr)= $11.285*10^{-3}$mm,Bore diameter (d) =20mm, Outside diameter (Do) =47mm, Pitch diameter (Dp) =33mm.

2.1Preparation of Defective Bearing

The natural defective bearing takes lot of time so author created artificial defect on the bearing.The defect to the outer race of a bearing is produced by Wire Cut EDM (Electro Discharge Machining). It consists of a through circular hole of 0.8 mm diameter to the outer race of a bearing. The defective samples of various width size of 0.5mm to 1.5mm with constant depth of defect 1mm has been prepared.



2.1Experimental test rig

The developed test rig is as shown in Fig-2.1. Mounted on C-channel frame of size 480cm x 990cm with height of 150 cm.The mass of set up is1500kg approximately and special care is taken while design and fabrication to reduce the shocks and vibrations produced due to electric motor and rotating components etc. A set up consists of 3HP/5000 rpm three-phase induction motor and output shaft which is mounted on concrete basement. The vertical arrangement was created separately to apply radial load on the test bearing.Test bearing is mounted in between two support bearing. The support bearings(6204) are healthy (Defect free) bearings and the test bearings(NJ204) are healthy as well as defective.

2.2FFT Analyser

The acceleration sensor used is of piezoelectric type and used to sense the vibrations from test bearing having sensitivity 100 mV per m/s^2 .The accelerometer is connected to FFT analyser having 8 Analog inputs, 8 counter inputs and 2 can bus ports, Multi-sensor input, Simultaneous sampling, 200 kHz/channel, 24 bit, alias-free, variable voltage range (10 V, 1 V, 100 mV, 10 mV) , ± 5 V, 12 V sensor supplyThe output of analyzer is connected to computer which has the relevant hardware and the software to acquire the data..

2.2FFT Kit

The data has been stored and displayed in the form of time domain signal.

The shaft with test bearing was operated at different speeds ranging from 0 to 1500rpm and with load varies from of 5kg to 20kg. Sensor has mounted at the maximum position in the load zone that is at the top of bearing. Proper cleaning of bearings was carried out before application of grease to make them free from contaminants, if any. Support bearings are healthy during the entire experimentation and there vibration levels are also measured time to time for confirmation. In experimental approach a focus is on Time domain analysis for defected outer race.

3.0 RESULTS AND DISCUSSION:

The analytical and experimental results at different speeds, loads and defect sizes are plotted and comparison is made for following cases.

Cases	Type of Bearing	Radial Load in N	R.P.M.
1	H.B.	1000	600
2	D.B	1000	600
3	H.B.	1000	900
4	D.B	1000	900
5	H.B.	1000	1200
6	D.B	1000	1200
7	H.B.	1000	1500
8	D.B	1000	1500
9	H.B.	1000	1800
10	D.B	1000	1800

Table I. H.B=Healthy Bearing, D.B.=Defective Bearing

3.1FFT Analysis

DEWESoftX software has been used to for the collection of data and analysis has been made from same. the amplitude of acceleration values has been exported to Excel the following investigation was carried out.

3.1.1Stastical Analysis

RMS Value Analysis

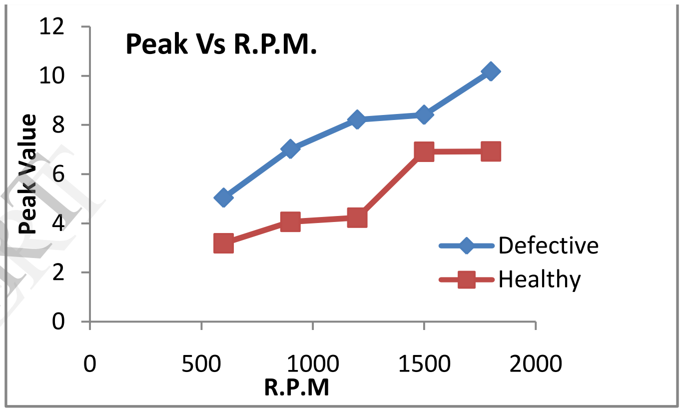
For a dispersed data having N number of data points & Xm as an arithmetic mean, a root mean square value is defined as square root of sum of squares of all deviation values divided by Number of samples

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(xi - xm)^2}{N}} \qquad \text{--------------(3.1)}$$

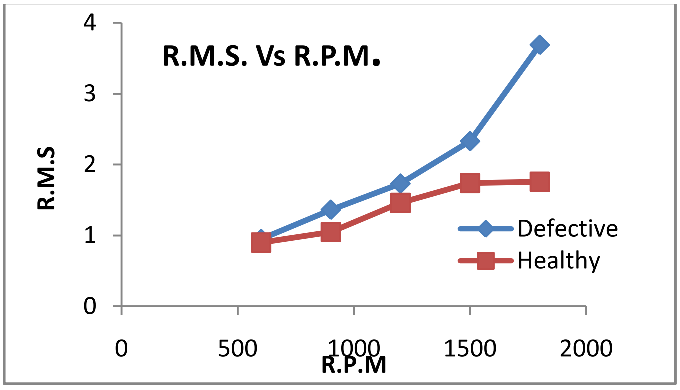
Peak Value Analysis

For a dispersed data having N number of data points, a peak value is defined as half of the difference between maximum & minimum ordinate values

$$\text{Peak value} = \frac{\text{Maximum ordinate} - \text{Minimum ordinate}}{2} \qquad \text{------(3.2)}$$



3.1Peak Value Vs R.P.M.



3.2 R.M.S. Vs R.P.M

0.9 m/s^2,1.04 m/s^2,1.46 m/s^2,1.76 m/s^2,1.1 m/s^2 are the RMS values at 600,900,1200,1500,1800 rpm respectively for healthy bearing.0.94 m/s^2,1.36 m/s^2,1.74 m/s^2,2.33 m/s^2,3.69 m/s^2 are the RMS values of at 600,900,1200,1500,1800 for defective bearing.With increase in the RPM, the RMS value of each bearing increases accordingly.

3.19m/s^2,4.06m/s^2,4.23m/s^2,6.91m/s^2,6.92$m/s^2$are the peak values for healthy bearing at 600,900,1200,1500,1800rpm respectively.5.04,7.02,8.822,8.416,10.18 are the peak values at600,900,1200,1500,1800 for defective bearing. With increase in the RPM, the Peak value of each bearing increases accordingly

3.1.2Harmonic Analysis

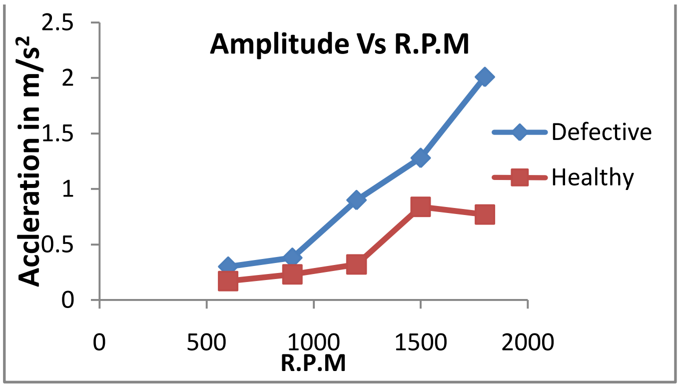
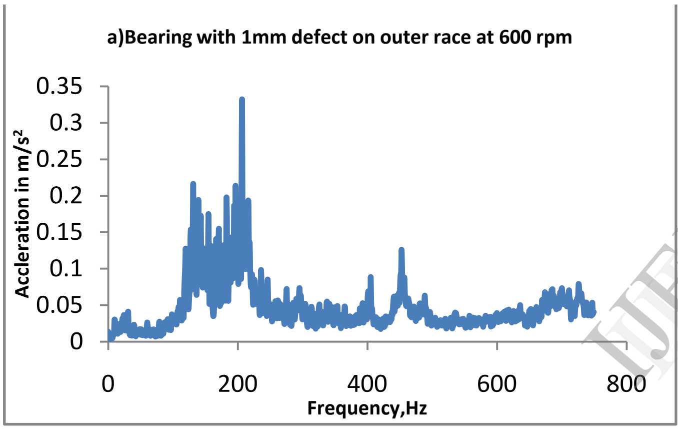
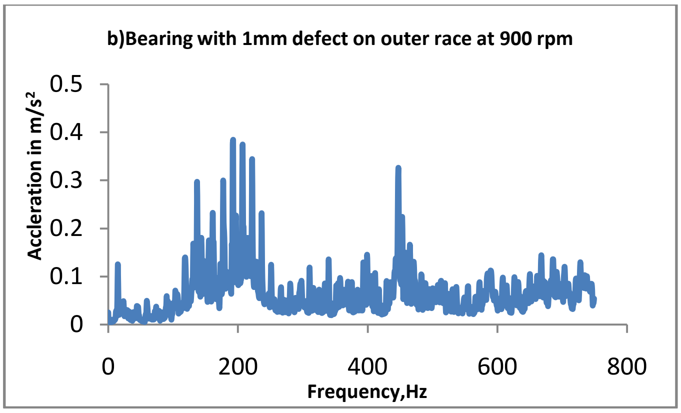
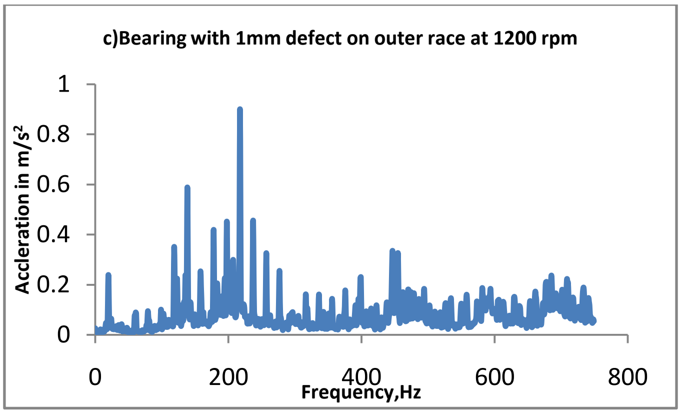
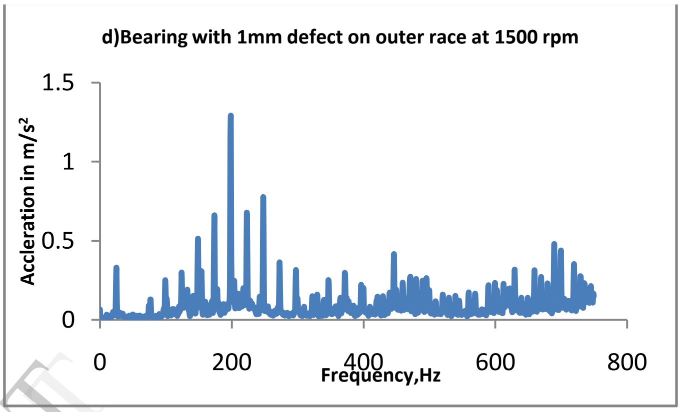


Fig 3.3Accleration Vs RPM









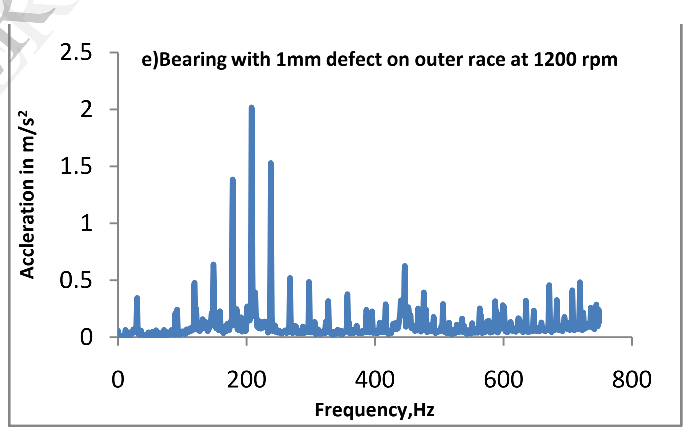


Fig.3.4 Frequency domain plot for bearing with 1mm defect on inner ring at RPM a)600 b) 900 c) 1200 d) 1500e)1800

Here the impulses are obtained at every BPFO period . A strong peak at outer race defect frequency is clearly observed as shown in Figs3.4 It also shows some harmonic peaks corresponding to fo+fs, fo-fs, 2fs etc. For any speed and defect size, the outer ring defected bearing gives better response in terms of peaks and characterized defect

The maximum amplitudes measured in the spectra of healthy test bearing are 0.17m/s^2 at 600rpm and 0.23m/s^2 at 900rpm,0.32 m/s^2 at 1200rpm,0.84m/s^2 at 1500rpm and 0.77m/s^2 at 1800 rpm. The maximum amplitudes measured in the spectra of defective bearing are 0.30m/s^2 , 0.38m/s^2, 0.9 m/s^2 , 1.28/ m/s^2 , 2.8 m/s^2 at 9fo,6fo,5fo,3fo,2fo for 600rpm, 900rpm,1200rpm,1500rpm and 1800 rpm. respectively for defect size of 1mm.

The efforts have also been carried out in measurement of amplitudes of vibration of outer ring defected bearing in which defect is manually shifted to new position in the load zone. In this situation, it is observed that, the position of defect has significant effect on the peaks. During the experimentation, some non zero amplitudes even outside the load zone are observed which may be due to influence of other source of vibrations in the set up at higher speed.

4.CONCLUSION

Bearing failure is one of the main causes of interruption of rotating machinery operation. This generally leads to unscheduled shut down thereby increasing the cost of operations. One of the major concerns in bearing diagnostics is the detection of the defect at its incipient stage and subsequently alerting the operator before it develops into a catastrophic failure. The ability to achieve accurate bearing diagnostics is essential to the optimal maintenance of rotating equipment with respect to cost and productivity.

The Statistical method is most suitable for random signals which are collected from bearings. From the Stastical and Harmonic analysis of experimental result carried out in the present work,following conclusions are drawn.

1. 0.9 m/s^2,1.04 m/s^2,1.46 m/s^2,1.76 m/s^2,1.1 m/s^2 are the RMS values at 600,900,1200,1500,1800 rpm respectively for healthy bearing.0.94 m/s^2,1.36 m/s^2,1.74 m/s^2,2.33 m/s^2,3.69 m/s^2 are the RMS values of at 600,900,1200,1500,1800 for defective bearing.With increase in the RPM, the RMS value of each bearing increases accordingly.

Hence it is concluded that, the outer race defected bearings has higher amplitudes of vibration in comparison with healthy bearings for the same speed. The RMS value of healthy bearing decreases slightly after 1500 rpm

2. At constant defect size and constant load with different speeds of rotation, amplitudes of vibration varies with increase in speed.

3. The RMS value analysis validates that the ball bearing health can be fairly monitored using frequency domain Analysis.The Proposed Statistical analysis proves to be a simple, quick & cost effective method in the condition monitoring of ball bearings

4. At constant speed condition, the peak value of acceleration observed at BPFO, increases with the increase in the defect size of the bearing as compared to value of healthy bearing.

Hence it is concluded that Maximum values of amplitudes are observed at corresponding characteristics defect frequencies (fo in case of outer ring defect).

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