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Vibration Analysis of Defective Rolling Contact Bearings

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ABSTRACT

Rotary machines are recognized as crucial equipment in various industries, such as power stations, chemical plants and automotive industry that require precise and efficient performance. In this fault diagnosis of high speed rolling element bearings due to localized defects using response surface method has to be done. The localized defects as spalls on outer race, on inner race, and on rolling elements are considered for this study, the mathematical formulation accounted for tangential motions of rolling elements and inner and outer races with the sources of nonlinearity such as Hertzian contact force and internal radial clearance. The nonlinear stiffness is obtained by the application of Hertzian elastic contact deformation theory. The mathematical formulation predicts discrete spectrum having peaks at the characteristic defect frequencies and their harmonics. Experimentation has also been performed to validate the results obtained from the mathematical model and it shows that the model can be successfully used to predict amplitude ratios among various spectral lines with localized surface defects. Combined parametric effects have been analyzed and their influence has been considered with design of experiments and surface response methodology is used to predict the dynamic response of rotor bearing system.

Keywords— **Hertzian contact force, outer race, inner race**

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I. INTRODUCTION

Rolling element bearings are essential parts of rotating machinery. A machine could be seriously jeopardized if faults occur in bearings during service. Early detection of the defects in bearings, therefore, is crucial for the prevention of damage to the other parts of a machine. Bearing defects may be categorized as localized and distributed. The localized defects include cracks, pits and spalls caused by fatigue on rolling surfaces. The other category, i.e. distributed defects, includes surface roughness, waviness and misaligned races and off size rolling elements. These defects may be due to manufacturing errors and operating conditions. Hence, condition monitoring of bearings has been considered to be an essential and integral part of any modern manufacturing facility. Adequate monitoring predicts the possibility of a breakdown before it actually occurs. Different methods are used for detection and diagnosis of the bearing defects. They may be classified as vibration measurement, acoustic measurement, temperature measurement and wear analysis. Vibration based condition monitoring has been the most widely used technique. Both time domain and frequency domain methods are used for monitoring the health of bearings.

The main sources of bearing induced vibrations are the defects in the bearing components. Bearing defects can be categorized to the distributed and localized defects. When a localized defect passes its mating surface, a short force pulse is generated. Under a constant rotational speed, these pulses are generated at nominal defect frequency. Theoretical models of vibration generation mechanism in bearings due to a single point and multiple defects, and the influence of various parameters such as loading and the transmission path help our understanding about the generated vibration at the beginning of failure.

The rolling element bearings are used in any rotating machinery to support the load and reduce the friction. The failure of these bearings resulted in sudden break down or catastrophic failure of machine. Major causes of premature bearing failure in the machinery are dirt, misassemble, misalignment, insufficient lubrication, overloading, corrosion and manufacturing error. The bearing defects are mainly categorized in 'Localized defect' and 'Distributed defect'

II. PROBLEM STATEMENT

The different machineries using rolling contact bearings, namely axles, bicycles, cars and trucks etc. Rolling-element bearings often work well in non-ideal conditions, but sometimes minor problems cause bearings to fail quickly and mysteriously. For example, with a stationary (non-rotating) load, small vibrations can gradually press out the lubricant between the races and rollers or balls (false brinelling). Without lubricant the bearing fails, even though it is not rotating and thus is apparently not being used. For these sorts of reasons, much of bearing design is about failure analysis. Vibration based analysis can be used for fault identification of bearings. There are three usual limits to the lifetime or load capacity of a bearing: abrasion, fatigue and pressure-induced welding. Abrasion occurs when the surface is eroded by hard contaminants scraping at the bearing materials. Fatigue results when a material becomes brittle after being repeatedly loaded and released. Where the ball or roller touches the race there is always some deformation, and hence a risk of fatigue. Smaller balls or rollers deform more sharply, and so tend to fatigue faster. Pressure-induced welding can occur when two metal pieces are pressed together at very high pressure and they become one.

There are different defects which affects the bearing performance, if defects are more then while taking the readings through FFT the peaks will be large in number, where there is peak, there will be the defect in the bearing. According to the depth of the defects there are different defects which are being mentioned below.

A. Distributed Defects

Distributed defects are mainly caused by manufacturing error, inadequate installation or mounting and abrasive wear. Distributed defects include surface roughness, waviness, misaligned races and unequal diameter of rolling elements. The change in contact force between roiling elements and raceways due to distributed defects cause an increased in the vibration level. Hence, the study of vibrations generated by distributed defects is mainly for quality inspection of bearings as well as for condition monitoring.

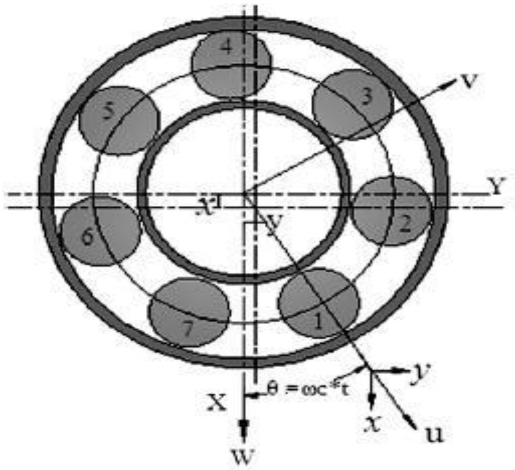

Fig. 1 Schematic diagram of a ball bearing

B. Localized Defects

These defects include cracks, pits and spalls on rolling surfaces caused by fatigue. The common failure mechanism is the crack of the races or rolling elements, mainly caused when a crack due to fatigue originated below the metal surface and propagated towards the surface until a metal piece is detached causing a small defect or spall. This defect accelerate when the bearing is overloaded or subjected to shock (impact) loads during their functioning and also increase with the rotational speed. Spalling can occur on the inner ring, outer ring, or rolling elements.

(a) FTF - Fundamental Train Frequency (frequency of the defected cage):

$$f\,(\mathrm{Hz}) = \frac{1}{2} S \left[1 - \left(\frac{BD}{PD}\cos\beta\right)\right]$$

(b) BPFI - Ball Pass Frequency of the Inner race (frequency produce when the rolling elements roll across the defect of inner race):

$$f\,(\mathrm{Hz}) = \frac{n}{2} S \left[1 + \left(\frac{BD}{PD}\cos\beta\right)\right]$$

(c) BPFO – Ball Pass Frequency of Outer race (frequency produce when the rolling elements roll across the defect of outer race):

$$f\,(\mathrm{Hz}) = \frac{n}{2} S \left[1 - \left(\frac{BD}{PD}\cos\beta\right)\right]$$

(d) BSF – Ball Spin Frequency (circular frequency of each rolling element as it spins):

$$f\,(\mathrm{Hz}) = \frac{PD}{2BD} S \left[1 - \left(\frac{BD}{PD}\cos\beta\right)^2\right]$$

(e) Rolling Element Defect Frequency or 2 x BSF-

$$f\,(\mathrm{Hz}) = \frac{PD}{BD} S \left[1 - \left(\frac{BD}{PD}\cos\beta\right)^2\right]$$

Where, S=Speed(revolutions per second)
n= No. of rolling elements
β= contact angle (degrees)
BD=ball or roller diameter
PD=pitch diameter

III. LITERATURE REVIEW

M.S. Patil, Jose Mathew, P. K. Rajendrakumar, Sandeep Desai [1] analyzed the model for predicting the effect of a localized defect on the ball bearing vibrations. In the analytical formulation, the contacts between the ball and the races are considered as non-linear springs. The contact force is calculated using the Hertzian contact deformation theory. A computer program is developed to simulate the defect on the raceways with the results presented in the time domain and frequency domain. The model yields both the frequency and the acceleration of vibration components of the bearing. The effect of the defect size and its location has been investigated. Numerical results for 6305 deep groove ball bearing have been obtained and discussed. The results obtained from the experiments have also been presented.

M. Akbari. Jami, M.R. Ashory, H. Ghoshchian, A. Bakhshizade [2] The rolling element bearings are one of the machine elements which their failure can endanger the machine seriously. Therefore, the early detection of their damage can prevent damages to the other parts of machine. In this article a numerical model is used to predict the effect of localized defect on the ball bearing vibrations. The contact forces in the model are estimated using non-linear Hertzian contact deformation theory. In order to identify the type and location of defect, the envelope analysis is applied to the response of bearing housing in the numerical model. The influence of defect size, defect location and radial load on the time domain statistical parameters and a frequency domain parameter are investigated using this model.

Dipen S. Shah, Vinod N. Patel [3] The rolling elements bearings are widely used in industrial and domestic machines. The existence of even tiny defects on the mating surfaces of the bearing components can lead to failure through passage of time. Their failure leads to economical and personal losses. The vibration monitoring technique is mostly used in the industries for health monitoring of bearings. Significant studies are available in open literature for vibration analysis of healthy and defective rolling elements bearings. Various researchers have studied the vibrations generated by bearings through theoretical model and experimentations. The researchers have developed the dynamic model of shaft bearing systems for the theoretical studies. This paper reviews different dynamic models for rolling bearing in presence and absence of local and distributed defects. Moreover, the techniques used for the improvement of fault detection have also been summarized.

Shyam Patidar, Pradeep Kumar Soni [4] Rolling element bearings comes under the critical category in many rotating machineries, mainly in chemical industry, aviation, nuclear power stations etc. Vibration monitoring and analysis is useful tool in the field of predictive maintenance. Health of rolling element bearings can be easily identified using vibration monitoring because vibration signature reveals important information about the fault development within them. Numbers of vibration analysis techniques are being used to diagnosis of rolling element bearings faults. This paper attempts to summarize the recent research and developments in rolling bearing vibration analysis techniques. Bearing defects and bearing characteristic frequencies (BCF) are also discussed.

Manish yadav, Dr. Sulochana wadhwani [5] Ball bearings are among the most important and frequently encountered components in the vast majority of rotating machines, their carrying capacity and reliability being prominent for the overall machine performance. Fault detection and diagnosis in the early stages of damage is necessary to prevent their malfunctioning and failure during operation. This paper presents fault detection of ball bearing using time domain features of vibration signals. The vibration signals are recorded at bearing housing of 5hp squirrel cage induction motor. These extracted features are used to train and test the neural network for four bearing conditions namely: Healthy, defective Outer race, defective Inner race and defective ball fault condition. The experimental observation shows that the proposed method is able to detect the faulty condition with high accuracy.

IV. EXPERIMENTATION

An Experimental set up is prepared for analysis of defective bearings. Figure 2 shows the set up for analysis of defective rolling contact bearings. It contains different parts such as motor, belts, supporting structure, shaft, pulleys and two housings for mounting defective bearings. Different kinds of defective rolling contact bearings can be taken for analysis. FFT is used to check the vibrations at different frequency. The set up has been arranged in such a way that there is an arrangement for removing the bearings by one end, so that we can change the bearings and by the use of FFT the different readings can be taken for different rpm.

Fig.2 Set up for analysis of bearings

There are various parts present in the Experimental set up, which are being mentioned below

A FFT Analyzer

FFT Spectrum Analyzers, such as the SR760, SR770, SR780 and SR785, take a time varying input signal, like you would see on an oscilloscope trace, and compute its frequency spectrum. Fourier's theorem states that any waveform in the time domain can be represented by the weighted sum of sines and cosines. The FFT spectrum analyzer samples the input signal, computes the magnitude of its sine and cosine components, and displays the spectrum of these measured frequency components. An FFT spectrum analyzer works in an entirely different way. The input signal is digitized at a high sampling rate, similar to a digitizing oscilloscope. Nyquist's theorem says that as long as the sampling rate is greater than twice the highest frequency component of the signal, the sampled data will accurately represent the input signal. In the SR7xx (SR760, SR770, SR780 or SR785), sampling occurs at 256 kHz. To make sure that Nyquist's theorem is satisfied, the input signal passes through an analog filter which attenuates all frequency components above 156 kHz by 90 dB. This is the anti-aliasing filter.

The resulting digital time record is then mathematically transformed into a frequency spectrum using an algorithm known as the Fast Fourier Transform, or FFT. The FFT is simply a clever set of operations which implements Fourier's theorem. The resulting spectrum shows the frequency components of the input signal. Now here's the interesting part. The original digital time record comes from discrete samples taken at the sampling rate. The corresponding FFT yields a spectrum with discrete frequency samples. In fact, the spectrum has half as many frequency points as there are time points. (Remember Nyquist's theorem.) Suppose that you take 1024 samples at 256 kHz. It takes 4 ms to take this time record. The FFT of this record yields 512 frequency points but over what frequency range? The highest frequency will be determined by the period of two time samples or 128 kHz. The lowest frequency is just the period of the entire record or 1/(4 ms) or 250 Hz. Everything below 250 Hz is considered to be DC. The output spectrum thus represents the frequency range from DC to 128 kHz, with points every 250 Hz.

B Motor

The motor used in this set up is 3 phase 2 pole motor. It is used to give power supply to the shaft, further shaft transmits power from one shaft to another shaft. Maximum 2800rpm we can achieve with this motor.

C. Pulley

Pulleys are used to transmit power from one shaft to another shaft. Four pulleys are being used in the set up. One is attached to the motor, second and third are keyed to the intermediate shaft, and last one is keyed to the last shaft. A pulley is a wheel on shaft that is designed to support movement and change of direction of a cable or belt along its circumference. Pulleys are used in a variety of ways to lift loads, apply forces, and to transmit power.

D. Pedestal Bearing

This type of bearing consists of I) a cast iron pedestal, ii) gun metal, or brass bush split into two halves called “brasses”, and iii) a cast iron cap and two mild steel bolts.
The rotation of the bush inside the bearing housing is arrested by a snug at the bottom of the lower brass. The cap is tightened on the pedestal block by means of bolts and nuts. Plummer block or Pedestal bearing is used for long shafts, requiring intermediate support.

E. Separable Pedestal Bearing

These kinds of pedestal bearings are very useful, because we can remove half part of the housing easily and we can change the bearings.

READINGS AND GRAPHS

The readings of different defective rolling contact bearings are being taken by the use of FFT analyser. These readings are of outer race and are being taken at different rpm, which are being mentioned in below table.

TABLE I
FREQUENCIES AT DIFFERENT RPM

RPM	**BPFO**		
	1x	**2x**	**3x**
100	5.95	11.90	17.85
500	29.76	59.51	89.27
800	47.61	95.22	142.83
1000	59.51	119.02	178.53
1200	71.41	142.83	214.24
1500	89.27	178.53	267.80
1700	101.17	202.34	303.51
1800	107.12	214.24	321.26
2000	119.02	238.04	357.07
2400	142.83	285.65	428.48
2900	172.58	345.16	517.74

GRAPHS FOR DIFFERENT RPM

1. **Outer race Reading at 1000rpm**

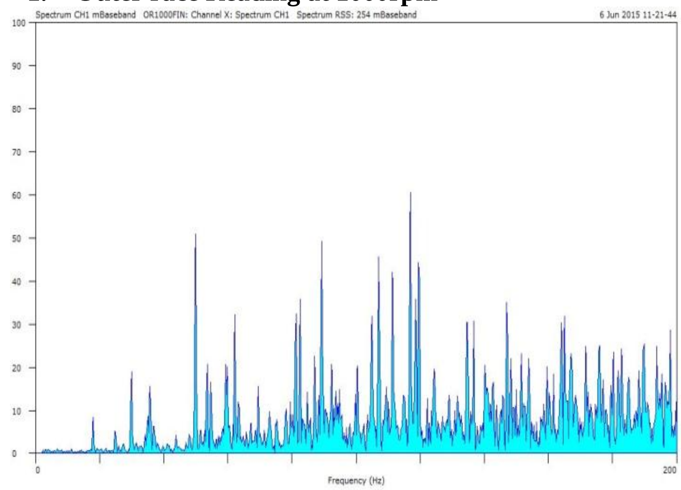

Fig. 3 Outer race reading at 1000rpm

The peaks in the graph indicate the bearing is having defect at that frequency. The bearing used is rolling contact bearing. In this graph we have got the peaks at 59.51Hz, 119.02Hz,178.53Hz, it means that the bearing is defective at above frequencies.

2. **Outer race Reading at 1700rpm**

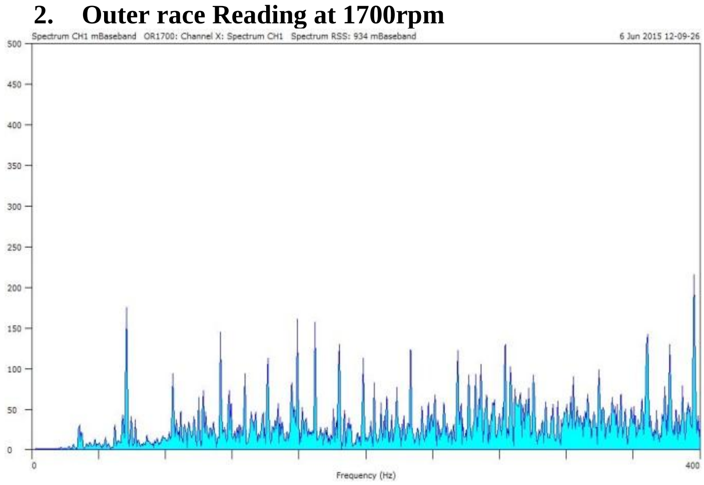

Fig.4 outer race readings at 1700rpm

The peaks in the graph indicate the bearing is having defect at that frequency. The bearing used is rolling contact bearing. In this graph we have got the peaks at 101.17Hz, 202.34Hz, 303.51 Hz, it means that the bearing is defective at above frequencies.

3. **Outer race Reading at 1800rpm**

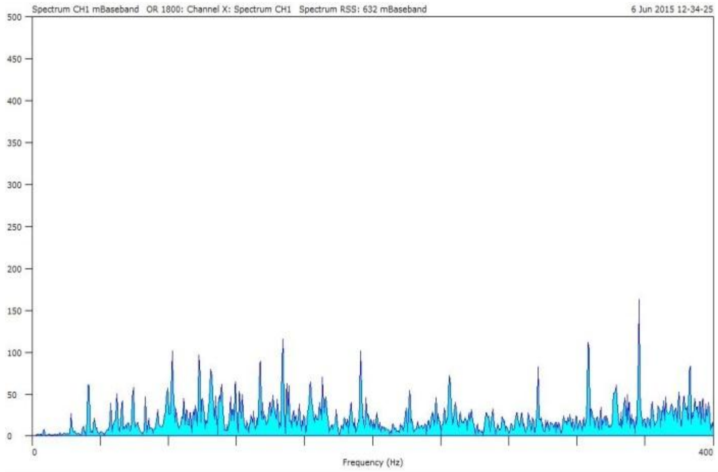

Fig.5 outer race readings at 1800rpm

The bearing used is rolling contact bearing. In this graph we have got the peaks at 107.12Hz, 214.24Hz, 321.26 Hz, it means that the bearing is defective at above frequencies.

4. Outer race Reading at 2900rpm

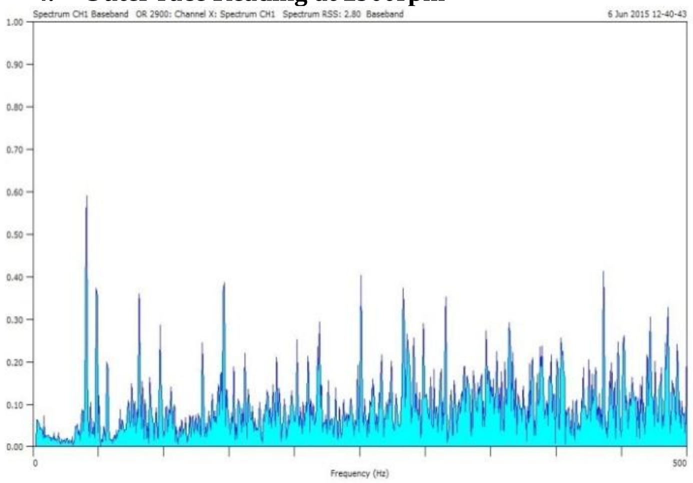

Fig.6 outer race readings at 2900rpm

The peaks in the graph indicate the bearing is having defect at that frequency. The bearing used is rolling contact bearing. In this graph we have got the peaks at 172.58Hz, 345.15Hz, 517.74Hz, it means that the bearing is defective at above frequencies.

V. CONCLUSION

This paper reports an evaluation of the bearings used in the industry. In particular, attention has been focused on defective rolling contact bearings. The different defective rolling contact bearings are being monitored with the help of FFT analyzer. In day today life in the industry there is a use of bearings in huge number, because of constant use bearing get defected, so the defected bearings has been tested by using FFT analyzer. Further investigations are needed to confirm such results and extend them to relevant industrial facilities.

ACKNOWLEDGMENT

The present study has been carried out in order to find out defects in the bearing at different frequency.

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