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Effect of Various Defects in Roller Bearings and Ball Bearings on Vibration.

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Abstract*: *The bearing is very important segment in any rotating machinery. It is continually running under changing speed and load conditions. Failure of bearing frequently results in extensive mechanical downtime that has monetary outcomes. Timely diagnosis of bearing breakdown is to avoid machines failure, as well as to decrease the maintenance cost of machine.
To analyze failure of the bearing artificial defect were created on various elements of the bearing and using vibration signature for monitoring its condition analysis is carried.In this paper the effect of various surface defects on the vibration response of outer race and inner race of the ball bearing and Roller bearing is discussed. Vibration spectrum produced by bearing with defect on inner or outer race under different load conditions is taken and effect of defect size and load on the vibration response has been investigated. Results are presented in time and frequency domain. The results obtained by experimentations are compared with MATLAB results.

Index Terms*: *Rolling element bearing, bearing elements defect, vibration spectrum analysis, FFT.

I. INTRODUCTION

Sound and vibration in machine elements are due to the moving parts, each machine has a own specific vibration signature related with its construction and the condition of the machine. The vibration signature will be changing as the condition or state of the machine changes and a change in the vibration signature can be used to detect developing defects before they become critical. This is called as the basics of vibration based condition monitoring (CM) methods. This technique is based on detecting the presence of a fault, diagnosing the root cause of the fault, assessing its level of severity and making arrangements for its correction. One of the most important element is in the machine is a Bearing. This paper discusses about the fault dignosis of the bearing.

II. LITERATURE SURVEY

H. Saruhan, S. Sardemir, A. Cicek and Uygur[1], In most of the rotating machinery the most important mechanical components to take into account is the bearing. Rotating machinery designs are complex and have numerous components that could potentially fail, majority of failure components rely on the Bearing.

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To increase operational reliability is important to monitor defects in the Bearings.
One of the most effective methods used for condition monitoring of the Bearing is vibration spectrum analysis. [1]
Sham Kulkarnia, S.B.Wadkar[2], When the machine component start rotating, the connected bearing rotates and bearing element i.e. balls rolls on the bearing races, forces between these intersecting structural elements will produce vibrations and rolling resistance, which in turn lead to noise, wear. Rolling bearing defects are categorized as point or local defects and distributed defects. Geometrical imperfections in the meeting surfaces due to irregularities during the manufacturing process as well as wear and tear causes vibrations on the individual bearing components. To monitor the condition of bearing the vibration signals of defective parts are used. Various techniques are available for condition monitoring.. Vibration signals are analyzed using time domain analysis, frequency domain analysis, and time-frequency domain analysis (wavelength). Faults are also classified using various artificial intelligence techniques to predict the meaningful results from the observations. Artificial neural networks (ANNs) support vector machine (SVM), fuzzy logic classifiers and other soft computing techniques are widely used tools to classify the faults for further processing. Signal processing techniques are used to extract the fault sensitive features to solve as the monitoring indices. Different techniques are being used to diagnose various bearing faults from the vibration signature obtained. [2] **S. Khanama, N. Tandona, J. K. Dutt[3],** To measure the fault size on the outer race of the ball bearing Symlet wavelet is used for decomposition of the vibration signal. The application of Symlet wavelet on the experimental signals indicates the entry and exit events in the decomposed signal; the level of decomposition depends on the choice of user. Faults in the bearing having significant depth will give rise to only two peaks amoung that one corresponding to the event at leading edge and the other to the impact at trailing edge.[3]
Dr. Girikapati Diwakar, RaviKumar[4], The Researcher tests K-S and A^2 over five data sets, on four different positions and detected faults with 100% reliability. From these tests K-S test values are determined at 5% significance and A^2 test values are determined at 10% significance. For Old machines A^2 test gives more appropriate solution than K-S test. The used algorithms are independent of the parameters like operational frequency, fault type, and loading. From the graphical representation it is concluded that A2 test is best goodness of fit test for fault detection of older machines having high probability of failures.[4]
Yogita K Chaudhari, Jitendra A Gaikwad, Jayant V Kulkarni[5], Frequency domain analysis of Healthy and faulty bearings are analyzed, which indicates various peaks at shaft frequency and fault frequencies.

For the bearing having faults on outer race and ball, rolling elements will be continuously moving with respect to accelerometer hence more transfer segments are observed. for such type of faults FFT alone will not give perfect analysis.

For the bearings having combined defects, defect frequencies peaks appear similar to that of harmonics peaks, thus discrete wavelet transform can be used for analysis.[5]

Arundhati Garad, K.B. Sutar e tal[6], The researcher utilizes the technique for computing Kurtosis factor for the vibration investigation of the bearing. It is seen that the estimation of kurtosis for defect free bearing is high at low speed and its worth reductions with speed. kurtosis is poor indicator of defect on outer race. [6]

Pravesh Durkhure, Akhilesh Lodwal[7], It is seen that the time space and its measurable examination can just foresee the deficiency in the bearing and can't give its inception. Recurrence examination gives the precise situation of issue in bearing. For sound bearing the kurtosis obtained is from 3 to 5 and increseases with the ferquency.[7]

Shyam Patidar, Pradeep Kumar Soni[8], As indicated by the scientist envolop examination is extremely helpful strategy to distinguish early failure of moving component bearing. Bearing deficiencies can be adequately identifying utilizing Time-recurrence methods because of its high goals ability. Artificial neural network (ANN) and fuzzy logic based fault diagnosis techniques can detect bearing faults very fast with better accuracy. [8]

Prashant P. Kharche, Dr.Sharad V. Kshirsagar[9], To have a long and useful life of Ball bearings it should be designed and must be properly installed, lubricated and maintained. The bearing failures are due to poor operating environment particularly moist or contaminated area and improper handling practices. Due to the Corrosion in a ball race results in rust, which is an abrasive and it can cause wear. This results in loss of preload or an increase in radial clearance. In grease-lubricated bearing the wear debris, impede lubrication, resulting in failure of lubrication system and subsequent overheating. In some cases, the imperfections may be virtually invisible to the naked eye. [9]

O. Djebili1, F. Bolaers, A. Laggoun and J. P. Dron[10], Sensitivity and linearity are two vibratory indicator, which is to be studied in depth. In term of sensitivity the evolution of the peak ratio indicator is more significant. The evolution of the bearing damage could be relatively expressed by the crest indicator.[10]

Linkai Niu, Hongrui Cao n, Zhengjia He,Yamin LiA[11], Elastohydrodynamic lubrication model is generated for simulating bearings' dynamic characteristics. The important factor that affects the BPF's is the shaft speed, which affects the skidding effect. At fixed shaft speed, the variation of relative error is due to the impact force when a ball rolls through the defect. Initial contact angle effects on BPFs under different radial loads can be attributed to the skidding effect.[11]

Evgeny A. Sikora[12], Crest factor method gives information to obtain bearing condition and does not give "maximum operating time to failure". The factors such as production schedules, the effects of secondary injury, availability of spare parts, helps to take the decision for the replacement of bearing.[12]

Dipen S. Shah, Vinod N. Patel[17], After the testing it is observed that the vibration amplitude of the defective bearing are more compare to the healthy bearing. The presence of bearing fault (local or distributed) and its location can be identified through the time and frequency domain analysis of the vibration signal. The developed model accuracy depends on the considerations like mass of shaft, bearing elements, housing, linear or non linear bearing stiffness, lubrication, speed, damping, defect, friction and presence of noise. signal processing techniques like envelope analysis, HHT, wavelet transform and noise cancellation are the other methods used for fault detection.[17]

V. N. Patela, N. Tandonb, R. K. Pandey[18], For the same defect angle as between two progressive balls, the vibration reaction of bearing having two imperfections is equivalent to the vibration reaction of bearing having single imperfection. The recurrence spectra of single defect and two defects are observed to be indistinguishable for example no extra frequencies are seen because of driving forces produced with time delay between two defects. Because of progress in stage points the extents of frequencies are differing dependent on the edges between two defects. [18]

III. MATLAB SIMULATION

Defects in a rolling element bearing may occur in the outer race, inner race, cage, or a rolling element. These faults are characterized by its own frequency, which is usually listed by the manufacturer or calculated from the bearing specifications. An impact of fault generates high-frequency vibrations in the gearbox or other structure between the bearing and response transducer. Assume that the gears in the gearbox or other attached parts are healthy and the bearings supporting the pinion shaft is affected by a localized fault in. Neglect the effects of radial load in the analysis.

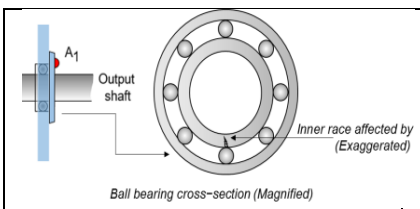


Fig No.1 Ball Bearing Cross Section with crack on Inner Race

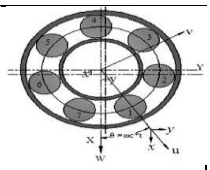


Fig. No 2. Schematic diagram of a ball bearing

A. Equation of Motion

The formulas of motion as well as other useful equations which are required for the conditioning monitoring of the bearing are discussed as below. Refer fig. no.2.

The equations of motion for two degrees of freedom system can be written as follows:

$$M\ddot{x} + C\dot{x} + F_x = W \quad \text{.....(I)}$$

$$M\ddot{y} + C\dot{y} + F_y = 0 \quad \text{.....(II)}$$

Where, M is the mass of rotor, C is the damping factor, W the radial load

F_x And F_y are the total Restoring forces in X and Y directions, respectively. [4] Bearing Frequencies for the stationary outer race can be calculated by using following expression.[3]

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

$$f_{FTF}\,(Hz) = fr\left[1-\left(\frac{db}{dp\cos\emptyset}\right)\right]$$

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

$$f_{BPFI} = \frac{n}{2}fr\left[1+\left(\frac{db}{dp\cos\emptyset}\right)\right]$$

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

$$fBPFO = \frac{n}{2}fr\left[1-\left(\frac{db}{dp\cos\emptyset}\right)\right]$$

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

$$fBSF = \frac{n}{2}fr\left[1-\left(\frac{db}{dp\cos\emptyset}\right)^2\right]$$

Where,

fr = rotor rrequency, n= No. of rolling elements, $\emptyset$= bearing contact angle (degrees), db=ball or roller diameter, dp= bearing pitch diameter

B. Simulation

MATLAB software is use for the analysis of the result. The variable RPM with the defected bearing is use for this analysis.

The bearings used are having defect size of 0.5mm for Ball Bearing (UC204 BRQ) & 1mm for defective Roller bearing (22205 C W33).

Following table shows the frequency variation with changing load condition.

Table no 1.

MATLAB Simulation Values of Acceleration for Healthy & Defective Spherical Roller Bearing (Defect Size 1mm)

Load (kg)	Defect Location	Acceleration (mm/s^2)	Load (kg)	Defect Location	Acceleration (mm/s^2)
Healthy spherical roller bearing			Defective spherical roller bearing		
0	IR	182.67	0	IR	97.10
5	IR	142.67	5	IR	92.75
10	IR	100.23	10	IR	32.89

- **SPHERICAL ROLLER BEARING 22205 C W33**

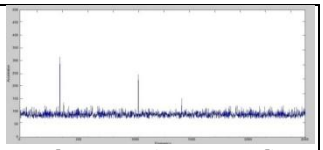
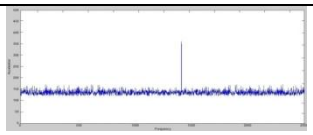
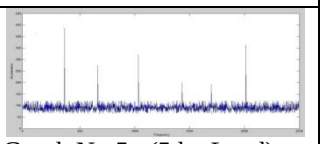
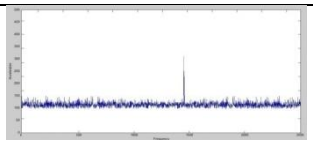
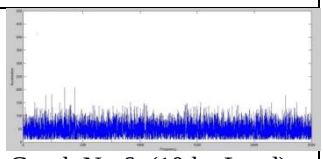
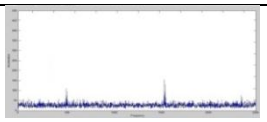
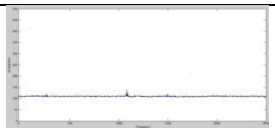
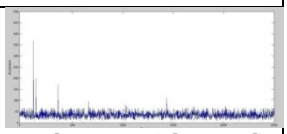
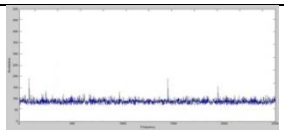
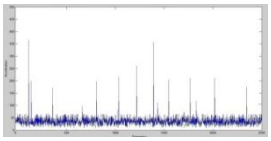
Healthy Bearing	Defective Bearing
 **Graph No.1** (0 Kg Load)	 Graph No.4 (0 Kg Load)
 Graph No.2 (5 Kg Load)	 Graph No.5. (5 kg Load)
 Graph No 3 (10 Kg Load)	 Graph No.6 (10 kg Load)

Table no 2. MATLAB Simulation Values of Acceleration for Healthy & Defective Ball Bearing (Defect Size 0.5mm)

Load (kg)	Defect Location	Acceleration (mm/s^2)	Load (kg)	Defect Location	Acceleration (mm/s^2)
Healthy Ball bearing			Defective Ball bearing bearing		
0	OR	125.13	0	OR	55.45
5	OR	103.41	5	OR	44.15
10	OR	93.56	10	OR	41.52

- **BALL BEARING UC204 BRQ**

Healthy Bearing	Defective Bearing
 Graph no 7 (0 kg load)	 Graph No.10 (0 Kg Load)
 Graph No.8 (5 Kg Load)	 Graph No.11 (5kg Load)
 Graph No. 9 (10 Kg Load)	 Graph no 12 (10 kg load)

IV. EXPERIENTAL VALIADATION

For the experimental validation experimental set up is fabricated as shown in fig. no. 3. The readings were taken using FFT analyzer

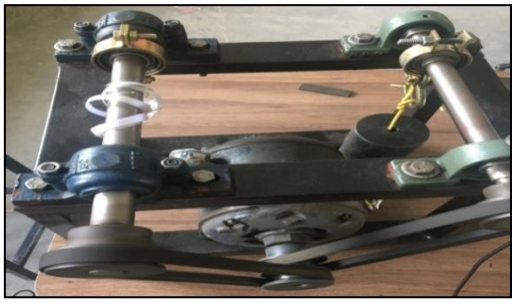
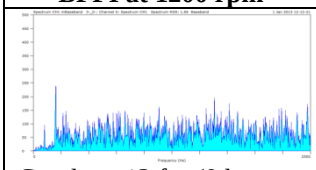
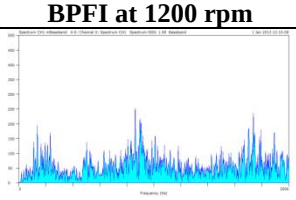
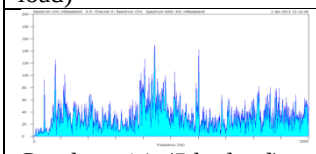
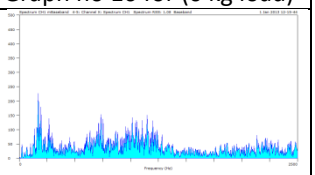
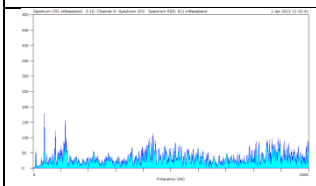
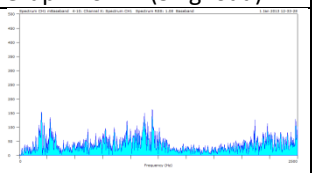
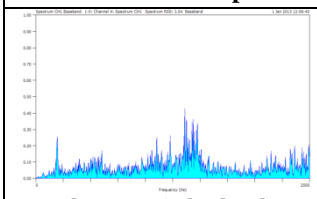
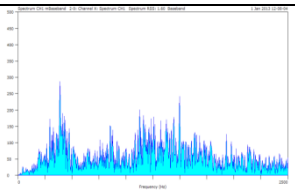
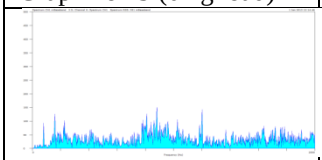
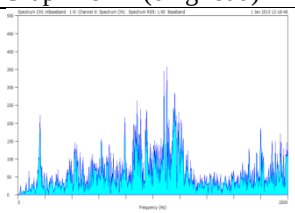
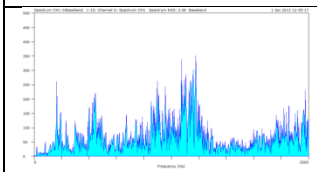
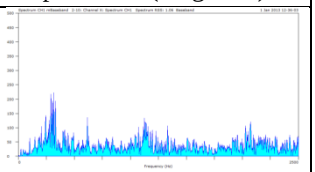


Fig.No 3 Experimental Setup with Load Arrangement

V. EXPERIMENTAL RESULTS

The readings which are obtained from the FFT Analyzer are presented in the graphical format for different frequencies at 1200 rpm by varying load arrangements from 0 kg to 10 kg. The graphs are plot for different frequencies as follows: -

Healthy Spherical Roller Bearing BPFI at 1200 rpm	Defective Spherical Roller Bearing BPFI at 1200 rpm
 Graph no 13 for (0 kg load)	 Graph no 16 for (0 kg load)
 Graph no 14 (5 kg load)	 Graph no 17 (5 kg load)
 Graph no 15 (10 kg load).	 Graph no 18 (10 kg load)

Healthy Ball Bearing BPFO at 1200 rpm	Defective Ball Bearing BPFO at 1200 rpm
 Graph no 19 (0 kg load)	 Graph no 22 (0 kg load)
 Graph no 20 (5 kg load)	 Graph no 23 (5 kg load)
 Graph no 21 (10 kg load)	 Graph no 24 (10 kg load)

VI. COMPARISON OF RESULTS

The results obtained from MATLAB and Experiments are compared as follows.

Table No. 3 Comparison of results for Spherical Roller Bearing 222050 C W33

Load (Kg)	Healthy Bearing		Defective Bearing	
	Experimental Frequency (Hz)	FEM Frequency (Hz)	Experimental Frequency (Hz)	FEM Frequency (Hz)
0	1363	1350	388	352
5	1378	1350	384	350
10	1472	1441	316	292

Above table shows the comparison between the Experimental & MATLAB results for inner race of Spherical Roller Bearings at different load conditions such as 0 kg, 5kg, & 10kg. Both results are nearly same but this difference may increase with increase in load on bearings. From above table, we can plot results of experimental & MATALB in the graphical form with the help of excel sheet.

Comparison of results for Deep Groove Ball Bearings (UC204 BRQ)

Load (Kg)	Healthy Bearing		Defective Bearing	
	Experimental Frequency (Hz)	MATLAB Frequency (Hz)	Experimental Frequency (Hz)	MATLAB Frequency (Hz)
0	200	200	1078	1053
5	1100	1068	169	152

The above graph shows the comparison between the results of Experimental & MATLAB simulation for inner race of Deep Groove Ball Bearings.

VII. CONCLUSIONS

At constant speed and constant load with different defect sizes on outer ring & inner ring, amplitudes of vibration vary with increase in defect sizes. With Increase in level of defect on Rollers and Balls, vibration acceleration values show increase in amplitude. Increased in amplitude is strong indication for damage in Roller and Ball bearings.

FFT analyzers can be used to analyze health monitoring for structural components

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