INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 2)
Available online at: www.ijariit.com

Condition Monitoring of Ball Bearings

G. Venkata Kishore Rakshit Raju
rakshitgvk@gmail.com
Vellore Institute of Technology University, Vellore, Tamil Nadu

M. Sree Veena
msreeveena@gmail.com
Chaitanya Bharathi Institute of Technology, Hyderabad, Telangana

M.C.S.Reddy
mcsriitm@gmail.com
University College of Engineering, Osmania University, Hyderabad, Telangana

ABSTRACT

Condition monitoring is gaining importance because of its advantages over conventional maintenance methods. Even though it is little costly, It is feasible especially in continuous process industries, where process costs are very High. In this paper, an attempt is made to monitor bearing faults. In condition monitoring, through vibration analysis, it is possible to predict different defects of different characteristics and would reveal the details of defects and inaccuracies so that it could be minimized, which leads to increase the plant efficiency. Condition monitoring through vibration analysis is an online technique, where we need not stop the machine for diagnosing the fault.

Keywords: *Condition Monitoring, Maintenance, Vibrations, Ball Bearings.*

1. INTRODUCTION

Vibration is the response of a system to an internal or external stimulus causing it to oscillate or pulsate. While it is commonly thought that vibration causes failure in the machines and structures, it does not. Instead, the damage is done by dynamic stress which causes failure in the material, and the dynamic stresses are induced by the vibration produced.

To identify the health condition, one of the most effective techniques which have gained considerable effectiveness in the maintenance sphere for monitoring machinery health condition is 'Vibration Analysis and Diagnostic Studies'. Vibration analysis is being applied on operating machines to identify the health condition, to pinpoint defects and inaccuracies and to schedule an optimum maintenance on individual machines.

The basis of this study is the measurement and analysis of vibration characteristics at specified locations on a machine. In vibration analysis, it is possible to predict different defects produced by the vibrations of different characteristics and would reveal the details of defects and inaccuracies so that it could be minimized, which leads to increase the plant efficiency.

Standards
ISO 10816- VIBRATION STANDARDS
Velocity measurements can be categorized as follows:

Class I Machines may be separated driver and driven or coupled units comprising operating machinery up to approximately 15kW (approx 20hp).
Class II Machinery (electrical motors 15kW(20hp) to 75kW(100hp), without special foundations, or Rigidly mounted engines or machines up to 300kW (400hp) mounted on special foundations
Class III Machines are large prime movers and other large machinery with large rotating assemblies *mounted on rigid and heavy foundations* which are Reasonably stiff in the direction of vibration.
Class IV Includes large prime movers and other large machinery with large rotating assemblies mounted on foundations which are relatively soft in the direction of the measured vibration (i.e., turbine generators and gas turbines greater than 10MW (approx. 13500hp) output.

VIBRATION SEVERITY CHART AS PER ISO 10816 (Old IS 2372)

RMS VELOCITY IN MM/SEC	CLASS I SMALL MACHINES	CLASS II MEDIUM MACHINES	CLASS III LARGE MACHINES WITH RIGID FOUNDATION	CLASS IV LARGE MACHINES WITH SOFT FOUNDATION
0.14				
0.30				
0.48		GOOD		
0.52				
0.66		SATISFACTORY		
0.81				
1.01				
1.42		JUST SATISFACTORY		
1.68				
2.20				
4.50		UNSATISFACTORY		
5.50				

Historical Review

In order to gain some perspective on modern maintenance programs, we will look at the history of maintenance practices a little more closely. The earliest type of maintenance was **run.to.failure (Break down)**, where the machine was run until a fault caused it to fail in service. This is obviously an expensive approach, with the major part of the cost being the unpredictability of the machine condition. It is surprising to learn how much of present-day maintenance activity is of this type.

Eventually, maintenance people hit on the idea of periodic **preventive maintenance**, where machines are disassembled and overhauled on regular schedules. The theory is that if machines are overhauled before their expected service life is exceeded, they will not break down in service. Preventive maintenance has been around for a long time, but became much more prominent in the early 1980s, as we will see. In the last ten years, predictive maintenance has become popular, where the machine is repaired only when it is known to have a fault. Smoothly running machines are not interfered with, on the theory that you shouldn't "fix it if it ain't broke".

The most recent innovation in maintenance is called **pro-active**, and it includes a technique called "root cause failure analysis", in which the primary cause of the machine failure is sought and corrected.

The machinery health condition monitoring is being accepted as an effective method to assess the requirements of maintenance and to increase the operating life of installed plant and machines. Many parameters can be monitored for an effective health condition monitoring but the selection of a particular parameter depends on the type of machine and on economic considerations.

2. LITERATURE REVIEW

Amit Shrivastava et al. (2012) have discussed the Condition Monitoring for Inner Raceway Fault of Induction Motor Ball Bearings. A test setup has been developed with a fault on inner raceway of the ball bearing.The vibration signal is analyzed with assuming contact angle β equal to zero degrees and motor operating without a load. A logarithmic plot of the vibration spectrum with healthy bearing and damaged bearing condition were compared. They concluded that the spectral analysis shows the characteristic vibration frequencies. Monitoring of these frequencies fault on a bearing of the induction motor can be detected. Tarle, et al. (2013) have presented about the vibration analysis of a ball bearing. They have done experimental analysis and stimulation of 4 different bearings which are healthy bearings, Inner Race fault, Outer Race faults and bearings with cage defect. Their study tells us that the data collection shows that FFT of intrinsic mode functions in Hilbert-Huang transform is a useful tool in finding out all possible root causes and predict root causes based on the systematic study. Also bearing failure is the High Severity Field Concern causing failure of the whole machine & affects the production rate as well as the Safety of the operator. The data was analyzed by using FFT analyzer. Input signals of FFT were given to MATLAB and simulate the data, and concluded that Amplitude at BPFO is higher than BPFI and BSF and Amplitude at BPFI is less than BPFO and BSF.

Ashesh Tiwari et al.(2013) presented about Fault Detection in Bearing Using Envelope Analysis. A variety of artificially fault induced in ball-bearing type SKF 6002-2Z was used. The type of fault included a defective outer-race, a defective inner race, and a defective ball. Although motor was set to rotate at 25 Hz, the actual rotating speed of faulty bearing monitored by the tachometer was found to be 2.05Hz. They discussed a method for fault detection of a ball bearing was based on a newly developed technique for obtaining the signal with the piezoelectric element. The work was also done with an accelerometer. The original vibration signal from piezoelectric element was obtained and characteristic frequency of different fault was found out by formulas. By correlating the fault frequency with the characteristic frequency they were able to find fault in bearing.

Nabhan et al. (2016) have discussed Vibration analysis of deep groove ball bearing with outer race defect using ABAQUS. Their main focus was about the effect of outer race defect of deep groove ball bearings for (SKF 6004) through experimental and numerical methods. Three-dimensional finite element model of the housing and outer race is simulated using ABAQUS/CAE. An angular position of the local defect on the outer race changes from 0 to 315 with angular intervals 45 was investigated through the dynamic finite element model. Experimental results were obtained using bearing test rig to validate the simulated results. They modified the design of the finite element model and concluded that:

- The defects located at the radial load distribution area have more effect than the defects located at the unloaded area.
- According to the RMS parameter for all time responses, the increase in the ratio between the time domain parameters of the defected and healthy bearings is due to the increase of the clearance value

Shelke et al.(2016) have presented about Condition Monitoring of Ball Bearing Using Vibration Analysis and Feature Extraction. The vibration analysis of ball bearing was carried out at no load, 1kg, 2kg, and 4kg at 1475 rpm. Based on the experiment carried out on vibration monitoring of bearings, it was concluded that FFT spectrum indicates the location of the fault. Additionally, they also mentioned RMS, Skewness, Variance, Mean, Standard Deviation, few of the statistical parameters were evaluated for above conditions of bearing. From the plots of extracted features against Load, it was clear that these features have potential to identify the defects in the bearing as the plots of healthy bearing and defective bearing are not overlapped.

Tadina et al.(2016) have developed the numerical bearing model to investigate the vibrations of the ball bearing during run-up. The numerical bearing model was developed with the assumptions that the inner race has only 2 DOF and that the outer race is deformable in the radial direction, and is modelled with finite elements. They have considered centrifugal load effect and the radial clearance effect. The contact force for the balls is described by a nonlinear Hertzian contact deformation. They have considered outer race, inner race and ball defects into account. They used the continuous wavelet transform (CWT) and envelope analysis to identify simulated bearing faults. The continuous wavelet transform (CWT) found better for vibration analysis of a bearing with ball fault.

Kankar et al.(2009) have discussed fault diagnosis of a rotor-bearing system using response surface method. They have considered the distributed defects such as internal radial clearance and surface waviness of the bearing components. They have studied ball waviness, inner race waviness, and outer race waviness individually and also taken readings of combined waviness. They investigate an accurate performance prediction, which is essential to the design of the high performance rotor-bearing system. They used mathematical formulation the contacts between the rolling elements and the races are considered as nonlinear springs, whose stiffnesses are obtained by using Hertzian elastic contact deformation theory. From the obtained responses following conclusions are drawn:

- Nonlinear dynamic responses are found to be associated with large internal radial clearance and distributed defects.
- It is shown that the system exhibit dynamic behaviors that are extremely sensitive to small variations of the system parameters, such as internal radial clearance and ball waviness.
- The system shows periodic nature when ball waviness is at its maximum level.

Bearing Components:

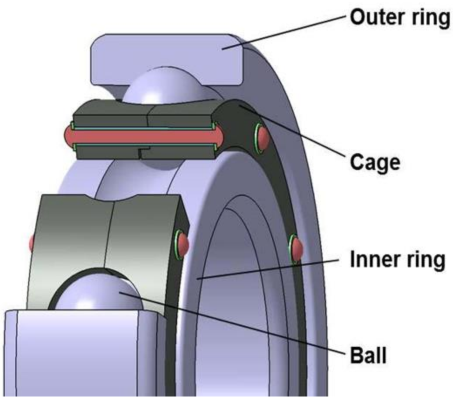


Fig.1

Bearings are an essential component in almost all machinery. Their main functions are to provide location and support for the moving parts while ensuring the minimum of friction under all conditions of load and speed. The main component of ball bearing is as shown in Fig.1

Outer Ring: The outer ring is situated on the housing of the machine and is stationary. It is the connection between inner peripheral and the outer peripheral.

Cage: This component keeps the balls separated and equally spaced and acts support to the balls.

Inner Ring: The Inner Ring is the smaller of the two bearing rings. The inner ring has a groove on its outer diameter to form a pathway for the balls. The surface of outside diameter path is finished to extremely tight tolerances and is honed to a very smooth. The inner ring is mounted on the shaft and it is the rotating element.

Ball: Balls of a bearing are the rolling elements that separate the inner ring and outer ring and permit the bearing to rotate with minimal friction. The radius of the ball is made slightly smaller than the grooved ball track on the inner and outer rings. This makes the balls to contact the rings at a single point

3. METHODOLOGY

Critical measurement locations on individual machines are identified and important vibration characteristics are measured at different locations. There can be many inaccuracies/defects in a machine such as component inaccuracies, unbalance of rotating machines, misalignment, intrusion of foreign particles, bearing problems, mechanical rubbing, excitation of resonances into machine structure, etc., which can produce vibratory forces into the system. Many machines may have one or more problems simultaneously and thereby make the analysis a complex one.

Based on the initial measurements, the machine's health condition shall be classified. Machines indicating unsatisfactory behavior should be attended to improve the health condition. Once the base line data is established, regular vibration studies at specified intervals can help in monitoring the deterioration.

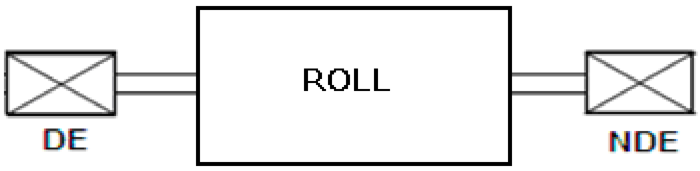
4. EXPERIENTIAL SETUP

The vibrational signal was collected by DC-12 and analyzed in DREAM software. The accelerometer is mounted on bearing housing with the help of a magnet, and the measurements are taken in Horizontal, Vertical and Axial directions.

The measurements are taken in the Driveend (DE) side and Non-Driveend (NDE) side in running condition of 210 MPM.

Table 1: Equipment Specification

Machine Drawing :



EQUIPMENT SPECIFICATIONS		
ROLL DIA	BEARING NO	
	DE	NDE
1500mm	23048 CCK C4 W33	23044 CCK C4 W33

The vibrational measurements are taken and are in Table 2

Table2: Vibrational Measurements

EQUIPMENT NAME	DATE	ROLL DE			ROLL NDE		
		H	V	A	H	V	A
MG ROLL	13.02.18	1.4	0.8	0.9	0.4	0.3	0.5

The Roll NDE bearing is exhibiting normal vibration trend with maximum overall amplitudes of 0.5 mm/sec RMS Velocity, but the roll DE bearing is exhibiting very high vibrational measurements of 1.4mm/sec RMS velocity.
As per the ISO standards, the obtained measurements are high and when spectrum analysis is performed it is found that there are Harmonics of "**Inner race bearing defect"** frequencies with side bands of the roll rotational frequency.

The vibration signals corresponding to the defective bearing with the defect on the bearing are shown in Fig.2.

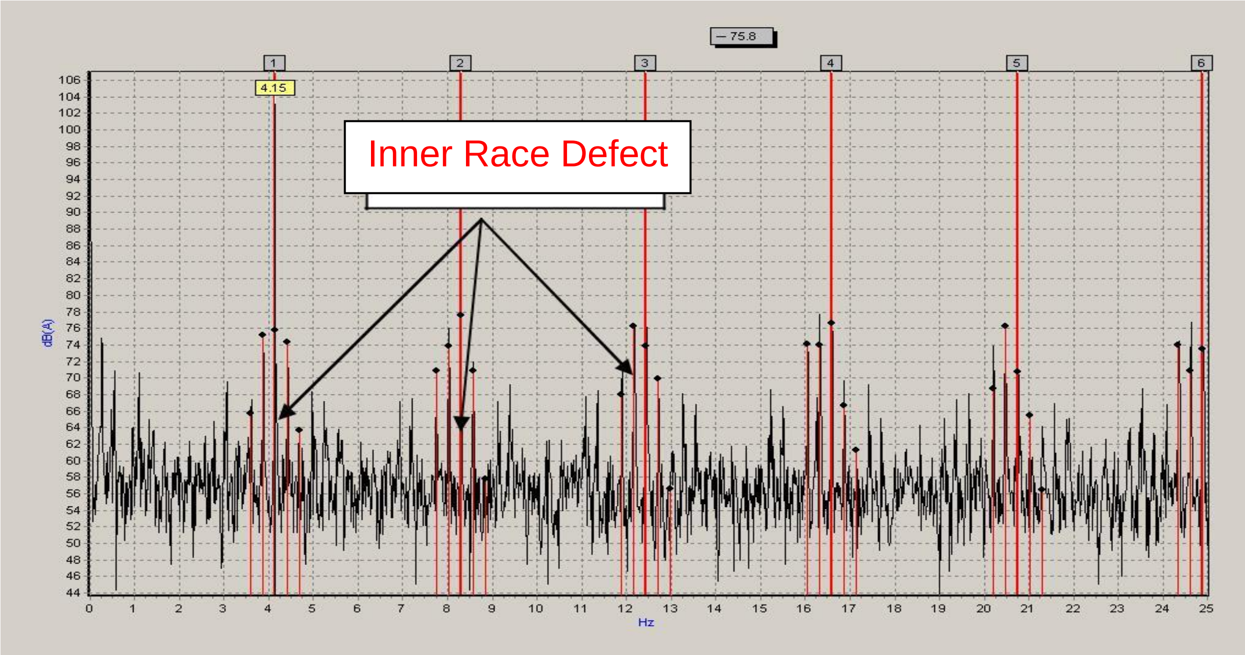


Fig. 2: Frequency Spectrum of Bearing

Analysis:

The peak at 4.15Hz is the shaft rotating frequency, also called as the fundamental frequency. The peak at 8.30 is 2*fundamental frequency harmonic and similarly, 12.45 is 3X harmonic,16.60 is 4X harmonic,20.75 is 5X harmonic and 25 is the 6X of the fundamental frequency. Due to the presence of fundamental frequency harmonics along with side bands, it indicates "Inner Race Defect".

From the spectrum analysis, it is conformed to be inner race defect.

5. RESULTS AND DISCUSSION

It is evident from the spectrum analysis that it possess inner race defect, as bearing housing was opened and observed, there is an inner ring crack (Fig.3).

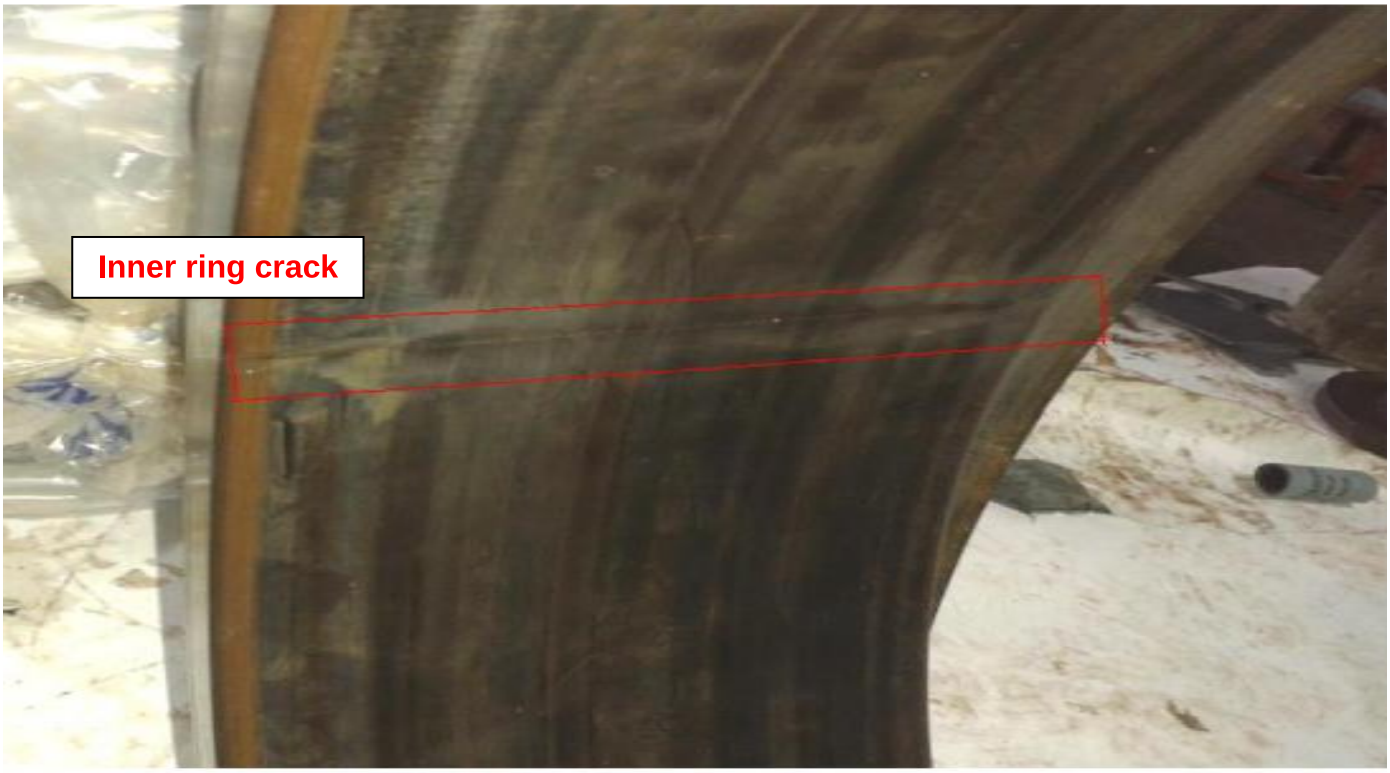


Fig. 3: Inner Ring Defect

After successful detection of the defect, the bearing is replaced and further monitored. After Replacement (Table 3) contains the vibrational measurements and (Fig.4) is the spectrum of the replaced bearing.

After Correction:

Table. 3

EQUIPMENT NAME	DATE	ROLL DE			ROLL NDE		
		H	V	A	H	V	A
MG ROLL	15.02.17	0.5	0.5	0.4	0.3	0.2	0.3

The Roll NDE & DE bearings are exhibiting normal vibration trend with maximum overall amplitudes of 0.3mm/sec & 0.5mm/sec RMS Velocity respectively.

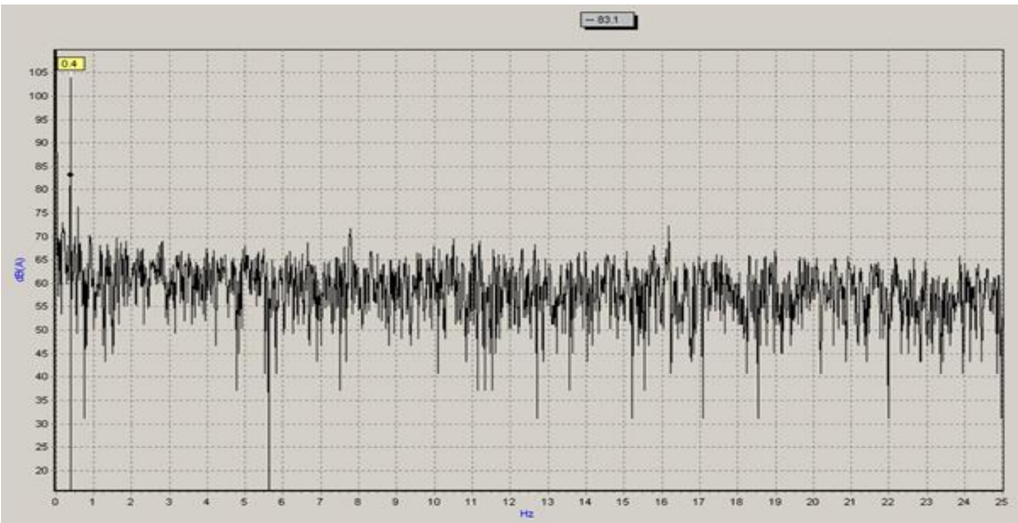


Fig.4: Spectrum of New Bearing

6. CONCLUSION

This research work presents a method for detection of ball bearing fault on the inner ring of a bearing by vibration analysis. An experimental study has been conducted in running condition with faulty bearings, measuring vibrations. The spectral analysis shows the characteristic vibration frequencies of inner race defect of a bearing. Spectral and vibration comparison of the bearing is made before and after replacement.

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