CONDITION MONITORING OF DEEP GROOVE BALL BEARINGS

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Abstract

Ball bearings are considered as most important mechanical components or factor in kinematics rotating system. It transmits rotational motion between fixed and moving parts as well as it provides support to rotating shaft. In most of the cases inner ring is movable and outer ring is fixed. In some cases inner ring is fixed and outer ring is movable that is vice versa. Condition monitoring has been gaining importance because of its advantages over traditional maintenance methods. Even though it has been costly, it has been capable especially in continuous processing plants or industries, where down time costs are very high. In this paper, an effort is made to monitor bearing faults. In condition monitoring, through vibration analysis, it has been possible to predict different types of defects having different characteristics and would reveal the details of defects and inaccuracies so that it could be minimized, by doing predictive maintenance which leads to increase the plant efficiency. Condition monitoring through vibration analysis is non destructive technique (NDT), where for diagnosing the fault there is no need of stop the machine.

Key Words: Ball bearings, rotational systems, nonlinear spring, dynamic behavior, vibration analysis, Condition Monitoring, Maintenance.
1 Introduction

Now a day with advanced manufacturing process though the geometry of a ball bearing has been perfect, it will still produce vibrations on nanometer scale. Vibration is defined as the response of a system to an internal or external impulse causing it to oscillate or pulsate. It is common consideration that vibration causes failure in the machines and structures, it does not. Instead, due to dynamic stress the damage has been occurred which causes failure in the material, and the dynamic stresses have been induced by the vibration produced. In healthy bearing the vibrations are caused due to the rotation of a finite number of loaded rolling element contacts between the balls with the guiding rings. These contacts are elastic in nature, so the bearing stiffness explicitly dependent on time. In general, the bearing stiffness changes with respect to time a time varying stiffness causes vibrations, even in the absence of external loads. Since the stiffness can be regarded as a system parameter, the variable stiffness leads to a so called parametric excitation. It is one of the major sources of vibration in ball bearings. Apart from this the savior vibrations occurred due to local or distributed defects. Which can be prevented by condition monitoring or predictive maintenance or condition based maintenance. The doctor can diagnosis the diseases or health of human being by observing the pulses of hand similarly engineer can diagnosis the defects or health of machine by observing the pulses or vibration signature and carried out the productive maintenance with the help of FFT analyzer or IRD Mechanalyser. Vibration analysis has being applied on operating machines to identify the health condition, to identify 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 tell the details of defects and inaccuracies so that it could be minimized, which leads to increase the plant efficiency.

Standards

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Standards

ISO 10816- VIBRATION STANDARDS Velocity measurements can be categorized as follows:
VIBRATION SEVERITY CHART AS PER ISO 10816 (Old IS 2372). Abbreviations used are as follows. G-Good, S- Satisfactory, J S- Just Satisfactory, U S- Unsatisfactory

<table>
<thead>
<tr>
<th>Class I</th>
<th>Machines may be separated driver and driven or coupled units comprising operating machinery up to approximately 15kW (approx. 20hp).</th>
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<tbody>
<tr>
<td>Class II</td>
<td>Machinery (electrical motors 15kW(20hp) to 75kW(100hp), without special foundations, or rigidly mounted engines or machines up to 300kW(400hp) mounted on special</td>
</tr>
<tr>
<td>Class III</td>
<td>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.</td>
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<tr>
<td>Class IV</td>
<td>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.</td>
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</table>

RMS Velocity in mm/sec | Class I Small Machine | Class II Medium Machine | Class III Large Machine with rigid Foundation | Class IV Large Machine with soft Foundation |
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<td>J S</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
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<td>U S</td>
<td>J S</td>
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<tr>
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<td>4.50</td>
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<tr>
<td>5.50</td>
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**Historical Review**

In order to gain some perception 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) maintenance, where the machine was run until a fault caused it to fail in service. This is noticeably 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 well-known 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 isn’t broke”. It is condition based maintenance. 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**

The Condition Monitoring for Inner Raceway Fault of Induction Motor Ball Bearings have discussed by [1]. 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 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. The vibration analysis of a ball bearing have presented by [2]. 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. Fault Detection in Bearing Using Envelope Analysis has been presented by [3]. 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. Vibration analysis of deep groove ball bearing with outer race defect using ABAQUS has been discussed by [4]. 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 in-
crease in the ratio between the time domain parameters of the de-
fected and healthy bearings is due to the increase of the clearance
value.

Condition Monitoring of Ball Bearing Using Vibration Analysis and
Feature Extraction have presented by author [5]. 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 vibra-
tion monitoring of bearings, it was concluded that FFT spectrum
indicates the location of the fault. Additionally, they also men-
tioned 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. The numerical bearing model to investigate the
vibrations of the ball bearing during run-up has been developed by
author [6]. 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 ra-
dial 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 trans-
form (CWT) found better for vibration analysis of a bearing with
ball fault. Fault diagnosis of a rotor-bearing system using response
surface method has been discussed by author [6]. They have con-
sidered 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 mathemat-
ical 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.

3 Roller Bearing

The bearing is a mechanical component permitting rotation of one part relative to another by reducing friction. It has three main functions:

- Forces transmission
- Rotation with minimum friction
- The position of a shaft with respect to the housing

Thus, if we describe a ball, we find rolling elements, separated at equidistance by a cage, an inner ring and an outer ring provided with raceways (Figure 1). The ball bearing may replace the sliding friction by rolling one. However, various body contacting (inner raceway and balls or outer raceways and ball) showing differences speed in their contact areas that will generate local slipping. Indeed, the friction generated by the fastest surface will tend to pull the slow surface.
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.
To ensure a long life, the roll bearings are lubricated with grease or oil. According to their operating conditions (load, speed etc.), different regimes of lubrication can be occurs:- A system of elasto-hydrodynamic lubrication (EHL).

3.1 The E.H.L Contacts in Bearing

A ball bearing can force the position of shaft relative to system. The rolling elements transmit the forces applied by the shaft to the inner race and then to the outer ring which is fixed to the housing. They make easy also the rotation of shaft relative to housing (Figure 2). Geometry of rolling elements and raceways (inner and outer ring) differs depending on the loading conditions (axial and / or radial direction moments) and speed. Angular contacts ball bearings are designed to collect radial and axial loads simultaneously (Figure 3). They can operate at very high speed, moderate and low speed. Due to the own weight of the shaft and the unbalance effects the axial component of the thrust and the radial component generated is engagement in the case of the use of a speed reducer.

4 Methodology

On individual machines critical measurement locations have been identified and important vibration characteristics have been measured at different locations in horizontal (H), vertical (V) and axial (A) directions. There has many inaccuracies or distributed defects
in a machine such as geometrical imperfection, unbalance of rotating machines, misalignment, intrusion of foreign particles, bearing problems, mechanical friction, waviness, excitation, resonances into machine structure, etc., which can produce vibration 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 machines health condition may be classified. Machines indicating unsatisfactory behavior should be attended to improve the health condition. Once the base line data or alarm value has been established, regular vibration studies at specified intervals of time can help in monitoring the deterioration.

5 Experiential Setup

The vibration signal was collected by IRD Mechanalyser and analyzed in software. The accelerometer probe has been mounted on bearing housing with the help of a magnet, and the measurements are taken in Horizontal, Vertical and Axial directions. The measurements have been taken in the Drive End (DE) side and Non Drive End (NDE) side in running condition of 250 RPM.

Table 1. Equipment Specification and machine drawing

![Vibration measurement of Healthy bearing](image)
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 vibration measurements of 1.3mm/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.

**Analysis:**

The peak at 4.16Hz is the shaft rotating frequency, also called as the fundamental frequency. The peak at 8.32 is 2*fundamental frequency harmonic and similarly, 12.48 is 3X harmonic, 16.64 is 4X harmonic, 20.80 is 5X harmonic and 24.96 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.

6 Results and Discussion

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

![Image](image.png)

Figure 3. Inner Ring Defect

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

After Correction:

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>ROLL DE</th>
<th>ROLL NDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAME</td>
<td>H</td>
<td>V</td>
</tr>
<tr>
<td>MG ROLL</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The Roll NDE, DE bearings are exhibiting normal vibration trend with maximum overall amplitudes of 0.3mm/sec 0.5mm/sec RMS Velocity respectively.
Table 3. Fig.

Figure 4. Spectrum of New Bearing and Defective Bearing

7 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.

References


