Condition Monitoring of Ball Bearing Using Vibration Analysis and Feature Extraction

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Abstract—*Different types of machines having rotary component are linked together in process industries, to perform the process of manufacturing. The failure of any single machine rotary component in the process can results in loss of rupees per down time hours. In order to continue the working machines, it is necessary to monitor the health of machine during its operation, with a view to diagnosis the fault in the machine. Condition based maintenance is preferred in industries now a days. Monitoring of these parameters gives idea about abnormalities in the machine, resulted due to faults like wear, crack, corrosion, fatigue etc. Among the various techniques used for this purpose, vibration analysis technique is very popular now days. In the present work vibration analysis of ball bearing is done by using FFT analyzer. The data taken up in frequency domain and Time domain for healthy and defective bearing operating under certain load. In order to check the validity of the experimental results with the theoretical, feature extraction is done*.

Keywords**— Ball Bearing, condition monitoring, vibration analysis, FFT analyzer, feature extraction.**

I. Introduction

A ball bearing is a type of rolling element bearing that uses balls to maintain separation between moving parts of bearing. The purpose of ball bearing is to reduce the friction and support loads [1]. Most of engineering applications such as electric motors, bicycles and roller skates use these bearings, which enable rotary motion of shaft from complex mechanisms of engineering such as power transmissions, gyroscopes, rolling mills and aircraft gas turbines. In general ball bearings are made of four different components, inner ring, outer ring, ball and cage. The cage element helps in separating the rolling elements at regular intervals and also it holds them in place within the inner and outer raceways to allow them to rotate freely [2]. Bearing failures result in serious problems, mainly in places where machines rotate at constant and high speed. In order to prevent any catastrophic consequences caused by bearing failure bearing condition monitoring techniques have been developed to identify existence of flaws in running bearings. Vibration analysis is most commonly accepted technique due to its ease of application [3].

The typical failure mode of ball bearing is fault or scratch on surface which is the result of surface fatigue, caused by the repeated loading of the shaft and it is difficult to avoid in operating conditions. Thus the main problem of malfunction detection of bearing is to examine whether there is a surface defect on the bearing. When a defective surface contacts with its matching surface it will produce a short pulse that may excite the resonances of the bearing assembly. If the bearing is rotating at a constant speed, the contact pulse will occur periodically with a frequency which is a function of a bearing geometry, the rotational speed and the crack location [4]. For on-line monitoring purposes, it is always desirable to reduce the large amount of information contained in the on-line vibration signal to a single index or small number of features that reflects the overall characteristics of the signal. This procedure, known as signal feature extraction [5].

II. Bearing Failure Mechanism

All paragraphs must be indented. All paragraphs must be justified, i.e. both left-justified and right-justified. Bearing has Inner Race, Outer race, Balls as rolling elements. Each bearing is associated with it some characteristic frequencies which are dependent on bearing geometry. Fig. 1 shows the basic elements of Bearing.

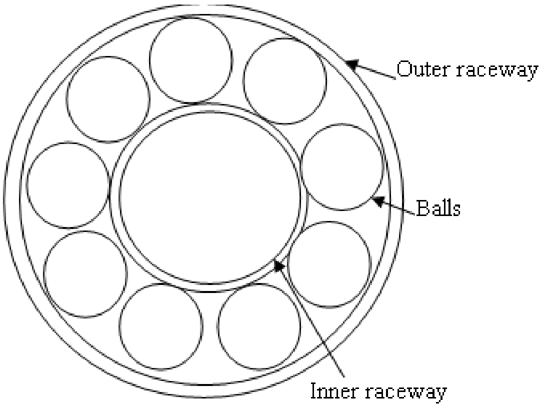


Fig.1 Sectional view of bearing

Such as ball diameter, Pitch diameter, Inner race diameter, Outer race diameter, rotational speed etc. There are number of mechanisms that can lead to bearing failure, including mechanical damages, cracks, wear and tear, lubricant deficiency and corrosion etc. Wear results in gradual deterioration of bearing components when lubrication is not proper the friction between metal to metal increases. Poor lubrication increases the bearing component temperature, which speeds up the deterioration process. Bearing that operates in an environment of high humidity may subjected to surface oxidation and produce subjected rust particles and pits. These particles can produce rapid wear [7].

III. Characteristic Failure Frequencies

The characteristic fault frequencies can be calculated by the following equations:

A. *Ball Pass frequency outer race (BPFO):*

Title must be in 24 pt Regular font. Author name must be in 11 pt Regular font. Author affiliation must be in 10 pt Italic. Email address must be in 9 pt Courier Regular font. Received, revised and accepted dates must be in 10 pt regular point. : if the bearing inner race has a defect such as crack, the fundamental vibration frequency resulting from ball passing over the defect is called Ball Pass Frequency Outer race (BPFO) and obtained as;

$$BPFO = \left(\frac{N}{60} * \frac{n}{2}\right) * \left(1 - \frac{d}{D}\cos\varphi\right)$$

B. *Ball Pass frequency inner race (BPFI):*

No more than 3 levels of headings should be used. All headings must be in 10pt font. Every word in a heading must be capitalized except for short minor words as listed in Section III-B. If the bearing inner race has a defect such as crack, the fundamental vibration frequency resulting from ball passing over the defect is called Ball Pass Inner Race frequency (BPFI) and obtained as ;

$$BPFI = \left(\frac{N}{60} * \frac{n}{2}\right) * \left(1 + \frac{d}{D}\cos\phi\right)$$

C. *Ball Spin Frequency (BSF):*

If roller or ball has a defect such as pit, the pulse repetition rate occurs each time, the defect is struck, is known as the Ball Spin Frequency (BSF) and obtained as;

$$BSF = \frac{N}{60} * \frac{D}{d} * \left(1 - \left(\frac{d}{D}\cos\phi\right)^2\right)$$

D. *Fundamental Train Frequency (FTF):*

For a defect occurring in the bearing cage, the Fundamental Train Frequency (FTF) is given by

$$FTF = \left(\frac{N}{60} * \frac{1}{2}\right) * \left(1 - \frac{d}{D}\cos\varphi\right)$$

Where ‘d’ is ball diameter, ‘D’ is pitch diameter, ‘n’ is number of balls and ‘N’ is shaft rotation in RPM, ‘ϕ’ is contact angle [9].

IV. FFT Approach To Condition Monitoring And Fault Detection

The most common technique in frequency analysis is done usually by FFT (Fast Fourier Transform). Fault diagnosis of such systems is of particular importance in several industries. The success in vibration analysis of these systems depends largely on the techniques used in processing the vibration signals. By using an appropriate signal processing method, it is possible to detect changes in vibration signals caused by faulty components and to judge the conditions of the machinery. Traditional analysis has generally relied upon spectrum analysis based on Fast Fourier Transform (FFT) [6].

V. Procedure For Industrial Vibration Analysis By FFT

- Firstly decide the areas where to take readings.
- Clean that area with the help of clean cloth.
- One end of accelerometer connects to the FFT port.
- FFT analyzer then connected to Laptop having RT Photon pro software installed in it.
- Another end of accelerometer mounts on the bearing housing in radial direction.
- This set up gives the analysis in the form of time and frequency domain curves.
- Wait for 1 minute to achieve accurate graphs.

• With the help of all standard results diagnose that what causes take place into each equipment and conclude their remedies for each equipments [8].

VI. EXPERIMENTAL SETUP.

The test bearing is supported at the end of the shaft, which is supported with two support bearing. In order to obtain vibration response of bearing for monitoring condition of bearing four 6004 bearings were tested. The defect of same size was introduced on outer race, inner race and ball of three different bearings. The specifications are listed below:

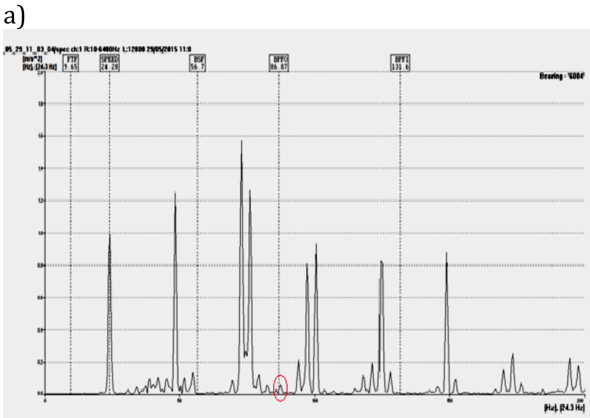
Number of balls = 9
Ball diameter = 6.35mm
Pitch diameter = 31mm
Angle of contact = 0^0

The vibration analysis of ball bearing was carried out at no load, 1kg, 2kg and 4kg at 1475 rpm.

Fig.1 Experimental setup

VII. OBSERVATIONS

a)



b)

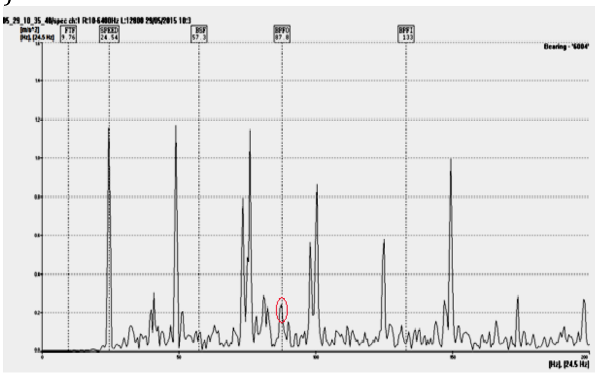
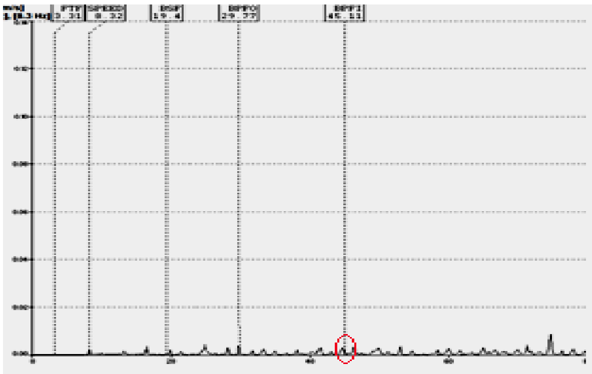


Fig.3 a)Frequency spectrum for Healthy bearing, b)Frequency spectrum for bearing with outer race defect

As shown in fig 3b peak for defective bearing is more as compare to peak for healthy bearing which is shown in fig 3a.

a)



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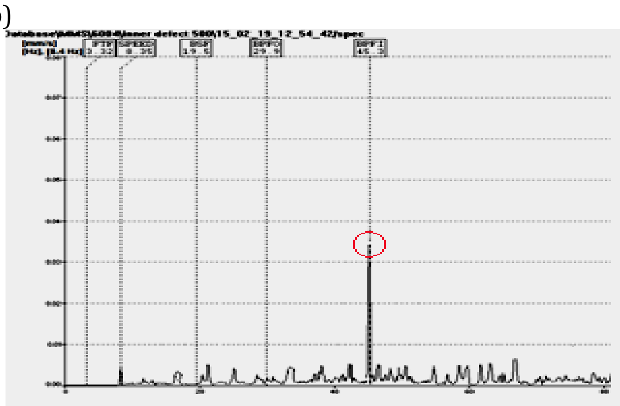

Fig.4 a)Frequency spectrum for Healthy bearing, b)Frequency spectrum for bearing with inner race defect

As shown in fig 4b peak for defective bearing is more as compare to peak for healthy bearing which is shown in fig 4a.

Similar to above two cases frequency spectrums were obtained for Ball bearings with inner race defect, ball defect at no load, 1kg, 2kg and 4kg, at 1475rpm.

From obtained spectrums statistical features like RMS, Skewness, Variance, Mean and standard deviation are evaluated and plotted against load.

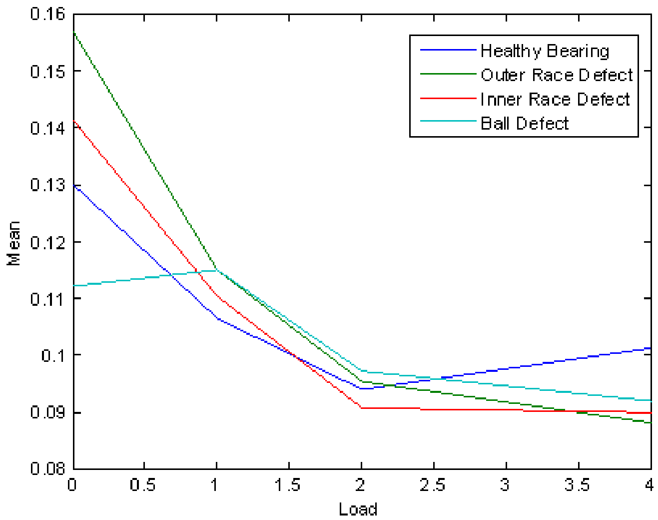

Fig.5 Mean vs Load plot for Healthy, outer race defective, inner race defective and ball defective bearing

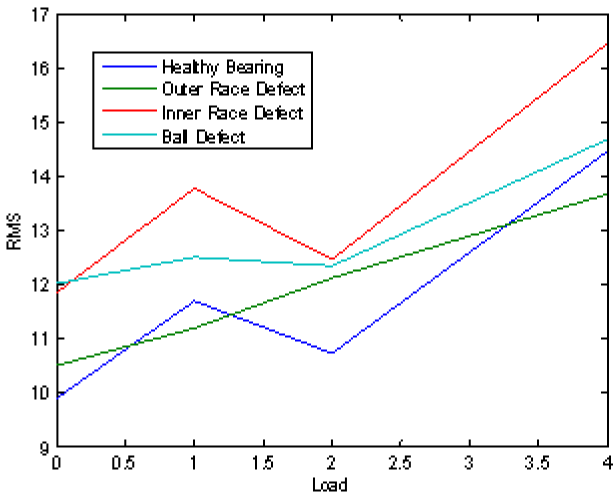

Fig.6 RMSvs Load plot for Healthy, outer race defective, inner race defective and ball defective bearing

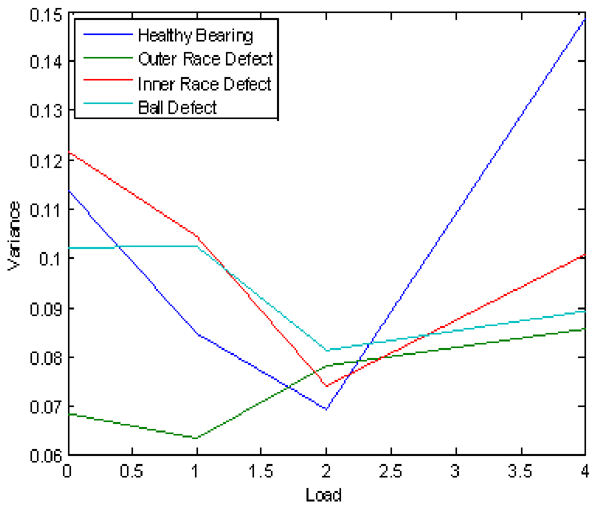

Fig.7 Variance vs Load plot for Healthy, outer race defective, inner race defective and ball defective bearing

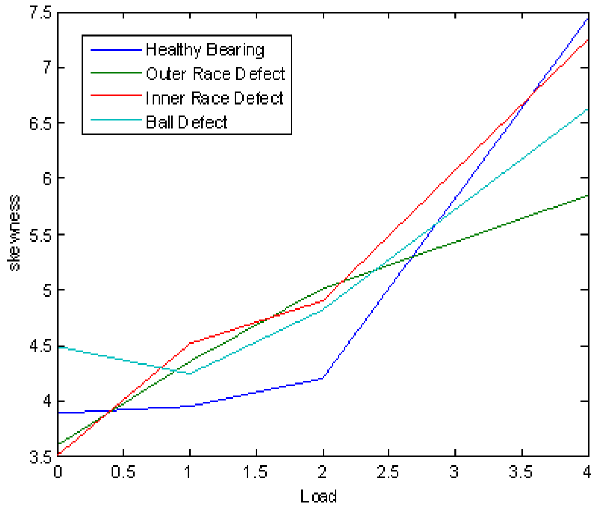

Fig.8 Skewness vs Load plot for Healthy, outer race defective, inner race defective and ball defective bearing

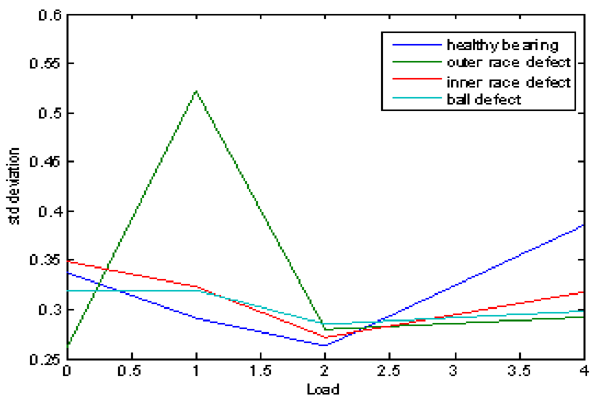

Fig.9 Standard deviation vs Load plot for Healthy, outer race defective, inner race defective and ball defective bearing

V. Conclusions

Based on the studies carried out on vibration monitoring of bearings, it can be concluded that FFT spectrum indicate the location of the fault. Additionally, RMS, Skewness, Variance, Mean, Standard Deviation, few of the statistical parameters are evaluated for above conditions of bearing.

From the plots of extracted features against Load, it is 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.

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