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Fault detection in ball bearing using vibration analysis technique

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ABSTRACT

The performance of the bearing critically affects the functioning of the machinery. The bearing defect results in reduction of efficiency. Sometimes it even results in severe damage to the machine. Avoiding failure of bearing is prime importance. Condition monitoring using vibration analysis is best suited tool to monitor the behavior of different types of bearings. The typical failure modes of rolling bearings are pitting, erosion, fatigue, scratched crack, improper lubrication and the inclusion of foreign material. Among these scratched crack, pitting, erosion and fatigue are fault initiators in bearing assembly. These are caused by the deviations in loading of the shaft and it is difficult to avoid this through the management of operating conditions. Thus the main problem of malfunction detection of bearing is to examine whether there is a surface defect on the bearing. This paper deals with the vibrations generated due to defect on inner race. It shows that defect excites the system at its characteristic frequency. The Fast Fourier Transform spectrum is used to analyze and understand the behavior of defect. Also, kurtosis, feature extraction parameters are used to analyze the defect.

Keywords— **ball bearing, fault detection, feature extraction parameters, vibration analysis**.

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I. Introduction

Rolling element bearings find widespread domestic & industrial application which includes all types of bearings that make use of the rolling action of balls or rollers to permit minimum friction, from the constrained motion of one body relative to another. In industrial application, these bearings are considered as critical mechanical components and defect in such bearing, unless detected in time cause malfunctioning and may even lead to catastrophic failure of the machinery. The initial detection of rolling bearings of is important from view point of system maintenance and process automation.The typical failure mode of rolling 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. A lot of researchers published various work on the detection & diagnosis of bearing defects by vibration and acoustic methods. Tandon and Choudhury [1] presented a details review of vibration and acoustic measurement methods for fault detection of rolling bearings. By considering the defect into two categories, localized & distributed defect the detection of it can be measured by vibration and noise generation in bearings [2]. The rolling elements, the outer ring and the inner ring are in contact under heavy dynamic loads and relatively high speeds. The Hertzian contact stresses between the rolling elements and the rings are one of the basic mechanisms that initiate a localized defect [3].When a rolling element strikes to a defect on one of the races, an impulse is generated. Since the rolling element bearing rotates, those impulses will be periodic with a certain frequency. A model to describe the vibration pattern produced by a single point defect on the inner race is described by McFadden and Smith [4]. In this study, vibration response of the rolling bearings to the defects on outer race, inner race and the rolling elements is obtained and analyzed. Kurtosis one of the statistic indicator is also evaluated for different condition of bearing.

II. TECHNIQUES OF VIBRATION BASED CONDITION MONITORING

There are so many methods developed to monitor the condition of machines. Although a variety of approaches maybe used in condition monitoring applications, the vibrationmonitoring and analysis is the most widely used technique to determine the mechanical condition of machinery and their parts since last 50 years [5]. Vibration signals collected from bearings carry rich information on machine health conditions. Therefore, the vibration-based methods have received intensive study during the past decades. It is possible to obtain vital characteristic information from the vibration signals through the use of signal processing techniques [6]. A number of transducer types exist for measuring machine vibration signals, including proximity probe, velocity transducers,accelerometers etc. The measurement of machine casing acceleration is the most common method used for bearing fault detection. This is normally achieved by mounting piezoelectric accelerometer externally on the machine casing, preferably near or on the bearing housing, or on the portion of the casing where relatively rigid connection exists between the bearing support and transducer. Piezoelectric sensors are less sensitive to temperature which is important since most machinery fault results in temperature increase. This will allow the bearing vibration to transmit readily through the structure to transducer. Sawalhi and Randall [7] have discussed the Vibration response of spalled rolling element bearings, Observations, simulations and signal processing techniques to track the spall size and investigated vibration signatures of seeded faults at different speeds. The acceleration signals resulting from the entry of the rolling element into the spall and exit from it are of different natures. Accelerometers have the advantage of providing a wide dynamic range and a wide frequency range for vibration measurement. They have been found to be the most reliable, versatile and accurate vibration transducer available. Many researchers [8, 9] have used different approaches and different descriptors under different environments to investigate the relationship between the tested bearing and changes in vibration response under operating condition.

A. Frequency domain approach

Your Energy in sound signal is distributed over a range of frequencies. Frequency analysis separates individual frequency components in a complex signal and indicates amplitude of each. There are various techniques available under non real time analysis. e.g. fixed filter, sweeping filter, high speed analysis etc. In real time analysis, the analysis is made so quickly that results are provided almost immediately.

One of methods under real time analysis is FFT analysis which makes use of FFT (Fast Fourier Transform) algorithm to calculate spectra of blocks of data. The FFT algorithm is an efficient way of calculating the Discrete Fourier Transform (DFT). The basic relationships used to transform information from time domain to frequency domain, or vice versa, are Fourier transform pair. The basic indicator is the characteristic defect frequencies in the frequency domain analysis. Spectral analysis of vibration signal is widely used in bearing diagnostics. It was found that frequency domain methods are generally more sensitive and reliable methods [10]. The characteristic defect frequencies depend on the rotational speed and the location of the defect in a bearing. The existence of one of the defect frequencies in the direct or processed frequency spectrum is the main indicator of the fault. The interaction of defects in rolling element bearings produces pulses of very short duration whenever the defect strikes or is struck owing to the rotational motion of the system. These pulses excite the natural frequencies of bearing elements and housing structures. These frequencies depend on the bearing characteristics and are calculated according to the relations as shown below [1, 5, 6, and 8].

$$fs = N/60 \tag{5}$$

$$fid = (n/2)(N/60)[1 + (bd/pd)\cos\Phi] \tag{6}$$

$$fod = (n/2)(N/60)[1 - (bd/pd)\cos\Phi] \tag{7}$$

$$fcd = (1/2)(N/60)[1 - (bd/pd)\cos\Phi] \tag{8}$$

$$fcd = (pd/2bd)(N/60)[1 - (bd/pd)^2(\cos\Phi)^2] \tag{9}$$

Where,

n = Number of balls, Φ= Contact angle, pd = pitch diameter. bd = ball diameter, N= rotational speed in rpm. *fs*=Shaft rotational frequency, *fcd*=Cage defect frequency*fod*=Outer race defect frequency, *fid*=Inner race defect frequency, *fbd*=Ball defect frequency.

B. Time domain approach

Signal analysis in the time domain has been used to monitor the machine conditions. However, complex signals are difficult to analyze, when frequently encountered in industrial equipment. Some of the time domain techniques can be used or applied for condition monitoring, such as root mean square (RMS), mean, peak value, crest factor, kurtosis, and shock pulse counting. The mean acceleration signal is the standard statistical mean value. Unlike RMS, the mean is reported only for rectified signals since for raw time signals, the mean

remains close to zero. As the mean increases, the condition of
the bearing appears to deteriorate. Peak value is measured in the time domain or frequency domain. Peak value is the maximum acceleration in the signal amplitude. Crest factor is the ratio of peak acceleration over RMS. This metric detects acceleration bursts even if signal RMS has not changed. The
shock pulse method has been used successfully in the detection of defects in rolling element bearings [15]. Tandon [13] has shown that defect detect ability of overall power to be the best followed by peak and RMS measurements. However, crest factor can be counterintuitive. At advance stages of
material wear, bearing damage propagates, RMS increases, and crest factor decreases. But crest factor is unreliable to locate defects in rolling elements.

$$RMS(x) = \sqrt{\frac{x_i^{\,2}}{N}} \tag{10}$$

$$Mean(\bar{x}) = \frac{1}{N} * \sum_{i=1}^{N} x_i^{\,2} \tag{11}$$

$$\text{Crest Factor} = \frac{\text{Peak acceleration}}{\text{RMS(x)}} \tag{12}$$

$$Skewness = \frac{1}{N-1}\sum_{i=1}^{N}(x-\bar{x})^3 \tag{13}$$

The forth moment, normalized with respect to the forth power
of standard deviation is quite useful in fault diagnosis. This quantity is called kurtosis which is compromise measure between the intensive lower moments and other sensitive higher moments. It was reported that kurtosis is the good criterion to distinguish between damaged and healthy bearings
[11]. A healthy bearing with Gaussian distribution will have a
kurtosis value about 3.When the bearing deteriorates, this value goes up to indicate damaged condition which reduces again when the defect is well advanced. One of the advantages of this method is that there is no need to know time history of the signal and bearing condition can be monitored by observing kurtosis.

$$Kurtosis = \frac{(N-1)\sum_{i=1}^{N}(x_i-\bar{x})^4}{\sum_{i=1}^{N}(x_i-\bar{x})^2} \tag{14}$$

There are several methods of follow-up in time and frequency
domain and their results on rolling element bearings have been presented [4]. Spectral subtraction is a method based on
Short Time Fourier Transform. It allows removing the stationary noise of a signal. Estocq et al. [12] have shown that
the method improves the sensibility of temporal indicators such as the kurtosis and the crest factor. Su and Lin [14] suggested need of time domain analysis along with frequency
signature of vibration for monitoring of bearings reliably.

III. EXPERIMENTAL SETUP AND MEASUREMENTS

A. *Test rig*

The test rig used in the present work consists of 1Hp, 1400 rpm. Crompton Greaves three phase induction AC motor. The test bearing is mounted at the end of the shaft and is loaded. Vibration isolation rubber was placed under the test rig to reduce the vibration transmission from ground to the test bearing. In order to obtain vibration response of rolling element bearing for detection of fault, 6205 (SKF) deep grove ball bearings were tested. The specification are listed as follows, No of balls are 9, diameter of the ball is 8.5mm, Pitch diameter is 38.5mm, and the angle of contact is 00. The line defect of 1mm is introduced on bearing on its inner race to acquire its vibration data. The schematic diagram of experimental set-up is shown in Fig. 1

Fig.1 Experimental setup

IV. RESULTS AND DISCUSSION

A. FREQUENCY DOMAIN APPROACH

Fig. 2 shows FFT spectrum for the defective bearing with defect on inner race at 200 rpm and its. The theoretical frequency for the inner race defect closely matches with the experimental one. The spectra in Fig. 2 to Fig.4 show the presence of defect on inner race of bearing at 200, 400 and 600 rpm respectively. The shaft rotational frequency is also shown in spectrum. The theoretical frequencies for all the cases of defects and shaft rotational frequency at different speeds calculated by equations (5) to (9) are shown in TABLE I.

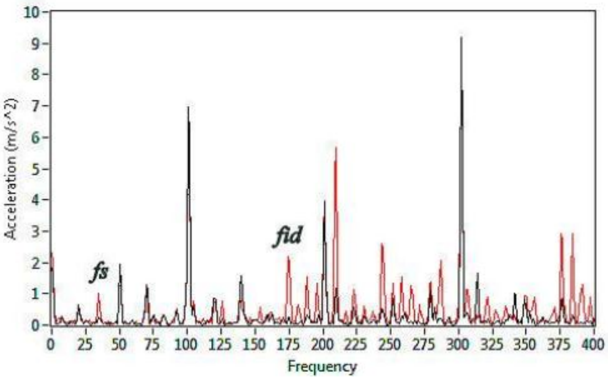


Fig.2 Spectum of defective bearing at 200 rpm

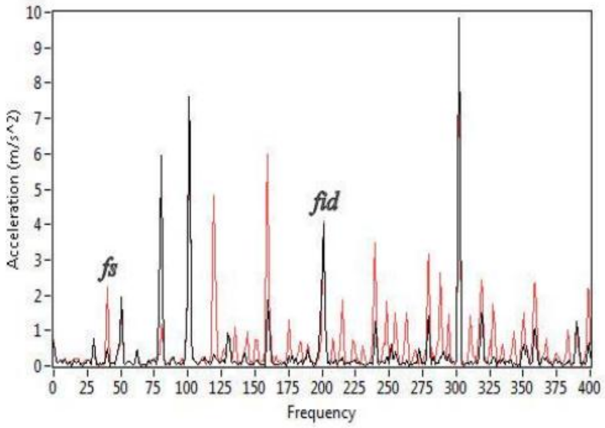
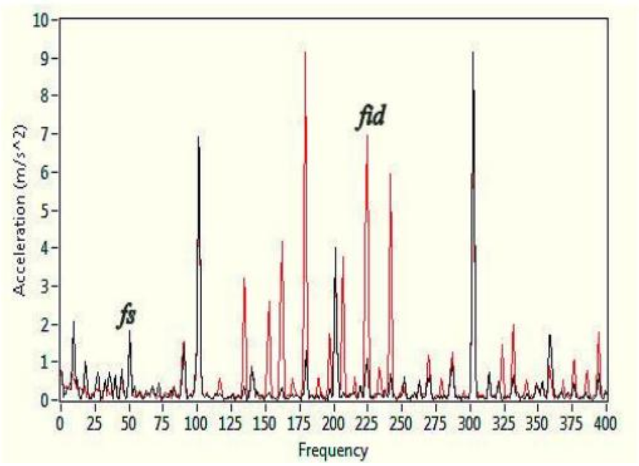


Fig.3 Spectum of defective bearing at 400 rpm



. Fig.4 Spectum of defective bearing at 600 rpm

TABLE I. Characteristic frequencies at different speeds

Speed (rpm)	Inner race defect freq.
200	165
400	192
600	220

B. TIME DOMAIN APPROACH

Kurtosis is one of the important statistical indicators for fault detection in rolling bearings. First kurtosis is calculated for defect free bearings at different speeds. Then kurtosis is calculated for defective bearings using equation (14) for defect at different locations. TABLE II shows the kurtosis values for different cases.

TABLE II. Kurtosis Values

Condition Of Bearing	Kurtosis value
Defect free	3.02778
Inner race defect	5.85179

V.CONCLUSION

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, kurtosis, one of the statistical parameters is evaluated for the above cases of the defects on the bearing. Kurtosis though indicates state of the bearing; it cannot detect the location of fault. The results reveal that vibration based monitoring method is effective in detecting the faults in the bearing.

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