Review of Fault Detection in Rolling Element Bearing

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Defective bearings are the source of vibrations in machines. Due to constructional features of bearing, they generate vibrations. As the condition of bearings changes during use, the nature of vibrations also changes and it has a definite characteristics depending upon the cause. This characteristic feature of bearing makes them suitable for vibration monitoring. This is a review paper for fault detection technique in rolling element bearing, it covers rolling element bearing components and its geometry, bearing failure modes, bearing condition monitoring techniques, time domain and frequency domain techniques.

Key Words: Condition Monitoring, Rolling Element Bearing, Time domain Techniques, Frequency domain techniques

I. INTRODUCTION

The robustness and reliability of the bearings are essential qualities for the health of a machine. Defects in bearings may arise during use or during the manufacturing process. Therefore, the detection of these defects is important for condition monitoring as well as the quality inspection of bearings [1]. This paper is a review of fault detection in rolling element bearing. Most mechanical failure is caused by bearing fault. Serious bearing fault will induce vibration, noise, low efficiency, even breakdown of equipment. Traditional bearing maintenance is periodic replacement, which possibly lead to 90 percent of bearing effective life waste. The effective maintenance is to establish a condition monitoring program to check the satisfactory operation of bearings and carry out repair according to practical running condition and fault diagnosis [2].

At the present time, monitoring and diagnosis techniques of rolling bearing include vibration, temperature, grindings, acoustic emission, oil film resistance. Among them, vibration measurement is the most widely used and effective way. Using vibration diagnosis, such common bearing faults as crushing, crack, indentation, wear can be detected effectively [2].

Tandon and Choudhury [3], considered detection of two categories of defect: localized and distributed defect. vibration and noise generation in bearings measured Detection of defects. They reviewed Acoustic measurement techniques such as sound pressure, sound intensity and acoustic emission. They concluded that Vibration in the time domain can be measured through parameters such as overall RMS level, crest factor, probability density and kurtosis. Among these, kurtosis is the most effective. The shock pulse method has also gained wide industrial acceptance. In acoustic measurement both sound pressure and sound intensity have been used for the detection of the bearing defect. The sound intensity technique seems to be better than sound pressure measurements for bearing diagnostics.

Pratesh Jayaswal, A.K.Wadhwani & K.B.Muchandani [4] investigated the feasibility of fast Fourier Transform (FFT) & band pass analysis for fault identification of REB with multiple faults. They experimented three faulty & healthy conditions bearing. They have confirmed that the filtered signals under three frequency bands can be valuable signatures for faulty identification & the RMS values of filtered signals can be further utilized as parameters of diagnostic important.

M Amarnath, R Shrinidhi, A Ramachandra, S B Kandagal [5], describes the suitability of vibration monitoring and analysis techniques to detect defects in antifriction bearings. Time domain analysis, frequency domain analysis and spike energy analysis have been employed to identify different defects in bearings.

II. ROLLING ELEMENT BEARING COMPONENTS AND GEOMETRY

Bearing geometry is a critical factor for diagnosing bearing defects because the geometry of ball bearings determines the dynamics of the bearing components and their vibration characteristics. Figure 2.1 shows a typical deep groove ball bearing and figure 2.2 shows components, applied force, load zone and load distribution.

Ball bearings have smaller sizes and limited load carrying capacity compared to the other rolling element bearings, but they can support both axial and radial loads. Axial force is defined as the force applied parallel to the shaft whereas the radial force is applied perpendicular to the shaft. Correct alignment, placement where it is used, enough lubrication are the important points to take care of to maximize the life-span of this equipment [6].

As it can also be observed from Figure 4.3, a ball bearing consists of an inner race, an outer race, balls, a cage holding the balls apart from each other and a shaft. The load zone and load distribution are also given with the direction of applied force in the figure. In most cases, the outer race is held stationary where the inner race and the balls rotate. Most of the defects on the inner side of outer race such as cracks or pits occur on the locations subject to the load zone, since they are directly under the applied force.

Figure 2.1: Typical deep-groove ball bearing [6]

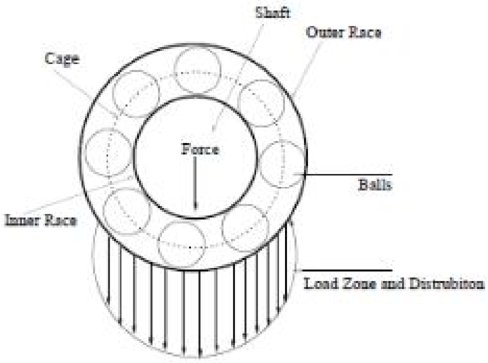

Figure 2.2: Ball bearing components, applied force, load zone and load distribution [6].

III. BEARING FAILURE MODES

The normal service life of a rolling element bearing rotating under load is determined by material fatigue and wear at the running surfaces. Premature bearing failures can be caused by a large number of factors, the most common of which are fatigue, wear, plastic deformation, corrosion, brineiling, poor lubrication, faulty installation and incorrect design. Common modes of bearing failure are discussed below [7]:

A. Fatigue

Fatigue damage begins with the formation of minute cracks below the bearing surface. As loading continues, the cracks progress to the surface where they cause material to break loose in the contact areas. The actual failure can manifest itself as pitting, spalling or flaking of the bearing races or rolling elements. If the bearing continues in service, the damage will spread in the locality of the defect is due to stress concentration [7].

B. Wear

Wear is another common cause of bearing failure. It is caused mainly by dirt and foreign particles entering the bearing through inadequate sealing or due to contaminated lubricant. The abrasive foreign particles roughen the contacting surfaces giving a dull appearance. Severe wear changes the raceway profile and alters the rolling element profile and diameter, increasing the bearing clearance. The rolling friction increases considerably and can lead to high levels of slip and skidding, the end result of which is complete breakdown [7].

C. Plastic deformation

Plastic deformation of bearing contacting surfaces can be the result of a bearing subject to excessive loading while stationary or undergoing small movements. The result is indentation of the raceway as the excessive loading causes localized plastic deformation. In operation, the deformed bearing would rotate very unevenly producing excessive vibration and would not be fit for further service [7].

D. Corrosion

Corrosion damage occurs when water, acids or other contaminants in the oil enter the bearing arrangement. This can be caused by damaged seals, acidic lubricants or condensation which occurs when bearings are suddenly cooled from a higher operating temperature in very humid air. The result is rust on the running surfaces which produces uneven and noisy operation as the rust particles interfere with the lubrication and smooth rolling action of the rolling elements [7].

E. Brinelling

Brinelling manifests itself as regularly spaced indentations distributed over the entire raceway circumference, corresponding approximately in shape to the Hertzian contact area. Three possible causes of brinelling are,
(1) Static overloading which leads to plastic deformation of the raceways,
(2) When a stationary rolling bearing is subject to vibration and shock loads and
(3) When a bearing forms the loop for the passage of electric current [7].

F. Lubrication

Inadequate lubrication is one of the common causes of premature bearing failure as it leads to skidding, slip, increased friction, heat generation and sticking. At the highly stressed region of Hertzian contact, when there is insufficient lubricant, the contacting surfaces will weld together, only to be torn apart as the rolling element moves on. The three critical points of bearing lubrication occur at the cage-roller interface, the roller-race interface and the cage race interface [7].

G. Faulty installation

Faulty installation can include such effects as excessive preloading in either radial or axial directions, misalignment, loose fits or damage due to excessive force used in mounting the bearing components [7].

H. Incorrect design

Incorrect design can involve poor choice of bearing type or size for the required operation, or inadequate support by the mating parts. Incorrect bearing selection can result in any number of problems depending on whether it includes low load carrying capability or low speed rating. The end result will be reduced fatigue life and premature failure [7].

IV. BEARING CONDITION MONITORING TECHNIQUES

There are two types of defects: Localized Defects, Distributed Defects. Localized defects include cracks, pits and spalls on the rolling surfaces. Distributed defects include surface roughness, waviness, misaligned races and off-size rolling elements [2]. Condition monitoring systems are of two types: periodic and permanent. In a periodic monitoring system (also called an off-line condition monitoring system), machinery vibration is measured (or recorded and later analyzed) at selected time intervals in the field; then an analysis is made either in the field or in the laboratory. In a permanent monitoring system (also called an on-line condition monitoring system), machinery vibration is measured continuously at selected points of the machine and is constantly compared with acceptable levels of vibration. The permanent monitoring system can be costly, so it is usually used only in critical applications [2]. Various methods are used for the diagnosis of bearing defects. The methods are broadly classified as acoustic measurements, current and temperature monitoring, wear debris detection, and vibration analysis [8].

A. Acoustic Measurement

The most effective acoustic-based bearing health monitoring is acoustic emission. It is a transient impulse generated by the rapid release of strain energy in solid material under mechanical or thermal stress. The detection of cracks is the prime application of acoustic emission; therefore, this technique can be used as a tool for condition monitoring of bearing faults and shaft cracks. The measurement of a machine’s sound can also be employed for detecting defects in bearings. Typically, the accuracy of these methods depends on sound pressure and sound intensity data [8].

B. Temperature Monitoring

Bearing distributed defects generate excessive heat in the rotating components. Monitoring the temperature of a bearing housing or lubricant is the simplest method for fault detection in rotary machines [8].

C. Electrical Motor Current Monitoring

The operating conditions of a machine can be monitored by analyzing the spectrum of the motor current. The changes in the electric background noise are associated with the changes in the mechanical components of the machine; therefore, fault signatures can be detected by motor current signal processing techniques [8].

D. Wear Debris Analysis

In this method, the presence of metallic particles in the lubricant is detected by sensitive sensors. Furthermore, the spectrographic analysis of the different metallic elements in the lubricant can facilitate the location of the fault [8].

E. Vibration Measurement

Since the abnormal vibration of rotary machines is the first sensory effect of rotary component failure, vibration analysis is widely employed in the industry. The fault vibration signal generated by the interaction between a damaged area and a rolling surface occurs regardless of the defect type. Consequently, a vibration analysis can be employed for the diagnosis of all types of faults, either localized or distributed. Furthermore, low-cost sensors, accurate results, simple setups, specific information on the damage location, and comparable rates of damage are other benefits of the vibration measurement method [8].

Condition monitoring using vibration measurement can be classified into time domain technique, frequency domain technique and time-frequency technique [7].

1) Time Domain Technique

Some of the time domain techniques can be used or applied for condition monitoring, such as root mean square (RMS), mean, peak value, Mean Square, crest factor, Skewness, kurtosis, Variance, Standard Deviation, Clearance Factor, Impulse Factor, Shape Factor [7][9].

Root mean square

Root mean square (RMS), measures the overall level of a discrete signal.

$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} f_n^2} \qquad (1)$$

Where N is the number of discrete points and represents the signal from each sampled point.

RMS is a powerful tool to estimate the average power in system vibrations. A substantial amount of research has employed RMS to successfully identify bearing defects using accelerometer and AE sensors [10].

Mean

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 [10].

$$\mathrm{Mean} = \frac{1}{N} \times \sum_{i=1}^{N} f_n \qquad (2)$$

Peak value

Peak value is measured in the time domain or frequency domain. Peak value is the maximum acceleration in the signal amplitude.

$$P_v = \frac{1}{2}[\max(f_n) - \min(f_n)] \qquad (3)$$

Crest factor

Crest factor is the ratio of peak acceleration over RMS. This metric detects acceleration bursts even if signal RMS has not changed.

$$\text{Crest Factor} = \frac{P_v}{\mathrm{RMS}} \qquad (4)$$

Skewness

Machined or ground surfaces in bearings show a random distribution of asperities that are commonly described with the normal distribution function. For this reason, various statistical moments can describe the shape of distribution curves therefore, assessing bearing surface damage level. Equation defines the third moment or skewness as [7]

$$\mathrm{Skewness} = \frac{\frac{1}{N}\sum_{n=1}^{N}(f_n - \bar{f})^3}{\mathrm{RMS}^3} \qquad (5)$$

Where f is the mean value. For normally distributed data sets the odd moments are zero, unless the time domain signal is rectified. Hence, skew can easily track for bearing conditions [7].

Kurtosis

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.

$$\text{Kurtosis} = \frac{\frac{1}{N}\sum_{n=1}^{N}(f_n - \bar{f})^4}{RMS^4} \qquad (6)$$

Variance

$$\text{variance} = \sigma^2 = \frac{\sum_{n=1}^{N}(f_n - \mu)^2}{N} \qquad (7)$$

Standard Deviation

$$s = \left(\frac{1}{N-1}\sum_{n=1}^{N}(f_n - \bar{f})^2\right)^{\frac{1}{2}} \qquad (8)$$

Clearance Factor

$$Cl_f = \frac{P_v}{\left(\frac{1}{N}\sum_{n=1}^{N}|f_n|\right)^2} \qquad (9)$$

Impulse Factor

$$I_f = \frac{P_v}{\frac{1}{N}\sum_{n=1}^{N}|f_n|} \qquad (10)$$

Shape Factor

$$S_f = \frac{RMS}{\frac{1}{N}\sum_{n=1}^{N}|f_n|} \qquad (11)$$

2) Frequency Domain Technique

There are five basic motions that can be used to describe dynamics of bearing movements. Each motion generates a unique frequency, the five characteristics frequencies are [4]:

Shaft rotational frequency

$$(FOR) = \frac{N}{60} \qquad (1)$$

Inner race defect frequency

$$(FID) = \left(\frac{n}{2}\right)\left(\frac{N}{60}\right)\left[1 + \left(\frac{b_d}{p_d}\right)\cos ø\right] \qquad (2)$$

Outer race defect frequency

$$FOD = \left(\frac{n}{2}\right)\left(\frac{N}{60}\right)\left[1 - \left(\frac{b_d}{p_d}\right)\cos ø\right] \qquad (3)$$

Ball defect frequency

$$FBD = \left(\frac{p_d}{b_d}\right)\left(\frac{N}{60}\right)\left[1 - \left(\frac{b_d}{p_d}\right)^2 (\cos \emptyset)^2\right] \qquad (4)$$

Cage defect frequency

$$FCD = \frac{1}{2}\left(\frac{N}{60}\right)\left[1 - \left(\frac{b_d}{p_d}\right)\cos\emptyset\right] \qquad (5)$$

Where,

n = Number of balls.

ϕ = Contact angle.

p_d = pitch diameter.

b_d = ball diameter.

N= rotational speed in rpm.

V. EXPERIMENTAL SETUP

The model of experimental setup is shown in the figure 5.1. It will consist of a shaft with the support bearings. The shaft at one end is connected by a gear coupling to a drive unit consisting of a 3 phase induction motor & variable frequency drive (VFD) for changing the speed. It will also consist of an arrangement for loading the bearing in axial & radial directions. The gear coupling connecting the main shaft to the drive unit isolates the shaft from the vibrations of the drive unit to a certain extent.

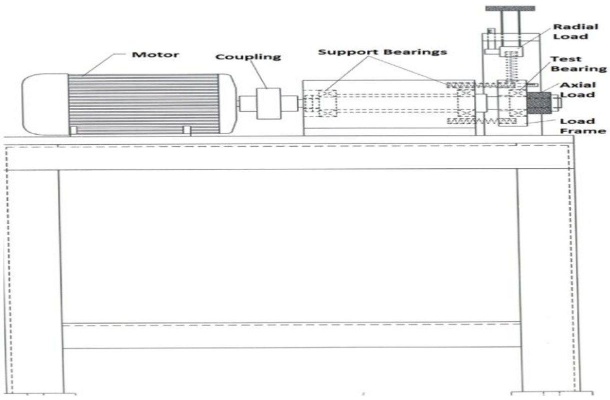

Figure 5.1: Model of Experimental Setup

We will have to take the vibration signals using FFT from this setup. Then we will analyze the signals, extract the features and calculate the frequencies and classify the fault signals using MATLAB.

VI. CONCLUSIONS

In review paper for fault detection technique in rolling element bearing, we covered rolling element bearing components and its geometry, bearing failure modes, bearing condition monitoring techniques. From review, we had taken some points of considerations for future work. Vibration measurement in time domain and frequency domain are key points for doing work. So, we will use time domain and frequency domain for feature extraction and fault diagnosis in our work.

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