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A Review of Vibration Analysis on Deep Groove Ball Bearing by Using Signal Processing Techniques

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ABSTRACT: Vibration analysis is used as a conditioning monitoring tool for bearing fault detection and diagnosis. This paper reviews some of the important factors which effect on the bearing vibration, including different modes of failure. The more common techniques which were used comprise time and frequency domain techniques. These include of technique such as RMS, crest factor, probability density function, correlation function, band pass filtering prior to analysis, power and cross power spectral density function, transfer and coherence function as well as cepstrum analysis, narrow band envelope analysis and shock pulse method.

KEYWORDS: time domain technique, frequency domain technique, envelope analysis

I. INTRODUCTION

Deep groove ball bearings are the most common type of ball bearings. They are widely used in our daily life and industries. Deep groove ball bearings are commonly used in electric motors and in household appliances, car motors, office machinery, automation control, and garden and household tools. Rolling element bearings include 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. Rolling element bearings are used to permit the rotation of a shaft relative to a fixed structure. In some cases the bearings permit translation, relative linear motion, and few rolling bearing designs permit a combination of relative linear and rotary motions between two bodies.

Important effectiveness and cost saving can be achieved by equipment availability, reliability and maintainability. High production volume system consists of several automatic and interconnected machine tools; the working environment is very difficult. The human approach for measurement and inspection during the running operation (running machine) is generally time consuming and measuring equipment has to be very robust. The large production cost on large transfer line (in high production volume) can be as high as Rs 10, 00,000 per hour. Unexpected bearing failure and tool breakages are the main causes to excess 25% average downtime of machine. A predictive maintenance system is capable of only partial reduction of these stoppages, and thus increases the manufacturing productivity.

The machine conditioning and monitoring system also provide the smooth running of roller element bearings, which is vital for the proper functioning of the machine. To avoid sudden failure, it is important to monitor the condition of the bearings. Several techniques are currently available for detection of defect in roller bearing elements. These consist of technique such as RMS, crest factor, probability density function, correlation function, band pass filtering prior to analysis, power and cross power spectral density function, transfer and coherence function as well as cepstrum analysis, narrow band envelope analysis and shock pulse method.

II. LITERATURE REVIEW

Many research works had been done in the field of signal analysis in rolling element bearing. Following is the literature review of some paper giving more information about their contribution in signal analysis of defect in rolling element bearing.

Mr. R. D. Borole et. al in this paper, we discussed about the vibration based analysis of rolling element bearing. We also covered rolling element bearing components and its geometry, bearing failure mechanisms, Vibration based analysis of rolling element bearing in time domain and frequency domain. Using these features in time domain and frequency domain we can diagnose the condition of rolling element bearing. [1]

Ping Chen in this work, segmentation parameters are proposed to further improve the sensitivity and reliability of the technique. Parameters extracted from the segmentation analysis reflect the variation of vibration signals associated with the bearing dynamics. A three-layered artificial neural network is applied to accomplish the non-linear mapping from the feature space to the two dimensional classification space. The mapping is conducted to create the best cluster effect for training samples belonging to the same class. Successful non-linear mapping through the neural network eliminates intra-class transformations as used in Sun, et al, 1981. Numerical experiments' are performed to illustrate the effectiveness of the method. [2]

B. M. Vamsi Krishna et. al In this paper, an attempt to summarize the recent research and developments in the vibration analysis techniques for diagnosis of rolling element bearing faults has been made. This study found that the time domain techniques only can indicate the fault(s) present in the bearing but it can't identify the location. Frequency domain techniques have ability to identify the location of fault(s) in bearing. Vibration peaks generates in spectrum at the bearing characteristics frequencies, from that we can easily understand which bearing element is defected. [3]

Sham Kulkarni et. al The present work emphasizes the comparison of some vibration parameters to characterize the distributed defects in the bearing, RMS, Peak and peak to peak which are used in the detection defects in the bearing. These parameters are measured at various load and speeds with simulated defect on bearing parts. This paper also shows the sensitivity of kurtosis in condition monitoring of ball bearing. It has been shown that vibration based monitoring is an effective method for detecting the faults in the bearing. [4]

Orhan et al. have studied the vibration monitoring for defect diagnosis of rolling element bearings as a predictive maintenance tool. In this study, the vibration monitoring and analysis case studies were presented and examined in machineries in real operating conditions. Failures formed on the machineries in the course of time were determined by the spectral analysis. Diagnosing techniques of the ball and cylindrical roller element bearing defects were investigated by vibration monitoring and spectral analysis as a predictive maintenance tool. Ball bearing outer race defect and a cylindrical bearing outer race defect were successfully diagnosed. It was shown that ball and cylindrical roller bearing defects were progressed in identical manner without depending on rolling element type. It was concluded that if vibration monitoring is applied within regular selected periods, capable instrumentation and if vibration analysis is performed by experienced personnel, impending failures can be easily detected. [5]

H. MohamadiMonavar, H. Ahmadi and S.S. Mohtasebi this paper describes the suitability of vibration monitoring and analysis techniques to detect defects in roller bearings. Triaxial vibration measurements were taken at each end of the coupling on the motor and rotor bearing housings. The results indicate that bad bearing has a strong effect on the vibration spectra. [6]

M.S. Patil, Jose Mathew, P.K.Rajendrakumar this paper is intended as a tutorial overview of bearing vibration signature analysis as a medium for fault detection. An explanation for the causes for the defect is discussed. He suggested that there is an inverse relationship between the fault detection ease and the importance to user of that fault detection. [7]

Bubathi Muruganatham, M.A.Sanjith, B.Krishnakumar, S.A.V.SatyaMurty in this paper, a simple time series method for bearing fault feature extraction using singular spectrum analysis of the vibration signal is proposed. The method is easy to implement and fault feature is noise immune. Singular spectrum analysis is used for the decomposition of the acquired signals into an additive set of principal components. A new approach for the selection of the principal components is also presented. [8]

Manish yadav, Dr.Sulochana wadhwani this paper present fault detection of ball bearing using time domain features of vibration signal. The vibration signals are recorded at bearing housing of 5hp squirrel cage induction motor. These extracted features are used to train and test the neural network for four bearing condition namely healthy, defective outer race, defective inner race and defective ball fault condition. [9]

III. BALL BEARING TERMINOLOGY

A ball bearing consists of an inner ring (IR), an outer ring (OR), a complement of balls, and a separator. See Figure 1 The outer diameter of the inner ring (IROD) and the inner diameter of the outer ring (ORID) have a groove in which the balls roll. The groove is commonly called the pathway. The raised surface on each side of the pathway is called the shoulder. The balls are held equally spaced around the annulus of the bearing by the separator. The basic dimensions of the bearing are the bore (B), outside diameter (OD), and the width (W). The radius of curvature of the pathway must be closely controlled in relation to the ball diameter in order for the bearing to operate satisfactorily. If the radius of curvature is too close to the ball diameter, the bearing will operate with a high amount of friction. If the radius of curvature is too large in relation to the ball diameter, the bearing will operate

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under a high stress level. Both conditions will contribute to premature bearing failure.

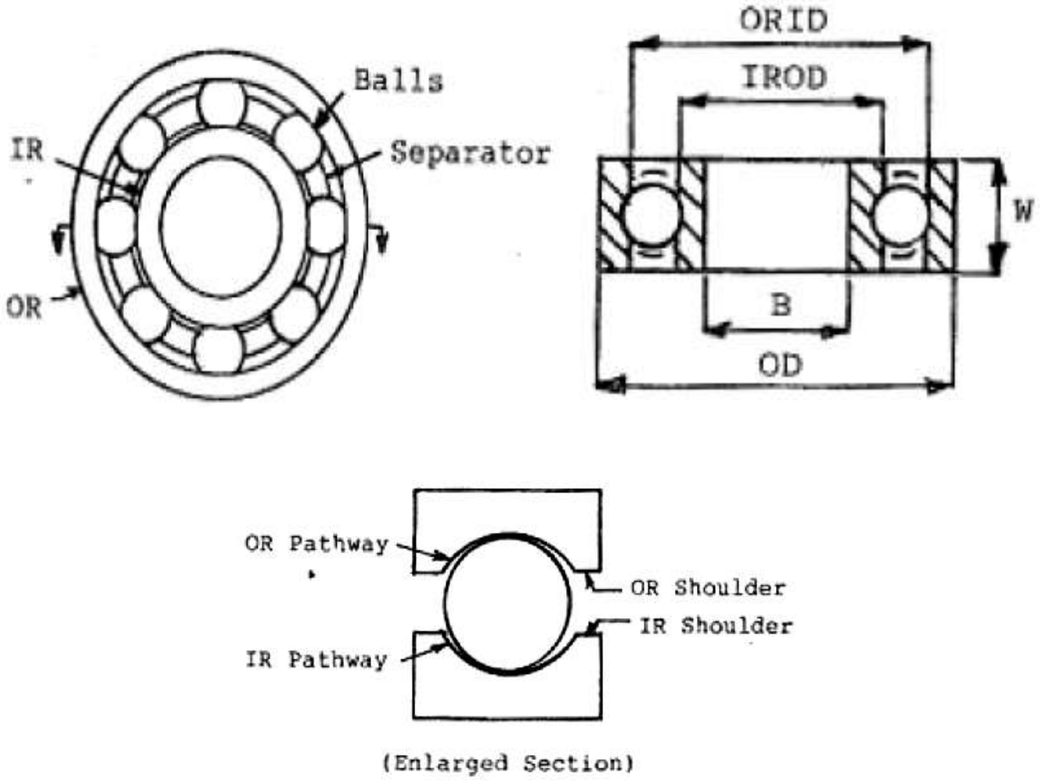

Figure1: Ball bearing terminology

IV. 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:

Fatigue

Fatigue failure is characterized by spalling (flaking) on the raceways and/or the recirculating elements (balls or rollers). As the bearing operates—carrying a load and experiencing forces due to its motion—the repeated stresses on the recirculating elements and raceways cause the material to fatigue. Fractures begin to form in the bearing's internal structure, and as those fractures reach the surface, small pieces of material begin to flake away.

Wear

Wear occurs when surfaces slide against each other and there is insufficient or no lubrication to keep them apart. If a full hydrodynamic lubricant film can be maintained at all times, wear will not occur. In reality, however, this is very rarely the case and so wear is almost always unavoidable. Unlike other causes of rolling bearing failure, such as fatigue, corrosion and overloading, wear appears in many different forms.

Plastic deformation

During the bearing installation process, cannot use steel hammer or other direct percussion, and the installation froce of the bearing cannot pass through the rolling body. Otherwise, plastic deformation will occur and the bearing will be damaged. This kind of damage is mainly manifested in the shape change of bearing parts, so the failure marks in different working conditions are different, which needs to be analyzed concretely.

Corrosion

Due to the high degree of surface finish, bearing rollers and raceways are particularly susceptible to corrosion. However, corrosion can also occur on unloaded areas, such as roller end faces. It produces yellow or reddish-brown stains of various size and shape. If the operating conditions are not changed, corrosion will be

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progressive. It will etch contact surfaces, promoting flaking and the formation of corrosion pits. This will eventually lead to macro pitting.

Lubrication

According to a recent study, up to 80 percent of bearing failures are caused by improper lubrication. This includes insufficient lubrication, use of improper lubricants or excessive temperatures that degrade the lubricant.

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.

Overheating

Overheating is generally the result of excessive operating temperatures and improper lubrication. High temperatures can cause grease to bleed (purge the oil), which reduces the lubricant's efficiency. In elevated temperature conditions, oxidation can lead to the loss of lubricating oils from the grease, leaving a dry, crusty soap that can seize the bearing. Higher temperatures also reduce the hardness of the metal, causing early failure.

V. VIBRATION MEASUREMENT TECHNIQUES

Vibration signal processing techniques and signal metrics commonly used to detect bearing defects**.** Condition monitoring using vibration measurement can be classified into time domain technique, frequency domain technique and envelope analysis.

A. Time domain technique

Signal analysis in the time domain has been used to monitor the machine conditions. However, complex signals are difficult to analyses, 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.

Root mean square

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

$$RMS(X) = \sqrt{\frac{x_i^2}{N}} \qquad (1.1)$$

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

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.

$$X = \frac{1}{N} \times \sum_{i=1}^{N} x_i \qquad (1.2)$$

Peak value

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

$$\text{Peak value} = \frac{\text{Maxi. ordinate} - \text{Mini. ordinate}}{2} \qquad (1.3)$$

Crest factor

Crest factor is the ratio of peak acceleration over RMS. This metric detects acceleration bursts even if signal RMS has not changed. However, crest factor can be counter intuitive. 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.

$$\text{Crest Factor} = \frac{\text{Peak acceleration}}{\text{RMS }(x)} \qquad (1.4)$$

Kurtosis

A good surface finish has a theoretical kurtosis of 3, and when kurtosis increases the surface finish deteriorates, the skew and kurtosis are insensitive to loads and speeds. However, the level of noise between individual readings hampered the detection of bearing damage.

$$\text{Kurtosis} = \frac{(N-1)\sum_{i=1}^{N}(Xi-x)^4}{\sum_{i=1}^{N}(Xi-x)^2} \qquad (1.5)$$

Shock pulse counting

Shock pulse counting records the number of pulses larger than a threshold value. This approach works because bearing defects generate, sharply rising impulses with amplitudes larger than noise. However, this technique does not localize the damage of the defect.

B. Frequency domain techniques

Another methode is processing the vibration signals in the frequency domain. The primary indicator is the predictable defect frequencies in the frequency domain analysis. The predictable defect frequencies depend on the rotational speed and the location of the defect in a bearing. The presence of the defect frequencies in

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the direct or processed frequency spectrum is the powerful sign of the fault. The signature of the defected bearing is spread across a large frequency band and can be simply masked with low frequency machinery vibrations and noise. The consecutive impact between the defect and rolling elements excites the resonances of the structure and the resonant frequencies dominate the frequency spectrum. Therefore, the predictable defect frequencies cannot be easily noticed because of their low amplitudes with respect to resonant amplitudes. There are three standard techniques used for monitoring the machine condition. The signal average method, cepstrum analysis, and high-frequency resonance technique.

Signal average

Signal averaging improves statistical accuracy, but it does not improve signal-to noise ratio. Signal average is used to develop an average scheme. When the vibration signature is a generalized periodic function, then spectrum analysis detects peaks at its characteristic defect frequencies.

Cepstrum analysis

This technique groups patterns of sidebands and harmonics from the spectrum into one signature.

Cepstrum detects periodicities in the spectrum while being insensitive to transmission path. The technique works well if the defect frequency signal has not been convoluted with other signals.

High- frequency resonance technique (HFRT)

The high-frequency resonance technique (HFRT) is an important signal processing technique which helps in the identification of bearing defects by extracting characteristic defect frequencies from the vibration signal of the defective bearing.

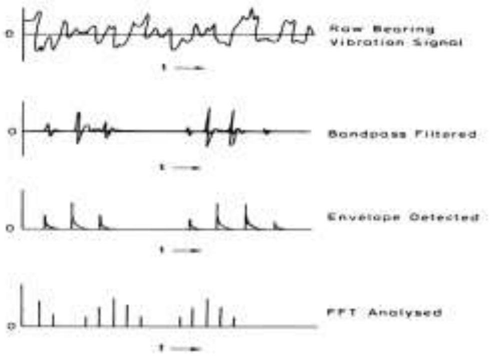

Figure2: the process of extraction of demodulated spectra by HFRT

Each time a defect strikes its mating element, a pulse of short duration is generated that excites the resonances periodically at the characteristic frequency related to the defect location. The resonances are thus amplitude modulated at the characteristic defect frequency. By demodulating one of these resonances, a signal indicative of the bearing condition can be analysis. In practice, the signal is band-pass filtered around one of the resonant frequencies, thus eliminating most of the unwanted vibration signals from other sources. This band- pass filtered signal is then demodulated by an envelope detector in which the signal is rectified and smoothed by low-pass filtering to eliminate the carrier or band-pass filtered resonant frequency. The spectrum of the envelope signal in the low- frequency range is then obtained to get the characteristic defect frequency of the bearing. The process of extraction of demodulated spectra by the high-frequency resonance technique is showing Fig. 2

C. Envelope Analysis

The envelope detection process is the heart of the HFRT diagnostic system. An accelerometer signal entering the envelope detector may be either attenuated or pre amplified. The resulting signal is then sent through a band pass filter set for an appropriate carrier frequency. The filtered signal is then rectified and demodulated in order to extract the envelope of the modulated carrier frequency signal. This envelope is then analyzed for frequency content using a real-time frequency spectrum analyzer. The energy levels of amplitude of the defect frequencies, as it appears in the spectrum, can be used to diagnose the condition of the rolling element bearing.

Fundamental of Envelope analysis is concept that each time localized defect in rolling element bearing make contact under load with another surface in the bearing, an impulse of vibration is generated. This impulse will have an extremely short duration compared to interval between impulses and so its energy will be distributed across a very wide frequency range. The result is that various resonances of bearing and the surrounding structure will be excited by the impacts. The excitation is normally repetitive because contacts between the defect and mating surfaces in the bearing essentially periodic. The frequency of occurrence of the impulses is referred to as the characteristic bearing defect frequencies. It is usual to consider the resonance as being amplitude modulated at the characteristic defect frequency which makes it possible not only to detect the presence of defect by excitation of

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resonance but also to diagnose component of the bearing. Envelope analysis provides the mechanism for extracting out the periodic excitation or amplitude modulation of the resonance.

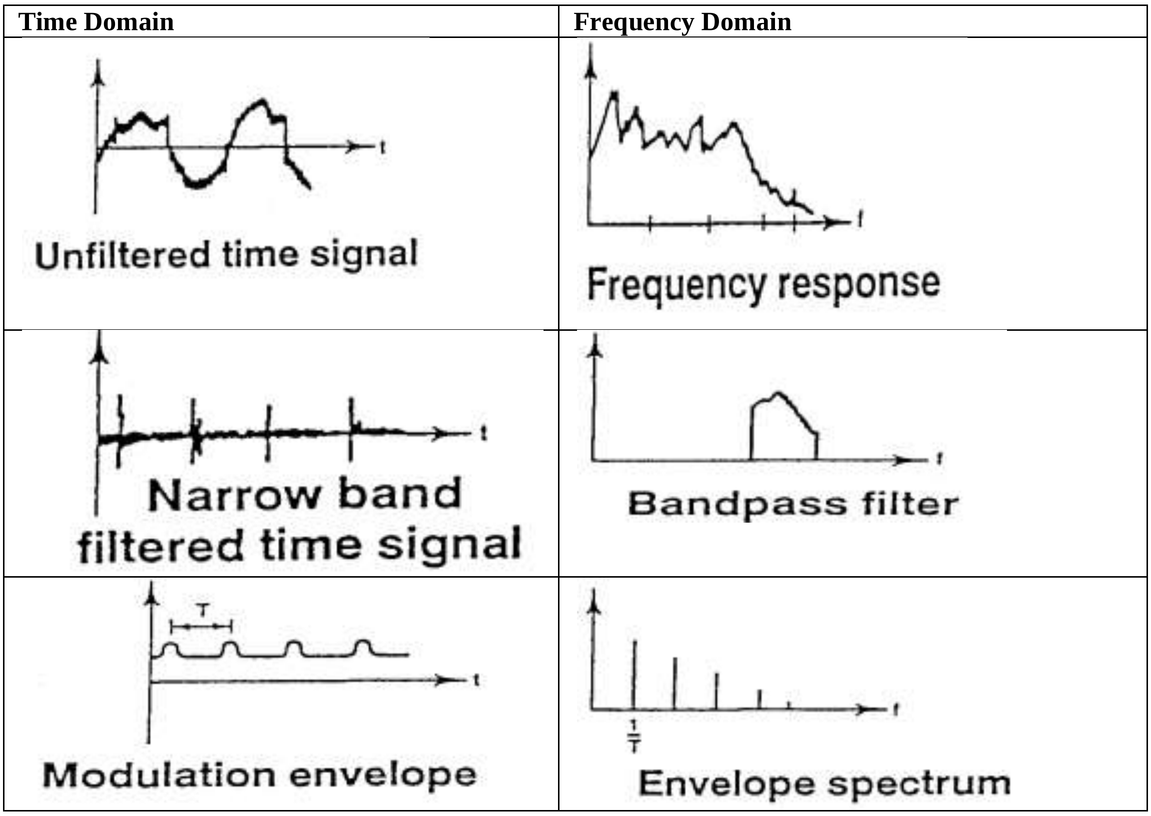

Figure3: Principal of analogue enveloping

VI. CONCLUSION

In review paper for fault detection technique in rolling element bearing, we covered rolling element bearing terminology, 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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