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Fault Diagnosis of Ball Bearing using Time Domain Analysis and Fast Fourier Transformation

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Abstract

In this study Fault diagnosis of Ball bearings is done by statistical analysis under various time domain parameters. The objective of this study is to investigate the correlation between time domain and frequency domain analysis of vibration signature to judge and find the fault in bearing. This is achieved by vibration analysis and investigating different time domain parameter like Kurtosis, Skewness, Crest factor, RMS Value. For this purpose the bearing is coupled to the motor and observation were taken at 810 rpm. Vibration of the bearing are converted in voltage signal (milivolt) using an accelerometer/piezoelectric transducer. The bearing is taken under two different conditions viz Healthy (normal bearing) and Faulty (defected outer race bearing) with the aim of fault detection. Vibration data of healthy bearing are used as a standard for the analysis of vibration spectra of faulty bearing. Vibration signals are analyzed through different operations performed in MATLAB software. The result shows that the statistical analysis through different time domain parameters and its fast Fourier transformation provides efficient representation of fault detection in rolling element bearings. So as an initial stage if we find kurtosis and skewness values it can predict a fault. And if we get higher values of time domain parameters then only it needs to go for its frequency domain analysis. In this paper we also get exact fault position for defective bearing by its frequency domain analysis.

Keywords- Rolling Element Bearing, Bearing Fault, Vibration signatures, Fault Diagnosis.

Introduction

Every rotating machine has the possibility of failure after long period of working. This failure is mainly occurs due to wear in its different parts which converts in some form of vibration at which causes the failure. Every machine requires some maintenance throughout its life to prevent shutdown. Condition monitoring is a technique in which we monitor the condition of machine every time and give it required maintenance. Ball bearing is one of the essential elements of the rotating machinery and one of the important issues in Ball bearing application is the reduction of noise and vibration originating from these bearings. Proper functioning of bearings is most important in nuclear power stations, chemical plants, aviation industries and also process industries. A large survey on faults in the electric motor was carried out by Electric Power Research Institute (EPRI) in 1985 and found that 41% of faults related to worn motor bearings [1]. These bearings generate vibrations during operation even if they are geometrically and elastically perfect. Hence the bearing is the machine component in rotary system those are particularly prone to failures due to uninterrupted operation, heavy load, harsh working conditions etc. So by monitoring the health of a bearing we can prevent any big failure. Therefore detection of these defects and online monitoring of their health condition is important for condition monitoring and fault diagnosis. The aim of this study is to investigate the correlation between vibration analysis and fault diagnosis in a rolling element bearing.

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Description of the Experimental Setup used

Table1 : Specification of the Experimental SetUp

S. No.	Component	Dimensions (mm)
1.	Diameter of shaft	20
2.	Bearing type	Ball Bearing
3.	Outside Diameter (D)	52
4.	Bore Diameter (d)	25
5.	IR width (B)	34
6.	Weight	.21(kg)
7.	Cage	Steel
8.	Heavy Mild Steel basement	Better stability
10.	Motor	2.1A/230V/1500 rpm

Figure 1: Experimental Setup

Analysis of bearing vibration Signature

First the time versus amplitude data of berating in its running condition is collected . For this purpose an accelerometer is used as a collector device to convert the mechanical signal into an electrical signal. Matlab is a software that helps to collect data in the Computer dadtabase. Then this data is represented in the form of time domain signal (Vibration Siganture).The whole procedure was dome at 810 rpm.

Figure 2(a) Healthy Bearing

Figure2(b) Faulty Bearing

The vibration signatures of both the healthy & the faulty Bearing obtained in time domain are:

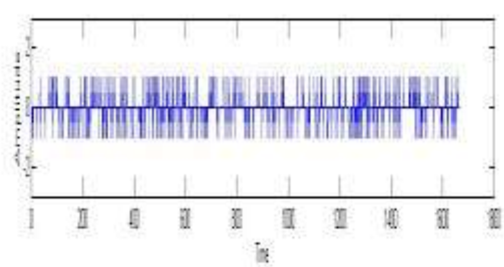

Figure 3: Vibration Signature of the Healthy Bearing in Time Domain

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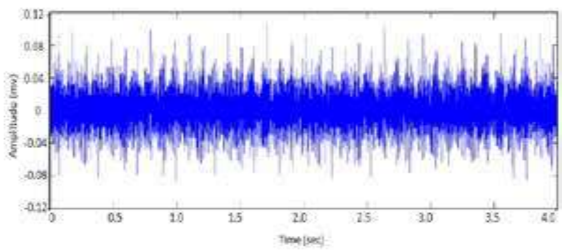

Figure 4:Vibration Signature of the Faulty Bearing in Time Domain

As it is very difficult to compare figure 3 & 4 in time domain therefore this signal is converted in frequency domain.

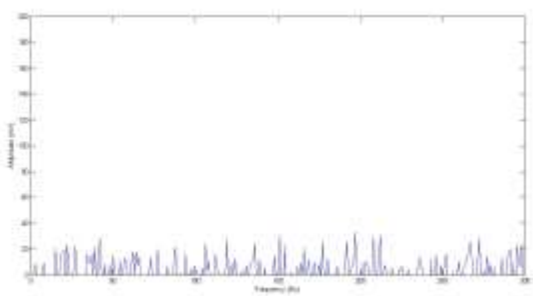

Figure 5: Vibration Signature of the Healthy Bearing in Frequency Domain

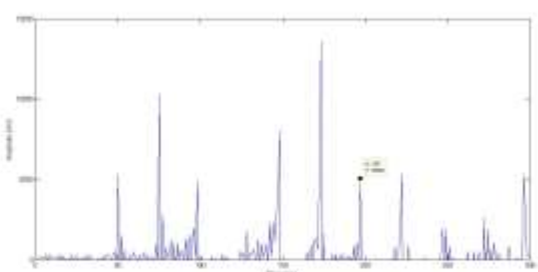

Figure 6: Vibration Signature of the Faulty Bearing in Frequency Domain

Statistical parameter

In the field of fault diagnosis, statistical feature parameters calculated from the signals are normally used to identify the machinery condition because they express information indicated by a signal measured for diagnostic purposes. Statistical feature parameters are 'RMS' value, the 'skewness', the Kurtosis, the crest factor (CF) and the shape factor (SF). These indicators are mathematically expressed as follows:

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

$$\text{Kurtosis} = \frac{\frac{1}{N}\sum_{n=1}^{N}[y(n)-y]^4}{\sigma^4} \qquad (2)$$

$$\text{skewness} = \frac{\frac{1}{N}\sum_{n=1}^{N}[y(n)-y]^3}{\sigma^3} \qquad (3)$$

$$\text{crest factor} = \frac{\max(|y(n)|)}{\text{RMS}} \qquad (4)$$

$$\text{shape factor} = \frac{\text{RMS}}{y} \qquad (5)$$

The root mean square (RMS) value and crest factor have been applied in diagnosing bearings and gears [2].The RMS of a vibration signal is a time analysis feature that measures the power content in the vibration signature. This feature can be very effective when detecting an imbalance in rotating machinery. The most basic approach to measuring defects in the time domain is to use the RMS approach which is often not sensitive enough to detecting incipient faults in particular. Another measure is to use the "crest factor" defined as the ratio of the peak value of the input signal to the RMS value. Hence, peaks in the time domain signal will result in an increase in the crest factor. This characteristic is used to detect changes in the signal pattern due to impulsive vibration sources such as tooth breakage on a gear or a defect on the outer race of a bearing. Kurtosis is a statistical parameter used to characterize a signal. In essence it gives a measure of the "peakedness" of a random signal. Signals that have a greater kurtosis value have more peaks that are greater than three-sigma; these are, peaks that are greater than three times the RMS value of the signal. In the real world different types of vibration environments are characterized by signals that have high kurtosis value. The statistical parameter kurtosis represent a very good indicator for the analysis of damage in low speed machineries with no continuous shocks. The kurtosis is the result of a mathematical algorithm on the fixed frequency band of the time signal. It describe the impulsive shape of the time signal [3]. Without impulsive phenomena in time signal, vibration measurements on good bearings give kurtosis values close to 3. As bearing damage develops, with the generation of impulsive oscillation bursts, kurtosis values rise, and it can reach the value of 50 with an impulse or shocks.The Skewness of a distribution is defined as the lack of symmetry. Skewness is a measure of symmetry distribution and

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it characterizes the degree of asymmetry of a distribution around its mean. A distribution or a dataset is regarded to be symmetrical if it is equal at the top and bottom around the center point. Skewness is a common parameter when analyzing dynamic signal. Apparently the Skewness is a dimensionless measures, and it measures to what degree the signal is non symmetric around it's mean. If the signal is symmetric , the Skewness is zero. For many vibration signals the probability distribution is symmetric around the mean such as normal distribution. Thus Skewness differing from zero in many cases indicates that something is wrong.

FFT

Fast Fourier Transform is used in conventional frequency domain signature analysis techniques for conversion of time domain signal in frequency domain signal. Vibration signal of rotating parts are analyzed either using time domain characteristics or the frequency domain characteristics. The different component of a machine vibrate at one or more discrete frequencies; different malfunctions cause vibrations at different discrete frequencies. The combination of these different discrete frequency vibration result in the complex vibration waveform at the measurement point. The measured signal is therefore analyzed by reducing to its discrete frequency components. Fast Fourier Transform is the commonly used analysis method for bearing fault because each fault represent itself at particular frequency or in other words all the coefficient amplitudes present in the FFT spectrum is the representation of one or other fault with severity depends upon the relative values of amplitude. Bearing element rotation generates vibrational excitation at a series of discrete frequencies which are a function of the bearing geometry and the rotational speed. These are the frequencies which provide information about condition of inner race, outer race, rolling element of the bearing element. There are five basic motions that can be used to describe dynamics of bearing movements. Each motion generates unique frequencies, the five characteristics frequencies. Regardless of the type (ball, cylindrical, spherical, tapered or needle), rolling element bearing consist of an inner and outer race separated by the rolling elements which are held in the cage. Defect may develop in any of these components. When the bearing rotates, each type of defect generates a vibration component of a particular frequency. By identifying the bearing characteristic frequency, the cause of defect can be determined. These characteristic frequencies are in same range as the low frequency vibration (0-2 kHz) caused by the normal operation of the machine. The bearing Characteristic or defect frequencies are: ball pass frequency outer race (BPFO), Ball pass frequency inner race(BPFI), Ball/Roller spin frequency(BSF) and fundamental train frequency/cage frequency (FTF). These frequencies depend on the bearing characteristics and are calculated according to the relations as shown below-

Shaft rotational frequency (fs)-

$$(fs) = \frac{Nr}{60}$$

Ball pass frequency outer race (BPFO)-

$$BPFO = \left(\frac{n}{2}\right)\left(\frac{Nr}{60}\right)[1 - (\frac{d}{D})\cos\theta]$$

Ball pass frequency inner race(BPFI)-

$$BPFI = \left(\frac{n}{2}\right)\left(\frac{Nr}{60}\right)[1 - (\frac{d}{D})\cos\theta]$$

Ball spin frequency/Rolling element Frequency (BSF)-

$$BSF = (\frac{D}{2d})\left(\frac{Nr}{60}\right)[1 - (\frac{d}{D})\cos\theta^2]$$

Fundamental Train frequency (FTF)/Cage Frequency-

$$FTF = (\frac{1}{2})\left(\frac{Nr}{60}\right)[1 - (\frac{d}{D})\cos\theta]$$

Where,

d = Roller/ball diameter
D = Pitch diameter
n = number of roller/rolling element
θ = angle of contact
Nr = rotational speed (rpm)

The bearings, when defective, present characteristic frequencies depending on the localization of the defect. Defects in rolling bearings can be foreseen by be the analysis of vibrations, detecting spectral components with the frequencies (and their harmonics) typical for the fault. There are five Characteristic frequencies at which faults can occur. They are the shaft rotational frequency fs, fundamental train/cage frequency FTF, ball pass Frequency inner race BPFI, ball pass frequency outer race BPFO, and the ball spin frequency BSF. The characteristic fault frequencies, for a bearing with stationary outer race, can be calculated by the above described formulas. Fundamental defect frequencies depend upon the bearing geometry and shaft speed. Once we identify the type of bearing installed we can calculate the defect frequency ourselves. There is also a bearing database available in the form of

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commercial software that readily provides the value upon entering the requisite bearing number. There will be occasions when the calculated defect frequencies do not exactly match the bearing defect frequencies that appear on the vibration spectra. This is due to higher than normal thrust loads which cause the bearings to run at a different contact angle. These abnormal thrust loads can be caused by sources such as misalignment. Also not all bearing manufacturers use the same number of rolling element in a particular bearing size. The most common bearing problem is the outer race defect then inner race faults are the next most common. It is very rare to see a fault at the bearings ball spin frequency or BSF.

Results and discussion

The data collection in the form of its time amplitude values are done at 810 rpm.

Following results are observed-

1. From Time Domain Analysis:

	Healthy Bearing	Faulty Bearing
Kurtosis	3.48	9.8
Skewness	0.03	0.46

2. From Frequency Domain Analysis:

Frequency versus amplitude graph shows some frequencies at 49, 99, 149 Hz. This frequencies matches with the outer race frequency of bearing.

Conclusion

In this paper it is concluded that the time domain and its statistical analysis only predict the fault. We can never say about the fault origin with the help of time domain analysis. But the frequency domain analysis gives the fault position accurately. In this paper both time and frequency domain were analysed for fault . We find that for healthy signal we got kurtosis value from 3 to 5 and in its frequency domain we didn’t get any remarkable pick at working frequencies. But as the kurtosis value increases we get substantial pick in the frequency domain for different bearing frequencies.

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