Condition Monitoring of Deep Groove Ball Bearing using FFT Analyzer

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Abstrac t- **Rolling element bearings are one of the major machinery components used in industries like power plants, chemical plants and automotive industries that require precise and efficient performance.Bearing failure occurs due to heavy dynamic loads and also contacts forces which exist between the bearing components, study of vibrations plays an important role in condition monitoring of the ball bearing/machinery. Unfortunatelywe cannot observe that defects by naked eyes in initial stage of failure. But when these faults are increased to large amount, they will leads to severe damage so it is very necessary to detect faults in bearing at an earlier stage.FFT analyzer can helps to detects in various components without disturbing setting of that component. Condition monitoring of bearings is important to avoid severe failures. Vibration analysis gets much advantage in factories as a predictive maintenance technique. In presented paper vibration response of non-defective bearing has taken and then purposefully various defects various component of bearings have made. It shows that every defect excites the system at its characteristic frequency. The location of the faults is indicated by the FFT Frequency domain spectrum. Also Signature analysis of bearing to observe unbalance, misalignment with increase in speed has done.**

Index Terms: FFT analyzer, Condition monitoring, Envelop analysis, Fault detection.

1. INTRODUCTION

In any manufacturing or processing plant where rotating equipment is used, the majority of the Maintenance capital expenditure is spent on bearings. Every time an overhaul is performed, salesmen from the major bearing manufacturing make it their business to ensure that the bearings are replaced. Whatever the reason which caused the machine to break down, nine time out of ten times the bearings are replaced, and are indeed very often blamed for the machine breakdown. However, the bearing failure is a result of a number of different problems: a machine running unbalanced, misaligned, at a critical speed; a bearing fitted incorrectly; the wrong grease being used; or maybe no grease being used at all. [1]

A vibration-based method to detect and identify bearing damage is more common due to the ease in measurement, and the measured data can then be further processed in the time domain, frequency domain and time-frequency domain to extract useful information that can be related to the severity and type of bearing damage [4]. For medium scale industry annual maintenance cost is 2 to 3 corers. If equipments are not maintained properly then breakdown occurs which results in different losses as production loss, loss due to accidents, parts replacement loss etc. Cost of these losses is more than 3 corers.

Vibration monitoring is generally the key component of most condition based maintenance programmes. Maintenance programmed must include other monitoring and diagnostic techniques. These techniques include: Vibration analysis, Corrosion analysis, Lubricant analysis, Process parameter monitoring, visual inspections. [2]

2. CONDITION MONITORING OF BALL BEARINGS

Faults in rolling bearings may occur prematurely as a consequence of operating the bearing under in appropriate loading conditions (including misalignment) and at excessive speeds. Alternatively they may be produced simply as part of the normal wear process during the life of the bearing. Traditionally machines with rolling element bearings would have their bearings renewed regularly, as part of the normal maintenance schedule, irrespective of their wear. This would be done in an effort to avoid a bearing failure at a later time, which would necessitate machine stoppage, at an inconvenience (and more costly) moment. The growing trend, however, is to monitor the condition of rolling element bearings continually so that bearing wear may be detected at an early stage, and enables the engineer to ensure that the bearing is replaced at a convenient time before the bearing fails completely.

Defects in the bearing may develop on either raceway, on the rolling elements themselves, or on the cage; subsequent vibrations are forced as a consequence of impact between the fault and other bearing components, so that the frequency of the resulting vibrations is largely dependent on the frequency of impacting. These frequencies are also called as characteristic frequency and can be calculated using following formulae's.

Outer race frequency$= \frac{n}{2} \frac{N}{60} \left(1 - \frac{d}{D} \cos \alpha\right)$

Inner race frequency$= \frac{n}{2} \frac{N}{60} \left(1 + \frac{d}{D} \cos \alpha\right)$

Rolling element frequency $= \frac{D}{d} \frac{N}{60} \left[1 - \left(\frac{d}{D}\right)^2 \cos^2 \alpha\right]$

Case frequency$= \frac{N}{120} \left[1 - \frac{d}{D} \cos \alpha\right]$

Where N=Shaft Speed in RPM

α =The contact angle,

n=the number of rolling elements

Whilst the characteristic frequencies can be easily calculated, the process of diagnosing a fault can be complicated by a number of factors. Some of the characteristics frequencies may be very close to harmonics of rotational speed; as wear of the bearing progresses the frequency spectrum changes further. Sometimes higher-order harmonics of the defect frequency become present, sometimes with their own sidebands, and can dominate the spectrum. In addition, wear particles are transported around the bearing and accelerate the development of further defects at other locations, leading to high level of vibration at many frequencies so that peaks which are characteristic of particular defect difficult to distinguish. A most important feature of condition monitoring of bearings (and rotating machinery in general), is the collection of 'baseline' reference measurements of vibration taken when the machine is first commissioned (or re-commissioned after overhaul). It is only when the engineer is in possession of these that a confident diagnosis of a significance and cause of peaks in the vibration spectrum can be made. Micro-irregularity on bearing contacting surface gives very high frequency components in the response.[5]

So it is highly unreliable to do vibration analysis of bearing for location of fault detection by only the frequency domain analysis, we should do it by time domain analysis also to crosscheck the results obtained by frequency domain analysis and vice-versa.

Generally speaking, the process of the roller bearing fault diagnosis consists of three steps:

(1) The collection of the roller bearing fault

Vibration signal

(2) The extraction of the fault features

(3) Condition identification and fault diagnosis.

3.FFT ANALYSER

An FFT spectrum analyzer works in an entirely different way. The input signal is digitized at a high sampling rate, similar to a digitizing oscilloscope. The resulting digital time record is then mathematically transformed into a frequency spectrum using an algorithm known as the Fast Fourier Transform or FFT. The FFT is simply a clever set of operations which implements Fourier's basic theorem. The resulting spectrum shows the frequency components of the input signal. Now here's the interesting part. The original digital time record comes from discrete samples taken at the sampling rate [2].

Fourier's basic theorem states that any waveform in the time domain can be represented by the weighted sum of pure sine waves of all frequencies. If the signal in the time domain (as viewed on an oscilloscope) is periodic,

then its spectrum is probably dominated by a single frequency component. What the spectrum analyzer does is represent the time domain signal by its component frequencies. [3]

4. EXPERIMENTAL SETUP

4.1Test Rig

The fully assembled test rig as shown in figure 4.1 is initially placed with the AC three phase induction motor of Crompton Greaves having the maximum speed of 1500 rpm and 0.5 HP. It is connected with the coupling having rubber bushes to avoid vibrations and shaft is joined and extended to 1meter and having a diameter of 20mm horizontally the power is transmitted. There are 2 disc of 15 Newton each and is inserted in shaft to achieve no load readings. Furthermore, two deep groove ball bearings are inserted in the shaft which is supported with the self manufactured Split type housing, to minimize the efforts in mounting and dismounting of bearing. Moreover, the opposite side of shaft that is to which the pulley is connected to the dynamometer which is connected with the help of B-22 belt size.
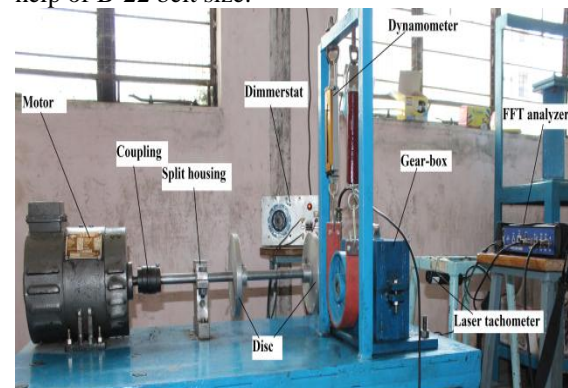

Figure 4.1 Experimental setup

4.2 Instrumentation:

Vibration signal from the tri axial accelerometer (figure 4.4) of sensitivity 5mV/g mounted on housing was passed to Fast Fourier Transform; the speed of the shaft is calculated by the laser Tachometer (figure 4.3). Fast Fourier Transform Adash VA4-PRO 4400(figure 4.2) is used for achieving desired graphs and results were of Time Domain and Frequency Domain. The readings and graphs of FFT were analyzed with the DDS software installed in PC.[1]

Figure 4.2 FFT analyser

Figure 4.3 Laser tachometer

Figure 4.4 Accelerometer

4.3 Measurement Condition:

The analysis of the vibrations was conducted on the various speeds of the motor that is 500, 750, 1000, 1250, 1500 rpm. From two of the bearing, the one nearest to the motor is kept unchanged that is good bearing and the other bearing placed forward was changed various times according to the defects taken(on inner race, outer race, ball) also the combination has been done(two defects on outer race, one outer race and one inner race). The different velocity and frequency graphs were obtained by making combinations of bearing and speeds.Defects are as shown in following figures

Figure 4.5 Outer race defect (0.8 mm hole)

Figure 4.6 Outer race defect (0.8 mm hole)
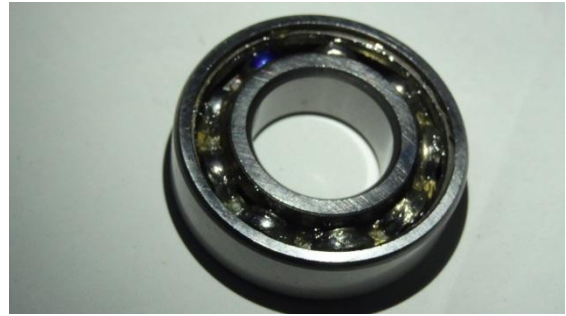
Figure 4.7 Ball defect (0.5 mm)

Figure 4.8 Inner-outer defects(0.8 mm holes)

Figure 4.9Two-outer race defects at 90 degree (0.8 mm holes)

5. FREQUENCYDOMAIN ANALYSIS

The Frequency domain refers to the treatment of signals expressed as a function of frequency using the time domain signal. Whiles certain information is more easily interpreted in the time domain, the most detailed analysis of rotating machinery .vibration data is often conducted in the frequency domain. Frequency-domain or spectral analysis of the vibration signal is perhaps the most widely used approach for bearing defect detection. It is often the case that signature spectral comparisons are not suitable for detecting damage to rolling element bearings. This is because the energy produced by the bearing defect is overpowered by more dominant signals from other rotating elements, nearby machinery and noise. For this reason, envelop detection is a commonly used signal processing technique for detecting incipient defects in rolling element bearings. This technique involves a high-pass filtering operation to eliminate dominating low frequency components from the original signal. This signal is then rectified, demodulated, and a low-pass filter is finally used to eliminate the carrier high frequency. The processed signal is then displayed in the frequency spectrum showing the isolated bearing defect frequencies. [1]

$$S_x(f) = \int\limits_{-\infty}^{+\infty} x(t)e^{-i2\pi ft}\,dt$$

$$x(t) = \int\limits_{-\infty}^{+\infty} S_x(f)\,e^{-i2\pi ft}\,df$$

This is called basic Fourier transform.

There are two types of frequency analysis

1.Envelope spectrum analysis.

2. Velocity spectrum analysis.

6. ENVELOPE SPECTRUM ANALYSIS

Envelope analysis is the method used to disclose the bearing condition information hidden in high energy resonance bands. This is done by describing the two main components in an envelope analysis: band limiting the signal to the resonance band by means of a band-pass filter and enveloping this band limited signal in order to obtain the frequency of the periodic mechanical impacts caused by the bearing fault.

Following spectrums shows envelope spectrums of different bearings obtained at different RPMs

ENVELOPE SPECTRUM ANALYSIS AT 1500 RPM
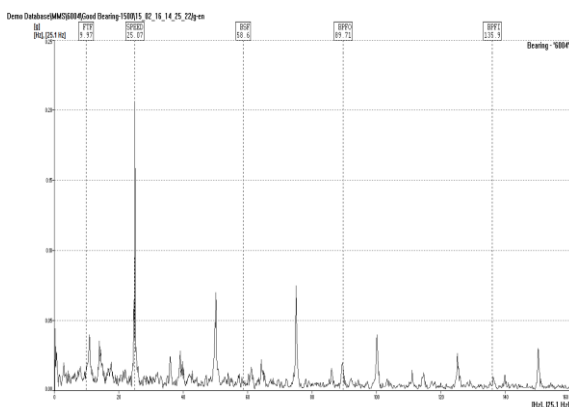
Figure 6.1 Non-Defective bearing

From above spectrum we can see that there is no any peak in the range of bearing characteristic fre frequencies.so we can easily conclude that there is no any kind of defect available in this bearing.
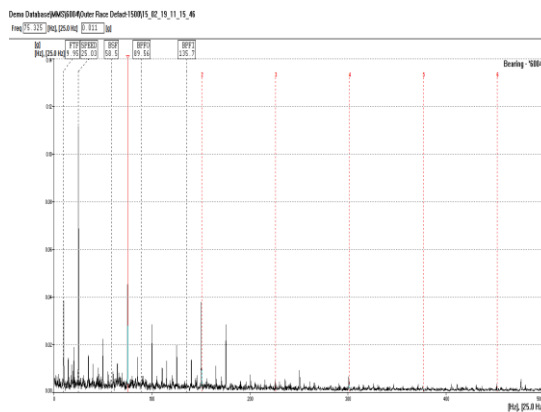
Figure 6.2 Defective Outer race bearing spectrum

From above spectrum we can see that there is peak at 85Hz which is just near to outer race characteristic frequency 89Hz,and its harmonics are also repeating marked as the numbers 1,2,3 ,4….so we can clearly conclude that there is outer race defect in above mentioned bearing.
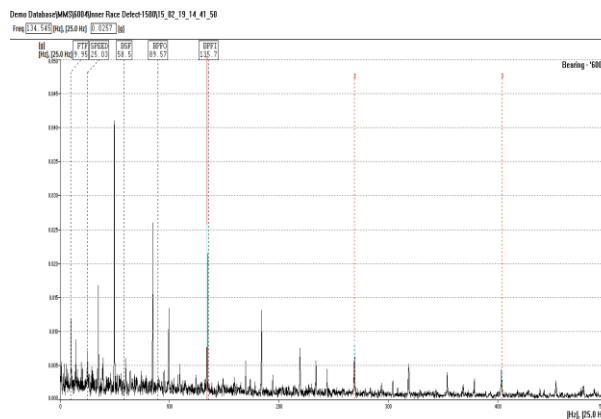

Figure 6.3 Defective Inner race spectrum

From above spectrum we can easily identify that there is peak in frequency spectrum at 135 Hz which is the inner race characteristic frequency and its harmonics are also repeating as shown by numbers 1,2,3…. ,so we can conclude that there is defect in inner race of above mentioned bearing.
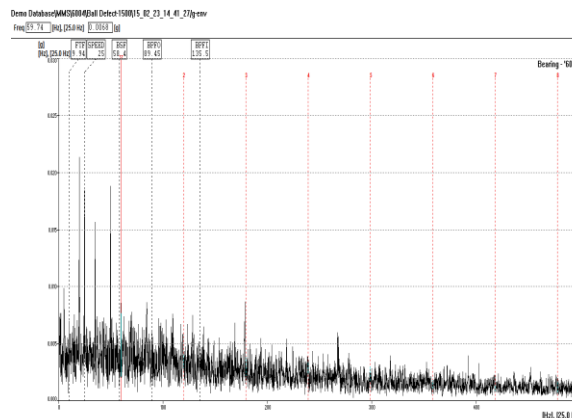

Figure 6.4 Defective Ball Spectrum

From above spectrum we can easily identify clearly that there is peak in frequency spectrum at 59 Hz which is just near to the defective ball characteristic frequency 58.4Hz and its harmonics are also repeating as shown by the numbers 1,2,3…. ,so we can conclude that there is defect in ball of above mentioned bearing. As its peak is not as high as others conclude also that there is minor defect in ball as compare to other defects.

7.VELOCITYSPECTRUM ANALYSIS

This is one of the frequency domain analysis in which we are plotting the velocity v/s frequency graphs obtained by FFT transformer. 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 f_s, fundamental train or cage frequency FTF;balls 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.

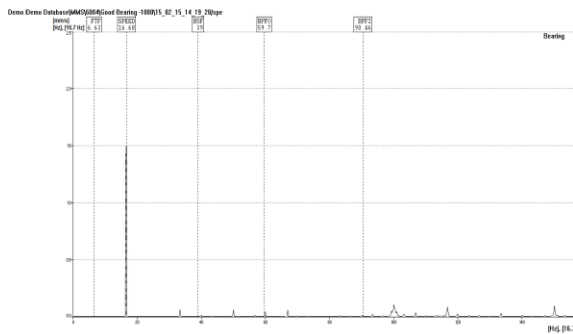*Velocity spectrum analysis at 1000 RPM*

Figure 7.1 Velocity v/s frequency spectrum for Good Bearing

From above spectrum we can see that there is no any peak in the range of bearing characteristic fre frequencies.so we can easily conclude that there is no any kind of defect available in this bearing.
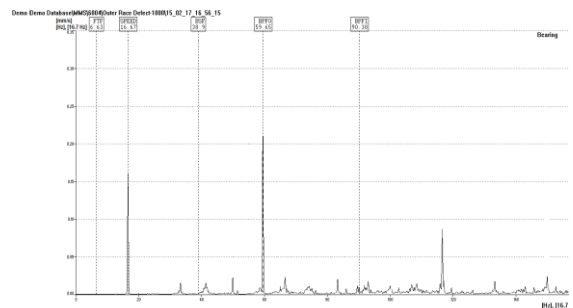

Figure 7.2 Velocity v/s frequency spectrum for defective outer race Bearing

From above spectrum we can see that there is peak at 60Hz which outer race characteristic frequency, and its 2nd harmonics is also repeating, so we can clearly conclude that there is outer race defect in above mentioned bearing.
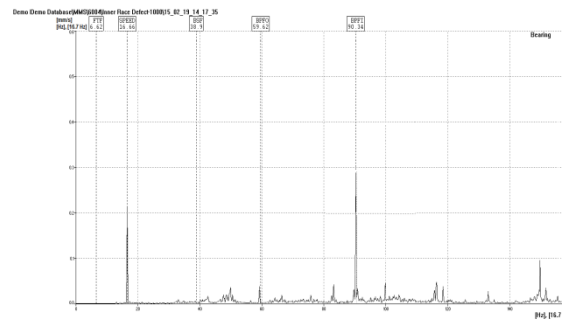

Figure 7.3 Velocity v/s frequency spectrum for defective inner race bearing.

From above spectrum we can easily identify that there is peak in frequency spectrum at 90 Hz which is the inner race characteristic frequency, so we can conclude that there is defect in inner race of bearing under consideration.
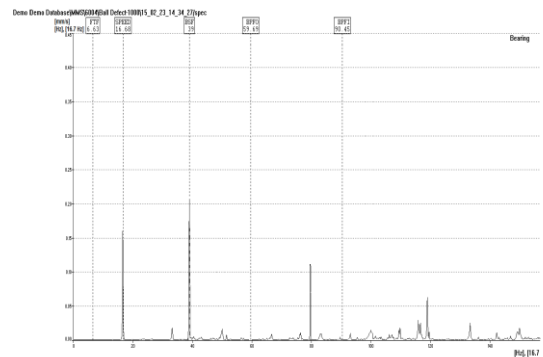

Figure 7.4 Velocity v/s frequency spectrum for ball defect in bearing.

From above spectrum we can easily identify clearly that there is peak in frequency spectrum at 40 Hz which is just near to the defective ball characteristic frequency 39Hz and its next harmonics are also repeating so we can conclude that there is defect in ball of above mentioned bearing. As its peak is not as high as others conclude also that there is minor defect in ball as compare to other defects.

8. SIGNATURE ANALYSIS

Condition monitoring of machine implies the determination of condition of machine and its change with time. The condition of machines may be determined by measuring physical parameters like Vibration, Noise, Temperature, Wear etc.Change in these parameters called as signatures. Signature indicates change in machine condition.

If f = vibration frequency [cycles/min] or [Hz]

n = Bearing rotation speed [rpm]

There are different causes of vibration as below

A. When f = n

1. Unbalances in rotating bodies - Intensity
Proportional to unbalance, mainly in the radial
Direction, increases with speed.
2. Eccentricity in pulleys, gears- When the rotation
Axis does not coincide with the geometricaxis

B. When f = 2n
Misalignment - There is strong axial vibration.
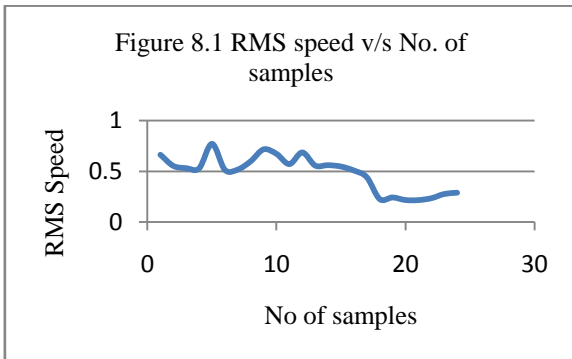**C. When f = n/2**

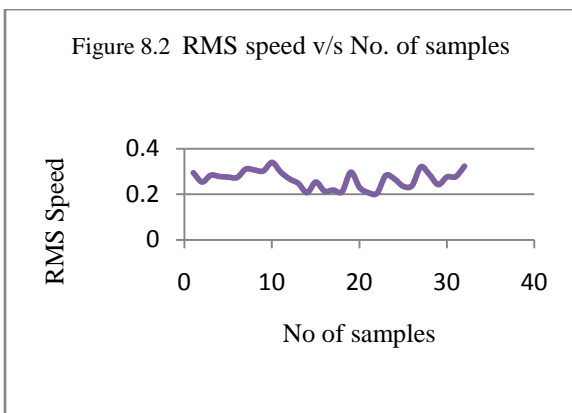Mechanical weakness in rotor- This is a sub-harmonic, often present but hardly ever important.

When f= n,2n,3n…….
Mechanical looseness- Loose bolts, excessive play in the mobile parts and bearings, cracksand breaks in the structure: there are upper grade sub-harmonics.
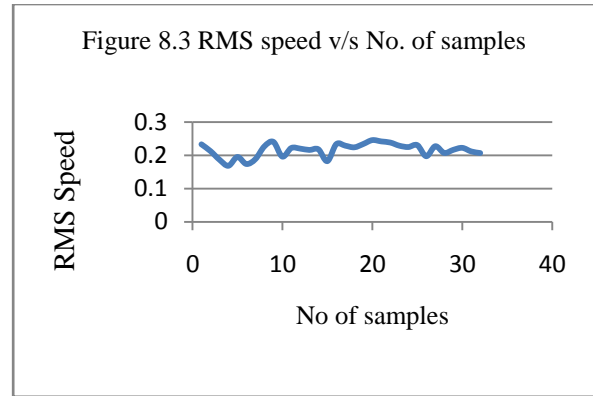 **RMS speed V/S no. of samplesat 500 RPM**
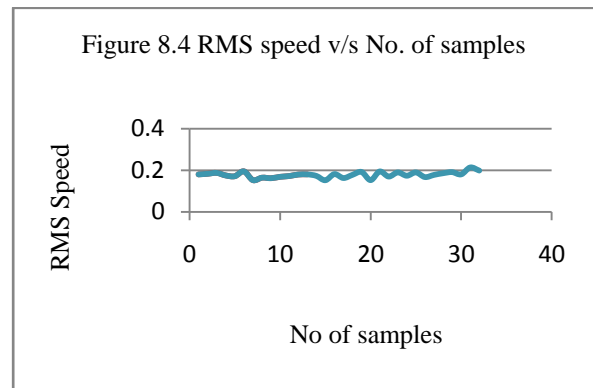
a. Good Bearing

Figure 8.1 RMS speed v/s No. of samples

b. Defective Outer Race

Figure 8.2 RMS speed v/s No. of samples

c. Defective Inner Race:

Figure 8.3 RMS speed v/s No. of samples

d. Defective Ball:



Figure 8.4 RMS speed v/s No. of samples
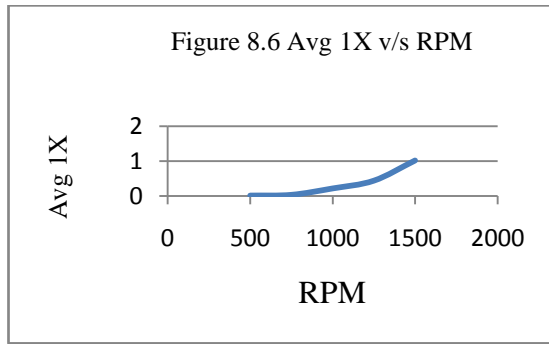
RESULT AND DISCUSSION:

From above graphs we can observe that at same speed the RMS values of velocity are changing due to fluctuation in loads caused by vibrations or some other factors like unbalance, misalignment etc. so we can conclude that for condition monitoring of any bearing, whether it is non-defective or defective at any shaft speed, we can't do condition monitoring perfectly with just one reading. Instead of it we should take number of reading based on accuracy of component such as dimmerstat and other unknown disturbing parameters such as unbalancing, misalignment etc. and then we have to normalize these values to get proper result.
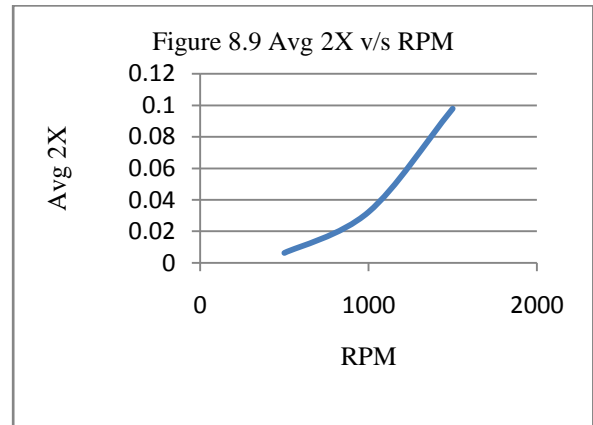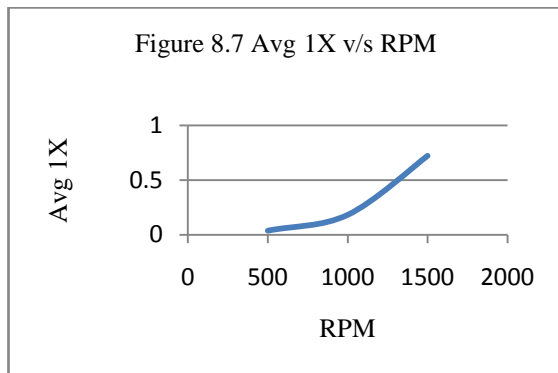
8.2 Avg 1X&RPM
a. Outer race defect

Figure 8.5 Avg 1X v/s RPM
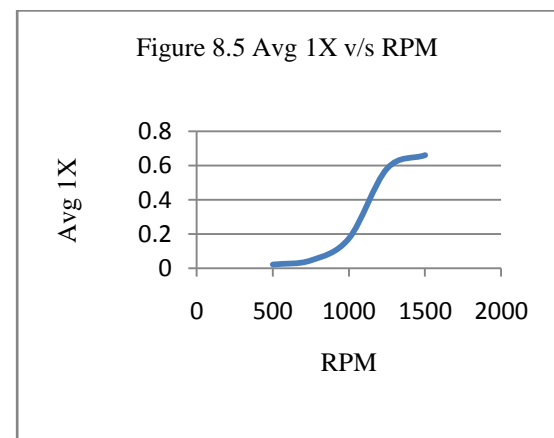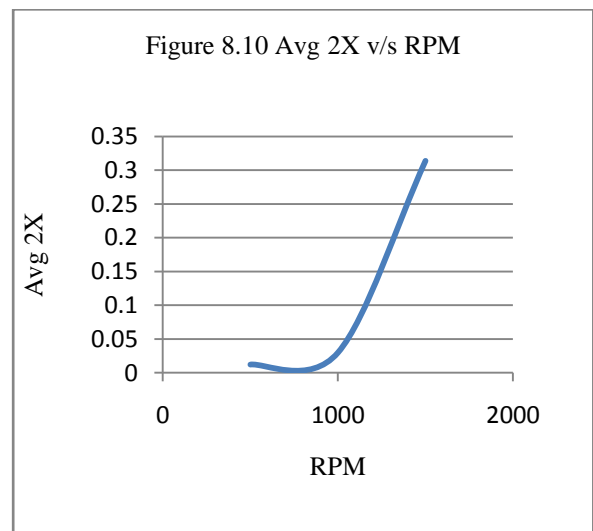
b. Inner race defect

Figure 8.6 Avg 1X v/s RPM

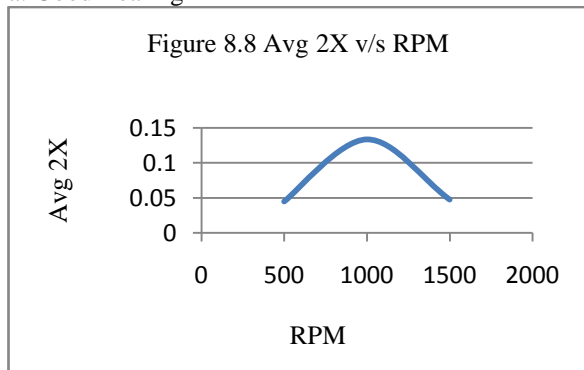d. Ball-Defect

Figure 8.7 Avg 1X v/s RPM
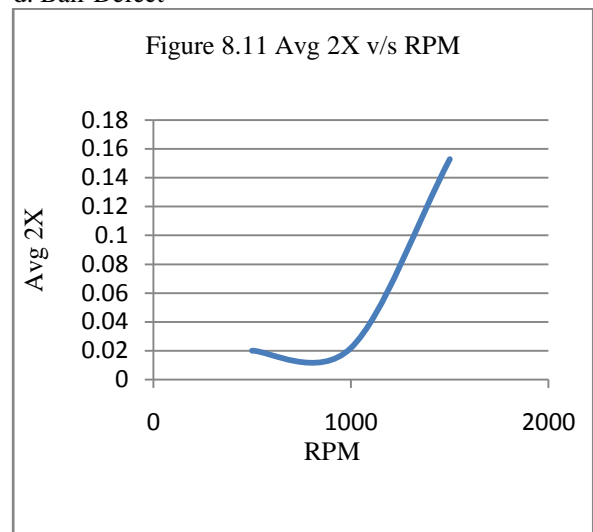
RESULT AND DISCUSSION:

From above graphs we can observe that as speed increases, 1X value also increases .But 1X value represent the unbalance in system so we can conclude that as speed increases for any bearing whether it is defective or non-defective , unbalance in system also increases.

8.3 Avg. 2X&speed

a. Good Bearing

Figure 8.8 Avg 2X v/s RPM

b. Outer race defect

Figure 8.9 Avg 2X v/s RPM

c. Inner-race defect

Figure 8.10 Avg 2X v/s RPM

d. Ball-Defect

Figure 8.11 Avg 2X v/s RPM

8.3.1 RESULT AND DISCUSSION:

From above graphs we can observe that excluding good bearing, in all defective bearings value of 2X increases as speed increases. But as 2X value corresponds to misalignment, Misalignment in the systems increases with increase in speed for defective bearings. For good bearing misalignment decreases at higher speeds. So for good bearing,at higher speed misalignment decrease.

CONCLUSION

Velocity spectrum analysis is the effective tool for finding location of defect in ball bearing, also as radial load on bearing increases, the amplitude of the vibration increases. So by applying heavy loads we can easily find location of defect in ball bearing as compare to light loads. Envelope analysis is also the very useful tool for detection of location of defect in ball bearing. So the signature analysis is very useful tool for observing the change in vibration parameters like RMS velocity, 1X, 2X etc. with time. This analysis not useful to find location of defect in ball bearing. It'suseful to find state of bearing whether it is defective or non-defective.

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