Investigation of Spherical Roller Bearing and Deep Groove Ball Bearings with Various Defects Using Fft Analyser and Matlab Simulation

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Abstract

The bearing is very essential component in any mechanism. It is always running under high speed and high load conations. Failures in bearings often results in lengthy industrial downtime that has economic consequences. Prompt diagnostics of bearings failure is essential not only for the safe operation of machines, but also for the reduction of maintenance cost of any machine.

Different methods are used for detection and diagnosis of defects of bearings; they may be broadly classified as vibration and acoustic measurements, temperature measurements and wear debris analysis. The most fundamental tool for bearing diagnosis is vibration analysis. The strength and weakness of vibration represents the location of defects.

This paper discuss about the bearing failure diagnosis using vibration analysis. Crest factor is defined as the ratio of the peak value of a waveform to its RMS value. Comparative analysis is made between damaged and healthy Rolling and Ball bearings.FFT analyzer and accelerometer is use to perform experimental measurements in axial and radial directions.

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1. INTRODUCTION

Diagnosis of the wearing parts of machines and engines, which improve the availability, safety and help to reduce material usage. The diagnosis of bearings can be used for predictive maintenance or to prevent Sevier damages in mechanical systems after a defect in the bearing was detected. During operation, the bearings are subjected to heavy and dynamic loadings generated by machines and transmitted through the components of rolling element bearings. There are different methods for the diagnosis of these defects in the bearings viz. acoustic measurement, temperature monitoring, wear debris analysis and vibration measurement.

Ball bearings are designed to have a long and useful life. Assuming the application is correct to begin with, maximizing longevity means bearings must be properly installed, lubricated and maintained. Poor operating environment particularly moist or contaminated area and improper handling practices invite premature bearing failure. When a bearing does fail, it is important to determine the exact cause so appreciate adjustments can be made. Examination of the failure mode often reveals the true cause of failure. This procedure is complicated by the fact that one failure mode may initiate another. For example, corrosion in a ball race leaves rust-an abrasive-which can cause wear, resulting in loss of preload or an increase in radial clearance. The wear debris can, in a grease-lubricated bearing, impede lubrication. Resulting in lubrication, failure subsequent overheating. Flaws, in most cases, are readily apparent. In some cases, the imperfections may be virtually invisible to the naked eye. Specific remedies for each situation are also suggested. [9]

Rotary machines are recognized as crucial equipment in various industries, such as power stations, chemical plants, and automotive industry, that require precise and efficient performance. Rolling element bearings are used in a wide variety of rotating machinery from small hand-held devices to heavy duty industrial systems and are the primary cause of breakdowns in machines. Such breakdowns can lead to expensive shutdowns, drifts in production, and even human casualties. Vibration measurements are widely used for detection of defects in bearings. Rolling bearing defects may be categorized as point or local defects and distributed defects. The vibrations are generated by geometrical imperfections on the individual bearing components and these imperfections are caused by irregularities during the manufacturing process as well as wear and tear. The vibration signals contain information of defective parts and a variety of vibration based techniques have been developed to monitor the condition of bearing. Vibration signals are analyzed using time domain analysis, frequency domain analysis, and time-frequency domain analysis (wavelet). Faults are classified using various artificial intelligence techniques to predict the meaningful results from the observations. Artificial neural networks (ANNs) support vector machine (SVM) fl-tt), fuzzy logic classifiers and other soft computing techniques are widely used tools to classify the faults for further processing. In these works, after a vibration signal is measured, different signal processing techniques are employed to extract the fault sensitive features to solve as the monitoring indices. Then, these techniques are used to diagnose various bearing faults from the vibration signature obtained. [2]

Among the other mechanical components, researchers pay great attention to the rolling element bearings due to their unquestionable industrial importance. Rolling element bearings are frequently encountered in rotating machinery due to their carrying capacity and low-friction characteristics. Rolling element bearings work under different conditions and frequently under heavy loadings generated in the machinery and they are subjected to time and space varying dynamic loads. The complexity of the loading mechanism in the bearings shows its effect in the form of local defects. It is important to detect a defect at its incipient stage in order to prevent long-term breakdowns or in some cases possible catastrophic failures. Different monitoring techniques are used in industry to prevent machinery failures caused by the rolling element bearings and new techniques are being developed. Vibration analysis is among the most common method used in the monitoring applications since a local defect produces successive impulses at every contact of defect and the rolling element, and the housing structure is forced to vibrate at its natural modes. The vibration pattern of a damaged bearing includes the low-frequency components related to the impacts and the high-frequency components in which the structural information of the bearing structure or the machine is stored. [1]

Different techniques are employed in the studies related to the rolling element bearings. A detailed review of these methods the vibration signal containing the information about the anomaly in the bearing structure is created artificially using the theoretical considerations or collected from the experimental measurements. Basically, the time domain, the frequency domain and recently the time–frequency domain analyses are used to extract useful information about the existence of a localized defect. A well-established model including the load distribution around the circumference of the rolling element bearings having localized defect and the impulse response of the bearing structure are proposed. Multi-point defect case with arbitrary locations is analyzed. Wang and Harrap presented a method which combines the time-synchronous averaging and envelope spectral analysis techniques for diagnosing multiple element defects of rolling bearings. Natural modes are used to obtain the dynamic response of the rings and the vibration signal is modeled as the combination of different components such as fault, modulation due to non-uniform loading, inner or outer ring modes, structural vibrations and noise. [1]

Different kinds of defective rolling contact bearings can be taken for analyzing, the set up called as FFT (Fast Fourier Transform) analyzer can be used to analyze the defective rolling contact bearings.

- The setup has been arranged in such a way that there is an arrangement for attaching the weight to defective rolling contact bearings, then gradually the load is being applied on the bearing and by the use of FFT the different readings will going to be taken for different loads.
- Then whatever the result or readings we will get, from that readings will going to plot graphs with the help of FEA modeling software.
- Frequency domain methods are used for monitoring the health of bearings.

2. MATLAB SIMULATION

Localized faults in a rolling element bearing may occur in the outer race, the inner race, the cage, or a rolling element. Each of these faults is characterized by its own frequency, which is usually listed by the manufacturer or calculated from the bearing specifications. An impact from a localized fault generates high-frequency vibrations in the gearbox structure between the bearing and response transducer. Assume that the gears in the gearbox are healthy and that one of the bearings supporting the pinion shaft is affected by a localized fault in the inner race. Neglect the effects of radial load in the analysis.

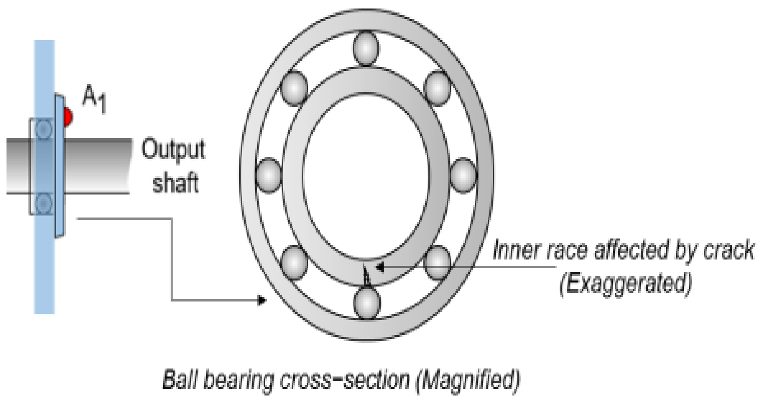


Fig No.1 Ball Bearing Cross Section with crack on Inner Race

2.1 Equation of Motion

The formulas of motion as well as other useful equations which are required for the conditioning monitoring of the bearing are discussed in this chapter. For that purpose we are considering the following fig.

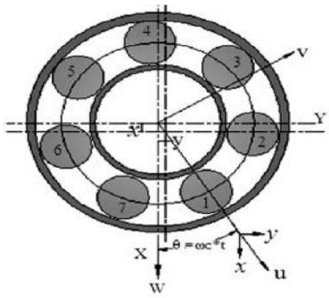


Fig. No 2. Schematic diagram of a ball bearing

The equations of motion for two degrees of freedom system can be written as follows:
$M\ddot{x}$ + **C**$\dot{x}$ + F_x = **W ……………(I)**

$M\ddot{y}$ + **C**$\dot{y}$ + F_y = **0 ………..…(II)**

Where,
M is the mass of rotor,
C is the damping factor
W the radial load
F_x And $F_y$are the total Restoring forces in X and Y directions, respectively.
Equations (VI) and (VII) are the second order non-linear differential equations. The solutions to these equations are derived by converting these into two first order differential equations using state space variable method [III]. [4]

(a) **FTF** - Fundamental Train Frequency (frequency of the defected cage):

f (Hz) = $\frac{1}{2}$ **S** $\left[1-\left(\frac{BD}{PD}cos\beta\right)\right]$

(b)**BPFI** - Ball Pass Frequency of the Inner race (frequency produce when the rolling elements roll across the defect of inner race):
f (Hz) = $\frac{n}{2}$ **S** $\left[1+\left(\frac{BD}{PD}cos\beta\right)\right]$

(c**) BPFO** – Ball Pass Frequency of Outer race (frequency produce when the rolling elements roll across the defect of outer race):

$$f\ (Hz)\ =\ \frac{n}{2}S\left[1-\left(\frac{BD}{PD}cos\beta\right)\right]$$

(d) **BSF** – Ball Spin Frequency (circular frequency of each rolling element as it spins) $f\ (Hz)\ = \frac{PD}{2BD}S\left[1-\left(\frac{BD}{PD}cos\beta\right)^2\right]$

(e) Rolling Element Defect Frequency or 2 x BSF-

$$f\ (Hz)\ =\ \frac{PD}{BD}S\left[1-\left(\frac{BD}{PD}cos\beta\right)^2\right]$$

Where,

S=Speed (revolutions per second)

n= No. of rolling elements

β= contact angle (degrees)

BD=ball or roller diameter

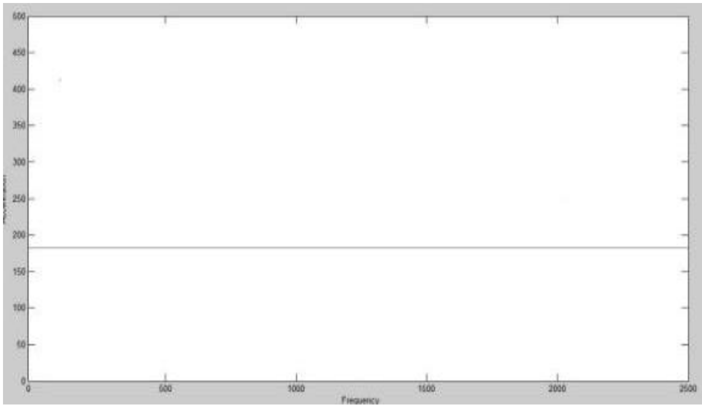
PD=pitch diameter

2.2 MATLAB SIMULATION

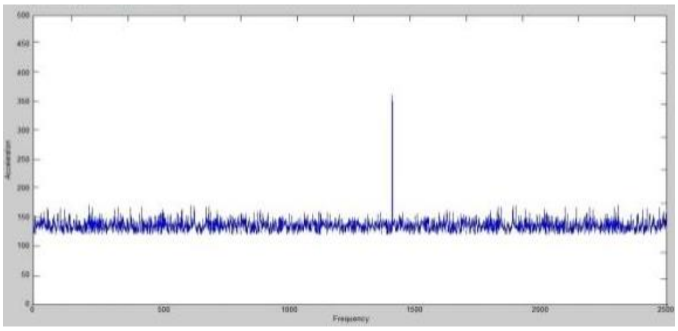
The FEM results are discussed in this chapter. These results are obtained from the Matlab software. The validation of these results is as follows. The various frequencies range is 1200 rpm. The various defect sizes are 0.5mm & 1mm which are obtained on the outer race & inner race.

Now we can obtain the results for the defect size of 0.5mm for defective Ball Bearing (UC204 BRQ) & 1mm for defective Roller bearing (22205 C W33) with the help of MATLAB software. As we are taking the results for the frequencies 1200rpm on the inner race and outer race the following graph &table shows the readings for different frequencies for their respective defect sizes:-

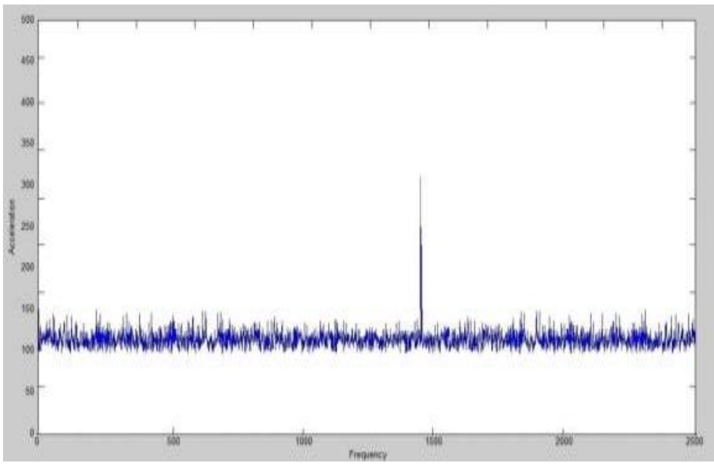
- **SPHERICAL ROLLER BEARING 22205 C W33**



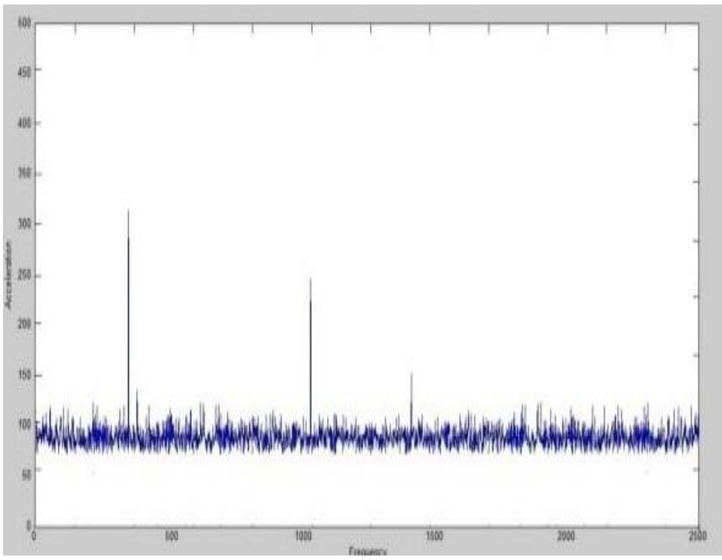
Graph No.1 Healthy Spherical Roller Bearing (0 Kg Load)



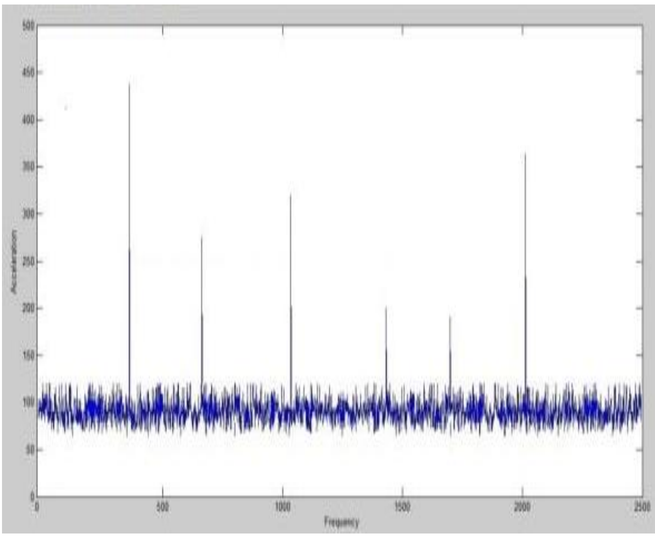
Graph No.2 Healthy Spherical Roller Bearing (5 Kg Load)



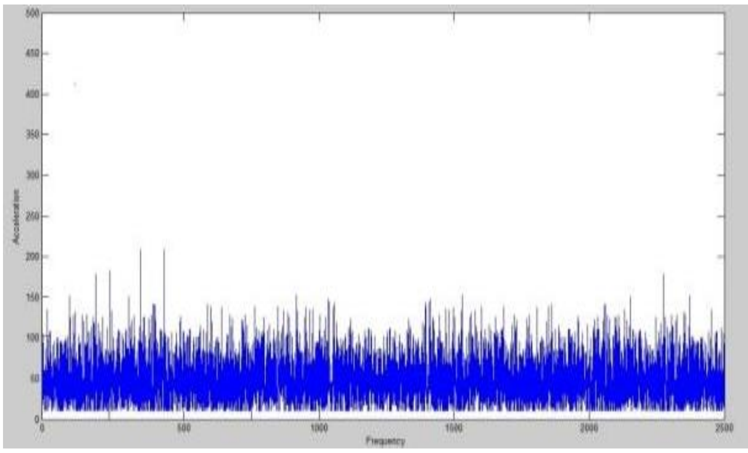
Graph No 3 at Healthy Spherical Roller Bearing (10 Kg Load)



Graph No.4 Defect Size 1mm of Defective Spherical Roller Bearing (0 Kg Load)



Graph No.5. Defect size 1mm of Defective Spherical Roller Bearing (5 kg Load)

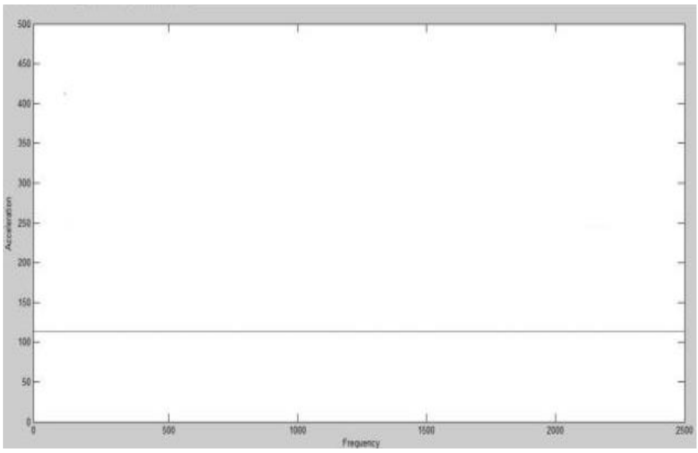


Graph No.6 Defect size 1mm of Defective Spherical Roller Bearing (10 kg Load)

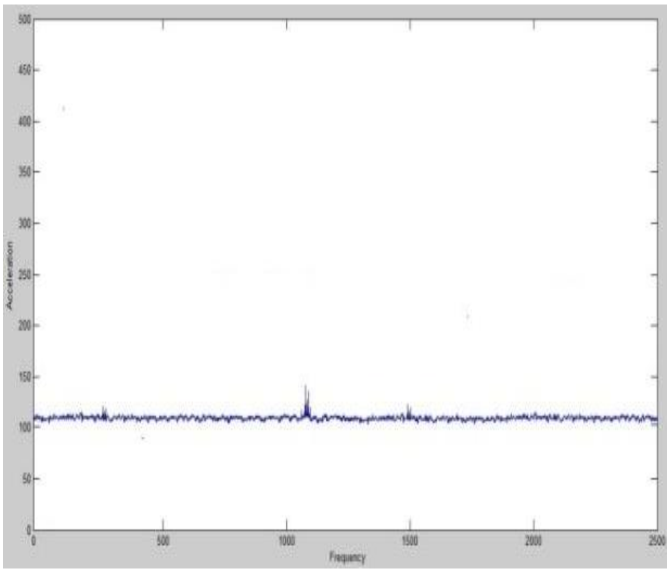
Sr. No	**Load (kg)**	**Defect Location (mm)**	**Acceleration (mm/s^2)**
HEALTHYSPHERICAL ROLLER BEARING			
1	0	IR	182.67
2	5	IR	142.67
3	10	IR	100.23
DEFECTIVE SPHERICAL ROLLER BEARING			
4	0	IR	97.10
5	5	IR	92.75
6	10	IR	32.89

Table no 3. MATLAB Simulation Values of Acceleration for **Healthy Roller Bearing &Defective Spherical Roller Bearing** (Defect Size 1mm at Inner Race)

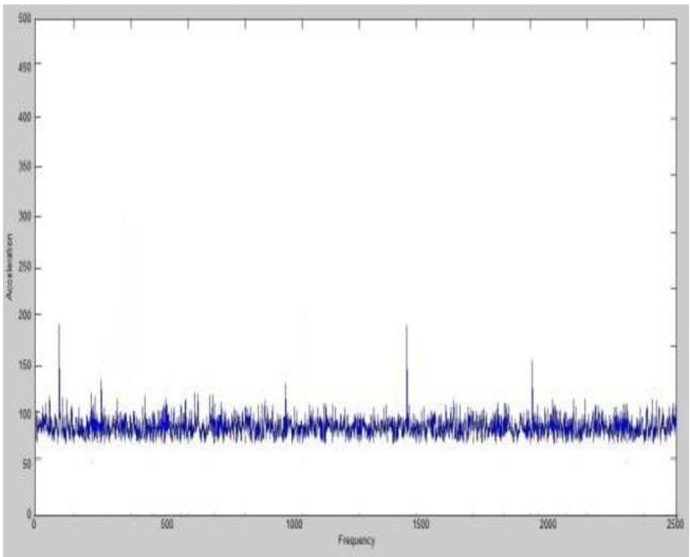
- **BALL BEARING UC204 BRQ**



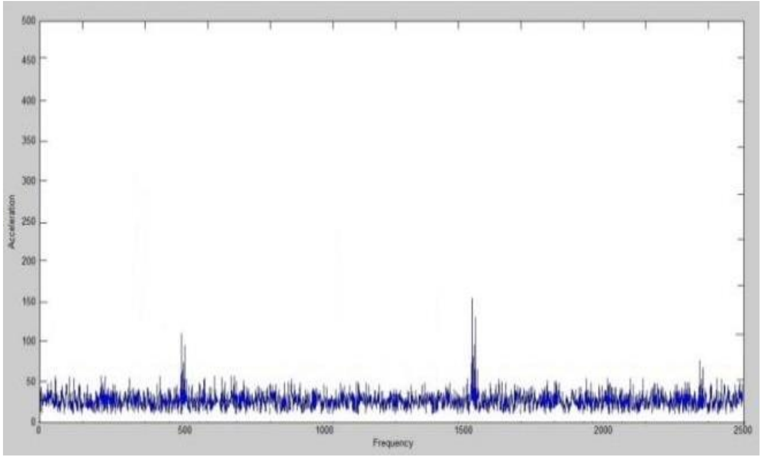
Graph no 7 for HEALTHY BALL BEARING (0 kg load)



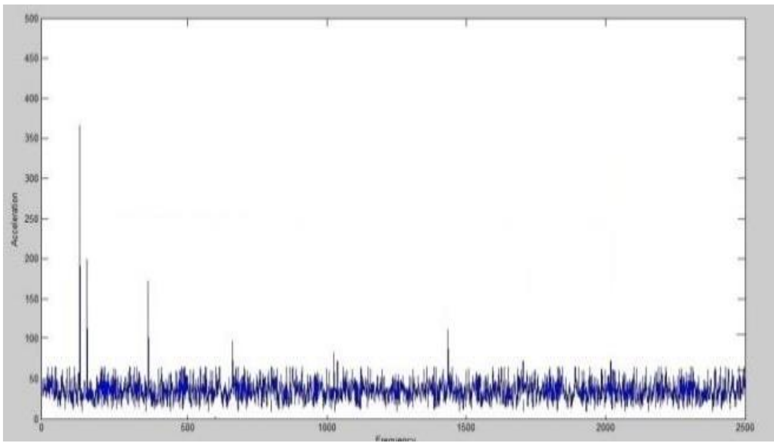
Graph No.8 for Healthy Ball Bearing (0 Kg Load)



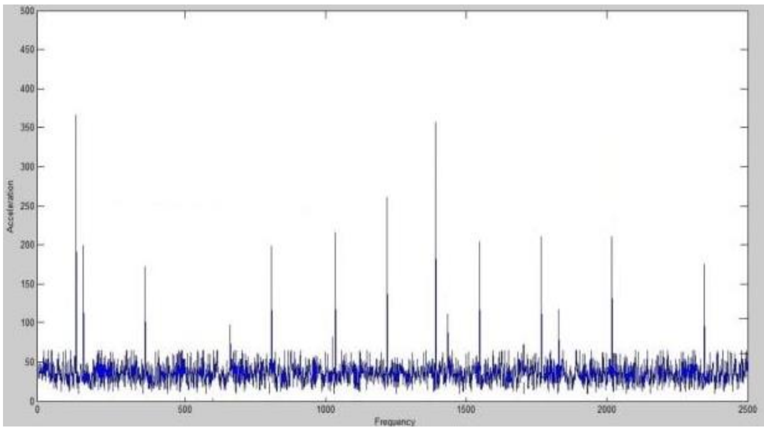
Graph No. 9 for Healthy Ball Bearing (0 Kg Load)



Graph No.10 Defect Size 0.5mm of Defective Ball Bearing (0 Kg Load)



Graph No.11Defect Size 0.5mm of Defective Ball Bearing (5kg Load)



Graph no 12 Defect size 0.5mm of Defective Ball Bearing (10 kg load)

Sr. No	**Load (kg)**	**Defect Location (mm)**	**Acceleration (mm/s^2)**

HEALTHY BALL BEARING			
1	0	OR	125.13
2	5	OR	103.41
3	10	OR	93.56
DEFECTIVE BALL BEARING			
4	0	OR	55.45
5	5	OR	44.15
6	10	OR	41.52

Table no. 4 MATLAB Simulation values of acceleration for **Healthy Ball Bearing & Defective Ball Bearing** (Defect size 0.5mm at outer race)

So, from above discussion and from the entire FEM result's table we can conclude that, the acceleration of outer race is greater than that of the inner race at different speeds but considering the fact we have two different bearings.

From above tables (i.e. table no. 3.7.1& table no. 3.7.2) we can say that, the acceleration (mm/s^2) goes on increasing as load decreases for defective ball bearing as well as for spherical roller bearing. We have maximum acceleration for healthy Ball bearing as well as for spherical roller bearing.Also, acceleration for spherical roller bearings is more than deep groove ball bearing for conditions given above

3. EXPERIENTAL VALIADATION

The experimental setup for the measurement of conditioning monitoring of the deep groove ball bearing requires following materials:-

Name	Quantity
Electric motor	1
V cone pulley	4
Rotating shaft	2
Defective spherical roller bearings	1
Healthy Roller contact bearings	1
Defective Ball bearings	1

Healthy Ball bearings	1
Pedestal bearing	2
Plummer block	4
V belt "A35"	2
Nuts	16
Bolts	16
Washer	16
Key	2

Table no 5 List of material & its quantity

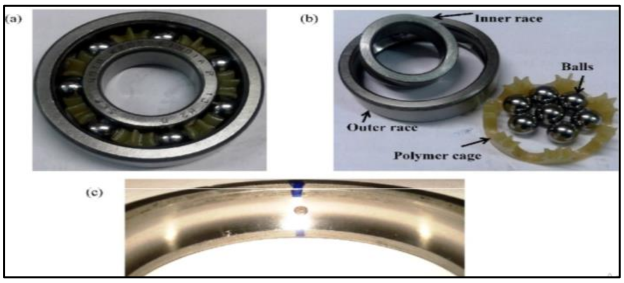


Fig.No 20 Image of the test bearing and the defect (a) test bearing (b) components of the test bearing (c) circular defection outer race

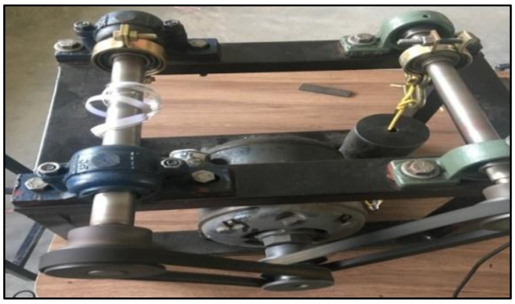
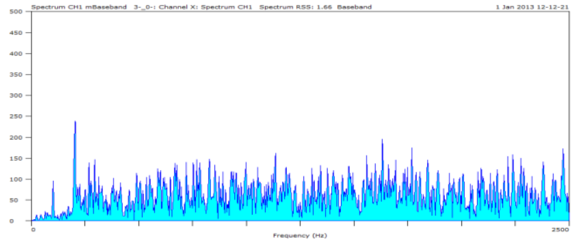


Fig.No 21 Photographic view of Experimental Setup with Load Arrangement

Fig No. 22 Experimental Setup
(TOP VIEW)

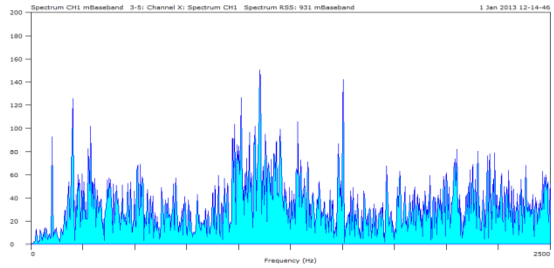
3.1 Experimental Results

The readings which are obtained from the FFT Analyzer are in the graphical format. For different frequencies at 1200 rpm by varying load arrangements from 0kg to 10 kg. The graphs are taken for different frequencies such as follows: -



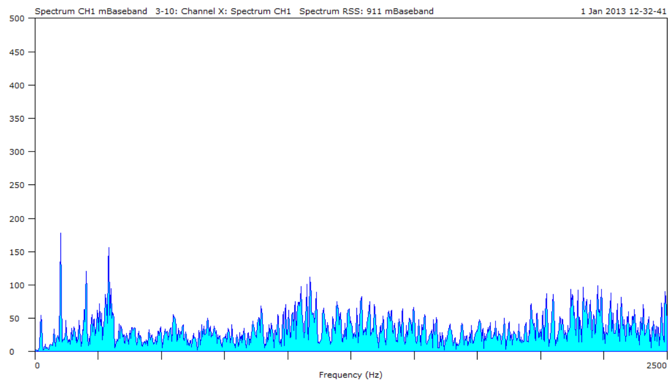
Graph no 13 BPFI at 1200 for rpm for Healthy Spherical Roller Bearing (0 kg load)

The above graph shows the ball passes frequency of inner race at 1200rpm. The graph will show maximum pick at 200 Hz.



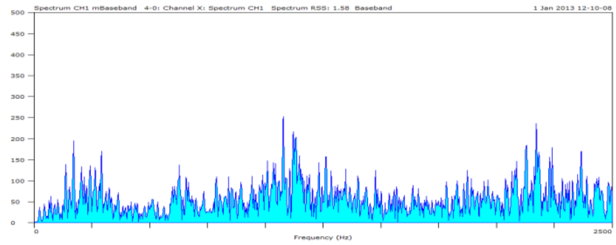
Graph no 14 BPFI at 1200 for rpm for Healthy Spherical Roller Bearing (5 kg load)

The above graph shows the ball passes frequency of inner race at 1200rpm. The graph will show maximum pick at 1100 Hz.



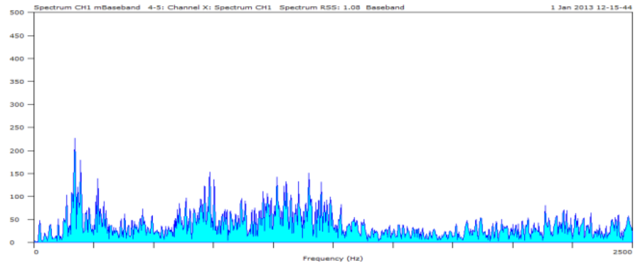
Graph no 15 BPFI at 1200 for rpm for Healthy Spherical Roller Bearing (10 kg load)

The above graph shows the ball passes frequency of inner race at 1200 rpm. The graph will show maximum pick at 100 Hz.



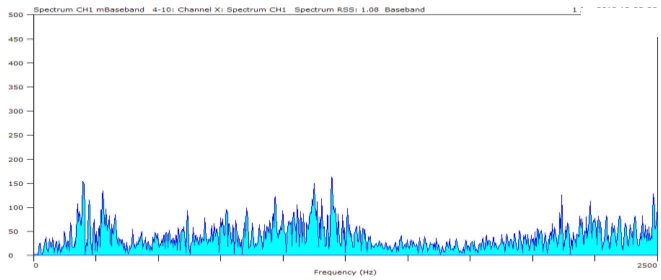
Graph no 16 BPFI at 1200 for rpm for Defective Spherical Roller Bearing (0 kg load)

The above graph shows the ball passes frequency of inner race at 1200 rpm. The graph will show maximum pick at 1078 Hz.



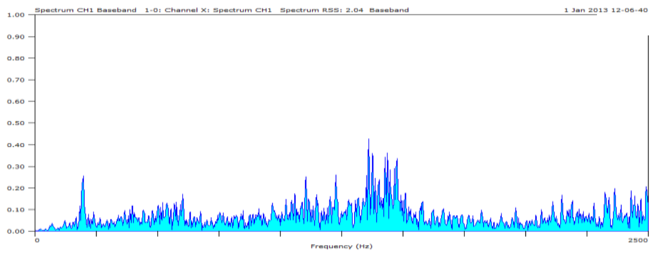
Graph no 17 BPFI at 1200 for rpm for Defective Spherical Roller Bearing (5 kg load)

The above graph shows the ball passes frequency of inner race at 1200 rpm. The graph will show maximum pick at 169 Hz.



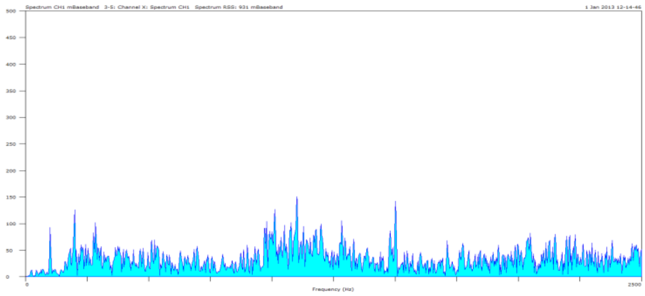
Graph no 18 BPFI at 1200 for rpm for Defective Spherical Roller Bearing (10 kg load)

The above graph shows the ball passes frequency of inner race at 1200 rpm. The graph will show maximum pick at 1194 Hz.



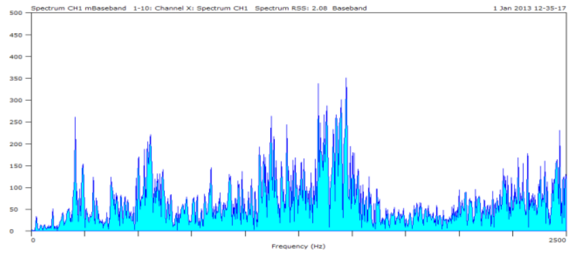
Graph no 19BPFO at 1200 for rpm for healthy Ball Bearing (0 kg load)

The above graph shows the ball passes frequency of outer race at 1200rpm. The graph will show maximum pick at 1363 Hz.



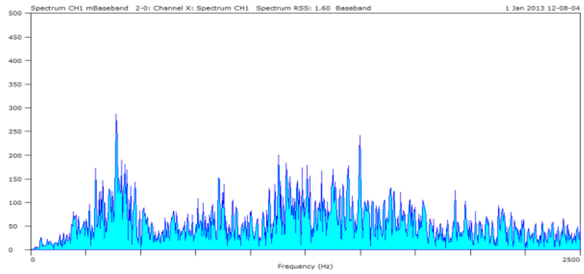
Graph no 20 BPFO at 1200 for rpm for healthy Ball Bearing (5 kg load)

The above graph shows the ball passes frequency of outer race at 1200rpm. The graph will show maximum pick at 384 Hz.



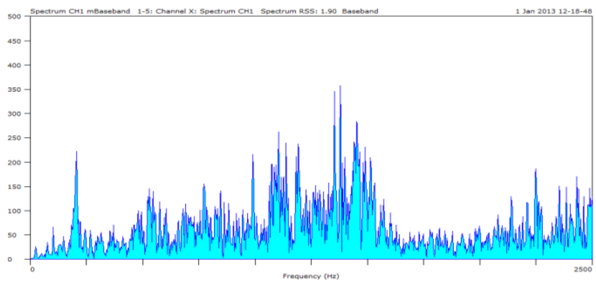
Graph no 21 BPFO at 1200 for rpm for healthy Ball Bearing (10 kg load)

The above graph shows the ball passes frequency of outer race at 1200rpm. The graph will show maximum pick at 1472 Hz.



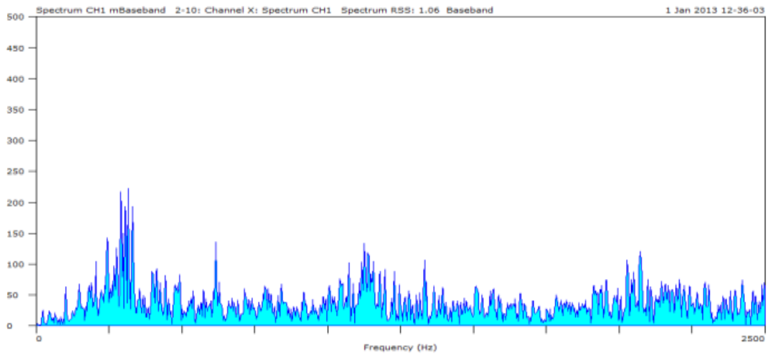
Graph no 22BPFO at 1200 for rpm for Defective Ball Bearing (0 kg load)

The above graph shows the ball passes frequency of outer race at 1200 rpm. The graph will show maximum pick at 388 Hz.



Graph no 23BPFO at 1200 for rpm for Defective Ball Bearing (5 kg load)

The above graph shows the ball passes frequency of inner race at 1200rpm. The graph will show maximum pick at 1378 Hz.



Graph no 24 BPFO at 1200 for rpm for Defective Ball Bearing (10 kg load)

The above graph shows the ball passes frequency of outer race at 1200rpm. The graph will show maximum pick at 316 Hz

4. Comparison of Results

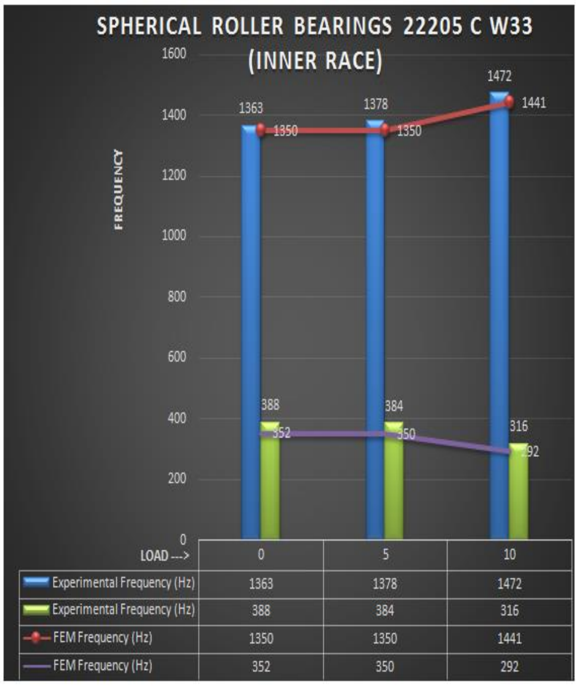
As we have obtained results by both the methods i.e. by experimental & by using MATLAB. Now we can compare those results for frequency parameter. We are comparing those results for Spherical Roller Bearing (i.e. Healthy as well Defective) and for Deep Groove Ball Bearing (i.e. Healthy as well as Defective).

4.1 Comparison of results for Spherical Roller Bearing 222050 C W33

Load (Kg)	Healthy Bearing		Defective Bearing	
	Experimental Frequency (Hz)	FEM Frequency (Hz)	Experimental Frequency (Hz)	FEM Frequency (Hz)
0	1363	1350	388	352
5	1378	1350	384	350
10	1472	1441	316	292

Table No. 6 Comparison of results for inner race of Spherical Roller Bearings (22205 C W33)

The above table shows the comparison between the Experimental & MATLAB simulation for inner race of Spherical Roller Bearings. For different load conditions such as 0 kg, 5kg, & 10kg those results were taken. Experimental & MATLAB simulation results are nearly same but this difference may increase with increase in load on bearings. From above table, we can plot results of experimental & MATALB in the graphical form with the help of excel sheet.



Graph No. 25 Comparison of results for inner race of Spherical Roller Bearings (22205 C W33)

The above graph shows the comparison between the results of Experimental & MATLAB simulation for inner race of Spherical Roller Bearing.

The above graph which is obtained from excel sheet clearly shows the Comparison of results for inner race of Spherical Roller Bearings (22205 C W33) graphically. Both the results which are obtained from the Experiment & MATLAB simulation are nearly same with slightly difference of 10-25 Hz.

4.2Comparison of results for Deep Groove Ball Bearings (UC204 BRQ)

Load (Kg)	Healthy Bearing		Defective Bearing	
	Experimental Frequency (Hz)	FEM Frequency (Hz)	Experimental Frequency (Hz)	FEM Frequency (Hz)
0	200	200	1078	1053
5	1100	1068	169	152
10	100	93	1194	1156

Table No.7 Comparison of results for Deep Groove Ball Bearings (UC204 BRQ) for outer race.

The above table shows the comparison between the Experimental & MATLAB simulation for inner race of Deep Groove Ball Bearings. For different load conditions such as 0 kg, 5kg, & 10kg those results were taken. Experimental & MATLAB simulation results are nearly same but this difference may increase with increase in load on bearings. From above table, we can plot results of experimental & MATALB in the graphical form with the help of excel sheet.

LOAD-->	0	5	10
Experimental Frequency (Hz) Healthy Bearings	200	1100	100
Experimental Frequency (Hz) Defective Bearings	1078	169	1194
FEM Frequency (Hz) Healthy Bearings	200	1068	93
FEM Frequency (Hz) Defective Bearings	1053	152	1166

Graph No. 26. Comparison of results for Deep Groove Ball Bearings (UC204 BRQ) for outer race.

The above graph shows the comparison between the results of Experimental & MATLAB simulation for inner race of Deep Groove Ball Bearings.

The above graph which is obtained from excel sheet clearly shows the Comparison of results for inner race of Deep Groove Ball Bearings (UC204 BRQ) graphically. Both the results which are obtained from the Experiment & MATLAB simulation are nearly same with slightly difference of 20-30 Hz.

5. Conclusions & Future Scope

- At constant speed and constant load with different defect sizes on outer ring, amplitudes of vibration vary with increase in defect sizes.
- Similarly, at constant speed and constant load with different defect sizes on inner ring, amplitude of vibration varies with increase in defect size.
- With Increase in level of defect on Rollers and Balls, vibration acceleration values show increase in amplitude.
- The increased in amplitude is strong indication for damage in Roller and Ball bearings.
- Hence FFT analyzers can be used to analyze health monitoring for structural components
- The scope of this work is limited to measurement of amplitudes of vibration at the outer and inner ring defects with only load variation.
- Focus is not on the defects on the balls & roller in the bearings as vibrations of balls& rollers are controlled by misalignment, lubrication and ball slip.
- However, by controlling these parameters, a model can be developed for defected ball as well as rollers to which the excitation forces may be produced by impact of both (balls and rollers) on inner ring and outer ring.
- Crest factor value can be used to determine defects in bearings.

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