# Pre-detection of Fault in Bearing using MATLAB and Validation through FFT Analysis

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## ABSTRACT

*Rolling element bearings find widespread domestic and industrial applications as it is an important factor in the failure of rotating machines and therefore bearings are the ones that are exposed the most towards getting damaged and failure. In industrial applications, these bearings are considered as a critical mechanical component and a defect in such a bearing, unless detected in time, causes malfunction and may even lead to catastrophic failure of machinery which results in significant time and economic loss. These types of failures might take place during the manufacturing process and therefore it is important to review the problem and monitor the condition of roller bearings so that early detection and indication are necessary for the safety and reliability of monitoring techniques suitable to analyze the defect. This paper focuses on conditioning monitoring tech. vibration analysis and acoustic analysis methods. An experimental set up is used to testify and investigate good bearing and faulty bearing by using different measurement tools pulse software, visteck analyzer to measure amplitude, sensors to obtain faulty signals and computer-oriented programming software MATLAB for finding faulty frequencies at the inner race.*

**Keywords:** *-Fault diagnosis, Matlab, Roller bearing diagnosis, Vibration analysis.*

## 1. INTRODUCTION

### 1.1 Background

In the 21st century, managing the industries has become one of the challenging tasks due to change in management structure, increased global competition, intense change in technology, reliability, health, and safety, consumer demands towards quality and environmental considerations [9]. Taking into consideration all the above factors there is a great chance to improve the opportunities as well as strategic plans and therefore make the most benefits of modern manufacturing techniques and methods. Advanced manufacturing methods and techniques, quality of human resources has greatly persuaded the productivity in the manufacturing industry. [9] Manufacturing companies in India payout three times as much every year in replacing the machinery and maintaining the existing plant. As there have been several sectors in manufacturing affected by the different issues related with the rotating machinery, one of the major issues in the manufacturing has been early detection of faults which has result in the unplanned breakdowns, maintenance cost and so it has been disaster failure in machinery or process [7]. To overcome and therefore prevent these failures, different techniques of maintenance management like corrective maintenance, breakdown maintenance, preventive maintenance, time-based maintenance, and condition-based maintenance are widely utilized [15]. All these techniques are viable in some and the other way for the different failure machinery for the manufacturing industry. Above all, condition-based maintenance is one of the best methods in the early detection of faults in rolling element bearing. Usually, these faults in the rolling bearing element occur due to corrosion, overheating, excessive load, lubrication failure, misalignment, tight fits, normal fatigue failure, and contamination.

### 1.2 Vibration Analysis

Vibration analysis is the most powerful tool for fault diagnosis of bearing. Accuracy of operation of bearing is related to elements like housing, shafts, and nuts. Some of the bearings fail earlier in service because of the poor lubrication, tight-fitting, loose-fitting, contamination, and misalignment.

### 1.3 Acoustic Analysis

Acoustic analyzer captures the sound waves and analyze, this analysis helps to find the leakage faults, detection of crack, and another bearing defects. Acoustic analysis is a cost-effective and less complicated technique of CM. Sound from the bearing is usually complex and its combination of many sinusoidal waves which provides the exact fault information. Tools like vistec (amplitude meter), pulse software, different sensors, acoustic analyzer, and more are used to measure the different parameter produce from the rolling element bearing. [10] These tools are used to obtain time domain and frequency domain of the different vibration signals. High-frequency signals in the range 100-150 kHz. Regular mechanical bearing vibrations do not exceed 30 kHz and impact waves arising in a faulty bearing frequency are reaching 50 kHz and more [8]. Acoustic analyzer captures the sound waves and analyze, this analysis helps to find the leakage faults, detection of crack, and another bearing defects.

### 1.4 Characteristic Frequencies of the Bearing

The vibration analysis technique gives precise and early information about the failure of bearing. According to Tondon and Choudhary [12], faults in bearing (inner race, outer race, and cage fault) produce the particular defective frequencies which are calculated by using the following equations.

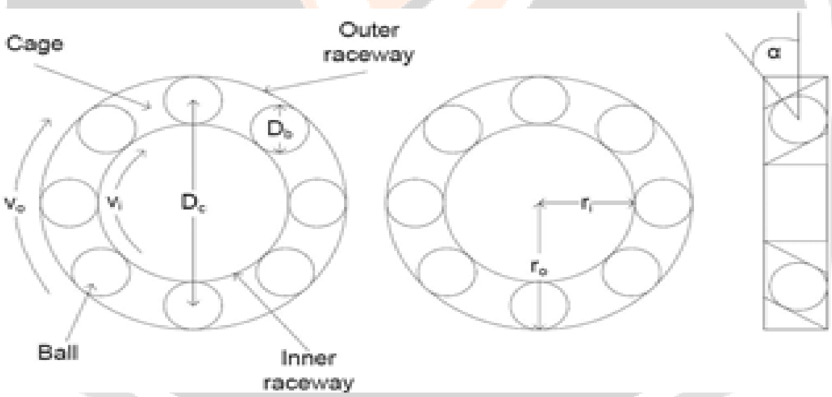


**Figure 1** Standard Rolling-Element Bearing

Ball Pass Frequency at inner race of bearing (BPFi)

$BPFi=fr*(1+(d/D)*\cos(A))*B/2$ (1)

Ball Pass Frequency at inner race of bearing (BPFo)

$BPFo=fr*(1(d/D)*\cos(A))*B/2$ (2)

Cage malfunction frequency

$FTF=fr/2*(1+(d/D)*\cos(A))$ (3)

Ball Spin Frequency

$(BSF)=fr*(1(d^2/D^2)*(\cos(A))^2)*d/(D*2)$ (4)

Where,

fr=running frequency, n = no of balls

d = roller diameter , D = pitch diameter

A = contact angle , N = revolution/ minute

These equations are based on the good rolling races; nonetheless practically additional sliding motion might cause changes in characteristic frequencies.

### 1.5 Condition Monitoring

According to Hutton [4], conditioning monitoring mostly focuses on the vibration data including a sample of lubricant, temperature readings, and measurement of shocks from rolling element bearing defects. Beebe[2] defined conditioning monitoring as "conditioning monitoring on or off-line is a type of maintenance inspection where an operational asset is monitored and the data obtained analyzed to detect signs of degradation, diagnose the cause of faults, and predict for how long it can be safely or economically run". There are several benefits of conditioning monitoring which potentially affect improved productivity, maintenance cost, and increased plant availability. [9] the following methods are generally used for condition monitoring of the bearings:

- Vibration analysis, Oil debris analysis
- Acoustic analysis, Visual inspection
- Corrosion analysis

Some of the important and majorly used measurement techniques within the conditioning monitoring are as follows:

### 1.6 Vibration Analysis

Vibration analysis is the most tangible and established technique in conditioning monitoring [9]. McFadden and Smith, [8] stated that vibration analysis has been used comprehensively in the diagnosis of bearing in the rotating machine. Like most of the other techniques, where we need to shut down the equipment to detect the problems, vibration analysis doesn't require to shut down the equipment and so it can be performed online by the computer-based machine monitoring system.[5]To identify the faults of bearings, the received vibrating signals are processed by different methods. Karimi [7] stated that these methods are traditionally been used either in terms of the time-domain or frequency domain. These techniques are broadly classified as follows:

- Time-domain analysis.
- Frequency domain analysis.
- Combined time-frequency domain analysis.

#### 1.6.1 Time Domain Analysis

The time-domain analysis is nothing but a display or analysis of the vibration data as a function of time. To detect the fault, the time domain method analyzes phase information and amplitude of the vibration time signals [14]. Changes in vibration signals due to faults were detected by studying the time domain waveform using equipment like vibrographs, oscilloscope, or oscillographs.[14] The time-domain analysis focuses principally on statistical characteristics of vibration signals such as Standard deviation., Peak level., Skewness., Kurtosis., Crest factor. To detect the faults at the bearing, the differences of phase and vibration amplitude due to damage of components are used. Mathew & Alfred son [8] discovered that time-domain analysis can be used to identify the damage occurring in bearings such as cracks on outer and inner races. Also, to diagnose the fault of bearing, kurtosis of phase modulation and its derivatives are used.

#### 1.6.2 Frequency Domain Analysis

Frequency domain analysis is the classical bearing diagnostic technique also known as spectral analysis. Karimi [7] stated that the frequency domain analysis method is more reliable and most sensitive than the time-domain analysis method. The vibration data is analyzed as a function of frequency by frequency domain analysis. The spectrum of faulty bearing and the bearing in good condition is compared and its difference is used in detecting faults on bearing [12]. Obtaining narrowband spectra easily and more efficiently is mostly done by using Fast Fourier Transform (FFT). Fast Fourier transform algorithm is used to process time domain vibration signals into the frequency domain. In other words, the frequency spectrum is achieved as the frequency-domain method mainly uses numerical fast Fourier transform to the vibration signal. There are different methods of frequency-domain vibration signature analysis which are as follows:

- Shock Pulse
- Enveloped Spectrum.
- Signature Spectrum.
- Band Pass Analysis.
- Cascades.

### 1.6.3 Computer Oriented Programming for Vibration Analysis (MATLAB)

Matlab is a fourth-generation programming language and is a kind of software programming or it is kind of a system that is usually used for numerical computation. It usually helps in lowering down routine tasks associated with numerical problem solving, which ultimately allows us to spend more time in thinking and giving more time to discover the experiment. It is so easy and functional that even big operations can be carried out using a couple of commands. One can build its own set of functions for a particular application. Matlab provides excellent graphic facilities and therefore it is widely used in vibration analysis.

## 2. METHODOLOGY

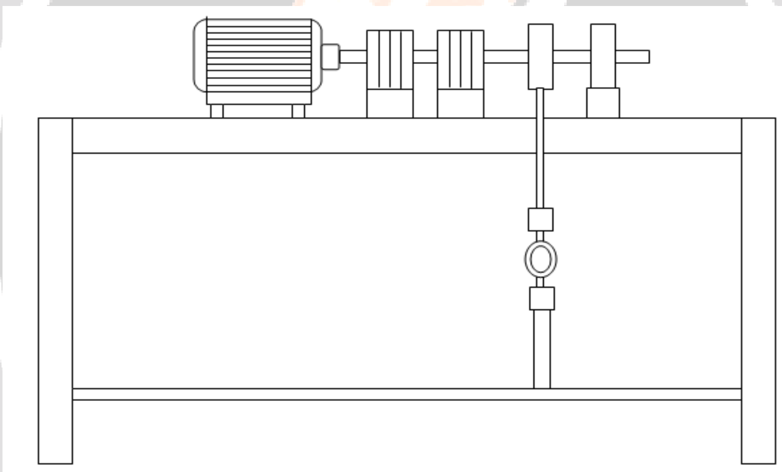

**Figure 2** Experimental Set-up

The experimental test rig is designed to investigate the failure and a vibration characteristic of the ball bearing. This design is a conventional machine design and hence not discussed in detail here. The test rig used in this dissertation work consists of a 3 HP phase induction motor driving the V-belt drive. Vibration isolation rubber sheets are also provided under the motor and it's supporting legs to reduce the vibration transmission from ground to the test bearing. The test bearing is mounted on the output shaft. The loading arrangement along with the load cell is placed between these two support bearing. A piezoelectric accelerometer is mounted on the housing of the test bearing by using a magnetic mount. The accelerometer is connected to the charge amplifier, the output of which is connected to a computer. The computer contains relevant hardware and the software to acquire the data, store it, and display the time domain and frequency domain signals.

## 3. RESULTS AND DISCUSSIONS

Each different bearing has unique characteristic rotational defect frequency which depends on the kinematics consideration of bearing. These frequencies can be calculated by knowing the geometry of the bearing and its rotational speed; usually, these frequencies sited in the low-frequency range (less than 500Hz). When a certain defect is present in a bearing element, increasing in the vibration levels at a characteristic frequency. That's why the frequency-domain analysis of vibration reading is usually carried out to determine the condition of motor bearings. Frequency-domain or spectral analysis of vibration signal is the most widely used approach for bearing defect detection. Usually Fast Fourier Transform (FFT) is applied to the vibration signal which converts it into a series of discrete frequency components. In a frequency domain, plots have frequencies on X-axis and the displacements, velocity, and acceleration signals on Y-axis. The defects and its location, variable loading & speed condition are experimentally observed. The measured signals and the calculated fundamental defect frequency diagnosed carefully.

### 3.1 Vibration Analysis at Constant Load with Different Speeds

The vibration analysis was carried out for speeds 2880 at a constant load of 20 kg. It is carried out for the healthy bearing (B-HTY), bearing with inner race defect (BPFi) and bearing with outer race defect (BPFo). The vibration signals of the healthy bearing are shown in Figure 3. To assess the clarity in different defects in bearings at above mentioned operating conditions, the spectrum analysis. In spectrums, there is a peak close to shaft rotational frequency at 49.375 Hz. The estimated shaft rotational frequency is 48 Hz. It is observed that the vibration amplitude increases for 1X with the increase of the shaft running speed. Vibration amplitude has increased significantly.

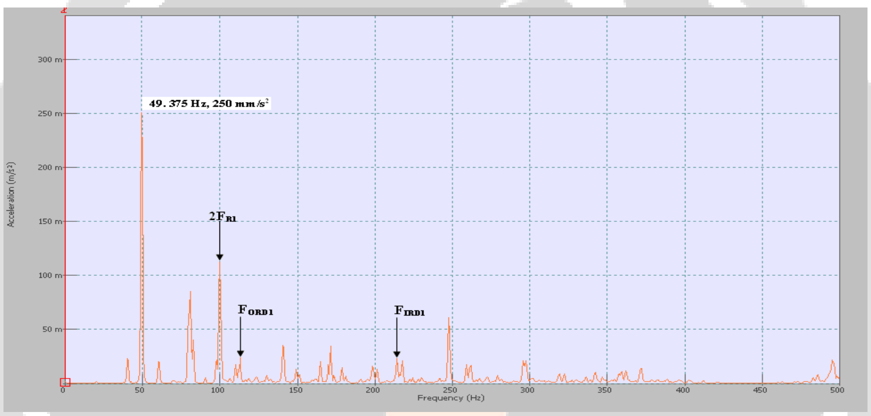


**Figure 3** Spectrum of healthy bearing with 20 kg load at 2880 rpm

These vibrations are caused by unbalancing that occurs at a frequency equal to 1 x RPM of the unbalanced component also vibration amplitude is proportional to the amount of unbalance present. The frequency spectrum of the vibration signals with FFT analyzer from the inner race defect bearing, It shows peaks at 47.5 Hz and 210 Hz. Amongst them first one is shaft rotational frequency ($F_{R1}$) & the second one is inner race defect frequency (BPFi). The difference between estimated inner race defect frequency & experimental inner race defect frequency is only 6.09 Hz since the measured bearing defects frequencies normally deviate from the calculated ones, and this deviation can reach several hertz in some cases. The MATLAB output of the same defect shows this defect frequency (BPFi) at 228 Hz, which varies by 11.91 Hz from theoretical and by only 18 Hz from measured one. This output in the frequency domain is shown in Figure 4 and its respective spectrum in Figure 6.

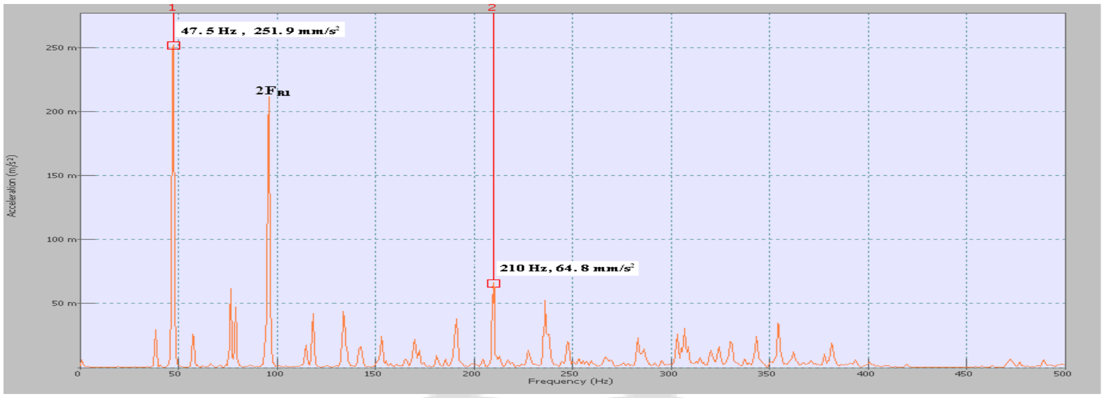


**Figure 4** Spectrum of bearing with inner race defect with 20 kg load at 2880 rpm

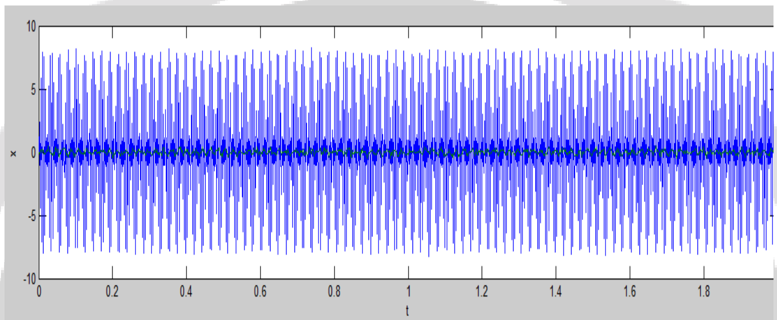


**Figure 5** Time-domain MATLAB output of bearing with inner race defect with 20 kg load at 2880 rpm

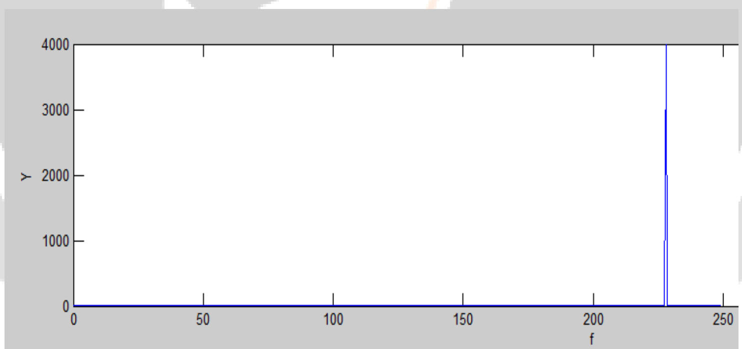


**Figure 6** Spectrum of MATLAB output of bearing with inner race defect with 20 kg load at 2880 rpm

The spectrum of the vibration signals from the outer race defect bearing at speed 2880 rpm is shown in Figure 6. It shows peaks at 49.375 Hz and 120 Hz. Amongst them first one is shaft rotational frequency ($F_{R1}$) & the second one is outer race defect frequency (BPFo). There is a difference 0.10 Hz between estimated & experimental for outer race defect frequency. The MATLAB output of the same defect shows this defect frequency (BPFo) at 108 Hz, which varies by 1.90 Hz from theoretical and by only 12 Hz from measured one. This output in the time domain is shown in Figure 8 and its respective spectrum in Figure 9.

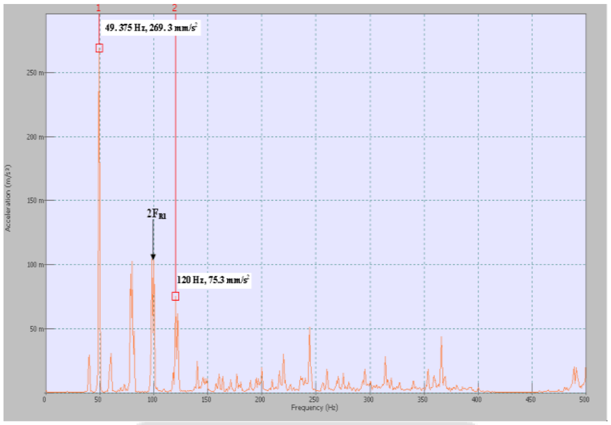


**Figure 7** Spectrum of bearing with outer race defect with 20 kg load at 2880 rpm

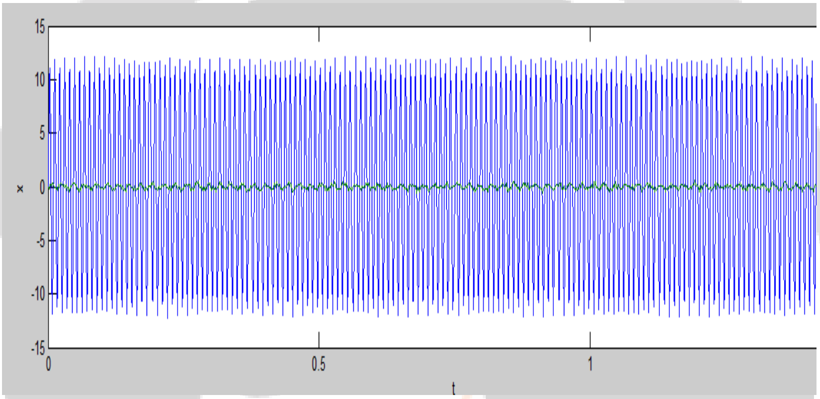


**Figure 8** Time-domain MATLAB output of bearing with outer race defect with 20 kg load at 2880 rpm

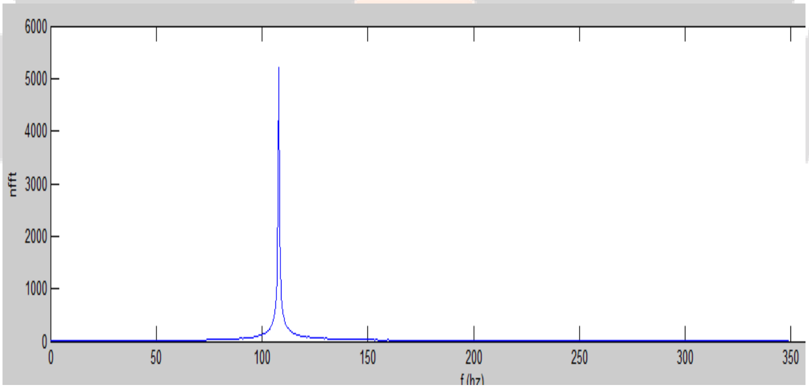


**Figure 9** Spectrum of MATLAB output of the outer

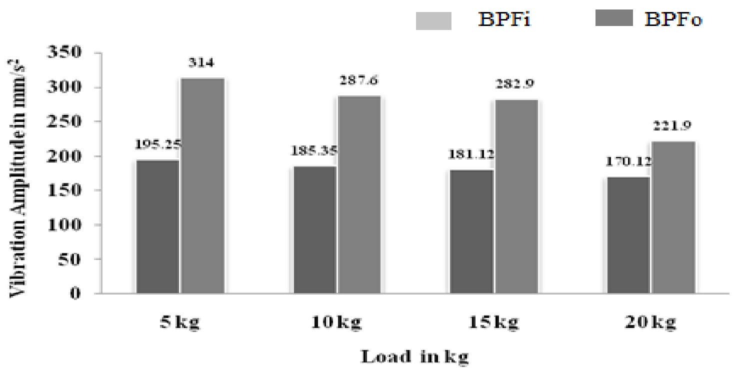


**Figure 9** Load effect on vibration amplitude for the bearing with inner race defect & bearing with outer race defect

The agreement between the calculated frequencies and those obtained from the FFT analyzer is quite excellent. It is seen that there is a decrease in the vibration amplitude when the load on the bearing is increased under constant speed as shown in Figure 9. The variation in amplitude has the same trend in both cases (i.e. bearing with inner race defect and bearing with outer race defect). The vibration amplitude decreases to 170.12 $mm/s^2$ for a maximum load of 20 kg for bearing with inner race defect. However, the vibration amplitude decreases to 221.9 $mm/s^2$ for bearing with outer race defect at a maximum load of 20 kg. The study predicts the amplitude of vibration due to outer race defect to be much higher as compared to those due to inner race defect race fault bearing.

## 4. CONCLUSION

Through the experimental results, it can be seen that the calculated inner race and outer race frequencies of the bearings at operational speeds of 2880rpm, with a constant load, is applied are 228.25 Hz, 108 Hz, if we compare these result with MATLAB results there is a very small deviation in results. As per experimental results, it was observed that peaks were generated at the characteristic frequencies. It is been observed that from the acquired graphs there is an increase in amplitude as the defect size level increases. Considering all the results and analysis, the thesis reveals that the defect in ball bearing exists at the inner race and outer race of a faulty bearing. Also, it was proved that faulty frequencies obtained through the vibration analysis are similar to faulty frequencies obtained through MATLAB programming. An algorithm was generated to find the faulty frequencies. Looking at all the results and analysis, all the objectives like to discover graphical analysis by using nv gate software and investigate bearing vibrations which occur at certain peak frequencies and designing an algorithm that helps in detecting the faulty frequencies by putting all the parameters were proved. Further at different load test and constant speed analysis is done on FFT it shows that as load increases there are more peaks occur at high frequencies generated. were taken Hence the thesis concludes that the vibrating signals created on the inner race and outer race of the bearing are analyzed evaluated and simulated respectively thus fulfilling the aim.

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