B. TECH PROJECT REPORT

On

Fault identification of Bevel Gearbox using Vibration analysis

BY

Alok Kumar

DISCIPLINE OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

NOVEMBER 2016

Fault identification of bevel gearbox using vibration analysis

A PROJECT REPORT

Submitted in partial fulfillment of the
Requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in

MECHANICAL ENGINEERING

Submitted by:
ALOK KUMAR

Guided by:
DR. ANAND PAREY

INDIAN INSTITUTE OF TECHNOLOGY INDORE
NOVEMBER 2016

CANDIDATE'S DECLARATION

I hereby declare that the project entitled "**Fault identification of bevel gearbox using vibration analysis** " submitted in partial fulfillment for the award of the degree of Bachelor of Technology in '**Mechanical Engineering'** completed under the supervision of '**Dr. Anand Parey, Associate professor, Mechanical Engineering Department'** IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student with date

CERTIFICATE by BTP GUIDE

It is certified that the above statement made by the students is correct to the best of my knowledge.

Signature of BTP Guide with dates and their designation

Preface

This report on “Fault identification of bevel gearbox using vibration analysis" is prepared under the guidance of Dr. Anand Parey.

Through this report, I have tried to give different methods to identify the fault in bevel gearbox using vibration analysis for worn pinion which will be helpful in diagnosis of gearbox and it also helps in preventive maintenance of gearbox technically and make maintenance process reliable, which is the need of changing world.

I have tried to the best of my abilities and knowledge to explain the content in easy way. It will easily understandable to anyone because I have compare result and plot clear graphs for better and easy to understand and apply it for maintenance of gearbox and making human life easy and secure.

Alok Kumar
B.Tech. IV Year
Discipline of Mechanical Engineering
IIT Indore

Acknowledgements

I wish to thank **Dr. Anand Parey** for his constant and kind support and valuable guidance. I would also like to thank for giving me the opportunity to work on this topic of my liking. I am also greatly indebted to **Mr. Vikash Sharma,** PhD scholar for guiding me along all difficulties and helping me to make the project reality. His sound advice and insights helped me to put my best step forward.

I would also want to use this opportunity to thank **Mr. Sandeep Patil** for giving me valuable insights and helped in experiment work.

Last but not the least, I would like to thank **my parents** for their unwavering support and encouragement.

It is their help and support, due to which I became able to complete the project and able to form report.

Alok Kumar

B.Tech. IV Year

Discipline of Mechanical Engineering

IIT Indore

Abstract

Gearbox is most important part of rotating machinery, like rotating machine is a part of human life. Therefore it is necessary to care of gear box. So for it, predictive maintenance of gear box without dissembling it is essential and reliable. Obviously we can predict the fault conditions and identify the fault of any rotary machinery by using vibration analysis with help of FFT analyzer, MATLAB, MFS machine.

In this project, vibration signals are carried out at different speeds and loads from healthy and worn pinion with help of MFS machine, FFT analyzer and computer. Thereafter we detect the fault by extracting features like RMS value, Variance, Kurtosis and Crest factor and by comparing it. Secondly we analyze the FFT spectrum of vibration signature and compare it to detect the fault in worn pinion which is generally tough to identify.

KEYWORDS: Fault identification, Vibration analysis, FFT Spectrum, Bevel gearbox.

Table of Contents

1. Introduction

Gear is the most important part used in any power transmission system. Bevel gear is generally used to transfer power from one shaft to another shaft when two shafts are perpendicular to each other. A Bevel gear is used in transmit power coming from shaft to other in drilling machine, rotorcraft etc. One study found that 65% of gear box damage is due to faults in the gears (5).

As the gears are power transmitting elements, certain faults are getting created in the gears. The faults like tooth damage, wear, pitting, chipping are getting created in the gears due to various reasons like excess loading, large friction and fatigue loading, etc. Also some of the faults like backlash, eccentricity, run out and alignment error are caused during assembling and manufacturing of gear. The faults will create the noise and vibrations during its working condition. These parameters can be used to identify the fault condition as each and every fault condition creates a different vibration spectrum. So it becomes necessary to identify the fault conditions in gear box by using proper vibration analysis technique.

In this study, an experimental setup is prepared on MFS machine for two different pinion, one is healthy and other one is worn pinion. There after vibration signals are carried out at different loads and speeds with help of computer, FFT analyser, accelerometer and other accessories.

The results are obtained and are compared with the results obtained for healthy gear pair. The results obtained are compared different features like RMS, variance etc, FFT power spectrum and computational techniques.

2. Objectives

The objectives of my project are as follows:

1. **Learn to operate and applications of MFS machine**: MFS machine is an innovative tool for common machinery fault signature without compromising with production and it is a versatile machine in which we can use for analyzing fault of different components like gear, bearing, compressor, pump etc. This machine is frequently used in industries for fault diagnosis.
2. **Fault detection by feature extraction**: To detect the faults in gearboxes with healthy and worn pinion by comparing its feature like RMS, Variance, Crest factor, Kurtosis.
3. **Fault detection by FFT spectrum:** To observe and study the change in vibration signature in FFT spectrum for healthy and worn pinion and find the fault conditions.

In this project, my main motive is to identify the fault of gearbox with different methods which can be helpful to apply in for worn pinion. Because fault identification of the worn pinion is tough to identify as it is similar in to healthy pinion in before complete wear in this type of gear.

3. Vibration-based Fault Detection

3.1 Why Fault Detection of Gearbox ?

A large amount of research has been carried out into the fault detection of gearboxes, but it is a fact that remote gearbox fault detection under different operational conditions (different load and speed) has not been studied in depth. Most of the published research either investigates fault detection at constant load and speed. This project will attempt to use the vibration signals collected from bevel gearbox under different load conditions and shaft speeds. The effect of operational conditions on the vibration signals will be examined by recording vibration signals at different shaft speeds, 600 rpm to 900 rpm and at different loads ranging from 0% load to 80% of the full load.

3.2 The importance of fault identification for maintenance:

It has been estimated that US industry has spent more than $300 billion a year on plant maintenance and repair, and the vast majority of this huge sum has been used to correct chronic and catastrophic failures of machines and systems. Although chronic failures may be small and invisible, because they occur more frequently, they are more costly than catastrophic failures which, while dramatic and even fatal, are much rarer occurrences. Both types of failure can cause severe disruption to work schedules, lower product quality, increase costs, and increase risk to machine operators. Downtime, because it can halt production, often exceeds maintenance costs by many magnitudes. Regular maintenance can reduce downtime by minimizing failures, and so increase productivity and improve operational safety.

The most common methods of managing maintenance operation and maintenance practice are reactive maintenance, preventive maintenance and predictive maintenance. Historically, industrial plant was maintained and repaired either when it developed a fault (reactive) or according to rigid and inflexible timetables. However, advances in computer technology have allowed many industries to implement responsive periodic time-based preventive maintenance strategies. By the 1990s, advances in technology enabled the development of cost-effective instrumentation and technologies for predictive maintenance, allowing the identification of machine problems by measuring the condition of the machine and predicting maintenance requirements.

3.3 Vibration analysis for fault diagnosis of bevel gearbox:

Due to the industrial importance of gears in power transmission systems, the effective condition monitoring of gearboxes is essential and for condition monitoring, Fault identification of gearbox is necessary. There is constant pressure to improve measuring techniques and tools for the early detection of gearbox faults.

The gears themselves are the most important elements in the gearbox, and the degree of wear and fatigue to which they are subjected even under normal operating conditions means that they are often subject to premature failure [8].

As the teeth mesh, the vibration will travel via the gear to the mounting shaft, to the bearings and to the gear casing where it is detected, usually by an accelerometer. As the vibration travels from the point of generation to the accelerometer on the gear casing it will be attenuated and contaminated by vibrations from a multitude of other sources. Thus the detected signal will usually need processing and, possibly, filtering.
Analysis of vibration signals is very appropriate for monitoring gearboxes because any change in the vibration signature of the gearbox is most likely a result due a change in gearbox condition. This is because as defects on a gear will alter both the amplitude and phase modulations of the gear’s vibrations. Thus, any changes in vibration signal can be analysed to provide an indication of possible faults [8].

Most natural phenomena are non-linear and the majority of these signals have varying frequency content. The vibrations of multi-stage gearboxes contain non-stationary transients, e.g. the short periodic impulsive components produced by impacts between components. Typically, vibration signals generated in gearboxes will contain three main components, (1) periodic components such as those resulting from interactions between the gears during meshing, transient components caused by short duration events, such as repeated impacts due to a tooth having broken off, and (3) broad-band background noise. In the early stages of damage and fault initiation, the resulting low amplitude vibration signal will be masked by other sources present in the gearbox and cannot therefore be used directly for damage detection. However, it is precisely at this stage that detection of these faults is important. As a result, more effective signal processing methods are required to better analyse vibration measurements and more reliable gearbox fault detection.
Analysis of the time-domain signal uses statistical parameters such as variance, root mean square (RMS), kurtosis and Crest factor (CF) and their use is well established in assessing the condition of gears [6].

These measures are suitable for detection when mechanical faults take the form of impulses which impose periodic pulses of short time duration (wide frequency bandwidth) onto the base vibration signal [8].
However, the most common method used for detection of gear failure is spectral analysis of the vibration signal in the frequency-domain. This is because the most important elements in the vibration spectra of gears are: the tooth meshing frequency, harmonics and sidebands (due to modulation phenomena) located on either side of the gear tooth meshing frequency. The sidebands are separated by integer multiples of the gear rotation frequency. The behaviour of these sidebands can be strongly indicative of the presence of a fault, e.g., through an increase in the number of sidebands and their relative amplitudes.

The first three gear meshing harmonics and their sidebands provided sufficient information for gear fault identification [9].

Thus tracking and monitoring changes in the amplitude of particular sidebands in the spectrum can provide a good predictor of gear failure. In practice, it is often difficult to extract meaningful information from vibration spectra based on a simple Fourier Transform (FT) of time-domain to frequency-domain. In the early stages of fault development, important defining frequencies have low amplitude and can be masked by other vibration sources or buried in background noise [8]. This is particularly relevant because the individual vibration impulses generated by gear defects typically tend to be of short duration causing the corresponding frequency pulse to spread over a wide frequency band with low amplitude [9]. It can also be very difficult to identify a particular frequency indicative of a defect when a large number of spectral components are present.
Today, combined time and frequency analysis is increasingly used in gear fault identification and is gradually replacing conventional time-domain analysis and frequency-domain analysis. Representing the signal in the time and frequency-domains simultaneously is a powerful tool for examining non-stationary vibration signals and the results can be easily interpreted. Wang and McFadden claim that it is relatively easy to characterise the local features of the signal, and all distinctive components in the frequency range of interest, their sequences causality and changes with time can be displayed on a single chart [10].

3.4 Bevel Gear:

The bevel gear is often used to transfer power from one shaft to another when shafts are at 90°. The teeth of these gears are formed on a conical surface and normally the two shafts would be at right angles to each other and “intersect” at the apex of the cone. Bevel gears have teeth that are cut straight, and are all parallel to the line pointing to the apex of the cone on which the teeth are based. However, they cannot be used for parallel shafts and can be noisy at high speeds [1].

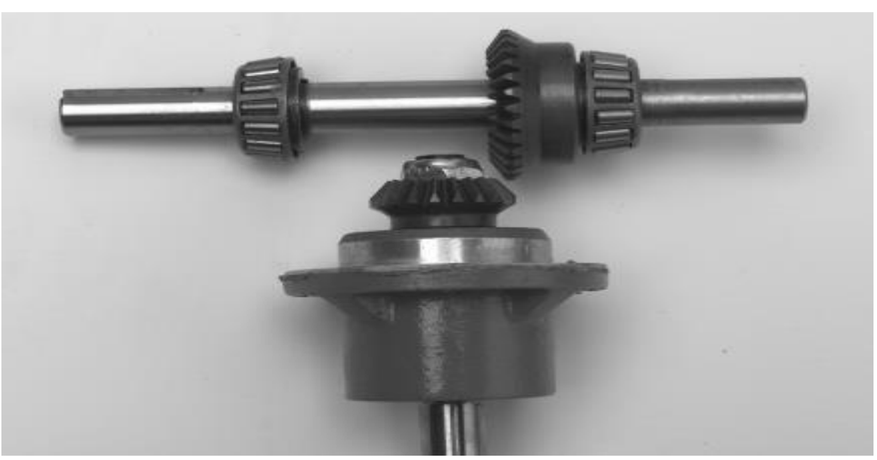


Fig-1

3.5 Gear Failures:

Gear failures tend to occur when a gear is working under high stress conditions [3]. Local faults are the more dangerous because they tend to develop rapidly once initiated, and usually have significant effects on power transmission. If not detected early there can be dramatic consequences with tooth breakage, pitting and scoring are the most important local faults.

A typical distributed gear fault is tooth wear. Wear occurs when layers of metal are removed more or less uniformly from the surface and can take two forms:

Adhesive Wear: characterized by transfer of metal particles from one tooth to its mating tooth by welding action.

Abrasive Wear: caused by to abrasive particles in the meshing area.

3.6 Gear vibration and modulation:

Nowadays, vibration measurement is the most common technique for monitoring the fault detection of gear transmission systems. Signals from accelerometers mounted on gearboxes have a distinct frequency spectrum dependent on internal meshing dynamics. Since the gear transmission system is periodic, its spectrum contains components at shaft frequencies and associated harmonics, as well as the fundamental gear mesh frequencies and harmonics. These are considered the regular components of the system.

Ideally, in the absence of defects, gear systems are dominated by the regular component and the Gaussian noise floor resulting in smooth and uniform power transmission and angular motion. Any deviation from the ideal causes variation in the transmitted power which results in a fluctuating force between the meshing teeth. Even when the gear speed and load are constant there can be a varying force on the gear. If the teeth on a pair of meshing gears are not perfectly rigid, the contact stiffness will vary periodically both with the number of teeth in contact and the position of contact on the tooth surface. The varying force will excite a vibration at the tooth meshing frequency [4].

Gear meshing frequency, GMF can be found out by

$$GMF = f \times T$$

Where, f= Shaft rotation frequency

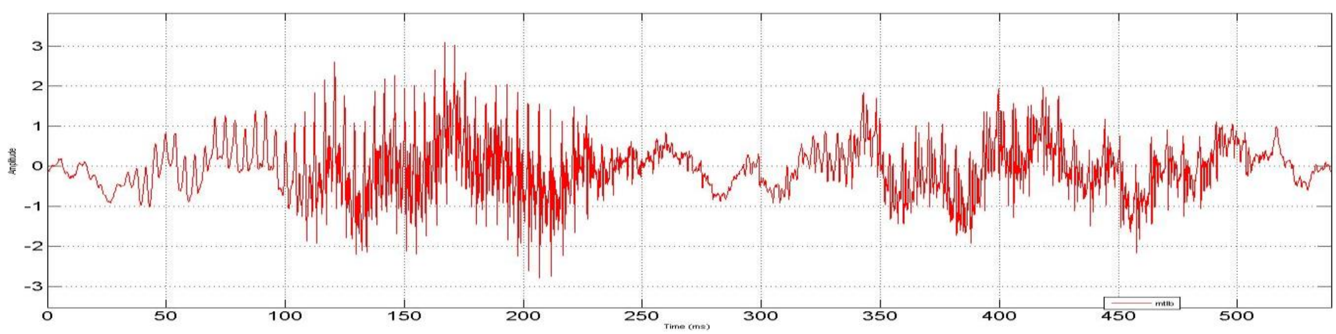
T= Number of teeth in gear

4. Literature Review

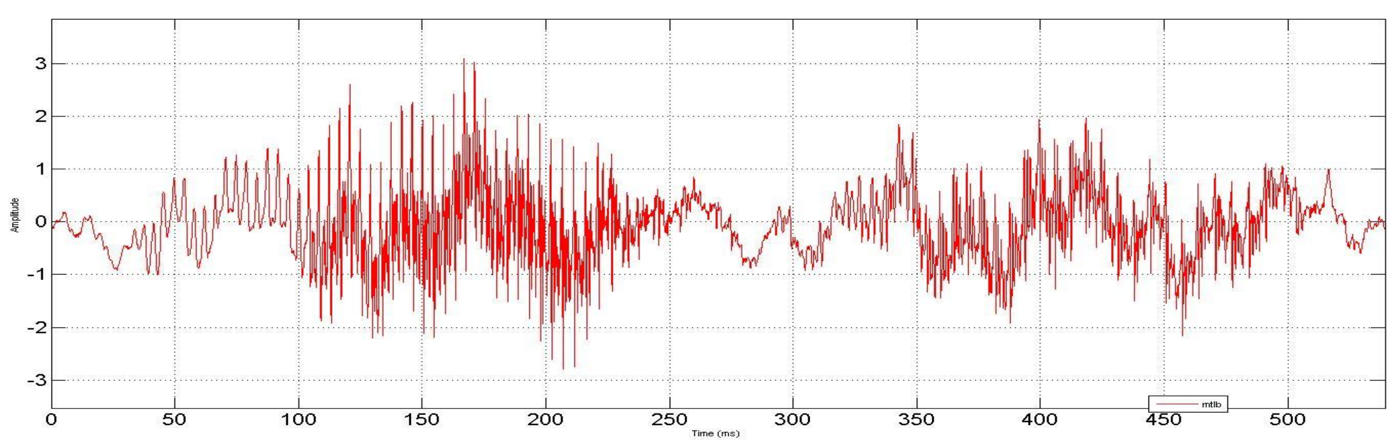
This chapter presents a literature review of signal processing techniques which are used identification of faults in geared transmission systems based on vibration signals. Relevant techniques are briefly discussed here to assist the understanding of the results presented in the following chapters of this thesis.

4.1 Time-domain Analysis:

Time domain analysis of vibration signals is one of the simplest and cheapest fault detection approaches. Conventional time-domain analysis attempts to use the amplitude and temporal information contained in the gear vibration time signal to detect gear faults. The amplitude of the signal can be used to signal that a fault is present and the periodicity of the vibration can then indicate a likely source for the fault. Time domain approaches are appropriate when periodic vibration is observed and faults produce wideband frequencies due to periodic impulses [8]. Use of the waveform enables changes in the vibration signature caused by faults to be detected. The gearbox vibration waveform for healthy and faulty gear systems are shown below.



Amplitude- Time waveform of healthy gear



Amplitude- Time waveform of faulty gear

Some mechanical systems generate high vibration levels throughout their operation. When these systems develop a progressive fault, the resulting vibration level is likely to increase consistently with time but the increase in vibration may be very small and difficult to identify. If the rate of development of the fault vibration is small, it may not be possible to clearly determine a fault symptom from variations in the waveform of the signal [5].
Mechanical systems are termed deterministic if their properties such as displacement, acceleration, etc. can be predicted over time. Mechanical systems such as a gearbox with a localised fault reveal characteristics which cannot be estimated over time. The characteristics of such systems, termed random or non-deterministic, cannot be accurately predicted, but they can be estimated by statistical parameters and these parameters can be used to predict fault progression [6].

Statistical indicators, which are commonly used for mechanical fault detection and based on the time-domain waveform include: Variance, Root Mean Square (RMS), Kurtosis and Crest Factor (CF) [4]. These indicators are also referred to as "condition indices", [5]. The vibration signal from a gearbox is processed and a single value returned to indicate whether its condition is within normal operating parameters or not.
The condition index should increase as the fault increases; indicating the deteriorating condition of the gearbox. Sometimes this analysis can be performed by simple visual observation of the vibration time-domain waveform, but it is more likely that the time-domain signal will be processed to provide a statistical parameter (feature) which bears a known relation to the severity of the vibration.

4.2 Variance:

It would be useful to have a measure of scatter that has the following properties:

1. The measure should be proportional to the scatter of the data (small when the data are clustered together, and large when the data are widely scattered).
2. The measure should be independent of the number of values in the data set (otherwise, simply by taking more measurements the value would increase even if the scatter of the measurements was not increasing).
3. The measure should be independent of the mean (since now we are only interested in the spread of the data, not its central tendency).

The variance (σ^2) is a measure of how far each value in the data set is from the mean. Here is how it is defined:

1. Subtract the mean from each value in the data. This gives you a measure of the distance of each value from the mean.

2. Square each of these distances (so that they are all positive values), and add all of the squares together.
3. Divide the sum of the squares by the number of values in the data set.

The Equation Defining Variance

Now that you know how the summation operator works, you can understand the equation that defines the variance:

4. $$\sigma^2 = \frac{\sum (X - \mu)^2}{N}$$

The variance (σ^2), is defined as the sum of the squared distances of each term in the distribution from the mean (μ), divided by the number of terms in the distribution (N).

4.3 The Root Mean Square (RMS):

RMS is related to the energy of the signal and the presence of defects can be directly detected by the increase in the vibration signal [5].

The RMS is the normalized second central moment of the signal; it is used for overall vibration level measurements [4]. It can be effective in tracking system noise, but it does not give meaningful information to identify which component is failing.

RMS can be defined as

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(x(n) - \bar{x}\right)^2}$$

$$\bar{x} = \frac{1}{N}\sum_{n=1}^{N} x(n)$$

where ; N is the number of samples taken in the signal

x(n) is the amplitude of the signal for the nth sample

x is the mean value of the N samples.

From this definition it is clear that RMS is not sensitive to sudden short duration, isolated peaks in the signal and, thus is often not sensitive enough to detect incipient tooth failure. RMS becomes more useful as tooth failure progresses and is a measure of the overall vibration level of the system. It is therefore considered a very good descriptor of the overall condition of gearboxes and is sensitive to changes in operational conditions such as load and speed [5].

4.4 The Crest Factor:

The overall vibration level does not produce any essential information about the waveform of the vibration signal. With several types of gear fault, the shape of the signal is a better indicator of damage rather than the overall vibration level. CF is the ratio of the peak value of the input signal to the RMS value. It is useful in detecting the change in the signal pattern due to impulsive vibration sources such as tooth breakage in the gear and is typically used on the raw vibration signal. A discrete fault on a gear will theoretically generate an impulsive (short duration) signal during meshing.

The peak value of the impulsive signal will increase as the damage grows while the RMS level of the overall acceleration (vibration) will change only slightly because the time over which the impulse acts does not significantly increase [6]. CF is useful for detecting discrete impulses above the background signal which do not occur frequently enough or have sufficient duration to significantly increase the RMS level.

Crest Factor can be defined as

CF= PV/RMS

Where PV is peak value and RMS is root mean square.

4.5 Kurtosis:

Kurtosis is a non-dimensional quantity used to detect the presence of significant peaks in the time-domain of the vibration signal. Kurtosis is the 4th order statistical moment of the vibration signal, and because it raises the signal to the fourth power it effectively amplifies the isolated peaks in the signal [61]. The normalized kurtosis for a distribution x(t) given by its sample values *xi,….,xN* measured at times *ti,…., tN* can be defined as

$$kurtosis = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^4}{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2\right]^2}$$

The higher the kurtosis value the sharper the peak(s), and the longer the tails of the signal. The lower the kurtosis, the more rounded the peak(s).

When the vibration signal is random noise, then it follows Gaussian (Normal) distribution and has a kurtosis value equal to 3.0 and -1.5 for a pure sine wave. A vibration signal collected from a healthy gear usually shows a uniform pattern and the value of kurtosis is approximately 3.0 or lower. As the gear fault progresses, kurtosis increases indicating that the distribution of the vibration is no longer a Gaussian distribution. This is primarily due to impulses (isolated peaks with high amplitude) generated by the affected gears. Consequently, kurtosis is commonly used as a parameter for the detection of gear faults [6].

4.6 Frequency Spectrum Domain Analysis:

Frequency-domain analysis is a powerful conventional technique for vibration analysis and has been demonstrated as a useful tool for detection and diagnosis of faults in simple rotating machinery. Using this technique, the time-domain of the vibration signal is transformed into its frequency equivalent. It has been found that the spectral content of the measured signal is often much more useful than the time-domain for determining gear condition because the complex time-domain signal can be broken down into several frequency components. It is therefore easy for analysts to focus on these frequencies which are valuable in fault diagnosis [4], whereas the overall vibration is a measure of the vibration produced over a broadband of frequencies; the spectrum is a measure of the vibrations over a large number of discrete contiguous narrow frequency bands. Thus the common approach to vibration CM is use the Fast Fourier Transform (FFT) to transform the vibration signal to the frequency domain. This approach is perfectly acceptable if the measured signal does not vary in spectral content over time (i.e. no variations in the rotational speed of the machine). For machines operating with known constant speed, the vibration frequencies of the vibrations produced by each component in the machine can be estimated. Therefore, any change in vibration level within a particular frequency band can be related to a particular component. Analysis of relative vibration levels at different frequency bands can provide some diagnostic information.

Sidebands generated by either amplitude modulation or frequency modulation of the vibration signal often provide useful information. Amplitude modulation is attributed to tooth fracture or eccentricity of the gear or shaft with a damaged tooth generating pulses at a rate equal to the gear speed. Frequency modulation, on the other hand, is caused by errors generated during gear manufacture (e.g. non-uniform tooth spacing). As previously stated, Randall has claimed that the first three gear meshing harmonics and their sidebands provide sufficient information for the successful identification of gear faults [6].

Therefore, changes in the amplitude of a particular frequency peak or sidebands of a signal can provide a good indicator of potential gear failure. In practice, the spacing of the sidebands depends on periodic properties of the loading and on the transmission path, it can be difficult therefore to extract useful features directly from vibration spectra based solely on a FFT. When the signal to noise (S/N) is low and the vibration spectrum has a large number of frequency components due to the complexity of the system, it becomes almost impossible to distinguish the peaks due to faults from peaks from other sources. This is the most difficult problem associated with the FFT based fault detection approach.

4.7 Meshing Frequency Characteristics:

Every gear set generates a unique profile of frequency components which is highly dependent upon the speed of rotation of the participating gears [6]. The gear-mesh frequencies can appear as transients in the spectrum when the transmission is subjected to angular acceleration and as harmonics when the transmission is operating at a steady speed.

The fundamental gear-mesh frequency is the product of the number of gear teeth and the speed of rotation of the gear. The amplitudes of the gear-mesh frequency components are a strong function of the torque transmitted by participating gears, and any modulating effects on them.

4.8 Sidebands Characteristics:

Vibration spectra of machines have their energy distributed in multiple frequencies. In geared transmission systems, mesh-force modulation is a phenomenon which is commonly observed. The modulation processes transfer energy from the actual frequency to the sidebands around both sides of the gear mesh fundamental frequencies and their harmonics. In rotating systems, multiple sidebands are observed about each harmonic which are symmetrically spaced about the harmonics and decay exponentially as they separate further away from the gear-mesh frequency. The sidebands need not be symmetric. When analysed in detail, this spectral information provides significant information about gear tooth condition as well as fluctuations in the drive system and condition of the gearbox bearings [6].

Sidebands can be caused by amplitude modulation or frequency modulation, or a combination of both. The modulating components often manifest as sidebands surrounding the gear-mesh harmonics. Sideband

structures are often observed in the measured vibration signatures of rotating machinery such as gearboxes. Such spectral information is usually used for gear fault identification [7].

5. Experimentation

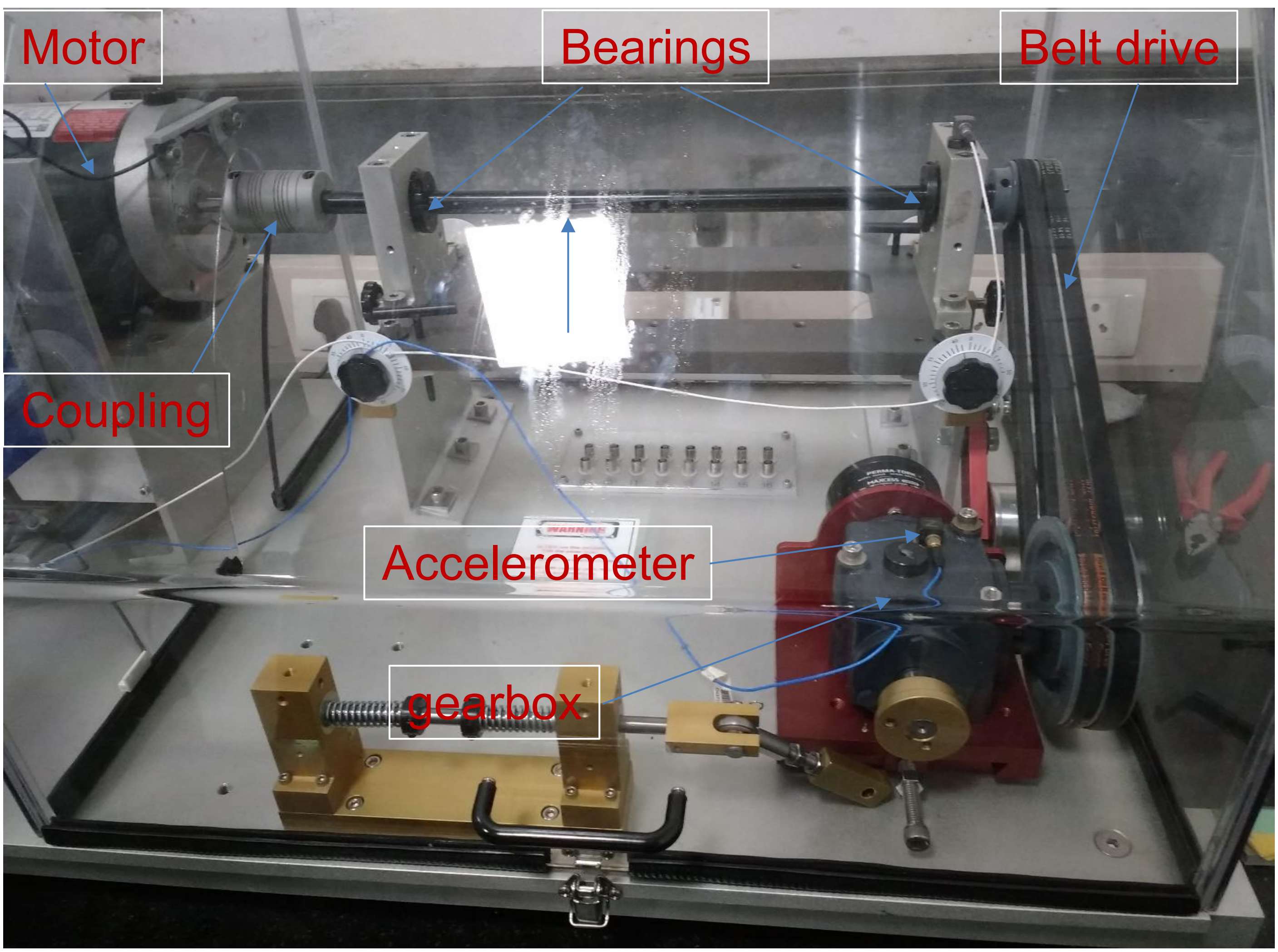
This chapter describe the experimental facility and fault identification for the experimental study of gearbox vibrations. It starts by describing the experimental setup components and summarising the main specifications of the gear under test conditions. It then explains the instrumentation of the vibration measurement by describing each component involved.

Finally, the baseline data of the vibration are evaluated under different operating conditions using manual methods to get vibration signals which are referenced for comparison with more advanced methods.

5.1 Experimental Setup:

In order to evaluate gearbox fault identification techniques, experimental work was carried out on MFS machine at IIT Indore, India. The experimental setup of MFS machine shown below:

Fig-2



The setup of machinary fault simulator machine consists of following tools:

1. 3 phase, 1 HP motor
2. Bevel gearbox
3. 3/4" diameter, steel shaft
4. Horizontally split bracket bearing
5. Coupling
6. Belt drive
7. Accelerometer mounted on gearbox

It was chosen for this research not only because it is widely used in industry, but also because it allows easy simulation and fault detection to be extensively evaluated.

5.2 Features of gear and Pinion wheel:

Parameters	Gear wheel	Pinion wheel
No. of teeth	27	18
Pitch diameter	1.6875 inch	1.125 inch
Pitch angle	56 degree	34 degree
Pressure angle	20 degree	20 degree
Tolerance	0.001-0.005 inch	0.001-0.005 inch
No. of bearings	03	01
Material	Forged steel	Forged steel

Above table shown the features of gear and pinion wheel which I have used in my experiment in both healthy and faulty conditions. The main features of these gears is for power transmission when two shafts are perpendicular to each other.

5.3 Vibration Measurement Instrument:

The most commonly used transducer for vibration measurement is the piezo-electric accelerometer. This sensor gives stronger signals in a wide frequency range to capture vibrations from different sources such as shaft rotations with a frequency as low as several Hz and gear mesh processes with frequencies as high as several thousand Hz. The piezo-electric accelerometer also has high sensitivity for measuring low amplitude signals such as incipient faults. In addition, it is relatively small in size, highly durable, with good measurement stability and linearity [2].

The piezo-electric accelerometer consists of three main parts: the base, piezo-electric crystal and a series of seismic masses [2]. The piezo-electric crystal works as spring when placed between the seismic mass and the accelerometer base. The seismic masses vibrate with the same magnitude and phase as the accelerometer base. When the accelerometer is subjected to vibration, the seismic mass mounted on the crystal exerts a force on the piezo-electric elements equal to the product of their mass and acceleration (F=ma). This force causes the piezo-electric crystal to generate a charge proportional to the acceleration level to which it is exposed. The charge can be applied by either an external or an internal charge amplifier for signal recording. The internal charge amplifier accelerometer, also known as an ICP accelerometer, allows for longer distance transfer when compared with a transducer using external amplifiers.

The ICP transducers used in this work are low output impedance transducers containing built-in integrated circuits to convert the charge signal to a voltage signal. These are used on most vibrating surfaces because their mass does not significantly affect the movement of the surface, and possess a wide enough frequency range appropriate for measuring gearbox vibration (0.5Hz to over 10 kHz). They are environmentally robust enough to withstand the conditions existing on gearboxes and are of an adequate sensitivity.

To avoid unwanted distortion of the signal the accelerometers were rigidly attached to gearbox surfaces by glue which gives stability to accelerometer and also, I get an accurate vibration signal of the gearbox.

5.4 Data Acquisition System:

A data acquisition system is an electronic device designed to acquire data from sensor and transducers and monitor parameters such as vibration, sound, temperature, etc by conversion of physical analog quantities into digital data and rescaling them into physical quantities according to transducer sensitivities. A DAQ has two parts: hardware and software. The hardware consists of the data acquisition card and a host PC computer with control software and data storage space. The software controls the data collection process and has basic data analysis tools such as spectrum calculation for online data inspection.

The data acquisition card used in this study is a 4 band FFT analyser (Oral-34). It has 4-bit data resolution and a sampling frequency of up to 50 kHz for 4 channels.
Important parameters of the data acquisition system such as low pass (anti-aliasing) filters, quantization and sampling frequency involved in the ADC process are outlined below:

5.5 Low Pass Filter

During data acquisition the accelerometer (analog) vibration signal is passed through a low-pass filter before the signal is sampled and recorded. The anti-aliasing filter built into the data acquisition system automatically adjusts the cut-off frequency of this low pass filter according to the pre-selected sampling rate. This is to guarantee that the aliased frequencies are not digitized. During data acquisition the low pass filter was adjusted at a cut-off frequency equal to 16 kHz.

5.6 Test Procedures (variable speed and load Test):

Gearboxes are regularly operated under fluctuating or varying load conditions and the assumption that variations in the measured vibration signal (response) occur as a result of a faulty gearbox may be invalid. The change in induced load and rotating frequency is known to modulate the amplitude of the measured response. This may lead to situations where the value of a measured response of a normal (healthy) condition corresponding to a unique combination of induced load and rotating frequency of the shaft may belong to an abnormal (faulty) condition with higher levels of induced load and rotating frequency. Thus, extracting features in such situation may turn out to be tricky and future develops into a challenging task for accurate recognition of the gearbox condition [1].
Commonly, researchers who have investigated the condition of gearboxes when operated at constant loads and rotating speed do not mention the details of these conditions, the fact that a gearbox may operate at different levels of loads and rotating speeds (frequencies) has not been adequately investigated. In this work I will investigate the vibration signals originating from the gearbox at different loading conditions and shaft speeds (rotating frequencies).
This research studies the effect of different rotating frequencies of the shaft on the vibration signals. This is carried out by recording vibration signals at different shaft speeds ranging from 600 rpm to 900 rpm. To investigate the different loading conditions, vibration signals are collected at different load levels:

- 0% full load (no load)
- 20% full load
- 40% full load
- 60% full load
- 80% full load

The vibration signals were collected using 3 axis accelerometers mounted on the gearbox. The signals were collected and measured simultaneously and were sampled at 4096 Hz.
The collected signals consisted of all three axis vibration signals data: one for a healthy gear and one for faulty gear, which were all collected under the same gear operating conditions with the help of data acquisition system i.e. FFT Analyser and computer containing NV Gate software.

Fig- 3, FFT Analyser (Oral-34)

6. Methodology

There should be a proper strategy and methodology for doing any work, So in that way for this project I have make a proper plan with the help of so many journals of machinery fault which help me to identify and make my plan of my project.

The chart given below is the overview of my project strategy:

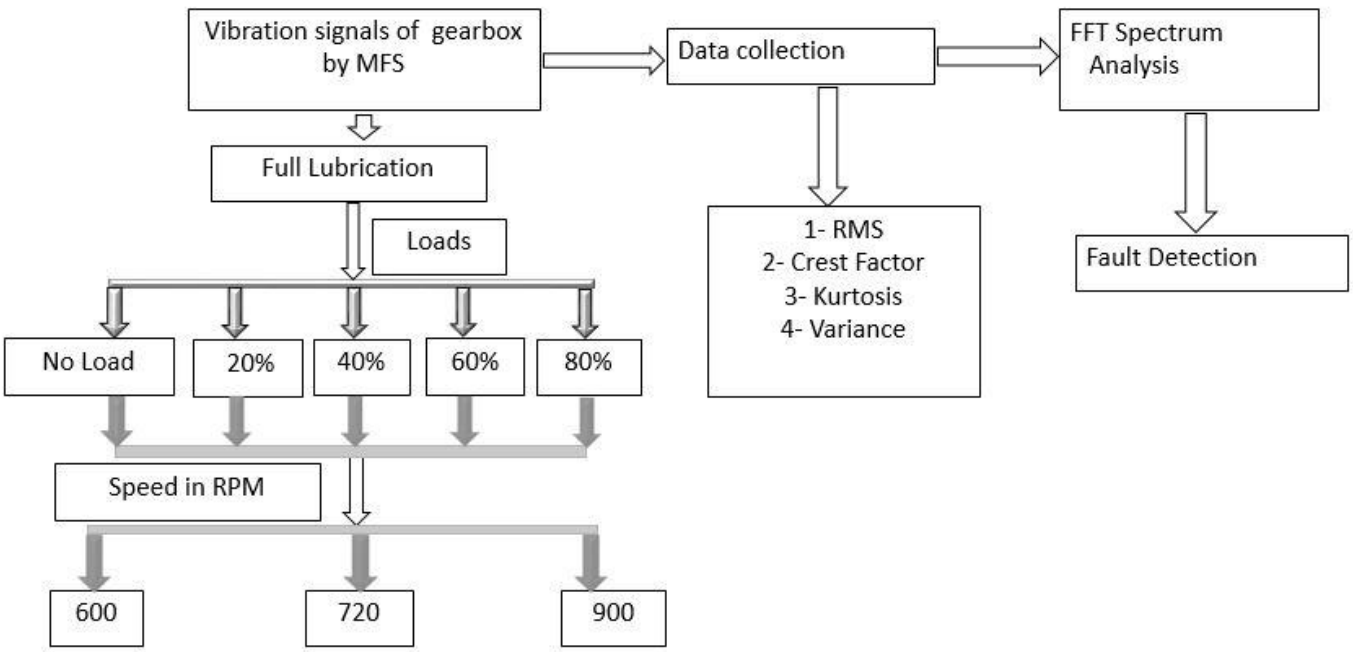


Fig- 4

7. Results and Discussions

7.1 Comparison of Features:

7.1.1 Comparison of RMS of Healthy and faulty Gear:

LOAD	SPEED (RPM)	HEALTHY PINION	FAULTY PINION
No load	600	2.8563	5.4464
	720	2.9186	7.0283
	900	3.6628	8.4476
20%	600	3.4699	5.6789
	720	3.5781	7.5765
	900	4.2969	10.2844
40%	600	3.5189	6.0519
	720	3.8901	8.5858
	900	5.2503	12.1219
60%	600	3.2670	6.0419
	720	4.3629	8.8407
	900	5.5616	12.0289
80%	600	3.9316	6.3663
	720	4.8402	10.0224
	900	6.2314	12.6377

7.1.2 Comparison of Variance of Healthy and Faulty Gear:

LOAD	SPEED (RPM)	HEALTHY PINION	FAULTY PINION
No load	600	6.8982	29.1299
	720	8.2448	49.3986
	900	13.4154	71.3643
20%	600	7.5515	32.3523
	720	12.3449	57.4058
	900	18.1753	105.7722
40%	600	10.9056	36.6225
	720	15.1054	73.7189
	900	22.1876	146.9456
60%	600	10.6736	36.5091
	720	19.0356	78.9518
	900	30.9352	144.7004
80%	600	15.4583	40.5308
	720	23.4287	100.4520
	900	38.8312	159.7177

7.1.3 Comparison of Kurtosis of Healthy and Faulty Gear:

LOAD	SPEED (RPM)	HEALTHY PINION	FAULTY PINION
No load	600	3.6979	3.5144
	720	3.3986	3.6414
	900	3.2512	3.3320
20%	600	3.5714	3.7443
	720	3.5138	4.2172
	900	3.1859	3.5555
40%	600	3.7319	3.9163
	720	3.1562	4.4919
	900	3.2049	4.8285
60%	600	4.5350	3.6717
	720	3.5231	4.5316
	900	3.2443	5.2330
80%	600	4.0877	3.5787
	720	3.6263	3.6320
	900	3.2050	5.2717

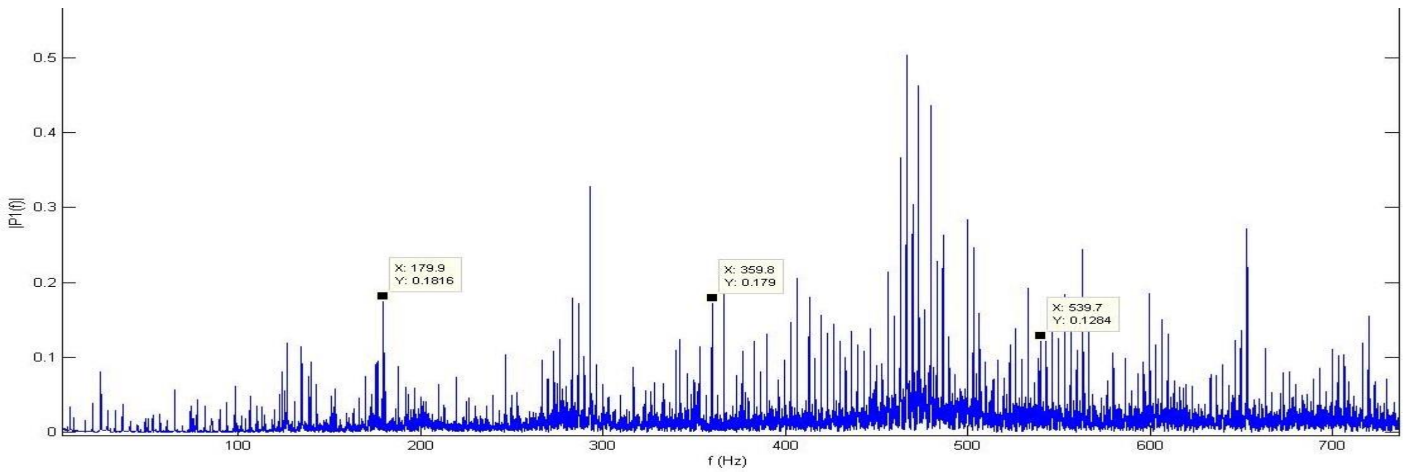
7.1.4 Comparison of Crest Factor of Healthy and Faulty Gear:

LOAD	SPEED (RPM)	HEALTHY PINION	FAULTY PINION
No load	600	5.2060	5.5236
	720	5.0096	5.6548
	900	4.8559	5.2209
20%	600	5.2946	6.6223
	720	5.1405	6.9870
	900	5.0100	5.7114
40%	600	4.8223	5.9435
	720	4.3645	6.0658
	900	4.3963	6.6373
60%	600	5.4593	6.6319
	720	4.5150	5.9379
	900	4.6893	6.7235
80%	600	4.7022	6.1917
	720	4.4081	6.4798
	900	4.2326	6.8454

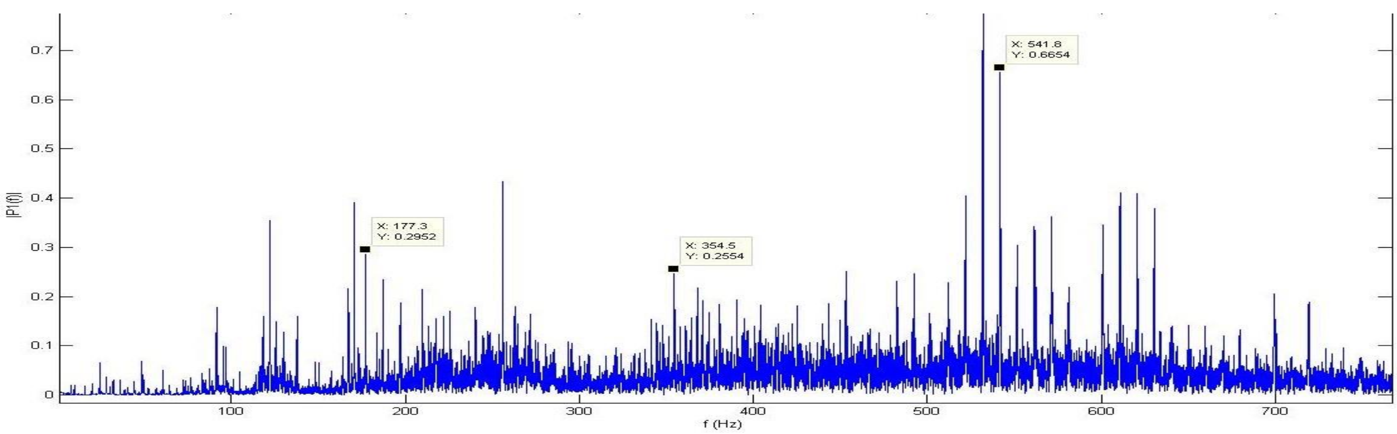
7.2 FFT Spectrum and it's comparison:

1- No load, 600 RPM:

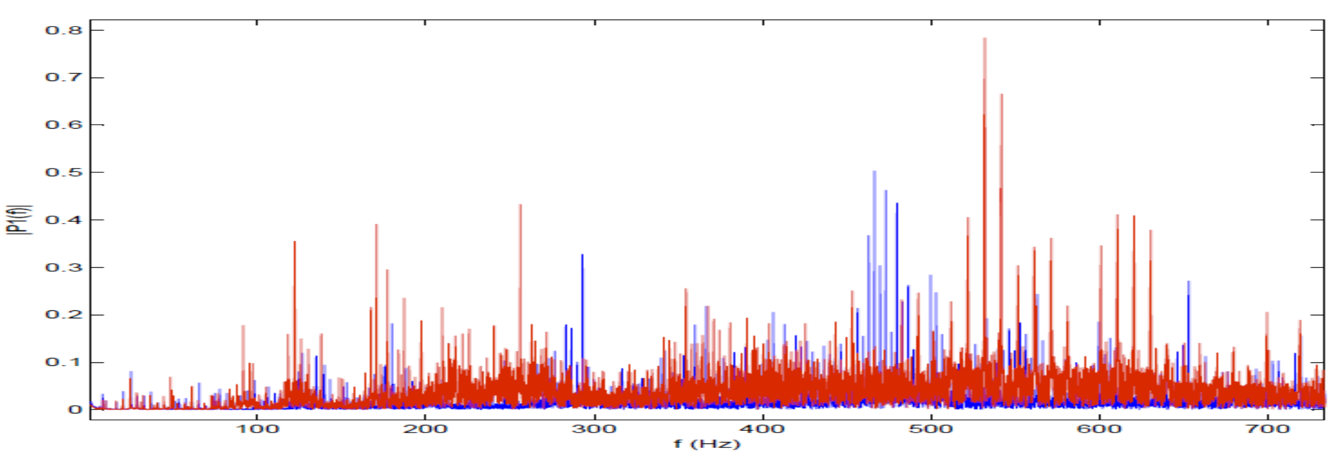
Health Pinion



Faulty Pinion

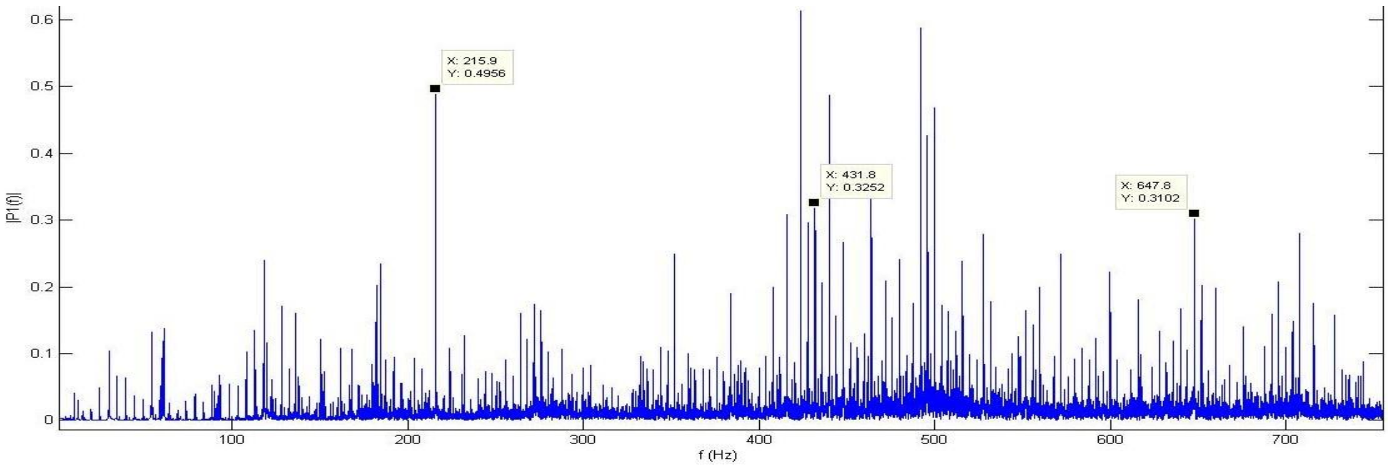


Comprarison of FFT spectrum healthy- Blue Faulty-Red

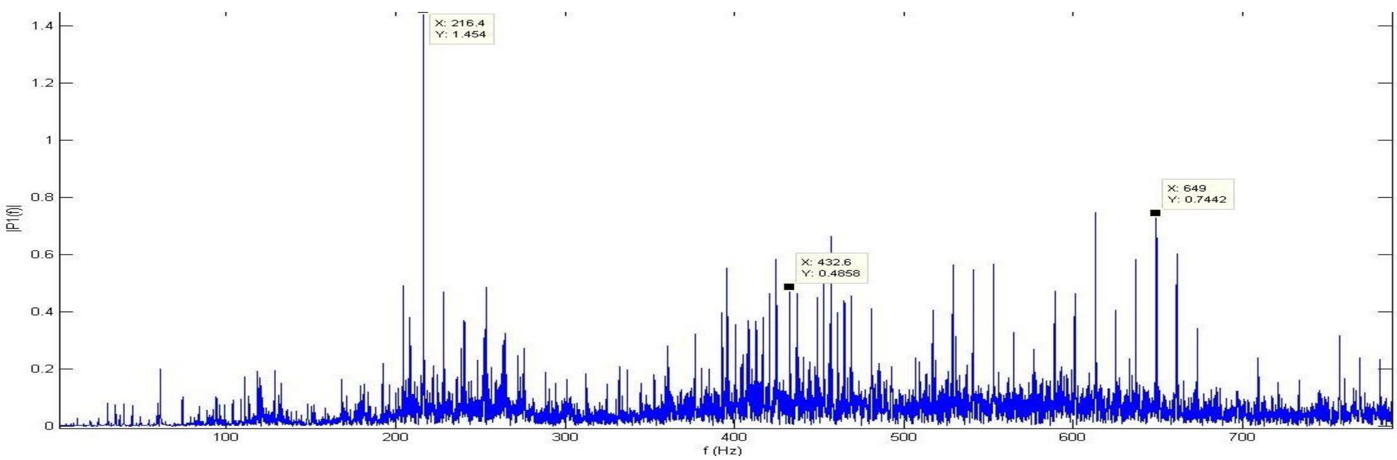


2- No load, 720 RPM:

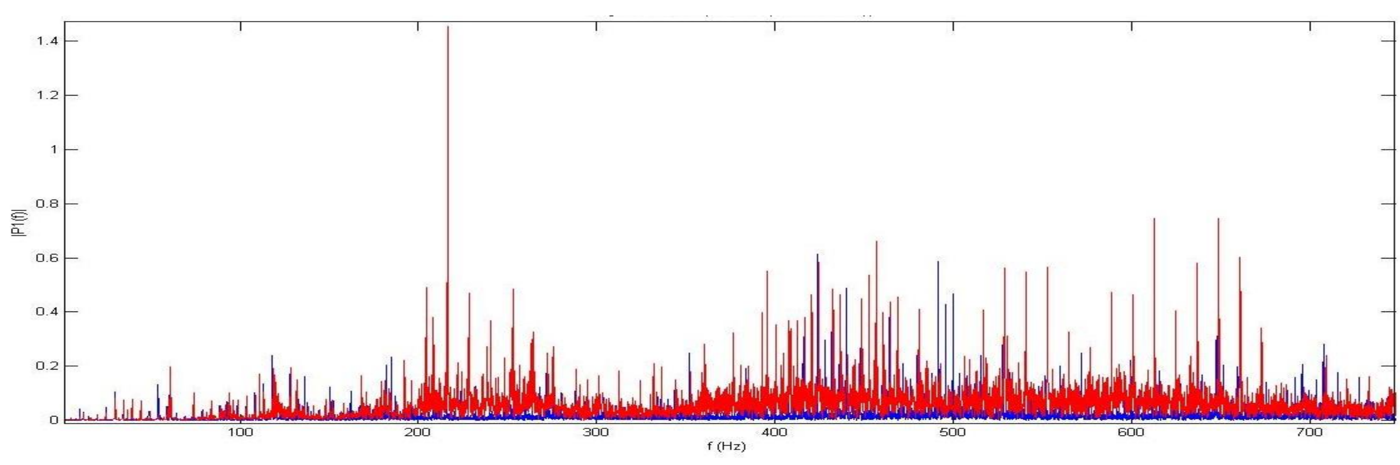
Health Pinion



Faulty Pinion

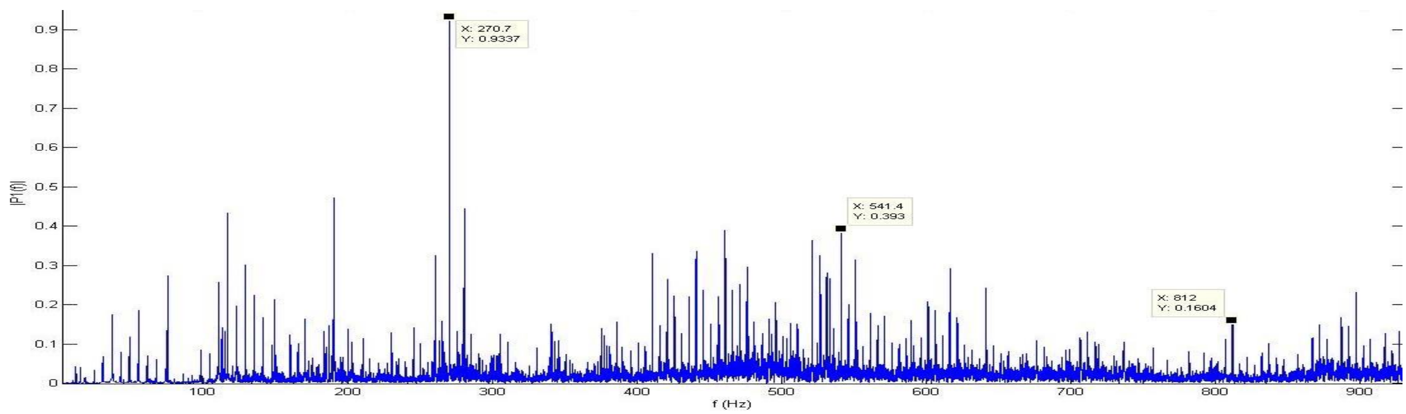


Comprarison of FFT spectrum healthy- Blue Faulty-Red

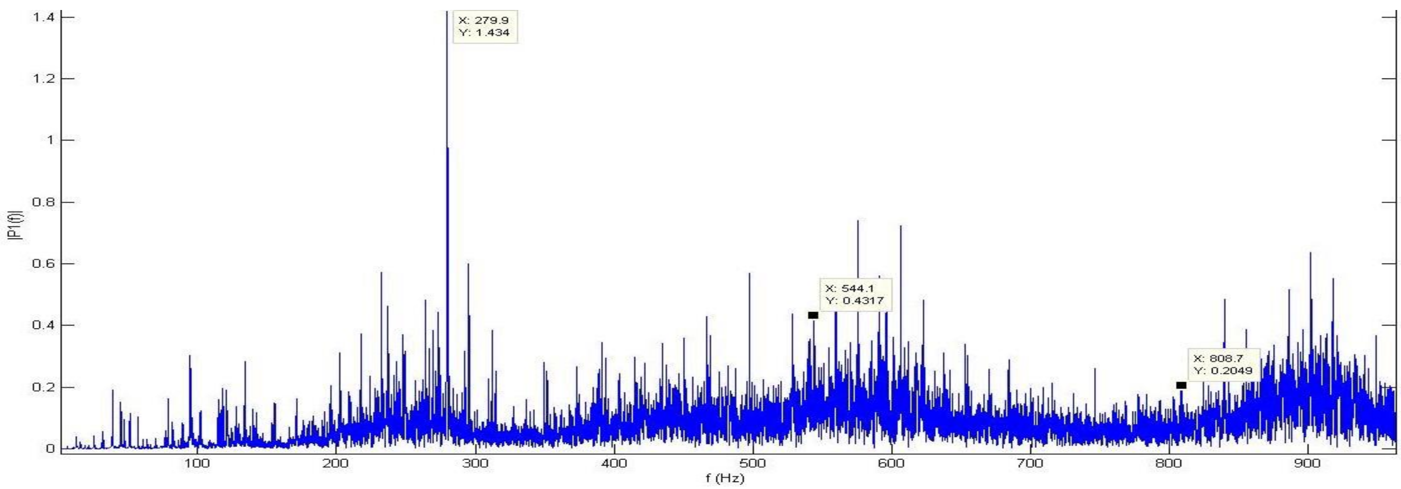


3- No load, 900 RPM:

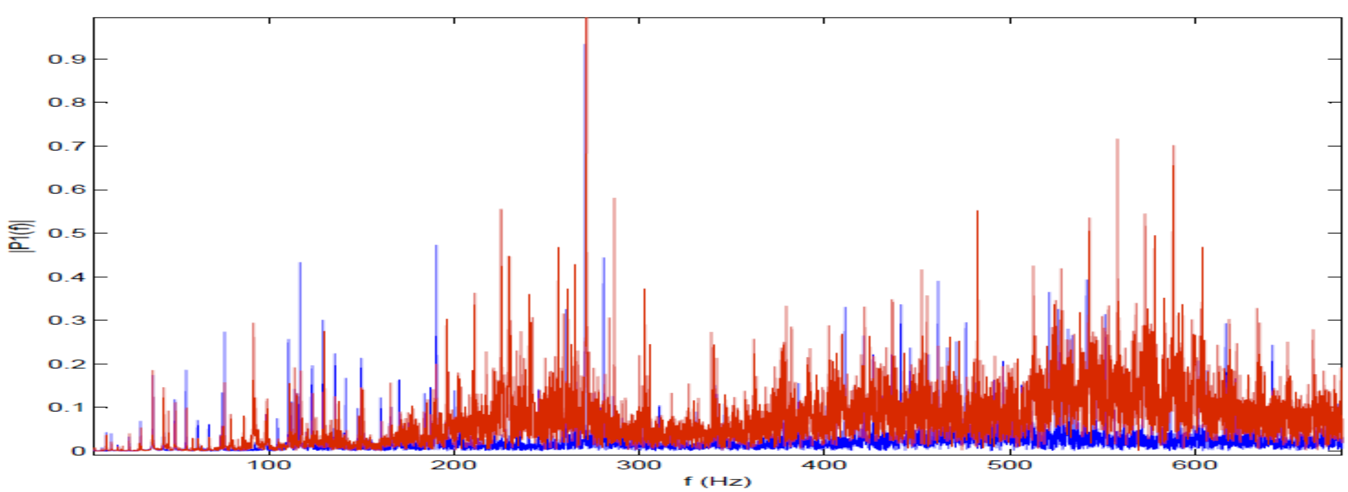
Health Pinion



Faulty Pinion

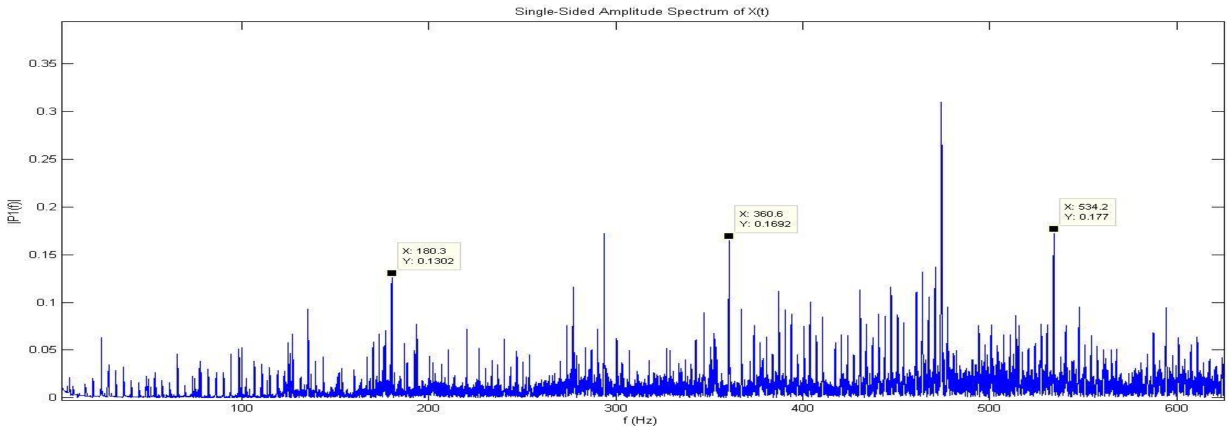


Comprarison of FFT spectrum healthy- Blue Faulty-Red

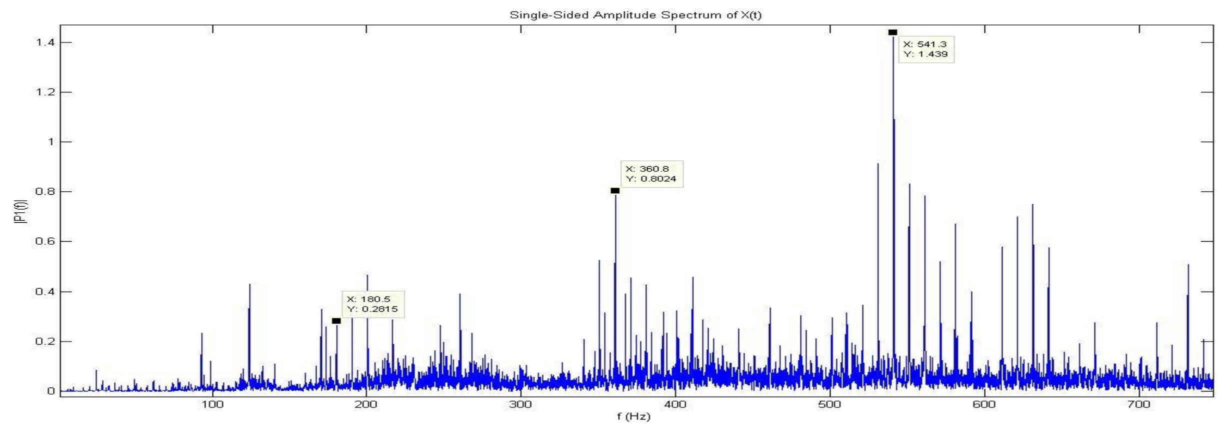


4- 20% load, 600 RPM:

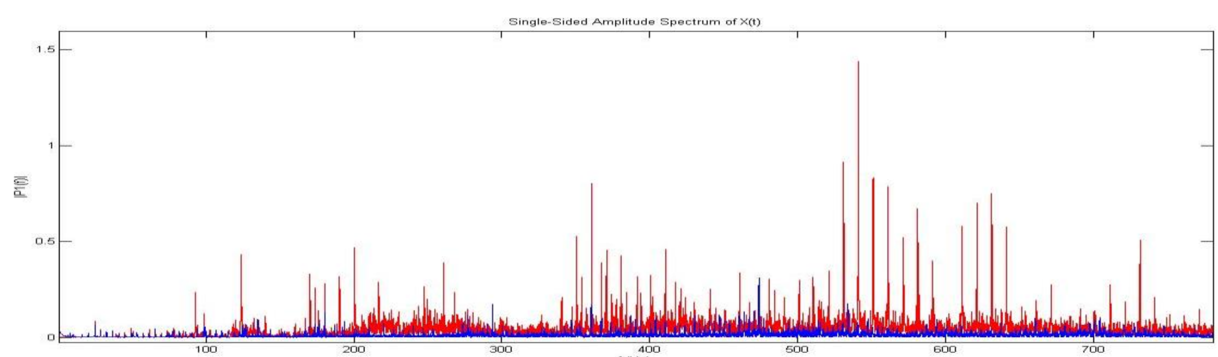
Healthy Pinion



Faulty Pinion

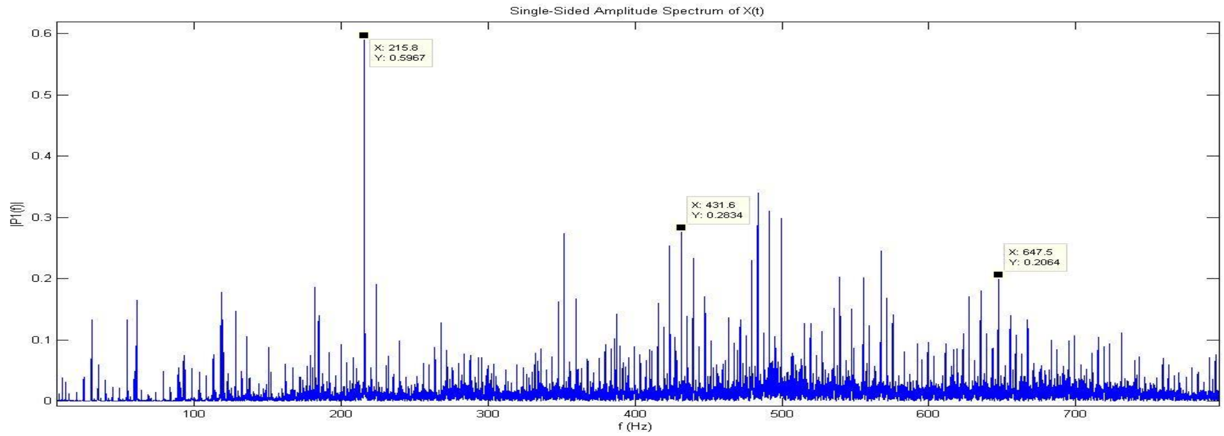


Comprarison of FFT spectrum healthy- Blue Faulty-Red

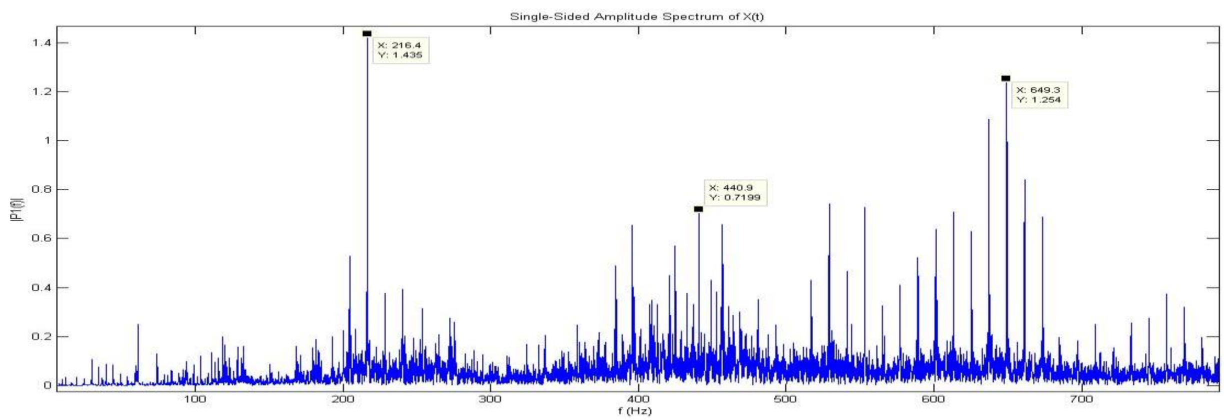


5- 20% load, 720 RPM:

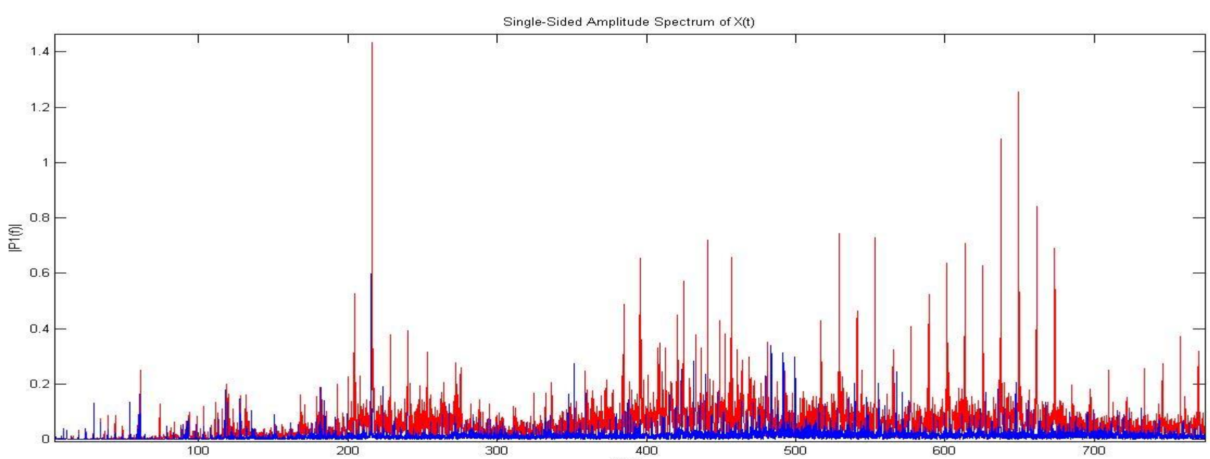
Healthy Pinion



Faulty Pinion

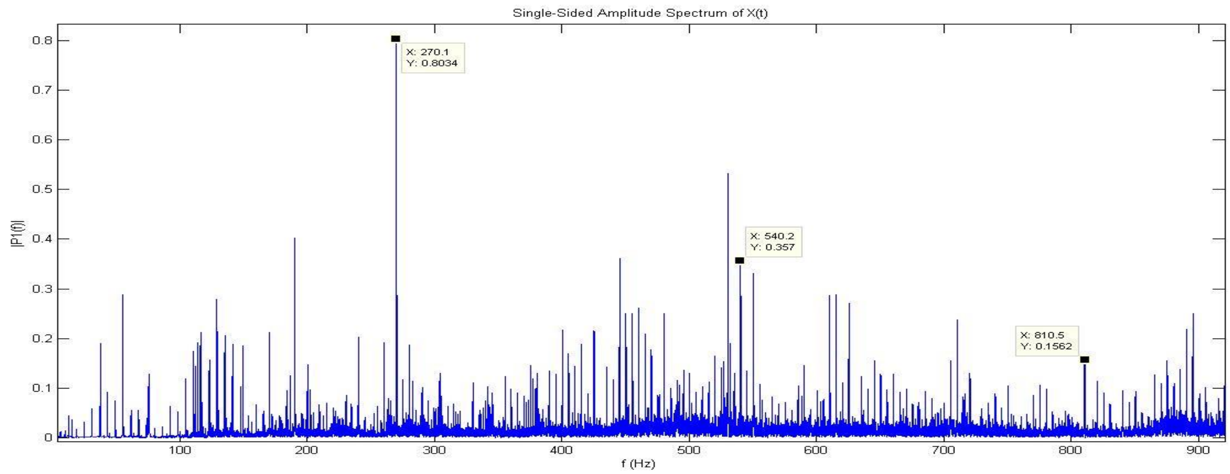


Comprarison of FFT spectrum healthy- Blue Faulty-Red

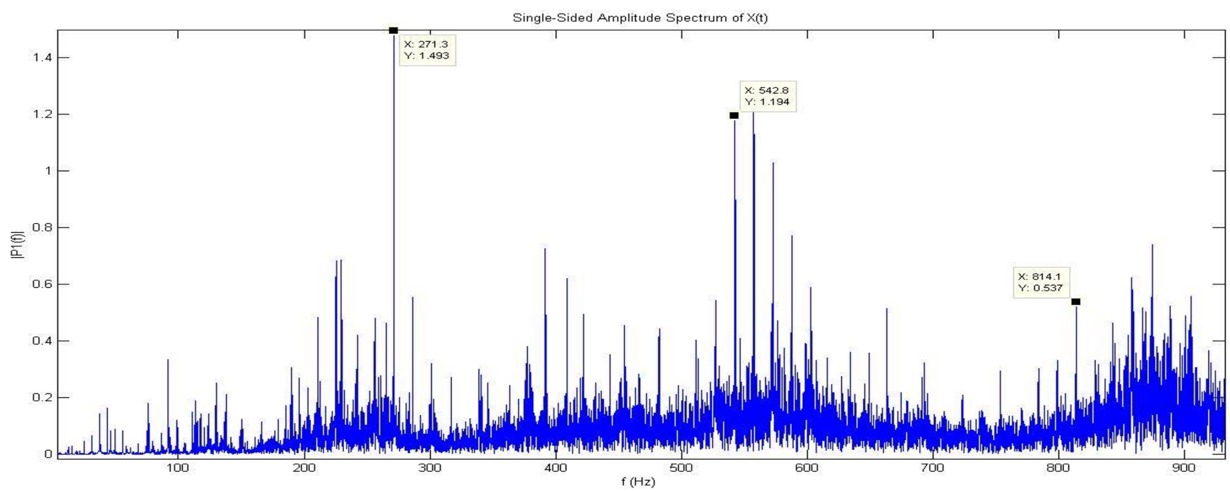


6- 20% load, 900 RPM:

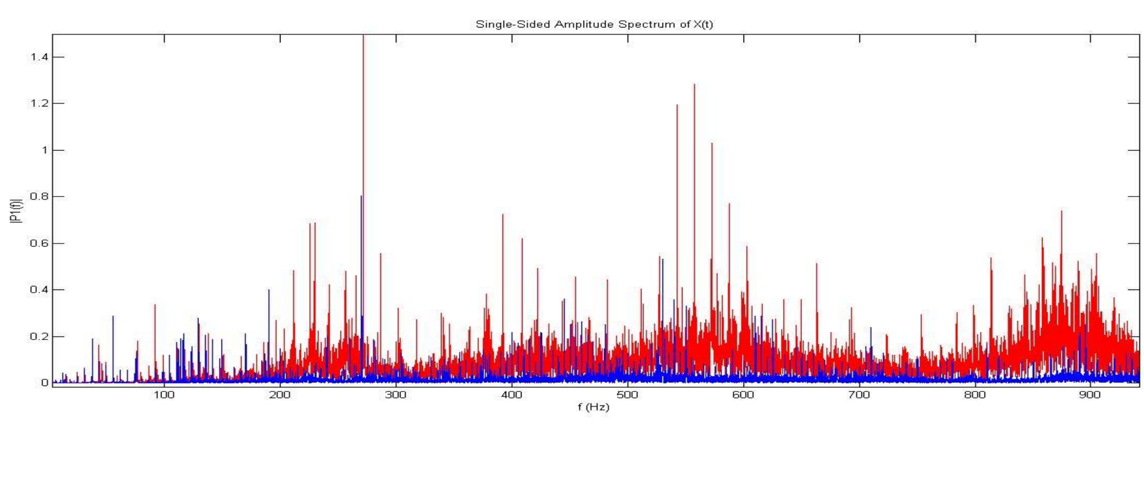
Healthy Pinion



Faulty Pinion

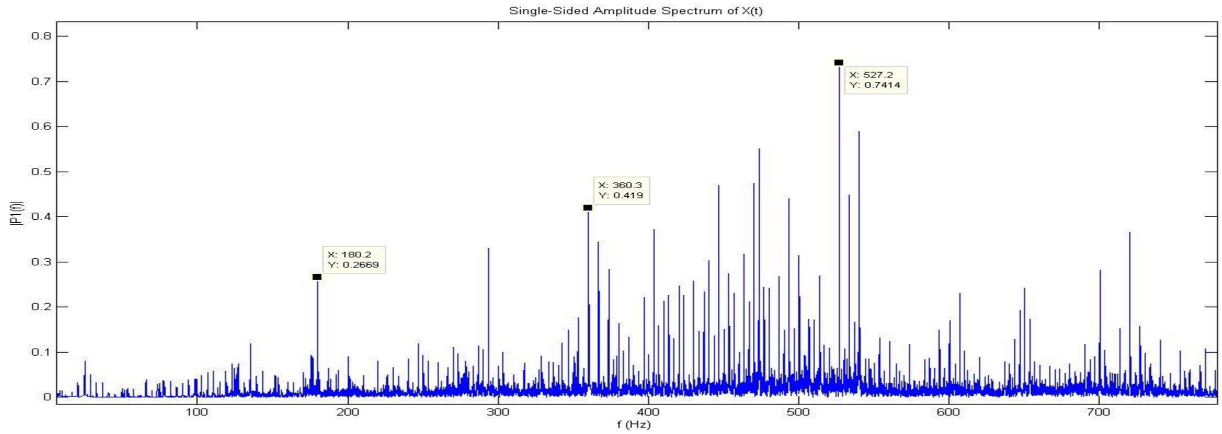


Comprarison of FFT spectrum healthy- Blue Faulty-Red

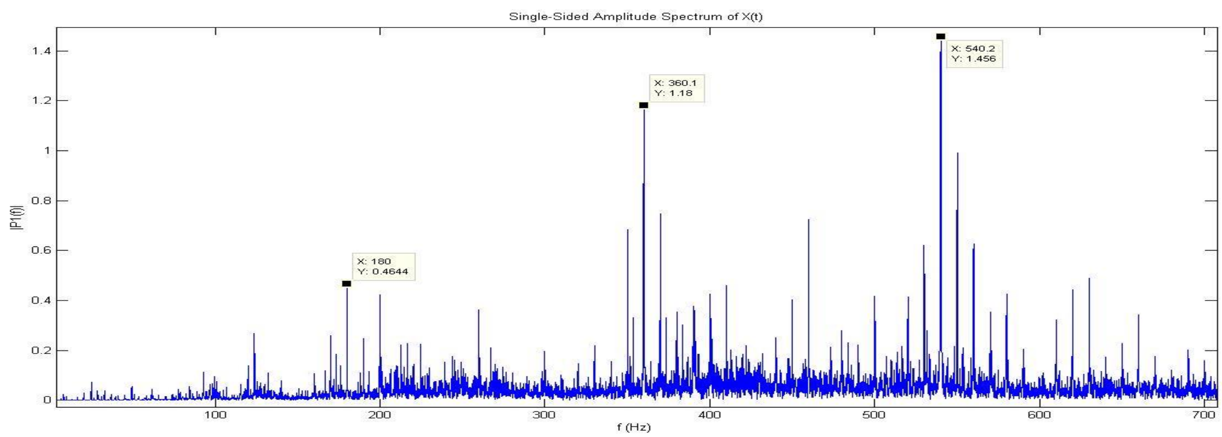


7- 40% load, 600 RPM:

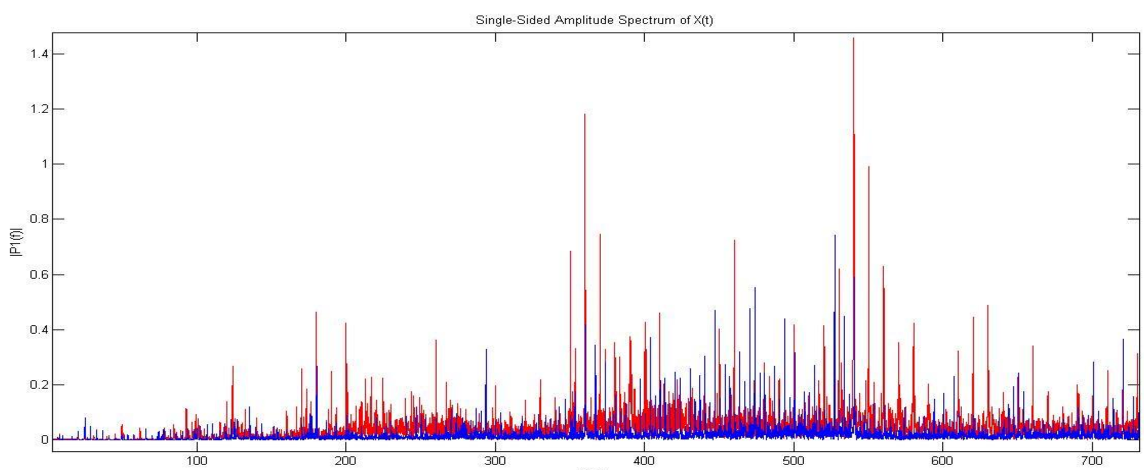
Healthy Pinion



Faulty Pinion

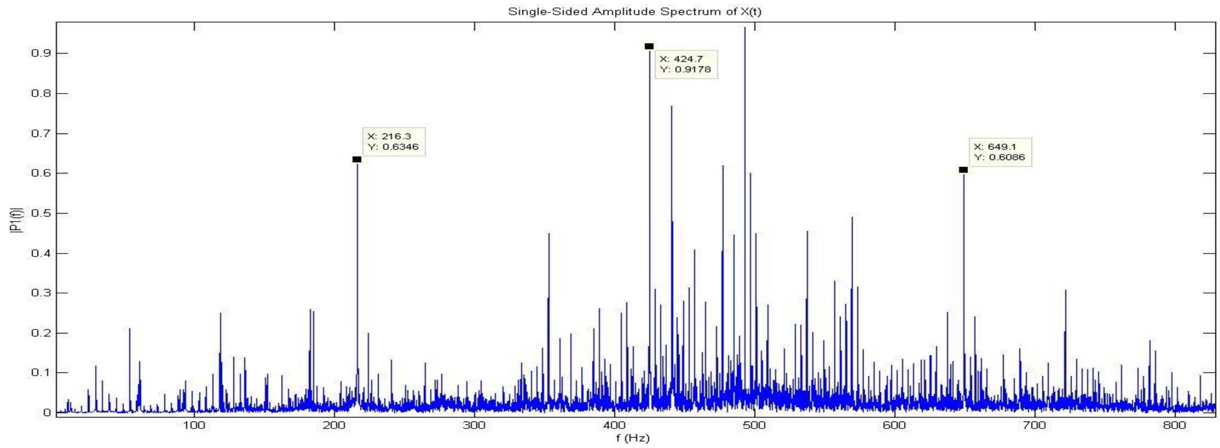


Comprarison of FFT spectrum healthy- Blue Faulty-Red

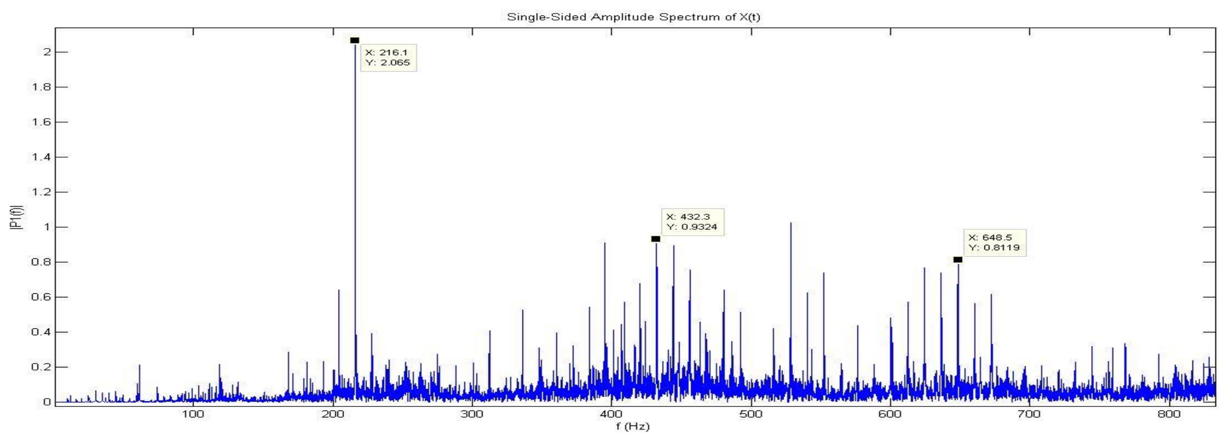


8- 40% load, 720 RPM:

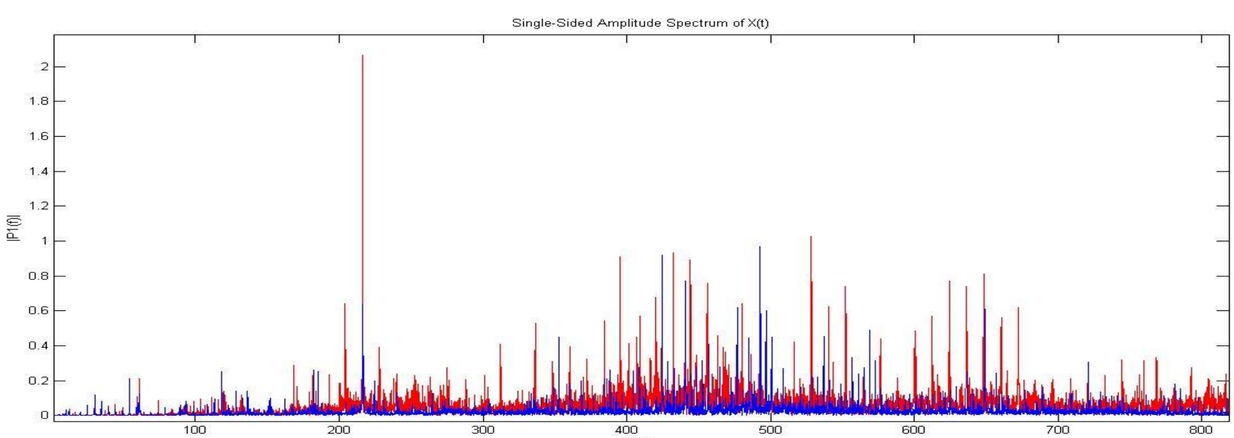
Healthy Pinion



Faulty Pinion

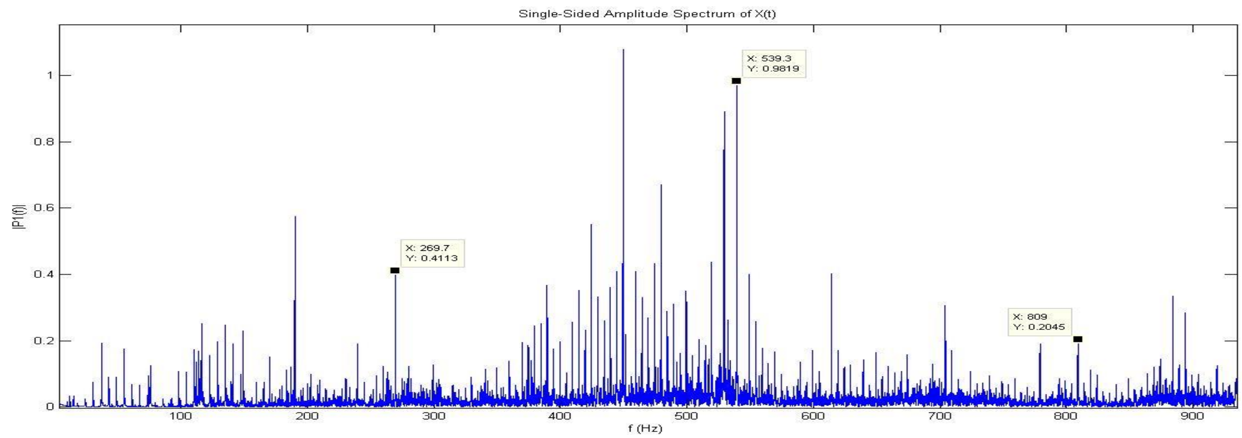


Comprarison of FFT spectrum healthy- Blue Faulty-Red

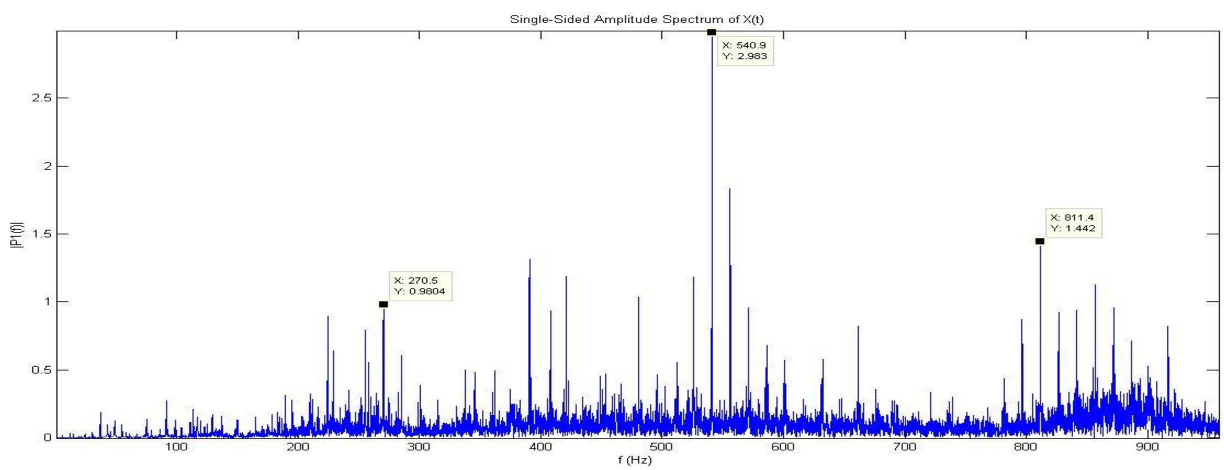


9- 40% load, 900 RPM:

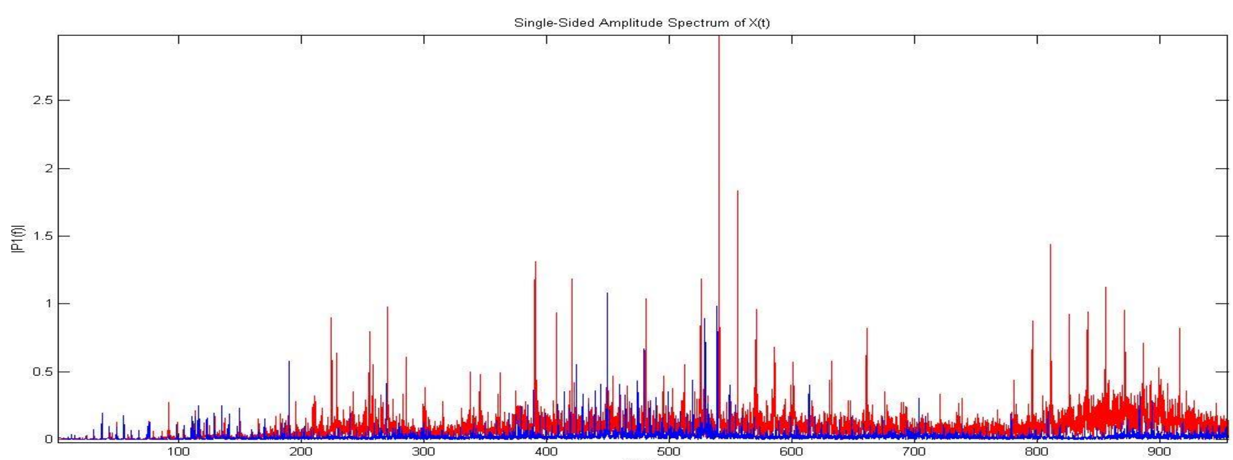
Healthy Pinion



Faulty Pinion

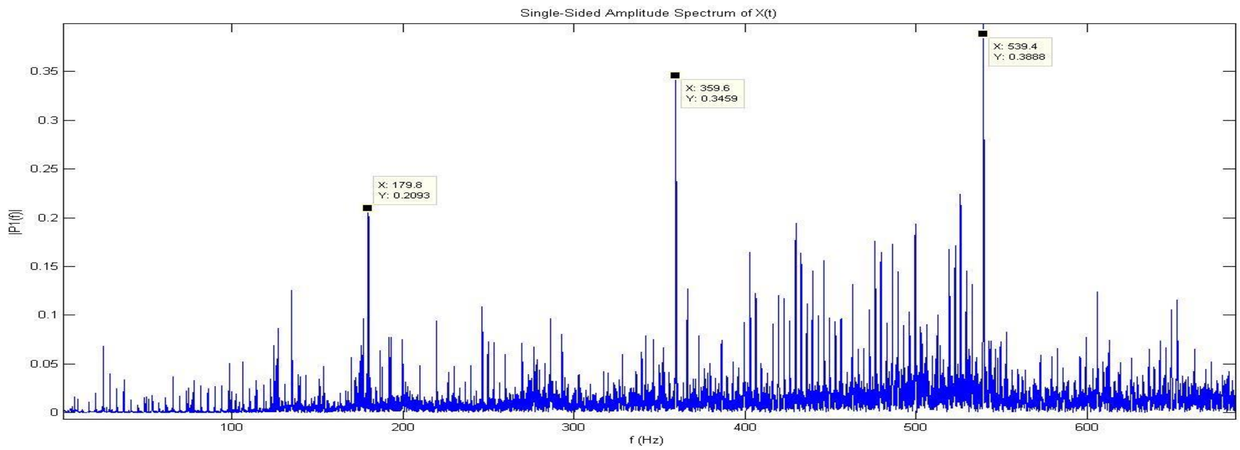


Comprarison of FFT spectrum healthy- Blue Faulty-Red

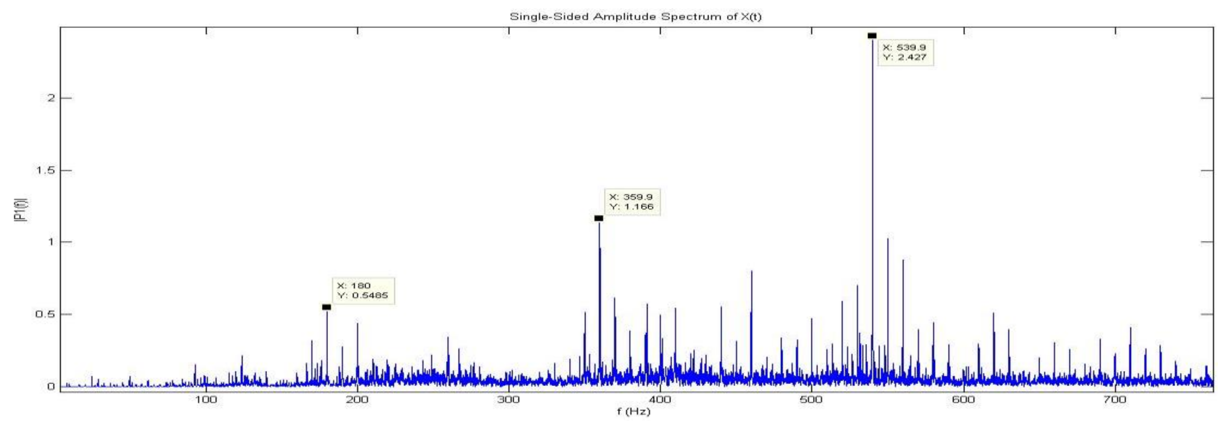


10- 60% load, 600 RPM:

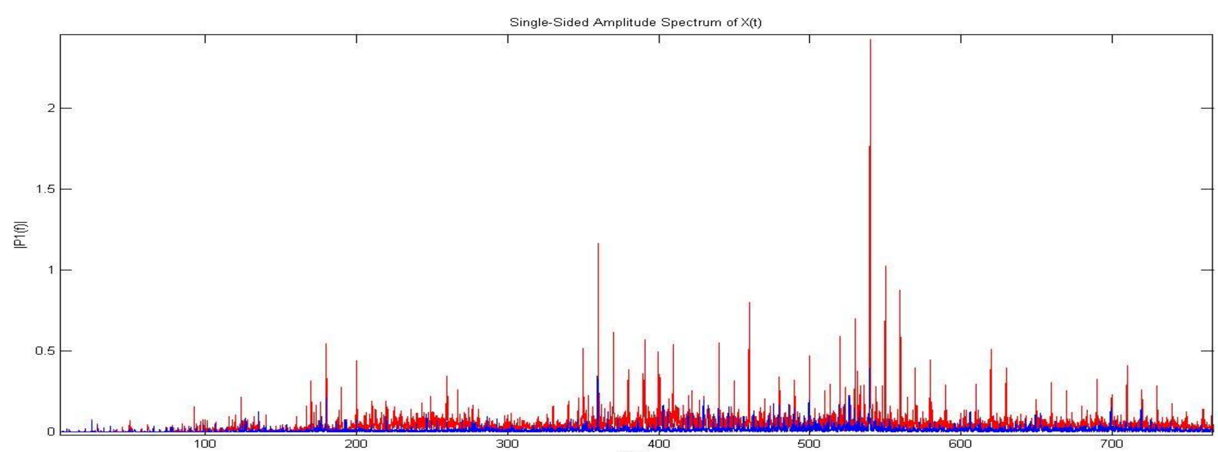
Healthy Pinion



Faulty Pinion

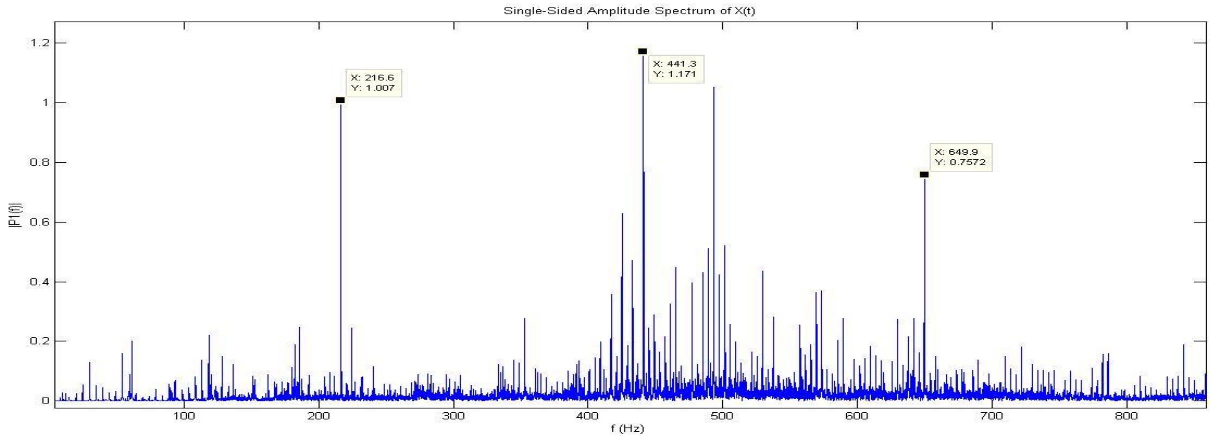


Comprarison of FFT spectrum healthy- Blue Faulty-Red

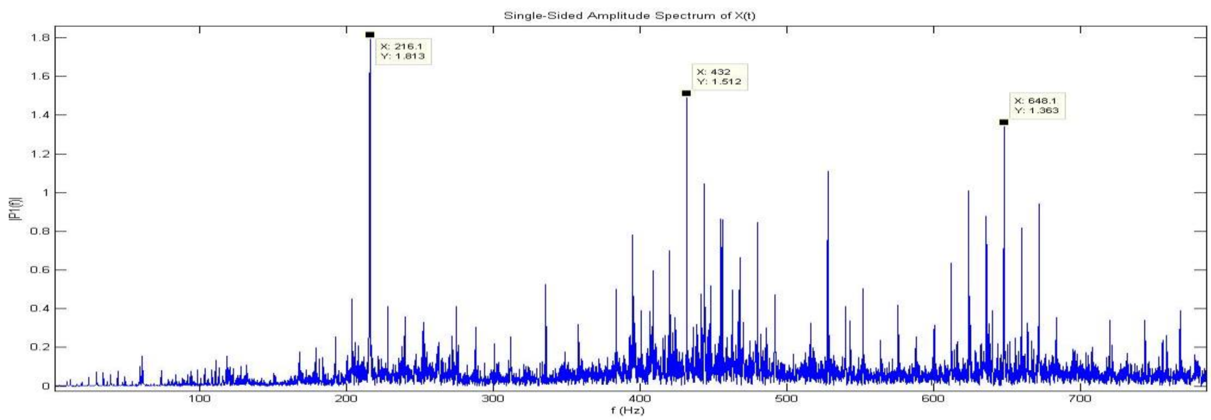


11- 60% load, 720 RPM:

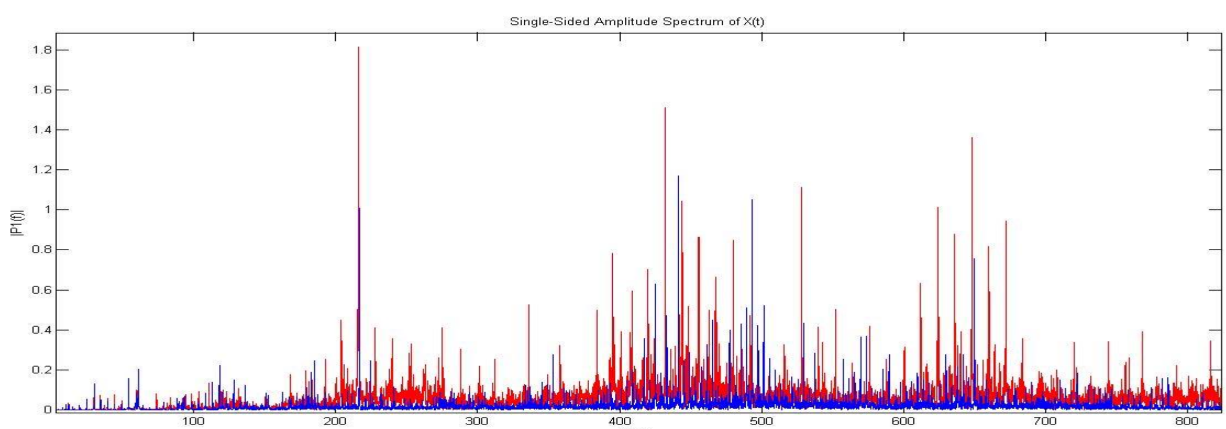
Healthy Pinion



Faulty Pinion

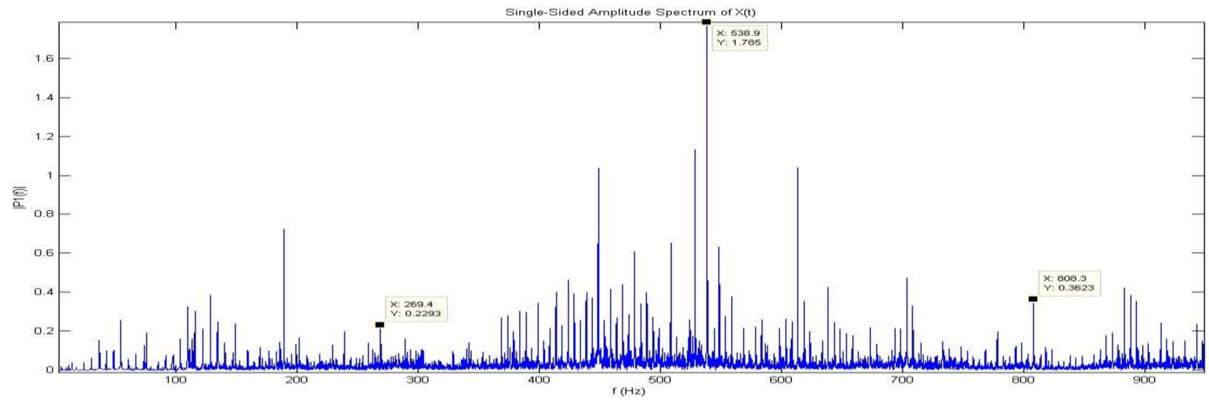


Comprarison of FFT spectrum healthy- Blue Faulty-Red

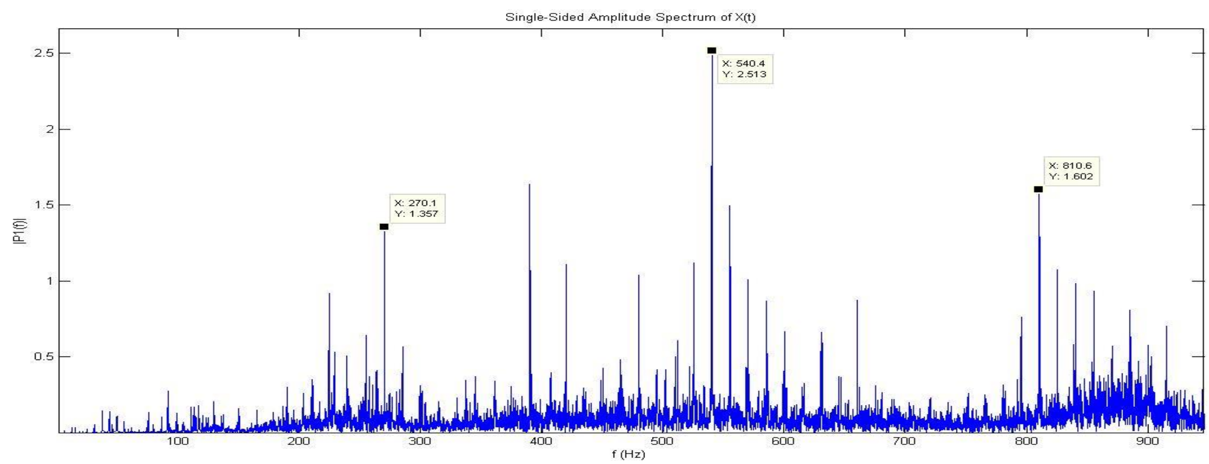


12- 60% load, 900 RPM:

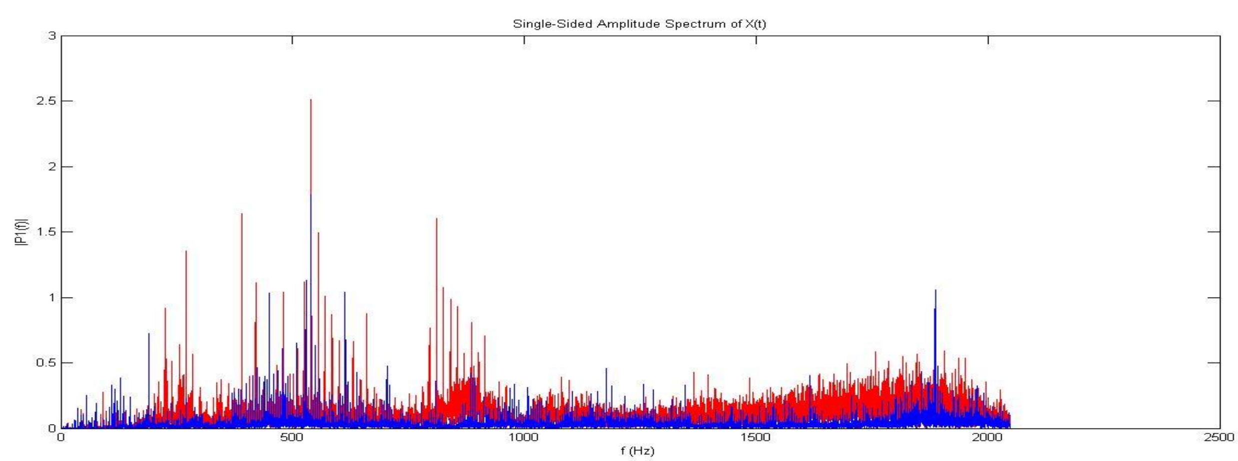
Healthy Pinion



Faulty Pinion

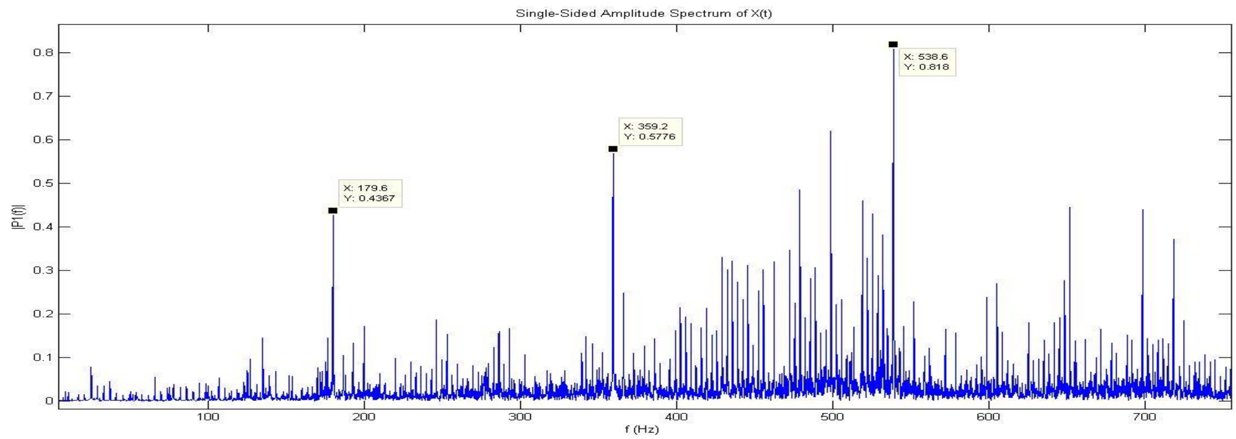


Comprarison of FFT spectrum healthy- Blue Faulty-Red

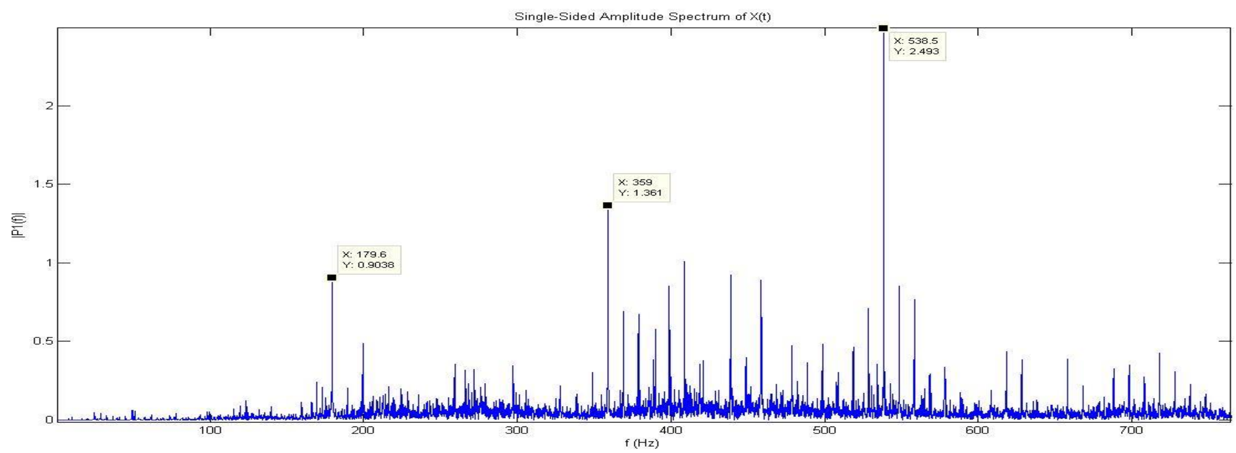


13- 80% load, 600 RPM:

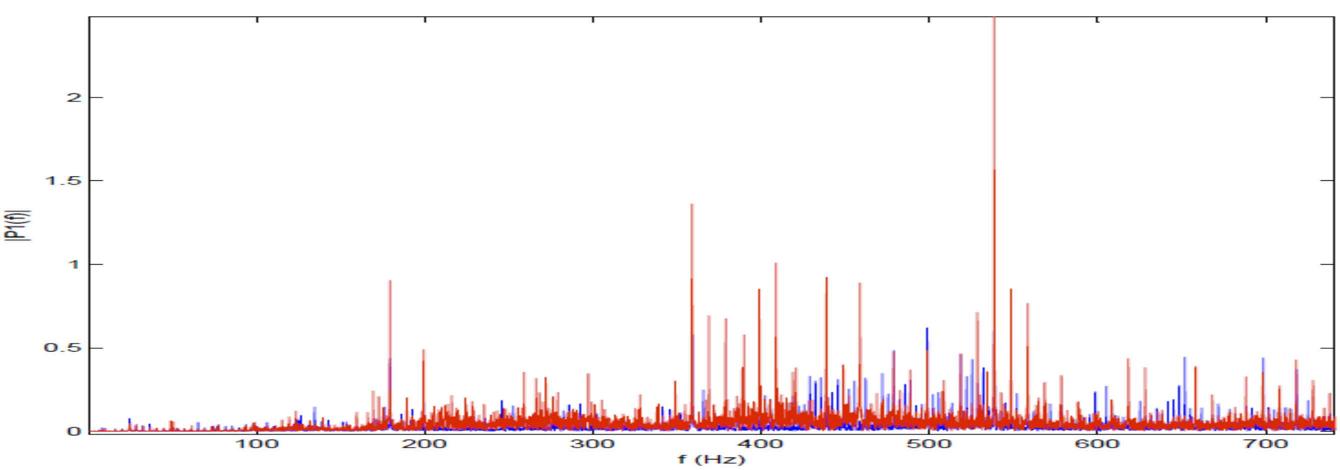
Healthy Pinion



Faulty Pinion

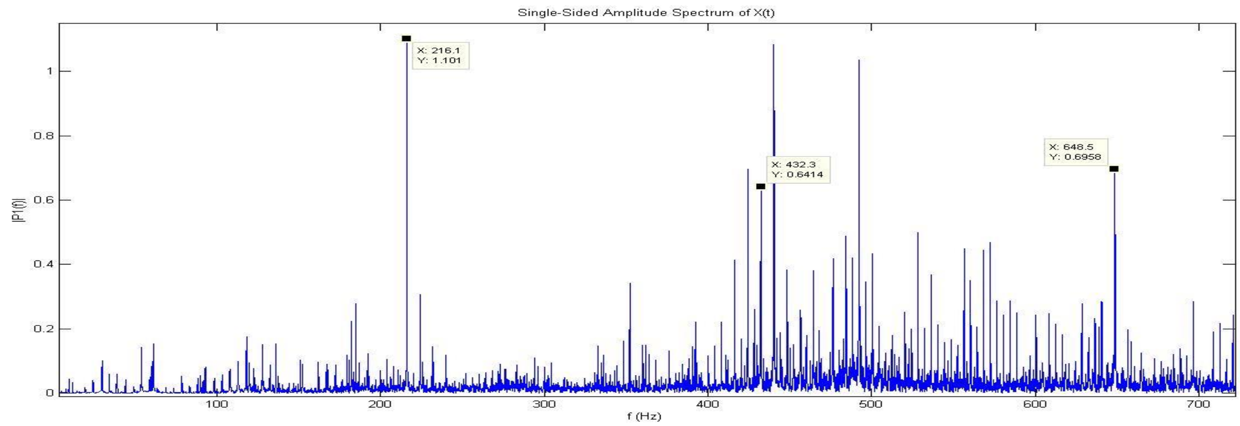


Comprarison of FFT spectrum healthy- Blue Faulty-Red

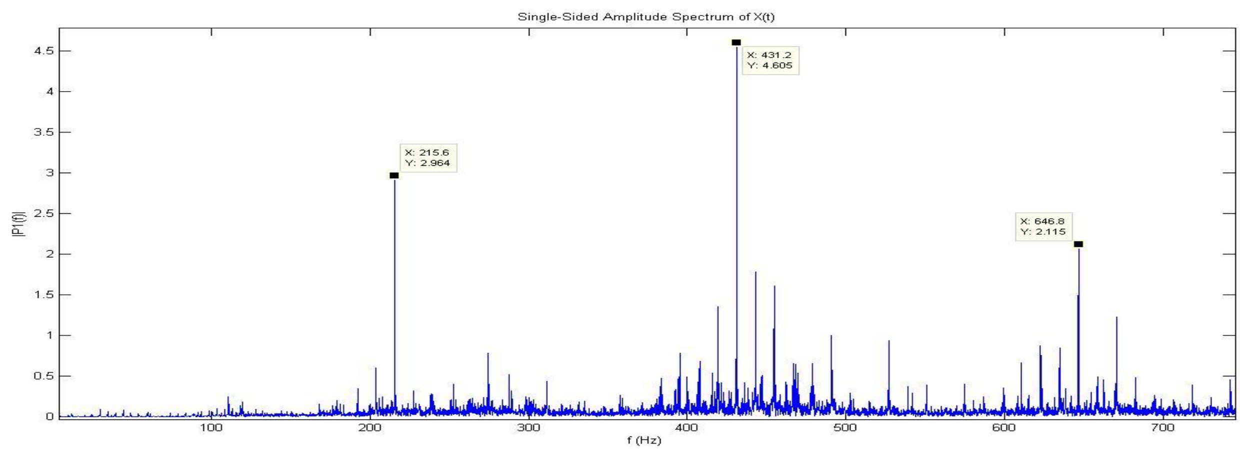


14- 80% load, 720 RPM:

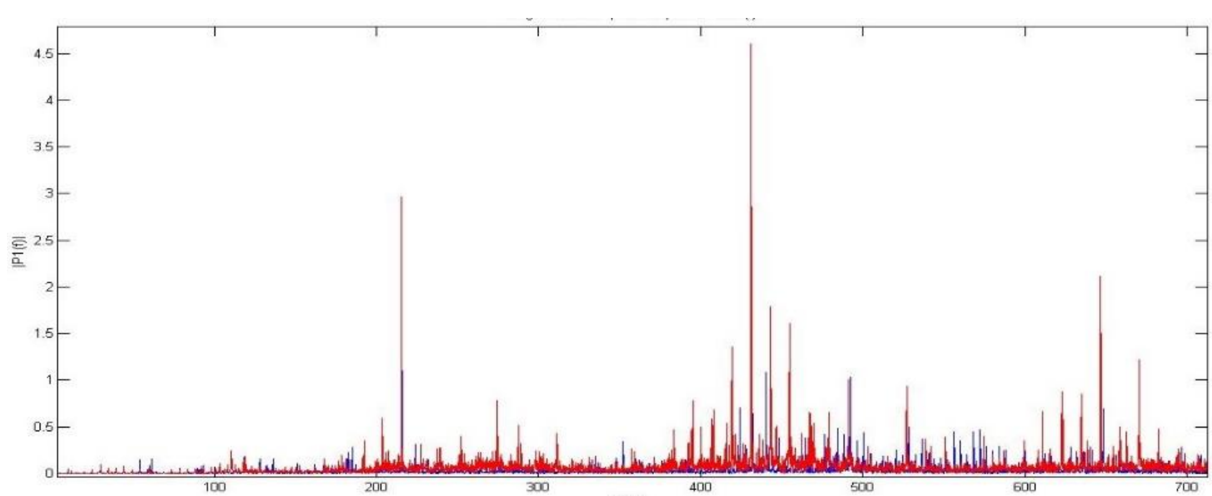
Healthy Pinion



Faulty Pinion

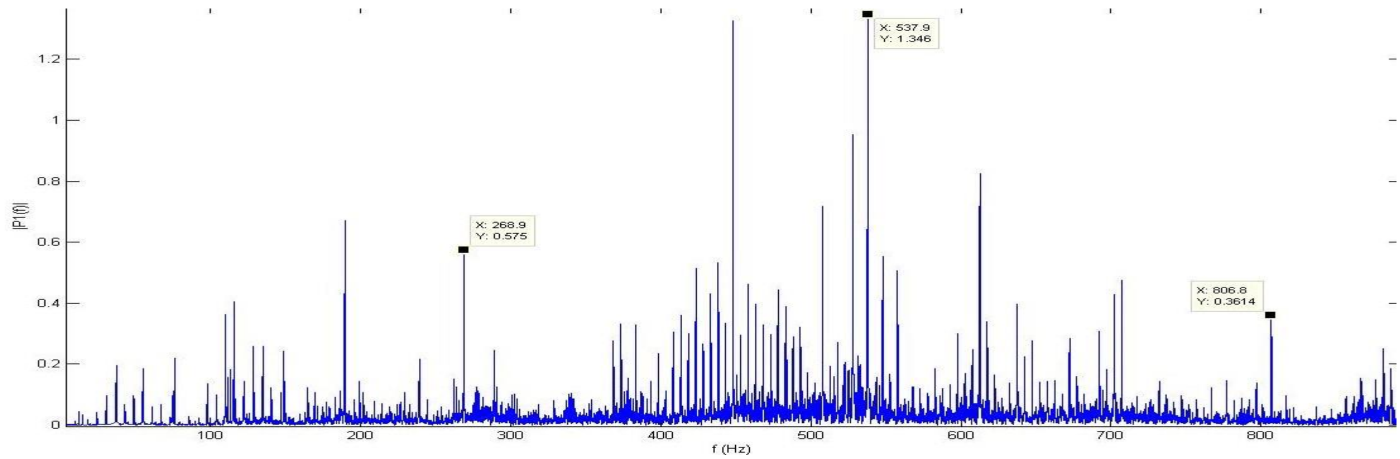


Comprarison of FFT spectrum healthy- Blue Faulty-Red

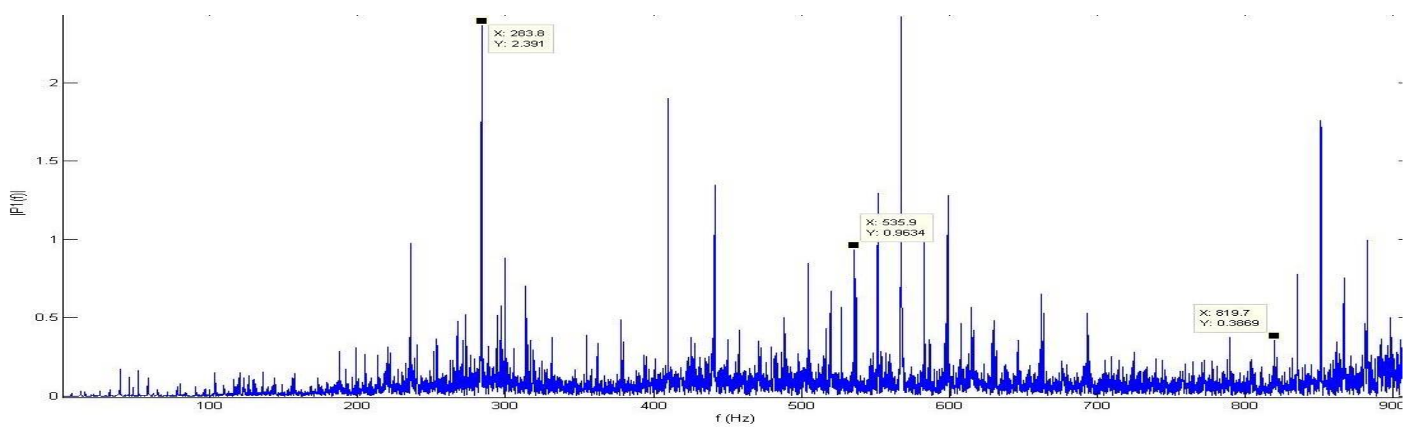


15- 80% load, 9000 RPM:

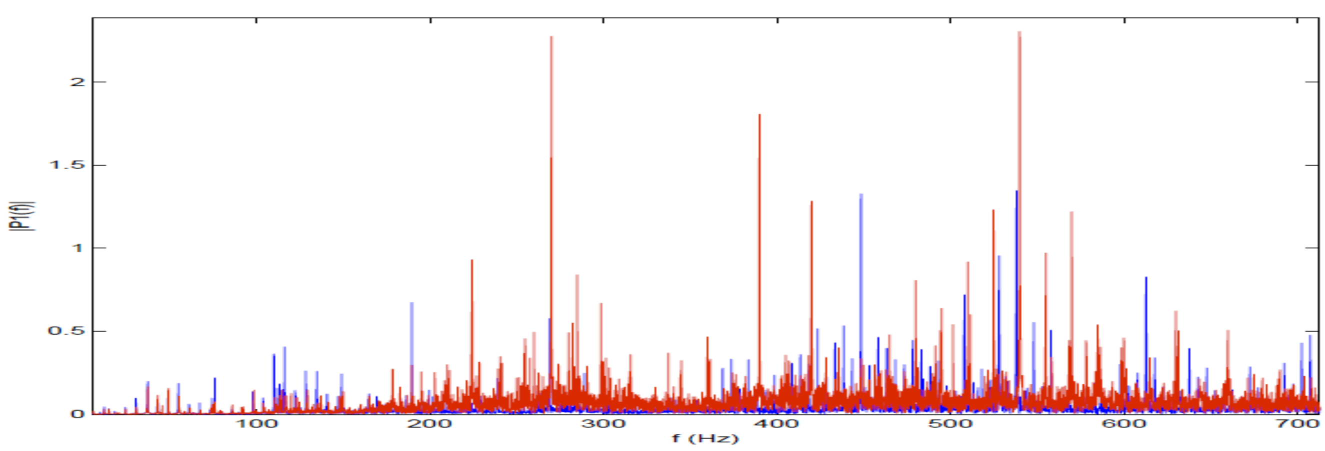
Healthy Pinion



Faulty Pinion



Comprarison of FFT spectrum healthy- Blue Faulty-Red



Conclusion and Scope of Future Work

Features and it's comparison gives some common fault signature:

1) RMS, Variance values are greater in case of worn pinion than the healthy pinion for every load and speed conditions, so it can be concluded that fault like wear can be identified by comparing various features.
2) Crest factor normal range is 2-6 for healthy gear, but it's value of more than 6 here shows the gear is faulty.
3) The unpredictable behaviour of kurtosis in worn pinion shows it's fault.

FFT spectrum gives some common fault signature:

1) Amplitude of harmonics, sub harmonics are increased in case of worn pinion.
2) Sidebands of pinion increases with damage.
3) In loading condition amplitudes become 2 to 3 times larger than amplitude in no load condition.

Scope in Future of This Project:

- Vibration measured in this project are based on worn pinion. So this vibration monitoring technique can be applied to detect wear strength of gear.
- Fault isolation can be done with help of these data and by applying any signal processing technique.
- Thermal effects on gear teeth are not considered in this study which also effect the vibrations

Citations and References

1. An investigation on gearbox fault detection using vibration analysis techniques, 2012 A review paper , Author- A Aherwar, Australian journal of mechanical engineering

2. Gear fault identification by using vibration analysis, 2016- A research article, Author- Ajanalakar sagar shivpur , International journal of current engineering and technology

3. Vibration based fault diagnosis of spur bevel gear box using fuzzy technique, 2009, Journal, Author- N. Saravanan, S. Cholairajan, Elsevier

4. Review of vibration analysis methods for gearbox diagnostics and prognostics, 2000 , Mitchell Lebold, Robert Campbell, Applied research Laboratory, Pennsylvania university

5. Fault Diagnosis of spur bevel gear box using discrete wavelet features and decision tree classification, 2009, Journal, N. Saravanan, K.I. Ramachandran, Elsevier

6. Time Synchronous averaging of gear meshing vibration transducer responses for elimination of harmonic contributions from the mating gear pair, 2015, Journal, William D mark, Applied Research laboratory, Pennsylvania university, Elsevier

7. Condition monitoring of gear systems using vibration analysis, 2012, Salem K. Al- Erbi, University of Huddersfield.
8. Vibration signature analysis of a faulted gear transmission system, 1996, journal of propulsion and power, choy F, Zakrasjek, Townstand D.
9. Condition indicator of gearbox condition monitoring systems, 2005, journal, P. Vacer, M. Kreidal, R. Smid, Czech technical university of prague.
10. Research of high- resolution vibration signal detection technique and application to mechanical fault diagnosis, 2005, Y. S. Fan, G.T. Zheng, Elsevier.
11. A review of vibration based techniques for helicopter transmission diagnostics, 2004, Paul D. Samuel, Darryll J. pines, Elsevier.