B. TECH. PROJECT REPORT

On

FAULT DIAGNOSIS OF ELECTRICAL MACHINES

BY

SAURAV KUMAR SAINI (150002032)

DISCIPLINE OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

December 2018

FAULT DIAGNOSIS OF ELECTRICAL MACHINES

A PROJECT REPORT

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

of
BACHELOR OF TECHNOLOGY in

ELECTRICAL ENGINEERING

Submitted by:
SAURAV KUMAR SAINI

Guided by:
Dr. Amod C. Umarikar and Prof. Anand Parey

INDIAN INSTITUTE OF TECHNOLOGY INDORE
DECEMBER 2018

CANDIDATE'S DECLARATION

I hereby declare that the project entitled **Fault Diagnosis of Electrical Machines** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in **Electrical Engineering** completed under the supervision of **Dr. Amod C. Umarikar, Associate Professor, Department of Electrical Engineering and Dr. Anand Parey, Professor, Department of Mechanical Engineering,** 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 Guides

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

Signature of BTP Guides with dates and their designation

Preface

This report on **Fault Diagnosis Of Electrical Machines** is prepared under the guidance of **Dr. Amod C Umarikar and Prof. Anand Parey.**

Through this report I have tried to explain various faults and their diagnosis using vibration spectrum analysis in a three phase induction motor.

I have tried to the best of my abilities and knowledge to explain the algorithm in detail. I have also added graphs and figures to make it more illustrative.

Saurav Kumar Saini
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

Acknowledgements

I wish to thank Dr. Amod C Umarikar and Prof. Anand Parey for their kind support and valuable guidance.

It is their help and support, due to which I became able to complete the design and technical report. They provided me quality machinery and a safe environment for conducting the experiments.

Without their support this report would not have been possible.

Saurav Kumar Saini
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

Abstract

The detection of faults in induction motors is important for the maintenance work. The detection at an early stage is important to prevent total breakdown of motor or processes. Fault diagnosis and identification in a timely and regular manner can increase the reliability of the system and provide replacement. Some defects originate in the manufacturing process and may remain hidden for quite some time before developing into more apparent problem . Fault diagnosis and detection has been developed over the years and uses various techniques such as analytical approaches, knowledge based system techniques ; others are based on process models.

Faults can also occur due to electrical breakdowns. Knowing the most important faults and having a proper fault detection technique the problems can be avoided quickly without spending a significant amount of time and money. Monitoring and analyzing the vibrations in different places of the motors, the cause of the vibration can be discovered. It is also important to solve these problems in time otherwise long term damages , immediate failure or loss of production may occur.

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CHAPTER 1

INTRODUCTION

The motors consume over 50% of the total electrical energy produced globally and around 60% of the industrial electrical load is constituted by the Induction motors. It plays an important role in safe and efficient operation of industrial plants. Compared to other electrical motors induction motors have many advantages like simplicity of their structure, high reliability and relatively low cost. However there is possibility of faults while converting electrical energy into mechanical energy. The detection of faults in induction motors is important for the maintenance work. The detection at an early stage is important to prevent total breakdown of motor or processes. Fault diagnosis and identification in a timely and regular manner can increase the reliability of the system and provide replacement. Some defects originate in the manufacturing process and may remain hidden for quite some time before developing into more apparent problem . Fault diagnosis and detection has been developed over the years and uses various techniques such as analytical approaches, knowledge based system techniques ; others are based on process models.

Faults can also occur due to electrical breakdowns. Knowing the most important faults and having a proper fault detection technique the problems can be avoided quickly without spending a significant amount of time and money. Monitoring and analyzing the vibrations in different places of the motors, the cause of the vibration can be discovered. It is also important to solve these problems in time otherwise long term damages , immediate failure or loss of production may occur.

Vibration analysis requires a lot of knowledge regarding type of vibration, cause of vibration and source of vibration. Vibrations are characterized by amplitude and frequency. Amplitude shows how strong the vibration is, and frequency shows the oscillation rate of vibration. These two provide the information to reach the root of vibration. It helps to detect unwanted vibrations and hence the problem can be detected in time. Vibration analysis consists of spectral analysis. The spectrum is a very useful analytic tool as it shows the frequencies at which vibrations occur. The resolution of the spectrum establishes the details in the spectrum.

CHAPTER 2

3 PHASE INDUCTION MOTOR

The three phase induction motor is the most widely used electrical motor. Almost 80% of the mechanical power used by industries is provided by three phase induction motors because of its simple and rugged construction, low cost, good operating characteristics, the absence of commutator and good speed regulation. In three phase induction motor, the power is transferred from stator to rotor winding through induction. The induction motor is also called asynchronous motor as it runs at a speed other than the synchronous speed. In case of three phase AC operation, most widely used motor is three phase induction motor as this type of motor does not require any starting device or we can say they are self-starting induction motors. This motor consists of two major parts viz. stator and rotor.

STATOR

Stator of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which we connect with 3 phase AC source. We arrange the three-phase winding in such a manner in the slots that they produce one rotating magnetic field when we switch on the three-phase AC supply source.

ROTOR

Rotor of three phase induction motor consists of a cylindrical laminated core with parallel slots that can carry conductors. The conductors are heavy copper or aluminum bars fitted in each slot and short-circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise and can avoid stalling of the motor.

Fig1.1squirrel cage rotor

The other parts, which are required to complete the induction motor, are:

1. Shaft for transmitting the torque to the load. This shaft is made up of steel.
2. Bearings for supporting the rotating shaft.
3. One of the problems with electrical motor is the production of heat during its rotation. To overcome this problem, we need a fan for cooling.
4. For receiving external electrical connection Terminal box is needed.
5. There is a small distance between rotor and stator which is called as air gap.

WORKING

The stator of the motor consists of overlapping winding offset by an electrical angle of 120º. When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed. According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor.

Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation; hence as per Lenz's law, the rotor will rotate in the same direction to reduce the cause, i.e., the relative velocity. Thus from the working principle of three phase induction motor, it may be observed that the rotor speed should not reach the synchronous speed produced by the stator. If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated. Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the advantage that no electrical connections need to be made to the rotor.

CHAPTER 3

FAULTS IN A 3 PHASE INDUCTION MOTOR

Induction motors are rugged, low cost, low maintenance, reasonably small sized, reasonably high efficient, and operating with an easily available power supply. They are reliable in operations but are subject to different types of undesirable faults. Faults can be electrical related faults or mechanical related. Some major faults that can be present in an induction motor are bearing faults, broken rotor bar faults, stator winding faults, rotor unbalance fault, rotor misalignment fault and voltage unbalance fault. In an induction motor multiple faults may occur simultaneously and in that case determination of the initial problem is quite difficult . Effects of such faults in induction motor result in unbalanced stator currents and voltages, oscillations in torque, reduction in efficiency and torque, overheating, and excessive vibration. Moreover, these motor faults can increase the magnitude of certain harmonic components of currents and voltages. Induction motor performance may be affected by any of the faults.

BROKEN ROTOR BAR FAULT

The squirrel cage of an induction motor consists of rotor bars and end rings. If one or more of the bars is partially cracked or completely broken, then the motor is said to have broken bar fault.

The broken bar fault in an induction motor can be due to manufacturing defects ,thermal stresses ,mechanical stress caused by bearing fault ,frequent starts of the motor at rated voltage or due to fatigue of metal of the rotor bar.

ROTOR UNBALANCE FAULT

This rotor mass unbalance occur mainly due to manufacturing defect, if not may occur even after an extended period of operation, for nonsymmetrical addition or subtraction of mass around the center of rotation of rotor or due to internal misalignment or shaft bending due to which the center of gravity of the rotor does not coincide with the center of rotation. In severe case of rotor eccentricity, due to unbalanced electromagnetic pull if rotor rubs the stator then a small part of material of rotor body may wear out which is being described here as subtraction of mass,

resulting in rotor mass unbalance fault. It is known that rotor is placed inside the stator bore and it rotates coaxially with the stator. In a healthy motor, rotor is centrally aligned with the stator and the axis of rotation of the rotor is the same as the geometrical axis of the stator. This results in identical air gap between the outer surface of the rotor and the inner surface of the stator. However, if the rotor is not centrally aligned or its axis of rotation is not the same as the geometrical axis of the stator, then the air gap will not be identical and the situation is referred as air-gap eccentricity. In fact air-gap eccentricity is common to rotor fault in an induction motor. Due to this air-gap eccentricity fault, in an induction motor electromagnetic pull will be unbalanced. The rotor side where the air gap is minimum will experience greater pull and the opposite side will experience lower pull and as a result rotor will tend to move in the greater pull direction across that gap . The chance of rotor pullover is normally greatest during the starting period when motor current is also the greatest. In severe case rotor may rub the stator which may result in damage to the rotor and/or stator . Air-gap eccentricity can also cause noise and/or vibration.

BEARING FAULT

Two sets of bearings are placed at both the ends of the rotor of an induction motor to support the rotating shaft. They held the rotor in place and help it to rotate freely by decreasing the frictions. Each bearing consists of an inner and an outer ring called races and a set of rolling elements called balls in between these two races. Normally, in case of motor, inner race is attached to the shaft and load is transmitted through the rotating balls—this decreases the friction. Using lubricant (oil or grease) in between the races friction is further decreased. Any physical damage of the inner race or in the outer race or on the surface of the balls is termed as bearing fault. In terms of induction motor failure, bearing is the weakest component of an induction motor. It is the single largest cause of fault in induction motor. When there is a fault in the bearing, it produces certain vibration which affects the air gap eccentricity between stator and rotor and induces a fault frequency into stator current . Faults that occur in bearing are categorized into two types; they are cyclic and non cyclic faults. Depending on location of fault the cyclic faults can furthermore classified as outer race, inner race, ball defect and cage fault. A cyclic fault creates an impact between bearing and raceway resulting in a detectable vibration .

STATOR WINDING FAULT

This fault is due to failure of insulation of the stator winding. It is mainly termed as inter-turn short-circuit fault. Different types of stator winding faults are (i) short circuit between two turns of same phase—called turn-toturn fault, (ii) short circuit between two coils of same phase called coil to coil fault, (iii) short circuit between turns of two phases called phase to phase fault, (iv) short circuit between turns of all three phases, (v) short circuit between winding conductors and the stator core called coil to ground fault, and (vi) open-circuit fault when winding gets break.

Short-circuit winding fault shows up when total or a partial of the stator windings get shorted.

Open-circuit fault shows up when total or a partial of the stator windings get disconnected and no current flows in that phase/line. Faults in stator windings may be due to mechanical stresses, electrical stresses and thermal stresses. Environmental stresses like too hot or too humid conditions can also result in this type of fault.

ROTOR MISALIGNMENT FAULT

Misalignment is one of the common mechanical fault in the induction machine. Misalignment increases loads on bearings and couplings and this activate a decrease in motor efficiency. Various factors such as improper assembly of machines, asymmetry in applied loads, unequal settlement of foundation, etc. are responsible for misalignment. Some misalignment is always present in the machine therefore a perfect alignment between rotor shafts cannot be achieved. Misalignment in a motor drive system is a condition where the centerlines of coupled shafts do not coincide. It is a severe and most frequently occurring condition in motor driven systems. Misalignment faults are eccentricity faults. Misalignment is a term given to the error in the alignment between two rotating shafts, which is commonly used in positioning electric machines coupled with a certain load machine Misalignment is divided in three main categories: parallel , angular and combined misalignment. Misalignment does not directly imply a failing of one of the coupled rotating machines, but the bearings of the coupled machines can be subjected to heavy static or dynamic loads which can easily lead into an unexpected premature failure. Misalignment fault can be both static and dynamic in nature. In the former the minimum air gap is fixed and in the later minimum air gap rotates with the rotor.

VOLTAGE UNBALANCE FAULT

Over and under voltages occur due to change of voltage level at supply end. Over voltage causes stress on insulation, whereas under voltage causes excessive line current increasing temperature of the winding. Overload occurs due to increase of mechanical load above the rating of the motor. At excessive mechanical load, rotor fails to rotate and gets blocked. This situation is equivalent to short circuit. For a three-phase motor when one of the phases gets lost then the condition is known as single phasing. Single phasing fault in an induction motor may be due to a downed line or a blown fuse of the utility system; due to an equipment failure of the supply system.; due to short circuit in one phase of the star-connected or delta-connected motor.

CHAPTER 4

CONCEPT DESIGN AND EXPERIMENTAL SETUP

VIBRATION FREQUENCY DOMAIN SPECTRUM ANALYSIS

For fault diagnosis in induction motors various techniques like motor current signature analysis, acoustic signal analysis, temperature analysis and vibration analysis can be used. In this project we have used vibration spectrum analysis technique. Induction motor generates vibrations at certain characteristic frequencies whereas in case of induction motor with certain kind of fault(s) these vibrations may be of higher magnitude and certain other vibrations may also be present at different frequencies. Study of such faults is easier using vibration frequency spectrum 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. It has been found that frequency domain spectrum is better for analysis than the time domain because the complex time domain signal can be broken down into several frequency components. It is therefore useful for analysis to focus on these frequencies. The spectrum is a measure of the vibrations over a large number of discrete contiguous narrow frequency bands. Thus the common approach to the vibration condition monitoring is the Fast Fourier Transform (FFT) to transform the vibration signal into the frequency domain. This approach is perfectly acceptable is the measured signal does not vary in spectral content over time which means that there should be no variation in the rotational speed of the machine. For machines operating with known constant speed, the vibration frequencies of the vibrations produced by the component in the machine can be estimated. Therefore , any change in vibration level with a particular frequency band can be related to a particular component. Sidebands generated by modulation in the vibration signal also provide useful information about the type of faults and their magnitude.

EXPERIMENTAL SETUP

The main apparatus being used to perform the experiments is the Machinery Fault Simulator manufactured by Spectra Quest Inc. The setup had a Variable frequency drive for varying the frequency of the motor. Different motors were used with built in faults. The motors were 3 phase squirrel cage induction motors manufactured by Marathon electric. The healthy motor had specifications of Rated Power as 0.75 HP and rated speed as 2850 rpm. Faulty motors were rated at 0.33HP and 2850 rpm. To measure the vibrations produced a tri axial accelerometer with sensitivity 10.57mV/(m/s^2). To record the vibrations and acquire the data , a data acquisition system was used. The system used was OROS NVGATE data acquisition system (DAS). For post analysis and signal processing MATLAB software was used. The sampling rate of data acquisition was set at 128000 samples/second.

The data acquisition system converted the data acquired into .mat and .txt format which was then used for processing the signal and carrying out the FFT in MATLAB. Motor was operated at different rotating frequencies starting from 5 up to 25 in steps of 5. The loads were given in the form of torque starting from 1 N-m to 4N-m which was the full load condition.

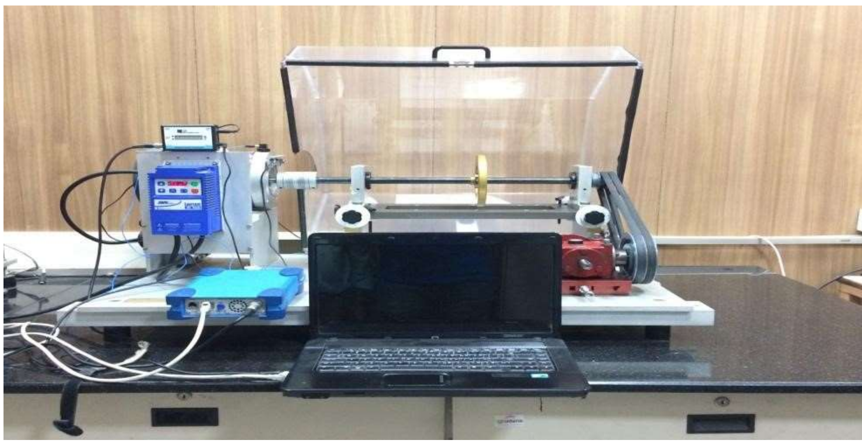


Fig. 4.1MFS and DAS

Fig.4.2 Experimental setup

Fig. 4.3 Data Acquisition system

Fig. 4.4 Tri-axial accelerometer

CHAPTER 5

OBSERVATIONS AND ANALYSIS

Slip is an important parameter in a three phase induction motor . To calculate slip and the effect of different faults on the rotational frequency, the tachometer data was taken into consideration and is compared in different conditions as shown below.

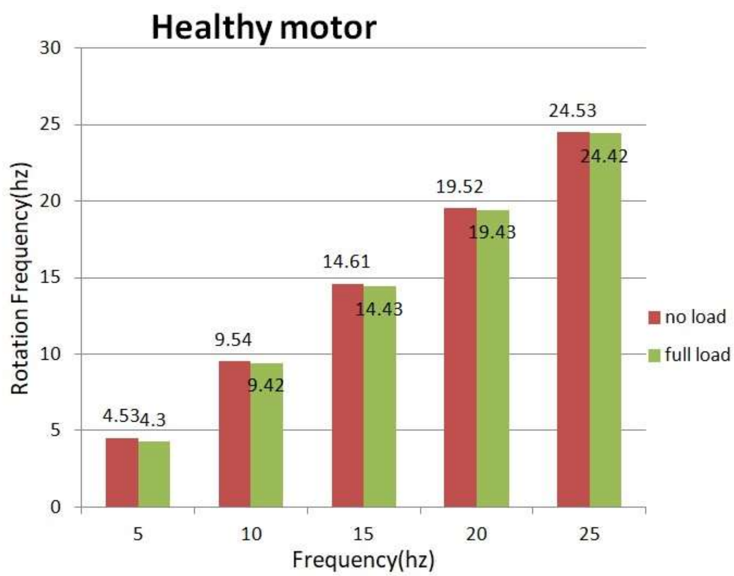


Fig5.1

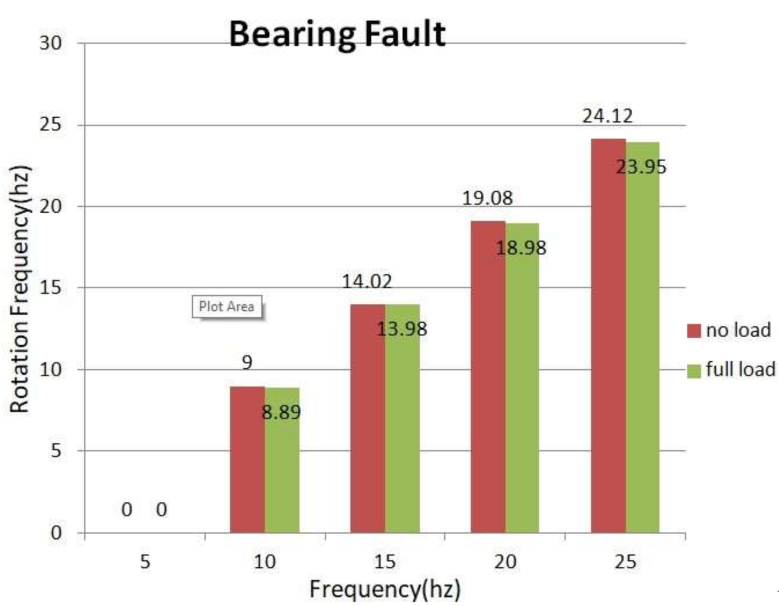


Fig5.2

Fig5.3

Fig5.4

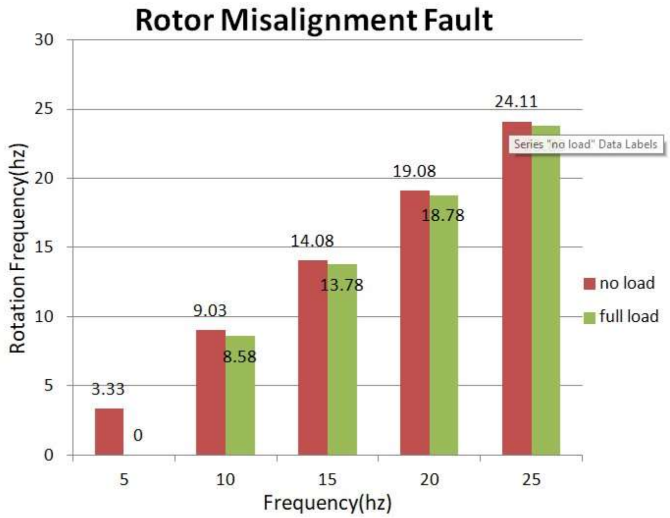
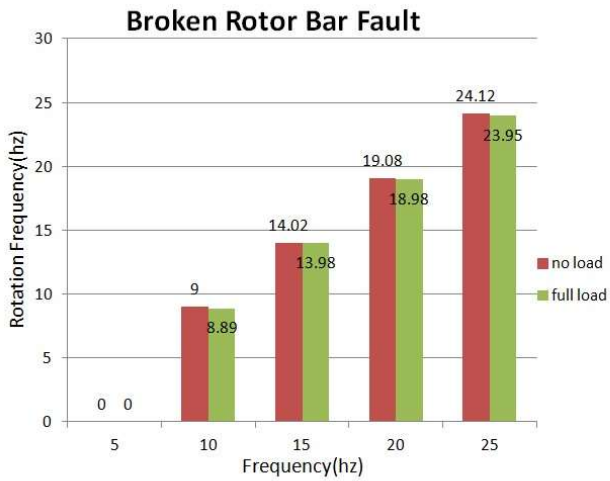
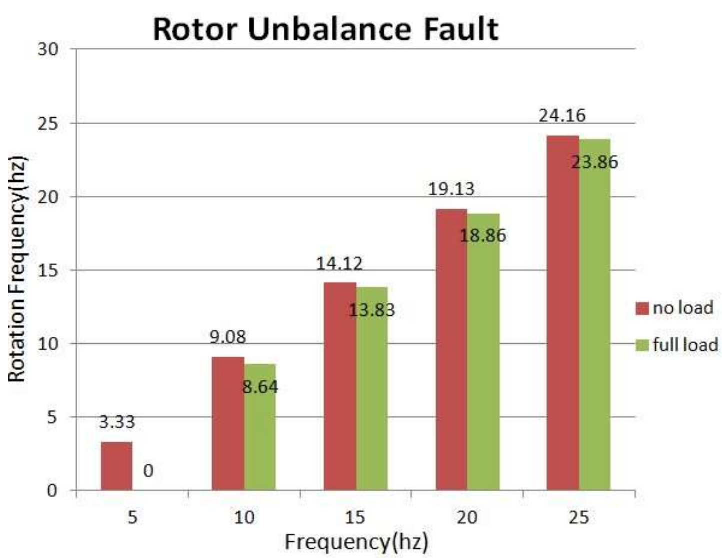

Rotor Misalignment Fault
Rotation Frequency(hz)
Frequency(hz)
30
25
20
15
10
5
0
5
10
15
20
25
3.33
0
9.03
8.58
14.08
13.78
19.08
18.78
24.11
Series "no load" Data Labels
no load
full load

Fig5.5


Broken Rotor Bar Fault
Rotation Frequency(hz)
Frequency(hz)
30
25
20
15
10
5
0
5
10
15
20
25
0
0
9
8.89
14.02
13.98
19.08
18.98
24.12
23.95
no load
full load


Rotor Unbalance Fault
Rotation Frequency(hz)
Frequency(hz)
30
25
20
15
10
5
0
5
10
15
20
25
3.33
0
9.08
8.64
14.12
13.83
19.13
18.86
24.16
23.86
no load
full load

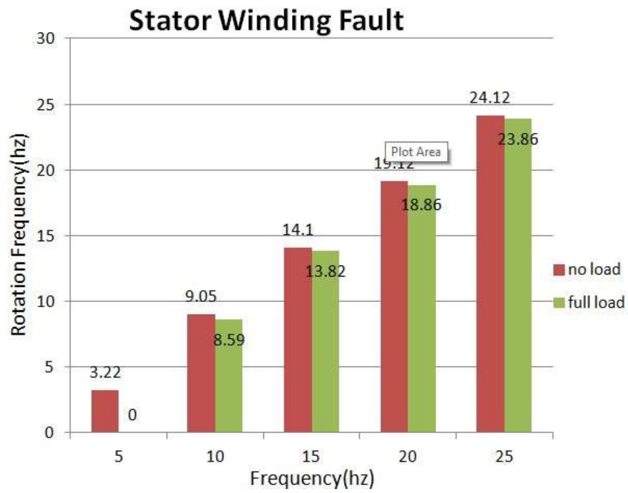


Fig5.6

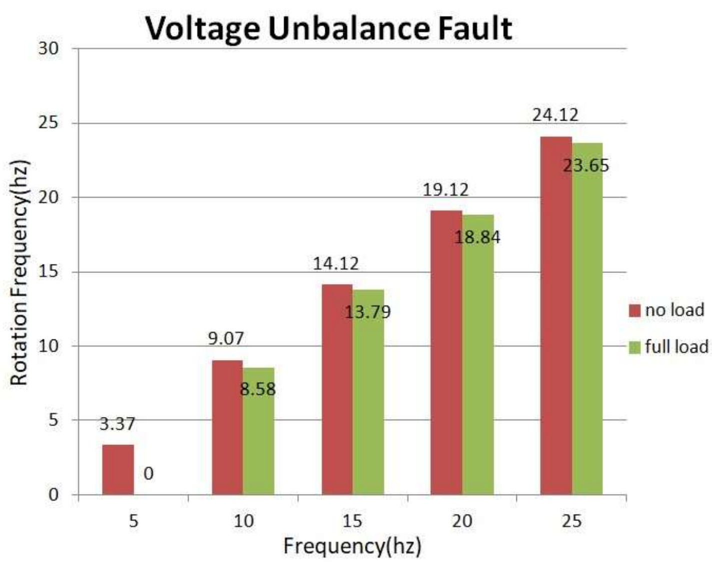


Fig5.7

As discussed earlier FFT is a good way to analyze the data in the frequency domain as it converts the time domain signal information into a frequency spectrum. In our experiment we have used a N point FFT where n is a variable depending upon closest power of 2 to the number of data points. The data was processed on MATLAB and the results for different conditions are as shown in the following figures.

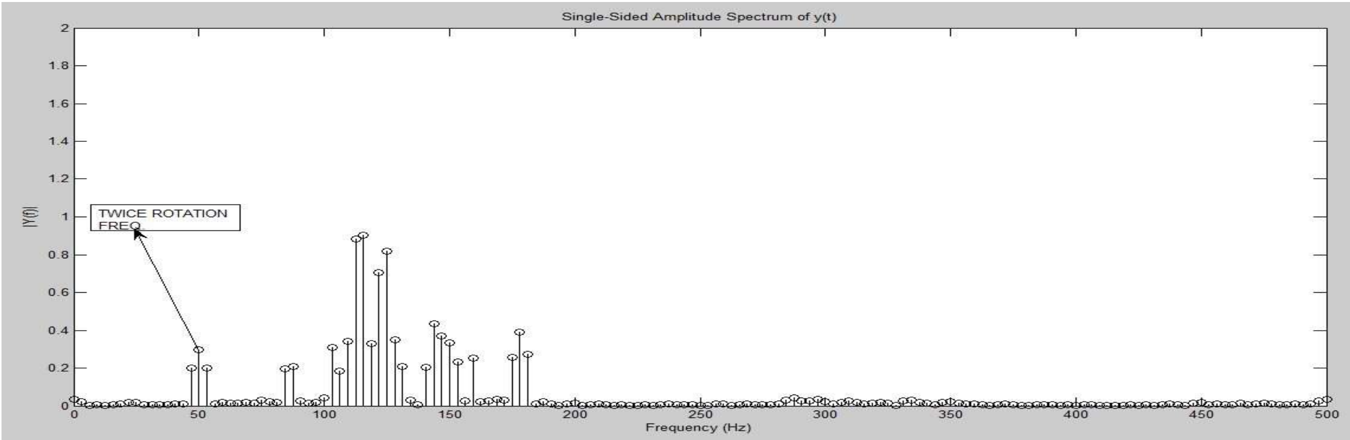


Fig5.8 Healthy motor, no load ,25hz

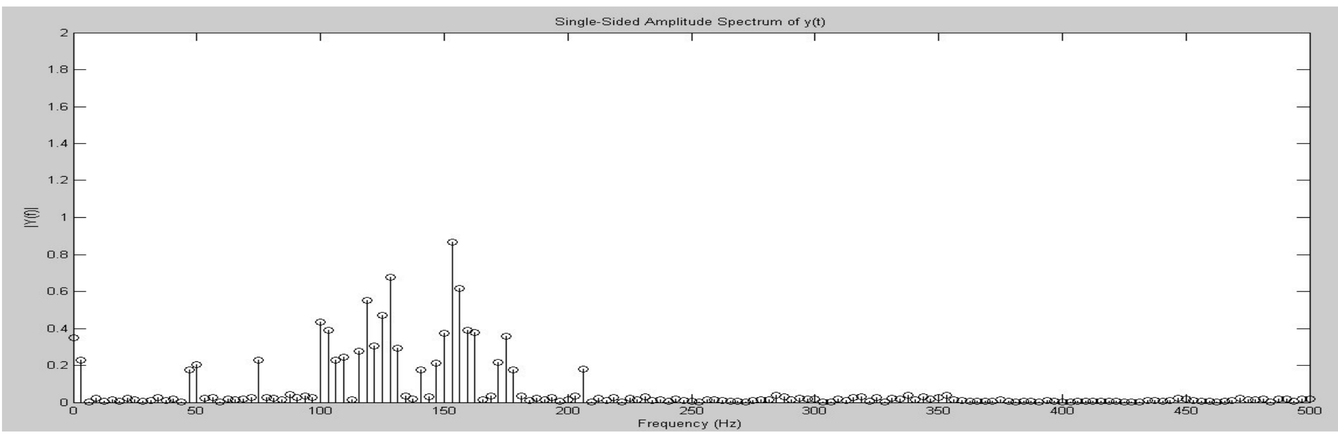


Fig.5.9 Healthy motor, full load,25hz

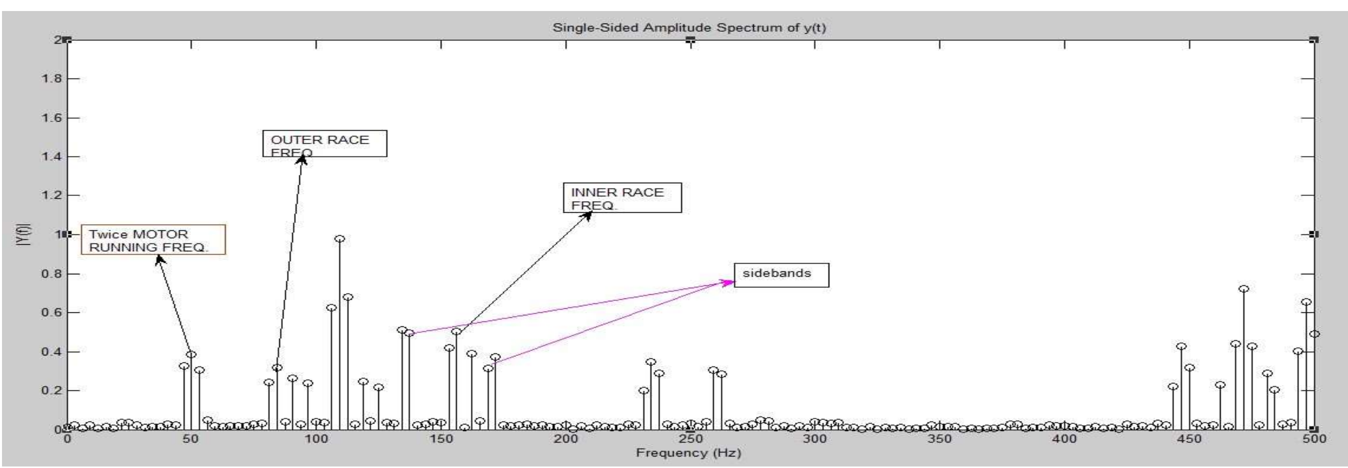


Fig.5.10 Bearing fault, no load, 25hz

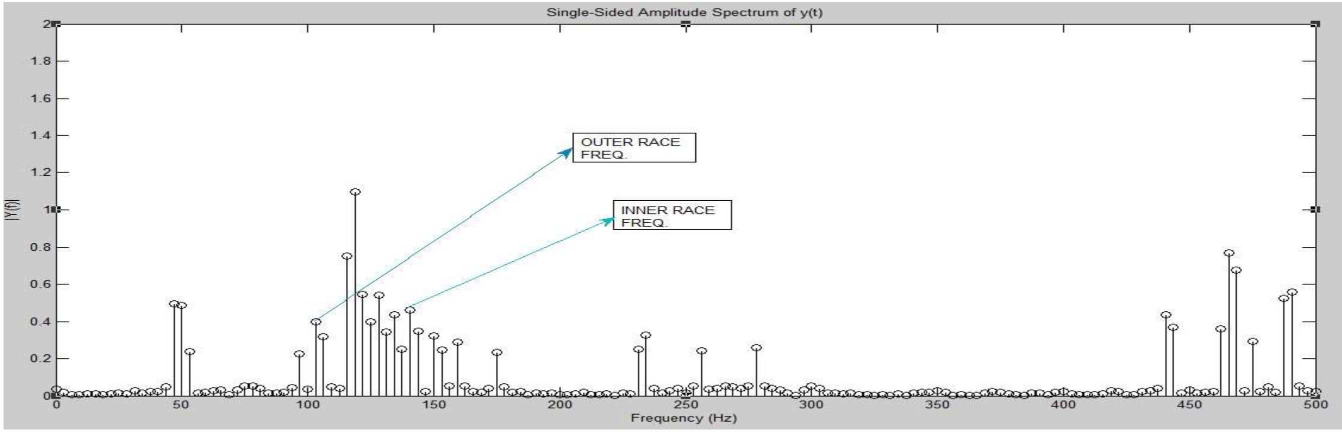


Fig.5.11 Bearing fault, full load, 25hz

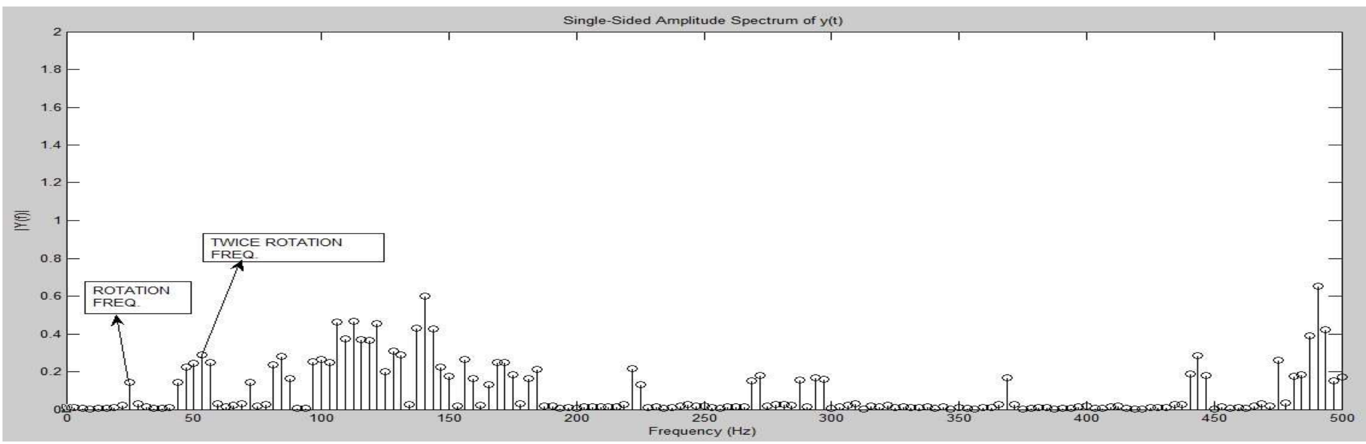


Fig.5.12 Rotor misalignment fault, no load, 25hz

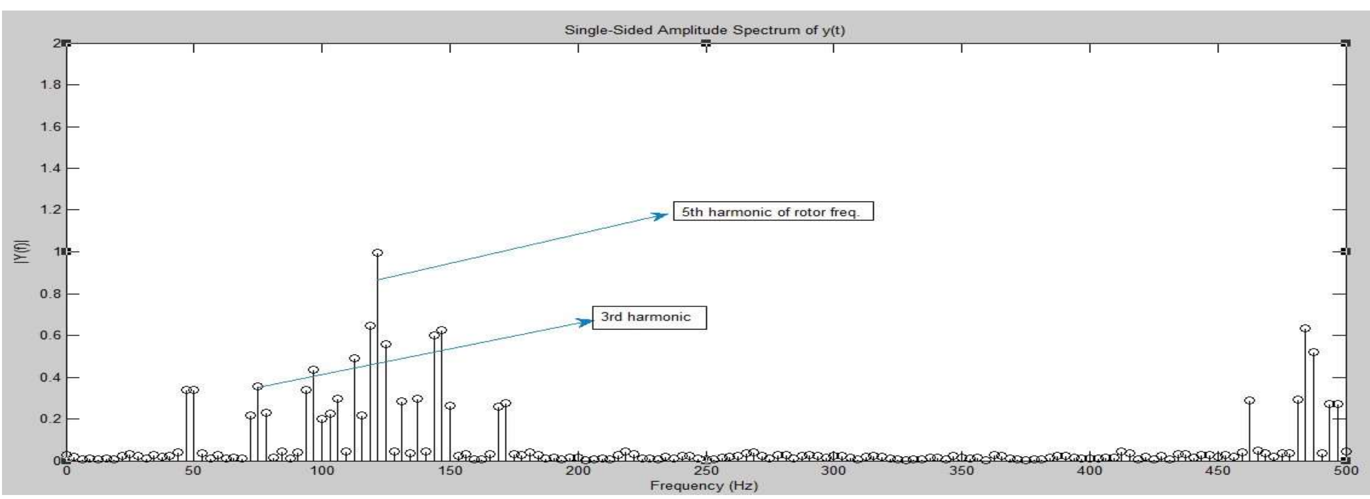


Fig.5.13 Rotor misalignment fault, full load, 25hz

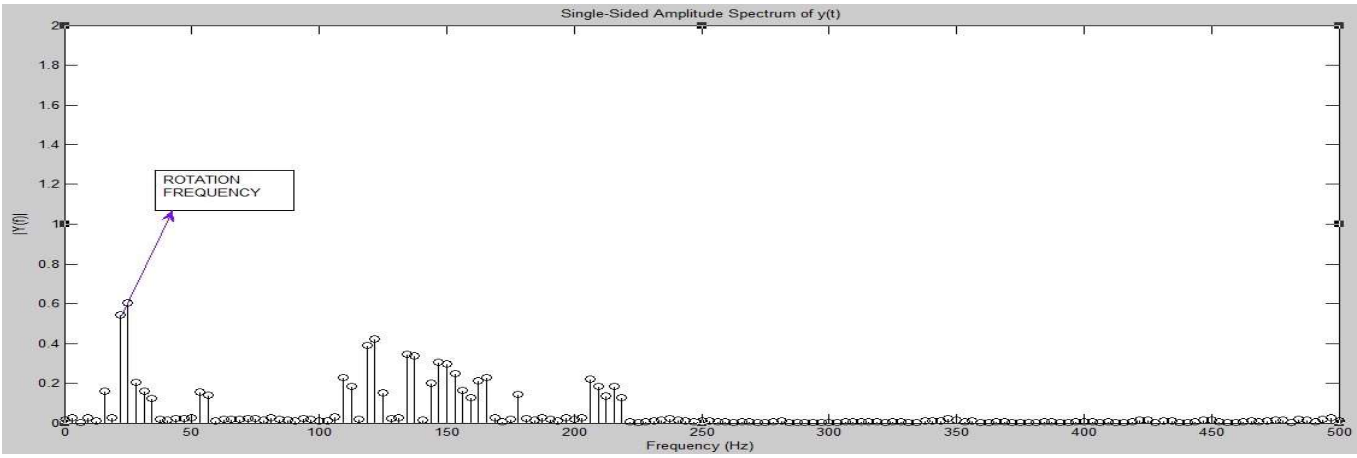


Fig.5.14 Broken rotor bar fault, no load 25hz

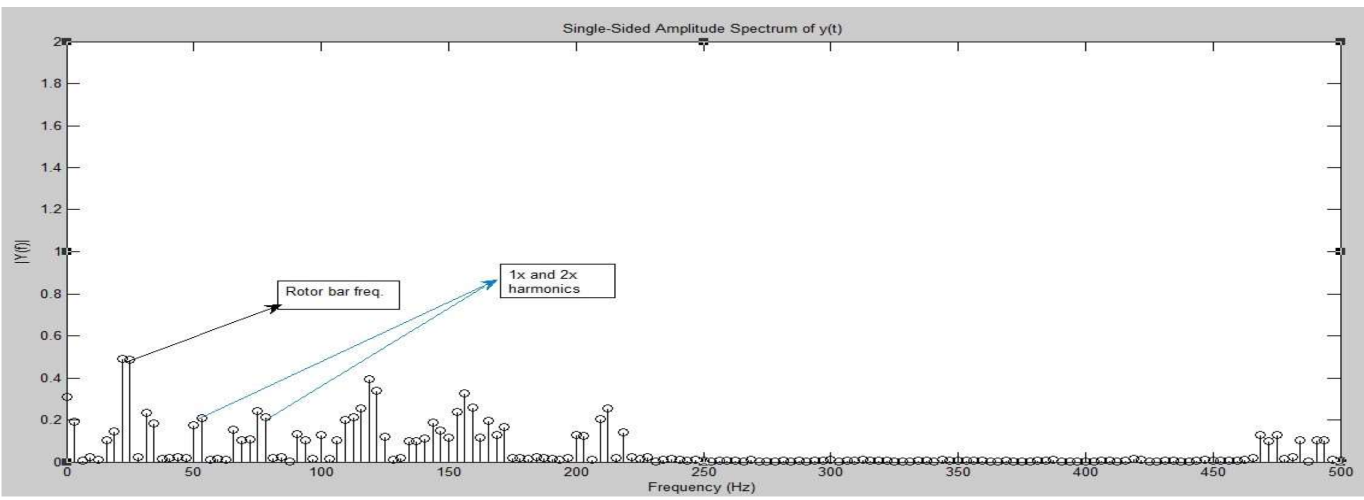


Fig.5.15 Broken rotor bar fault , full load , 25hz

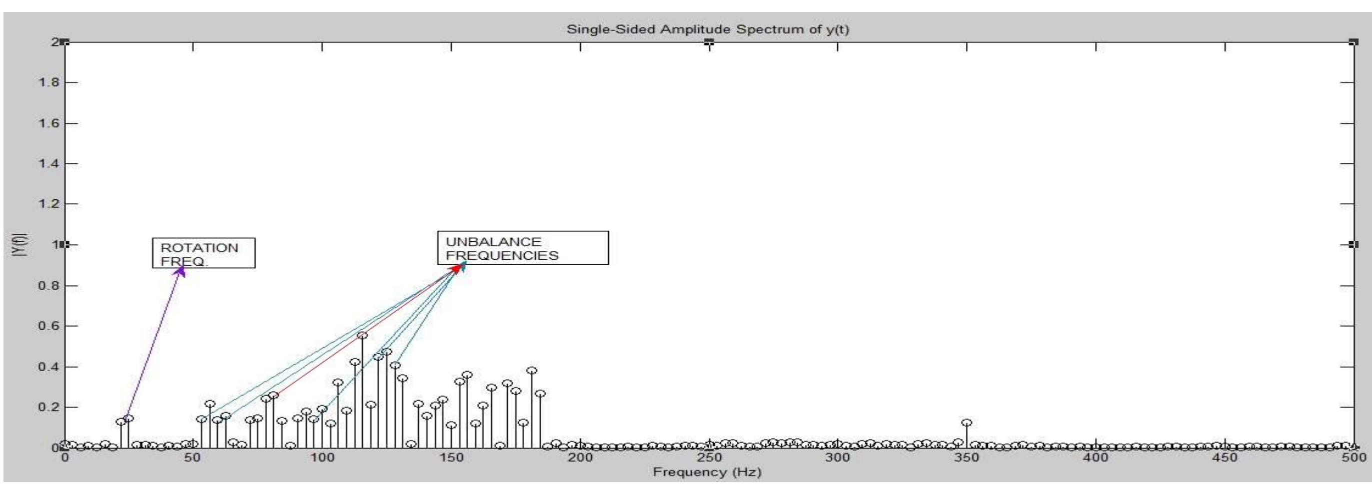


Fig.5.16 Rotor unbalance fault, no load, 25hz

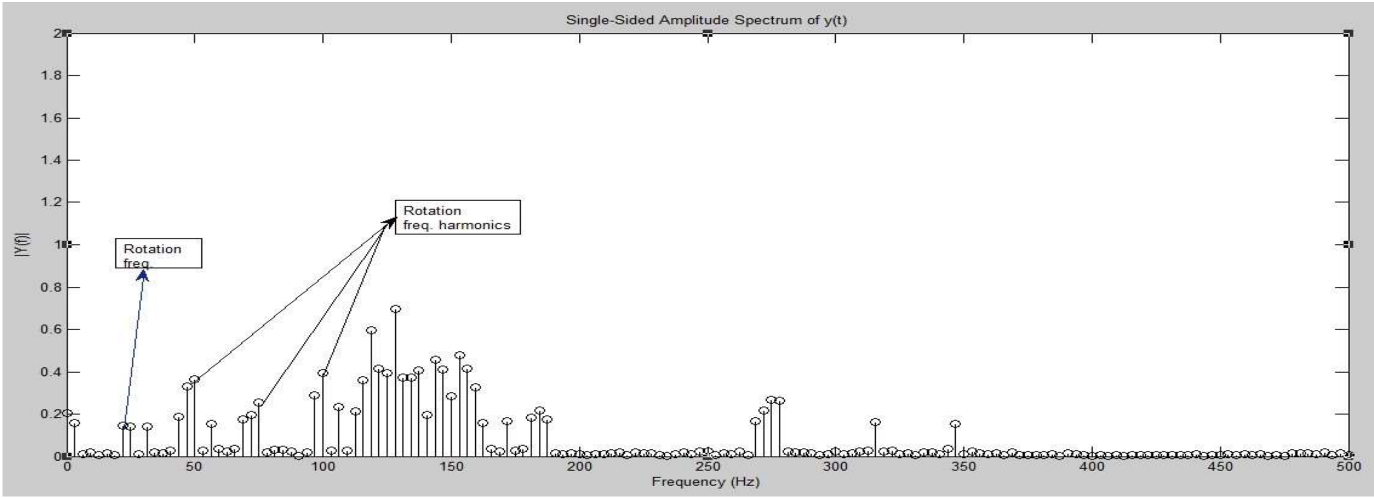


Fig.5.17 Rotor unbalance fault, full load, 25hz

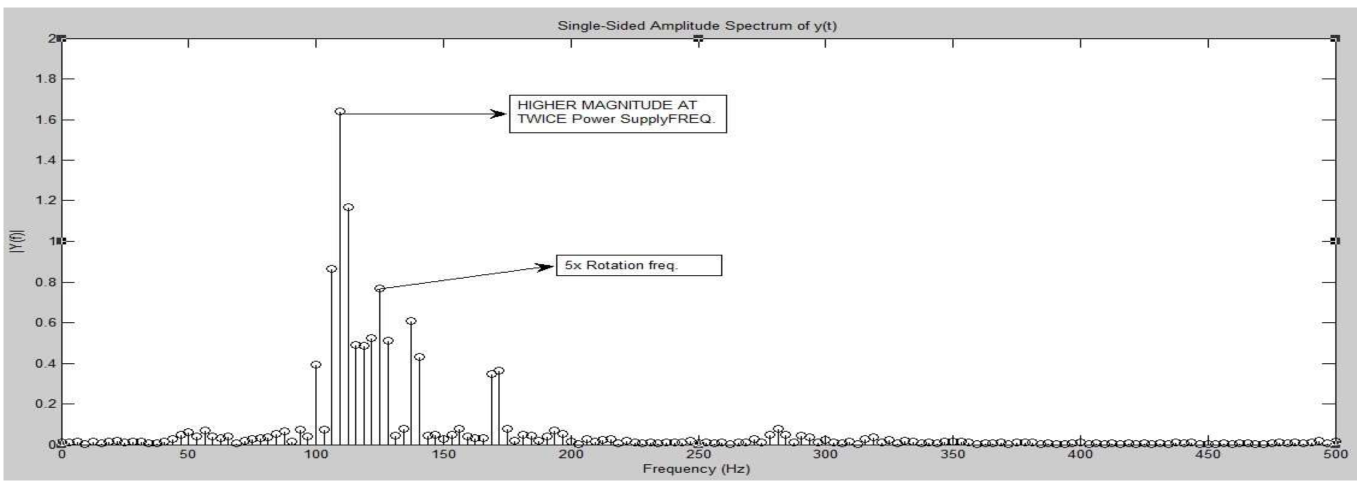


Fig.5.18 Voltage unbalance fault, no load, 25hz

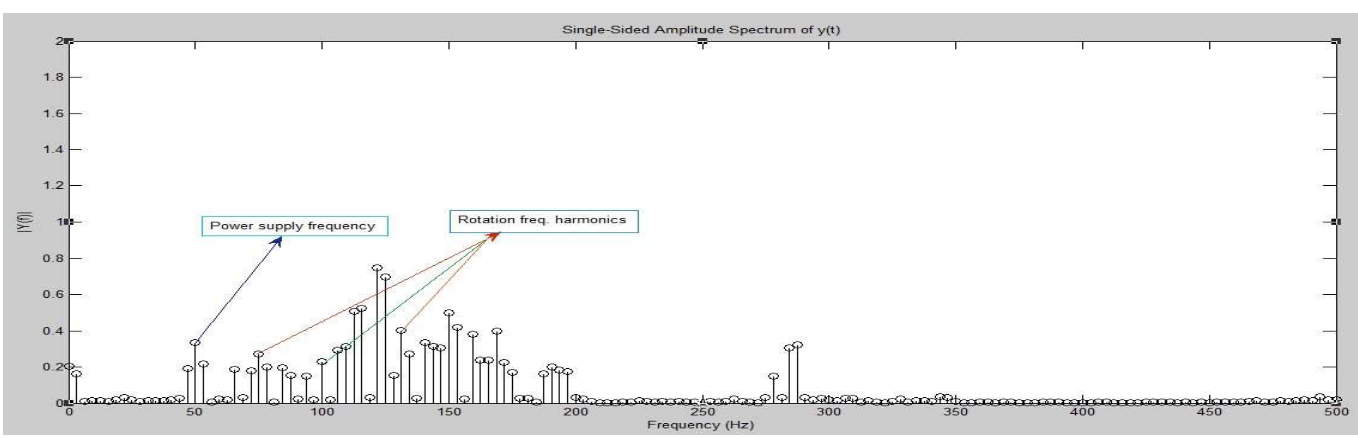


Fig.5.19 Voltage unbalance fault, full load 25hz

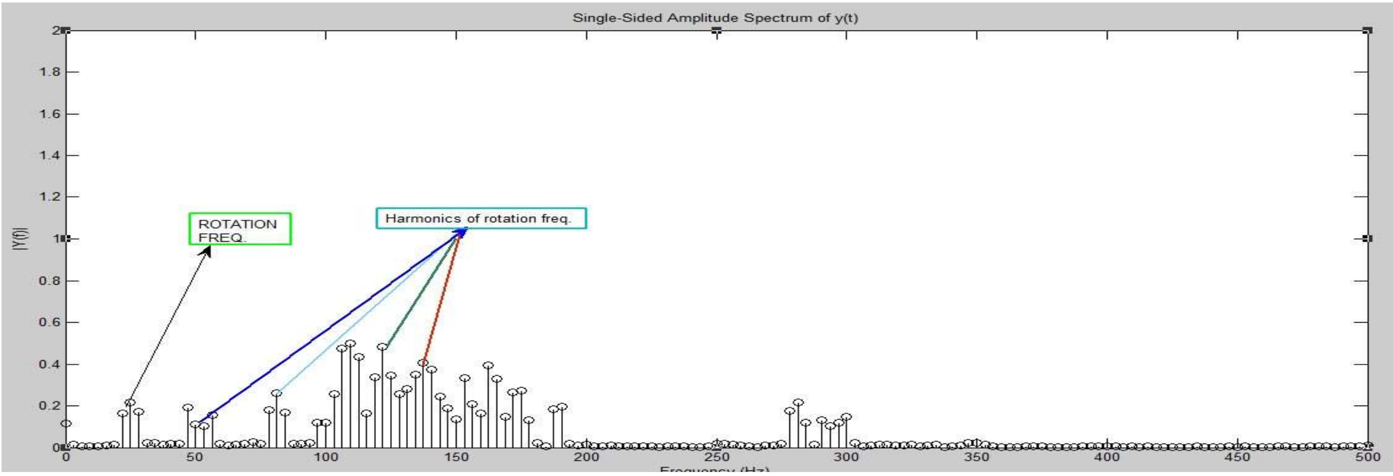


Fig.5.20 Stator winding fault, no load,25hz

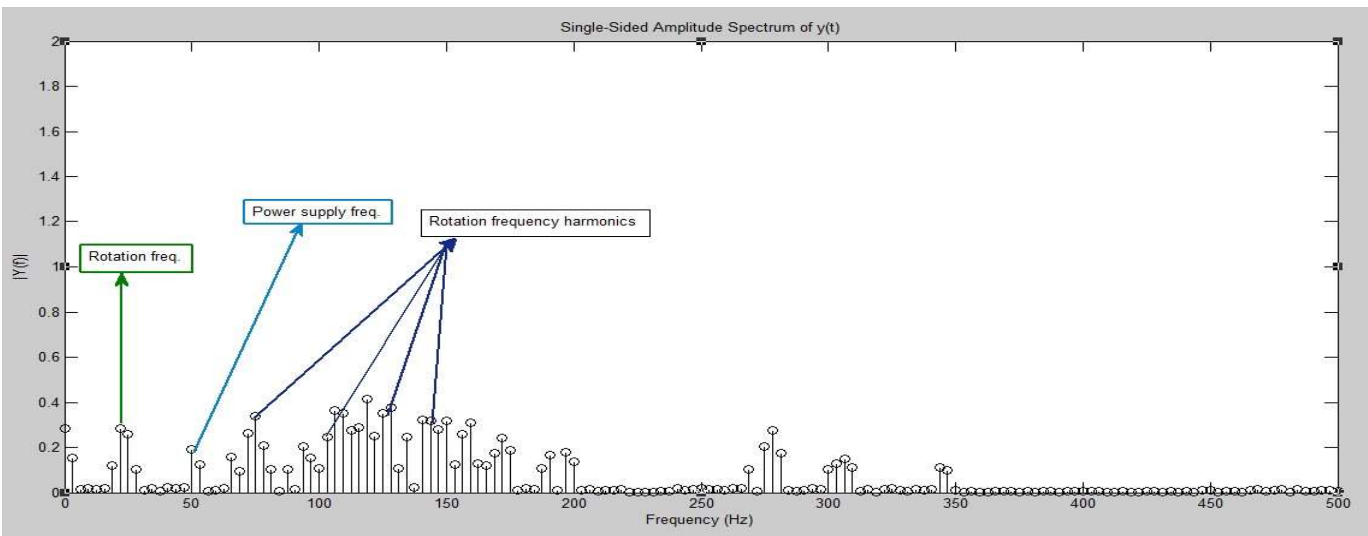


Fig.5.21 Stator winding fault, full load ,25hz

CONCLUSION

- By conducting experiments on different motors with built in faults and post analysis we get to know their various characteristics at different frequencies and effects of faults on amplitude of vibrations at different frequencies.
- The traits of the vibration spectrum of different faulty motors have been studied and will be helpful in diagnosing faults in a three phase induction motor if present.

FUTURE SCOPE

- A large set of data has been acquired and processed with Signal processing technique(FFT).These calculations and data can be used as training data in future for artificial intelligence based fault diagnosis of machines.
- Prognosis of the fault detected can be carried out after the fault diagnosis has been done

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