CONDITION MONITORING AND ANALYSIS OF ROTATING MACHINES IN STEEL INDUSTRY

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With Specialization in Measurement and Instrumentation)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work that is being presented in this dissertation report entitled "CONDITION MONITORING AND ANLYSIS OF ROTATING MACHINE IN STEEL INDUSTRY" submitted in partial fulfillment of the requirements for the award of the degree of **Master Of Technology** with specialization in "**Measurement & Instrumentation**", to the **Department Of Electrical Engineering, Indian Institute Of Technology, Roorkee**, is an authentic record of my own work carried out, under the guidance of **Dr. VINOD KUMAR, & Dr. S.P. GUPTA**, Professors, Department of Electrical Engineering.
I have not submitted the matter presented in this dissertation report for the Award of any other degree or diploma.

Date: 29|6|2005
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(PRAMOD MEHTA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

In recent years, progress in large size machine and advance factory equipment has contributed to the improvement of productivity, product quality. On the other hand, once trouble occurs economic losses are very great, and big problem arises also in safety control. In the recent years, a method for diagnosis the abnormality of equipment by measuring vibration and current harmonics for analysis is known as one of the efficient method of the equipment diagnosis. In the present thesis, work is to develop compact monitoring system for fast and efficient diagnosis the health of induction machines in steel Rolling mill and small induction motors used in labs. An attempt is to monitor the condition of the rotating machine in steel rolling mill and observe the changes in machine variables that occur at different situation. Changes in the various statistically and frequency parameters are observed from recorded vibration data at diiferntdirection (radial and axial) and at different load conditions. An attempt is made to develop a system that has ability to predict the machine condition in the same sense as that of professional expert

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ORGANIZATION OF THE THESIS

This thesis deals with diagnostic systems, which have been developed for identification of different faults of induction machine in steel rolling mill, after extracting and characterizing the features from the different pattern for diagnostic applications. The thesis is organized as following:

CHAPTER 1 INTRODUCTION

Introduces concept of condition monitoring for rotating electrical machines. It also gives the literature review on the area of fault detection in induction motor.

CHAPTER 2 FAULTS IN ROTATING ELECTRICAL MACHINES

It gives an overview of common faults in rotating electrical machines (Induction motor). Generation and characteristics of vibration signal under healthy and faulty conditions. The possibility of using stator current for fault detection is also explored in this chapter. The dominant frequency component of faulty component is also given

CHAPTER 3 DEVELOPMENT OF CONDITION MONITORING SYSTEM FOR STEEL INDUSTRY AND FOR SMALL MOTORS

This chapter gives details of use of hardware that includes selection and installation of various transducers to pick up desired signal from the test motor. It also describes the details of how the data transfer from transducer to computer memory through data acquisition card.

CHAPTER 4 FEATURE EXTRACTION FROM VIBRATION SIGNAL USING SIGNAL PROCESSING TECHNIQUES

This chapter describes briefly the signal processing techniques used for extracting the hidden information from the acquired raw vibration signal. These techniques reduce the dimensionality of the feature vector.

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CHAPTER 1

INTRODUCTION

This chapter introduces concept of condition monitoring for rotating electrical machines. It also gives the literature review on the area of fault detection in induction motor.

GENERAL

In recent years, progress in large size machine and advance factory equipment has contributed to the improvement of productivity, product quality. On the other hand, once trouble occurs economic losses are very great, and big problem arises also in safety control.

Electrical motors find wide use in industries as source of motive power. Different types of electric motors such as DC motors, induction motors, synchronous motors, and AC commutator motors are used in industries. Presently, induction motor with slip ring in steel industry and squirrel cage motor in lab is used for analysis. . With the advent of personal computers as fast and cost effective machines for data acquisition and processing of multiple signals, computers have received wide acceptance in industrial applications.

Motor reliability studies have been performed by both General Electric and the IEEE Industry Applications Society in order to evaluate the reliability of electric motors and identify design and operational characteristics that offer the potential to increase their reliability. The results of these studies show that bearing problems account for over 40% of all machine failures. Over the past several decades, rolling-element (ball and roller) bearings have been utilized in many electric machines while sleeve (fluid film) bearings are installed in only the largest industrial machines. In the case of induction motors, rolling element bearing are overwhelmingly used to provide rotor support.

Therefore, it is important that measures are taken to diagnose the state of the machine as and when it enters or about to enter into the fault mode

1.1 INTRODUCTION

The origins of inherent failures are due to mechanical or electrical forces acting in the machine enclosure. Researchers have studied a variety of machine faults such as winding faults, unbalanced stator and rotor parameters, broken rotor bars, eccentricity, and bearing faults. Different methods for fault identification have been developed and used effectively to detect the machine faults at different stages using different machine variables such as current, voltage, speed, efficiency, temperature, and vibrations.

Condition monitoring is used for increasing machinery availability and machinery performance, reducing consequential damage, increasing machine life, reducing spare parts inventories, and reducing breakdown maintenance. An efficient condition-monitoring scheme is capable of providing warning and predicting the faults at early stages.

In this dissertation work, following conditions in machine have been considered in the induction motor for steel rolling mill and small motor at lab:

(i) healthy condition

(ii) unbalance supply voltage

(iii) inner race fault in bearing

(iv) outer race fault in bearing

(v) misalignment, mechanical looseness or imbalance etc

In many situations, vibration-monitoring methods are utilized to detect the presence of an incipient fault.

1.2 RELATION BETWEEN MACHINE PARAMETER AND FAILURE MECHANISM

Machine never breaks down by chance. Their operating condition gradually deteriorates, and this gradual quantitative deterioration transforms into a failure manifesting a qualitative change.

When a fault take places, some of machine parameter is subjected to change. The change in machine parameter depends upon the degree of faults and the interaction with other parameters. In most cases, more than one parameter is subjected to change under abnormal condition. If these machine parameters can be measured, they give information relating to a developing fault and then maintenance can be planned for next available shutdown. Therefore, Condition monitoring requires measurement to be taken from machine on continuous basis and used to indicate the current working condition of that machine.

There are a number of parameters that can be considered for monitoring of the machine. For induction machines, monitoring parameters are terminal voltage, current, instantaneous power; temperature of stator, rotor speed, torque, and stator frame vibration, bearing vibrations etc.

The change in machine parameter is not always due to presence of fault but some time due to working environment, loading condition, and supply condition. For example, transient load may cause excessive vibration, increase in current harmonic and pulsation in torque and speed. Therefore, the relation between the fault phenomena and machine parameters are complex especially for low degree of faults.

A inspection of certain features of the time domain and spectral domain analysis give many information to identify faults, Artificial neural networks (ANNs) offer advantages for automatic detection and diagnosis of machine faults since they do not require an in-depth knowledge of the behavior of the system or its internal vibration generation mechanism. However they do require a large number of training data patterns.

1. 3 VIBRATION ANALYSIS

Many condition monitoring methods have been proposed for rotating machine using one or combination of mentioned parameters. In rotating electrical machinery, vibration signal is commonly used for fault diagnostic. This is because when machine or a structural component is in good condition, its vibration profile has the 'normal' characteristic shape and it will change as a fault begins to develop [1].

Forces produced in machine by shafts, gears and loads are usually transmitted through supporting bearings and therefore, most of the breakdowns in rotating machine are directly related to rolling element-bearing failure. Vibration reading taken on bearing housing can therefore provide a signature that contains information of the machine condition.

The bearing wear or defects occur in raceways and rolling elements and each particular defect of bearing generates its own vibration frequency obtained from the geometry of the bearing. Therefore, by identifying these frequencies in the vibration spectrum it is possible to monitor the bearing condition. Besides bearing defects, additional faults such as unbalanced shafts, misalignment, mechanical looseness bent shafts and damaged gear teeth and electrical faults such as unbalanced supply, broken rotor bar etc. can also be detected from vibration spectrum. [2]

1.4 LITERATURE REVIEW

The present day requirement of fault diagnostic in rotating machinery is more important than ever before and continues to grow constantly especially where large rotating machine are employed. Advances are continually being made in this area. The subject of fault diagnosis in rotating machinery is vast including the diagnosis of items such as rotating shafts, gears, bearings and pumps etc. The literature on the subject of fault diagnosis is vast and wide ranging, encompassing areas such as general surveys, general system modeling and methods applied to fault detection of the specific items of machinery.

Several papers have been written in recent times on fault detection and isolation general in the area of rotating machinery. Once the dynamic behavior of the system has been modeled, it should theoretically be possible to detect faults via analysis of changes of input parameters to the model

1.4.1 Vibration Monitoring

One of the major areas of interest in the modern day condition monitoring of rotating machinery is that of vibration. Vibration signal collected from the motor carries information on the fault(s). The knowledge of motor fundamentals and vibration analysis helps in reliable fault diagnosis. The vibration signatures of machine processes have been a potential input for an in-process monitoring tool.

As reported by Finely et al [3] the cause of vibration are various electrical and mechanical mechanisms developed during the operation of rotating electrical machines. These mechanisms generate vibration at known frequencies. Therefore by utilizing the proper data collection and analysis technique, the true source of increased vibration can be discovered.

Ellison & Moore [4] have reported a comprehensive study of the sources of noise and vibration in rotating electrical machines. The effect of different machine conditions on the noise and vibration emitted from the machine is demonstrated. The analysis and measurement of machine noise and vibration is discussed and some general rules to reduce the machine noise are given.

Tavner [8] presented a method for calculation of electromagnetic excitation forces in the air gap between stator and rotor three-phase squirrel cage induction motor. These forces are responsible for the generation of vibration and noise. The effect of skewness, eccentricity and slot opening were also analyzed. It is reported that vibration and noise in induction motor are mainly due to radial forces.

Condition monitoring techniques based on vibration data analysis are of two types; the level monitoring, which measure the level of the vibration signal (acceleration/velocity/ displacement) is measured in term of mean or rms (root mean square), peak value or any other statistical measure such as kurtosis or skewness. This value is then compared with a known standard chart for knowing the status of the machine health. Another technique, also known as spectrum monitoring, identifies the fault characteristic vibration frequencies for diagnosis of specific type of fault.

Following the successful application of Higher Order Statistics (HOS) in diesel engine condition Monitoring [Bradley Payne, Liang Bo, WeidongLi, Fengshou Gu, Andrew Ball] [6] investigates the capability of such an approach to monitoring of induction motor. Higher Order Statistics provide a convenient basis for comparison of data between different measurement instantances and are also sufficiently robust for on-line use. They are also fast in computation compared with frequency or time-frequency analysis. Furthermore they give a more robust assessment than lower orders and can be used to calculate higher order spectra.

Ruqiang Yan, and Robert X. Gao,[11] presents a machine health evaluation technique using the Lempel-Ziv complexity as a numerical measure. Comparing to conventional techniques such as spectral and time-frequency analysis, the presented approach does not require a linear transfer function of the physical system to be, and is thus suited for the condition monitoring of machine systems under varying operation and loading conditions. Theoretical foundation of the technique is introduced, and its performance is investigated through experimental study of realistic vibration signals measured from a rolling bearing system. The results demonstrated that complexity provides an effective measure for machine health condition evaluation. [11]

Samanta B. and. Al-Balushi K. R [15] presented time domain approach where the status of the machine in the form of normal or faulty bearing is classified by features namely root mean square, variance of the vibration signals. These features of vibration signal are used as inputs to the artificial neural network. The effects of preprocessing techniques like high-pass, band pass filtration, envelope detection and wavelet transform of the vibration signals are also studied. They also reported that accelerometer placed at bearing housing in radial direction carried maximum information.

Data Bulletin By Square D Company [16] has suggested technique for r.m.s acceleration level curve drawn against elapsed time, to predict the remaining life of the rolling element bearing. They found that the r.m.s acceleration level in the 5-12.5 kHz band give good estimation of the final failure time. In addition, they showed that the changes in the spectral content of acceleration data improved the reliability of the prediction.

Frequency-domain or spectral analysis of the vibration signal is the most widely used approach of bearing fault detection. The advent of Fast Fourier Transform (FFT) analyzers has made the job of obtaining narrow band spectra easier and more efficient. Both low-and high-frequency ranges of the vibration spectrum are of interest in assessing the condition of the bearing.

Mathew et al [20] have reviewed some popular condition monitoring techniques used for rolling elements bearing. They viewed the detecting of incipient failure of several rolling element bearing through the monitoring of their vibration signature. The progress of the fault is detected by continuos monitoring of the bearing using different vibration parameters.

FFT is one of the most widely used and well-established methods used in fault detecting techniques. Unfortunately, FFT based methods are not suitable for non-stationary signal analysis. Time-frequency analysis such as short time Fourier transforms (STFT) can be used for analysis of non-stationary signals. The problem with STFT is that it provides constant resolution for all frequencies since it uses the same window for the analysis of the entire signal. Therefore STFT is suitable for the quasi-stationary signal analysis (stationary at the scale of the window but not the real stationary signal). On the other hand, the wavelet transform can be used for multi -scale analysis of a signal through dilation and translation, so it can extract time-frequency features of a signal effectively.

Martin [26] has demonstrated the limitation of using Fourier Transform approach for bearing damage monitoring. The traditional treatment of vibration spectrum fluctuations is the averaging, which may ignore some features of short duration. The alternative approach to such non-stationary vibration signal is the wavelet transform. The paper presented the application of wavelet transforms of vibration signals for diagnosing the bearing faults. The authors presented a comparison between both approaches in predicting different bearing faults.

Rubini R. and Meneghetti U [21] reported limits of classical signal processing techniques by showing their application to bearings affected by different pitting failures on the outer or inner race or a rolling element. Results were compared with those obtained by an advanced signal processing method based on the evaluation of the wavelet transform. They concluded that when the contact between bearing surfaces flattens the flaw during operation, the envelope spectrum seems to become insensitive to the defect long before the wavelet transform function does, setting a more restrictive limit to monitoring policy. Also they found that the envelope spectrum sensitivity is rather dependent on the selected filtering band, while the average of the frequency sections gives an acceptable stability to wavelet transform results. On the grounds of these observations, it appears clear that the effectiveness of the spectral analysis for the bearing diagnostics not only depends on the fault dimensions, but is also influenced by other parameters, such as load intensity.

Dalpiaz et al [29] compared the effectiveness and the reliability of different vibration analysis techniques for fault detection. The results of the application of these techniques are given and their limitations are delineated. Since the obtained vibrations signal the are highly non-stationary, the wavelet transform is proposed for analysis. The result of this investigation showed the need to use more than one technique to obtain reliable diagnostic.

Martin H.R [26] presented a scheme for detection of bearing localized defects based on wavelet transform. In their paper they discussed briefly, important properties of the wavelet transform and its comparison with short-time Fourier transform. Then, a basic wavelet is constructed by utilizing exponentially decaying sinusoid function as mother wavelet. The effectiveness of the proposed method is then evaluated by using actual vibration signals measured from the bearings with defects in outer race and rolling elements.

Zeki Kiral et al [31] is proposed a technique to simulate the vibration of bearing structures which houses a ball bearing with or without a defect. A computer program is developed to model the dynamic loading of the bearing structure, considering the bearing kinematics and load distribution. The high frequency resonance technique (HFRT) is employed in the frequency domain analysis and its success is investigated. The effect of the rotational speed, geometry of the bearing structure and type of loading on the selection of the signal processing technique is illustrated by the vibration analyses for two different bearing structures and two different loading conditions at different rotational speeds. It is observed that both the time and frequency domain techniques are sensitive to changes in rotational speeds, structure geometry and loading type. The proposed method can be used to determine the ideal sensor position and signal processing technique, considering the rotational speeds, structural effects and loading conditions at the beginning of an industrial condition monitoring application

The signal processing tool "higher order spectra" (HOS) is a topic that has been of considerable interest to researchers in the signal processing arena, which has been recently extended to the area of condition monitoring because of some attractive properties. Historically, only a subset of the HOS tools, known as second order HOS measure (power spectrum), has been used for condition monitoring of induction machines.[38]

Murray et al [35] showed that higher order spectra specifically bispectrum of vibration signal for faults such as unbalanced electric supply and broken rotor bars provides an effective means of extracting important information to aid to diagnoses of faults in induction machine. They also reported that that use of HOS reduces effects of noise, which further aids advantage to condition monitoring.

Yang et al [36] presented in their paper the vibration analysis for different bearing fault condition based on the power spectrum, the bispectrum and the bicoherence. The feature extracted from these techniques is then used to train the neural network for automatic fault detection. They claimed that with summed bispectrum, the bearing conditions can be diagnosed with higher success rate.

Pineyro J.et al [37] demonstrated the application of three advanced spectral methods for detection / diagnosis of localized defects in rolling element bearings. They concluded that second order power spectral density proves to be useful as a tool for peak identification and an aid to classical linear spectra. There are limitations because peaks of interest must be well separated from neighboring points, and that extremely narrow band resonances cannot be distinguished from periodic signals. Bispectral techniques show its effectiveness in quadratic phase coupling peak detection, and because its a third order moment function noise background is eliminated in the estimation procedure, being capable of detecting them. One of the main drawbacks is the amount of memory needed during data processing. Wavelet analysis using a simplified technique via Haar transform proves to be applicable in early detection of the burst generated during a fault development. Amount of memory needed during data processing. Wavelet techniques based on the Haar transform, prove to be useful in short transient detection because after an appropriate filtering process it is possible to eliminate noise and periodic signals. The spectra of this denoised signal retain the main characteristic of frequency peaks in the spectra. On the other hand, this technique has failed in the detection of transients using acoustic emission sensors.

1.4.2 Stator Current Monitoring

Recently, current harmonic based condition monitoring of electrical machine got the attention of many researchers. With the advances in signal processing technique and diagnosis techniques, more information about the machine condition was obtained.

A comparison of vibration and current monitoring technique is given by Benbouid et al [40]. The paper first reviewed the presence of vibration frequency components for known faults such as eccentricity and broken rotor bars, shaft speed oscillations, rotor asymmetry and bearing failure. It was mentioned that all of these faults produce asymmetry in the air gaplength which causes variations in the air gap flux density. This affects the inductance of the machine and hence produces stator current harmonics with the known frequencies. However, inthese paper only electrical faults such as voltage unbalance and single phasing of supply is considered for demonstration of high resolution technique such as MUSIC and ROOT-MUSIC by using stator current. It is cleared that the approximate complexity of these techniques is N^3, whereas classical spectral analysis is N ($\log_2 N$). Where N is the number of samples.

Riley Caryn M et al [36, 37] concluded that for a known vibration frequency, the harmonic rms vibration level and rms current level are monotonically related. They proposed a new condition monitoring system that uses only stator current signals for determination of the operational state of the machine. In this system, a current signal of one phase of stator and vibration signal from a vibration sensor located at the bearing cap, under normal operating condition serves as baseline data. The relation between baseline vibration and current harmonic components are the calculated and the current signal is calibrated in terms of vibration magnitude.

Schoen et al [40] explained that variation in load torque at multiples of rotational speed has the same effect on the motor current spectrum as eccentric air gap and broken rotor bars do. Therefore, this variation in load can prevent the detection of fault conditions by producing same current component, which obscure the harmonicsrelated to fault condition of the machine. It is proposed that the load torque effect can be removed by comparing the actual stator current to a model reference current.

In another paper, Schoen R. R. et al [41] demonstrated a method for on line detection of motor incipient failure. The combination of rule base filter and neural network is proposed for prediction of presence of eccentricity and bearing damage developing in the machine. The method does not require user interpretation of spectrum of stator current even under unknown load conditions.

It is well-known that motor current is a non-stationary signal whose properties vary with respect to the time varying normal operating conditions of the motor. As a result Fourier analysis makes it difficult to recognize fault conditions from the normal operating conditions of the motor. Time-frequency analysis, on the other hand, unambiguously represents the motor current which makes signal properties related to fault detection more evident in the transform domain reported time-frequency method for the detection of broken bars and bearing faults.

1.4.3 Other Monitoring Techniques

Rough idea about some documented works including other than vibration parameter is presented here. In order to avoid thermal failure in stator or rotor winding, the winding temperature must be below the designed insulation class limit and rotor temperature must be limited to prevent fatigue and mechanical distortion. Therefore, rotor and stator temperature are of concern in both short term machine protection and in longer term condition monitoring. Smith et al demonstrated a system for measuring motor cage bar temperature. It is claimed that with temperature of the cage before starting, during acceleration and while motor is running gives better judgement about the condition of the rotor cage.

Beguenane et al [42] have presented thermal monitoring technique for induction motor using rotor resistance measurement. The paper describes an electrical model of induction motor by which the rotor resistance in that model is estimated from measurements of stator voltages, stator currents, and stator excitation frequency and rotor speed. The effect of unbalance supply voltage and non-sinusoidal voltage on induction machine thermal parameters

Several rotor cage faults of increasing severity were studied with various load levels by using Fast Fourier Transform. They reported that when an abnormality, such as the rotor cage fault, motor-load shaft misalignment, broken teeth in the load gearbox, or vibration, develops in the drive system, the current, torque, and speed of the motor are affected in a periodic manner and periodic disturbances modulate all the three line currents simultaneously with the fundamental frequency of the fault-induced oscillation.

1.5 REVIEW

There are several concerns attached to the condition monitoring research. These include obtaining the vibration signal under healthy and different faulty conditions, extractaction of important features and design of fault detection mechanism. These problems require immediate attention of researchers. Further, there is a problem of the availability of authenticated real time data in the industries. So to over come this problem our data acquiring system was made compact that is easily transferable. Also the knowledge base plays an important role and helps in deciding and perfecting the technique of acquisition, analysis and interpretation.

Computer aided feature extraction and analysis of the vibration signal for fault diagnostics has become necessary in the present time, as most of the diagnostics and treatment are dependent on the outcome of diagnostics results from such systems. Looking into the need of time it is clear that there is utmost need to develop reliable software based diagnostic systems to cope-up with the modern techniques of computation and interpretation. The review of literature showed that there are sufficient possibilities of carrying out useful and application oriented work in the area of condition monitoring of rotating electrical machines.

After literature survey, it came to our knowledge that there is still a lot of scope in the area of condition monitoring of rotating electrical machines for further investigations which may lead to early detection of the fault; so that the maintenance can be carried out at the initial stage of the fault without causing damage to such a state that the maintenance may become a remote possibility or no possibility at all.

1.6 PROBLEMS ENCOUNTERED IN VIBRATION SIGNAL ANALYSIS

Recent advancement in computer technology in the last 30 years has made automated quantitative vibration analysis feasible. For furtherance of development of quantitative diagnostic techniques, the need has emerged for adding automated decision making support to these techniques, so that, all data is processed in an integrated environment. With increased volume of information available from new technologies, the process of classifying sets of features and determining appropriate diagnostic actions becomes increasingdifficult. A single fault may manifest itself quite differently in different machines and at different fault stages. Furthermore, a single feature may be indicative if several different faults and the presence of several faults in a single machine may disrupt the expected symptom pattern of any one of them.

1.7 OBJECTIVES OF PRESENT THESIS WORK

The objective of the present work has been to build an efficient diagnostics system for faults in rotating electrical machines in steel industry. Effort has also been made to develop the diagnostics system, which takes less computational time and has improved system performance. The methodology to achieve the aims and objectives is as follows:

(i) The development of condition monitoring system and real time data has been recorded from the running motors in steel industry.

(ii) The change in various parameters is seen at different condition.

(iii) The features of the vibration signal invariably used for the fault diagnosis have been studied, selected and thereafter extracted from vibration signals.

CHAPTER 2

CLASSIFICATION AND ANALYSIS OF FAULTS IN INDUCTION MOTOR

This chapter contains overview of common faults in rotating electrical machines, generation and characteristics of vibration signal under healthy and faulty conditions and vibration standard chart for rotating machine

2.1 INTRODUCTION

The induction motor is having wide spread use in industry today. It is supposed to be a robust and fault tolerant machine. It is important that precautions should be taken to analyze the condition of the machine, when the fault is in incipient state. The failures in rotating electrical machines are caused by combination of various stresses that act on two components i.e. stator and rotor of the machines. Under normal operation, the interaction of these stresses leads to stable operation with minimum noise and vibration. However, under abnormal conditions the equilibrium among these stresses is lost which leads to further enhancement of the fault. Due to the destructive nature of most failures, it is not always easy to determine the cause.

In this chapter a procedure for analyzing these failures and determining their causes is introduced. There are two types of the faults: soft and hard. They are shown in fig 2.1. The soft fault develops gradually with time, which is a characteristic of many mechanical elements where wear takes place causing a gradual degradation of the operation of the element. The hard fault takes place instantaneously; makes the element is either on or it is off. This is the characteristic of many electric circuit elements but does not occur in mechanical element. The difference between these faults is important. The soft (trend) fault leads to a predictable situation; it lends

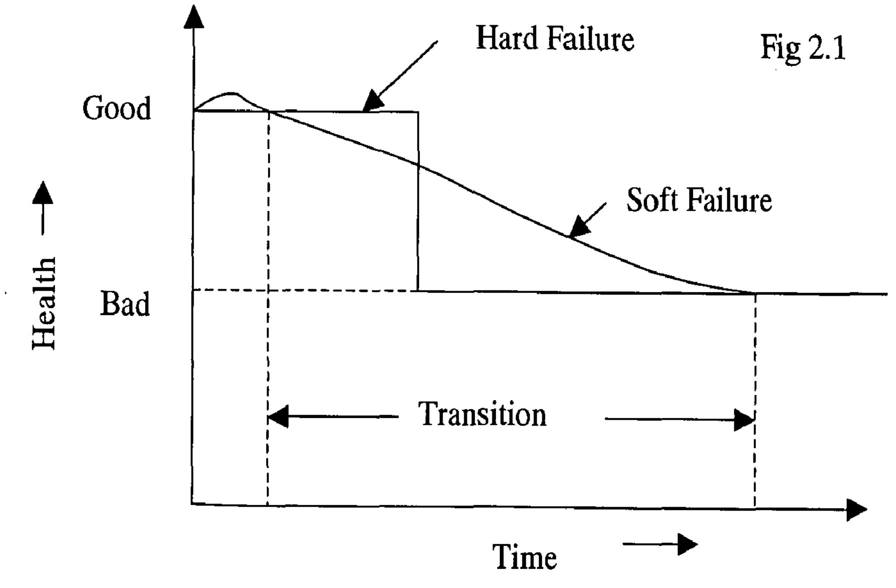


Fig 2.1 Hard and Soft Failure (from ref.2)

itself to condition monitoring. The hard fault is generally unpredictable. [ref 28]. There is a view that hard faults must exhibit some changes before the occurrence of the failure. For example, an electric fuse wire is sometimes quoted as an element, which suffers typically from a hard fault. However, it is quite probable, before the fuse burns out, that the dimensions of the fuse wire or perhaps the electrical resistance will change. Condition monitoring generally applied to system where trend faults develop.

2.2 FAULTS IN INDUCTION MOTOR

Broadly, the motor faults can be categorized into three types: mechanical, electrical and environmental. Mechanically, machines can be exposed to periods of intermittent running, frequent starting and arduous duty cycles, where load varies frequently between no-load to full-load with occasional overloads. These conditions lead to faults in stator and rotor of rotating machine.

For induction motor common mechanical faults in stator are namely: stator eccentricity and core slackening. The most common mechanical faults in rotor are rotoreccentricity static or dynamic and misalignment. Other mechanical faults such as rotor rubbing stator and rotor fatigue etc. are the consequence of the previous mentioned faults.

From electrical supply point of view a machine may be subjecting to variety of transients at its supply terminals. These may be slow fluctuations in the supply voltage or even unbalance between the three phases which causes several problems such as overheating, faults of winding and core systems, movement of electrical connection and overstressing of terminal boxes. Winding fault is due turn to turn, phase to phase earth short circuits. While core fault is due to core slackening, lamination short circuit and rotor strike.

Environmentally there are thermal and contamination problems The machine may run exceptionally hot because of cooling problem; ambient conditions or simply that machine is being operated to its rating limit. This can deteriorate its insulating materials. Also the machine may be operating in dirty environment because of industrial process in which it is operating. The cooling gas may also become damp because of ambient conditions, which leads to condensation of moisture on electrical insulation and connections giving a reduced insulation resistance.

Clearly a machine needs to be designed to meet mechanical, electrical and environmental disturbances it is likely to encounter during its life. But a monitoring system should be directed towards detecting this unwanted disturbance and hence prevents the machine from catastrophic failure. Table 2.1 and 2.2 show the faults and its origin for stator and rotor of induction motor.

Table 2.1 Causes and Analysis of Stator Failure [ref 2]

S. N.	**Stator Failure Cause**	**Type of failure**	**Remarks**
1.	Electrical Stresses	1. Dielectric failure	These stresses can be broken down into Phase-to-phase fault, Turn to ground fault.
		2.Transient Voltage Conditions	Motors exposed to transient voltage conditions results in reduced winding life or premature failures in terms of either turn to turn or turn to ground. The possible causes of transient voltages are line to line, line to ground and three-phase fault that cause over voltage approx. 3.5 times of normal value. Other causes are opening and closing of circuit breaker, capacitor switching etc.
2.	Mechanical Stresses	1. Coil Movement	The force produced in the stator winding causes this movement. This movement causes sever damage to the copper conductors.
		2. Rotor Strike	There are number of reasons why rotor strikes to stator. Some of most common are: bearing failure, shaft deflection, rotor to stator misalignment etc. If the strike only happens during startup, the rotor strike only causes the stator lamination to puncture the coil insulation, resulting in grounding coil. If the contact is made while the motor is running at full speed, the result is very premature grounding of the coil.

3.	Thermal stresses	1. Thermal aging	As a rule, for every 10 C increase in temperature, the insulation life is halved. Unless the operating temperature is very high, the normal effect of thermal aging is to render the insulation system vulnerable to other influencing factors that actually produce the failure.
		2. Thermal overloading	The causes of thermal overloading are voltage variation, unbalanced phase voltage, obstructed ventilation, ambient temperature etc.
4.	Environmental Stresses	1. Contamination	The presence of foreign material can have the following effects on the rotor: reduction in heat dissipation, which will increase operating temperature, breakdown of insulation failure etc,

Table 2.2 Causes and Analysis of Rotor Failure[ref 2]

S. N.	**Stator Failure Cause**	**Type of failure**	**Remarks**
1.	Magnetic Stresses	1. Uneven magnetic pull and rotor pullover	Unbalanced magnetic pull happens only when the air gap between rotor and stator decreases on one side while increasing on other side. As a result, rotor experiences greater force on small gap side. Rotor pullover may or may not be accompanied by physical contact with stator. If contact does occur, the first evidence may be noise, vibration or winding failure. If contact does not occur then evidence may be limited to noise and vibration.
		2. Lamination saturation and circulating current	Saturation and circulating currents result in poor performance of the motor.

2.	Mechanical stresses		Some of the more common causes of rotor failure due to mechanical stresses are: casting porosity, loose laminations, broken or fatigued parts, incorrect fit between shaft and core, poor rotor geometry, loss of air gap, bent rotor shaft, bearing failure, misalignment, incorrect materials and tooth resonance etc.
3.	Thermal Stresses	1. Thermal overload	The most common causes of thermal overload failures are: an abnormal number of consecutive starts, causing excessive bar or end-ring temperature, rotor rubbing, insufficient ventilation and unbalanced phase voltages etc.
		2. Thermal unbalance	The most common causes of thermal unbalance failure are: unequal heat transfer between the rotor bars and rotor core, rotor bowing due to unequal changing of stacking pressure associated with thermal cycling etc.
		3. Hot spots and rotor sparking	Some of the variable that causes these conditions are: smearing of lamination in the slot or on the rotor surface, irregular shorting of rotor bars etc.
4.	Dynamic Stresses	1. Centrifugal force	esign limits. If motor speed exceeds this limit entrifugal forces. If this fit is lost then high
		2. cyclic stress	Leads to an eventual failure. This stress can be caused by misalignment between drive equipment, over-tightened belts etc.
5.	Environmental stresses	Any environmental condition that affects the rotor is considered as a stress.	Examples: contamination, abrasion, foreign particles, restricted ventilation, excessive ambient temperature and unusual external forces etc.

2.3 RESULT OF FAULTS STUDY ON INDUCTION MOTOR FAILURE

In order to identify the weakest component in electrical motors that is subjected to failurestudy are conducted by EPRI, IEEE, and B&K .It has been found that major type of faults that induction motor is subjected occurs to is bearing fault, as most of the forces are acting on it. So most of the work is focusssed on early detection o bearing faults[Ref 2]

One of the results of IEEE is shown below:-

Result Of IEEE Study On Induction Motor Failure

FAULT PERCENTAGE	FAULT
1) 40%	Bearing faults
2) 35%	Stator faults
3) 10%	Rotor faults
4) 15%	Others

2.4 MACHINE VIBRATION

It has been observed that there is a relationship between the mechanical vibration measurable at the surface of the electrical machine and source of defect inside the machine. Table 2.3 indicates that for induction motor, almost all types of faults can be identified just by analyzing the vibration signal collected from the machine surface.

Table 2.3 Failure Mechanism of Induction Motor

S. N.	Fault	Cause	Early indication of fault
1.	Frame vibration	Defective assembly Defective installation Excessive mechanical vibration	Vibration
2.	Earth fault	Abrasion of Insulation	Vibration
3.	Broken rotor bars	Defective design Defective manufacture Thermal cycling due to excessive starting	Vibration Distorted air-gap flux Pulsating speed Supply current
4.	Mechanical unbalance	Movement of end rings Asymmetric blocking of cooling ducts shorted rotor bars	Vibration
5.	Mechanical misalignment	Defective installation Failure of bearing	Vibration Distorted air-gap flux Overheating
6.	Bearing misalignment	Incorrect bearing clearance Incorrect bearing loading	Vibration Debris in lubricating oil
7.	Loss of bearing lubrication	Contamination of lubricating oil Excessive bearing clearance	Vibration Debris in lubricating oil

The sources of the vibration in rotating electric machines may be divided into two groups: forces due to mechanical origin and the forces due to magnetic origin. These forces produce vibration directly on the machine structure. The relative importance of each type of source depends on the type and size of the machine.

2.4.1 VIBRATION DUE TO THE MECHANICAL FORCES

The vibration due to the mechanical forces may be either from surrounding environment or produced from the machine itself. For most machines, the vibrations due to the machine itself are produced by dynamic rotor imbalance, stator and rotor rubbing, and rolling motion in the bearing; which depend on the condition of the machine for a given operating mode. These forces may often be reduced to insignificant proportions by dynamically balancing the rotor accurately. When a machine has been in use for some time, the rotor balance may change owing to slight winding movement or bending of the shaft, so that this type of vibration may become greater as the machine ages.

Bearings are essential mechanical elements in rotating electrical machines to provide relative displacement between stator and rotor. They transmit some of the rotor forces to the stator. It is important to measure the vibrations at the bearings due to these forces as well as the vibration generated by the bearings themselves. The noise and vibration due to the response of the shaft bearing depend upon many factors, such as, type of bearing, size of the machine.

In bearing manufacturing, slight error in the geometric shape and dimensions and deviation in the properties of the material are unavoidable. All these factors make even new bearing to generate its own vibration. The degree of vibration depends upon material, tolerance, and assembly of the bearings.

Also, rolling elements as spheres or cylinders are deformed under the influence of high forces. The ball resonance frequency due to elastic deformation is increased with the decrease of the ball radius. The elastic deformation of the ball produces vibrations of high frequency.

In addition to these factors, the level and frequency of vibration can be significant to the working environment, such as temperature, dirtiness, lubrication, loading, speed, and mode of fittings.

2.4.2 VIBRATION DUE TO THE MAGNETIC FORCE

The radial force due to the air-gap field is the main source of the magnetic vibration of the electrical machines. In actual machines, when a three phases, sinusoidal currents displaced 120 degrees in time, flows in the machine winding, pulsating magnetic field by each coil with fundamental and harmonics are produced. The space harmonics of the three phase winding mmf create revolving fields that interact with the air gap permeance. The air gap permeance is not uniform due to the effect of slots, saturation and eccentricity. This interaction induce further flux density waves of pole number and frequency equal to the sum and difference of the corresponding orders of the stator mmf and permeance waves. Hence, the flux density wave along with its harmonics pass through the air gap and act on the rotor winding and induce voltage having a same order of harmonics.

Due to the closed circuit of the rotor, the current will flow in the rotor winding having same voltage harmonics plus another harmonics due to the rotor slotting, saturation and rotor motion. The mmf wave established due to the rotor current interacts with air gap permeance and produces a new set of flux density wave. The rotor current produces a torque similar to the current harmonics with different number of poles and with lower synchronous speeds. When the number of poles of the harmonic field present in the air gap is multiple of two, unbalanced radial magnetic forces and consequently radial vibration of the rotor as a whole are produced. Also, symmetrical radial forces of high frequency are produced by superposition of rotating magnetic fields of different pole numbers. These forces create stator noise and vibration. [Alger]

2.5 VIBRATIONS OF FAULTY INDUCTION MACHINE AND FREQUENCY COMPONENTS

Every rotating machine vibrates. These vibrations are due to the presence of electrical and mechanical forces. Additionally, interaction of these forces makes identification of root cause elusive. The induction motor is also subjected to various types of electrical and mechanical faults. The effect of these faults is to distort air gap flux of the machine. The degree of distortion depends upon the type and the degree of fault. This perturbation in flux produces machine vibrations. Although, the induced harmonics affected the whole frequency components of the vibration only some of these harmonics have a dominant value in the vibration spectrum. These frequency components can be used to detect the presence of the machine faults. Some of the electrical fault mechanisms are discussed here under along with frequency chart and vibration standard chart

2.5.1 ONE-TIME LINE FREQUENCY VIBRATION

Unbalanced magnetic pull may result in vibration at line frequency. This line frequency vibration is normally very small or nonexistent, but if the stator or rotor system has a resonance at or near line frequency the vibration may be large.

2.5.2 TWICE-LINE FREQUENCY VIBRATIONS

The power supply produces an electromagnetic attracting force between the stator and rotor which is maximum at a point on the stator when the magnetising current flowing in the stator is at maximum, (either positive or negative). As a result there will be two peak forces during each cycle of the voltage or current wave, reducing to zero at the point in time when the current and fundamental flux wave pass through zero. This will result in a frequency of vibration equal to 2*the frequency of the power source. This particular vibration is extremely sensitive to the motor's frame. It is also influenced by the eccentricity of therotor.

2.5.3 ROTOR BAR PASSING FREQUENCY VIBRATIONS

The electrical current in the rotor bars creates a magnetic field around the bars. This field applies an attracting force to the stator teeth and this force creates the vibration al the frequency RBPF given by

$$RBPF = {}^{RPM * Numberofrotorslots}\!\big/_{60} \qquad \ldots,\ [2.1]$$

As load increases, vibration frequencies also appears at RBPF plus side bands at + or - 2f, 4f and 6f Hz where f is supply frequency.

The frequency of this source of vibration can be picked up from the motor frame and bearing housings, but due to higher value, these frequencies will not be seen between shaft and bearing defect frequencies. For this reason, vibration specification requirements do not require these frequencies to be included in overall vibration.

2.5. 4 BROKEN ROTOR BAR

If a bar is broken or open braze joint exits, no current will flow in the rotor bar. As a result, the field in the rotor around that particular bar will not exist. Therefore, the force applied to that side of the rotor would different from that on the other side of the rotor, again creating unbalanced magnetic force that rotates at one times rotational speed and modulates at a frequency equal to slip frequency times the number of poles.

2.5.5 BEARING RELATED VIBRATIONS

Bearing related vibrations are common to all types of rotating equipment Rolling-element bearing generally consists of two rings, an inner and outer, between which a set of balls or rollers rotates in raceways as shown in figure 2.1. Under normal operating condition, fatigue failure begins with small fissures, located below the surfaces of the raceway and rolling elements, which gradually propagate to material to the surface. Continued stressing cause fragments of the material to break loose producing localized fatigue phenomena known as flaking or spelling. External source, such as improper installation, improper lubrication, contamination, corrosion. or brisling of the bearing, accelerates the bearing degradation . Eventually the failure results in rough running of the bearing that generates detectable vibrations and increasing noise level alteration in the uniformity if the bearing race surface produces vibrations at the characteristic frequencies described

Anti-friction bearings have four identifiable rotational defect frequencies for which formulas for calculation are given in literature [1]. These defect frequencies are for the inner race, outer race, ball spin and cage fundamental train.

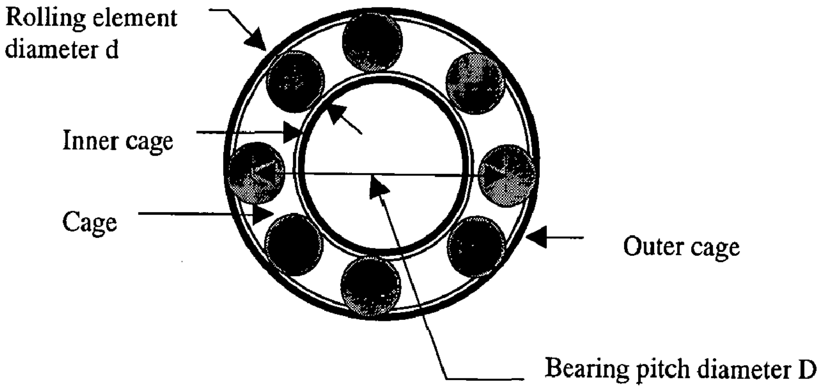


Fig 2.2 Schematic diagram of rolling element

If roller or ball has a defect such as pit, the pulse repetition rate occurs each time, the defect is struck, is known as the Ball Spin Frequency (BSF)

$$BSF = \frac{N}{60} * \frac{d}{2D} * \left(1 - \left(\frac{d}{D}\cos\phi\right)^2\right) \qquad \text{..... [2.2]}$$

If the bearing inner race has a defect such as crack, the fundamental vibration frequency resulting from ball passing over the defect is called Ball Pass Inner Race frequency (BPFI)

$$BPFI = \left(\frac{N}{60} * \frac{n}{2}\right) * \left(1 + \frac{d}{D}\cos\phi\right) \qquad \text{..... [2.3]}$$

Similarly, a defect of outer race is defined Ball Pass Frequency Outer race (BPFO)

$$BPFO = \left(\frac{N}{60} * \frac{n}{2}\right) * \left(1 - \frac{d}{D}\cos\phi\right) \qquad \text{..... [2.4]}$$

Finally, for a defect occurring in the bearing cage, the Fundamental Train Frequency (FTF) is given by

$$FTF = \left(\frac{N}{60} * \frac{1}{2}\right) * \left(1 - \frac{d}{D}\cos\phi\right) \qquad \text{.... [2.5]}$$

Where n is no of rolling elements , N rotor speed in RPM, D is bearing pitch diameter, d rolling element diameter, and βc the contact angle

These frequencies are all different and each creates its wide band harmonic series. Much research has proven that no absolute answer can be given to allowable amplitudes at bearing defect frequencies. Therefore, the most important thing to look for indicating significant bearing wear is the presence of a number of bearing defect frequency harmonics, particularly if they are surrounded by side bands independent of amplitude.

The given table 2.4 gives relationship between various faults and the corresponding frequency

Table 2.4 Vibration Frequencies Related to Specific Fault type

S.N.	Fault type	Important frequencies	Comments
1.	Unbalanced rotor	fr, 2fr	Very common fault in induction motor. It also causes unbalanced magnetic pull which gives 2fr vibration.
2.	Misalignment of rotor shaft	fr, 2fr,3fr,4fr	It also manifests as static eccentricity; therefore component generated from static eccentricity may also appear in the vibration spectrum.
3.	Looseness of shaft in bearing housing	fr, 2fr	Generates a clipped time waveform
4.	Oil whirl and whip in sleeve bearings	(0.43 to 0.48)fr	Generated in case of pressure fed bearings only.
5.	Rolling element bearing damage		--
6.	General electrical problem	nfr, nfs	A problem can usually identified as having electrical origin such as unbalanced supply voltage, single-phasing etc.
8.	Broken rotor bar	fr ±2sfs	
9.	Stator winding faults	fs, 2fs, 4fs	Difficult to differentiate fault type using vibration monitoring alone

fr=rotational frequency=RPM/60 Hz
fs=supply frequency
n=an integer
s =slip

2.6 VIBRATION STANDARDISATION:-

In general vibration can be measured in three related quantities, displacement, velocity and acceleration. If any of these quantities is known, others can be calculated by integration or differentiation. Due to the importance of vibration studies and increasing trends to employ it in different area of application, many organisation all over world have established the limits and specification of vibrations standard. For rotating machine there are many vibration standard available i.e. VDI2056, DIN45665, ISO 2372 etc. Table [2.5] represents the vibration limits according VDI vibration standard. Some of vibration standard by company are also given in the table [2.6]

Table 2.5 vibration limit according to (VDI 2056)

RMS Velocity (mm/s)	Group K Small Machines up to 15 Kw	Group M Medium machines 15-75 Kw or up to 300 Kw with special foundations	Group G Large machines with rigid and heavy foundation whose natural frequency exceeds machine speed	Group T Large machines operating at speed above foundation frequency (turbo machines)
45				*Not permissible*
18	*Not permissible*	*Not permissible*	*Not permissible*	Just tolerable
4.5		Just tolerable	Just tolerable	
2.8	*Just tolerable*			Allowable
1.8		Allowable	Allowable	
1.12	*Allowable*			
0.71		Good	Good	Good
0.18	*Good*			

2.6.1COMMERCIAL STANDARDS (DLI MACHINERY VIBRATION SEVERITY CHART):-

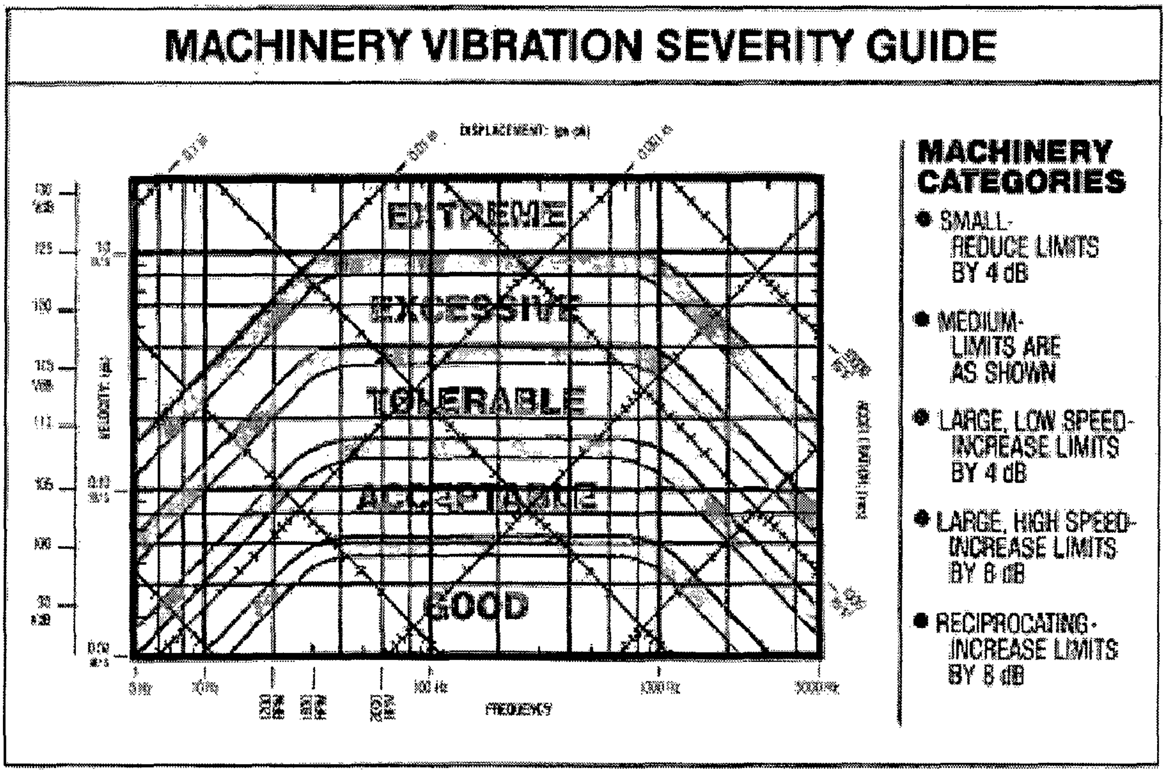
The chart shown in table [2.6] here can be applied to a large number of rotating machines with reasonable confidence. It is a distillation of data from a wide range of industrial machinery, and is considered more up to date and useful than the above mentioned standardsand chart

Table 2.6 DLI Machinery Vibration Severity Chart

Vibration Level	Below 30 Hz	30 Hz - 1000 Hz	Above 1000 Hz
Extreme	10 mils p-p	125 VdB rms	0.282 G rms
Excessive	4.2 mils p-p	117 VdB rms	0.020 G rms
Tolerable	1.5 mils p-p	108 VdB rms	0.007 G rms
Acceptable	0.6 mils p-p	100 VdB rms	0.003 G rms

The same information is shown graphically below:-

Fig 2.3



2.7 CONCLUSIONS

In this chapter different types of fault in induction machine their cause of occurrence have been discussed. The machine faults can be classified into different categories on different bases. The classification of faults can be performed on the bases of machine parts, machine parameters, or their origin. The classification, which considered here, is on the bases of stator and rotor. In order to distinguish between the machine faults, the relation between them and machine parameters has to be specified .Result Of faults Study on Induction Motor failure have discussed which shows that most of the fault occurs as bearing fault All the common faults of rotor and stator with their causes are demonstrated with the dominated frequency.Than various vibration standards for rotating machine has been given which shows the max vibration limit for rotating machine at different frequency range.

CHAPTER 3

DEVELOPMENT OF COMPACT CONDITION MONITORING SYSTEM

This chapter deals with the use of hardware and development of MATLAB software for recording of the voltage, current, vibration and temperature signal under healthy and faulty conditions in s teel Rolling Mill and for lab machines

3.1 INTRODUCTION

This chapter describes the main feature of monitoring system used for acquiring the condition of the machine. There is a procedure need to be followed in order to design, develop, and implement effective monitoring system.

This procedure includes three steps: First, economical study about the benefit of establishing such system from view of capital cost, production, and safety. Second, the technical study of machine-monitoring system which includes the characteristic and the operation of machine, analysis of expected faults, the parameters that subjected to change with faults, the selection of sensors used to measure these parameters, the data acquisition system, data processing and analysis, and the diagnostic task. And the third, development, installation, and the operation that needs the availability of the equipment needed for building such system, and the experience in developing and running the monitoring system.

At our institute, we developed a data acquisition system and also utilized the MK-500D (machine analyzer) having signal conditioning circuit in built, along with laptop, thus making our system compact for acquiring the data from the steel rolling mill. For lab machine we utilized the our own developed system .The system is capable of acquiring three line voltages, three line currents, vibration, and temperature at various points and speed.

3.2 VARIOUS PARAMETERS FOR FAULT DIAGNOSIS

There are various parameters, which can be used for knowing the status of the machine. Most commonly used parameter for fault diagnosis in industryare:-

1. Vibration Measurement
2. Current Measurement
3. Temperature Measurement
4. Voltage Measurement
5. Speed Measurement

3.3 VIBRATION MEASUREMENT

Vibration is a parameter that requires to be measured at several carefully selected points and directions to acquire the full information of the machine. Selection of the location and direction of the sensor measurement is the single most critical factor in the machinery vibration monitoring and analysis. If the raw signal does not contain the components that are representative of machinery condition, no amount of analysis will reveal that condition. For a complete vibration signature of the machine, tri-axial measurement should be made at each location with the rotating machinery, although adequate information can be usually obtained from an axial and a radial measurement at each location.

The different components of machine vibrate at one or more discrete frequencies; different malfunctions cause vibrations at different discrete frequencies. The combination of these discrete frequency vibrations results in the complex vibration waveform at the measurement point. The measured signal is therefore analyzed by reducing it to its discrete frequency components. The result of this type of analysis, presented as a plot of amplitude versus frequency, is referred to as the vibration signature of a machine.

Bearings are the best locations for measuring machinery vibration since this is where the basis dynamic loads and forces of the machine are applied and are critical component of the machinery condition. Vibration measurement should be made on the bearing cap of each bearing in a machine. If this is not feasible, the measurement should be made at a point as close as possible to the bearing with the minimum possible mechanical impedance between that point and the bearing. The actual vibration signature of a machine contains components, which can not be easily identified with a specific source of vibration. Some frequencies are caused by the mechanical resonance of various components the resonant frequency of which results from machine vibrations, which are periodic but not sinusoidal [6].

Vibration can be measured in terms of any of the three related quantities: displacement, velocity, and accelerations. The selection of suitable vibration transducer depends upon the specifications of the machine to be monitored and the required accuracy of information to be collected. It is suggested that as frequency of interest increases, it is better to progress from displacement device to a velocity transducer and ultimately to an accelerometer [2].

Accelerometers are the most popular devices used for vibration measurement due to their robustness, reliability, and availability in different size and range.

An ideal "state of the art" accelerometer used for industrial purpose has following characteristic [4]:

a. It provides a general specification compatible with the machinery in terms of electro/mechanical performance.
b. It included an initial signal processing, by the incorporation of integral electronics, producing a output via a low cost two wire system.
c. Include an integral low noise, soft line cable having an overall seamless stainless stæl flexible sheath, welded at the transducer end, terminated suitably for inclusion in a junction box or connector.
d. It Provide trouble-free installation where distance between the accelerometer to vibration monitor is typically 100 meters or so that system acquire signal without loss.

The measured acceleration can be used to derive other vibration quantities i.e. velocity and displacement by integration. There are two popular types of accelerometers: Piezoresistive and Piezoelectric. A piezoelectric transducer is a device that utilizes the piezoelectric effect to convert mechanical energy to electrical energy or vice versa. It consists of a crystal of piezoelectric material to which a seismic mass is attached. When the crystal is stressed in tension or compression, it generates an electrical charge, which is proportional to the acceleration level, it experiencing. In order to be made the output usable, the signal needs conversion into a voltage or current signal, which can be achieved by driving the sensor with a constant current source and conditioning its output. This device has no moving parts and offers long term stability and reliability. It has very wide frequency and dynamic range and signals can be integrated to give velocity and displacement value. The piezoelectric is a dynamic device and functions within a specified frequency range, normally from 1Hz to 30% of its natural frequency.

Piezoresistive transducer consists of a seismic mass that attached to cantilever beam. The beam is deflected whilst experiencing 'g' force and this movement is converted to an electrical signal by resistance changes in semiconductor sensing element. Internal electronic circuitry used to provide amplification of the signal and temperature compensation. The frequency rang of this device is lower than piezoelectric version, but has the advantage of being able to monitor static or DC acceleration level.

In order to reproduce precisely the vibration generated by the machine under surveillance, it is imperative that its mounting face of the transducer becomes part of the structure. The accelerometer mounting face should see a flat surface at the machine attachment, and not an irregular or curved plane, which will not allow correct transmission of vibration. Stud, integral stud, glue, and magnet are different types of adapters used for mechanical fixing of the accelerometer. Two types used here magnet andglue, which they give same results.

3.3.1 ENDEVCO MODEL ISOTRON® ACCELEROMETER MODEL 50/50M1 DESCRIPTION:-

The ENDEVCO® Model 50 and 50M1 used here are small piezoelectric accelerometers with integral amplifiers, developed specifically for vibration applications. In addition to having minimum unit-to-unit phase deviations, the built-in microcircuit has been configured to work in a constant current mode with a supply voltage as low as +12 Vdc, as with a car battery. The units are designed to be mounted with company adhesive or integral high strength magnet (50M1). A dielectric layer on the base isolates the case ground from the mounting surface to eliminate the potential ground loops.

The Piezoelectric transducer used here cover frequency range DC to 5000 Hz with measurement range up to 50 g. The device provides an output of 50mV/g in vertical position and zero mV/g. The schematic diagram of monitor system used in industry is shown in fig 3.2

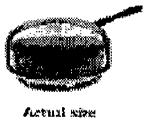
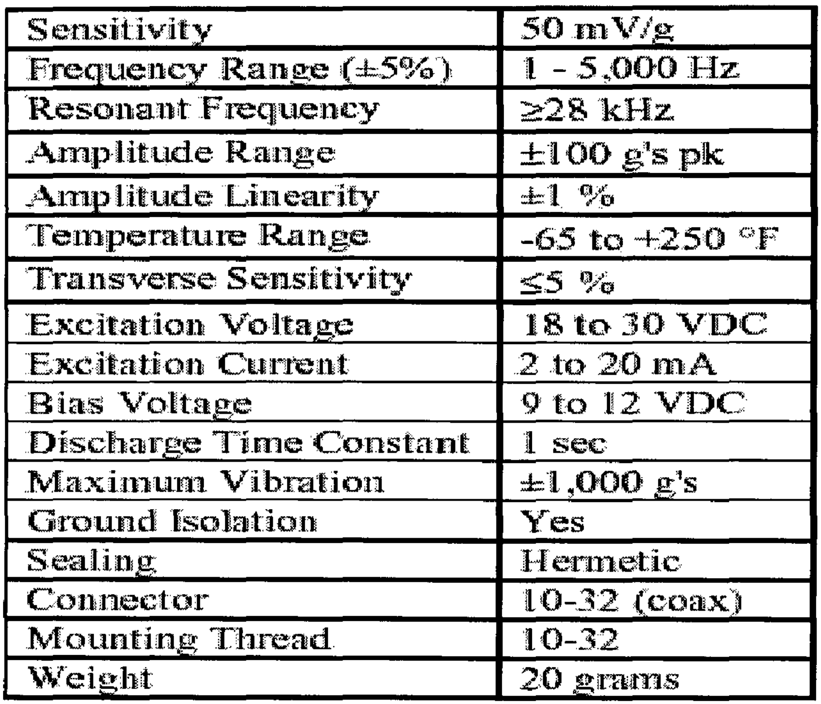


Fig3.1 Endevco Accelerometer

Table 3.1 Accelerometer Specification:-



Sensitivity	50 mV/g
Frequency Range (±5%)	1 - 5,000 Hz
Resonant Frequency	≥28 kHz
Amplitude Range	±100 g's pk
Amplitude Linearity	±1 %
Temperature Range	-65 to +250 °F
Transverse Sensitivity	≤5 %
Excitation Voltage	18 to 30 VDC
Excitation Current	2 to 20 mA
Bias Voltage	9 to 12 VDC
Discharge Time Constant	1 sec
Maximum Vibration	±1,000 g's
Ground Isolation	Yes
Sealing	Hermetic
Connector	10-32 (coax)
Mounting Thread	10-32
Weight	20 grams

in horizontal position, thus fulfilling all the requirement of industry.. In order to bring the accelerometer output to the input level of data acquisition system, AD524amplication device is used

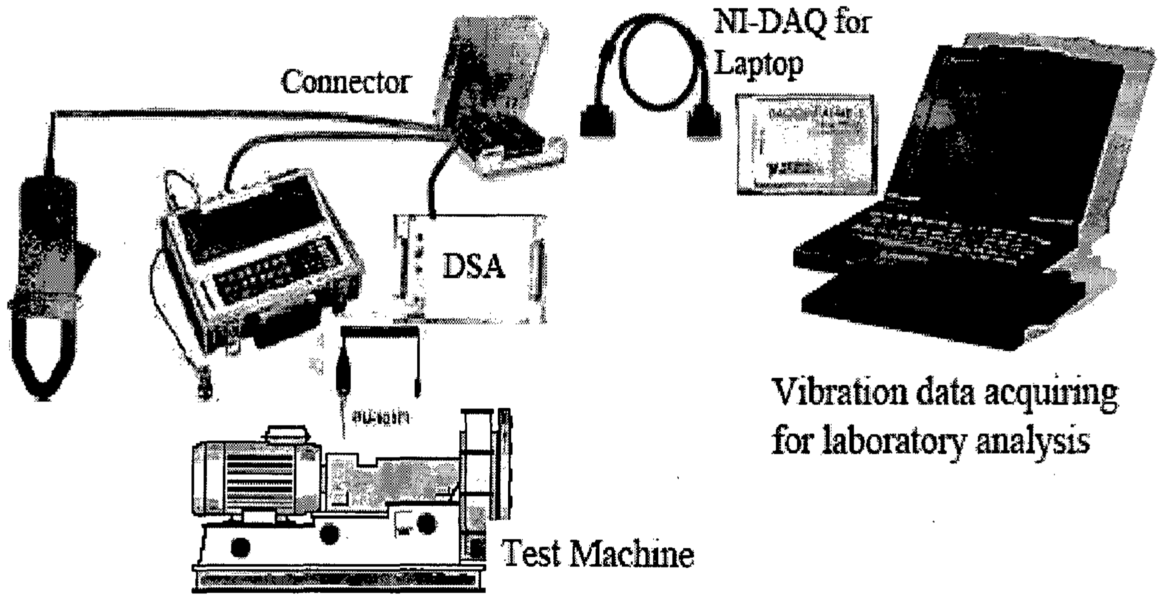


Fig 3.2 Schematic flow diagram of monitoring system used in rolling mills

3.3.2 ACCELEROMETER CALIBRATION

In most applications, it is important to know the exact accelerometer sensitivity at various frequencies of interest. Accelerometers are transducers that sense and convert motion into an electrical signal. The ratio of the output signal to the applied motion is the accelerometers' sensitivity.

The accelerometer of MK-500D and Model 50M accelerometer was calibrated at lab at different frequency and magnitude and correction factor was applied to second accelerometer before their use for acquiring the data along with MK-500D machine analyzer

3.3.3 AD524 (AMPLIFICATION)

Since vibration signals are of order 100mv/g so it requires amplifying the signals for this purpose we used AD 524 MONOLITHIC Instrumentation amplifier. We can set the gain to 1, 10, 100, and 1000. AD524 is a precision monolithic instrumentation amplifier designed for data acquisition applications requiring high accuracy under worst-case operating conditions. An outstanding combination of high linearity, high common mode rejection, low offset voltage drift and low noise makes the AD524 suitable for use in many data acquisition systems. The functional block of AD524 is given in fig 3.3

FUNCTIONAL BLOCK DIAGRAM AD524

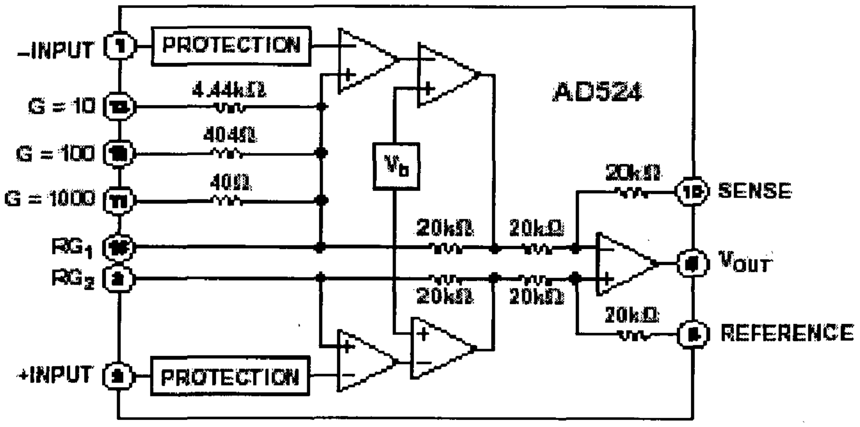


FIG 3.3

3.4 VOLTAGE MEASUREMENT

For high performance monitoring system hall-effect voltage transducer is used for lab machine. This type of transducer is designed to measure the wide frequency voltage (D.C to 100 kHz). These are especially used with non-sinusoidal voltage sources when high order of harmonics is expected. High cost is the disadvantage of such type of transducers.

In the present system, simple potential transformer is used as voltage transducer. The transformer is designed to provide 4 Volt at the output for 440 Volt at the input. The limitation of potential transformer is that the relation between input and output is not exactly linear.

3.5 CURRENT MEASUREMENT

In the present system three Hall-Probe current transducers HTP module (HTP 50) were employed to sense machine line currents for lab machine. These have a range of 50 Amperes with frequency from 0 to 100 kHz. The secondary to primary current ratio is 1000. (The data sheet and the specification of the transducer are given in Appendix 1). If the maximum expected machine current to is 50 Amperes and maximum output voltage is ± 5 Volt (according to data acquisition card specifications), the value of the resistance R is equal to:

$$R = V_o / I_o = 5/(50/1000) = 100\Omega \qquad \text{..... [3.1]}$$

The value of the resistance R used in the system developed is 100Ω, ¼ watt.

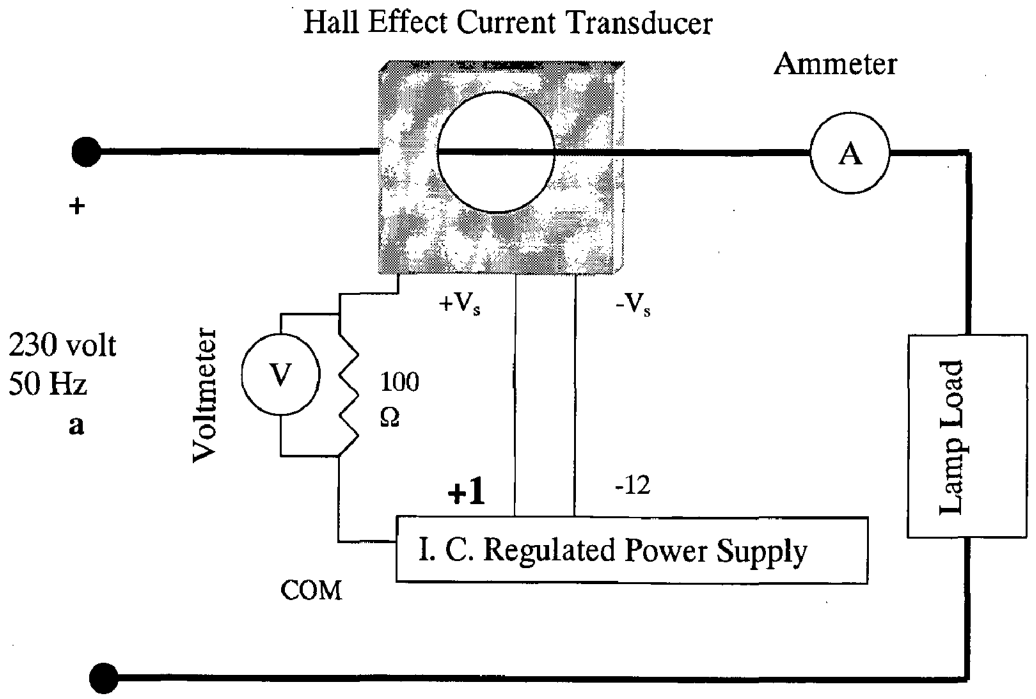


Fig. 3.4 Calibration of Hall Effect Current Transducer

3.6 SPEED MEASUREMENT

Vibration analysis is speed dependent, as almost all frequencies are calculated with the help of rotational speed of rotor. This necessitates the measurement of speed. In the present work, a digital pulse tacho-generator model TRD-1000-RZ (1000ppr) was employed for speed measurement.

3.7 DATA ACQUISITION

In order to transfer analog signals obtained from the monitoring system to the Laptop, they must be in digital form. For this purpose Notebook computer and National Instruments DAQ Card (DAQ Card-AI-16E-4) is attached in PCMCIA slot of notebook. we can get up to 250KS\s, 12bit resolution on 16 single–ended and eight differential analog input for measurements, which is able to acquire vibration signals, supply voltages, currents and temperature at three different points and speed of the test motor. The block diagram of the DAQ CARD is given in Appendix. The card is IBM-NOTEBOOK compatible, designed to install in the computer using general bus connector. The card provides eight/sixteen analog inputs, eight digital inputs, eight digital outputs, and three inputs for on board counter control registers. The card has a 12-bit successive approximation analog to digital converter A/D with typically 6 μSec conversion times. The card provides two modes for analogue input, differential input with eight channels, or single ended input with sixteen channels that can be controlled through jumper setting.. We get up to 500 kS/s single-channel (250 kS/s scanning), 12bit performance on16 single-ended analog inputs. Depending on our type of hard drive, these device scan stream to disk at rates up to 250 kS/s.These E Series DAQ devices feature analog and digital triggering capability, as well as two 24-bit, 20 MHz counter/timers; and

NI 604xE Hardware Block Diagram

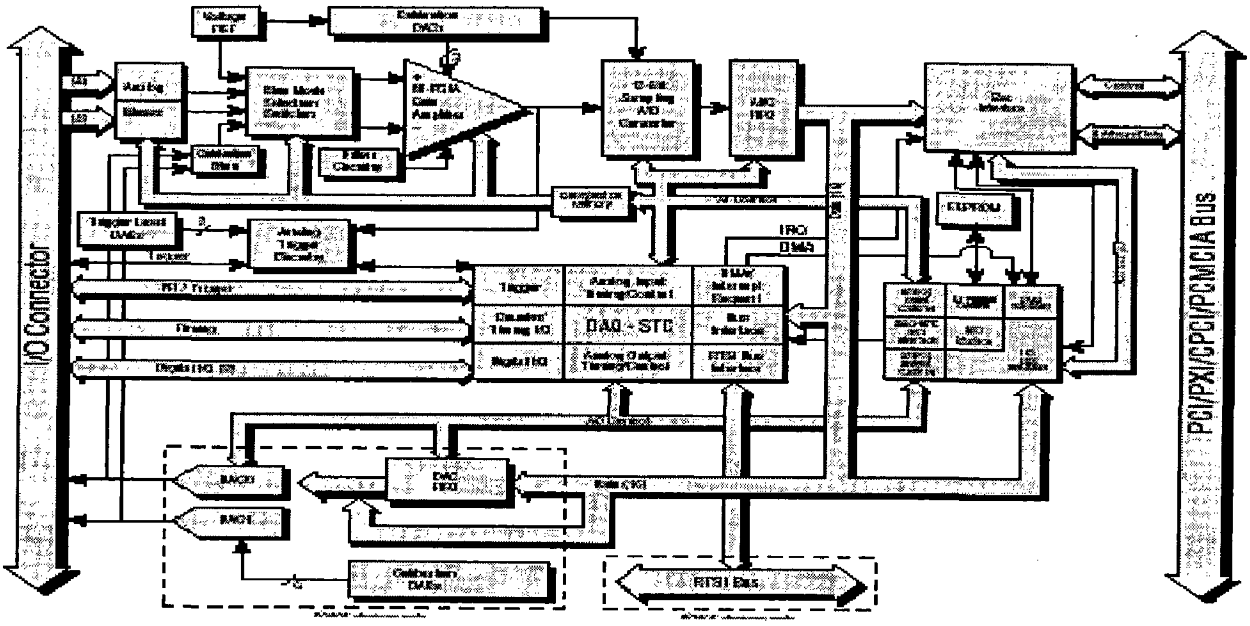


Fig3.5

Through the software, the number of channels to be scanned can control. The conversion initiated by internal programmable timer triggered (pacer trigger) or external TTL input triggered.. The data transfers to memory at the end of A/D conversion using Direct Memory Access DMA mode, or polling mode, or interrupt mode. The transfer mode can be selected by control register. In addition, the card provide three sixteen bits counters, two of them are cascaded and used to control the operation of A/D converter, while the third is free for user applications. The cascaded counters permanently connected to 8 MHz / 1 MHz clock that allow a delay of 2 μ seconds to 71 minutes.

In the present system, eight differential channels are used to feed three-phase current, temperature, three phase-voltages, and vibration to the A/D converter.

3.7.1 SCB-68 E SERIES I/O CONNECTOR:-

The SCB-68 is a shielded I/O connector block with 68 screw terminals for easy signal connection to a National Instruments 68- or 100-pin device. The SCB-68 features a general breadboard area for custom circuitry and sockets for interchanging electrical components. These sockets or component pads allow RC filtering, 4 to 20 mA current sensing, open thermocouple detection, and voltage attenuation. The open component pads allow signal conditioning to be easily added to the analog input (AI) signals and to the DAC0OUT, DAC1OUT, and PFI0/TRIG1 signals of a68-pin or 100-pin DAQ device.

3.8 TO ACQUIRE SIGNALS

Time Period Sampled:-

For most analysis work the instrument should be set up to see 6-12 revolutions of the Shaft being measured. The total sample period desired can be calculated by this formula

$$\text{Total sample period [seconds]} = \frac{60 \times \text{\# NO of revolutions desired}}{\text{RPM}}$$

In our case for steel rolling mill no revolution of motor was 736 rpm and 12 revolutions was desired for analysis so 1 sec sample point was taken for analysis and for lab machine no of revolution of machine was 1440 so .5 sec duration sample point was taken for analysis. For both type of machine sampling frequency was kept at 4000 samples \sec because most of the information of machine is with in range of 1000 Hz so keeping 4 times the sampling frequency. Fifty thousand discrete vibration signals, sampled at 4 kHz were recorded for each of the machine conditions. The time domain parameters used in this investigation were obtained by averaging 14 overlapping segments each of 4000 consecutive sample from the vibration record of 50,000 samples with overlap of 500 samples (Fig. 4.1). And for lab machine 32 overlapping segments each of 2000 consecutive sample from the vibration record of 50,000 samples with overlap of 500 samples. Also, to gain confidence on the observed results the average reading of three to four run at different time was taken.

To specify exactly the sampling frequency, mat lab interface program is used. This program is developed in mat lab to read and store multiple analogue channels for the initialization of A/D converter. Figure (4.1) shows the flowchart of this program. The following algorithm is used for A/D conversion and recording of the data:

Step 1: Input the desired value of sampling frequency.

Step 2: Input the number of start channel and stop channel to be scan from the keyboard. These channels are scanned one by one and when it reaches to stop channel automatically goes to the start channel.

Step 3: Set the number of samples using mat lab interface program.

Step 4: Check the start of A/D conversion.

Step 5: Check the end of A/D conversion..

Step 6: The obtained data is classified according to the scanned channel and stored in different locations in the data file.

Step 7: Check for the end of required number of sample

The complete set of monitoring system used in lab is given in fig 3.6

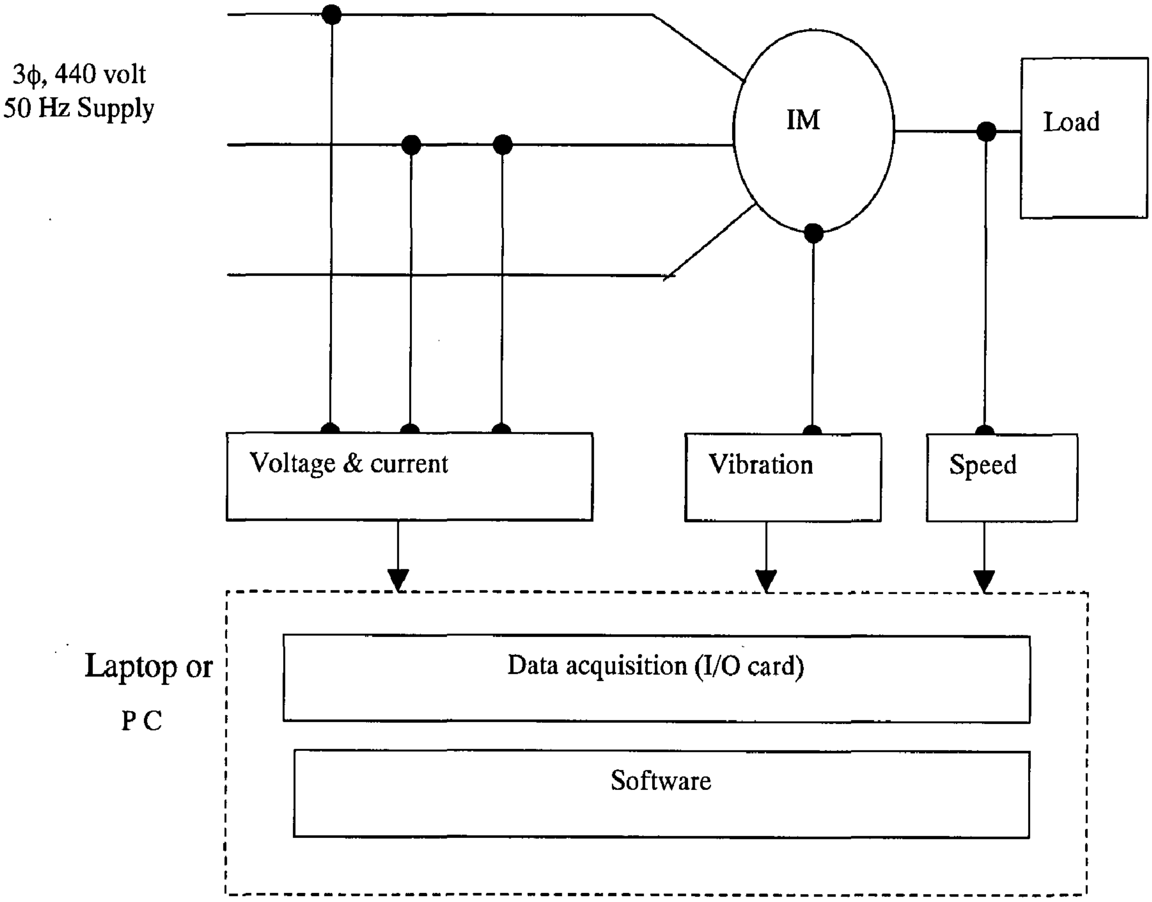


Fig. 3.6 Schematic diagram for monitoring system used in lab

3.8 CONCLUSION

The important requirements for the modern condition monitoring systemin industry are on-line monitoring as well as off-line monitoring capability. We developed such industrial based system which is compact, flexible, and has fast acquisition of signals and same can also be used for small machine, with a very little hardware and of high accuracy .The National Instrument card was used to acquire the signal with a high sampling frequency rate. The Matlab program with compatibility with NI card was used for storing the vibration data collected from the industry, thus utilizing the latest facility of software of Matlab and flexibility of NI card. This is to study the machine behavior at different operating conditions and to relate the change in the machine parameter with different fault phenomena. The efficiency of the monitoring system depends upon the accuracy of the information obtained using different types of sensing elements from the monitored machine. Selected machine parameters are considered for monitoring to achieve quality-monitoring system and to incorporate with industry environmental. The system is a modular in design and flexible to allow for expansion, yet easy to use. The hardware along with the software allows the user to effectively monitor, store, analyze machine parameters, and trend vibration operational process. The software was designed to provide the user to conduct on-line analysis on the machine and off-line using the stored database. Moreover, it is accept any required change in sampling frequency, no of sample, range of display and number of the machine parameters which make the system suitable to use for different types and size of machine with minor modifications.

The successful of the monitoring system was proven by comparing the picked up waveforms obtained from different types of transducers, with the waveforms obtained using standard instruments i.e. MK-500D The monitoring system comprises of three Hall Effect type current transformer for current measurements, digital plus-tachometer for speed measurement. The data is transferred to the computer using 12-bit A/D converter. The sampling frequency has been selected to get the higher resolution or the frequency collected. The sampling frequency is adjusted to 2 kHz for currents signal and 4 kHz for vibrations signal.

CHAPTER 4

FEATURE EXTRACTION AND CLASSIFICATION OF FAULTS FROM VIBRATION SIGNAL

Vibration monitoring presents a unique opportunity for condition monitoring of rotating electrical machines. This chapter contains the details of extraction of important time and frequency domain parameters from the acquired vibration signal from steel rolling mills and lab machine also some features from current spectrum for lab machine.

4.1 INTRODUCTION

Vibration signals carry a great deal of information about system condition An increasing level in the vibration signature generally indicates a warning and potential failure of a machinery component. The vibration signature of a machine can provide information on many components and structures such as gear meshing frequencies, bearings, structural resonance, and even electrical faults. This chapter deals with important features of vibration signal, which are usedfor extracting the feature of large machines in Steel Industry and is also used for small machines in lab separating them into various fault categories.

4.2 WHY VIBRATION MEASUREMENT FOR FAULT DIAGNOSIS OF MACHINE

One of the major areas of interest in the modern day conditionmonitoring of rotating machinery is that of vibration. Vibration signal collected from the motor carries information on the fault(s). The knowledge of motor fundamentals and vibration analysis helps in reliable fault diagnosis. The vibration signatures of machine processes have been a potential input for an in-process monitoring tool.

As reported, due to vibration various electrical and mechanical faults are developed during the operation of rotating electrical machines. These faults generate vibration at known frequencies. Therefore by utilizing the proper data collection and analysis technique, the true source of increased vibration can be discovered

1. Vibration monitoring is more suitable because it gives better result than current monitoring system. When oscillation in small amount current signature are minor, and there is no significant peak is observed in current spectrum

2. Voltage transducer have the limitation of saturation of core at low frequency and nonlinearity between the input and output voltage
3. Vibrations parameter can be easily broken down into various discrete time and frequency component and can be useful for detailed study for the fault diagnosis.

A simple approach for estimating the machine's condition is to measure the overall vibration signal power and to compare this with the reference measure when the machine is in a new and undamaged condition. Other approaches for estimating the machine's condition is to use a variety of features estimated from the vibration signal such as statistical comments or utilize frequency domain information through the use of power spectra. Different components and defects are generated at different frequencies. Any change in the system condition will result in the change in these frequencies. Therefore the frequencies can be used for system diagnosis.

Therefore, by using signal-processing techniques to analyze the time and frequency spectrums, it can be possible to determine the defect in various components of the rotating machines. The amplitude of the vibration signature gives an indication of the severity of the problem, while the frequency can indicate the source of the defect. However, it is still a difficult to isolate and characterize only those specific signatures from the vibration signals, which are relevant for the diagnosis of a particular condition. This chapter presents the investigation carried out in Steel Rolling Mill for a large machine and in the labs for small machine where fault were created knowingly in order to study electrical faults (voltage, unbalance etc.) and mechanical fault (mainly bearing faults) and misalignment, unbalance. The investigation was carried on the two machine with same specification connected at two different points. The bearing conditions considered is a normal bearing and bearings with balls and inner and outer race faults. The vibration analysis methods investigated are based on the time domain and frequency domain signal analysis. **Root mean square, peak value, standard deviation, variance, skewness, kurtosis, complexity and cumulant and probalibility distribution** of the vibration signals are used for time-domain analysis purpose to identify the operating status of the machine under investigations.

The vibration frequency analysis methods are based on the **STFT, the power spectrum, Envelope detection, Band Energy, harmonic activity Algorithm, bearing analysis algorithm and consideration of change in rotational frequency.**

4.3 FEATURE SELECTION AND EXTRACTION

Feature selection and extraction is important part of the diagnostic scheme. A number of parameters can be used to characterize the vibration signal. It is important that these parameters reflect those features that change with fault. Not all the parameters have proved useful due to variety of factors such as assessment, implementation and most importantly, their diagnostic utility. Precise definitions of these parameters become more important with computer aided analysis. Therefore the next step is to extract the features from the vibration signal for healthy machines and the machines having various fault conditions. Time and frequency domain analyses are the two methods used in this condition monitoring applications. The differences in the vibration signals of healthy and unhealthy machine are investigated by employing these two methods.

4.4 TIME DOMAIN ANALYSIS

4.4.1 Statistical Parameters

Several statistical parameters, calculated in the time domain, are generally used to denote average properties of machinery data. These statistical parameters may be used to perform a quick check of the changes in the statistical behavior of a signal.

For a given data set (x_i), its statistical character can be obtained by calculating the moments. The concept of moment is of great significance in statistical work. With the help of moments the central tendency of the set of observation i.e. they're variability, their asymmetry and the height of the peak can be measured.

As applied to statistics, Pearson first used the term moment in his 1893 letter to Nature where he suggested that the moments about the mean could be used to measure the asymmetry of a curve. The moments about the mean provide quantitative indices to describe deviations of empirical distributions from the normal distribution. The mean value, standard deviation, skewness, and kurtosis, complexity, third order cumulant are some of parameters used for such purpose. The sample mean and PDF (probability distribution function) summarize two aspects of a set of numbers: location and spread. Two other values that are sometimes computed from a set of numbers are the skewness and the kurtosis. The skewness is meant to summarize how asymmetric a data set is. That is, rather than having the symmetrical mount shape, the data is more spread out on one side of the median than the other. Kurtosis is meant to capture the presence of "extreme" values relative to the bulk of the data. The definition of these parameters is given as under:

(a) Mean value

For discrete time signal (x_i) the mean value is obtained by using following equation:

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

where N is the number of the data points.

(b) RMS value

The simplest and more common approach to vibration monitoring is to measure the overall intensity of an unfiltered vibration signal. This is normally achieved with the estimate o Root Mean Square (RMS) level of the time record. The RMS of the discrete time signal is calculated as

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

(c) Peak value: Measure of Maximum Amplitude of Signal in a window width.

(d) Crest factor

The crest factor yields the measure of the spikiness of a signal. It is meaningful where the peak values are reasonably uniform and repeatable from one cycle to another cycle.

$$Crest\ factor = {}^{\text{Peak value}}\!/_{\text{RMS value}}$$

(e) Standard deviation

Standard deviation is a statistical term that provides a good indication of volatility. It measures how widely values are dispersed from the average.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}\left(x(n) - \overline{x(n)}\right)}$$

(f) 2nd Central Moment: Variance

The variance about the meant of the given data set is calculated as

$$v \text{ (variance)} = \frac{1/N \sum (x_i - \mu)^2}{\sigma^2}$$

(g) 3rd Central Moment: Skew ness

Skew ness is a measure of symmetry, or more precisely, the lack of symmetry about its mean. A distribution, or data set, is symmetric if it looks the same to the left and right of the center point. The skewness of normal distribution is zero, and any symmetric data should have a skewness near zero. Negative values for the skewness indicate data that are skewed left and positive values for the skewness indicate data that are skewed right. By skewed left, mean that the left tail is heavier than the right tail. Similarly, skewed right means that the right tail is heavier than the left tail.

$$c \text{ (skewness)} = \frac{1/N \sum (x_i - \mu)^3}{\sigma^3}$$

(h) 4th central normalized moment: Kurtosis

A more recent development in the state of art of bearing fault detection is statistically based parameter called Kurtosis. It is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. A uniform distribution would be the extreme case. Positive kurtosis indicates a "peaked" distribution and negative kurtosis indicates a "flat" distribution

$$k \text{ (kurtosis)} = \frac{1/N \sum_{i=1}^{N} (x_i - \mu)^4}{\sigma^4}$$

The Kurtosis technique has the major advantage that the calculated discriminate takes a value, which is independent of load or speed conditions. It has been found that the Kurtosis factor for undamaged bearing is 3. In general, the initial appearance of flaws is marked by an increase in the value of Kurtosis. As the damage becomes more severe, the values falling back towards 3 [Ref16]

(i) **Cumulant Calculation:** - The measurement noise which often appears to be Gaussian disappears at the third or fourth order cumulant value.

It is defined with respect to moment The concept of moment is of great significance in statistical work. With the help of moments the central tendency of the set of observation i.e. their variability, their asymmetry and the height of the peak can be measured.[Ref 18]

Cumulant calculation:-

1st Order Moment, $m_1 = \frac{1}{n}\sum (x - \bar{x})$

2nd Order Moment, $m_2 = \frac{1}{n}\sum (x - \bar{x})^2$

3rd Order Moment, $m_3 = \frac{1}{n}\sum (x - \bar{x})^3$

4th Order Moment, $m_4 = \frac{1}{n}\sum (x - \bar{x})^4$

1st Order Cumulant, $c_1 = m_1$

2nd Order Cumulant, $c_2 = m_2 - m_1^2$

3rd Order Cumulant, $c_3 = m_3 - 3m_2m_1 + 2m_1^3$

4th Order Cumulant, $c_4 = m_4 + 4m_3m_1 - 3m_2^2 + 12m_2m_1^2 - 6m_1^4$

(j) Complexity as Measure of M/C Health:-

THE following Alogarithm can be implemented [Ref 11]

1. Indicate degree of randomness or orderliness of time series
2. Tool for analysis involving nonlinear dynamics
3. Insensitive to interferences from external signal and noise
4. Effective for detection of incipient condition which are short in duration an magnitude
5. Low computational time

Fig 4.1 Flow Chart for Calculating Complexity Value

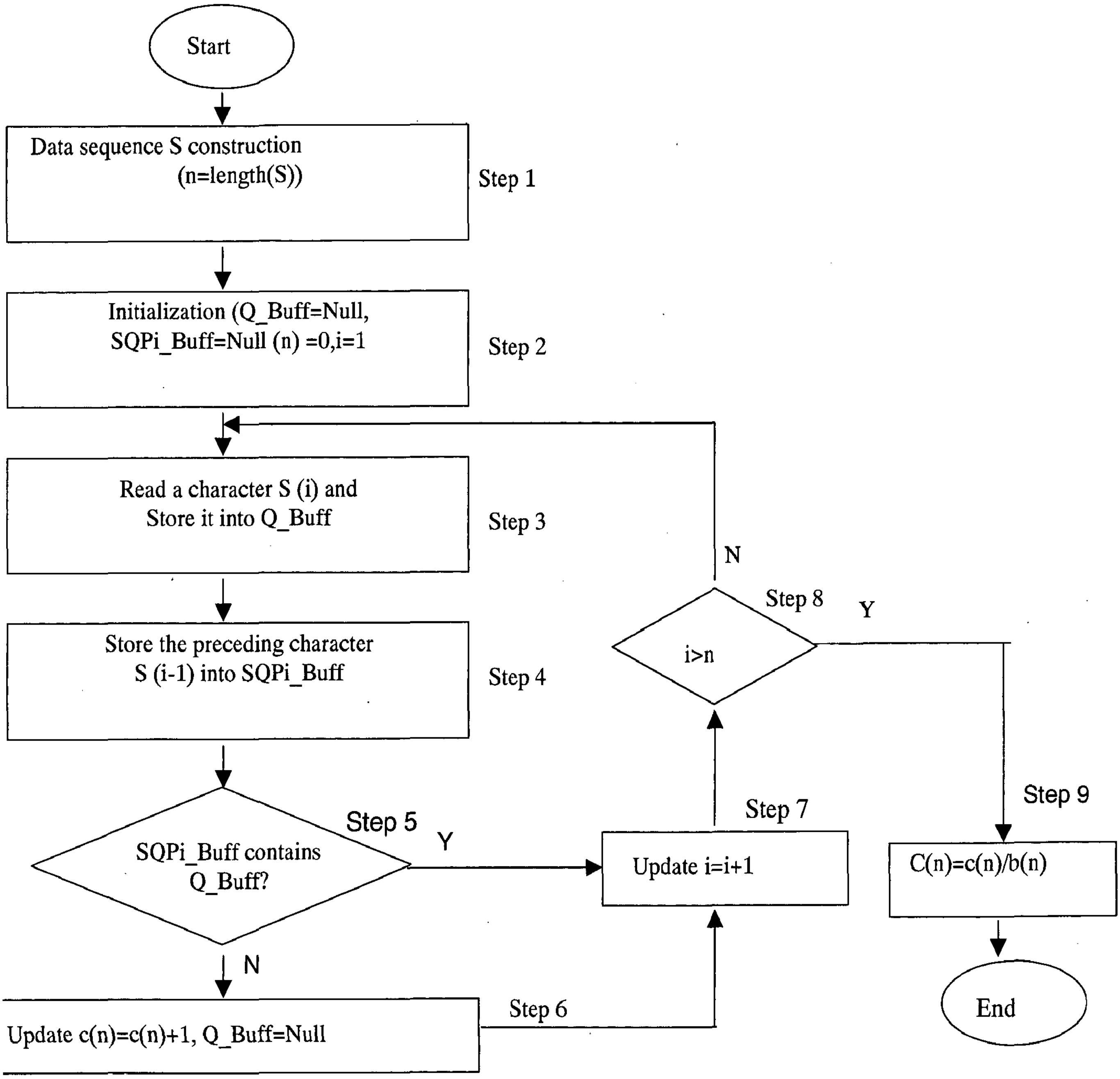
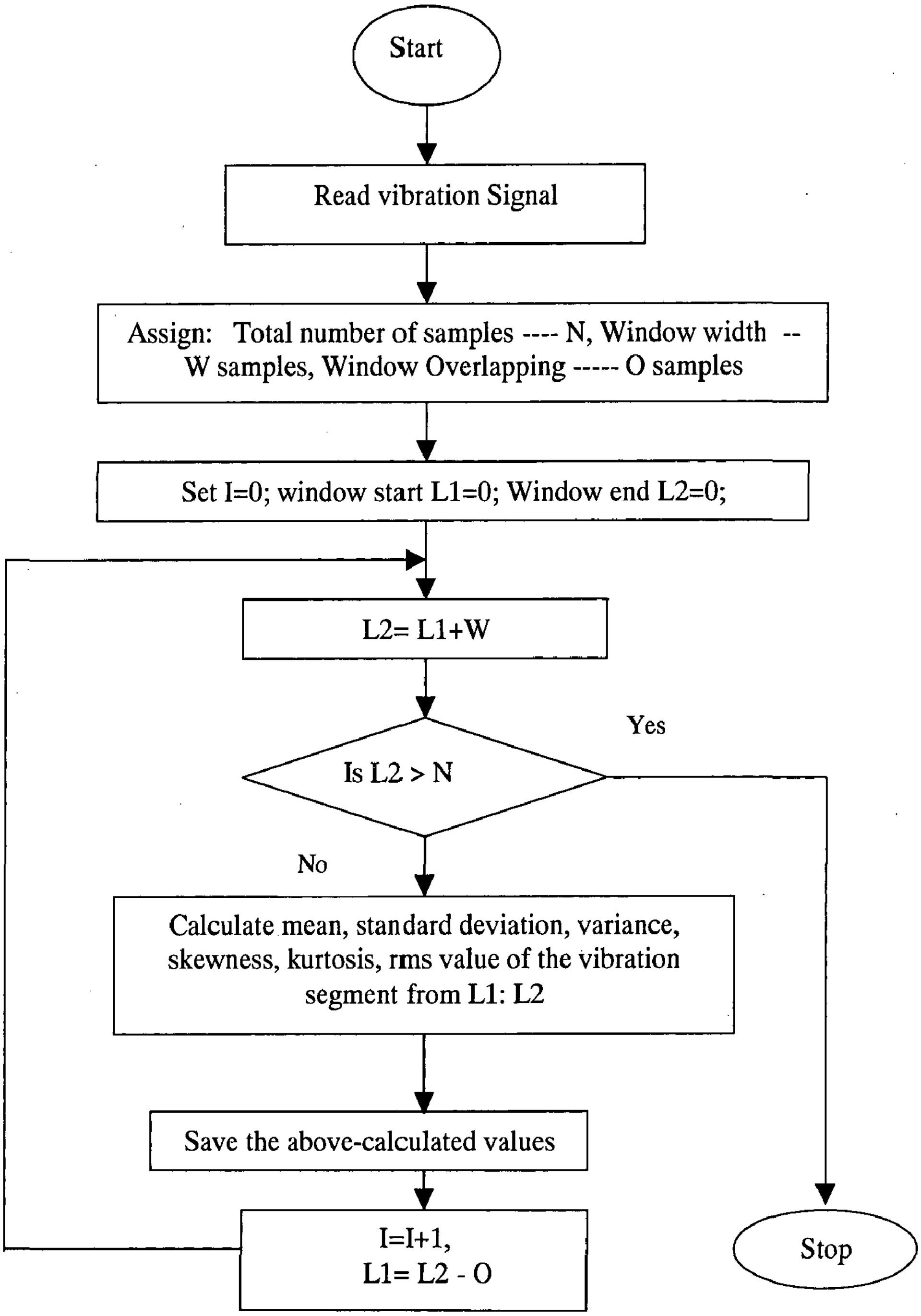


Fig 4.2 Flowchart for calculation of time domain parameters from Vibration signal



4.5 TEST RESULTS AND DISCUSSION

DATE 22-4-05

Specification of motor of **STEEL INDUSTRY**: - Machine 1 And Machine 2 Are Same

1. Ampere 835
2. Load in Ampere (800)
3. Voltage 415
4. Frame Kcw45028
5. Rpm 738
6. Connection Deltas
7. Type Induction
8. Brgs Nu324
9. Made Kirlosksr
10. Rotor Slip Ring
11. Rotational Frequency 12.2 Hz

TABLE 4.1 Statistical Parameters

S.NO	RESULT	MACHINE 1 (Average value)	MACHINE 2 (Average value)
1	Mean	-.001196	-.0071
2	Rms	.14	.2632
3	Crest	4.3	2.86
4	Variance	.066	.27
5	Standard Deviation	.25	.51
6	Skew ness	.0030	.030
7	Kurtosis	3.1	2.8
8	Third Order Cumulant	.00016	.0037
9	Fourth Order Cumulant	.0018	-.0162
10	Peak	.61	.7502
11	Complexity	.33	.63

DATE 12-05-05

Specification of motor: - Machine 1 and Machine 2 are same (with reduced load)

1. Ampere 835
2. Load in Ampere (650)
3. voltage 415
4. Frame Kcw45028
5. Rpm 738
6. Connection Deltas
7. Type Induction
8. Bearing NU 324
9. Made Kirlosksr
10. Rotor Slip Ring
11. Rotational Frequency 12.2

TABLE 4.2 Trend Graph for Same Machine With Respect To Time under Reduced Load

S.NO	RESULT	MACHINE 1 (Average value)	MACHINE 2 (Average value)
1	Mean	-.0009	-.0007
2	Rms	.13	.22
3	Crest	3.2	3.045
4	Variance	.06	.15
5	Standard Deviation	.26	.35
6	Skew ness	-.004	.027
7	Kurtosis	3.06	2.65
8	Third Order Cumulant	.00014	.0018
9	Fourth Order Cumulant	.001	.0007
10	Peak	.42	.67
11	Complexity	.28	.59
12			

4.6 In this thesis, the aim is to monitor the condition of rotating machine in the **STEEL INDUSTRY**. For this purpose two induction machine of same rating is selected .The signal in the form of vibration was taken from the machine for monitoring purpose..The average reading from three runs was taken for observation. And reading was taken at two different dates. On the first dates load in the machine was more(max 800 Ampere) but during the next date due to problem in load variation machine was stopped and was restarted with reduced load(max 600 Ampere) and it was found that vibration was reduced in the machine which was reflected both in satatical parameters and frequency spectra

Step1: Read the vibration data file.
Step2: Take first 4000 samples.
Step3: 'moment' of the MATLAB Toolbox is used for calculation of moments of required order.
Step4: Calculate the mean and rms value and other parameter of the data segment.
Step5: Take another data segment overlapping the previous segment by 500 samples.
Step6: Repeat step 3 to 5.

1. The RMS value for 4000 vibration data was taken for machine 1 and machine 2 and it was found that Rms value of machine 2 was more than machine 1
2. The Crest factor didn't show much change in reading for machine 1 but changes in crest factor for machine 2 was observed at two different dates
3. The standard deviation for machine 1 was constant when taken at two different dates where as it was changed for machine 2 and was higher than machine 1
4. skew ness that represent degree of deviation from the symmetry of normal distribution was much less for machine 1as compared to machine2
5. kurtosis that represent peak ness of distribution was near to 3 for machine 1 indicating good condition of the bearing where as for machine 2 it varied on two different dates (2.6~2.8) due to changes in load
6. Third order cumulant also gave the information of machine. For machine 1 it was much less as compared machine 2
7. Peak value for machine1 was also less as compared to machine2 two and it was also affected due to load change
8. In order to further analysis our result complexity of the machine for 12000 sample points was calculated as

$$C(n) = \frac{c(n)}{b(n)}$$

Where c (n) is no of complex value above mean value and b (n) is normalization of c (n)

$$C(N) = \frac{300}{\frac{((12000))}{(\mathrm{Log}2\,(12000))}}$$

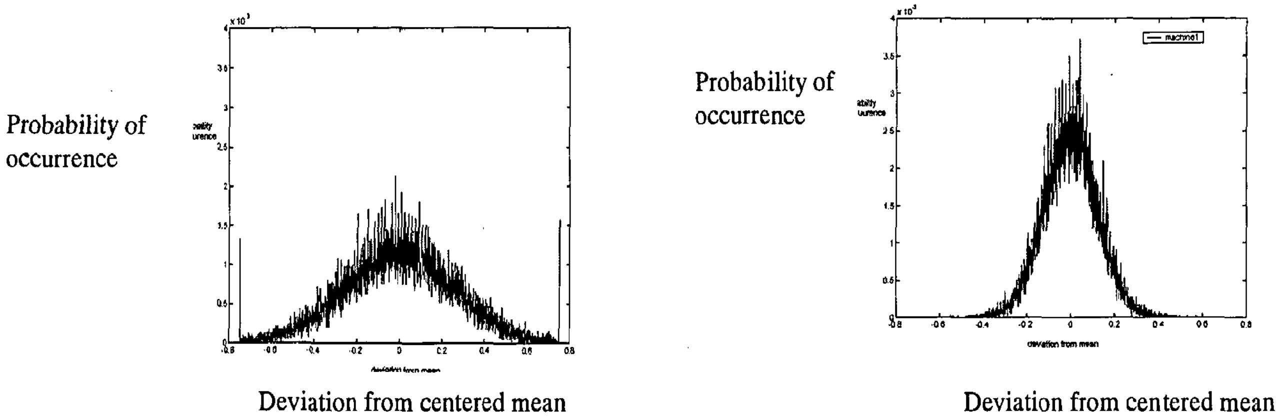
C (n) =.33 for machine 1 and .63 for machine 2

4.6.1 PROBABILITY DISTRIBUTION FUNCTION:-

To analyze the raw vibration signal, we plotted for motor monitor data a probability Distribution of the vibration signals. A probability distribution is a histogram relating to the number of times vibration acceleration peak occurs during defined time period. Figure shows a vibration acceleration signal for machine1 and machine2. A machine in good condition has a vibration probability distribution that depicts roughly Gaussian (bell shaped) curve. For a defect in machine, more varied peaks occur several times throughout the sample as seen in machine 2as compared to machine1

Date22-04-05 **FIG 4.3 (PDF of signals)**

Machine 2 Machine1



Probability of occurrence

Probability of occurrence

Deviation from centered mean

Deviation from centered mean

4.7 IMPLEMENTAION OF SIGNAL FILETRING:-

Due to fluctuation in the vibration signal band of frequency rather than individual frequency component are taken to identify the machine condition. The band pass filter used is FIR filter. The normalized frequency scale is use which is obtained by dividing the pass band frequency by folding frequency (fs/2).

FOR the purpose of diagnosis, variable tuned band pass filter is used to separate four frequency regions related to some common type of machine faults. The first filter is tuned to pass a frequency band of 1Hz to 200Hz; this band is related to the first and second harmonics of the bearing characteristic frequencies and shaft frequency which is related to mechanical unbalance. A narrow band filter is tuned to pass a frequency of 2f (+,-) 4 Hz i.e. 96 to 104 he for 50 Hz supply frequency. This band is related to supply condition ire unbalance supply, single phasing etc.The third frequency band 220 to 400 Hz, which covers the higher order harmonics of bearing characteristic frequency. The filter is than tuned to pass the frequency band of 550 to 950 Hz, this band is related to the vibration of electromagnetic origin i.e. rotor and stator slot harmonics. Later to filtering this band RMS value are calculated and than used for diagnosis.

RMS value (g) of selected frequency band of radial vibration

Date 22-04-05

TABLE 4.3

FREQUECY BAND	MACHINE1(RMS)	MACHINE2(RMS)
1-200 HZ	.02	.06
96-104 HZ	.009	.008
220-400 HZ	.02	.1183
550-950 HZ	.06	.05

Date 12-05-05

FREQUECY BAND	MACHINE1(RMS)	MACHINE2(RMS)
1-200 HZ	.02	.04
96-104 HZ	.007	.007
220-400 HZ	.023	.1178
550-950 HZ	.04	.04

From the given data RMS value for machine2 is more in band 1 (1-200 Hz) and in Band 3(220-400 Hz) as compared to machine 1indicating some unbalance and bearing condition of higher order harmonics and the effect of reduced load is also reflected

For analyzing the numerical data, MATLAB is a simple and very efficient tool. Hence MATLAB has been used in this work. In general, the automated fault diagnostics is being carried out by observing the limits of the vibration signal parameters and by applying different criteria for the fault classification. Therefore, the reliability of the fault diagnosis is totally dependent on the accuracy of the estimates of vibration signal parameter. The correctness of the method has been validated by comparing the program results with the standard results available in the literature for various fault categories.

4.8 FREQUENCY DOMAIN ANALYSIS

Another conventional approach to process the vibration signals is in the frequency domain. Frequency domain features (Fast Fourier Transform, Power Spectral Density,Harmonic Activity Locator (HAL) Algorithm and change in rotational frequency) have been taken in to consideration for analysis

Frequency analysis of a signal highlights many important hidden features and extracts some useful information. The purpose of this analysis is to find out the frequency content of the vibration data so that the relationship between the frequencies and type of the fault can be established. The simplest way to identify the multiple sinusoid signals is Fourier transform spectrum analysis. By this method the machinery condition can be assessed by observing the presence of assumed stationary frequency components, noting the amplitude of these frequency components with respect to reference vibration level.

Vibration spectra in mechanical systems often contain mixtures of extraneous frequencies that provide little or no pertinent diagnostic information about the health of the machine. In rotating machinery applications, component characteristic defect frequencies generally occur as sideband modulations around the component-carrier frequency (or multiple harmonics thereof). Disturbances due to localized component defects cause wide band impulses to be generated periodically at the characteristic defect frequency. These impulses, in turn, excite the component and its supporting structure, producing short-lived ringing signals of random amplitude. The strongest defect frequency is generally the one closest to the ringing signal. Since there is no reliable way of predicting the ringing modes of a component and its supporting structures, many potential defect frequencies must be monitored. Additionally, the dominant ringing mode may depend on defect severity.

Traditional diagnostic vibration analysis attempts to match spectral lines with *a priori* known defect frequencies that are characteristic of the examined machinery components. Short term Fourier transforms, and related time-frequency and time-scale techniques, are often used to detect non-stationary component failure signatures, which generally result from the presence of a localized defect (e.g. bearing pitting or gear tooth fracture). The fact that typical component defects are localized spatially and have characteristic defect frequencies makes it possible to associate particular vibration patterns with specific machinery components.

One of the major difficulties in machinery diagnostics is the problem of sorting through the enormous number of frequency lines present in vibration spectra to extract useful information associated with the health of a particular component. This is true even when synchronous averaging of time-series vibration signals is performed to reduce the 'smearing' of the frequency lines due to fluctuations in machine speed.

4.8.1 FOURIER TRANSFORM

Signal analysts already have at their disposal an impressive arsenal of tools. Perhaps the most well known of these is Fourier analysis, which breaks down a signal into constituent sinusoids of different frequencies. Fourier transform is a mathematical approach used to express any deterministic periodic and non-periodic functions by an infinite sum of periodic complex exponential functions. The purpose of using Fourier transform is to obtain the frequency components of the function (signal) and to present it in frequency domain. The Fourier transform can be expressed by the following equation:

$$X(f) = \int_{-\infty}^{+\infty} x(t)e^{-j2\pi ft}\,dt \qquad \ldots\ldots.4.1$$

where x(t) is the original function in time domain, X(f) the Fourier transform of the function. The real and complex terms are multiplied by the function and integrated over the time interval from $-\infty$ to $+\infty$. Moreover, if the signal (function) is in discrete time form, Discrete Fourier Transform (DFT) process can be used to analyze it. DFT can express by

$$X(f) = \sum_{n=0}^{N-1} x(n)\, e^{-j2\pi nf/N} \qquad \text{... ....4.2}$$

where, x(n) is the discrete time function and X(f) the Fourier transform of the function.

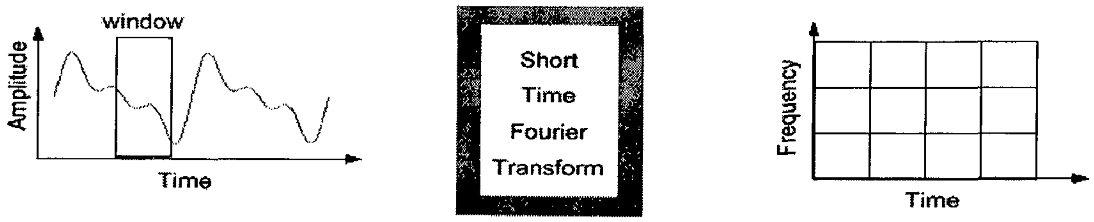
It can be noticed that the number of complex mathematical operations required to perform DFT is equal to N^2. Therefore, this process needs long computational time for large values of N. An algorithm called Fast Fourier Transform (FFT) has been introduced to perform DFT with only $N \log_2 N$ operations, although the number of sample must be equal to 2^k, where k is an integer number. The frequency resolution is given by:

$$\text{Frequency resolution } (\Delta f) = \frac{\text{Sampling frequency}}{\text{Number of samples}} \qquad \text{...4.3}$$

4.8.2 SHORT TERM FOURIER TRANSFORM

In an effort to correct this deficiency of Fourier transform, Dennis Gabor (1946) adapted the Fourier transform to analyze only a small section of the signal at a time —a technique called *windowing* the signal. Gabor's adaptation, called the*Short-Time Fourier Transform* (STFT), maps a signal into a two-dimensional function of time and frequency.

Fig 4.4



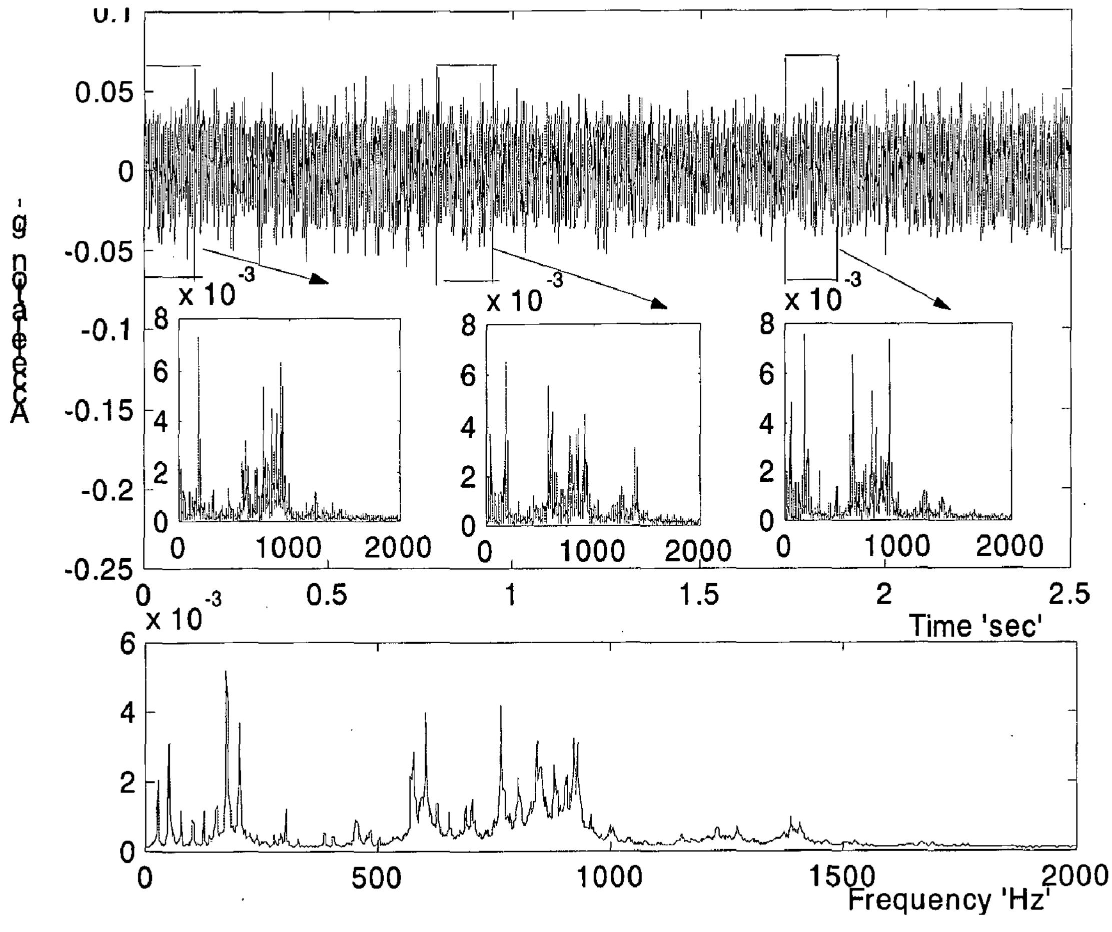
The difference between Short Term Fourier Transform (STFT) and the FFT I only dividing the signal into a small segment using a window function (W) instead of taking whole signal. Then FFT is performed for each segment .The STFT for discrete signal is given by the expression:

$$X(f,k) = \sum_{n=0}^{N-1} W(n-k)x(n)e^{-j2\pi/n} \qquad ...4.4$$

where W(n-k) is the window function and the width of window

The width and type of window depends upon the topology of signal and the information to be extracted. The width of window is adjusted to make each segment of signal stationary. Then the spectrum will give the frequency component of that non-stationary part of the signal that corresponds to that particular segment.

Fig 4.5 Fig Implementation of STFT using moving rectangular window &averagespectrum



4.8.3 TEST RESULTS AND DISCUSSION (Steel Industry):-

The frequency spectra for machine 1 and machine 2 was observed for different frequency resolution and at different dates to see the changes that occur during the time interval and at reduced load condition

TABLE 4.4

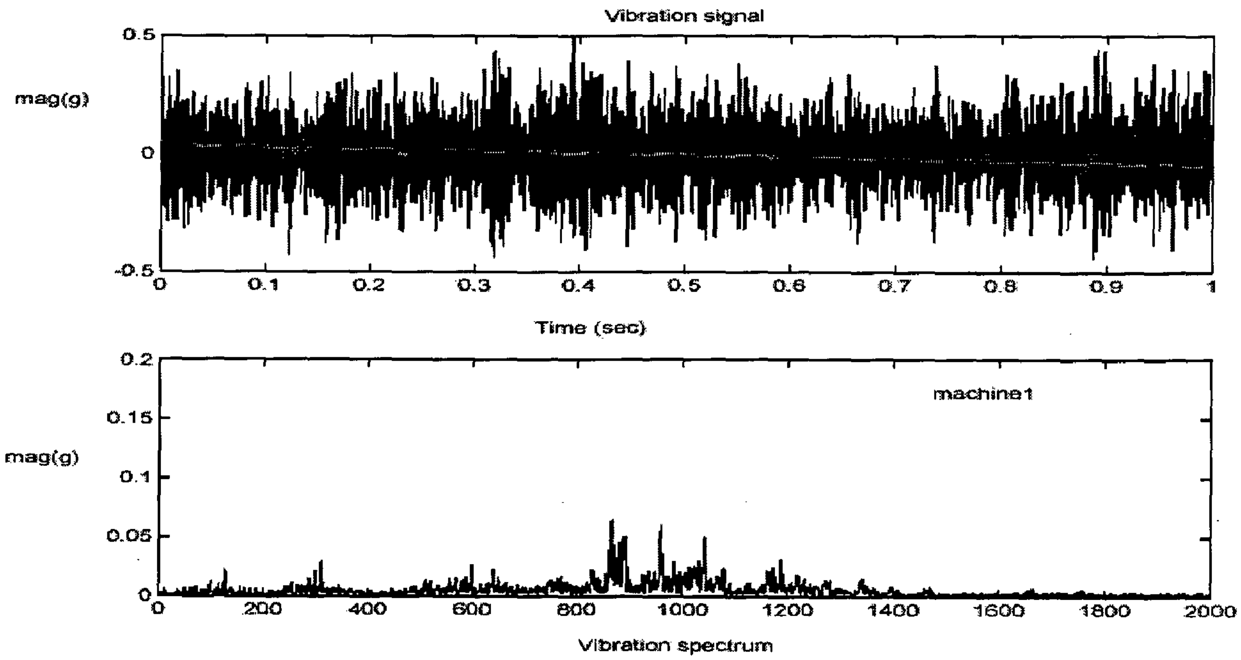
The magnitude of key frequencies for the bearing used in the test motor.

Bearing Type (NU324)	D = 205.0 mm, d = 38 mm, n = 14, β = 0°			
Vibration Frequency	f_o	f_I	fb	Fc
Magnitude (Hz)	70	101.2	64	5

Date 22-04-05

Machine 1

FIG 4.6 (Machine1 vibration spectrum with full load 800Amp)



Machine 2

Fig 4.7(Machine2 vibration spectrum with full load 800Amp)

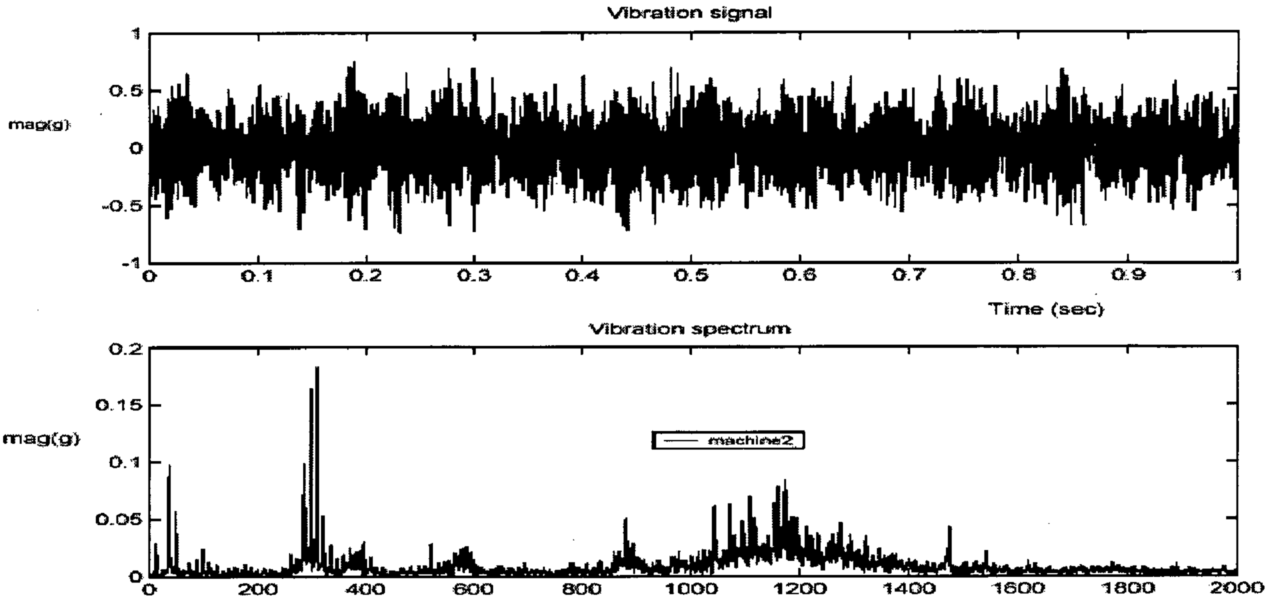
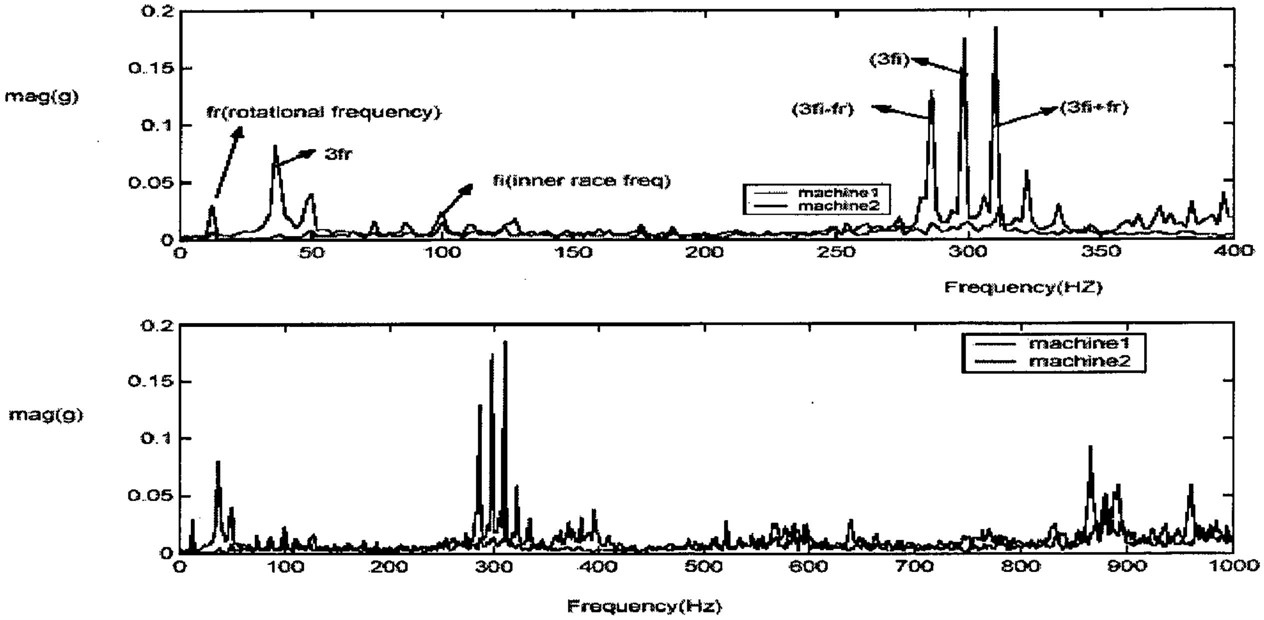


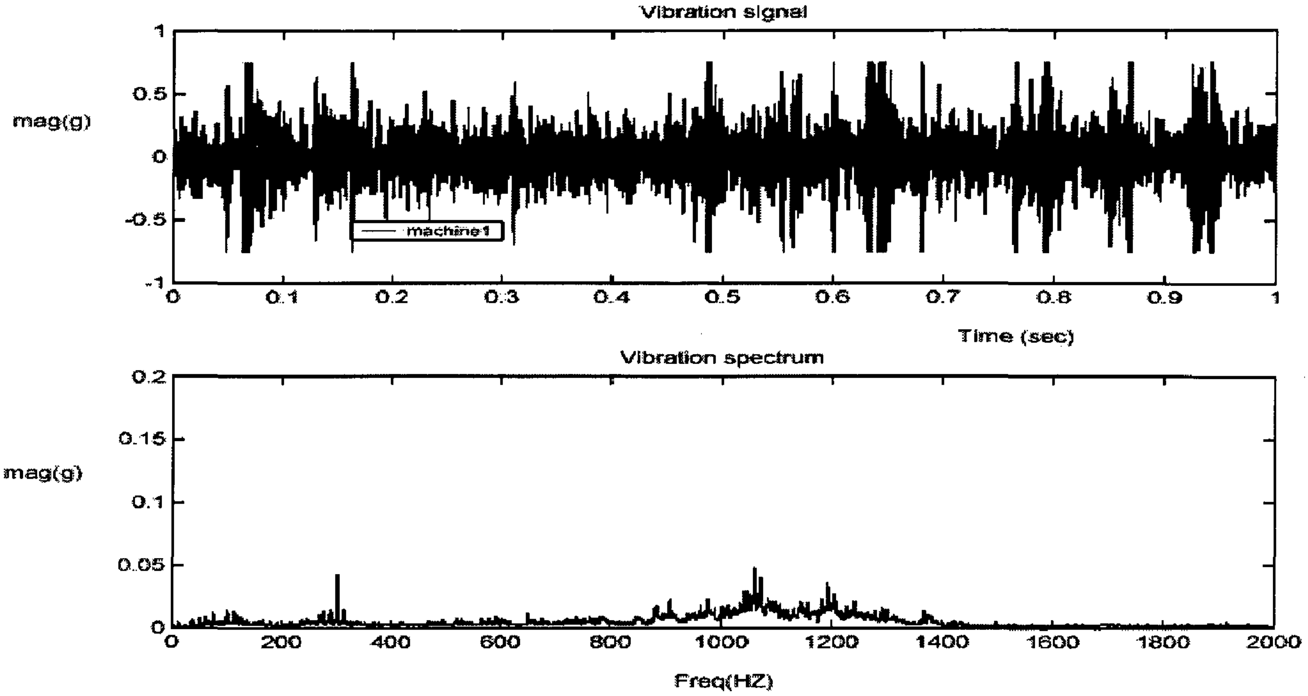
Fig 4.8 (Enlarged spectrum of m/c1&m/c2)



Date 12-05-05

Machine 1

FIG 4.8 (Machine 1 vibration spectrum under reduced load 650 Amp)



Machine 2

FIGS 4.9(Machine 2 vibration spectrums under reduced load 650 Amp)

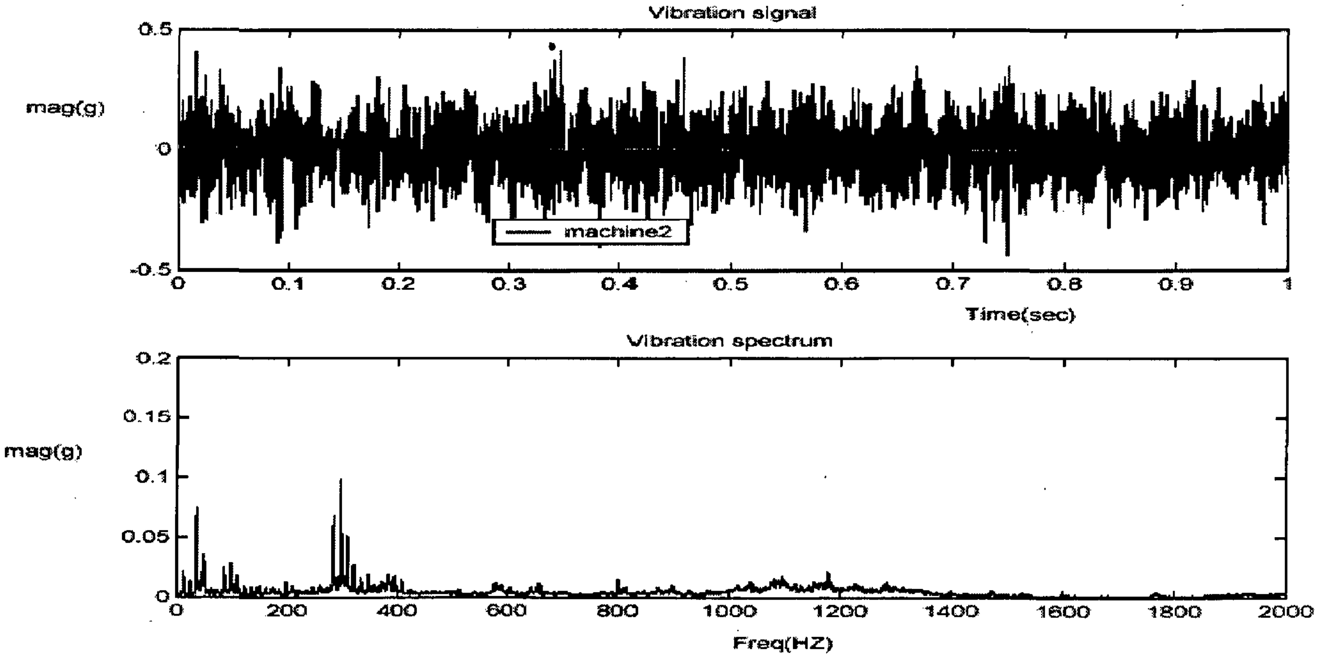
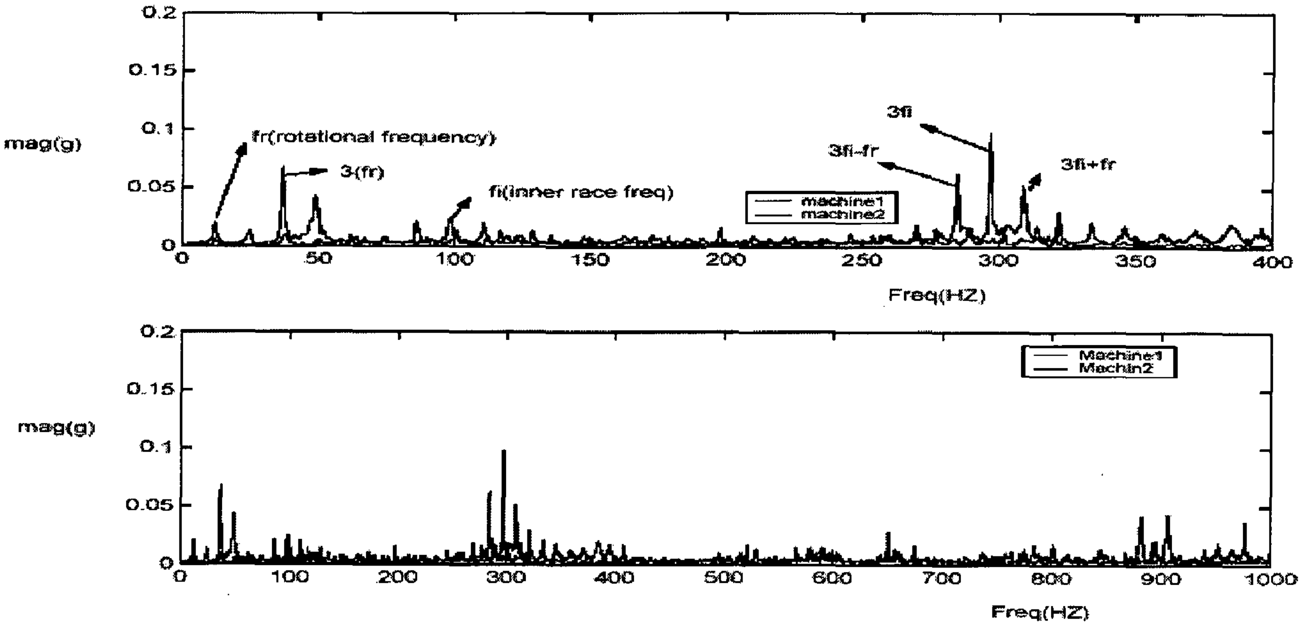


FIG 4.10 (Enlarged spectrum of m/c1&m/c2)



1. From the given spectra in given fig 4.8 it is found that rotational frequency harmonics at 12.2hz and its multiple at 24 and 36 and 48 Hz and inner race frequency of bearing at102hz and its multiple at 300 Hz harmonics are dominated in machine 2 and their magnitude is more than the normal value.
2. It is also seen that corresponding magnitude are reduced with reduction in load as shown in fig 4.10 when the reading were taken after one months but still the magnitude is more than threshold limit
3. Higher order harmonics were noted in both machine1 and machine 2 near to 1000 HZ.

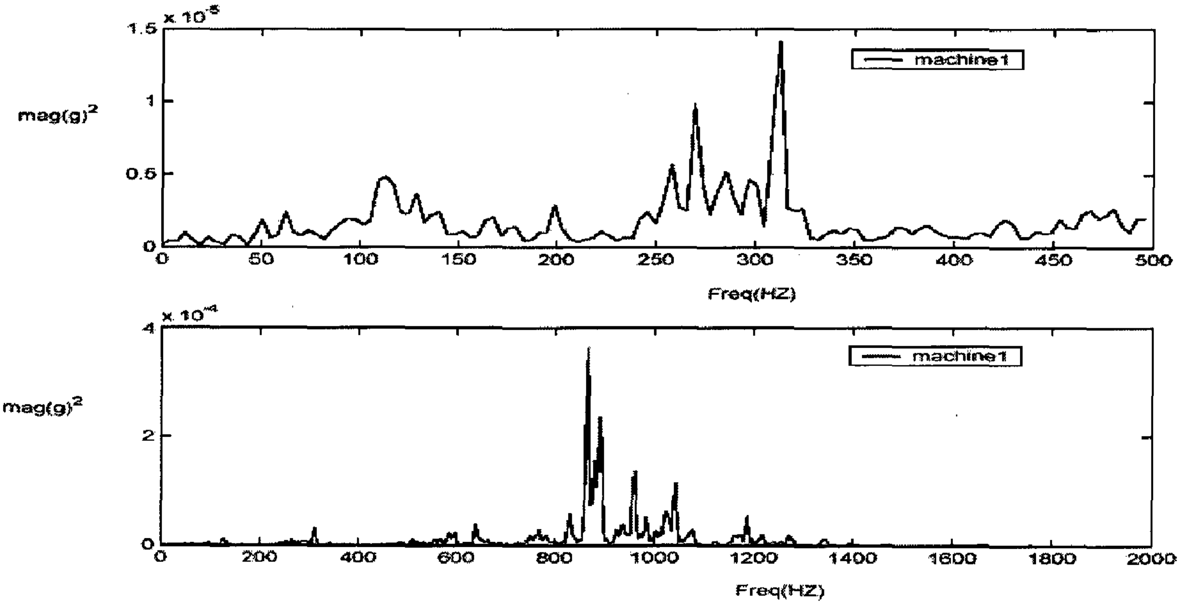
4.8.4 PSD (POWER SPECTRAL DENSITY):-

In order to further enhance our result PSD was calculated and was found that energy of signal in machine 2 for rotational frequency and its multiple at 3fr and inner race frequency and its multiple was dominating than energy in other frequency band where as for machine 1 energy of the signal was same for all frequency band and was below threshold value. However higher frequency energy i.e. at 1000 HZ was dominating at load and no load condition.

DATE 22-04-05

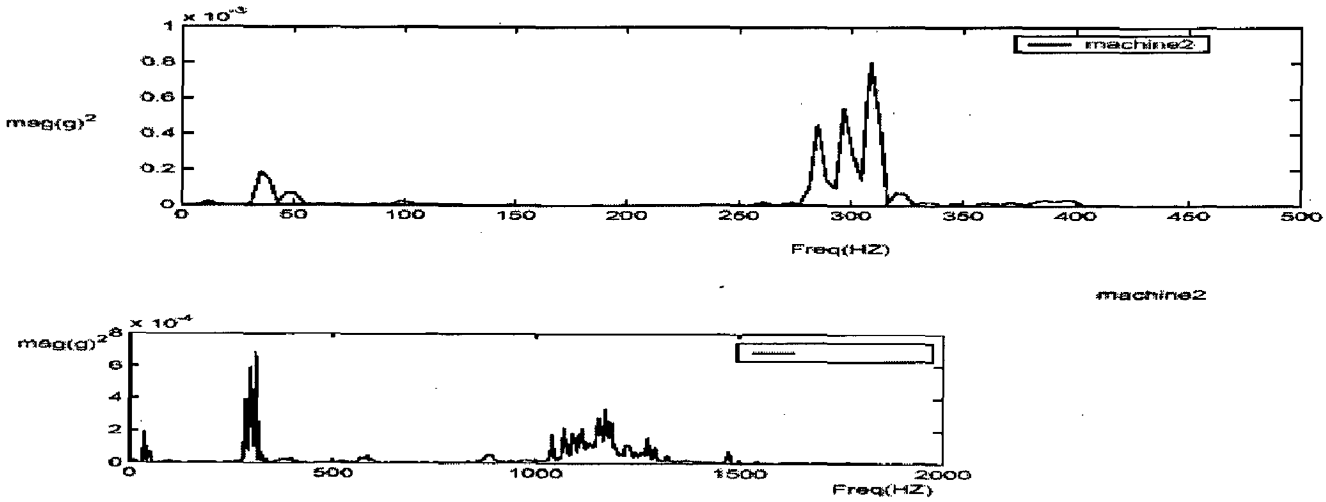
Machine1

FIG 4.11 PSD (Power Spectral Density of Normal Machine)



Machine 2

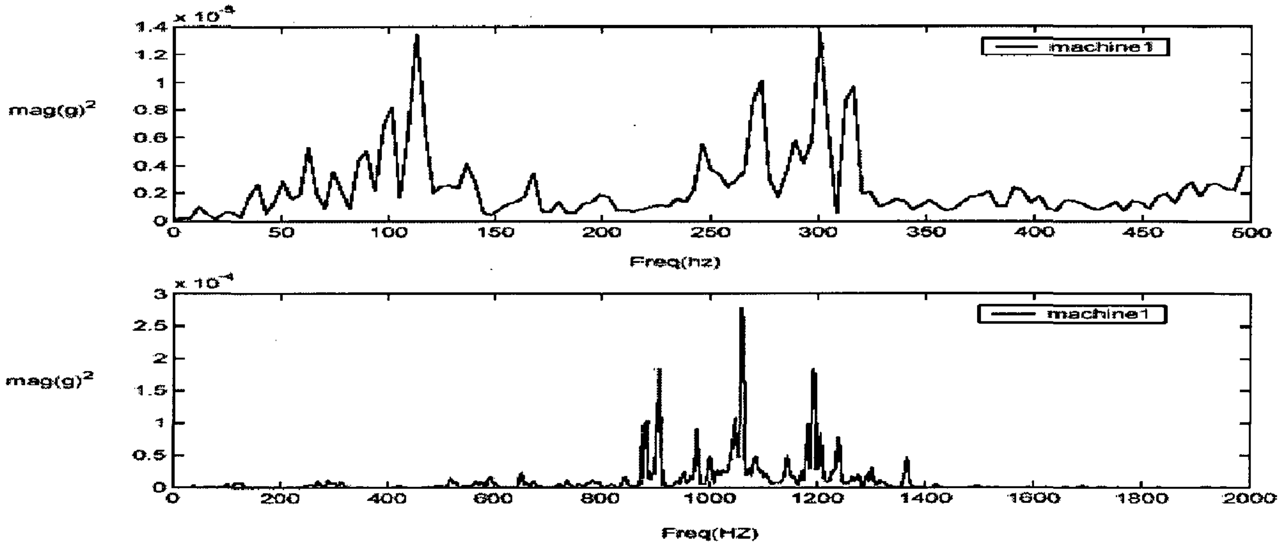
FIG 4.12PSD (Power Spectral Density with Imbalance and Inner Race Harmonics)



Machine 1

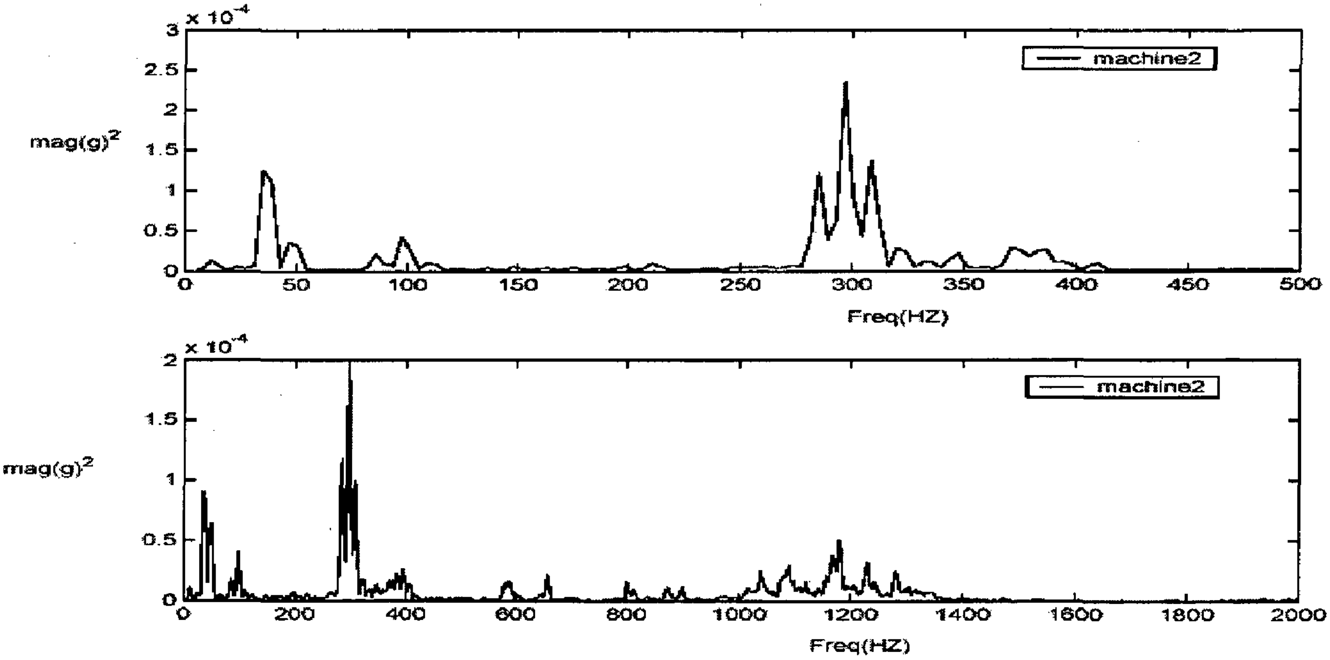
DATE 12-05-05

FIG 4.13 PSD (Power Spectral Density of M/C1 under Reduced Load)



Machine2

FIG 4.14 PSD (Power Spectral Density of M/C2)



Band energy

TABLE 4.5

FREQUECY BAND	MACHINE1(g)	MACHINE2(g)
1-200 HZ	.0006	.0048
220-350 HZ	.0009	.028
350-500 HZ	.0003	.0021
500-1000 HZ	.0101	.0092

4.8.5 CHANGE IN THE ROTATIONAL FREUENCY CONSIDERATION - As we know the rotational speed of the machine changes time to time so instead of taking the individual frequency component for analysis a band of 2 %was taken in to consideration so any shift in the frequency component is taken in to consideration and the maximum amplitude with in that band was taken in to consideration for analysis. From the result it was found that inner race frequency magnitude was much large of machine 2 as compared to other magnitude.

4.9 HARMONIC ACTIVITY LOCATOR (HAL) ALGORITHM

Spectrum analysis is a powerful tool used to diagnose various problems that a machine might develop. The absolute amplitudes of specific spectral components, implemented through the use of spectrum band alarms, allow us to set limits on when a problem is identified by the component's amplitude exceeding preset thresholds. The spectrum band alarm is apowerful tool for focusing on mechanically identifiable spectral components, and assigning alert and danger thresholds to those components for reporting to the analyst when either criterion is exceeded. Its limitation, in some circumstances, is that it requires specific components to reach certain preset limits without regard for the character of the data. HAL was designed to identify the presence of these series of harmonics regardless of the amplitude of any of the individual harmonic components. In many mechanical cases, harmonic series can be identified in spectra long before any of the individual components reach their alert or danger thresholds. Table 4.6 presents just a few of the common rotating machinery problems and their signature features in the vibration spectrum.

TABLE 4.6 Mechanical Problems and Their Expected Spectral Feature

Problem	Symptom	Candidate For Harmonic Indicator
Imbalance	A Single Spectral Peak At Running Speed	NO
Mechanical Looseness	Harmonic Series At Running Speed	Yes
Rotor Rubbing	Harmonic Series At Half Of Running Speed	Yes
Bearing Damage	Harmonic Series With Fundamental Frequency At Characteristic Frequency Of Specific Defect Types	Yes

How Does the HAL Algorithm Detect a Harmonic Series?

The HAL algorithm used provides an index number indicative of the existence of harmonic series for each mechanical component identified in a measurement. The algorithm first identifies all the peaks within each mechanical fault component's fundamental frequency search window. The frequency search window's location and width are determined by the characteristic frequency of the problem being investigated. For example, if misalignment is the target of the investigation, the center frequency of the search window will be the machine running speed, the recommended width of the search window will be 2% of the center frequency.

Once the peaks within the search window are identified, the HAL algorithm takes each identified peak that is potentially the measured fundamental frequency of a probable harmonic series, finds its harmonic frequencies, and averages the amplitudes at these frequencies. The harmonic average amplitude is then divided by the average of all of the non-harmonic spectral line amplitudes to result in the HAL index number. For example, if the spectrum were perfectly flat, the HAL index would be 1. For machine 1 and 2 rotational frequency harmonics and inner race frequency and it multiple harmonics were dominating and were taken for calculating HAL INDEX NO.

For machine 1 the HAL INDEX came to be near to 1.1indicating good condition and for machine 2 HAL INDEX was 3.3 exceeding the threshold limit (2.5)

4.10 BEARING ANALYSIS ALGORITHM: - A large concern in predictive maintenance is the early detection of bearing element failures. Calculating the various frequencies requires information that is typically unknown, such as:

- Inner and outer race diameter
- Ball size
- Number of balls

To create a motor monitor that does not require a user to obtain bearing geometry information, the monitoring system uses a statistics-based algorithm that is not limited to any specific type of rolling element bearing. To analyze the vibration spectrum, algorithm creates a Fast Fourier Transform (FFT) composed of 1000 lines across a 2000 Hz frequency Spectrum. To reduce the impact of noise and improve the repeatability of data used in determining bearing status, the amplitudes of this vibration spectrum are averaged into 16 intervals. The resulting 16-point spectrum is the **averaged spectrum** used in determining the changes in the spectrum over time.

(i) Low Frequency Absolute spectrum Changes (LFA):-The Low Frequency Absolute Spectrum Change is described by the below expression, where A0 and B0 are the first intervals of averaged vibration spectrum and of the baseline spectrum respectively. (Baseline refers to good machine)

LFA = A0/ B0

(ii) Low Frequency Range (LFR):- The LFR is defined by the first interval of the averaged acceleration spectrum covering 10–156 Hz. This includes at least the first three first orders of 30 Hz and 45 Hz rotation frequency and the first two orders of 60 Hz rotation frequency. In general, it covers a wide enough frequency band to cover the first few harmonics of the fundamental vibration signal.

(iii) Low Frequency Relative Change (Lfr):-Low Frequency Relative Change is calculated as follows LFR=LFA/ASC.The LFA is compared to the ASC to detect an increase in the first interval relative to an increase in the full spectra. In general, as an increase in high frequency energy occurs, the full spectrum ratio increases faster than the low frequency ratio, so the LFR value decreases. As machine imbalance occurs, the LFA increases faster than the full spectrum, so the LFR value also increases

(iv) Averaged Spectrum Changes:-The ASC value is described by the below expression: where Ai is the magnitude of the averaged spectrum for each subsequent vibration scan, Bi is the magnitude of the averaged baseline spectrum; and N is the number of intervals in the averaged spectra. In the averaged spectrum used by the motor monitor N equals 16.

$$\text{ASC}=\left[\prod_{i=0}^{N-1} Ai \Big/ Bi\right]^{1/N}$$

(v) Bearing Condition (BC) Calculation:-The following parameters are combined to characterize changes in bearing condition over time:

- CFRatio
- KU
- LFR

The motor monitor assigns a value to the bearing condition by the following expression:

$$\text{BC}=\sqrt{CFRartio * KU \Big/ LFR}$$

(vi) Overall Vibration Condition (OV) Calculation:-The following parameters are used to characterize changes in overall vibration condition over time:

- RMSRatio
- ASC
- PKRatio

The motor monitor assigns a value to the overall vibration using the following expression

$$\text{OV}=3\sqrt{RMS * PEAK * ASC}$$

(vii) Calculating the Bearing Status indicator (BSI):-The motor monitor combines BC and OV to assign a value to the status of the bearings according to the following expression: BSI=BC*OV

Results:-

TABLE 4.7 Sample parameters value for various bearing condition

@50HZ	NORMAL	INNER RACE FAULT	OUTER RACE FAULT	M/C1&M/C2of Steel industry
ASC	1	16.8	16.12	1.96
RMS RATIO	1	11.52	16.6	1.8
CF RATIO	1	1.36	1.41	1.2
LFR	1	.64	.80	1.29
LFA	1	10.78	13.02	2.9
KU(kurtosis)	-.04			.8

Machine condition	BC(bearing condition)	OV(overall value)	BSI(bearing status indicator
1 Normal	1	1	1
2 Inner Race Fault	2.4	14.6	35.26
3 Outer Race Fault	3.2	11.8	37.8
4 M/C1&M/C2	1.38	1.79	2.8

4.11 TEST RESULT OF LAB MOTOR

Specification of motor: - Machine 1 And Machine 2 Are Same

1. Ampere 10
2. 7.5 H.P
3. Rpm 1440
4. Connection Deltas
5. Type Induction
6. Bearing Type (SKF 6306)
7. Made PSG COMBITORE
8. Rotor Squirrel Cage
9. Rotational Frequency 24 Hz

TABLE 4.8 The magnitude of key frequencies for the bearing used in the test motor.

Bearing Type (SKF 6306)	D = 50.8 mm, d = 12.3 mm, n = 8,β = 0°			
Vibration Frequency	f_0	f_I	fb	Fc
Magnitude (Hz)	75.1	123	96.2	9.4

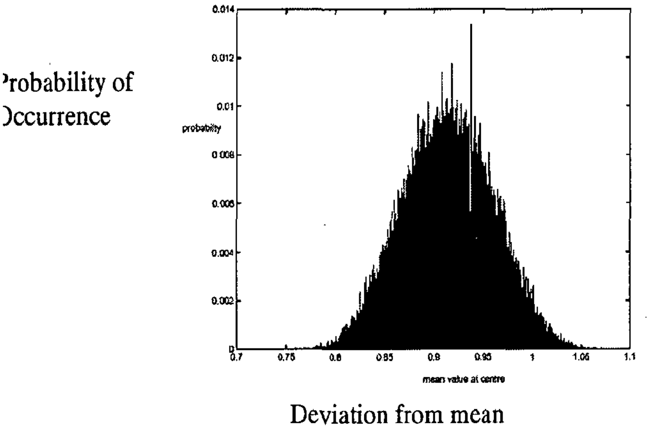
STATTICAL PARAMETER: - **TABLE 4.9**

S.NO	RESULT	MACHINE 1 (healthy machine)	MACHINE 2 (machine with Inner race fault)
1	Mean	.001	.08
2	RMS	.02	.53
3	Crest	2.8	3.099
4	Variance	.009	.98
5	Standard Deviation	.3	.98

6	Skew ness	.008	-.62
7	Kurtosis	3.01	2.7
8	Third Order Cumulant	.000009	-.615
9	Fourth Order Cumulant	-.00004	-218
10	Peak	.0833	1.64
11	Complexity	.07	.8

Healthy machine PDF (Gaussian shape)

FIG 4.15



Bearing fault (inner race) machine PDF

FIG 4.16

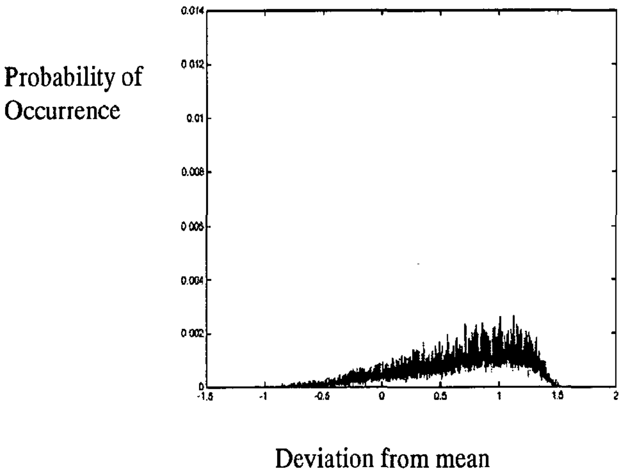


Fig 4.17Healthy Machine

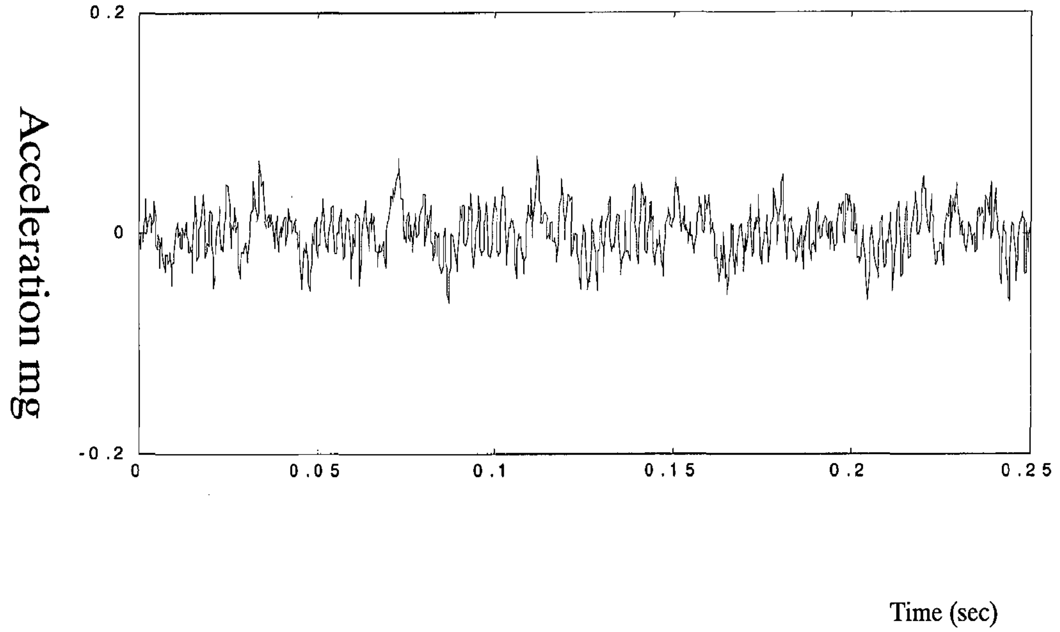
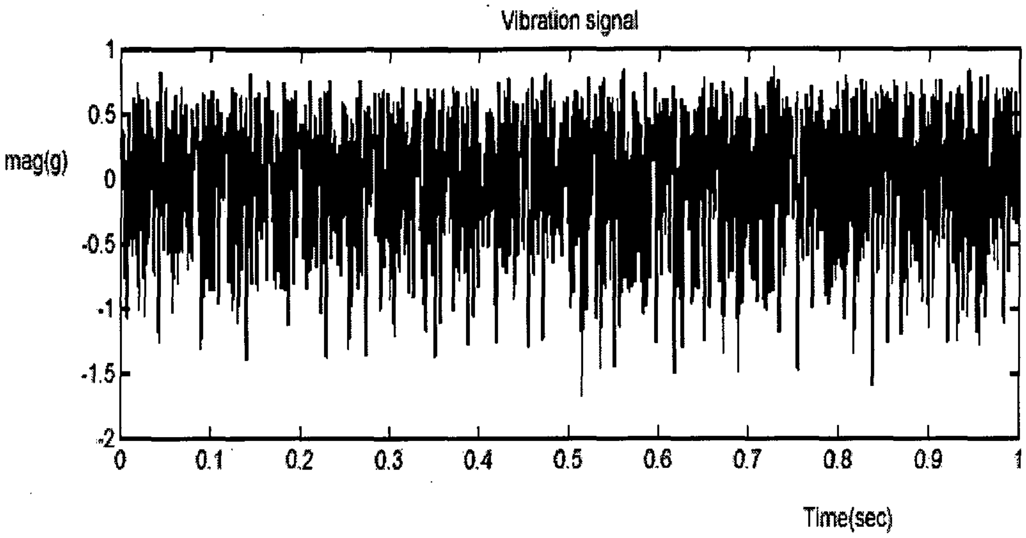
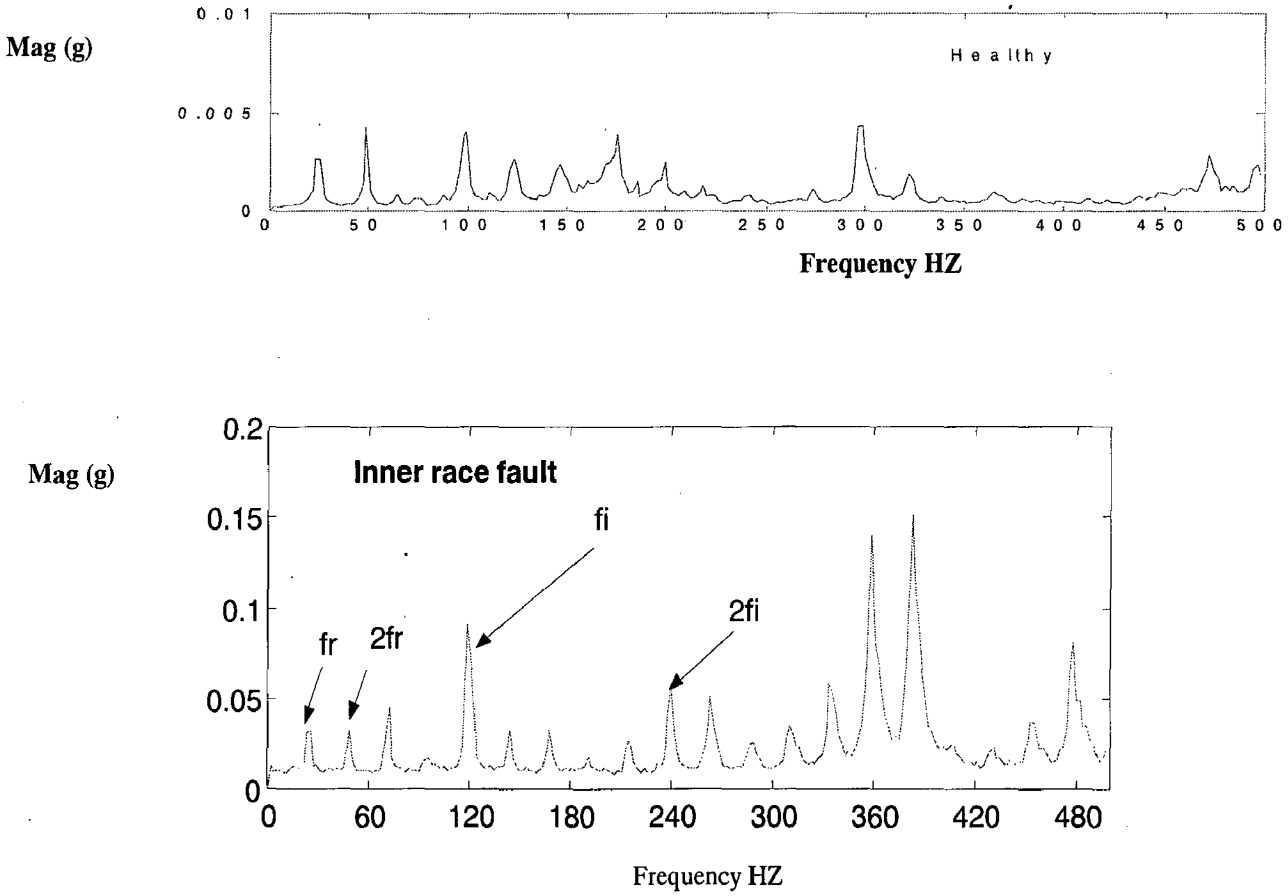


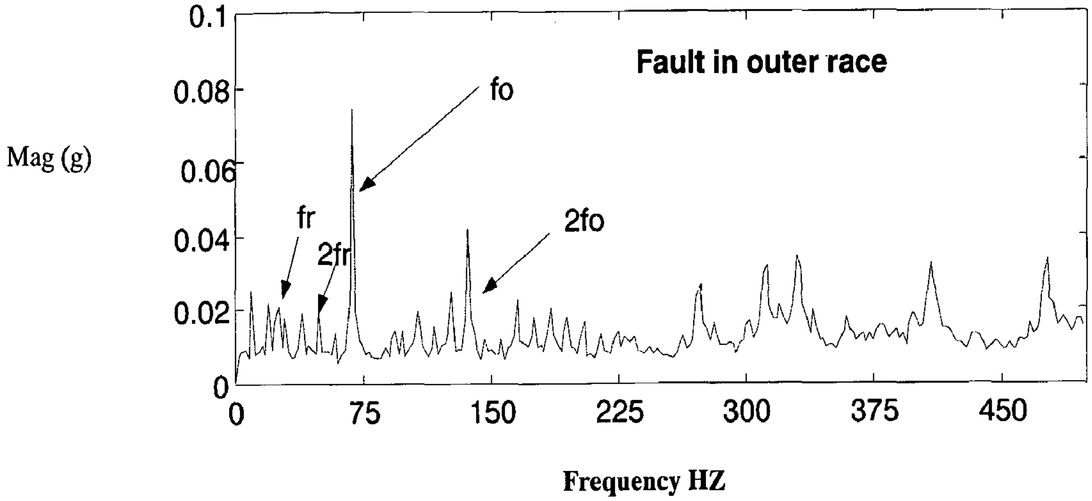
FIG 4.18 faulty machines (Inner race bearing fault)

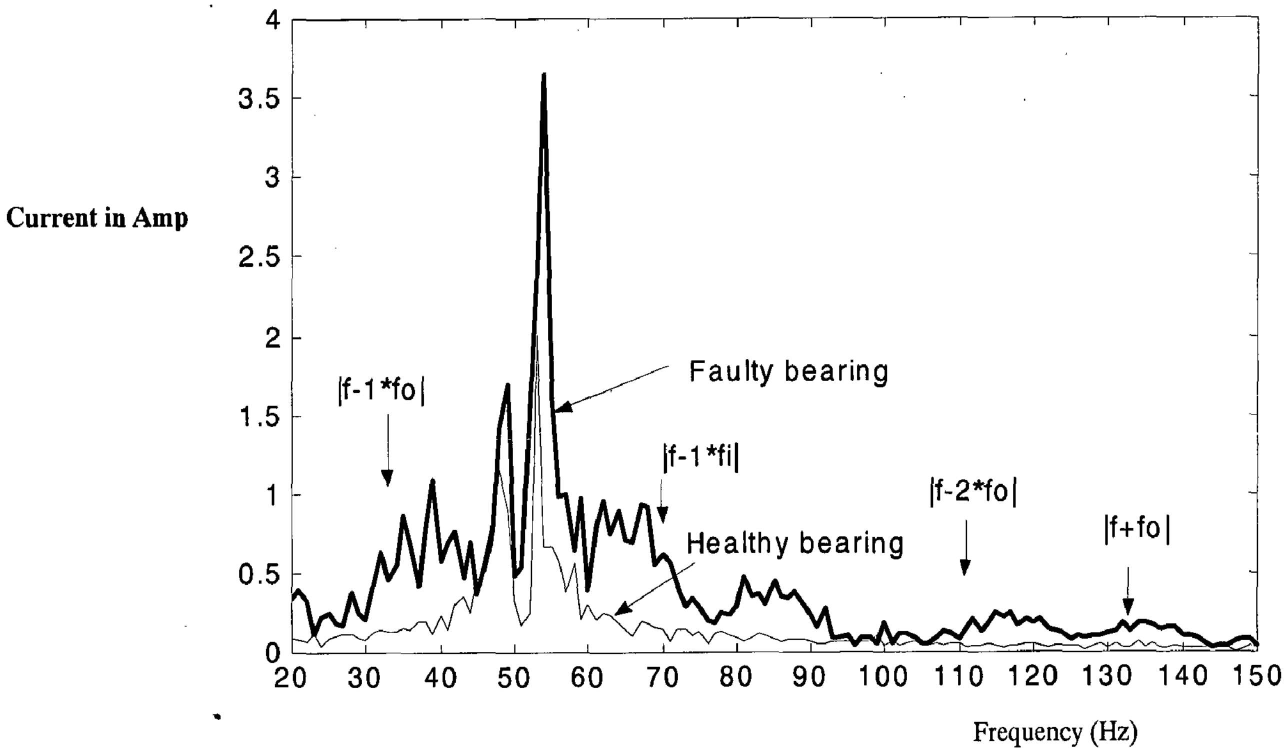


Spectrum of Healthy, Faulty bearing Induction Motor

Fig 4.19







Current spectrum of loaded induction motor with healthy bearing and bearing with fault in outer race

4.12 TEST RESULT and DISCUSSION

Several statistical parameters, calculated in the time domain, are used to denote average properties of machinery data. These statistical parameters are used to perform a quick check of the changes in the statistical behavior of a signal.

In this thesis, considering a vibration signal of the motor, all statistical parameters from first moment to forth moment is computed by using following steps:

Step1: Read the vibration data file.

Step2: Take first 2000 samples.

Step3: 'moment' of the MATLAB Toolbox is used for calculation of moments of required order.

Step4: Calculate the mean and rms value of the data segment.

Step5: Take another data segment overlapping the previous segment by 500 samples.

Step6: Repeat step 3 to 5.

It is found that statistical examination of vibration measurements related to each aging cycle has a Gaussian distribution and deviates from Gaussian distribution as faults develops. The second moment, also termed "standard deviation," appears to be the most dominant parameter employed throughout the analysis. Then, a critical standard deviation is determined comparing the standard deviations of the initial (healthy case) with those of each aging level data. This critical standard deviation is an early-fault detection level or alarm level at the same time. Also, comparing the time and frequency presentations of the vibration signals for initial and aged cases, the frequency characterization of the bearing damage can be defined between 2 and 4 kHz and unbalanced condition can be defined between low frequency levels between 10 to 140 HZ.

For incipient condition, the RMS of the signal remains virtually unchanged, whilst an increase is noted to the peak value. As damage to the motor progress, the RMS value increase due to the presence of more peaks, but without necessarily increasing the level of the peak signal.

Eventually as the damage became more advanced both the RMS and peak values increase steadily.

The fourth order parameter, referred as kurtosis, produces a value of 2.8 to 3.3, of healthy motor. An increase in the kurtosis measurement, typically 2.65 to 2.85and also greater than 3.4 signifies incipient bearing damage or some fault in the motor. Once the damage becomes more severe and commences to spread, the signal becomes less coherent and becoming random in character, therefore the kurtosis reduces back to less than 3. Similarly other time domain features such as complexity and cumulant were also calculated and matched with standard result to predict the condition of the machine.

The developed software has successfully extracted the time and frequency domain features. For analyzing the numerical data, MATLAB is a simple and very efficient tool. Hence MATLAB has been used in this work. In general, the automated fault diagnostics is being carried out by observing the limits of the vibration signal parameters and by applying different criteria for the fault classification. Therefore, the reliability of the fault diagnosis is totally dependent on the accuracy of the estimates of vibration signal parameter. The correctness of the method has been validated by comparing the program results with the standard results available in the literature for various fault categories.

4.12.1FREQUENCY DOMAIN ANALYSIS

Another conventional approach used to process the vibration signals is the frequency domain. Frequency domain features (Fast Fourier Transform, Power Spectral Density, and harmonic activity algorithm and bearing analysis algorithm) of the vibration signal provided additional information in the assessment of condition monitoring of rotating electrical machines.

Frequency analysis of a signal highlights many important hidden features and extracts some useful information. The purpose of this analysis was to find out the frequency content of the vibration data so that the relationship between the frequencies and type of the fault is established. The simplest way to identify the multiple sinusoid signals was Fourier transform spectrum analysis. By this method the machinery condition is assessed by observing the presence of assumed stationary frequency components, noting the amplitude of these frequency components with respect to reference vibration level.

It is known that structural defects in rotating machinery components (e.g. bearings and gears) can be detected through monitoring vibration and/or sound emissions.

Vibration spectra in mechanical systems often contain mixtures of extraneous frequencies that provide little or no pertinent diagnostic information about the health of the machine. In rotating machinery applications, component characteristic defect frequencies generally occur as sideband modulations around the component-carrier frequency (or harmonics thereof). Disturbances due to localized component defects cause wide band impulses to be generated periodically at the characteristic defect frequency. These impulses, in turn, excite the component and its supporting structure, producing short-lived ringing signals of random amplitude. The strongest defect frequency is generally the one closest to the ringing mode. Since there is no reliable way of predicting the ringing modes of a component and its supporting structures, many potential defect frequencies were monitored. Additionally, the dominant ringing mode may depend on defect severity.

Traditional diagnostic vibration analysis attempted to match spectral lines with *a priori* known defect frequencies that are characteristic of the examined machinery components. Short term Fourier transforms, bearing analysis algorithm, and harmonic activity theorem are used to detect non-stationary component failure signatures, which generally result from the presence of a localized defect (e.g. bearing pitting or gear tooth fracture). The fact that typical component defects are localized spatially and have characteristic defect frequencies makes it possible to associate particular vibration patterns with specific machinery components.

One of the major difficulties in machinery diagnostics was the problem of sorting through the enormous number of frequency lines present in vibration spectra to extract useful information associated with the health of a particular component. This is true even when synchronous averaging of time-series vibration signals is performed to reduce the 'smearing' of the frequency lines due to fluctuations in machine speed. For this a band of frequency was taken instead of single known frequency of faulty component

Power spectral analysis has been applied to characterize and interpret vibration signatures emanating from faults. Third and higher-order cumulants vanished for purely Gaussian processes. Other technique such as HAL methods has the potential to increase the SNR (signal to noise ratio) in a large class of mechanical fault-detection applications.

For the lab machine no of sample point taken was 2000 points for analysis as the rotational frequency was 24HZ. The Vibration and current spectra of healthy machine and machine with bearing fault created were taken. The inner race fault was clearly seen on the machine spectra with multiple harmonics dominated with high magnitude where in case of healthy machine spectra it was below threshold limit The HAL INDEX NO was very low for healthy machine(2.1) where as it was very high for faulty bearing machine 4.7.The bearing analysis algorithm was also tested for the same and was found successful in indicating the fault

CHAPTER 5

CONCLUSION

The main aim of work in this thesis is condition monitoring of the rotating machine in steel rolling mill and observes the changes in machine variables that occur at different situation. Changes in the various statistical and frequency parameters are observed from recorded vibration data on two different days, at different direction such as radial and axial directions and at different load conditions. It is discovered from the rolling mill observations that statistical parameters and magnitude of frequency spectra changed at different condition on the two different days.

Observation and analysis on the Laboratory models are good to verify the relationship between various peaks in spectra with the corresponding fault and under multi fault conditions. Analysis of rolling mill data is used to predict the slow changes on the machine at various load situations. For further advance prediction a new parameter HAL INDEX number is calculated. HAL INDEX number is able to identify the presence of series of harmonics regardless of the amplitude of any of the individual harmonic components. The result was further analyzed by bearing analysis algorithm .In many mechanical cases, harmonic series can be identified in spectra long before any of the individual components reach their alert or danger thresholds enhancing us to predict precautionary measure before severe conditionoccur.

SUGGESTION FOR FUTURE WORK

The area of condition monitoring is wide and include in many topics. It is suggested to make some improvement in the present monitoring system through the use of the following

1 Estimation of various parameters such as current, temperature and voltage for monitoring in steel industry and correlating them with vibration parameters results

2 Building a database for vibration harmonics using experimental and theoretical investigation for various size and design standard of three phase induction motors. Through this a new standard for vibration can be established instead of traditional one which depends on RMS velocity of vibration rather than harmonics amplitude.

3 Employing wavelet tool box and expert system for fault diagnosis of induction motor using rules based weight obtained from neural network. This combination of ANN and expert knowledge may enhance the monitoring system for diagnosis

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APPENDIX A-1

ENDEVCO MODEL 50/50M1

ISOTRON® Accelerometer

SPECIFICATIONS

The following performance specifications conform to ISA-RP-37.2 (1964) and are typical values, referenced at +75°F (+24°C), 4 mA, and 100 Hz, unless otherwise noted. Calibration data, traceable to National Institute of Standards and Technology (NIST), is supplied.

DYNAMIC CHARACTERISTICS	Units	
RANGE	g	± 40
VOLTAGE SENSITIVITY ±10 % typical	mV/g	50
FREQUENCY RESPONSE		See Typical Amplitude Response
RESONANCE FREQUENCY	kHz	10
AMPLITUDE RESPONSE		
± 5%	Hz	2 to 4 000
± 1dB	Hz	1 to 5 000
TEMPERATURE RESPONSE	± 5%	See Typical Curve
TRANSVERSE SENSITIVITY	%	≤ 5
AMPLITUDE LINEARITY	%	< 1 to Full Scale
OUTPUT CHARACTERISTICS		
OUTPUT POLARITY		Acceleration directed into the base of the unit produces positive output
DC OUTPUT BIAS VOLTAGE	Vdc	+ 6.8 typical
OUTPUT IMPEDANCE	Ω	≤ 150
FULL SCALE OUTPUT VOLTAGE	V	± 2.0
RESOLUTION 1-5 kHz	equiv. g rms	≤ 0.001
GROUNDING		Signal ground isolated from mounting surface
POWER REQUIREMENT		
SUPPLY CURRENT	mA	+ 2.0 to + 10.0
VOLTAGE [1]	Vdc	+ 9 to + 24
WARM-UP TIME	sec	< 3
ENVIRONMENTAL CHARACTERISTICS		
TEMPERATURE RANGE		- 4°F to + 185°F (-20°C to + 85°C)
HUMIDITY		Hermetically Sealed
SINUSOIDAL VIBRATION LIMIT	g pk	40
SHOCK LIMIT [2]	g pk	2000
BASE STRAIN SENSITIVITY	equiv. g pk/μ strain	0.015
ELECTROMAGNETIC SENSITIVITY	equiv. g rms/gauss	0.0003
PHYSICAL CHARACTERISTICS		
DIMENSIONS		See Outline Drawing
WEIGHT Without cable	gm (oz)	3.8 (.14)
CASE MATERIAL		Stainless Steel
MOUNTING [3]		Adhesive or Integral Magnet (50M1)
CALIBRATION		
SUPPLIED:		
SENSITIVITY	mV/g @100Hz	

ACCESSORIES

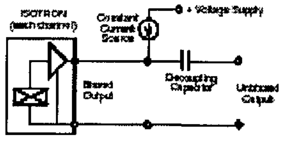
24 AWG OUTPUT WIRES (3 METERS) SOLDERED TO TERMINALS

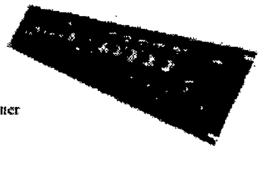
OPTIONAL ACCESSORIES

Model 2950M24	TRIAXIAL MOUNTING BLOCK
3024-120	CABLE ASSEMBLY
P/N 31849	ADHESIVE MOUNTING KIT
Model 4475	10 CHANNEL ISOTRON SIGNAL CONDITIONER

NOTES:

1. Compliance voltage as low as +9Vdc may be used in conjunction with a constant current source to provide power to the accelerometer. However, the dynamic range may be limited to a maximum of ±35 g's.
2. Built-in mechanical stops inside the piezoelectric sensor greatly increases the shock survivability of the accelerometer.
3. Depending on the dynamic and environmental requirements, adhesives such as petro-wax, hot-melt glue, and cyanoacrylate epoxy (super glue) may be used to mount the accelerometer temporarily to the test structure. An adhesive mounting kit (P/N 31849) is available as an option from Endevco.
4. Maintain high levels of precision and accuracy using Endevco's factory calibration services. Call Endevco's inside sales force at 800-982-6732 for recommended intervals, pricing and turn-around time for these services as well as for quotations on our standard products.





Model 4475
Signal Conditioner

Appendix A-2

Specification of the Hall Effect Current Transducer

Type: LEM Module LA 50-P

Execution: : Insulated Plastic Injected

Mounting: : Mounting on printed circuit by three pins

Weight: : 25g

Operating temperature: : 0 to 70 degree centigrade

Current direction: : Direction of the arrow obtain positive Measuring direction

Minimum burden resistance: : 100 ohms

Nominal primary current: : 50 Amp (RMS)

Measuring Range: : TO 70Amp

Turn ratio : 1000

Frequency Range For 1 % Error: : DC to 40 KHZ

Accuracy : : +-.5% of input at 25degree C

Linearity : .1%

Response Time : Better Than 1 Microsecond

Test Voltage : 2kv RMS (1 min)

Supply Voltage: : +-15v, +-15%

Current Drain: : 10 Ma (N.L Current)

Data acquisition card specification (NI6024E)

E Series Multifunction DAQ – 250 kS/s, 12-Bit, 16 Analog Inputs

Nominal Range (V)		Absolute Accuracy								Relative Accuracy		
		% of Reading			Noise + Quantization (mV)				Absolute Accuracy at Full Scale (mV)	Resolution (mV)		
					Single Pt.					Single Pt.		
Positive FS	Negative FS	24 Hrs	1 Year	Offset (mV)	NI 6040E	NI 6041E	Averaged	Temp Drift (%/°C)		NI 6040E	NI 6041E	Averaged
10	-10	0.0872	0.0714	7.38	4.64	5.37	0.846	0.0010	15.373	8.27	6.77	1.11
5	-5	0.0272	0.0314	3.70	2.32	2.69	0.423	0.0005	5.697	3.14	3.39	0.557
2.5	-2.5	0.0872	0.0714	1.86	1.16	1.34	0.211	0.0010	3.859	1.57	1.69	0.278
1	-1	0.0872	0.0714	0.757	0.464	0.537	0.085	0.0010	1.556	0.827	0.677	0.111
0.5	-0.5	0.0872	0.0714	0.389	0.269	0.269	0.042	0.0010	0.789	0.339	0.339	0.056
0.25	-0.25	0.0872	0.0714	0.205	0.134	0.153	0.021	0.0010	0.405	0.169	0.184	0.028
0.1	-0.1	0.0872	0.0714	0.095	0.076	0.098	0.010	0.0010	0.176	0.088	0.111	0.013
0.05	-0.05	0.0872	0.0714	0.058	0.056	0.078	0.006	0.0010	0.100	0.084	0.091	0.008
10	0	0.0272	0.0314	3.70	2.32	2.69	0.423	0.0005	7.269	3.14	3.39	0.557
5	0	0.0872	0.0714	1.86	1.16	1.34	0.211	0.0010	5.645	1.57	1.69	0.278
2	0	0.0872	0.0714	0.757	0.464	0.537	0.085	0.0010	2.271	0.827	0.677	0.111
1	0	0.0872	0.0714	0.389	0.269	0.269	0.042	0.0010	1.146	0.339	0.339	0.056
0.5	0	0.0872	0.0714	0.205	0.134	0.153	0.021	0.0010	0.583	0.169	0.184	0.028
0.2	0	0.0872	0.0714	0.095	0.076	0.098	0.010	0.0010	0.247	0.088	0.111	0.013
0.1	0	0.0872	0.0714	0.058	0.056	0.078	0.006	0.0010	0.135	0.084	0.091	0.008

Note: Accuracies are valid for measurements following an internal E Series Calibration. Averaged numbers assume dithering and averaging of 100 single-channel readings. Measurement accuracies are listed for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of external or factory-calibration temperature. One-year calibration interval recommended. The Absolute Accuracy at Full Scale calculations were performed for a maximum range input voltage (for example, 10 V for the ±10 V range) after one year assuming 100 pt averaging of data. See overview on page 312 for an example calculation of this type.

Table NI 604xE Analog Input Accuracy Specifications

Nominal Range (V)		Absolute Accuracy					Absolute Accuracy at Full Scale (mV)
		% of Reading					
Positive FS	Negative FS	24 Hrs	90 Days	1 Year	Offset (mV)	Temp Drift (%/°C)	
10	-10	0.0177	0.0197	0.0219	5.93	0.0005	8.127
10	0	0.0177	0.0197	0.0219	3.49	0.0005	5.685

Note: Temp Drift applies only if ambient is greater than ±10 °C of previous external calibration. See page 312 for example calculations.

Table NI 6040E Analog Output Accuracy Specifications

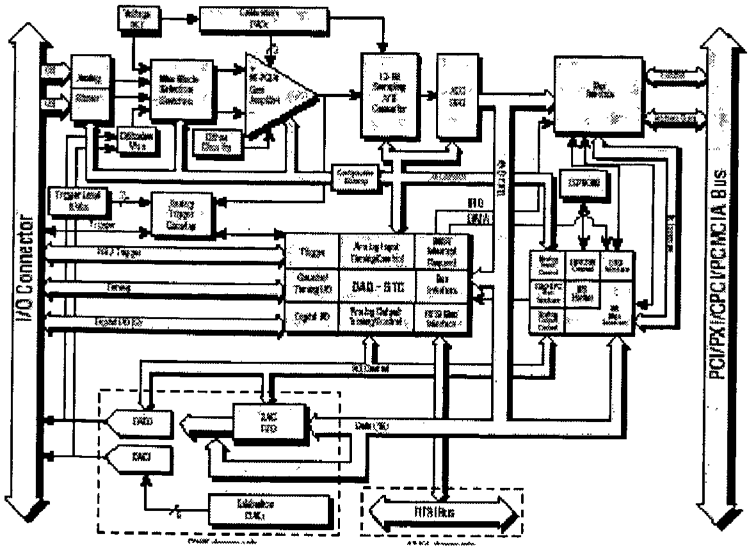
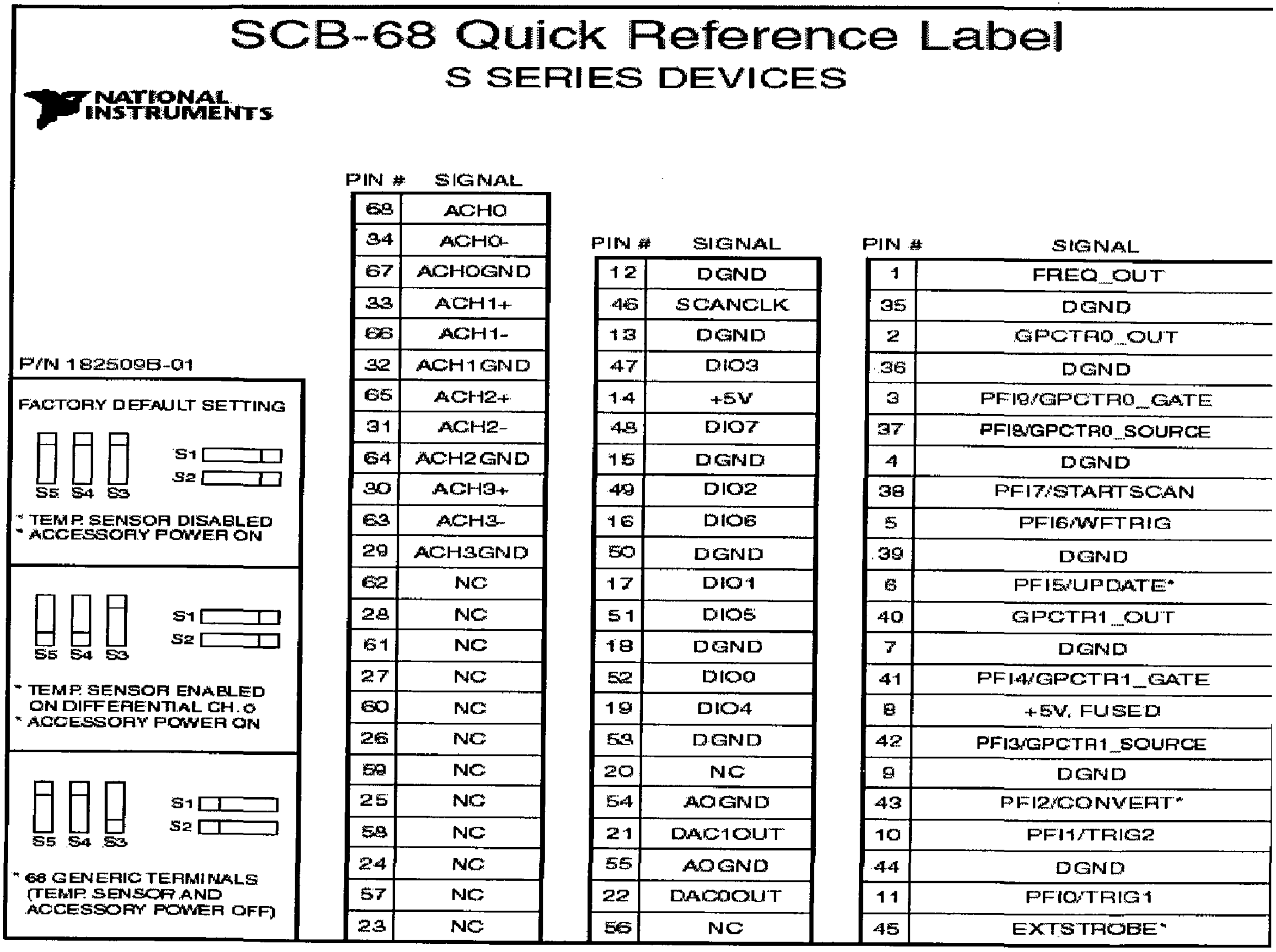


Figure NI 604xE Hardware Block Diagram



SCB-68 Quick Reference Label

S SERIES DEVICES

NATIONAL INSTRUMENTS

P/N 182509B-01

PIN #	SIGNAL
68	ACH0
34	ACH0-
67	ACH0GND
33	ACH1+
66	ACH1-
32	ACH1GND
65	ACH2+
31	ACH2-
64	ACH2GND
30	ACH3+
63	ACH3-
29	ACH3GND
62	NC
28	NC
61	NC
27	NC
60	NC
26	NC
59	NC
25	NC
58	NC
24	NC
57	NC
23	NC

PIN #	SIGNAL
12	DGND
46	SCANCLK
13	DGND
47	DIO3
14	+5V
48	DIO7
15	DGND
49	DIO2
16	DIO6
50	DGND
17	DIO1
51	DIO5
18	DGND
52	DIO0
19	DIO4
53	DGND
20	NC
54	AOGND
21	DAC1OUT
55	AOGND
22	DAC0OUT
56	NC

PIN #	SIGNAL
1	FREQ_OUT
35	DGND
2	GPCTR0_OUT
36	DGND
3	PFI9/GPCTR0_GATE
37	PFI8/GPCTR0_SOURCE
4	DGND
38	PFI7/STARTSCAN
5	PFI6/WFTRIG
39	DGND
6	PFI5/UPDATE*
40	GPCTR1_OUT
7	DGND
41	PFI4/GPCTR1_GATE
8	+5V, FUSED
42	PFI3/GPCTR1_SOURCE
9	DGND
43	PFI2/CONVERT*
10	PFI1/TRIG2
44	DGND
11	PFI0/TRIG1
45	EXTSTROBE*

Figure B-4. S Series Devices