A DIAGNOSTIC APPROACH THROUGH CONDITION BASED MONITORING USING VIBRATION ANALYSIS

A project report submitted in partial fulfilment of the requirements for the Award of the Degree of

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

by

K.L.Induja	**(315126520093)**
K.Somesh	**(315126520101)**
K.Sai Praveen	**(315126520108)**
Koushik Paul	**(315126520110)**
T.L.Prathyusha	**(315126520114)**

Under the guidance of

Dr. K.SIVA PRASAD, M.Tech., Ph.D., MISTE
Professor

PRAGNANAM BRAHMA
ANITS

DEPARTMENT OF MECHANICAL ENGINEERING
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
(Approved by AICTE, Affiliated to Andhra University, Accredited by NBA, NAAC- 'A' grade approved)
SANGIVALASA, VISAKHAPATNAM (District) – 531 162

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

(Affiliated to Andhra University)

Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

PRAGNANAM BRAHMA

ANITS

CERTIFICATE

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APPROVED BY

13.4.19

(Dr.B.Naga Raju)
Head of the Department
Dept. of Mechanical Engineering
ANITS, Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa 531 162 VISAKHAPATNAM Dist A.P.

PROJECT GUIDE

(Dr. K.Siva Prasad)
Professor
Dept. of Mechanical Engineering
ANITS, Visakhapatnam.

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINATIONS

EXTERNAL EXAMINER:

INTERNAL EXAMINER:

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES

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Professor
Dept. of Mechanical Engineering
ANITS, Visakhapatnam.

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INTERNAL EXAMINER:

EXTERNAL EXAMINER

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K.L.Induja

K.Somesh

K.Sai Praveen

Koushik Paul

T.L.Prathyusha

ABSTRACT

Any industry is equipped with multitude of machinery which have to work uninterruptedly for continues production. For effective operation of the organization, early diagnosis of technical problems is very much essential so as to reduce the breakdown time and increase the availability of equipment. This will maintain sustained output of the plant. So, machinery maintenance is one of the important factors for efficient and cost effective operation of any industry and it is mandatory to continuously monitor the condition of the machinery, which is generally known as "Condition Monitoring".

The main objective of this project is to provide the insight into the predictive maintenance through condition maintenance of equipment using vibration analysis. The various strategies of machinery maintenance, fundamentals of vibration based condition monitoring, selection of sensors, monitoring locations, instrumentation used for vibration measurements and analysis are studied and practical demo of vibration measurements on an induction motor is carried out. And finally to understand the machinery condition monitoring using vibration analysis, an industrial fan is considered with and without imbalance for studying vibration response using practical vibration measurements.

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INTRODUCTION

Condition monitoring is the process of monitoring a parameter of machinery reflecting the condition of its components, such that its pattern or a significant change in it is indicative of a developing situation which may lead to failure at some point of time in future. It is a part of major component of predictive maintenance. The use of condition monitoring allows maintenance to be optimally scheduled, or other actions to be taken to avoid the consequences of failure, before the failure occurs. Nevertheless, a deviation from a reference value (e.g. temperature, vibration behaviour, quality of lubricant) must occur to identify impeding damages.

The condition of rotating components in a machine is assessed from the amount of vibration they generate. This vibration level is a good indicator of the condition of the equipment. However, using detailed vibration analysis (spectrum and waveform analysis) the exact machinery problems such as Unbalance, Mechanical Looseness, Misalignment, Gear tooth wear mesh defects, bearing defects etc. can be very precisely predicted. Equipments covered are Diesel Engines, Alternators, Pumps, Gear Boxes, Blowers, and Turbines etc.

1.1 BATHTUB CURVE

The life of a machine follows a typical bathtub curve as shown in **Figure 1.1**. Machine vibration level also follows the shape of the bathtub curve. The beginning of a machine's useful life is usually characterized by a relatively high rate of failure. These failures are referred to as *"wear-in"* failures. They are typically due to such things as design errors, manufacturing defects, assembly mistakes, installation problems and commissioning errors. As the causes of these failures are found and corrected, the frequency of failure decreases.

The machine then passes into a relatively long period of operation, during which the frequency of failures occurring is relatively low. The failures that do occur mainly happen on a random basis. This period of a machine's life is called the *"normal wear"* period and usually makes up most of the life of a machine. There should be a relatively low failure rate during the normal wear period when operating within design specifications.

As a machine gradually reaches the end of its designed life, the frequency of failures again increases. These failures are called *"wear-out"* failures. This gradually

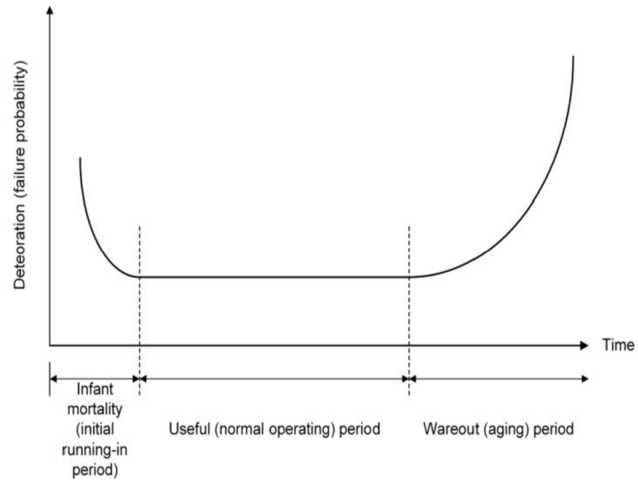


Figure 1.1 Bathtub curve for the life of the machine

increasing failure rate at the expected end of a machine's useful life is primarily due to metal fatigue, wear mechanisms between moving parts, corrosion, and obsolescence. The slope of the wear-out part of the bathtub curve is machine-dependent. As time progresses, the failure rate continue to increase, leading ultimately to failure or breakdown of machine.

1.2 SCOPE OF THE STUDY (PROBLEM STRATEGY)

The condition of rotating components in a machine is assessed from the amount of vibration they generate. This vibration level is a good indicator of the condition of the equipment. however, using detailed vibration analysis (spectrum and waveform analysis) the exact machinery problems such as unbalance, mechanical looseness, misalignment, gear tooth wear defects, bearing defects etc can be very precisely predicted. Equipments covered are diesel engines, alternators, pumps, gear boxes, blowers, and turbines etc.

1.3 OBJECTIVE

Predictive maintenance of rotating machinery is done to increase the production time i.e., to reduce total down time.

- By vibration analysis, problem can be detected early, when defects are minor and also not effect machine operations and if we can diagnose the nature of the problem and repairs can be scheduled(if necessary) at a convenient time.
- Extensive damage to the machine resulting from forced failure can be minimized.
- Machine in good condition can continue to run as long as no problems developed.
- Time and money are not wasted, dismantling the machine which already operating smoothly.

1.4 METHODOLOGY

Vibration is a vectorial parameter, requiring measurement in three directions. These measurements are required to be carried out at selected locations and directions. Selection of the location and direction of the sensor is a critical factor in vibration monitoring. Vibration characteristics of a machine are directly related to its physical condition. Changes in the condition of machinery can be effectively detected by vibration monitoring. Vibration monitoring may be viewed to serve the following purposes:

i. Monitor the condition of the machinery and detect changes in its operational characteristics.

ii. Correlate these changes to anticipate possible failures.

iii. Suggest remedial action.

The output of vibration measurements is what is generally known as, and is most important, the vibration signal or vibration signature for the purpose of vibration monitoring, the information contained in the measured signal needs to be reduced to single values which represents the overall value of the signal. For diagnostic purposes, it is necessary to view the vibration signal in its entirety and complexity in order to locate the possible source of fault. The absolute level of vibration indicates the health of the machine. A trend analysis helps to predict the occurrence of failure.

Vibration Monitoring Methodology (VMM) can be viewed as a sequential operation as shown in **Figure 1.2.**

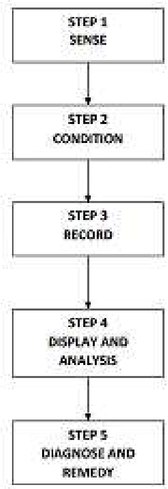


Figure 1.2 Steps in Vibration Monitoring Method

1.4.1 STEP 1 – SENSE:

The first step in VMM is to sense or acquire the vibration experienced by the structure this is done by using a transducer, a device that converts the vibration motion into an optical, mechanical, or most commonly electrical signal that proportional to the experienced motion. There are a number of transducers available which measure each of the vibration parameters, viz. acceleration, velocity, displacement. The transducers which are commonly used are for measuring:

i) Displacement : Linear Variable Differential Transducer (LVDT)

Eddy Current Proximity Probes

ii) Velocity : Moving coil velocity transducers, Laser velocity transducer

iii) Acceleration: Accelerometers, generally of the piezoelectric type

Generally, to investigators, the destructive force of vibration is of most interest. Force is proportional to acceleration, and hence measurement of acceleration is increasingly popular and most used. Displacement is a good indicator of machinery condition at low frequencies, whereas at high frequencies, acceleration measurement gives better results. Velocity is measurable at almost all frequencies of interest. Accelerometer is nearly always the best transducer to use for the following reasons:

i. It is self generating, no moving parts to wear, robust and compact

ii. It has a large dynamic range and wide frequency range

iii. It is relatively cheap

iv. It is very reliable with long term stability

v. It is easy to calibrate and use

vi. It can be used in any orientation to measure acceleration along its axis

vii. It is relatively insensitive to the normal environmental changes

- **Mounting methods and Selection of mounting points:**

There are various types of mounting methods based upon the application. The selection of the mounting method depends upon the application and the

i. Steel stud

ii. Mica washer isolated stud

iii. Thin layer wax

iv. Cementing stud

v. Magnet

vi. Probes

- **Mounting point selection:**

The position and the orientation of the mounting of the accelerometer play a crucial role in obtaining accurate results from the condition monitoring. Table 1 below shows typical locations for some machines. These locations are ideal, but can be changed with the possibility and accessibility of those locations for mounting. This is only for guidance in selecting monitoring points .It is needless to mention that depending on operating parameters and other factors, locations would have to be chosen for each case carefully according to application.

Machine	Location
1) Steam turbine/ large pump/ compressor with fluid film bearings.	Radial, horizontal and vertical at each bearing Axial at each end of machine.
2) Gas turbine or medium size pump.	Radial, horizontal and vertical at each Bearing.
3) Motor/fan both with fluid-film bearings.	Radial at each bearing. One axial to detect thrust wear.
4) Motor/pump or compressor with rolling element bearings.	Radial at each bearing. One axial, usually on motor to detect thrust wear.
5) Gear box with rolling element bearings.	Transducers as close to each bearing as Possible.
6) Gear box shafts with fluid film bearings.	Radial horizontal and vertical at each bearing. Axial to detect thrust wear.

Table 1.1: Typical mounting locations for particular machines

1.4.2 STEP 2- CONDITION:

The vibration data acquired or sensed, in its raw form, is often complex and random, and contains in addition to that required for knowing of machinery condition, data which is not useful. The output from the transducer, i.e, the signal may be at a low level or at high impedance. it may also contain noise .This signal needs to be conditioned before recording. This is achieved by filtering the signal. In filtering, certain components of the signal are either eliminated or attenuated. Various filters are commercially available, which serves this purpose.

A Preamplifier is generally used to condition the signal, which incorporates both the filter and integration circuits. Vibration preamplifier performs the task of converting the high impedance output of piezoelectric accelerometer into a low impedance signal suitable for transmission to measuring and analysis instrumentation. These devices have integration networks built into them in addition to the filtering devices, to obtain velocity and displacement information from an accelerometer, or displacement information from a velocity meter. Transducers usually provide low level signals, and amplifiers help in providing a high signal-to-noise ratio.

1.4.3 STEP 3- RECORD:

Magnetic tape recorders and electronic data collectors are the most commonly used devices for recording vibration data .portable, hand held ,and pocket fit analyzers are currently available which provide ready-made information on the condition of the machine, but, the conventional method of recording is advantageous as it allows for simultaneous recording of data in multiple channels facilitating diagnosis. Experience has indicated that prediction of failure based on the overall level of vibration is not sufficiently accurate, as the amplitude of vibration of certain critical components could increase to an alarming level without making any appreciable change in overall level information on the individual discrete frequency components result in better interpretation and intelligent monitoring of machinery .

There are two types of magnetic tape recorders, depending upon the mode of recording –Direct mode (AM) or Frequency Modulated (FM).In the direct mode the tape is magnetized in proportion to the signal level. When the tape is played back, changes in magnetization induces a voltage in the tape head .The playback depends on the rate of change of magnetic flux required to induce voltage in the tape head. But this does not work well at lower frequencies and hence there is a lower frequency limit of about 100 Hz. However, higher frequencies of the order of 50 - 60 KHz can be recorded by this method and is particularly useful in under water acoustic measurements.

Electronic data collectors are more useful as indispensable parts of any company's predictive maintenance program .For the purpose of vibration monitoring, the amount of information contained in the measured signals needs to be reduced to a single value which represents the overall value of the signal. Electronic data collectors allow measurement of vibration at different portions on periodic basis. The data is stored digitally within the data collector and can be viewed by the user as an overall value of the measured signal.

The digitized data is fed to a host computer which analyses the machine condition .Digital data storage, a unique feature of data collectors; make them advantageous over magnetic recorders, albeit with some inherent drawbacks.

1.4.4 STEP 4- DISPLAY AND ANALYSIS:

Relevant information from the vibration signature recorded needs to be extracted to serve the ultimate purposes of monitoring, viz. condition assessment, and fault diagnosis. This is possible through the use of display and analysis instrumentation. The measured variable needs to be viewed in some form. Viewing the signal is possible by measuring an overall value of the signal in a vibration meter, or view the signal in the time domain as with the oscilloscope, or view the signal in the frequency domain using spectrum analyzer.

- **Common Machine Faults using Vibration Measurements**

Each machine defect produces a unique set of vibration components that can be used for identification. Some common machinery faults which occur in rotating machinery are

i) Imbalance and Misalignment,

ii) Mechanical Looseness, Eccentric rotor, Bent shaft, and Rotor rubs

iii) Resonance

iv) Rolling element bearing defects and Gearing defects

1.5 SCHEDULE

- Visited various test facilities of the laboratory such as High Speed Towing Tank, Cavitation Tunnel, Acoustic Test Centre, Vibration Test Facility, Shock Test Facility, CNC Centre.

- Carried out literature review of machinery maintenance strategies and its relevance in the industries of the contemporary world.
- Literature review of Condition Monitoring strategies, Condition based maintenance using vibration measurements and analysis.
- Study about the various instrumentation used in the condition monitoring based on vibration that is to learn about the sensors, analyzers and software used for analysis of vibration data.
- Carried out vibration measurements of an induction motor and identified discrete frequencies using condition monitoring based on vibration analysis.
- Conducted an experiment to understand machinery fault diagnosis using vibration measurements. An industrial fan with and without imbalance is considered for study vibration response using practical vibration measurement and analysis.

1.6 EXPECTED OUTCOMES OF THE STUDY

i. To gain brief knowledge on machinery maintenance strategies, condition based maintenance techniques and in particular condition monitoring based on vibration.

ii. Hands-on experience of various vibration measuring equipment like sensors, analyzers, and software and procedure required to perform the condition monitoring based on vibration.

iii. Carrying out practical field vibration measurements using vibration condition monitoring methodology.

1.7 TYPES OF MAINTENANCE

PREVENTIVE MAINTENANCE VS CORRECTIVE MAINTENANCE:

- When we do preventive maintenance we are doing a task before a failure has occurred. That task can be aimed at preventing a failure, minimising the consequence of the failure or assessing the risk of the failure occurring.

- When we are conducting corrective maintenance the failure has now occurred and we are basically reinstating equipment functionality. To be clear, corrective maintenance can be the result of deliberate run-to-failure strategy.

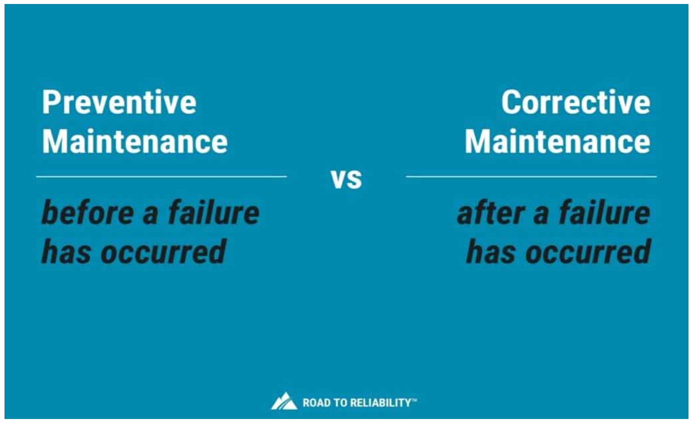


Figure 1.3 Preventive maintenance vs corrective maintenance

1.7.1 PREVENTIVE MAINTENANCE

Preventive maintenance can be defined as "an equipment maintenance strategy based on replacing, or restoring, an asset at a fixed interval regardless of its condition. Scheduled restoration tasks and replacement tasks are examples of preventive maintenance tasks."

Preventive maintenance (or preventative maintenance) is basically a type of maintenance that is done at a regular interval while the equipment is still functioning with the objective of preventing failure or reducing the likelihood of failure.

Apart from the regular interval approach there are also other types of preventive maintenance:

- Time Based Maintenance (TBM)
- Failure Finding Maintenance (FFM)
- Risk Based Maintenance (RBM)
- Condition Based Maintenance (CBM)
- Predictive Maintenance (PDM)

TIME BASED MAINTENANCE (TBM):

Time Based Maintenance refers to replacing or renewing an item to restore its reliability at a fixed time, interval or usage regardless of its condition. This is what is called as Scheduled Restoration or Scheduled Discard tasks.

I limit the use of that phrase as for some reason people then jump to the conclusion that other maintenance is not scheduled. When in fact of course all maintenance should be scheduled through our Weekly Schedule. The only exception would be Emergency Maintenance, which due to its very nature of requiring immediate attention cannot be scheduled.

FAILURE FINDING MAINTENANCE (FFM)

Failure Finding Maintenance tasks are aimed at detecting hidden failures typically associated with protective functions. Think pressure safety valves, trip transmitters and the like.

This type of equipment won't be required to function until something else has failed. That means that under normal operating conditions you will not know whether this equipment is still functional i.e. the failure modes are hidden.

RISK BASED MAINTENANCE (RBM)

Risk Based Maintenance (RBM) is when you use a risk assessment methodology to assign your scarce maintenance resources to those assets that carry the most risk in case of a failure (remembering that risk = likelihood x consequence).

As a result, equipment that has a higher risk and a very high consequence of failure would be subject to more frequent maintenance and inspection. Low risk equipment may be maintained at a much lower frequency and possibly with a much smaller scope of work.

Risk Based Maintenance is essentially preventive maintenance where the frequency and scope of the maintenance activities is continuously optimised based on the findings from testing or inspection and a thorough risk assessment.

CONDITION BASED MAINTENANCE (CBM)

Most failure modes are not age related. However, most failure modes do give some sort of warning that they are in the process of occurring or are about to occur.

If evidence can be found that something is in the early stages of failure, it may be possible to take action to prevent it from failing completely and/or to avoid the consequences of failure. Condition Based Maintenance as a strategy therefore looks for physical evidence that a failure is occurring or is about to occur.

An important concept within Condition Based Maintenance is the P-F curve shown in the figure below:

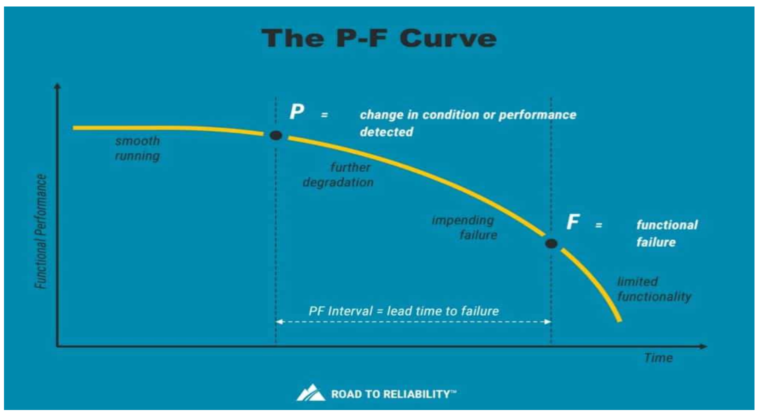


Figure 1.4 P-F Curve

The curve shows that as a failure starts manifesting, the equipment deteriorates to the point at which it can possibly be detected (point "P").

If the failure is not detected and mitigated, it continues until a functional failure occurs (point "F"). The time range between P and F, commonly called the P-F interval, is the window of opportunity during which an inspection can possibly detect the imminent failure and give you time to address it.

It is important to realise that CBM as a maintenance strategy does not reduce the likelihood of a failure occurring through life-renewal, but instead is aimed at intervening before the failure occurs, on the premise that this is more economical and should have less of an impact on availability.

How much more effective CBM is above breakdown maintenance depends on how long the P-F interval is. With plenty of warning the rectification can be planned, materials and resources can be mobilised and breakdown prevented. When the P-F interval is only a few days the resulting organisational and workplace actions are much like a breakdown and the value of CBM is largely lost.

PREDICTIVE MAINTENANCE (PDM)

Up until recently when people spoke about Predictive Maintenance (PDM) this was essentially as a synonym for Condition Based Maintenance. But in my view with the advent of Artificial Intelligence, much lower costs of equipment sensors (IIoT) and machine learning there is clearly a difference appearing between Predictive Maintenance (PDM) and Condition Based Maintenance (CBM), at least in my view.

1.7.2 CORRECTIVE MAINTENANCE (CM)

A Run to Failure or Corrective Maintenance strategy only restores the function of an item after it has been allowed to fail. It is based on the assumption that the failure is acceptable (i.e. no significant impact on safety or the environment) and preventing failure is either not economical or not possible.

Apart from being the outcome of a deliberate Run to Failure strategy Corrective Maintenance is also the result of unplanned failures which were not avoided through preventive maintenance.

DEFERRED CORRECTIVE MAINTENANCE

In the chart of maintenance types I broke ‘corrective maintenance’ into two sub-types:

- Deferred corrective maintenance
- Emergency maintenance

And that was very deliberate because it is so essential that we absolutely minimize the amount of Emergency Maintenance we allow into our organisations. As I already pointed out above Emergency Maintenance is expensive, various sources have suggested that Emergency Maintenance is 3 to 5 times as expensive as ‘normal’ preventive maintenance. Emergency Maintenance typically leads to longer equipment outages and more production impact. And it is less safe. So when a corrective maintenance work request is raised it is essential that you prioritise it properly to make sure that where possible you defer the work request and give your team the time to properly plan and schedule the work.

EMERGENCY MAINTENANCE (EM)

Emergency Maintenance is corrective maintenance that is so urgent that it breaks into your Frozen Weekly Schedule. It upsets your plans and schedules and typically throws everything into disarray. Some people thrive in this type of environment and often get heralded as heroes when they've worked 16 hrs non-stop to get production back online. But when it comes to the Road to Reliability, it is a dead end.

TYPES OF MAINTENANCE: A COMPARISON CHART

Comparison of Maintenance Types

Maintenance Type	Preventive Maintenance					Corrective Maintenance	
	Time Based Maintenance	Failure Finding Maintenance	Condition Based Maintenance	Predictive Maintenance	Risk Based Maintenance	Deferred Maintenance	Emergency Maintenance
Task Type	Scheduled Overhaul / Replacement	Functional Test	Measurement of condition	Calculation and extrapolation of	Inspection or Test	Repair / Replace	Repair / Replace
Objective	Restore or replace regardless of condition	Determine if hidden failure has occurred	Restore or replace based on a measured condition compared to a defined standard		Determine condition and conduct risk assessment to determine when next inspection, test or intervention is required.	Restore or replace following failure. Result of a Run to Failure Strategy or an unplanned failure.	Restore or replace following unplanned failure.
Interval	Fixed time or usage interval e.g. 1 month, 1,000hrs or 10,000 km	Fixed time interval (can be set based on risk assessment e.g. SIL)	Fixed time interval for condition measurements / inspections		Time based interval between tasks and scope of task is based on risk assessment	Not applicable, but intervention is deferred to allow for proper planning & scheduling.	Immediate intervention required.

ROAD TO RELIABILITY™

Figure 1.5 Comparisons of Maintenance Types

BREAKDOWN MAINTENANCE

And frequently asked question is 'what is breakdown maintenance' and as it's not in my explanation I thought I'd just covered it here briefly. As far as I am concerned, breakdown maintenance is simply corrective maintenance and not another type of maintenance in itself. In the case of breakdown maintenance you've had a failure and so now it needs to be fixed. And depending on the risk associated with that breakdown it could be urgent or less urgent.

AUTONOMOUS MAINTENANCE

The above table of types of maintenance does not include Autonomous Maintenance or Autonomous Care (also referred to as Front Line Maintenance in other organisations). The CLAIR (Clean, Lubricate, Adjust, Inspect and Repair) activities conducted under Autonomous Care are essentially a combination of the above strategies, but conducted on a higher frequency by frontline staff.

1.8 Types of Condition Monitoring

There are different types of monitoring the condition of a machine and calculating its life time:

i. Vibration Analysis

ii. Infrared Thermography

iii. Wear particle analysis

iv. Oil Analysis

v. Motor current analysis

vi. Acoustic emission

- **Vibration Analysis**

Vibration analysis of industrial machinery has been around for many decades, but gained prominence with the introduction and widespread use of the personal computer. Vibration Analysis refers to the process of measuring the vibration levels and frequencies of industrial machinery, and using that information to determine the "health" of the machine, and its components.

When an industrial machine (such as a fan or pump) is operated, it generates vibration. This vibration can be measured, using a device called an accelerometer. An accelerometer generates a voltage signal, proportional to the amount of vibration, as well as the frequency of vibration, or how many times per second or minutes the vibration takes place. This voltage signal from the accelerometer is fed into a data collector, which records this signal as either a time waveform (amplitude vs. time), as a Fast Fourier Transform (amplitude vs. frequency), or as both. This signal can then be analyzed by a trained vibration analyst, or by the use of a "smart" computer program algorithm. The analyzed data is then used to determine the "health" of the machine, and identify any impending problems in the machine, such as misalignment, unbalance, a bearing or lubrication problem, looseness, and more.

- **Infrared Thermography**

  Infrared thermography is equipment or method, which detects infrared energy emitted from object, converts it to temperature, and displays image of temperature distribution. To be accurate, the equipment and the method should be called differently, the equipment to be called as infrared thermograph and the method to be called as infrared thermography. Recently, however, more and more public literatures show tendency not to pay attention to such appellative. We call our equipment as infrared thermography considering such generalization of the terminology.

It captures as a temperature distribution on a surface, and it can display as visible information. Temperature can be measured from a distance without contacting an object. Temperature can also be measured in real time.

- **Wear Particle Analysis**

Wear particle analysis is a powerful technique for non-intrusive examination of oil-wetted parts of a machine. The particles contained in the lubricant carry detailed and important information about the condition of the machine.

This information may be deduced from particle shape, composition, size distribution, and concentration. The particle characteristics are sufficiently specific so that the operating wear modes within the machine may be determined, allowing prediction of the imminent behavior of the machine.

Ferrographic analysis prevents catastrophic equipment failure through timely and accurate prediction of abnormal or critical machine wear.

- **Oil Analysis**

Oil analysis is a routine activity for analyzing oil health, oil contamination and machine wear. The purpose of an oil analysis program is to verify that a lubricated machine is operating according to expectations. When an abnormal condition or parameter is identified through oil analysis, immediate actions can be taken to correct the root cause or to mitigate a developing failure.

An obvious reason to perform oil analysis is to understand the condition of the oil, but it is also intended to help bring to light the condition of the machine from which the oil sample was taken. There are three main categories of oil analysis: fluid properties, contamination and wear debris.

- **Motor Current Analysis**

Motor current analysis has proven to be a highly valuable predictive maintenance tool. Although it is a relatively young, rarely utilized technology, it is rapidly gaining acceptance in industry today. Mechanical faults related to belts, couplers, alignment and more are easily found through the use of a demodulated current spectrum.

MCA is simply the process by which motor current readings are recorded and analyzed in the frequency domain. It has been around since 1985 and proven itself well over the years in locating rotor faults and air gap problems in motors.

The motor current signature is recorded in a time domain format. The current is represented in a graph form with the amplitude shown on the “Y” axis and the time on the “X” axis. The result is a typical current sinewave shown in Figure 1.

In order to analyze the data, a Fast Fourier Transform (FFT) is performed. An FFT is a mathematical operation designed to extract the frequency information from the time domain and transform it into the frequency domain. An example of an FFT spectrum is shown in Figure 2.

While the FFT spectrum is a great source for identification of rotor bar problems in motors, it proved difficult to analyze most other frequencies. In order to address this problem, the demodulated current spectrum was developed.

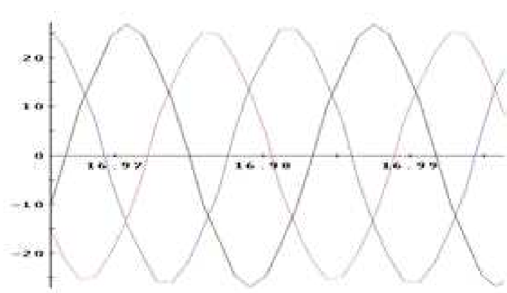


Figure 1.6 Time Domain Format

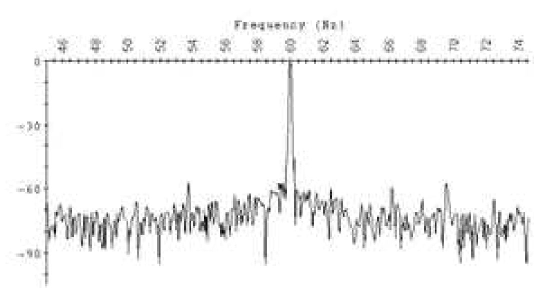


Figure 1.7 FFT Format

- **Acoustic Emission**

Acoustic emission (AE) is the phenomenon of radiation of acoustic (elastic) waves in solids that occurs when a material undergoes irreversible changes in its internal structure, for example as a result of crack formation or plastic deformation due to aging, temperature gradients or external mechanical forces. In particular, AE is occurring during the processes of mechanical loading of materials and structures accompanied by structural changes that generate local sources of elastic waves. This results in small surface displacements of a material produced by elastic or stress waves generated when the accumulated elastic energy in a material or on its surface is released rapidly. The waves generated by sources of AE are of practical interest in structural health monitoring (SHM), quality control, system feedback, process monitoring and other fields. In SHM applications, AE is typically used to detect, locate and characterise damage.

Out of all the above, vibration based monitoring is the most reliable, effective and most used one in the industry because of its advantages over the others. Using electronic instruments to measure vibration we can see if those levels have increase and detect if there is any problem. Through the vibration pattern we can find out following machinery faults:

- If the machine is out of balance
- If the machine is out of alignment
- Problems with rolling elements (bearings)
- Gearing problems
- Belt and coupling problems
- Broken rotor bars
- Soft foot
- Electrical Faults

1.9 POTENTIAL BENEFITS OF CONDITION MONITORING:

Adoption of a formal condition based maintenance program should yield a number of potential benefits. The following list of benefits is derived from an extensive survey carried out in 1988.

In 1988 a survey of over 500 plants was conducted by technology for Energy Corporation to identify the impact of condition based maintenance on the economic operation process and manufacturing industry. The survey included plants from power generation, pulp and paper, metals, food processing, textiles in America, Canada, Europe and Australia. All participants had been operating the program for three or more years.

Among other significant findings, the following facts emerged:

- 50-80% reduction in repair costs
- 30% increase in revenue
- 50-80% reduction in maintenance costs
- Spare inventories reduced by more than 30%
- Overall profitability of plants increased by 20-60%

1.10 VIBRATION MONITORING AS A TOOL FOR PREDICTIVE MAINTENANCE:

Vibration analysis is non-destructive technique, which help in early detection of machine faults by measuring and evaluating the machine data. Any small change in the machine behaviour shall change the vibration pattern in the machine. Hence vibration monitoring and analysis provides reliable information on operating condition of the machine.

Various instruments have been developed over the years to measure the actual level or amount of vibration. Modern instrumentation for measuring vibration on rotating and reciprocating machinery not only minimizes the need for extensive human experience but makes it possible to detect developing problems, which are outside the range of human sense of touch and hearing. Instrumentation that actually measures a machines vibration level and assign numerical value to the vibration, not only overcomes the limitation of inexperience but the limitation of human perception as well.

CHAPTER - II

LITERATURE REVIEW

Condition monitoring is an advanced and very useful tool of predictive maintenance techniques. It has made good progress in recent years in identifying many types of deterioration in industrial machinery, so that pro-active maintenance can be performed, improving overall industry productivity. There is a very wide range of condition monitoring techniques currently in use for the diagnosis and prediction of machinery faults, but little attention has paid to the occurrence and detection of vibration analysis of rotating equipments.

S. V. Shelke et al [1], this paper discusses about Condition based maintenance which is preferred in industries now a days. Monitoring of these parameters gives idea about abnormalities in the machine, resulted due to faults like wear, crack, corrosion, fatigue etc. Among the various techniques used for this purpose, vibration analysis technique is very popular now days. In the present work vibration analysis of ball bearing is done by using FFT analyzer. The data taken up in frequency domain and time domain for healthy and defective bearing operating under certain load. In order to check the validity of the experimental results with the theoretical, feature extraction is done.

Kiran Kumar M V et al [2], this paper gives a relative of various techniques used for finding the fault in the bearings based on vibration analysis method. A Bearing is one of the important components in the Rotary machines and has been widely used in various industries in many of the applications such as shaft mountings, to reduce friction as well as facilitate relative motion between the two components etc. It is therefore very essential to determine the early faults conditions from bearings. There are various methods to detect faults in the bearings, such as vibration monitoring, wear debris monitoring, temperature monitoring, soap techniques, non destructive test etc. Vibration analysis has been used as a predictive maintenance procedure in the machine maintenance. By detecting and analyzing the machine vibration, it is possible to determine and predict the machine failure. Early fault detection of the bearings is possible by analyzing the vibration signal using different techniques.

Chenxing Sheng et al [3], this paper highlights the mechanical equipments that are widely used in various industrial applications. Generally working in severe conditions, mechanical equipments are subjected to progressive deterioration of their state. The mechanical failures account for more than 60% of breakdowns of the system. Therefore, the identification of impending mechanical fault is crucial to prevent the system from malfunction. This paper discusses the most recent progress in the mechanical condition monitoring and fault diagnosis. Excellent work is introduced from the aspects of the fault mechanism research, signal processing and feature extraction, fault reasoning research and equipment development. An overview of some of the existing methods for signal processing and feature extraction is presented. The advantages and disadvantages of these techniques are discussed. The review result suggests that the intelligent information fusion based mechanical fault diagnosis expert system with self-learning and self-updating abilities is the future research trend for the condition monitoring fault diagnosis of mechanical equipments.

Manish Vishwakarma et al [4], this paper aims at the protection, consistency and effectiveness of rotating machinery in industries. Condition monitoring of a machines helps to retain the effectiveness and performance of a machine to its optimal level. The condition monitoring of a rotating machine is efficient, but often it is difficult and labour intensive task for maintenance crew to troubleshoot the machine. Vibration analysis is a method used for condition monitoring of the machine. Effective vibration signal extracting techniques have a critical part in diagnosing a rotating machine. Many vibration signal extracting techniques have been proposed during past some years. The paper presents review of some vibration feature extraction methods applied to different types of rotating machines.

C. Wang et al [5], this paper discusses the vibration behaviour of a 2.2 kW induction motor structure is investigated using both experimental modal testing and finite-element modal analysis techniques. Five different experimental conditions are used to assess the influence of various structural parts such as the rotor, endshields and isolators on the vibration behaviour of the motor structure. Based on the experimental results obtained, the motor structure is modelled using the finite-element method. By comparing the calculated natural frequencies and mode shapes with the corresponding experimental results, appropriate models for each part of the motor structure are developed. The effects of the stator, casing, support and endshields on the vibration behaviour are discussed.

Ilahn Asilturk et al [6], this paper attempts to summarize the results of an evaluation of vibration analysis techniques as a method for diagnosis of gear faults. Temperature, vibration, noise, current, voltage, acoustic emission, etc., all of the measurements are used for machine condition monitoring. Measuring vibration signals is one of the non-destructive testing (NDT) methods that are widely used to detect machine faults. There are many studies to predict mechanical wear, fault and failure in this area for several decades. Signal processing techniques are used to obtain vital characteristic information from the vibration signals. The most effective vibration techniques are discussed and experimentally compared, concerning an industrial gearbox. Their advantages and disadvantages have been shown.

A. Moosavian et al [7], this paper proposes the data mining method based on feature extraction and selection. Vibration technique in a machine condition monitoring provides useful reliable information, bringing significant cost benefits to industry. By comparing the signals of a machine running in normal and faulty conditions, detection of faults like journal-bearing defects is possible. This paper presents an appropriate procedure for the fault detection of main engine journal bearing based on vibration analysis. The frequency-domain vibration signals of an internal combustion engine (IC engine) with normal and defective main journal-bearings were obtained.

K. F. Martin et al [8], this paper describes the activity around the world in the way of research, development and application of techniques for condition monitoring and fault diagnosis of machine tools. The paper initially discusses the necessity for planned maintenance, the extension of this into condition based maintenance and the necessity for condition monitoring. It then discusses some definitions relating to this field of activity and in particular differentiates between hard and soft faults and the reason the latter can be used for prediction, whereas the former is easier to diagnose. The paper endeavours intentionally to restrict itself to the condition monitoring and fault diagnostics of the machine tool itself. Thus there is no real discussion of research into tool or process monitoring--although many areas of this type of work cut across that of the machine itself. For this reason there are notes on area of tool condition monitoring where these have techniques and expertise which lend themselves to the machine itself. There is a discussion on on-line and off-line monitoring followed by a brief survey of the automatic monitoring presently available on machine tools. Much of this is related to hard fault diagnostics but there are signs that soft faults are now being monitored.

C. Evans [9], briefly reviews the philosophy of wear debris based condition monitoring and the methods available. Greater emphasis is given to a recently developed technique, ferrography, which separates wear debris and contaminant particles from a lubricant and arranges them according to size on a transparent substrate for examination. Wear debris is characteristic of the conditions under which it was formed: isolation and study of these wear particles can yield significant information about the state of the surfaces from which they were produced. The original aim of capturing wear particles in lubricated systems was to limit the secondary damage that they might cause. The realisation that the shape, size, and quantity of particles gave some indication of the mechanical health of the machine, and then viewed by an experienced operator was the birth of this type of incipient failure detection.

Nitin Ambhore et al [10], focuses at the increasing demands of process automation for un-manned manufacturing in the field of on-line monitoring of machining processes. In view of this, extensive research work is taking place world-wide in the area of on-line tool condition monitoring system (TCMS). Tool wear is the most undesirable characteristic of machining processes as it adversely affects the tool life, which is of foremost importance in metal cutting owing to its direct impact on the surface quality of the machined surface, and its dimensional accuracy, and consequently, the economics of machining operations. Therefore, methods for cutting tool wear sensing are crucial in view of the optimum use of cutting tools. With an effective monitoring system, the damages to the machine tool, downtime and scrapped components can be avoided.

CHAPTER - III

THEORY OF VIBRATIONS

3.1 VIBRATIONS

3.1.1 Definition

A periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed (as when a stretched cord produces musical tones or molecules in the air transmit sounds to the ear) is called vibration.

3.1.2 Main Causes

The main causes of setting up vibratory motion in a body are

(I) Unbalanced centrifugal forces.

(II) Elastic nature of system.

(III) External excitations.

(IV) Winds.

(V) Dry friction between mating surfaces.

3.1.3 Advantages

Advantages of vibration are

- Vibrations are employed to simulate earthquakes for geological investigations.
- Vibration may be used for drilling of geotechnical wells.
- Vibrations are also employed in agriculture for harvesting by forced vibrations of fruit bearing trees.

3.1.4 Disadvantages

Disadvantages of vibration are

- Unwanted vibrations produce unpleasant stresses in machine parts.
- Many structures, buildings and bridges fall because of vibration.

- The vibration causes rapid wear of machine parts such as bearings and gears.
- Excessive vibration is also dangerous for human beings.

3.2 ELEMENTARY PARTS OF VIBRATING SYSTEM

The elementary parts of Vibrating system are:

(1)Mass

(2) Spring

(3) Damper

Description of parts

- The mass element is considered as a rigid body which executes vibration and can gain or lose kinetic energy which is proportional to change in velocity of body.
- The spring element has elasticity and assumed to be of negligible mass.
- The damping element neither has mass nor elasticity.

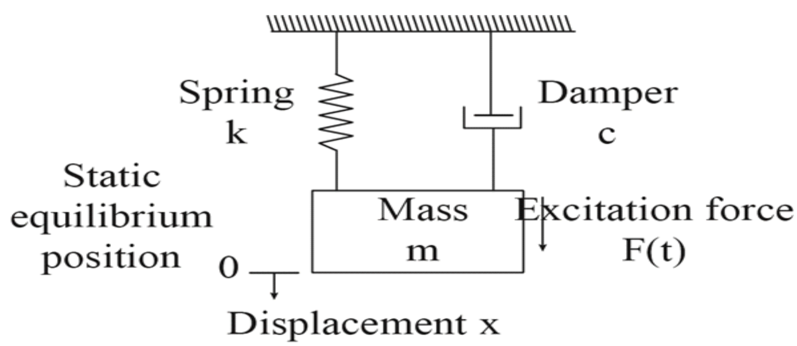


Figure 1.8 Vibrating System Elements

Equation:

The stiffness, of the spring is defined by the relation

K=F/X

Where,

F is the force applied on the body

X is the displacement produced by the force

3.3 CLASSIFICATION OF VIBRATIONS

Vibration can be classified in several ways. Some of the important classifications are

- Free and Forced Vibration
- Damped and Undamped Vibration
- Linear and Non-linear Vibration
- Deterministic and Random Vibration

3.3.1 Free and Forced Vibration

Free Vibration

If a system is initialised with interference, so it vibrates by itself, then the vibration is called free vibration. No external force works on the system. The motion of back and forth of a pendulum is an example of free vibration.

Forced Vibration

If a system is subjected to an external force (more precisely the repetitive force), then the vibrations that arise on the system are known as forced vibrations. The vibrations that arise on a working diesel engine is one example of forced vibration. If the frequency of an external force is exactly same as the vibration frequency of the system, a condition known as resonance occurs. Resonance is very dangerous. Damage from the structures of buildings, bridges, turbines, and airplane wings is often associated with the resonance of the vibrations.

3.3.2 Undamped and Damped Vibration

If there is no energy lost or dissipated due to friction or other resistance during vibration, then the vibration is known as Undamped Vibration. Whereas, if a vibration experiences a gradual reduction of energy, it is called Damped Vibration. In various systems, the value of the damping is so small that it is often disregarded for most engineering purposes. But also vice versa, there are other systems that put damping system into important components, shock absorber in vehicles for example. Consideration of damping becomes extremely important in analyzing vibratory systems near resonance.

3.3.3 Linear and Nonlinear Vibration

If all the basic components of a vibration system the spring, mass, and damper behave linearly, the resulting vibration is known as Linear Vibration. However, if one or more of these basic components behaves nonlinearly, then the vibration is called Nonlinear Vibration. Differential equations are made to describe the behavior of linear and nonlinear vibration systems. If the vibrations are linear, the superposition principle applies, and the mathematical analysis technique is well developed. For nonlinear vibrations, the superposition principle becomes invalid, and the analytics technique becomes more difficult. Since all vibration systems tend to behave nonlinearly as oscillation amplitude increases, knowledge of nonlinear vibrations is more developed in handling practical vibration systems.

3.3.4 Deterministic and Random Vibration

If the value or magnitude of the excitation (force or movement) acting on the vibration system is known at any given time, the excitation is called deterministic, and the resulting vibration is known as Deterministic Vibration. In some cases, excitation is nondeterministic or random; excitation values at certain times cannot be predicted. In this case, extensive excitation data may indicate some statistical regularity. Under these conditions it is possible to estimate averages such as the mean and mean square values of excitation. Examples of random excitation are wind speed, roughness of the road, and ground movement during an earthquake. If the excitation is random, the resulting vibration is called Random Vibration. In this case the vibration response of the system is also random; and that condition can only be explained through statistical calculations.

3.4. CHARACTERISTICS OF VIBRATION

3.4.1 Frequency

A vibrating object moves back and forth from its normal stationary position. A complete cycle of vibration occurs when the object moves from one extreme position to the other extreme, and back again. The number of cycles that a vibrating object completes in one second is called frequency. The unit of frequency is hertz (Hz). One hertz equals one cycle per second.

3.4.2 Displacement

The total distance travelled by the vibrating part, from one extreme limit of travel to the other extreme limit of travelled is referred to as the peak-to-peak displacement. Peak- to-peak vibration is usually expressed in mills, where

One mill=1000th of an inch (0.001 inch)

3.4.3 Velocity

Since the vibrating weight is moving, it must be moving at some speed. However the speed of the weight is constantly changing. At the top limit of motion the speed is zero since the weight must come to stop before it can go in the opposite direction. The speed of velocity is greatest as the weight passes through the natural position. Vibration velocity is expressed in terms of inches-per-sec peak for english units.

3.4.4 Acceleration

The speed of a vibrating object varies from zero to a maximum during each cycle of vibration. It moves fastest as it passes through its natural stationary position to an extreme position. The vibrating object slows down as it approaches the extreme, where it stops and then moves in the opposite direction through the stationary position toward the other extreme. Speed of vibration is expressed in units of metres per second (m/s).Acceleration is a measure of how quickly speed changes with time. The measure of acceleration is expressed in units of (metres per second) per second or metres per second squared (m/s2). The magnitude of acceleration changes from zero to a maximum during each cycle of vibration. It increases as the vibrating object moves further from its normal stationary position.

3.4.5 Phase

Phase is defined as the position of vibrating part at the given instance ith reference to a fixed point or another vibrating part.

3.5 CAUSES OF VIBRATION IN MACHINES

Excessive vibrations on rotating equipment like pumps, gearboxes, turbines and compressors are a clear sign that the equipment is not functioning properly. Equipment that is showing excessive vibrations will most likely not achieve the expected lifespan, and can be the source of unscheduled downtime or dangerous situations. Therefore, it is important to find the root cause of vibrations by measuring and analysing the vibration signals. Common causes of vibrations are discussed below.

3.5.1 Alignment problems

When two or more rotating machines are connected, the correct alignment is crucial. Typical alignment errors are:

- **Parallel Misalignment**
  The shaft centre lines are parallel but are not in line. This can be both horizontal and vertical. Parallel misalignment is also known as offset misalignment.
- **Angular Misalignment**
  The shafts meet at a point, but are not parallel. This can be both on the horizontal and vertical axis. Angular misalignment is also known as gap misalignment.
- **Combined parallel-angular misalignment**
  A combination of both parallel and angular misalignment. Combined parallel-angular misalignment is the most common misalignment.

3.5.2 Unbalance

When the centre of gravity of a rotating object is not exactly in the centre line, it causes machine unbalance resulting in vibration. When a machine is unbalanced, it can cause damage to the machine itself, the foundation, pipes, etc. There are three types of unbalance: static unbalance, coupled unbalance and dynamic unbalance.

- **Static unbalance**

Static unbalance is when the centre of gravity axis (inertia axis) is not in line with the centre of rotation (shaft centre line), and the heavy spot and the centre of gravity are in the same plane. Static unbalance can be the result of a parallel displacement of the principal mass axis relative to the shaft centre line, and can be caused by non-symmetric mass distribution or deformation. In theory, static unbalance can be detected by placing the object with a point of rotation on each end. When there is static unbalance and friction is zero, gravity will turn the heavy side downwards.

- **Coupled unbalance**

Coupled unbalance appears when a rotating object has two or more unbalanced masses in different planes, that equal each other out in rest position. The principal mass axis is no longer in parallel to the centre of gravity, but crosses the centre of gravity axis. When the system starts to rotate, these masses will be influenced by centrifugal forces, resulting in vibration.

- **Dynamic unbalance**

Dynamic unbalance is the most common type of unbalance and is defined simply as unbalance where the central principal axis and the rotating centerline do not coincide or touch. This type of unbalance exists whenever static and couple unbalances are present, but where the static unbalance is not in direct line with either couple component. As a result, the central principal axis is both tilted and displaced from the rotating centerline.

3.5.3 Resonance

Every machine has one or more resonance frequencies (natural frequency). When a rotation frequency coincides with the resonance frequency of the machine, resonance occurs. Resonance can have major impact.

3.5.4 Loose parts

Loose bearings, loose bolts and corrosion can cause the machine to vibrate excessively. Due to the mechanical forces in the machine, loose parts can rapidly cause damage.

3.5.5 Bearing damage

In rotating machinery, we come across two main types of bearings: roller bearings and sleeve bearings. A roller bearing can be damaged in several ways, each with its own vibration fingerprint:

- Damage to the inner ring
- Damage to the outer ring
- Damage to the cage
- Damage to rolling elements (e.g. cylinders, cones and needles)

Each part of a roller bearing has its own frequency. By calculating these frequencies, it is possible to use vibration analysis to determine whether the vibrations are a result of bearing damage.

In contrast to roller bearings, sleeve bearings do not use a rolling element, but use a fluid (oil) film to reduce friction. Vibrations can be caused by inaccuracies in the fluid film; if a stable oil film cannot be formed, it can break, resulting in an oil whip or oil whirl. Additionally, this type of bearing is more sensitive to external influences on the position of the shaft, because its position in the bearing is not fixed.

3.5.6 Damaged or worn out gears

Gearbox vibrations are often caused by damaged or worn out gear teeth. When gear tooth engagement involves a damaged tooth, the force cannot be transferred as with the other gear tooth engagements. If a gear tooth is broken, less force can be transferred at this point of the cycle. Vibrations occur as a result.

CHAPTER - IV

VIBRATION MEASUREMENTS

4.1 VIBRATION MEASUREMENT

As per ISO 2372 standard, vibration in velocity - rms (mm/sec) are measured with charge coupled accelerometer in the frequency range of 10Hz to 5.0 kHz. Over all vibration values are displayed color code, Green, yellow m and Red in the order of severity to indicate the vibration severity as per equipment class the vibration spectrum is also collected and stored in route, which can be down loaded using Trend and Analysis software. The analyzer setup can be to collect data in route mode not only vibration signature, but also bearing data with assigned fault conditions. Data after measurement superimposes assigned faults with faults frequencies to help find out the abnormality. Residual bearing life can be calculated for bearings which are on regular trend. Most suitable for single speed, constant load applications.

Trend software allows setting up machines with different characteristics along with common faults in the database for easy data collection in route mode. Report generation is simple and customized. Cascade plots for vibration and trend plots for bearing condition can be obtained. Speed can be measured using both non-contact and contact probes.

4.2 SENSORS

A device that detects the changes in electrical or physical or other quantities and thereby produces an output as an acknowledgement of change in the quantity is called as a sensor. Generally, this sensor output will be in the form of electrical or optical signal.

4.2.1 Different types of sensors

The most frequently used different types of sensors are classified as:

- Accelerometer
- Speed sensors
- Temperature sensors

- IR sensors
- Ultrasonic sensors
- UV sensors
- Proximity sensors
- Pressure sensors
- Humidity sensors
- Gas sensors
- Touch sensors

4.2.1.1 Accelerometer

An accelerometer is a sensor that measures the physical acceleration experienced by an object due to inertial forces or due to mechanical excitation. Acceleration is defined as rate of change of velocity with respect to time. It is a measure of how fast speed changes. It is a vector quantity having both magnitude and direction. As a speedometer is a meter to measures speed, an accelerometer is a meter to measure acceleration.

Piezoelectric accelerometers

Piezoelectric accelerometers employ piezoelectric effect. When piezoelectric materials are stressed, they are deformed and an electric charge is generated on the piezoelectric materials.

In piezoelectric accelerometers, piezoelectric material is used as an active element. One side of the piezoelectric material is connected to rigid base. Seismic or proof mass is attached to the other side. When force (generated due to acceleration) is applied, piezoelectric material deforms to generate the charge. This charge is proportional to the applied force or in other words, proportional to acceleration (as mass is constant). The charge is converted to voltage using charge amplifiers and associated signal conditioning circuit.

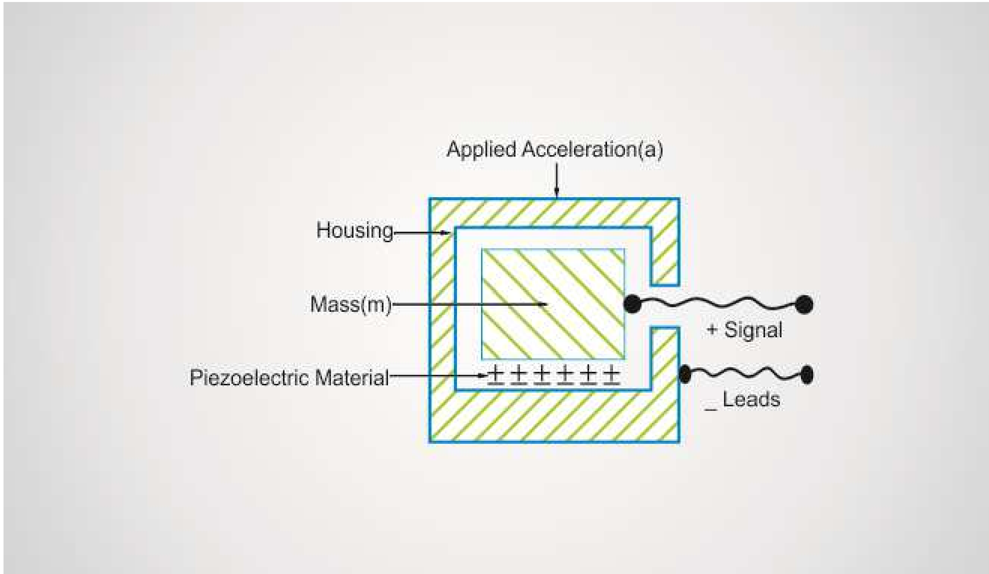


Figure 1.9 Schematic of a piezoelectric accelerometer

Compared to other type of accelerometers, piezoelectric accelerometers offer unique advantages –

- Wide dynamic range
- Excellent linearity
- Wide frequency range
- No wear and tear due to absence of moving parts
- No external power requirement

However, alternating acceleration only can be measured with piezoelectric accelerometers. These accelerometers are not capable of measuring DC response.

4.2.1.2 Speed Sensors

Sensors used for detecting speed of an object or vehicle are called as speed sensors. There are different types of sensors to detect the speed such as wheel speed sensors, speedometers, LIDAR, ground speed radar, pitometer logs, Doppler radar, air speed indicators, pitot tubes and so on.

Figure 2.0 Speed sensor

Application of Speed Sensors

PIC microcontroller based project for speed synchronization of multiple motors in industries using wireless technology is a typical application of the speed sensor

4.2.1.3 Temperature Sensors

A device which gives temperature measurement as an electrical signal is called as temperature sensor. This electrical signal will be in the form of electrical voltage and is proportional to the temperature measurement.

There are different types of sensors used for measuring temperature:

There are two basic types of temperature sensors:

- Contact Sensors – This type of sensor requires direct physical contact with the object or media that is being sensed. They supervise the temperature of solids, liquids and gases over a wide range of temperatures.
- Non contact Sensors – This type of sensor does not require any physical contact with the object or media that is being sensed. They supervise non-reflective solids and liquids but are not useful for gases due to natural transparency. These sensors use Plank's Law to measure temperature. This law deals with the heat radiated from the source of heat to measure the temperature.

Figure 2.1 Temperature sensor

4.2.1.4 IR Sensors

This device emits and/or detects infrared radiation to sense a particular phase in the environment. Generally, thermal radiation is emitted by all the objects in the infrared spectrum. The infrared sensor detects this type of radiation which is not visible to human eye.

Figure 2.2 IR sensor

Applications

- Thermography – According to the black body radiation law, it is possible to view the environment with or without visible illumination using thermography
- Heating – Infrared can be used to cook and heat food items. They can take away ice from the wings of an aircraft. They are popular in industrial field such as, print dying, forming plastics, and plastic welding.
- Spectroscopy – This technique is used to identify the molecules by analysing the constituent bonds. This technique uses light radiation to study organic compounds.
- Meteorology – Cloud heights; calculate land and surface temperature is possible when weather satellites are equipped with scanning radiometers.
- Photobiomodulation – This is used for chemotherapy in cancer patients. This is used to treat anti herpes virus.
- Climatology – Monitoring the energy exchange between the atmosphere and earth.
- Communications – Infra red laser provide light for optical fibre communication. These radiations are also used for short range communications among mobiles and computer peripherals.

4.2.1.5 Ultrasonic Sensors

The principle of ultrasonic sensor is similar to sonar or radar in which interpretation of echoes from radio or sound waves to evaluate the attributes of a target by generating the high-frequency-sound waves (around 40 kHz). The transducer used for converting energy into ultrasound or sound waves with ranges above human hearing range is called an ultrasonic transducer.

Figure 2.3 Ultrasonic sensor

Application of Ultrasonic Sensors

The distance measurement at inaccessible areas is a typical application of ultrasonic sensors.

4.2.1.6 UV sensors

These sensors measure the intensity or power of the incident ultraviolet radiation. This form of electromagnetic radiation has wavelengths longer than x-rays but is still shorter than visible radiation. An active material known as polycrystalline diamond is being used for reliable ultraviolet sensing. UV sensors can discover the exposure of environment to ultraviolet radiation.

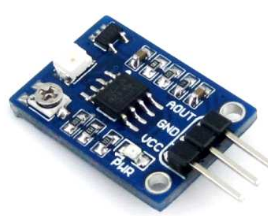


Figure 2.4 UV sensor

Applications

- Measures the portion of the UV spectrum which sunburns human skin
- Pharmacy
- Automobiles
- Robotics
- Printing industry for solvent handling and dyeing processes
- Chemical industry for the production, storage, and transportation of chemicals

4.2.1.7 Proximity Sensors

A proximity sensor detects the presence of objects that are nearly placed without any point of contact. Since there is no contact between the sensors and sensed object and lack of mechanical parts, these sensors have long functional life and high reliability. The different types of proximity sensors are Inductive Proximity sensors, Capacitive Proximity sensors, Ultrasonic proximity sensors, photoelectric sensors, Hall-effect sensors, etc.

Figure 2.5 Proximity sensor

4.2.1.8 Pressure Sensors

Pressure sensors are generally used to measure pressure of gas or liquids. Usually a pressure sensor acts as a transducer. It generates the pressure in analog electrical or digital signal.

Typical examples of pressure sensors are strain gauges, capacitive pressure sensors and piezoelectric pressure sensors.

Figure 2.6 Pressure sensor

Pressure Sensor Applications:

There are many applications for pressure sensor like pressure sensing, altitude sensing, flow sensing, line or depth sensing.

- It is used in real-time also, car alarms, and traffic cameras use pressure sensors to know whether someone is speeding.
- Pressure sensors are also used in touch screen displays to determine the point of application of pressure and give appropriate directions to the processor.
- They are also used in digital blood pressure monitors and ventilators.
- Industrial application of pressure sensors involves monitoring gases and their partial pressure.
- They are also used in aero planes to provide balance between the atmospheric pressure and the control system.
- They are also used to determine the depth of oceans in case of marine operations to determine suitable operating conditions for the electronic systems.

4.2.1.9 Humidity Sensors

A humidity sensor senses relative humidity. This implies that it measures both air temperature and moisture. Humidity sensing is essential in control systems in industries and well as in domestic. These are designed for high volume, cost sensitive applications for example office automation, automotive air control, home appliances, and industrial process control systems and also in applications where humidity compensation is required. Humidity sensors are generally of the capacitive or resistive type.

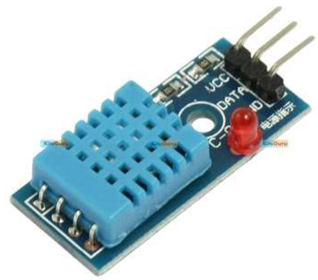


Figure 2.7 Humidity sensor

Application of Humidity sensors

Humidity sensors have wide range of applications such as industrial and domestic applications, medical applications and are employed to provide an indication of the moisture levels in the environment.

4.2.1.10 Gas Sensors

Gas sensors are a basic component in many security systems and modern methodology, providing key quality control feedback to the system. And these are available in wide specifications depending on the sensitivity levels, type of gas to be sensed, physical measurements and various different elements.

Gas sensors are generally battery operated. They transmit warnings via a series of audible and visible signals such as alarms and flashing lights, when hazardous levels of gas vapors are identified. Another gas is used as a reference point by the sensor as it measures gas concentration.

Figure 2.8 Gas sensor

Applications of gas sensors

Gas detectors can be used to detect burnable, flammable and poisonous gases, and oxygen consumption. This type of device is used widely in industry and can be found in a variety of areas example on oil rigs, to screen produce forms and emerging technologies such as photovoltaic. They might additionally be utilized within fire-fighting.

4.2.1.11 Touch Sensors

A touch sensor acts as a variable resistor as per the location where it is touched.

Figure 2.9 Touch sensor

Applications

The touch sensors being cost effective and durable are used in many applications such as

- Commercial – Medical, vending, Fitness and gaming
- Appliances – Oven, Washing machine/dryers, dishwashers, refrigerators
- Transportation – Cockpit fabrication and streamlining control among the vehicle manufacturers
- Fluid level sensors
- Industrial Automation – Position and liquid level sensing, human touch control in automation applications
- Consumer Electronics – Provides a new feel and level of control in various consumer products

4.2.2. Criteria to choose a Sensor

There are certain features which have to be considered when we choose a sensor. They are as given below:

1. Accuracy
2. Environmental condition - usually has limits for temperature/ humidity
3. Range - Measurement limit of sensor
4. Calibration - Essential for most of the measuring devices as the readings changes with time
5. Resolution - Smallest increment detected by the sensor
6. Cost
7. Repeatability - The reading that varies is repeatedly measured under the same environment

4.3 VIBRATION ANALYSER AND MEASUREMENT

A vibration analyser or vibration meter is used in manufacturing for machine condition monitoring, product testing and quality assurance. A vibration meter is typically a portable device with a memory for storing measurements. Most vibration meter models feature a built-in data logger for collecting and recording vibration measurement data over time. In this way, vibration measurement data can be acquired with great precision.

The measurement of vibrations can be done using various types of sensors. Although there are no direct vibration sensors, vibrations can be measured indirectly, deducing values from classic mechanical or optical quantities. These sensors differ in some features. Among other things they can be divided based on active and passive behaviour, there are sensors that measure relative and others absolute. Other distinctive features are frequency range, signal dynamics and the quality of the measurement data. The following sensors shown here were first structured in a contacting and a non-contacting group and within these in the sub items path, velocity and acceleration measurement.

4.3.1 Fast Fourier Transform (FFT)

- A Fourier series is a series of sine waves and we use fourier analysis to deconstruct a signal into its individual sine wave components. The result is acceleration or vibration amplitude as function of frequency.
- A discrete fourier transform(DFT) multiplies the raw wave form by sine waves of discrete frequencies to determine if they match and what they corresponding amplitude and phase are.
- A fast fourier transform(FFT) is just a DFT using a more efficient algorithm that takes advantage of the symmetry in sine waves.
- By using an appropriate signal processing method , it is possible to detect the changes in vibration signals caused by faulty components and to judge the conditions of the machinery.
- Traditional vibration signal analysis has generally relied upon the spectrum analysis via the fourier transform(FT).
- Fourier analysis transforms a signal f(t) from a time-based domain to a frequency-based one, thus generating the spectrum that includes all of the signal's constituent frequencies(fundamental and its harmonics).
- $$F(\omega) = \int_{\infty}^{\infty} f(t)\, e^{-i\omega t} dt$$

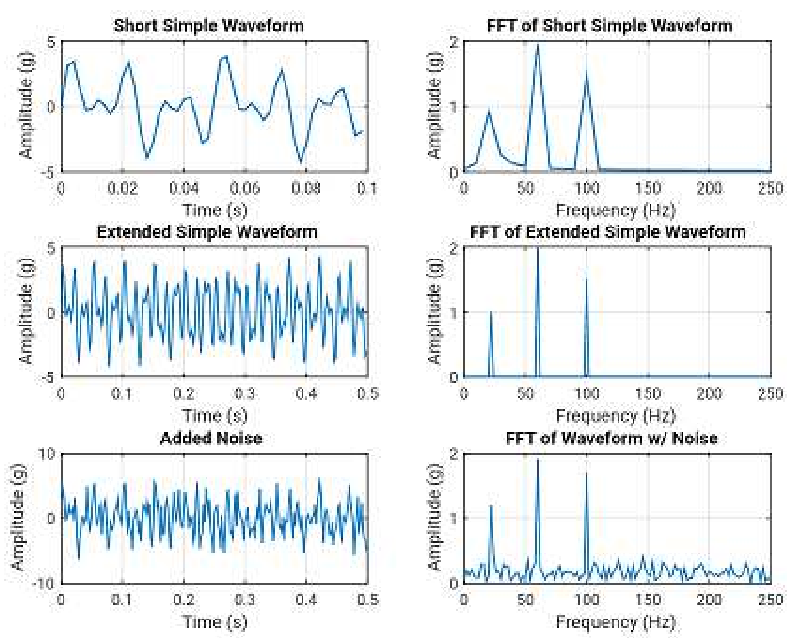


Figure 3.0 Fast Fourier Transform

4.4 INSTRUMENTS USED TO MEASURE VIBRATION

4.4.1 Multi-channel vibration number with time domain, orbit, frequency, coast up/down, and cross channel analysis. Photo tachometer with tri-axial ICP accelerometer is compatible

Figure 3.1 Multi-channel vibration analyser

Accelerometer: Triaxial-40 kHz. 4 BNC inputs, Photo Tachometer, 3200 lines resolution, Real Time with 4.2GB HDD, Touch Screen, Sound recording and Internet enabled with Diagnostic Software.

4.4.2 Single Channel Vibration Data Collectors with Trend Software's

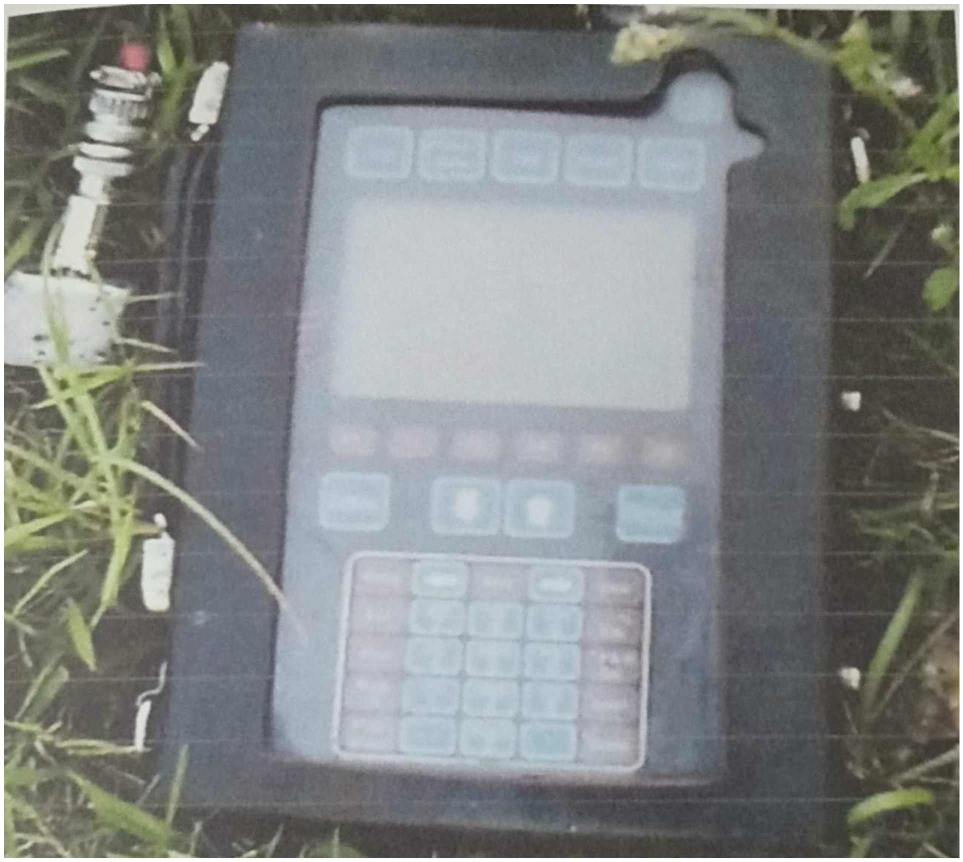


Figure 3.2 Single Channel Vibration Analyser

Accelerometer: 05-20 kHz, analyzer-0-80kHz

Lines: 6400 lines, Synchronous averaging, Continuous Monitoring, Photo Phase, Buffered Input. Data collection in route and off router mode.

2.5MB internal storage with RS 232 port for communication. Trend Software compatible.

Trend software

16 bit, open architecture, data management and trend software. Plant-area-machine-point hierarchy. Maximum 24 measuring points for each machine. Data manipulation facilities. Zoom, narrow band, parametric trending, date and point trending. Setup facilities for analysis parameters, fault frequencies along with alarm and alert levels

for each frequency band. Report generation and exception reports. Stand alone configured.

4.4.3 Shock pulse meter

Rolling element bearings are analyzed with the help of shock pulse meters. Meter deciphers the impact generated by both bearing inherent deformities and also induced mechanical defects. The signals are separated and numbered to compare with standard test available for cash bearing type under standard conditions. 32+/-5.0 kHz range signals are filtered to identify bearing faults. Condition codes like A,B,C,D will be generated in the order of seventy along with Lubrication index to indicate the lubrication condition like starvation or in adequate lubrication.

Figure 3.3 Shock pulse meter

4.5. Working of the measuring instrument

Before taking a vibration measurement, you need to attach a sensor that can detect vibration behaviour to the machine that is being measured. Various types of vibration sensors are available, but a type called accelerometer is normally used as it offers advantages over other sensors. An accelerometer is a sensor that produces an electrical signal that is proportional to the acceleration of the vibrating component to which the accelerometer is attached. The piezoelectric crystal in the accelerometer converts the vibrations into electric signals.

The acceleration signal produced by the accelerometer is passed on to the instrument that in turn converts the signal to a velocity signal. Depending on the user's choice, the signal can be displayed as either a velocity waveform or a velocity spectrum.

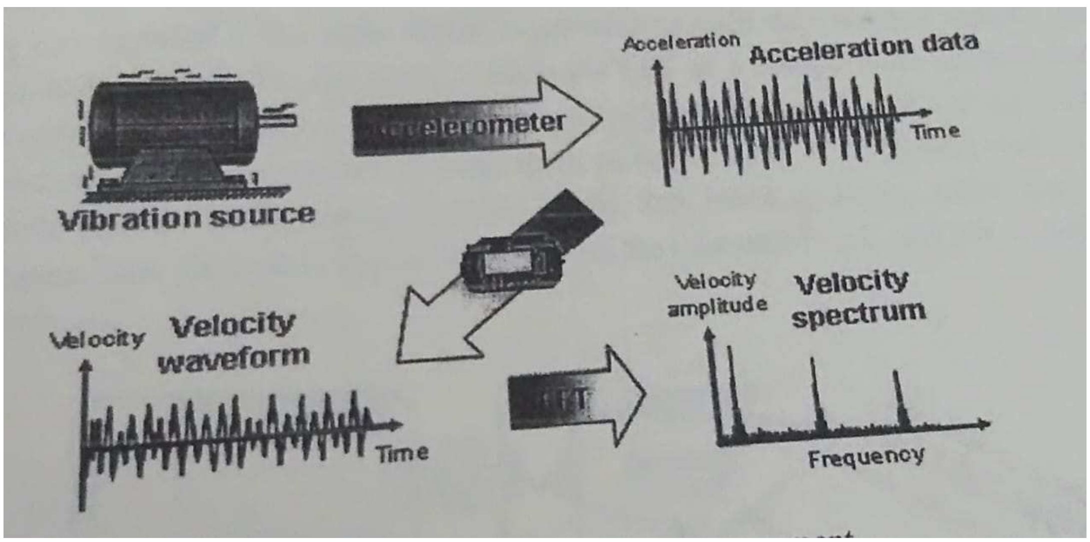


Figure 3.4 Vibration measurement

A velocity spectrum is derived from a velocity waveform by means of a mathematical calculation known as the Fast Fourier Transformation or FFT. The above diagram is a very simplistic explanation of how vibration data is acquired.

Data Processing within the Instrument

Triggering is a technique for capturing an event when you do not know exactly when it will occur. A trigger can start data acquisition and processing when a user-specified voltage level detected in an input channel. For example, you can setup a trigger to capture a hammer impact. After you arm the trigger, the analyser will wait until the impact occurs before it starts acquiring data.

Averaging improves the quality of the measurement. It applies to both the frequency and time domains. Frequency domain averaging uses multiple data block to smooth the measurements. You can average signals with a linear average where all data blocks have the same weight, or you can use exponential weighing. In this case, the last data block has the most weight and the first has the least. Averaging acts to improve the estimate of the mean value at each frequency point; it reduces the variance in the measurement. Time domain averaging useful in measuring repetitive signals to suppress background noise. An impact test is good example of repetitive signals. Both the force and acceleration signals are the same for each measurement. This assumes that the trigger point is reliable. The presence of high background noise may adversely affect the reliability of the trigger.

Windowing is a processing technique used when computing FFTs. Theoretically, the FFT can only be computed if the input signal is periodic in each data block it repeats over and over again and is identical every time). When the FFT of a non-periodic signal energy smearing out over a wide frequency range. Since most signals are not periodic in the data block time period, windowing is applied to force them to be periodic. A windowing function should be exactly zero at the beginning and end of the data block and have some special shaped in between. This function is then multiplied with the time data block, and this forces the signal to be periodic.

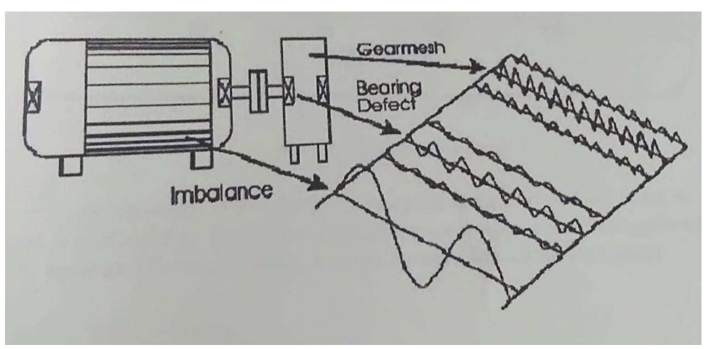


Figure 3.5 Windowing

4.6 DIFFERENT ANALYSIS TOOLS USED FOR FAULT DIAGNOSIS IN MACHINES

4.6.1 Time Waveform Analysis

One display commonly used by vibration analysis is the waveform. A waveform is a graphical representation of how the vibration level changes with time. Shown below is an example of a velocity waveform. A velocity waveform is simply a chart that shows how the velocity of a vibrating component changes with time. The amount of information a wave contains depends on the duration and resolution of the waveform. The duration of a waveform is the total time period over which information may be obtained from the waveform. In most cases a few seconds are sufficient.

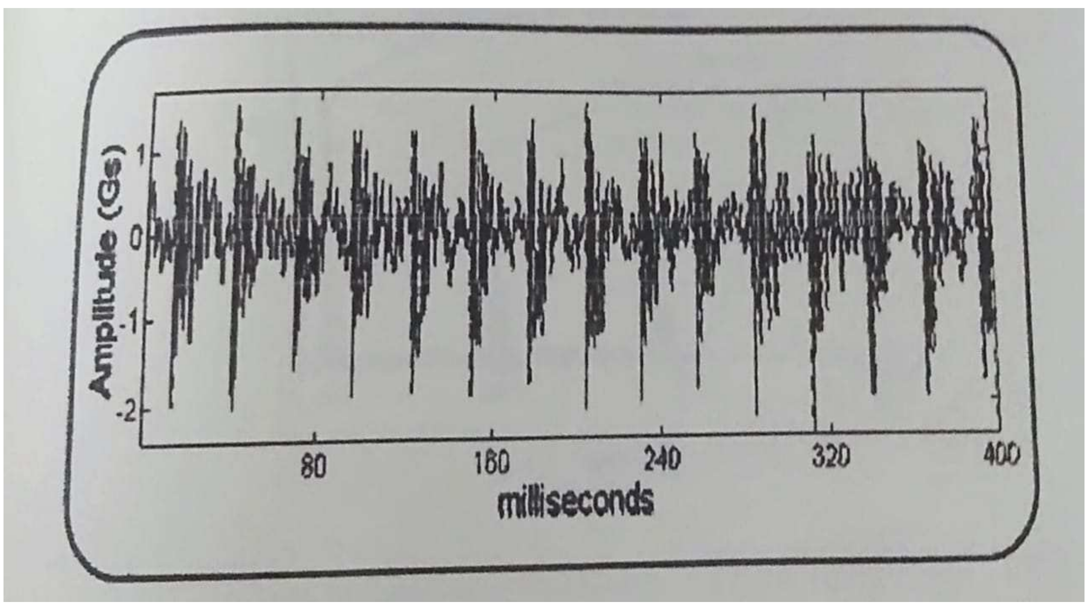


Figure 3.6 Velocity waveform

The resolution of a waveform is a measure of the level of detail in the waveform and is determined by the number of data points or samples characterizing the shape of the waveform. The more samples there are, the more detailed the waveform is.

4.6.2 Spectrum Analysis

Another kind of display commonly used by vibration is the spectrum. A spectrum is a graphical display of the frequencies at which a machine component is vibrating, together with the amplitudes of the component at these frequencies. Shown below is an example of a velocity spectrum.

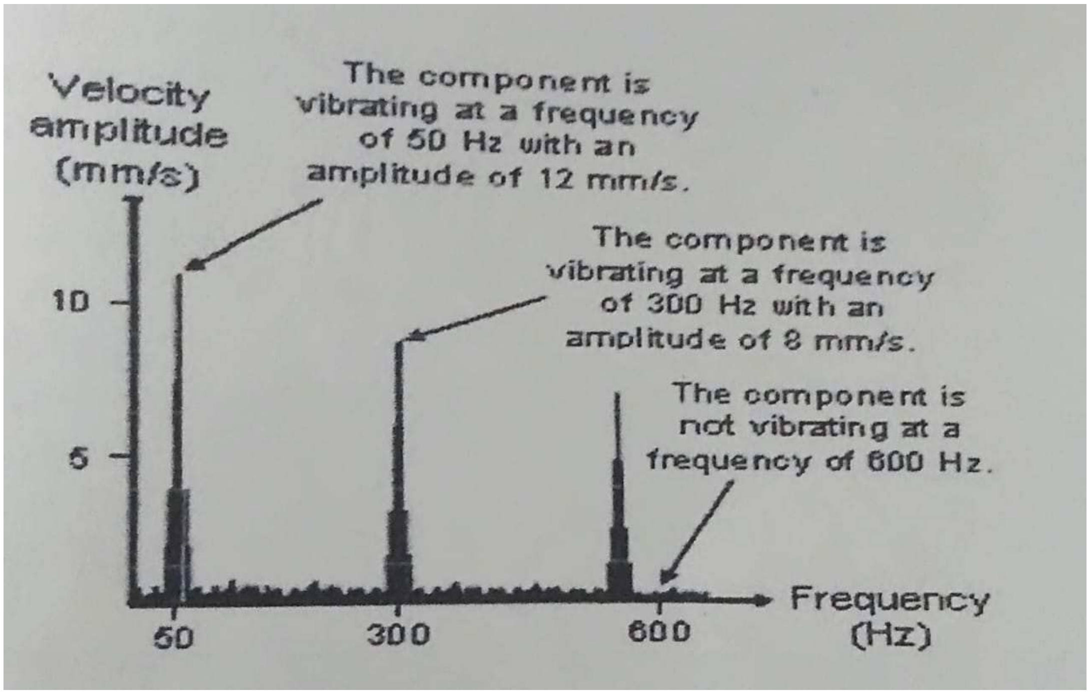


Figure 3.7 Spectrum analysis

A spectrum is derived from a waveform by means of a mathematical calculation known as the Fast Fourier Transform or FFT.

Machine vibration, as opposed to the simple oscillatory motion of a pendulum, not usually consist of just one simple vibratory motion. Usually, it consists of many vibratory motions taking place simultaneously.

Spectrum analysis is the most predominantly used tool for the analysis of vibration in machines. It is based on the observation of spectrum that 90% of the machine faults are diagnosed.

4.6.3 Phase Analysis

Phase analysis is another important technique that is used in vibration analysis.

Phase

The time relation of a signal to another signal of the same frequency, or the time relation of a vibrating object to another object vibrating at the same frequency. The vibratory motion of an object is 'in phase' with that of another object if they oscillate at the same frequency in a synchronized manner e.g. the two objects attain maximum positive displacement simultaneously and zero displacement simultaneously. If the motions of the objects are not synchronized and zero displacement simultaneously. If the motions of the objects are not synchronized e.g if one object attains maximum displacement when the other attains the minimum, and vice versa, the vibratory motions are said to be 'out of phase'.

Phase angle

A quantity that indicates the phase of a waveform or vibration motion in relation to other waveform or vibratory motion. Phase angle can be expressed in degrees or radians. For example, a waveform that leads a reference waveform by half a code, is ascribed a phase angle of 180°.

In Phase analysis a reflecting tape is placed on the rotating shaft and a photo tacho which generates pulses is focused on the reflecting tape. Whenever the reflecting tape pass through the photo tacho a pulse is generated. Photo tacho is connected to the analyzer which records the pulses generated by it.

Phase analysis gives us a clear idea of the transmission of vibration through the machines and the exact location of the fault. It is of great help while confining the problems of unbalance, misalignment, bent shaft, which cannot be easily done through spectrum analysis.

4.6.4 Orbit Analysis

In this method, based on the path of the centreline of rotating shaft within the clearance of the bearing different faults are being detected and analyzed. This analysis is valid for the machines having journal bearings. Different orbit plots indicate different machine faults.

Orbit shape	**problem**
Ellipse, circle	Unbalance
Banana, horizontal, 8 shaped loop	Misalignment
Double loo	Oil Whirl
Erratic	Rubbing

4.7 SPECTRUM ANALYSIS OF MACHINE FAULTS

4.7.1 Unbalance

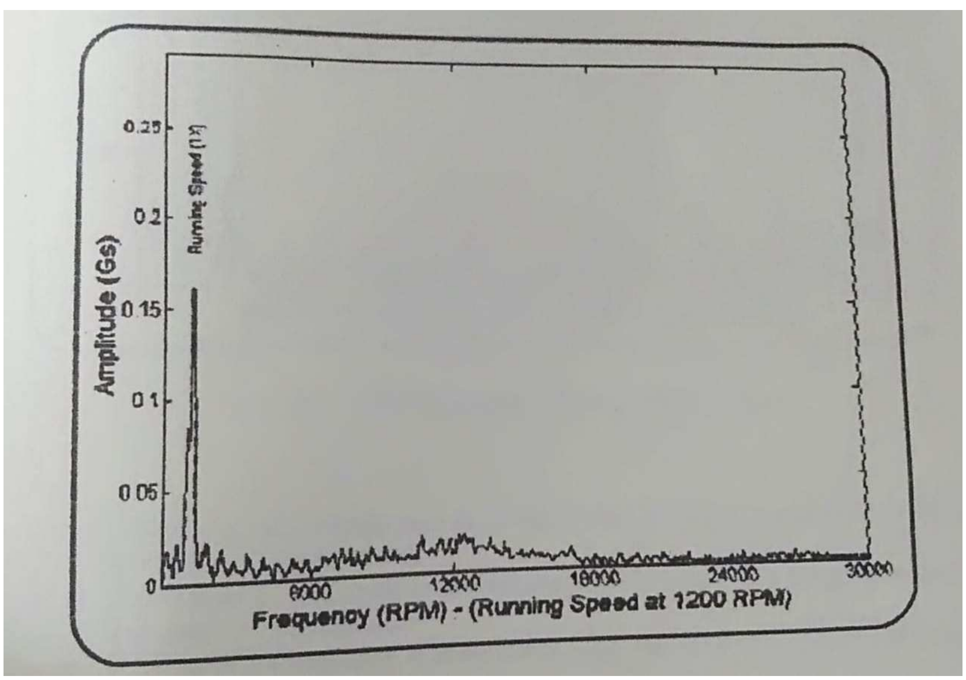


Figure 3.8 A FFT Spectrum Showing Unbalance

- If the radial measurements Ix amplitude is high, and harmonics (except vane passing) are less than 15% of the 1x, then there may be imbalance.
- If the majority of vibration is in the radial plane, and the 1x amplitude is medium to high in amplitude, and the phases from the vertical and horizontal measurements differ by 90°, +/-30° then may be imbalance.
- If there is a non-synchronous peak corresponding to the 1x running speed of a coupled machine, then there may be imbalance on the other machine.
- If the primary vibration plane is both axial and radial, and the machine has an overhung mass, and the axial phase measurements across the machine are in phase, then there may be imbalance.

4.7.2 Misalignment

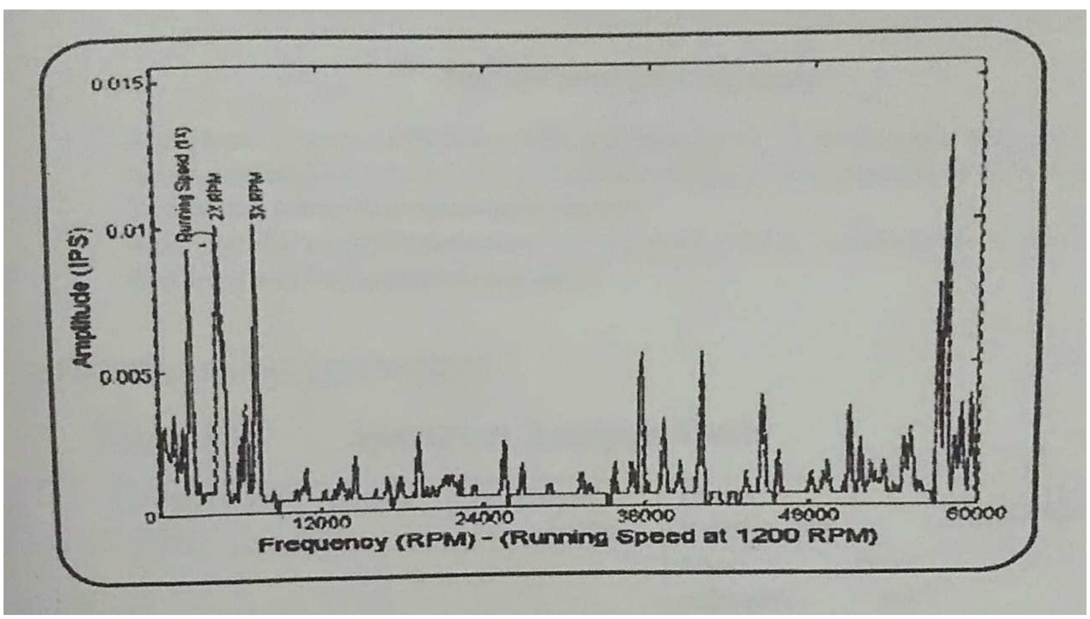


Figure 3.9 A FFT Spectrum Showing Misalignment

- If there is an abnormally high 2x/1x amplitude, and there is a coupling or belt, then there may be misalignment.
- If the radial 2x amplitude is abnormally, high and there is a coupling or belt, then there may be misalignment.
- If the axial 1x amplitude is abnormally, high and there is a coupling or belt, then there may be misalignment.

4.7.3 MECHANICAL LOOSENESS

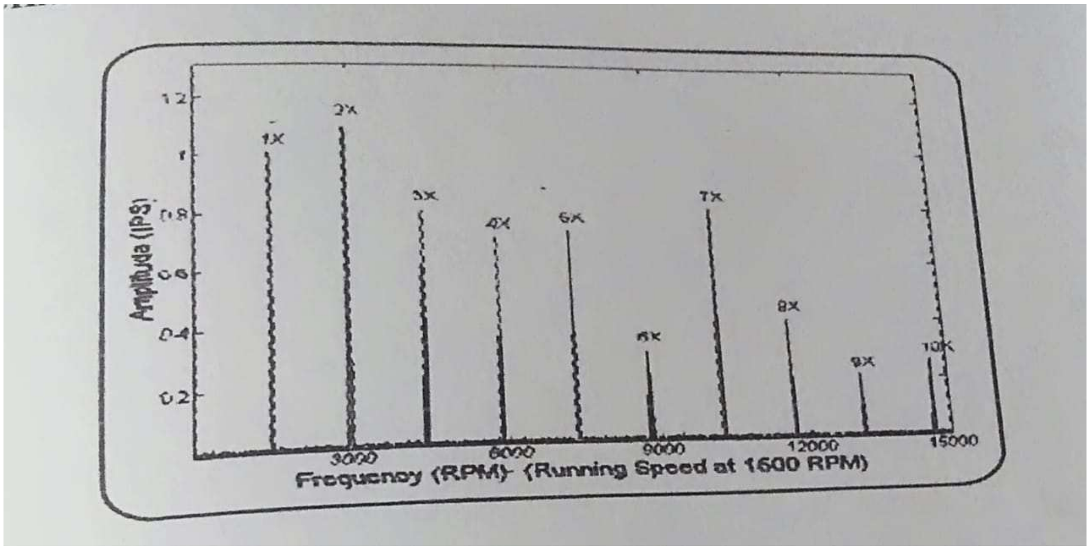


Figure 4.0 Mechanical Looseness

- If there are a series of three or more synchronous or synchronous multiples of running speed (range 2x to10x), and there magnitudes are greater than 20% of the 1x, then there may be mechanical looseness.
- If the machine is rigidly connected (no coupling or belt), and the radial 2x is high
  then there may be mechanical looseness.

4.8. SPECTRUM ANALYSIS TABLES

Table. 1.2 Spectrum Analysis Table

	Primary/Plane	**Detection Units**	**Dominant Frequencies**	**Phase Relationship**	**Comments**
Imbalance				**Note: Phase reference are accurate within +/- 30°**	
Mass	Radial	Acceleration/Velocity/Displacement	1X		Account for change in sensor orientation when making axial
Overhung Mass	Axial and Radial	Acceleration/Velocity/Displacement	1X		
Bent Shaft	Axial and	Acceleration/Ve	1X		

	Radial	locity/Displacement			measurements
Misalignment					
Angular	Axial		1X, 2X	A phase shift of 180° in the axial direction will exist across the coupling.	With severe misalignment, the spectrum may contain multiple harmonics from 3X to 10X. If vibration amplitude in the horizontal plane is increased 2 or 3 times, then the misalignment is again indicated.
Parallel	Radial		1X, 2X	A phase shift of 180° in the radial direction will exist across the coupling. Sensor will show 0 or 180° phase shift as it is moved from horizontal to vertical position on the same bearing.	
Combination of angular and parallel	Axial and Radial		1X, 2X	A phase shift of 180° in the radial and axial direction will exist across the coupling.	
Mechanical Looseness					
Structural	Radial	Acceleration/Velocity/Displacement	1X	Phase shifts of 180° will exist between the machines's feet, base plate, and/or foundation if	Usually caused when machine's foundation degrades to such an extent that it

				the machine is rocking.	is no longer stiff, causing the machine to “rock”.
Soft Foot	Radial	Acceleration/Velocity/Displacement	1X, 2X,...	Phase will shift when the machine foot is tightened.	Result of the machine footing coming loose from the foundation.
Wear/Fitting	Radial and Axial	Acceleration/Velocity/Displacement	1X, 2X,....,10X	Phase reading will be unstable from one reading to the next.	Vibration amplitudes may vary significantly as the sensor is placed at different locations around the bearing.

Local Bearing Defects					
Race Defect	Radial	Acceleration/Enveloping/SEE	4X,.....15X	No correlation.	With acceleration measurements, bearing defect frequencies appear as a wide “bump” in the spectrum. Bearing defect frequencies are non-integer multiples of running speed.
Gear Defect					
Gear Mesh	Radial	Acceleration/Enveloping/SEE	20X,......200X	No correlation.	The exact frequency relates to the number of teeth each gear has times the shaft rotation speed.
Electrically induced					
AC Motors	Radial	Acceleration/Enveloping/SEE	Line frequency(100 or 120 Hz)	No correlation.	Defect frequencies can be seen at exactly twice the line frequency.

4.9 SINGLE PLANE BALANCING

Single plane balancing is the process of making balance corrections to a rotor in only one axial location. Signal plane balancing can be very useful even for rotors that would normally be corrected using a two plane balance method when vibration amplitudes and phase readings allow static or couple corrections alone. The process of signal plane field balancing is shown below.

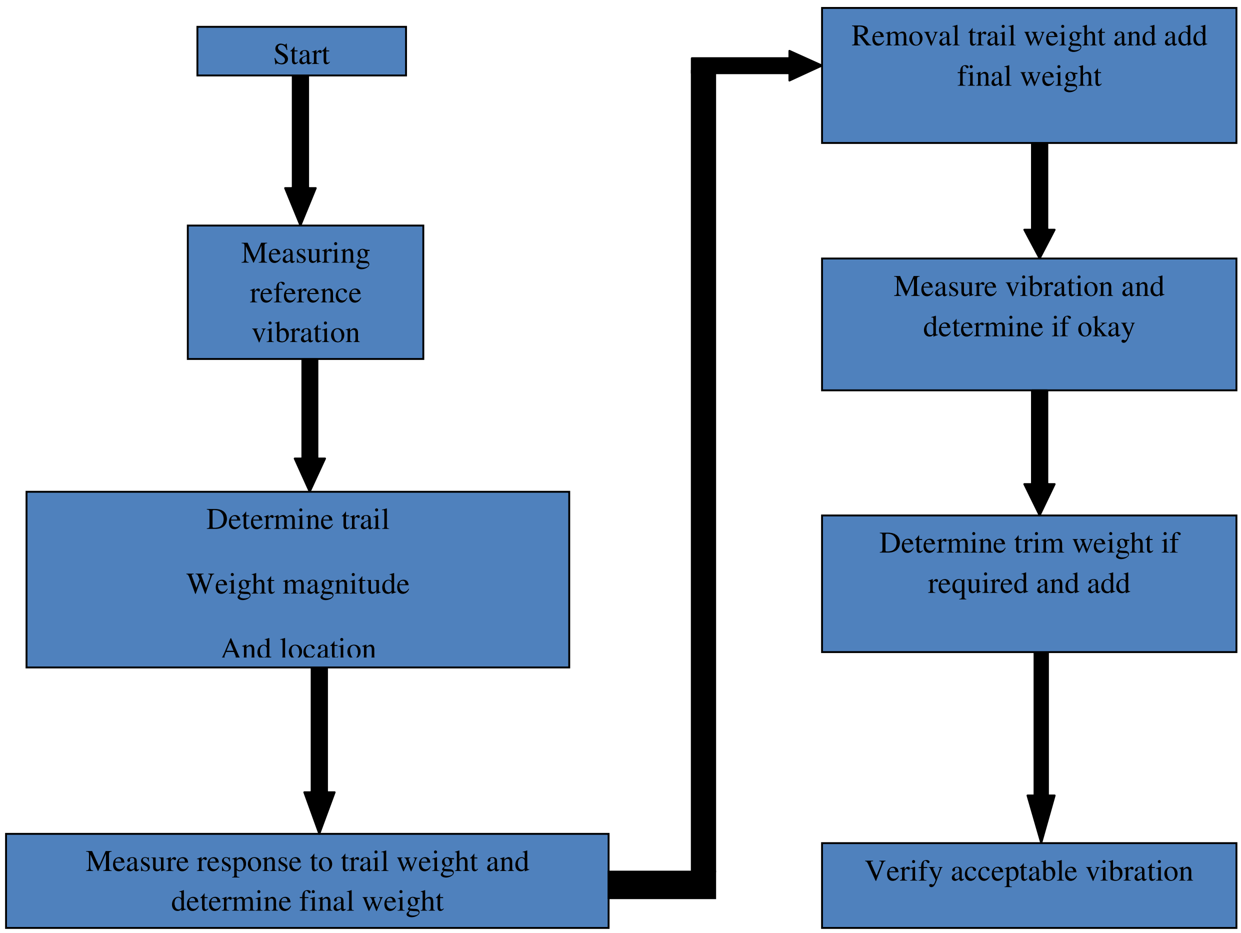


Figure 4.1 Steps involved in single plane balancing

The modern balancing instruments, including vibration analyzers like Scheck analyzer and data collectors take the original unbalance data, trail weight information and unbalance data resultant from the addition of trail weight information and unbalance data resultant from the addition of trail weights to calculate the needed balance corrections and will be displayed on screen.

The following steps summarize the single plane vector method of balancing

1. Operate the rotor at normal balancing speeds and record the original (O)

2. Unbalanced amplitude and phase readings. Record this data as "O”

3. Again operate the rotor at the balancing speed and record the new unbalance amplitude and phase readings Record this as "O+T".

4. Using polar graph paper, construct vectors representing "O and "O+T” using the same scale.

5. Construct vector "T" by connecting the end of the "O vector to the end of "O+T" vector.

6. Measure the length of the T" vector using the same scale that used for the vectors "O” and "O+T”, and calculate the amount of correct weight using formula. Correction weight = trail weight x ("O"/"T").

7. Using a protractor measure the included angle between the "O and T" vectors .Shift the corrected balance weight by this angle in a direction opposite the phase shifts between "O" and "T".

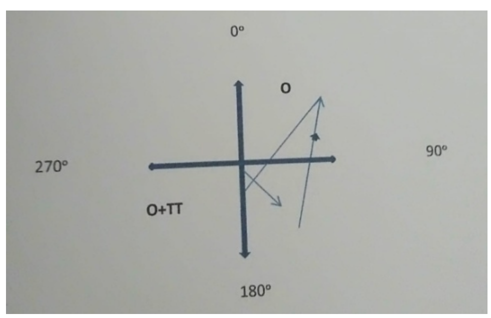


Figure 4.2 Balancing graph

4.10 TRIAL MASS

The fan is switched off; a trial weight is attached in the correction plane.

The mass of the trail weight can be made up using rule of thumb formula

M trail-30 Motor/trial

Where M trail = mass of the trial weight in gram

Motor-rotor mass in kg

R trail = radius at which the trail weight will beaded, in mm

The closet available trail weight is attached to the back plate of the fan at an angle (80°+ phase angle in initial run).

CHAPTER - V

FAULT DIAGNOSIS

5.1 VIBRATION MEASUREMENTS OF INDUCTION MOTOR

Carried out vibration measurements of an induction motor and identified discrete frequencies of the motor such as shaft rotating frequency (SRF) and its harmonics, drive end and non-drive end bearing frequencies, etc in the vibration spectra. The vibration measurements were carried by mounting accelerometer on the induction motor at various locations to acquire vibration data.

Equipment: Three phase induction motor

DE: Drive end bearing

.

NDE: Non drive end bearing

Figure 4.3 3-phase induction motor

5.2 EQUIPMENT SPECIFICATIONS

Make	:	Laxmi Hydraulic Pvt. Ltd. (LHP)
Power	:	75 KW/ 100Hp
Speed	:	2970 RPM
Type of bearings	:	Open type deep groove ball bearings
Material	:	Steel
Drive end bearing	:	6318C3
		Number of balls-8
		Ball diameter-1.25
		Pitch diameter-5.511
Non drive end bearing	:	6316C3
		Number of balls-8

Ball diameter-1.125

Pitch diameter-4.921

Contact angle	:	20
Accelerometer	:	B & K Type 4526
Analyzer	:	Dewetron
Type of mounting	:	Magnetic

5.3 MONITORING POINTS

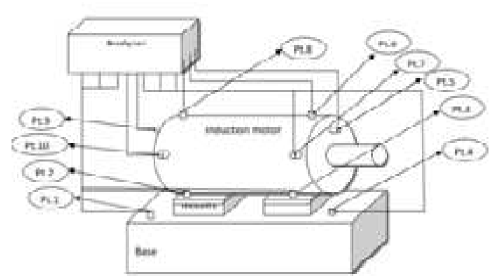


Figure 4.4 Accelerometer mounting points on induction motor

Details of monitoring points:

Pt.1: BM, V, NDE **Pt.2**: AM, V, NDE **Pt.3**: AM, V, DE **Pt.4**: BM,V, DE
Pt.5: AM, A, DE **Pt.6**: AM, V, DE **Pt.7**: AM, H, DE **Pt.8**: AM, V, NDE
Pt.9: AM, A, NDE **Pt.10**: AM, H, NDE

AM : above mount,

BM : Below Mount,

A : Axial,

H : Horizontal,

V : Vertical

DE : Driving End,

NDE : Non-Driving End

Vibration readings are taken and respective spectrums, time waves are collected in vertical, horizontal and axial directions at the drive end and non-drive end bearing points.

The discrete frequencies of both the end roller element ball bearings were calculated using the following formulae (Inner race rotating and Outer race stationary).

5.4 CALCULATION OF FREQUENCIES

- **Fundamental Train Frequency (FTF)**

The rate at which the bearing cage travels around the bearing is called fundamental train frequency. This is also called the Cage Rate.

- **Ball Pass Frequency Inner-race (BPFI)**

The rate at which a ball or roller will pass a point on the inner race is called ball pass frequency inner-race.

- **Ball Pass Frequency Outer-race (BPFO)**

The rate at which a ball or roller will pass a point on the outer race is called ball pass frequency outer-race.

- **Ball Spin Frequency (BSF)**

The rate at which a point on a ball or roller will contact the inner OR outer race is called ball spin frequency.

FTF (Fundamental Train Frequency): $(S/2)(1-(Bd/Pd)*\cos\phi)$

BPFI (Ball Pass Frequency of Inner Ring): $(Nb*S/2)(1+(Bd/Pd)*\cos\phi)$

BPFO (Ball Pass Frequency of Outer Ring): $(Nb*S/2)(1-(Bd/Pd)*\cos\phi)$

BSF (Ball Spin Frequency): $((Pd*S)/(2*Bd))[1-\{((Bd/Pd)^\wedge 2)*((\cos\phi)^\wedge 2)\}]$

Where

S = Revolutions per second/ relative speed between inner ring and outer ring = (RPS) = 49.5 Hz

Bd = ball diameter, Pd= pitch diameter

Nb = number of balls, Φ= contact angle

Discrete frequency values of DE & NDE Bearings given below:

DE 6318 C3:	**NDE 6316 C3**:
FTF=19.1362	FTF=19.0918
BPFI=242.9102	BPFI=243.2652
BPFO=153.0898	BPFO=152.7348

5.5 VIBRATION MEASUREMENT AND ANALYSIS

Sensing of the vibrations is done through the vibration transducers, that is, accelerometers mounted at various points of the motor. The data (electronic signal) from the accelerometers is conditioned by the built-in preamplifiers and is transmitted through co-axial cables to the analyzer. This conditioned data is recorded in the analyzer in the format of time domain signal and then it is converted into frequency domain through Fast Fourier transform (FFT) by the software used by analyzer. The recoded data is used for further processing and detailed analysis for fault diagnosis.

Some important precautions are to be followed while taking the measurements, such as

i. Note that the coaxial cables are untangled, straight, non-moving and in proper condition and are properly joined and fixed so as to prevent any losses in the accelerometer signal.

ii. Select carefully the type of mounting of the accelerometer, based on the application and intensity of the vibrations, and after mounting, check if they are properly mounted.

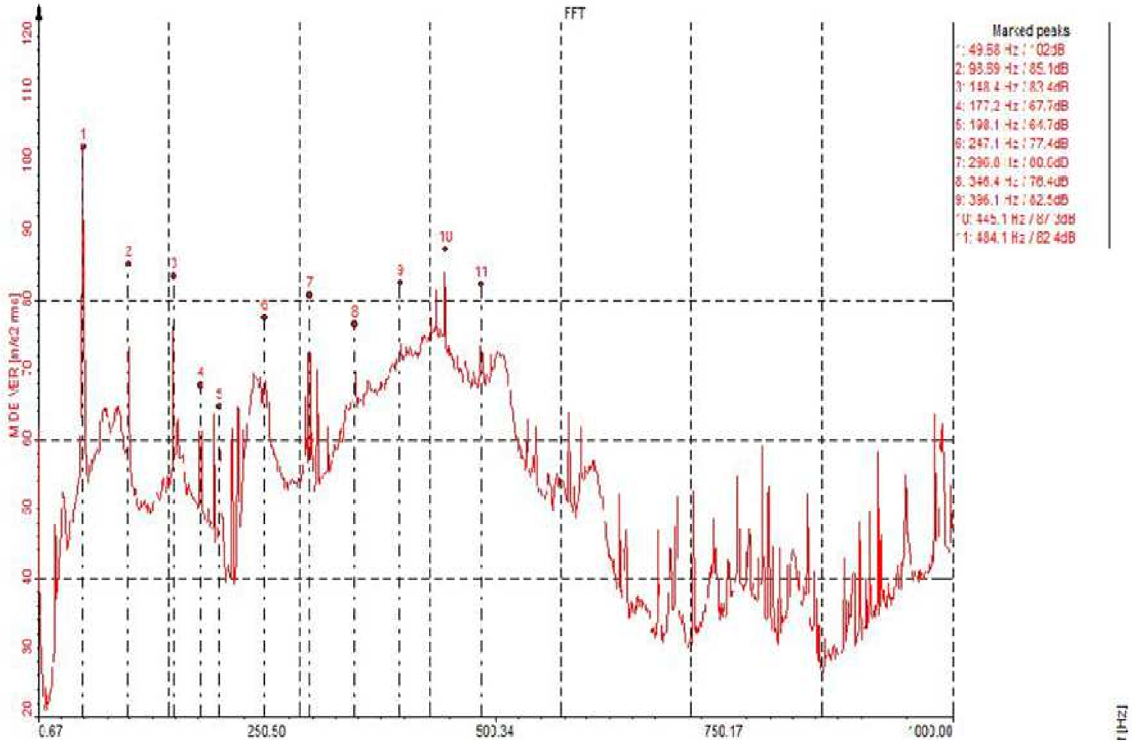
iii. Check if the machinery is properly grounded from any electric currents so as to prevent any variation of the accelerometer signal.

The vibration data is recorded at various mounting points and are analyzed in frequency domain to identify the discrete frequencies in the vibration spectra obtained for various location of the induction motor.

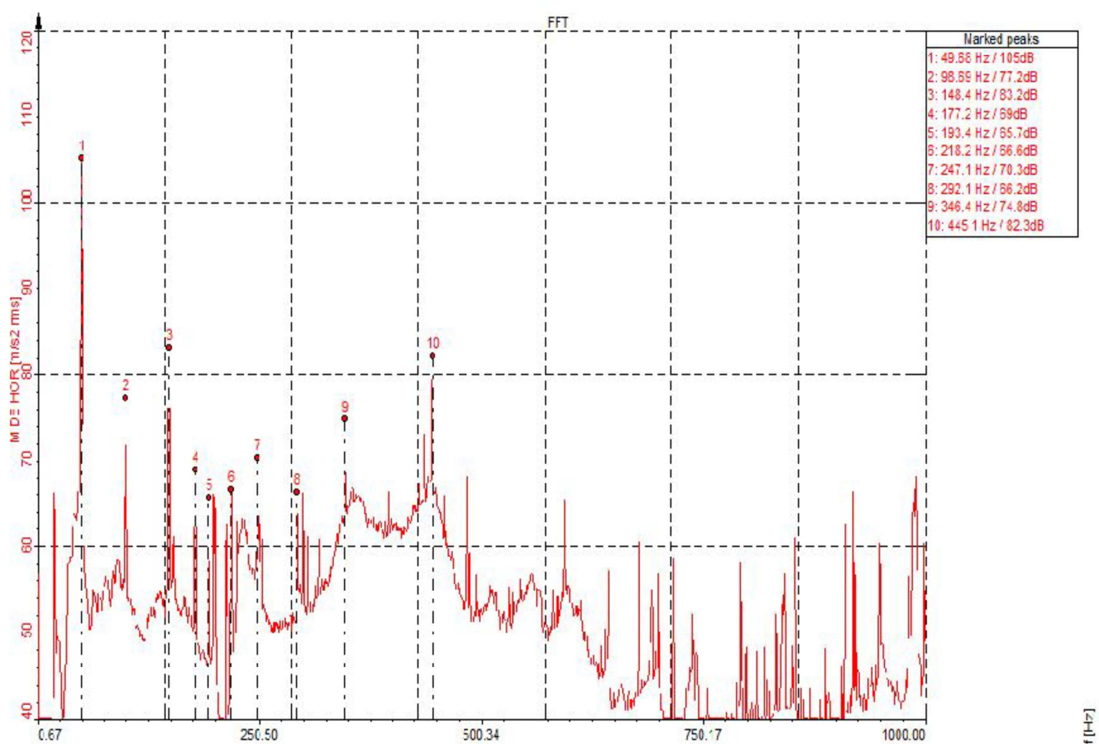
5.6 MEASUREMENT SPECIFICATIONS

- Frequency range of 1 kHz
- Horizontal axes of the spectra - frequency in Hz
- Vertical axes acceleration- amplitude in mm/sec^2.

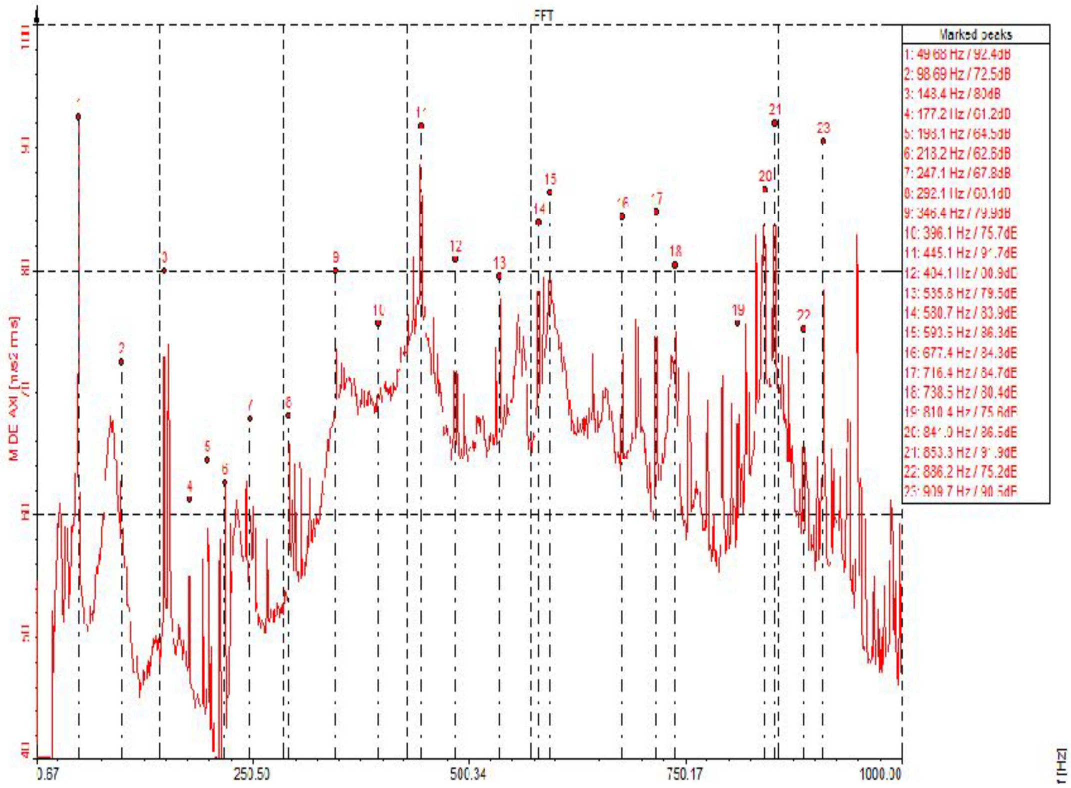
If there is any increase in the vibration frequency components indicate alarming levels of the machine leading to probable failure of the components.



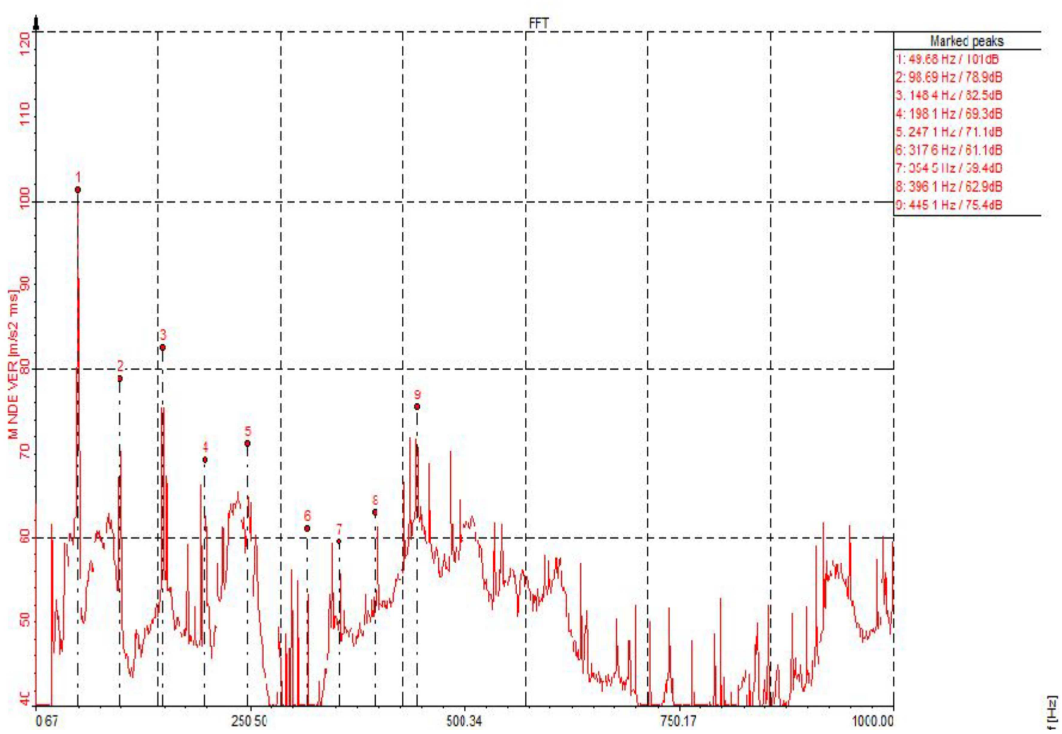
Vibration Spectrum of Induction Motor at DE Bearing (Vertical)



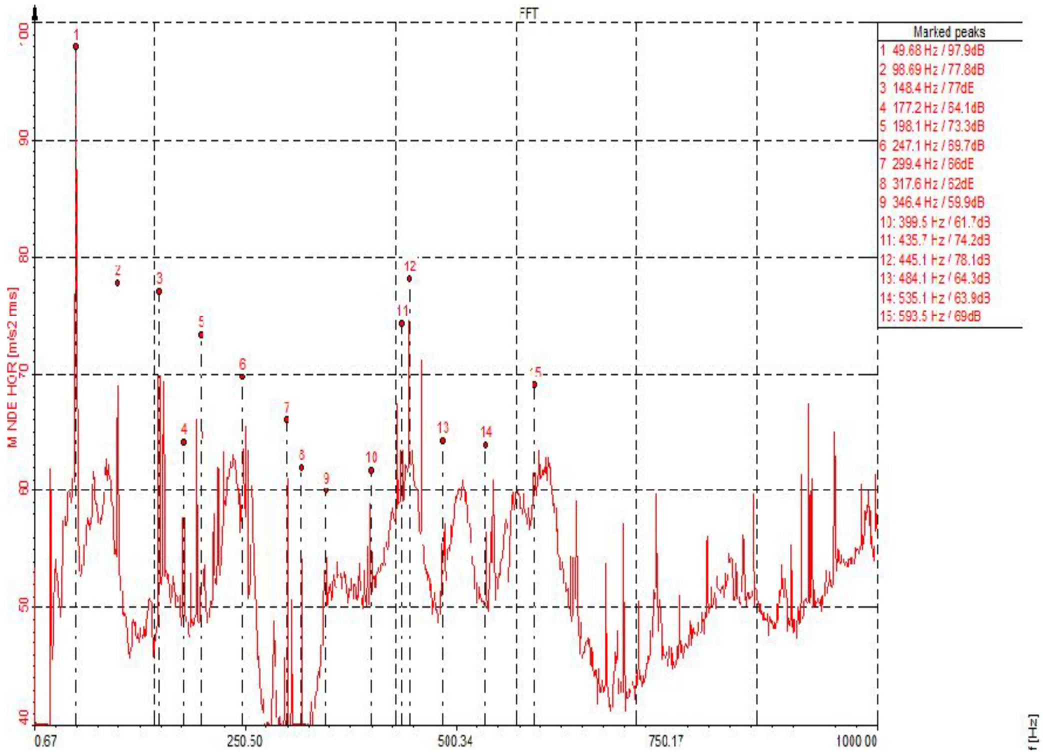
Vibration Spectrum of Induction Motor at DE Bearing (Horizontal)



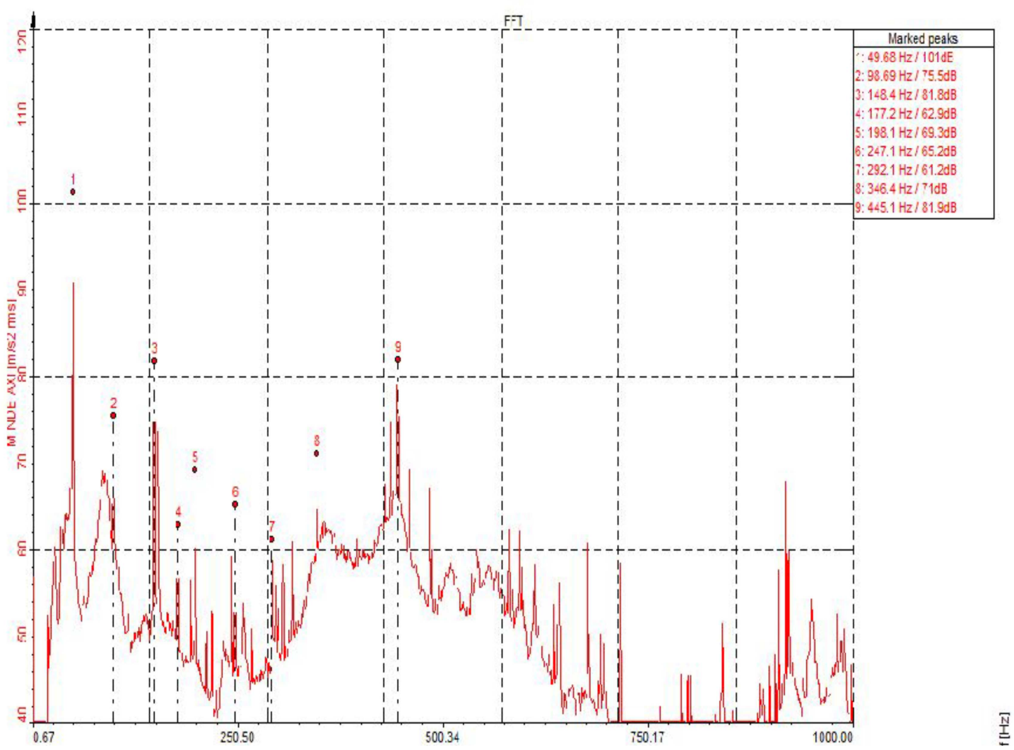
Vibration Spectrum of Induction Motor at DE Bearing (Axial)



Vibration Spectrum of Induction Motor at NDE Bearing (Vertical)



Vibration Spectrum of Induction Motor at NDE Bearing (Horizontal)



Vibration Spectrum of Induction Motor at NDE Bearing (Axial)

CHAPTER - VI
MACHINERY CONDITION MONITORING USING VIBRATION ANALYSIS

6.1 AIM

To understand the machinery condition monitoring using vibration analysis.

6.2 PROCEDURE

1. An industrial fan is considered with and without imbalance for studying vibration response using practical vibration measurements. Rotor imbalance exists to some degree in all machines.
2. The main characteristics of imbalance are:
It is sinusoidal at a frequency once per revolution.
It is a rotating vector and its amplitude increases with speed.
3. These characteristics are very much useful in differentiating imbalance from faults that produce similar vibration.
4. The vibration caused by pure imbalance is once per revolution sine wave, sometimes accompanied by low level harmonics.
5. Phase information plays a key role in detecting and analyzing imbalance. A state of imbalance occurs when the center of mass of a rotating system does not coincide with the center of rotation. It can be caused by a number of things, including incorrect assembly, material deformation and rotor sag.
6. Imbalance produces a vector that rotates with the shaft, producing the classic once per revolution vibration characteristic.
7. Hence, to study effect of imbalance in vibration measurements, an imbalance is created by adding some mass to one of the blades of an industrial fan with rated speed 1380 RPM.

6.3 OBSERVATIONS:

- Vibration measurements were carried out without and with imbalance of the fan blades and the vibration levels are compared.

- The increased vibration level is distinctly observed in vibration spectrum as a predominant peak at the shaft rotational frequency (1 X RPM) of the fan (23 Hz) due to imbalance of fan blade. Vibration spectra obtained for without and with imbalance are shown **Figures 4.5 & 4.6.**

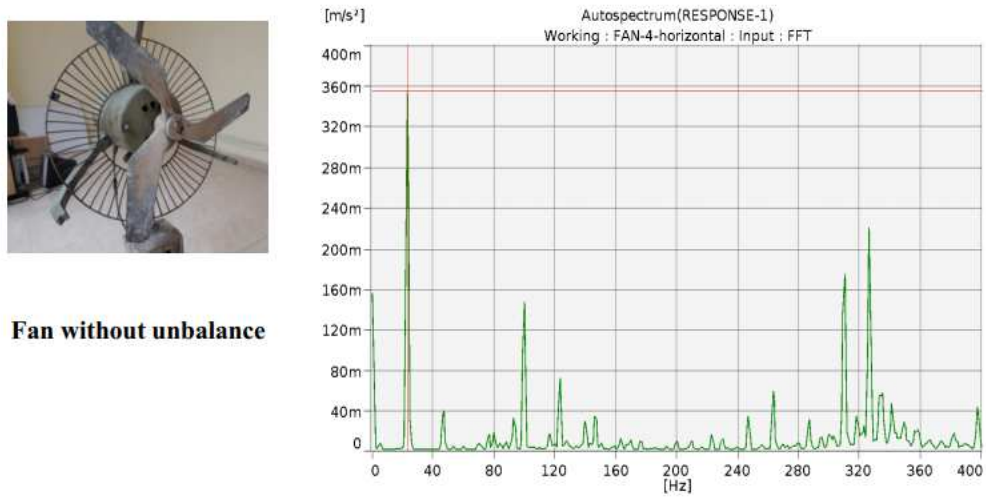


Figure 4.5 Vibration levels of fan without imbalance (at 23Hz 3.54cm/s^2)

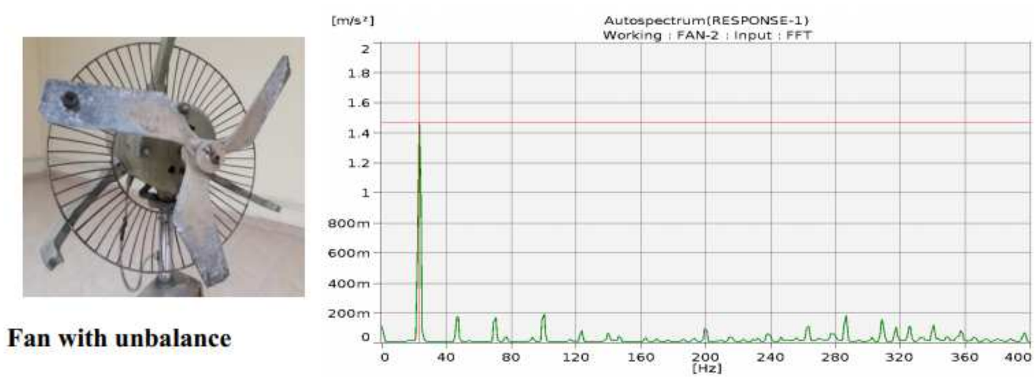


Figure 4.6 Vibration levels of fan with imbalance (at 23Hz 14.6 cm/s^2)

CHAPTER - VII

RESULTS AND ANALYSIS

- From the Figures 3.1, it can be observed a distinct peak at 1 X RPM of the fan, i.e., at 23 Hz, with an acceleration of 3.54 cm/s^2 when the blades of the fan is properly balanced.
- In Figure 3.2, there is a predominant peak at the same frequency of 23 Hz and it is now 14.6 cm/s^2.
- This increase in the vibration level at 1X RPM is due to the imbalance existed in the fan blade.

CHAPTER - VIII

CONCLUSIONS

1. The facilities exist in the laboratory, Machinery maintenance strategies, and conditions monitoring using vibration analysis are studied.
2. As part of practical learning, field vibration measurements and machinery fault diagnosis are explored.
3. It is understood that condition monitoring using vibration analysis is one of the most powerful condition based maintenance method, and is the key element of many predictive maintenance programs.
4. Applying vibration analysis for monitoring the condition of machinery is convenient, inexpensive, and reliable in diagnosing the machinery faults in their early stages and can avoid unscheduled shutdowns and expensive repair costs.

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