# PERFORMANCE OF ROTARY MACHINES USING SIGNAL PROCESSING

## A PROJECT REPORT

*Submitted by*

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**(An Autonomous Institution Affiliated to Anna University, Chennai)**

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# KUMARAGURU COLLEGE OF TECHNOLOGY
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## BONAFIDE CERTIFICATE

Certified that this project report titled "**PERFORMANCE OF ROTARY MACHINES USING SIGNAL PROCESSING**" is the bonafied work of "NIDHARSANA.A,PADMAVATHY.N, POORNIMA.D" who carried out the project work under my supervision.

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# ABSTRACT

In industries, Maintenance and Downtime has to be kept at a minimum to reduce monetary losses. In such situations, a system which continuously monitors the health of the machine would prove useful. Condition monitoring is the process of monitoring a parameter of condition in machinery (vibration, temperature etc.), in order to identify a significant change which is indicative of a developing fault. It is a major component of predictive maintenance.

The use of condition monitoring allows maintenance to be scheduled, or other actions to be taken to prevent failure and avoid its consequences. Condition monitoring has a unique benefit in that conditions that would shorten normal lifespan can be addressed before they develop into a major failure. Condition monitoring techniques are normally used on rotating equipment and other machinery (pumps, electric motors, internal combustion engines, presses). In this ,majority of the components are rotating machinery. Vibration and Thermal signals are two important indicators of the rotating machine behavior.

The vibration signals are obtained from the vibration sensors that are attached to the rotors in the machine. The time domain specifications are converted to frequency domain using FFT. The FFT is taken using MATLAB tool. The data is first collected for the normal and healthy mode of operation of the machinery and for operation under various levels of stress. The present data is compared to the collected data and the level of health of the machinery is determined. This would give prior information before the breakdown of the machinery.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| **MEMS** | Micro Electro Mechanical Systems |
| **FFT** | Fast Fourier Transform |
| **DCS** | Distributed Control Systems |
| **RMS** | Root mean square |
| **PLC** | Programmable Logic Controller |
| **ADC** | Analog to Digital Converter |
| **RPM** | Revolutions per minute |

# CHAPTER-1
# INTRODUCTION

# 1.INTRODUCTION :

Equipment maintenance is essential for long-term trouble-free operation. In the course of technological development, several types of maintenance have been established, the application of which depends on a number of circumstances that must be considered. Basic maintenance tasks are listed in the preceding paragraph. In considering them, however, costs should always be considered together with safety.

Each machine, if it has to work reliably throughout its planned life, must be maintained. For all large and expensive equipment, to which the vibration diagnostics mainly applies, operational life is an essential and often neglected part of the life of the machine .

Machines are at exactly the same situation. Based on a diagnostician's assessment they can either continue in operation, or a tiny intervention is necessary, or they need to be shut down and repaired thoroughly. a machine is repaired when its condition requires a repair rather than at predetermined intervals. Of course, it is necessary to know this condition, and therefore watch the machine in operation, i.e. to perform monitoring and diagnostics. This approach helps us to avoid unplanned shutdowns and failures. The key idea is the right information at the right time. If we know which part of the equipment requires replacement or repair, we can order spare parts, arrange it for staff, etc., and perform shutdown at the appropriate time. Such a planned shutdown is shorter and less costly than a shutdown forced by a failure of equipment or even an accident.

An increase of equipment lifetime, increased safety, fewer accidents with negative consequences for the environment, optimized management of spare parts, etc. are other advantages of predictive maintenance.

Purpose of all this is, in case of both humans and machines, to save the cost of repair or to prevent a disaster and its associated costs.

Condition monitoring pertains to providing information on the condition of plant so that it can be maintained properly. By having such knowledge of machine condition, we can predict incipient failures and stop the plant for maintenance in a planned manner so that the minimum loss of output occurs and so that the maintenance can be carried out as efficiently as possible.

Vibration diagnostics is one of the non-destructive methods used for condition monitoring of in machine operation. All the machines while operating vibrate more or less, and with most of them the vibrations are unwanted and the effort is to minimize them. Only with some types of machines, vibrations are directly a working principle of the machine and are caused deliberately (e.g. vibrating screeners). Though, this group of machines is not of interest to vibration diagnostics.

The golden means in terms of maintenance strategy will be carrying out preventive maintenance at what may be irregular intervals, but determining these intervals by the actual condition of the machine at the time. For such condition based maintenance to be possible, it is essential to have knowledge of the machine condition and its rate of change with time. The main function of condition monitoring is to provide this knowledge. The knowledge may be obtained by selecting a suitable parameter for measuring deterioration, and recording its value at intervals. Assessing the trend of this measurement can give useful lead information well in advance warning of incipient machine failure. This is known as trend monitoring.

In this condition monitoring of a machine can be done using vibration analysis. Vibration pickup is made by accelerometers permanently mounted on the monitored machines. These are highly sensitive, rugged transducers capable of withstanding long periods in "harsh" environments. The accelerometers are certified as intrinsically safe for use in the potentially explosive atmosphere.

The readings are taken using the accelerometer and saved in Digital Signal Oscilloscope(DSO). The readings are analyzed using MATLAB program. From that defects in the machine can be observed.

# CHAPTER-2

# CONDITION MONITORING

# 2.CONDITION MONITORING:

## 2.1 General Fault Symptoms of a real time machine:

Machine faults can be identified by a number of symptoms such as an increase or decrease in bearing temperature or mechanical and acoustic vibration, loss of performance, increase in emissions, etc. In the case of many types of faults, it is often possible to identify an increase in mechanical vibration before other symptoms appear.

Each rotating component in a machine has an effect on the overall vibration picture. These effects can be individually identified by a dissection of the total vibration into its constituent components, to create a clearer view and allow the individual causes to be seen and identified.

The most commonly used method used for this extraction is a frequency spectrum analysis – better known as an FFT. However some faults are easier to identify using a phase analysis – e.g. misalignment - due to the fact that an FFT does not show the phase information. Other types of faults, e.g. certain gear faults, require the original time-signature or a Cepstrum analysis to be identified.

However the task of accurately diagnosing faults is nevertheless a complex one and requires intensive training, experience, powerful vibration analysers and detailed technical information about the machine.

## 2.2 Fault detection:

In vibration measurements there are many techniques that may be used, but not all techniques are equally well suited for all purposes. The main challenge for maintenance is to keep track of the current status of the machinery: Are they in good shape – or are they getting worn out, and if so:

- What is the lead-time to failure?
- what is the developing fault?

The main objective is: To detect if faults are present.

Therefore the scope is to utilize techniques that easily reveal if any of the possible faults on a machine is present and developing.

Condition monitoring applies systematic recording and trending of process and vibration data – to make a history of operation. Performance monitoring uses the raw process data to look behind the actual measurements to:

- Keep track of operational losses to reduce operational cost.
- Increase availability by monitoring degradation of component performance.
- Gain better understanding of the machines behaviour.
- Make better maintenance decisions.

Integration of performance and vibration monitoring makes all relevant information available from the past to the present. It provides selectable overall overviews to satisfy different needs and users.

## 2.3 Block diagram:

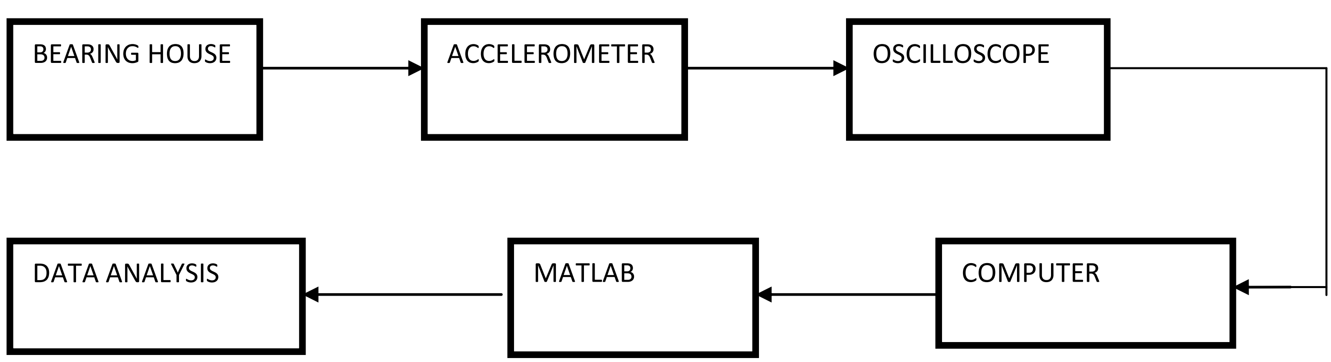


**Fig.2.1 Overall block diagram of the condition monitoring system**

## 2.4 Methods in condition monitoring:

Automatic supervision was in the past mostly realized by limit checking of important process variables, e.g, force, speed, pressure. Usually alarms are raised if limit values are exceeded and operators have to act or protection systems act automatically, especially for safety related processes. This is in many cases sufficient to prevent larger failures or damage. However, faults are detected rather late and a detailed fault diagnosis is mostly not possible with this simple limit-checking method.

Methods of modern system theory show the systematic use of mathematical process and signal models, identification and estimation methods of computational intelligence. With these methods it is possible to develop advanced methods of fault detection and diagnosis in order to detect already to detect already small faults early and to diagnose their origins. This is also called condition monitoring.

This can be described as all activities that lead to real-time or quasi-continuous knowledge of the condition of plant machinery. Our range of portable (off-line) and permanent (on-line) systems - both hardware and software - can ensure we have a finger on the pulse of every item of our plant and machinery.

Whether

- Exclusively Off-line data acquisition.
- Exclusively On-line data acquisition.
- On-line intermittent acquisition.
- On-line continuous acquisition.

- A mixture of intermittent/continuous.
- An integration of Off-line/On-line systems.

The goals of these methods are, for example:

- Increase of reliability and availability.
- Improvement of safety.
- Detection and diagnosis of faults in components.
- Process condition-based maintenance and repair.
- Supervision of processes in transient states.
- Deep quality control of assembled products .

Condition monitoring (or, colloquially, CM) is the process of monitoring a parameter of condition in machinery (vibration, temperature etc.), in order to identify a significant change which is indicative of a developing fault. It is a major component of predictive maintenance. The use of condition monitoring allows maintenance to be scheduled, or other actions to be taken to prevent failure and avoid its consequences. Condition monitoring has a unique benefit in that conditions that would shorten normal lifespan can be addressed before they develop into a major failure.

Condition monitoring techniques are normally used on rotating equipment and other machinery (pumps, electric motors, internal combustion engines, presses), while periodic inspection using non-destructive testing techniques and fit for service (FFS) evaluation are used for stationary plant equipment such as steam boilers, piping and heat exchangers.

## 2.5 Types of condition monitoring:

Some of the standard technologies in condition monitoring are:

1. Vibration Analysis
2. Oil Analysis
3. Thermal Analysis
4. Ultrasound Analysis

The vibrations produced in a machine are the best indication of a machine's health since the dawn of condition monitoring systems. Vibration monitoring can alert us to so many different conditions that may indicate potential machine failures. This may include

1. Unbalance misalignment
2. Bearing faults
3. Resonance
4. Looseness
5. Cavitations
6. Electrical problems
7. Hydraulic forces
8. Aerodynamic forces
9. Bent shafts
10. Gear problems
11. Frictional forces

Vibration analysis involves the measurement of amplitude, frequency and phase of the vibration.

Amplitude measures how much movement occurs or severity of the vibration.

Frequency measures how often the movement occurs or how many cycles are there in a period of time.

Phase shows what direction the movement is in.

Transducers simply convert mechanical vibrations into electrical signals

Vibration can be measured using any of the following:

1. Displacement-Shaft riders, Proximity probes
2. Velocity- velocity transducer
3. Acceleration- Charge type, line drive, Constant voltage& constant current.

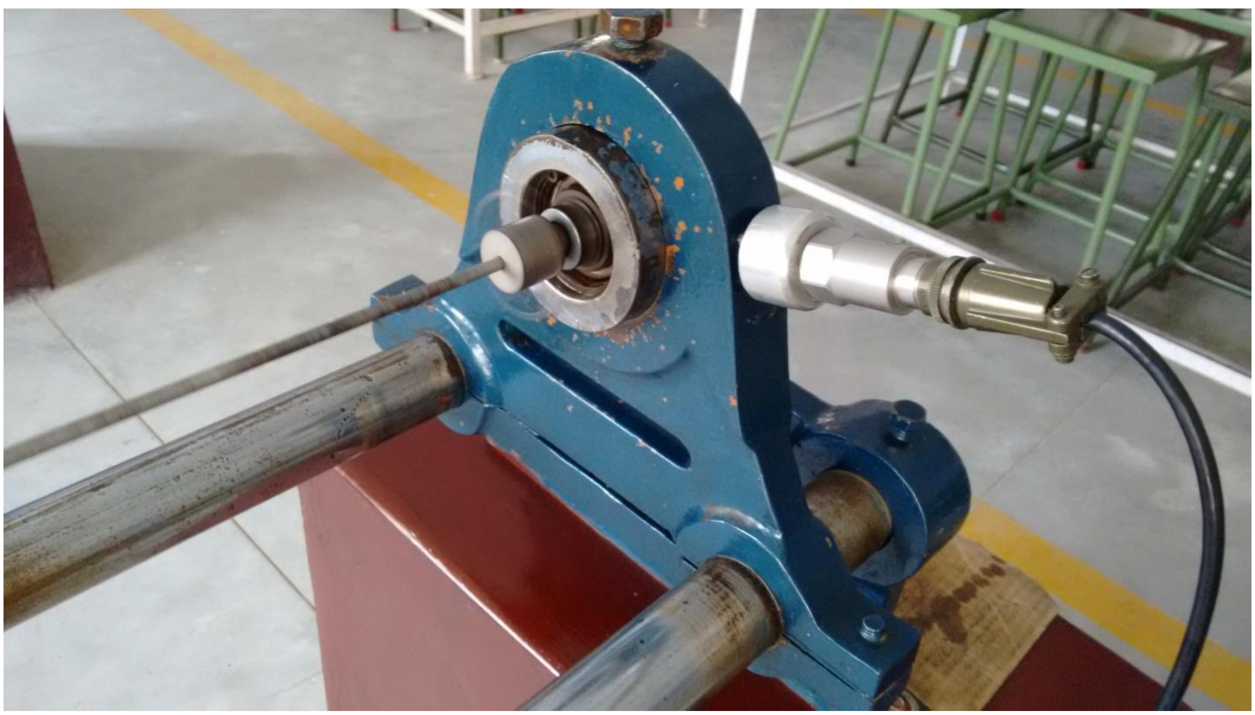

**Fig.2.2 Accelerometer mounted on bearing**

## 2.6 Advantages of condition monitoring:

| Lower costs | More efficiency | Better planning | Part of Totally Integrated Automation |
|---|---|---|---|
| **Customized systems** | **Optimized utilization of resources** | **Higher productivity** | **Transparency** |
| • Simple design | • Effective spare part inventories | • Longer life cycles | • Maintenance Station |
| • Easy system integration | • Device diagnos-tics | • Planned standstills | • Process data recording |
| • Open standards | • Planned maintenance | • Longer service intervals | • Quality assurance |
| • Web tools | • Simple cabling | • High availability | • Mechanical wear |
| • Expandability | • Ruggedness/ stability | • Investment pro-tection | • Worldwide service/support |

**Table.2.1 Advantages of condition monitoring**

# CHAPTER-3

# VIBRATION ANALYSIS

# 3.VIBRATION ANALYSIS:

The most commonly used method for rotating machines is called a vibration analysis. Measurements can be taken on machine bearing casings with accelerometers (seismic or piezo-electric transducers) to measure the casing vibrations, and on the vast majority of critical machines, with eddy-current transducers that directly observe the rotating shafts to measure the radial (and axial) displacement of the shaft. The level of vibration can be compared with historical baseline values such as former start ups and shutdowns, and in some cases established standards such as load changes, to assess the severity.

Vibration is a time-based (periodic/cyclic) displacement of an object around a center static position. The following contributing factors have a complex relationship with the magnitude and rate of the vibration:

- The object's own natural frequencies and stiffness
- The amplitude and frequencies of any external energy source(s) inducing the vibration
- The coupling mechanism between vibration energy source and the object of interest.

## 3.1 Vibration measurement:

Vibration measurement is complex because of its many components – displacement, velocity, acceleration, and frequencies. Also, each of these components can be measured in different ways – peak-to-peak, peak, average, RMS; each of which can be measured in the time domain (real-time, instantaneous measurements with an oscilloscope or data acquisition system) or frequency domain (vibration magnitude at different frequencies across a frequency spectrum), or just a single number for “total vibration.”

Vibration measurement is sometimes used as an indirect measurement of some other value. The final measurement goal determines the approach to the measuring vibration.Often, condition monitoring– predicting or monitoring wear, fatigue, and failure – requires vibration measurements meant to determine the kinetic energy and forces acting upon an object . This is often called inertial vibration.

Monitoring machinery motors (especially the bearings) in critical applications is an example. In these cases, the measurement of acceleration provides an easy conversion to units of force assuming the mass of the object is known.

## 3.2 Detection of the signal:

Interpreting the vibration signal obtained is an elaborate procedure that requires specialized training and experience. It is simplified by the use of state-of-the-art technologies that provide the vast majority of data analysis automatically and provide information instead of raw data. One commonly employed technique is to examine the individual frequencies present in the signal. These frequencies correspond to certain mechanical components (for example, the various pieces that make up a rolling-element bearing) or certain malfunctions (such as shaft unbalance or misalignment).

By examining these frequencies and their harmonics, the CM specialist can often identify the location and type of problem, and sometimes the root cause as well. For example, high vibration at the frequency corresponding to the speed of rotation is most often due to residual imbalance and is corrected by balancing the machine. As another example, a degrading rolling-element bearing will usually exhibit increasing vibration signals at specific frequencies as it wears.

Special analysis instruments can detect this wear weeks or even months before failure, giving ample warning to schedule replacement before a failure which could cause a much longer down-time. Beside all sensors and data analysis it is important to keep in mind that more than 80% of all complex mechanical equipment fail accidentally and without any relation to their life-cycle period.

## 3.3 Signal analysis:

Most vibration analysis instruments today utilize a Fast Fourier Transform (FFT ) which is a special case of the generalized Discrete Fourier Transform and converts the vibration signal from its time domain representation to its equivalent frequency domain representation. However, frequency analysis (sometimes called Spectral Analysis or Vibration Signature Analysis) is only one aspect of interpreting the information contained in a vibration signal.

Frequency analysis tends to be most useful on machines that employ rolling element bearings and whose main failure modes tend to be the degradation of those bearings, which typically exhibit an increase in characteristic frequencies associated with the bearing geometries and constructions. Depending on the type of machine, its typical malfunctions, the bearing types employed, rotational speeds, and other factors, the CM specialist may use additional diagnostic tools, such as examination of the time domain signal, the phase relationship between vibration components and a timing mark on the machine shaft, historical trends of vibration levels, the shape of vibration, and numerous other aspects of the signal along with other information from the process such as load, bearing temperatures, flow rates, valve positions and pressures to provide an accurate diagnosis. This is particularly true of machines that usefluid bearings rather than rolling-element bearings.

To enable them to look at this data in a more simplified form vibration analysts or machinery diagnostic engineers have adopted a number of mathematical plots to show machine problems and running characteristics, these plots include the bode plot, the waterfall plot, the polar plot and the orbit time base plot amongst others.

Handheld data collectors and analyzers are now commonplace on non-critical or balance of plant machines on which permanent on-line vibration instrumentation cannot be economically justified. The technician can collect data samples from a number of machines, then download the data into a computer where the analyst (and sometimes artificial intelligence) can examine the data for changes indicative of malfunctions and impending failures.

For larger, more critical machines where safety implications, production interruptions (so-called "downtime"), replacement parts, and other costs of failure can be appreciable (determined by the criticality index), a permanent monitoring system is typically employed rather than relying on periodic handheld data collection. However, the diagnostic methods and tools available from either approach are generally the same.

Recently also on-line systems have been applied to heavy process industries such as pulp, paper, mining, petrochemical and power generation. These can bededicated systems like Sensodec 6S or nowadays this functionality has been embedded into DCS.

## 3.4 Performance monitoring:

Performance monitoring is a less well-known condition monitoring technique. It can be applied to rotating machinery such as pumps and turbines, as well as stationary items such as boilers and heat exchangers. Measurements are required of physical quantities: temperature, pressure, flow, speed, displacement, according to the plant item. Absolute accuracy is rarely necessary, but repeatable data is needed. Calibrated test instruments are usually needed, but some success has been achieved in plant with DCS (Distributed Control Systems).

Performance analysis is often closely related to energy efficiency, and therefore has long been applied in steam power generation plants. Typical applications in power generation could be boiler, steam turbine and gas turbine. In some cases, it is possible to calculate the optimum time for overhaul to restore degraded performance.

# CHAPTER-4

# ACCELEROMETER

## 4.ACCELEROMETER:

An accelerometer behaves as a damped mass on a spring. When the accelerometer experiences an acceleration, the mass is displaced to the point that the spring is able to accelerate the mass at the same rate as the casing. The displacement is then measured to give the acceleration.

In commercial devices, piezoelectric piezoresistive and capacitive components are commonly used to convert the mechanical motion into an electrical signal. Piezoelectric accelerometers rely on piezoceramics (e.g. lead zirconate titanate) or single crystals (e.g. quartz, tourmaline). They are unmatched in terms of their upper frequency range, low packaged weight and high temperature range. Piezoresistive accelerometers are preferred in high shock applications. Capacitive accelerometers typically use a silicon micro-machined sensing element. Their performance is superior in the low frequency range and they can be operated in servo mode to achieve high stability and linearity.

Modern accelerometers are often small micro electro-mechanical systems (MEMS), and are indeed the simplest MEMS devices possible, consisting of little more than a cantilever beam with a proof mass (also known as seismic mass). Damping results from the residual gas sealed in the device. As long as the Q-factor is not too low, damping does not result in a lower sensitivity.

Under the influence of external accelerations the proof mass deflects from its neutral position. This deflection is measured in an analog or digital manner. Most commonly, the capacitance between a set of fixed beams and a set of beams attached to the proof mass is measured. This method is simple, reliable, and inexpensive. Integrating piezoresistorsin the springs to detect spring deformation, and thus deflection, is a good alternative, although a few more process steps are needed during the fabrication sequence. For very high sensitivities quantum tunneling is also used; this requires a dedicated process making it very expensive. Optical measurement has been demonstrated on laboratory scale.

Another, far less common, type of MEMS-based accelerometer contains a small heater at the bottom of a very small dome, which heats the air inside the dome to cause it to rise. A thermocouple on the dome determines where the heated air reaches the dome and the deflection off the center is a measure of the acceleration applied to the sensor.

Most micromechanical accelerometers operate in-plane, that is, they are designed to be sensitive only to a direction in the plane of the die. By integrating two devices perpendicularly on a single die a two-axis accelerometer can be made. By adding another out-of-plane device three axes can be measured. Such a combination may have much lower misalignment error than three discrete models combined after packaging.

Micromechanical accelerometers are available in a wide variety of measuring ranges, reaching up to thousands of g's. The designer must make a compromise between sensitivity and the maximum acceleration that can be measured.

Accelerometers are also used for machinery health monitoring to report the vibration and its changes in time of shafts at the bearings of rotating equipment such as turbines,pumps, fans, rollers, compressors or bearing fault which, if not attended to promptly, can lead to costly repairs. Accelerometer vibration data allows the user to monitor machines and detect these faults before the rotating equipment fails completely.

The most economic and versatile sensor for vibration measurements is the accelerometer. On rotating machinery these measure the radial forces on shafts and bearings. As the machine rotates a sensor fixed to the machine experiences a force on each revolution pushing or pulling it depending upon the orientation of the machine shaft. As the machine runs, a periodic vibration is observed at the sensor. The output of the sensor can be used to analyse the intensity and frequency of these vibrations which are a measure of the condition of the machine.

On moving objects, such as vehicles, or large structures such as tall buildings, towers or bridges, acceleration will not be periodic or, if so, it will be at very low frequency. In this case an accelerometer will still yield valuable data on the magnitude and time over which the forces are experienced or exerted.

Artificially created ground and building vibrations experienced during building, blasting, drilling or piling activities can also be sensed by accelerometers but as the vibrations are usually random the data must be acquired and analysed in quite different ways to allow sensitive vibration logging.

Natural ground vibrations, earthquakes and tremors are also detected by accelerometers built into measuring systems known as seismographs. Natural ground vibrations have long periods and generally require much higher sensitivities than machine vibration measurements and are outside Monitran's scope of supply.

Shocks, such as experienced in crash, gunnery and explosive tests can also be measured by accelerometers though in this case there is usually a sudden deceleration at vehicle impact or acceleration at projectile release. The signal is transient over small fractions of a second but will be of very high magnitude. Sensors with very low signal filtering and optimised electronics are needed for this. Again, this is not a Monitran speciality.

## 4.1 Types of accelerometer:

As with most technologies there are many ways a physical quantity can be sensed and there are numerous types of vibration sensor but for machine vibrations and many test and measurement applications piezoelectric and piezoresistive (strain gauge) sensors predominate.

## Piezoelectric accelerometer

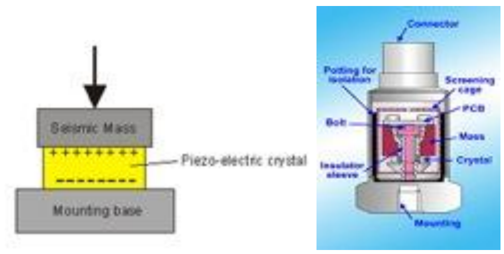


**Fig.4.1 Piezoelectric accelerometer**

This commonly encountered accelerometer consists of a piezoelectric crystal held in compression by a known mass which when mounted on a machine is periodically compressed and relaxed during each rotation. Charge in the crystal increases during compression and decreases during relaxation as force is periodically applied and released; generating an alternating current signal.

This minute signal of only a few Pico coulombs is then conditioned and amplified by either an internally or externally mounted charge amplifier to produce a useful alternating voltage for analysis. The accelerometer element alone can operate up to 250ºC without damage or severe loss of sensitivity while accelerometers with inbuilt amplifiers are limited to 125ºC or, in some cases, 140ºC maximum operating temperature.

- Vibration causes the mass to accelerate
- This produces a distorting force on the crystal
- The force on the crystal is proportional to the acceleration as F=ma
- Piezoelectric crystal produces a current proportional to the distorting force exerted.

As a machine rotates and vibrates the bearings, for example, experience periodic accelerations, for that is what vibration is. However, we could also measure the velocity or displacement that accompany these vibrations. At normal machine speeds displacement is too small to yield useful data though velocity measurements have some interesting properties.

- Secondly, if the AC signal is conditioned to give its RMS (average intensity) value then a simple DC signal is generated which is ideal for monitoring and control processes. Usually, this is presented as a 4-20mA signal proportional to the range of the sensor in mm/sec and accessible directly by a PLC or other industrial controller. No signal analysis or special power supplies are necessary and extended cable runs are possible, easily up to a kilometre with good quality cable.

## 4.2 Process for taking measurement:

Before taking a vibration measurement, we need to attach a sensor that can detect vibration behavior 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.

What is the acceleration of a vibrating component? It is a measure of how quickly the velocity of the component is changing.

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

The diagram below is a very simplistic explanation of how vibration data is acquired.

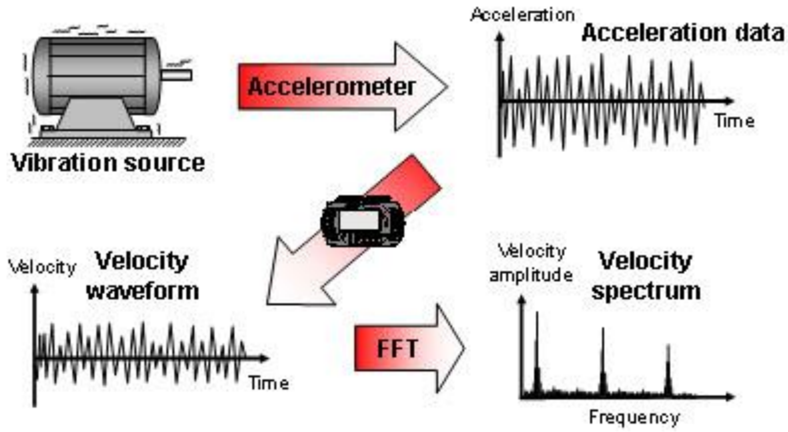


**Fig.4.2 Process of obtaining FFT spectrum**

## 4.2.1 Mounting of accelerometer:

Most machines involve rotary mechanisms. Motors, pumps, compressors, fans, belt conveyors, gearboxes, all involve rotary mechanisms and are frequently used in machines.

Most rotary mechanisms in turn have bearings that support the weight of rotating parts and bear the forces associated with rotary motion and vibration. In general, large amounts of force are borne by bearings. It is not surprising that bearings are often the place where damage occurs and where symptoms first develop.

Vibration measurements are thus usually taken at the bearings of machines, with accelerometers mounted at or near the bearings.

Since conclusions regarding machine condition - and hence whether or not money and human safety are risked - depend on the accuracy of measurements, we must be very careful how measurements are taken. It is important to always remember that the way in which we mount the accelerometer very much determines the accuracy of measurements. How should accelerometers be mounted to ensure measurements are accurate and how can we do so safely? Here are some guidelines:

When measuring vibration we must always attach the accelerometer as close as possible to the bearing. More specifically, we must attach it as close as possible to the centerline of the bearing to avoid picking up distorted signals.

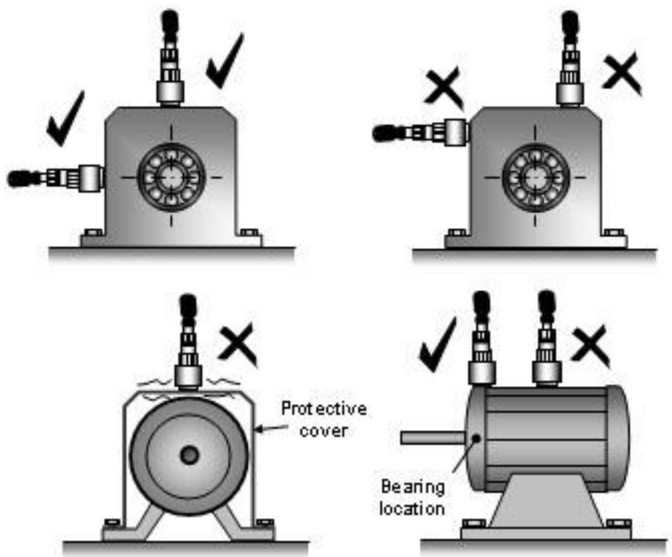


**Fig.4.3The mounting procedure**

For the accelerometer to detect true vibration behavior, it needs to undergo exactly the same vibratory movement as the vibrating component. An accelerometer must therefore be attached firmly to the vibrating component so that it does not rock or move independently of the component. A loosely mounted accelerometer produces signals distorted by its own independent movements and therefore gives the wrong message. Various mounting methods exist and convenience to the user. The magnetic mounting supplied in the Commtest vb kit can be attached very firmly, while allowing the user to measure multiple machines using the same accelerometer, with minimum time spent on attaching and detaching the accelerometer.

To ensure that the accelerometer is firmly attached, it must be stuck to a magnetic mounting surface this is even. The magnetic mount must sit securely on the surface with the accelerometer positioned in the prescribed orientation.

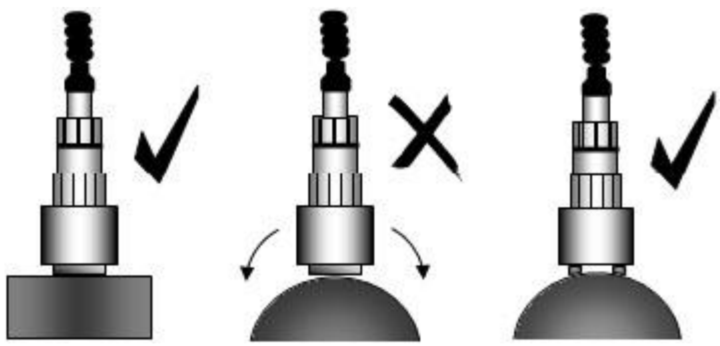

**Fig.4.4 Position of accelerometer**

For the surface to be even, it must be free of debris, rust, and flaking paint.


**Fig.4.5 Wrong mounting procedure**

The mounting surface must be truly magnetic (iron, nickel, or cobalt alloys). The magnetic mounting must not, for example, be attached to an aluminum surface by virtue of iron beneath the aluminum surface.

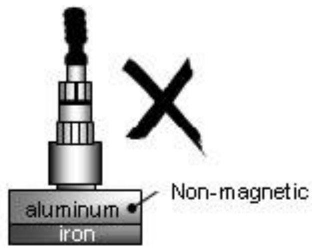


**Fig.4.6 Wrong mount on nonmagnetic material**

To avoid loss of magnetism, the magnetic mounting must not be dropped or heated. Care must also be taken not to strip the screw thread on the accelerometer and magnetic mounting.

**Fig.4.7 Improper removal of accelerometer**

Different situations require the accelerometer to be oriented differently. For example, to detect parallel misalignment the accelerometer is usually mounted in the radial direction of the bearings, but to detect angular misalignment the accelerometer needs to be mounted in the axial direction.

The signal produced by the accelerometer is dependent on the orientation in which the accelerometer is mounted, since the amplitude (amount) of vibration varies in different directions.

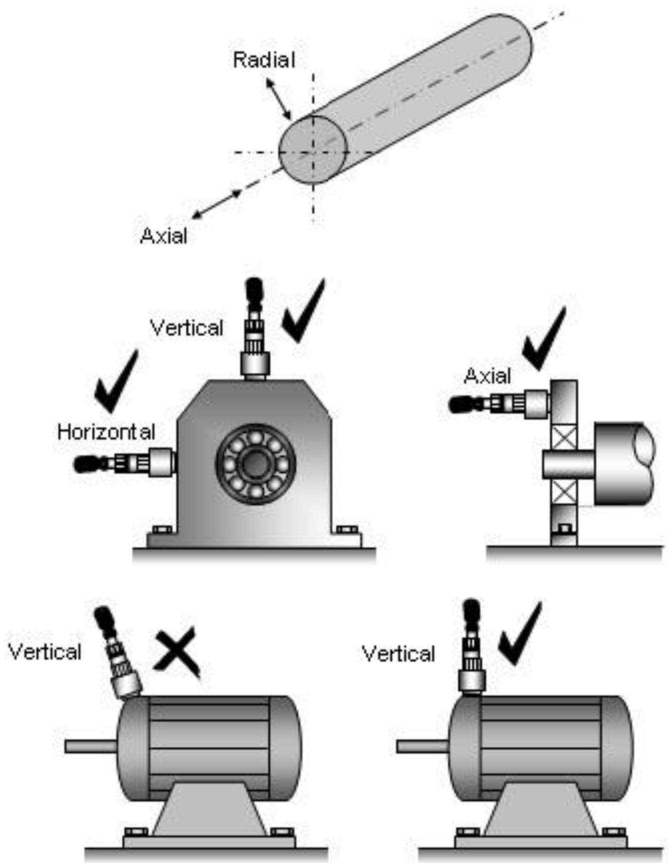


**Fig.4.8 Different kinds of mounting**

For a particular measurement point it is important to always mount the accelerometer at the same location to minimize measurement inconsistencies that may lead to wrong conclusions. Where possible, always use the same accelerometer for a particular measurement point.

The accelerometer must never be mounted on a very flexible part of the machine as the spectrum will be distorted by the flapping of the flexible part.

The accelerometer must never be used on structures that are very light as the weight of the accelerometer and magnetic mounting will distort the vibration behavior of the structure.

### 4.2.2 Safety of accelerometer:

If the accelerometer is treated roughly it may produce unreliable signals. Because of the strength of the magnetic mount, we must take care when attaching the accelerometer to a mounting surface. We can achieve this by approaching the mounting surface with the magnetic mounting tilted at an angle. When detaching the magnetic mounting, we must not use the accelerometer as a lever for breaking contact. Instead, the magnetic mounting should be gripped tightly and then tilted sideways to break the contact.

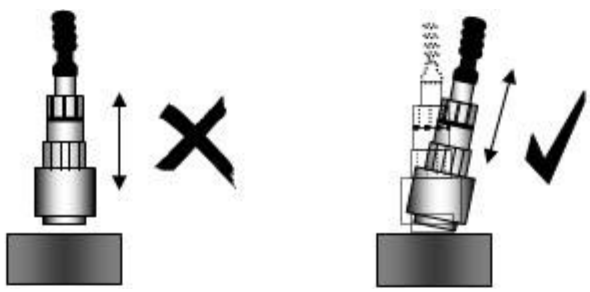

**Fig.4.9 Right way of removal**

The accelerometer cable should never be twisted acutely, but must be anchored in a manner that prevents it from being damaged. Twisted or freely swinging cables can distort the measured spectrum.

### 4.2.3 Averaging process:

When vibration is measured several spectra are usually measured and then averaged to produce an average spectrum. The average spectrum better represents vibration behavior as the averaging process minimizes the effect of random variations or noise spikes that are inherent in machine vibration.

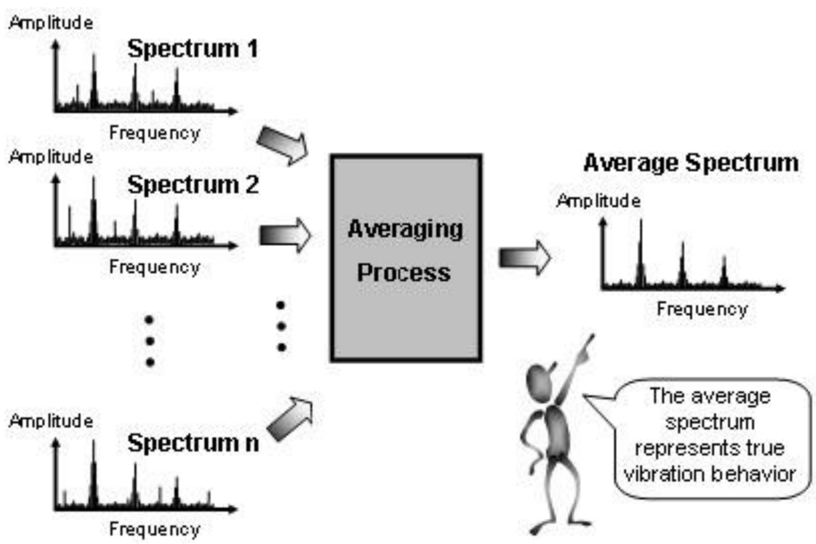


**Fig.4.10 Averaging process**

The parameter ‘Average type’ determines how spectra are averaged. ‘Linear’ averaging is recommended for most cases. ‘Exponential’ averaging is usually used only if vibration behavior varies significantly over time. ‘Peak hold’ does not really involve averaging but causes the worst-case (largest) amplitude for each spectral line to be displayed.

The parameter ‘Number of averages’ determines the number of consecutive spectra used for averaging. The larger the number of spectra used for averaging, the more noise spikes are smoothed out and the more accurately true spectral peaks are created.

However, the larger the number of averages, the more data needs to be collected, and therefore the longer it takes to obtain the 'average spectrum'. A 'Number of averages' of 4 is sufficient for most cases.

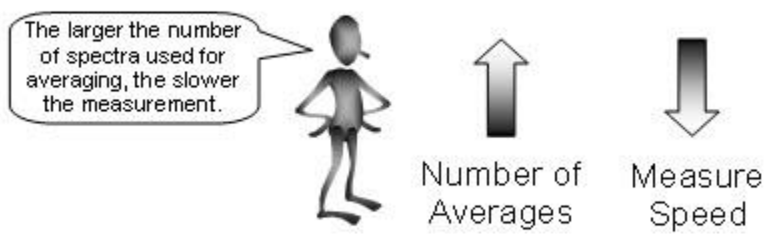


**Fig.4.11 Performance averaging relation**

The collected data is usually not directly used to generate a spectrum, but is often modified beforehand to cater for certain limitations of the FFT process (the process that transforms the data into a spectrum). Data is usually modified by multiplication with a correction window.

For vibration spectra, the peak amplitude at a particular frequency is exactly √2 times (roughly 1.4 times) the rms amplitude at that frequency. Thus which amplitude type is used is not really important since amplitude conversions[7] may be readily done. A switchover from the rms amplitude to the peak

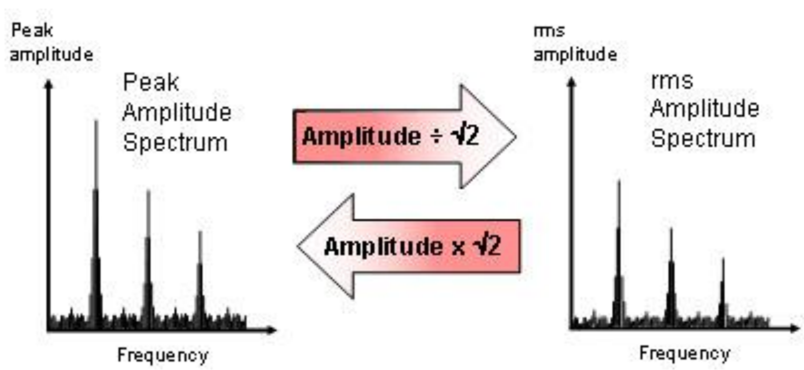


**Fig.4.12 Transformation process**

amplitude causes an apparent rise in vibration amplitude that might be mistakenly interpreted as machine deterioration. On the other hand, a switchover from the peak amplitude to the rms amplitude might hide a genuine rise in vibration amplitude.

Finally, the amplitude and frequency units to be used in the spectrum also need to be specified. Which units should be used is really a matter of personal choice, or more often, geographic location. The analogue signal from the vibration sensor passes through the input amplifier, anti-aliasing filter and A/D converter, where it is digitized and enters the data buffer. From the buffer it can be displayed either as a time waveform or can be further processed by the Fourier transform to obtain frequency spectrum.

# CHAPTER-5

# ROTATING SHAFTS

## 5.ROTATING SHAFTS:

Rotating shafts or rotors are part of most systems. All rotating shafts, even in the absence of external load, deflect during rotation due to self weight. The combined weight of a shaft and shaft-mountings can cause deflection that will create resonant vibration at some speed. Shaft deflection depends upon the followings:-

a) Material Stiffness and number of supports

b) Self Weight and mountings

c) Unbalanced centrifugal forces

d) Lubricant viscosity

These shafts exhibit excessive lateral vibrations at these speeds and the machines must not be run for any length of time in this particular speed which would otherwise prove derogatory to the health of the machine. Hence, it is imperative to find the speed with which this occurs. The angular velocity of the shaft at which this occurs is called a critical speed or whirling speed or whipping speed. At a critical speed, the shaft deflection becomes excessive and may cause permanent deformation or structural damage.

The critical speed is the theoretical angular velocity that excites the natural frequency of a rotating object, such as a shaft. As the speed of rotation approaches the object's natural frequency, the object begins to resonate, which dramatically increases system vibration. The resulting resonance occurs regardless of orientation.

Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force.

Free vibrations of any elastic body is called natural vibration and happens at a frequency called natural frequency. Natural vibrations are different from forced vibration which happen at frequency of applied force (forced frequency). If forced frequency is equal to the natural frequency, the amplitude of vibration increases manifold. This phenomenon is known as resonance.

Normally the centre of gravity of a loaded shaft will always displace from the axis of rotation although the amount of displacement may be very small. As a result of this displacement, the centre of gravity is subjected to a centripetal acceleration as soon as the Shaft begins to rotate. The inertia force acts radially outwards and bend the shaft. The bending of shaft not only depends upon the value of eccentricity, but also depends upon the speed at which the shaft rotates.

## 5.1 The theoretical formula for critical speed :

$f_n = K\sqrt{(EgI/wl^4)}$ and $N_c = f_n X 60$

Where,

$f_n$=natural frequency of vibration in Hz.

g = acceleration due to gravity, (9.81m/s2).

E= modules of elasticity of the shaft.

I = moment of inertia of shaft.

w=weight/unit length in N/m

L = effective length of the shaft between supports in m.

N=speed of the shaft in RPM.

K= constant .

Normally, the status of rotary machines cannot be evaluated directly. Since vibrations spike during resonance, the vibration signals produced by these machines must first be measured and then analyzed in detail. The information about a fault in the rotary machines is reflected by singular points of abrupt changing signals and, because of that, it is important to detect dynamic changes of the signal in time to get an anticipatory information about the fault.

For the shaft under observation, the critical frequency was a 25Hz and corresponding value in RPM was 1500 .

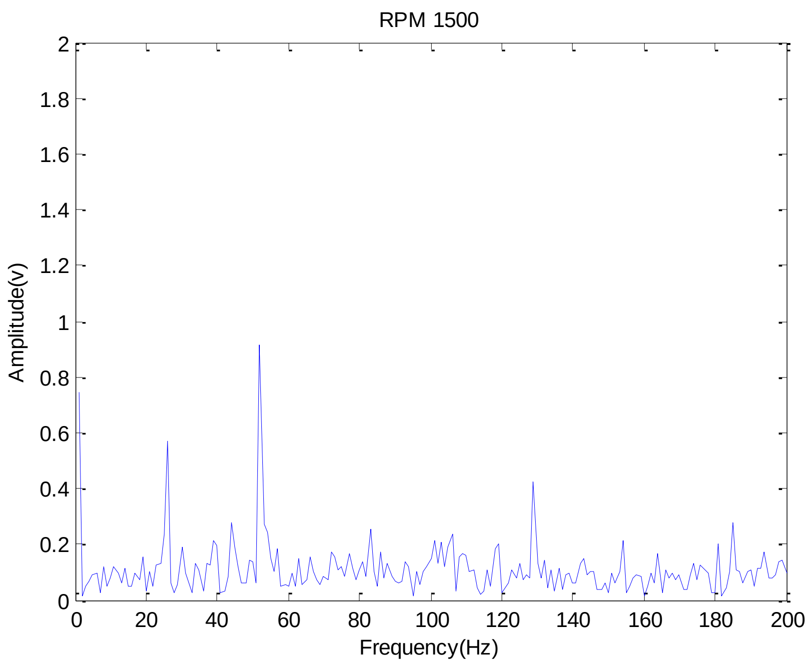


**Fig.5.1 Frequency response of 1500 RPM**

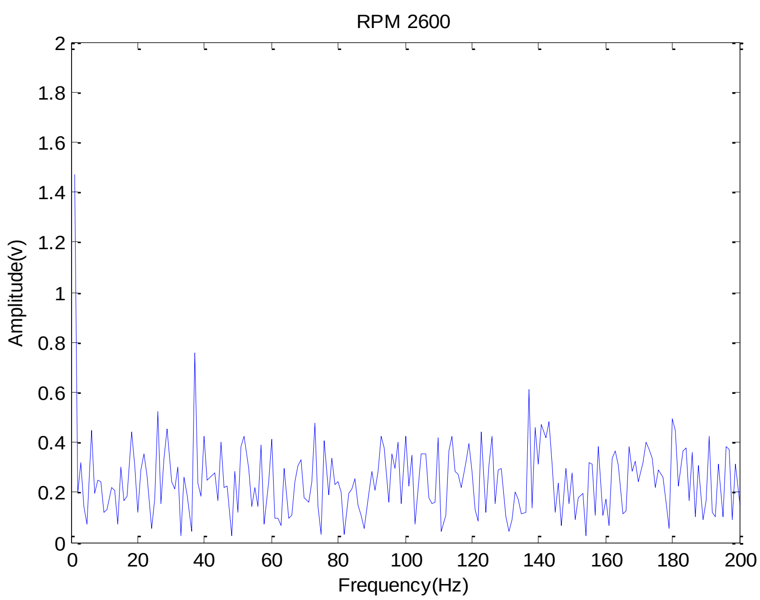


**Fig.5.2 Frequency response of 2600 RPM**

# CHAPTER-6

# BEA RING

# 6.**BEARING:**

Bearing failure is one of the most common faults in industrial machines. Proper condition monitoring is therefore of the highest importance. There are two main groups of bearing types:

- Rolling Element Bearings (REB)
- Journal Bearings

1. REB covers the whole family of Roller and Ball bearings, and the monitoring method is similar for Radial bearings of both types. The condition monitoring is normally done with one radial accelerometer and the use of some special measurement techniques with envelope detection as most important. REBs with thrust loads need additional measurements in the axial direction

2. Journal and plain bearings are in general tight-fitting cylinders, which encompass a shaft with some lubrication in between. The plane bearings are monitored with vibration, temperature and oil pressure as the most important parameters. Bigger radial bearings are normally monitored with a pair of displacement sensors, in order to measure shaft position, and shaft orbit and spectra are the major part of the vibration monitoring task.

All rotating equipment has one thing in common, bearings. In monitoring the health of our equipment, the condition of the bearings is of prime importance. Consider that if the bearings are good, even an out-of-balance, misaligned machine will operate. However, if the bearings are damaged, the machine will soon fail, even if properly assembled and managed.

A particularly common kind of rolling-element bearing is the ball bearing. “Ball bearings” use balls that roll on conformal raceways on the inner and outer rings' (races) outer and inner surfaces respectively. By having the raceway closely conform to the ball, rather than rolling on a pure cylinder, orders of magnitude greater load capacity are obtained. So common has this basic design become, that the term ball bearing has come to mean not just a spherical metal ball used in bearings, but a bearing itself that uses balls.

Thus, in principle, the ball contacts each race across a very narrow area. However, a load on an infinitely small point would cause infinitely high contact pressure. In practice, the ball deforms slightly where it contacts each race much as a tire flattens where it contacts the road. The race also yields slightly where each ball presses against it. Thus, the contact between ball and race is of finite size and has finite pressure. Note also that the deformed ball and race do not roll entirely smoothly because different parts of the ball are moving at different speeds as it rolls. Thus, there are opposing forces and sliding motions at each ball/race contact.

Rolling-element bearings often work well in non-ideal conditions, but sometimes minor problems cause bearings to fail quickly and mysteriously. For example, with a stationary (non-rotating) load, small vibrations can gradually press out the lubricant between the races and rollers or balls. Without lubricant the bearing fails, even though it is not rotating and thus is apparently not being used. For these sorts of reasons, much of bearing design is about failure analysis. Vibration based analysis can be used for fault identification of bearings.

For vibration analysis, a data collector is necessary. Common to most modern portable electronic data collectors is the accelerometer. These are generally constructed with a manmade piezoelectric crystal the generates an output voltage directly proportional to the acceleration applied. The accelerometer is usually placed on the bearing cap, or if not accessible, as near as possible. Since one of the analysis techniques involves trending of vibration levels, it is important data collection location be marked and the same location be consistently used each time.

Velocity measurements are used to monitor general machinery conditions and various engineering groups have derived acceptable conditions. Also ,it was accepted that slow speed equipment was very difficult to monitor because the signals were so low that they would be buried in the data collector's noise floor. There are good physical reasons for this; velocity is the resultant of dividing distance by relative long time results in a velocity of extremely low amplitude. Since we have difficulty measuring velocity, measuring the acceleration enables us to measure the amount of forces being generated inside the bearing.

Bearings are constructed of four parts: rolling element, inner ring, an outer ring and the cage. Each of these components will usually generate a unique frequency if damaged. As can be seen in the following frequency calculations, the frequency generated is based on the number of rolling elements, the shaft rotation speed, ball diameter and pitch diameter.

There is still a discussion if the rolling element excites the natural frequencies of bearing component when it passes the fault on any parts of bearing. Hence we need to identify the characteristics frequency of essential parts of the bearing. The bearing faults create impulses and results in strong harmonics of the fault frequencies in the spectrum of vibration signals. These fault frequencies are sometimes masked by adjacent frequencies in the spectra due to their little energy. Hence, a very high spectral resolution is often needed to identify these frequencies during a FFT analysis.

Hence, when the signal is sampled for FFT analysis, the sample length should be large enough to give adequate frequency resolution in the spectrum. Also, keeping the computation time and memory within limits and avoiding unwanted aliasing may be demanding. However, a minimum frequency resolution required can be obtained by estimating the bearing fault frequencies and other vibration frequency components and its harmonics due to shaft speed, misalignment, line frequency etc.

When the user examines the FFT display, if harmonics of the bearing components are present, there is damage. Then the user has to evaluate these damage indicators based on amplitude and shaft speed. For general machine condition, if the FFT displays multiple harmonics of the shaft rotation speed, this indicates looseness in the machine parts and not damage in the bearing. If there is a flaw on the rolling element, it will also generate a vibration although it will be at a different frequency. And it follows that if the cage has a defect, it will generate another frequency. So it is possible that a defective could generate four specific frequencies, all at the same time.

If the bearing is loose on the shaft, it will slowly rotate. The friction will generate heat, which in turn will cause the shaft and inner ring to expand. In this case, the shaft expanded more than the ring, to the point where all the fit tolerance were exceeded and then the ring cracked.

Approximately 90 percent of inner ring failures are caused by poor installation techniques. When the bearing is placed on the shaft by pushing on anything but the inner ring, damage will occur. Force on the cage will damage the cage and push the rolling elements against the lip of the races, causing damage to the rings. Even if the damage does not affect the machine operation, it will result in noisy bearings. When the misalignment occurs, an axial component is generated. When this excessive, the bearing begin to fail.

Tests with dry bearings show that lack of lubrication in plain bearings can have a marked effect on the form of whirl at the critical speed. The most important effect is the large increase in amplitude at the critical speed that would result from failure of the lubricating system. This is an important factor, especially in cases where a system is designed to have a critical speed below the operating speed, in edges of the bearings, or above that critical speed calculated on the assumption of linear which case a large amplitude of whirl may build up whilst running through the critical.

The length of bearing has no effect on the critical speed (except through the stiffening effect of the lubricant) unless the clearance is small or the unbalance forces are large, in which case the system will have non-linear stiffness characteristics and the critical speeds can only be estimated on the assumption of a known critical whirl amplitude or an accurate knowledge of the unbalance force and the damping in the system.

In the design stage, therefore, it would be necessary to calculate critical speeds assuming first a critical whirl amplitude within the first range of linear stiffness (support at the inner edges of the bearings only) and then a critical whirl amplitude which would be the maximum tolerable for smooth running of the system. Operating speeds should then be avoided between the two calculated criticals.

Due to initial bending under static load, a horizontal shaft-rotor system supported in long bearings is shown to be capable of having two critical speeds, near to, but less than, the speeds obtained by assuming linear stiffness with three or four-point support by the bearings. Ideally, a system of this type should be designed to operate at speeds below the critical speed calculated on the assumption of linear stiffness with simple support at the inner stiffness with four-point support across the bearings.

## 6.1 Defected frequency formulae:

Fundamental train frequency Nf=(1/2)*N*(1-(d/p))rpm.

Ball spin frequency Nb=(1/2)*N*(p/d)*(1-(d/p)^2))rpm.

Outer race frequency No=nz*Nf rpm.

Inner race frequency Ni=nz(N-Nf) rpm.

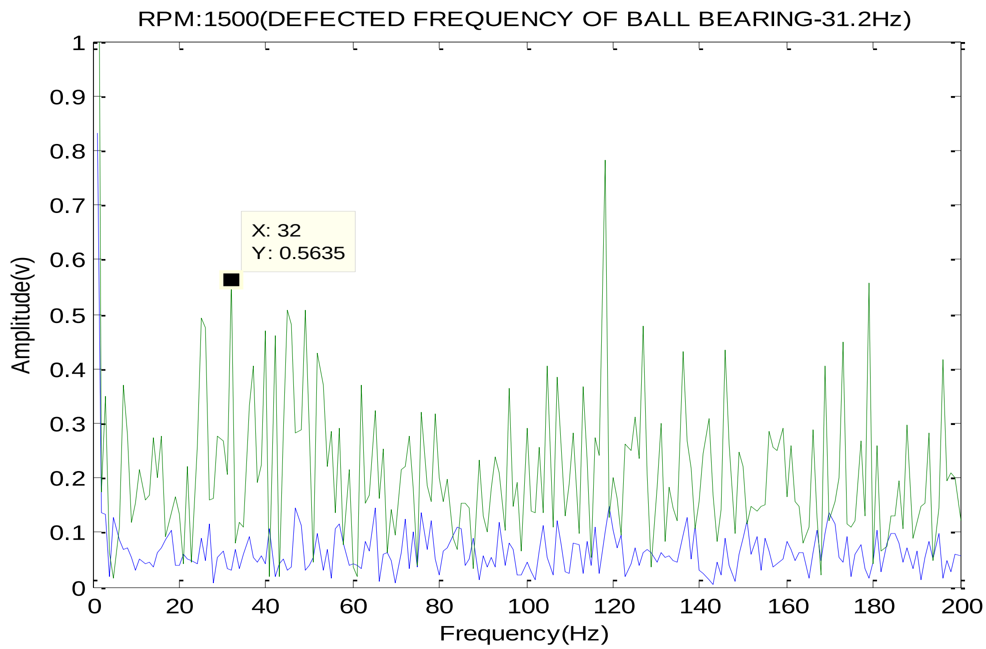


**Fig.6.1 Frequency response of 1500 RPM having ball spin defected frequency**

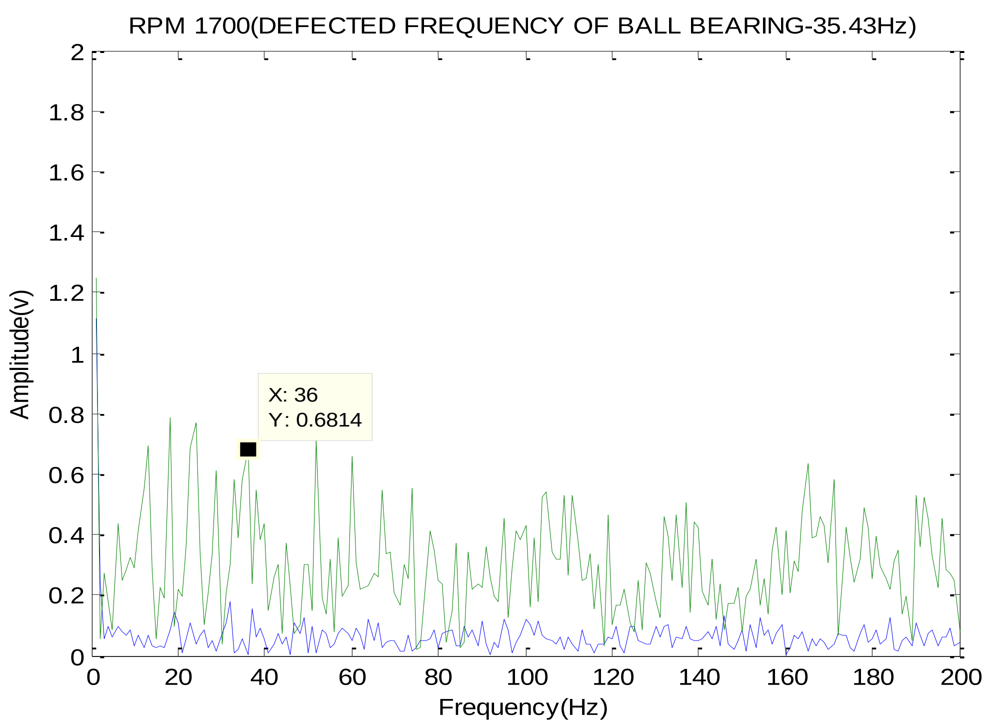


**Fig.6.2Frequency response of RPM 1700 having ball spin defected frequency**

# CHAPTER-7

# DYNAMIC BALANCING MACHINE

## 7.1 Study of a simple rotor:

Firstly,the behavior of a simple rotor is studied. The principal components of a rotor-dynamic system are the shaft or rotor with disk and the bearings. The shaft or rotor is the rotating component of the system. The other main components of rotor-dynamic systems are the bearings. The bearings support the rotating components of the system and provide the additional damping needed to stabilize the system.

When the features and response of the rotor is completely analyzed, any error that may occur can be pre-determined. The main reason for the rotor to result in error due to unbalance in the rotating device. It is because of this unbalance the efficiency of the rotor declines, the output deviates from original, the response varies.

In a rotor, the center of mass is the point about which the total mass of a rigid body is equally distributed. It is useful to assume that all the mass is concentrated at this one point for simple dynamic analyzes. A force vector that acts through this point will move the body in straight line, with no rotation, according to Newton's second law of motion, F=ma. The sum of all forces acting on the body ,F, cause a body to accelerate at a rate ,a, proportional to its mass,m. The axis of rotation is generally determined by geometric features on the rotor or by its support bearings a rotor with mass center slightly displaced from the axis of rotation will generate centrifugal force. This is the force associated with static unbalance. The shaft supports counteract the forces of unbalance which is the externally applied centripetal force. The location of the mass center and the principal inertia axes are determined by the distribution of mass within the part. Unbalance exists when the axis of rotation is not coincident with a principle inertia axis. Balance corrections can be accomplished by adding or removing weight. The correction can be made by adding weight at a particular spot or removing weight at an angle 180 degree opposite the weight add.

Unbalance in the rotor is the result of an uneven distribution of mass, which causes the rotor to vibrate. The vibration is produced by the interaction of an unbalanced mass component with the radial acceleration due to rotation, which together generate a centrifugal force. The vibration will be transmitted to the rotor's bearings and any point on the bearing will experience this force once per revolution.

## 7.2 Principle of Balancing:

A rotor is balanced by placing a correction mass of a certain size in a position where it counteracts the unbalance in the rotor.The size and position of the correction mass must be determined.The principle of performing field balancing is to make (usually temporary) alternations to the mass distribution of the rotor,by adding trial masses,and to measure the resulting phase and magnitude of bearing vibration.The effects of these trial corrections enable the amount and position of the required correction mass to be determined.

Any fixed point on the bearing experiences the centrifugal force due to the unbalance,once per revolution of the rotor.Therefore in a frequency spectrum of the vibration signal,unbalance is seen an increase in the vibration at the frequency of rotation.The vibration due to the unbalance is measured by means of an accelerometer mounted on the bearing housing.The vibration signal is passed through a filter tuned to the rotational frequency of the rotor,so that only the vibration at the rotational frequency is measured.The filtered signal is passed to a vibration meter,which displays the magnitude.The indicated vibration level is directly proportional to the force produced by the unbalanced mass.The phase meter measures and displays the phase between the signal from the tachometer probe(the reference signal)and the filtered vibration signal.The angle displaced by the meter enables us to locate the angular position on the rotor of the unbalance,relative to the datum position.

## 7.3Causes of rotor unbalance:

The unbalance in the rotor may be due to several factors.Some of the causes of unbalance are stated below:

### A)Manufacturing causes

Many causes are listed as contributing to an unbalanced condition, including material problems such as density,voids and blow holes. Fabrication problems such as eccentric machining and poor assembly.Distortion problem such as rotational stresses and temperature changes.

### B) Installed machine causes

When a rotor has been in service for some time, various other factors can contribute to the balance condition. These include corrosion, wear, distortion and deposit build up. Deposits can also break of unevenly, which can lead to severe unbalance. This particularly applies to rotating devices. Routine inspection and cleaning can minimize the effect, but eventually the machines will have to be removed from service for balancing. Large unbalances will of course require large weight corrections and unless care is taken, this can have a detrimental effect on the integrity of the rotor. Concentrating a weight at a given point can weaken the rotor.

The increase in amplitude of the signal due to addition of weiaht in the shaft is observed.

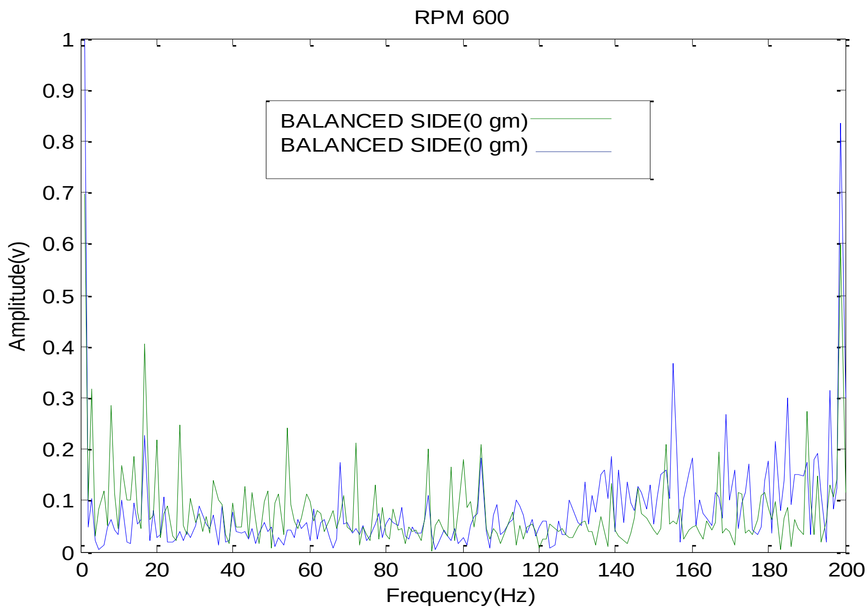


**Fig.7.1 Comparison of two balanced bearing**

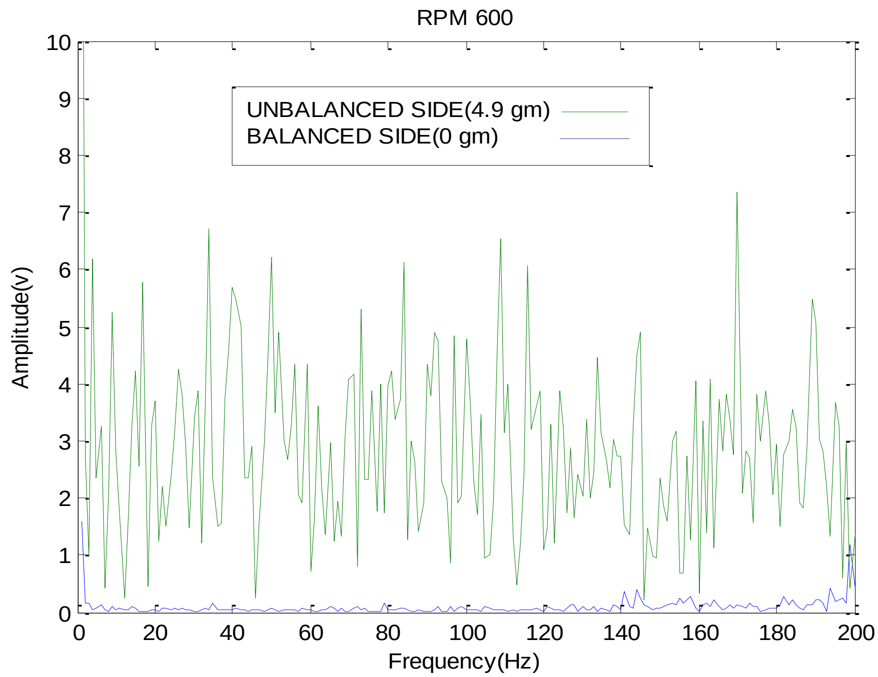


**Fig.7.2 Comparison of balanced and unbalanced bearing**

# CHAPTER-8

# CONCLUSION

# 8.CONCLUSION:

The current disparate condition monitoring systems, process computer and maintenance information databases do not allow or utilise data-warehouse operations, except to a limited extent at one plant.Thus,condition monitoring pertains to providing information on the condition of plant so that it can be maintained properly. By having such knowledge of machine condition, we can predict incipient failures and stop the plant for maintenance in a planned manner so that the minimum loss of output occurs and so that the maintenance can be carried out as efficiently as possible.

Normally, the status of rotary machines cannot be evaluated directly. Since vibrations spike during resonance, the vibration signals produced by these machine are measured and then analyzed in detail.After finding the critical speed of the shaft,we compared the vibrations between perfect and imperfect condition,thus analyzed the amplitude variations. From that ,we can able to find the defects in the rotary machines.

At present,we have found the defected peak frequency due to defects in the ball spin bearing.In future, defected peak frequencies due to defects in all essential parts in the rotary machines can be observed.

# CHAPTER -9

# REFERENCE

## 9.REFERENCE:


- The conditional monitoring of rolling element bearings using vibration analysis-by J.Mathew & R.J.Alfredson.
- Fault Detection and Diagnosis of Rotating Machinery-by Loparo K.A &Adams M.L.
- Experimental Investigation of Shafts on Whirling of Shaft Apparatus -Mr. Balasaheb Keshav Takle
- Detection of Fault in Rolling Element Bearing using Condition Monitoring by Experimental Approach-Sakshi Kokil, Prof. S. Y. Gajjal, Asst. Prof. M. M. Shah, Prof. S. D. Kokil
- Wear and multiple fault diagnosis on rolling bearings using vibration signal analysis D. Koulocheris, A. Stathis, Th. Costopoulos, A. Atsas

# CHAPTER-10

# APPENDIX

# 10.APPENDIX

## 10.1 MATLAB:

### 10.1.1 Introduction :

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C ,C++ and FORTRAN.Matlab is a case sensitive.

Typical uses include

- Math and computation.
- Algorithm development.
- Data acquisition Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an arraythat does not require dimensioning.

We can use MATLAB in a wide range of applications, including signal and image processing , communications, control design ,test and measurement, financial modeling and analysis and computational biology. Add-on toolboxes(collections of special-purpose MATLAB functions, available separately) extend the MATLAB environment to solve particular classes of problems in these application areas.

MATLAB provides a number of features for documenting and sharing your work. We can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications.

### 10.1.2 key feature :

- High-level language for technical computing.
- Development environment for managing code ,files and data.
- Interactive tools for iterative exploration, design and problem solving.
- Mathematical functions for linear algebra, statics, Fourier analysis, filtering, optimization and numerical integration.
- 2-D and 3-D graphics functions for visualizing data.
- Tools for building custom graphical user interface.
- Functions for integrating MATLAB based algorithms with external applications and languages ,such as C,C++, FORTRAN, Java, COM and Microsoft Excel.

  The MATLAB development environment lets you develop algorithms,interactively analyze data , view data files and manage projects.

### 10.1.3 MATLAB system:

The MATLAB system consists of five main parts:

### Development Environment:

This is the set of tools and facilities that help us touse MATLAB functions and files. Many of these tools are graphical userinterfaces. It includes the MATLAB desktop and Command Window, a commandhistory, an editor and debugger, and browsers for viewing help, the workspace,files, and the search path.

## The MATLAB Mathematical Function Library:

This is a vast collection ofcomputational algorithms ranging from elementary functions like sum, sine,cosine, and complex arithmetic, to more sophisticated functions like matrixinverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

## The MATLAB Language:

This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features.

## Graphics:

MATLAB has extensive facilities for displaying vectors and matricesas graphs, as well as annotating and printing these graphs. It includes high-levelfunctions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow us to fully customize the appearance of graphics as well asto build complete graphical user interfaces on our MATLAB applications.

## The MATLAB Application Program Interface (API):

This is a library thatallows us to write C and Fortran programs that interact with MATLAB. It includesfacilities for calling routines from MATLAB (dynamic linking), calling MATLAB computational engine, and for reading and writing MAT-files.

## Programming language is consist of:

(i) Data types

(ii) Algebraic and logical operators.

(iii) Mathematical relations.

(iv) Control statements

(v) Input and output accessing

(vi) Functions and subprograms.The MATLAB is very big package and but, it is almost equal to a language.

### 10.1.4 Commands:

Read  the input form excel sheet using the command

Xlsread('file name');

Getting the frequency response of the time domain signal using the command

Freqz('file name');