EXPERIMENTATION ON AN INDUSTRIAL FAN EQUIPMENT FOR FAULT DIAGNOSIS USING CONDITION BASED MAINTENANCE TECHNIQUE

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

BACHELOR OF TECHNOLOGY

in

MECHANICAL ENGINEERING

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CERTIFICATE

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ABSTRACT

Most industrial equipment demands intense cooling for its smooth uninterrupted operations. Industries commonly employ various fans or blowers for this application. Hence maintaining the cooling equipment is quite crucial for keeping the health of the industrial machinery. An industrial fan or blower used for the cooling application is thus important in keeping the critical component from failure due to inadequate cooling. The fans or blowers of industrial scale are comprised of motor, gearbox, bearings, couplings and other elements. The defects in any of these components may lead to sudden failure in the machine resulting in costly downtime. So, condition monitoring of this equipment is important to avoid failures. Condition Based Maintenance (CBM) is a proactive maintenance technique that helps to fault diagnosis of a machine in running condition. Several techniques are available and vibration analysis is one of them. Vibration analysis plays a vital role in identifying problems at an early stage with root cause. This study is concentrated on fault diagnosis of an industrial fan to avoid catastrophic failure of an Industrial fan and systems that rely on it for their cooling needs. The Fast Fourier Transform (FFT) analyser detects the frequencies of vibrations recorded in this equipment in horizontal, vertical and axial direction. The location of fault is indicated by FFT spectrum.

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CHAPTER 01

INTRODUCTION

1. INTRODUCTION

In Industrial context maintenance is an important activity to keep the equipment in healthy condition. Broadly speaking it is a set of activities to be carried out on any machinery to enhance the life of the equipment and to ensure the availability of machine for continuous and uninterrupted production. Maintenance is of two types i) Reactive Maintenance action taken after something is happened to the (breakdown) equipment. ii) Proactive Maintenance action taken before failure to avoid break down.

Condition Based Maintenance (CBM) is a proactive maintenance technique helps to fault diagnose of a machine system in running condition. This program is carried out in three steps i) Detection ii) Analysis iii) correction. In CBM techniques Vibration analysis plays a vital role in identifying problems at an early stage with root cause. It is performed by signal processing methods using FFT analysis. This project concentrated on fault diagnosis of an industrial fan used in Visakhapatnam Steel Plant, to prevent catastrophic failure of its critical component due to lack of cooling.

1.1 Overview of Visakhapatnam Steel Plant

Visakhapatnam steel plant, the first coastal based steel plant of India is located 16km from the west of City of Destiny i.e. Visakhapatnam (VSP). Bestowed with modern technologies, VSP has installed capacity of 4 million saleable steel. At Visakhapatnam, there is an emphasis on total automation seamless integration and structural products to meet stringent demands of discerning customers with India and abroad. VSP products met exalting international quality standards such as JIS, DIN, BIS, BS etc. VSP has become first steel plant to achieve the distinction of covering all process and products steam for ISO 9001.

VSP by successfully installing and operating efficiently Rs 460 core worth of pollution control equipment and converting the barren landscape by planting more than 3 million plants has made the steel plant, steel township and surround areas into a heaven of lush greenery. VSP exports quality pig iron and steel products to Far East, south east, middle east, Canada, USA, Australia, Europe and Africa. RINL VSP was awarded "star trading house ". Having a total manpower of about 17,250 VSP envisaged labour productivity of not less than 230 tons per with the International levels.

1.1.1 Particulars of Organisation

1. Name of the company	:	Rastriyaispat Nigam Limited
2. Company identification number	:	U27109AP198G01003404
3. Date of Incorporation	:	18th February,1982.
4. Mode of incorporation	:	Incorporated as Govt Company under the provisions of company act, 1956
5. Administrative ministry	:	Ministry of Steel, Government of India
6. Present Status	:	A Govt company (under section-617)

1.1.2 Major Departments in Visakhapatnam Steel Plant:

The major Departments in Visakhapatnam Steel Plant are as follows

a) Coke ovens

b) Sinter plant

c) Blast furnace

d) Rolling mills

e) Raw Material Handling Plant

a) Coke ovens

The coal is proposed before charging into coke ovens in coal tower. The prepared coal in the coal tower is drawn by changing car on the top of the batteries and charged into the ovens as per the sequence-0 the charged coal is gradually heated in absence of air to attain a temperature of 1000°c-1050°c which generally takes about l6hrs for the coke to be ready. The volatile matter escaping during carbonization is collected in a gas collection main through standpipe. The stone is cooled by ammonia liquid spray and sent to coal chemical plant. The ready coke is pushed out of the oven by a pusher car into a coke and is taken to the dry cooling plant for discharging the hot coke into cooling chambers. There are three batteries, each having 7 ovens. A mixture of blast furnace gas and coke oven gas having a calorific value of 1000 kcal/nm3 is supplying the heat for carbonization.

Fig:1.1 Coke Oven

b) Sinter plant

In sinter plant ore fines into sinter before being charged into blast furnace. An initial mix consisting of ore fines and blue dust, manganese ore, metallurgical wastes, dole-fines, sand, 80% of limestone and 80% of limestone and 80% of coke fines is prepared. The mix along with sinter returns, sinter screening 20% of lime fines and 20% of fine coke is stocked in bunkers. Moisturizing and palletizing is carried out in 4.2m x 24m drum mixers to obtain homogeneous mixture with partial palletizing and optimum moisture. 10-2 min size sinters used as hearth layers of about 40mm thick. This decreases dust entrapment by exhaust gases reduces great bar consumption. Sinter mix up to 300mm thick is laid on the health layer. A mixture of coke oven gas and blast furnace gas having a calorific value of 2,000 kcal.nm3 is used for ignition. The prepared sinters are crushed to about 15mm size and cooled by forcing atmospheric air. This sinter is then sent to blast furnace through conveyors.

Fig:1.2 Sinter Plant

c) Blast furnace

There are two blast furnaces of 3,200 cubic meter useful volumes, each capable of producing 1.7mt of hot metal per year while operating for 350 days are installed. There are four hot blast stores for each furnace with a total heating surface of 224,000 square meters. The dome can be heated to a temperature of 1450°c maximum while the waste flue temperature is up to 400°c. Stores are heated, by a mixture of blast furnace gas and coke oven gas having a calorific value of 1100kcal/n cum up to 1300°c pressure of mixed gas before burners is 600mm W.C.

Hot metal is discharged into 140t hot metal ladles by rocking runners in east house. There are four railway tracks for hot metal transportation., on service sub-track and once track for flue dust disposal independent running railway tracks are provided for delivery of hot metal to SMS requirement = 0.5-31 as per blowing conditions raw or calcined coke-used to increase lining life of converter. Lump coke-use to preheat the lining of newly lined converter.

Fig:1.3 Blast Furnace

Fig:1.4 Rolling Mills

d) Rolling mills

The cast blooms produced in SMS-CCD do not find much applications as such and are required to be shaped into products such as billets, rounds, squares, flats, angles (equal and unequal), T-bar, channels, I-PE beams, HF beams, wire rods and reinforcement bars by rolling them in three sophisticated high speed high capacity, fully automated rolling mills.

VSP has 3 sophisticated and large rolling mills namely:

1. Light & medium merchant mills (LMMM) comprising of bar mill & billet mill

2. Wire rod mill (WRM).

3. Medium merchant& structure mill (MMSM) with latest features of optimization & automation.

Fig:1.5 Continuous Casting

Fig:1.6 Raw Material Handling Plant

e) Raw Material Handling Plant

The raw material handling plant receives the basic raw materials required for the steel making process from various sources through railway wagons. The raw materials like iron are tines, iron ore lumps, sized iron ore, limestone. Dolomite etc is stocked in ore and flux yard. Imported coking coal, medium cooling coal and boiler coal is stocked in coal yard. These raw materials are sent in different proportions to nations departments through conveyor system.

1.1.3 Role of Technical Services Department in VSP Steel Plant

During early 90s, when all units of VSP came in to operation. The maintenance strategy planned was Preventive maintenance. Jobs are decided based on the visual inspection and reports prepared were more sophisticated than the other plants. Sometimes due lack of experience equipment's resulted in breakdowns just after maintenance. Thus, the breakdowns are induced by unnecessary maintenance. This situation resulted in several breakdowns, high equipment down time, low equipment availability.

During 1994, condition-based maintenance was introduced in VSP. It helped in reducing the maintenance workload, by monitoring the equipment health with gadgets. Thus, helping in evaluating the condition of equipment scientifically. This has helped in prioritizing maintenance activities and reduced unnecessary maintenance workload Thus relieving much need stress on maintenance managers. This has helped in planning manpower, spares and time of repair.

Various activities mainly done by technical services:

The following activities are mainly done by technical services department

1) Inspection of conveyors and cranes.
2) Vibration monitoring of critical drives.
3) Shock pulse monitoring (for accessing condition of antifriction bearings done by individual departments).
4) Wear debris analysis of critical gearboxes (analysis done by an external agency).
5) Thermography
6) Industrial endoscopy.
7) Ultra sonic leak detection of valves
8) Study breakdown of major equipment and repetitive breakdowns.
9) Coordinating statuary inspection of cranes, lifts, tackles, pressure vessels, etc
10) Central agency, for procurement bf condition monitoring equipment.
11) Tribology studies
12) Maintenance standards for critical equipment
13) Maintenance, auditing.
14) Preparation of reports on monthly and yearly (maintenance performance)

All critical cranes and conveyors of various production departments were identified. These are periodically inspected and the report is sent to the concerned department for Rectification. Cranes inspection includes measuring wheel flange thickness and any visual abnormalities of the crane. For some critical-cranes in SMS even vibration readings are noted down. Similarly, the conveyor are inspected for the condition of belt, idlers, pulleys, etc, and for some conveyors vibration monitoring of drives is also carried out.

At the central the department has identified critical drives which are directly related to production. Form 1998, onwards vibration analysers are being used. With the help of these analysers they can capture vibration signature of the equipment. These drives are regularly monitored with vibration analysers, signature is recorded and stored.

With the help of software these signatures are trended and analysed for faults in the incipient stage itself. Suitable recommendations are given to the respective departments for remedial actions. Multichannel vibration analysers are being used to analyse defects of high-speed equipment's like compressors and blowers, which can plot orbits. Vibration analysis has helped immensely in identifying problems and their root causes thus avoiding costly breakdowns.

Shock pulse (SPM) monitoring practices helped to re-lubricate the bearings in correct intervals, maximize the life of the bearings. Motor current signature analysis is being used to detect the rotor bar cracks in cage type induction motors. With this analysis the defective motors can be replaced well in-time and the motor could be repaired.

Wear debris analysis, on lube oils of various critical gearboxes, the components that are wearing out in gearbox and specific reasons for the wear out can be known. Hence corrective actions can be taken. With help of all these condition monitoring techniques no of breakdowns, severity of breakdowns, volume of maintenance work could be replaced. It has resulted in quality maintenance work, more uptime of equipment, availability, reliability of equipment, year after the year.

1.2 Industrial machinery

1.2.1 Bearings

Bearing is a mechanical element that permits relative motion between two parts such as shaft and housing with minimum friction. The function of bearing is as follows:

a) The bearing ensures free rotation of the shaft or the axel with minimum friction.
b) The bearing supports the shaft or the axel and holds it in the correct position.
c) The bearing takes up the force that act on the shaft or the axel and transmit them to the frame or the foundation.

1.2.2 Classification of bearings

Bearings are classified in different ways.

a) Depending upon the direction of force that acts on them the bearing are classified into two categories that are radial and thrust bearings.

Fig:1.7 Radial bearing

Fig:1.8 Thrust bearing

A radial bearing supports the load which is perpendicular to axis of the shaft. A thrust bearing supports the load, which acts along the axis of the shaft.

b) Depending on the type of friction, bearings are classified into two main groups sliding contact bearing and rolling contact bearing.

Sliding contact bearings are also called plain bearings, journal bearings or sleeve bearings. In this the surface of the shaft slides over the surface of the bush resulting in friction and wear. In order to reduce the friction, these two surfaces are separated by a film of lubricating oil. Rolling contact bearings are also called anti friction bearings or simply ball bearings. Rolling elements such as balls or rollers are introduced between the surfaces that are in relative motion. In this type of bearing, sliding friction is replaced by rolling friction.

1.2.3 Ball Bearings

A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the bearing races. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least three races to contain the balls and transmit the loads through the balls. In most applications, one race is stationary and the other is attached to the rotating assembly (e.g., a hub or shaft). As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling, they have a much lower coefficient of friction than if two flat surfaces were sliding against each other.

Types of ball bearings

1. Deep groove ball bearing
2. Cylindrical roller bearing
3. Angular contact bearing
4. Self-alignment bearing
5. Taper roller bearing

Deep groove ball bearing

The most frequently used bearing is the deep groove ball bearing. It is found in almost all kinds of products in general mechanical engineering. In this type of bearing the radius of the ball is slightly less than the radii of curvature of the grooves in the races. Kinematically, this give as point contact between balls and the races. Therefore, the balls and the races may roll freely without any sliding. Deep groove ball bearing has the following advantages:

a) Due to relatively large size of the ball, deep groove ball bearing has high load carrying capacity.
b) Deep groove ball bearing takes load in radial as well as axial direction
c) Due to point contact between the balls and races, frictional loss and resultant temperature rise are less in this bearing.
d) Deep groove ball bearing generates less noise due to point contact
e) Deep groove ball bearings are available from a few millimetres to 400 millimetres

The disadvantages of deep groove ball bearings are as follows:

i. Deep groove ball bearing is not self-aligning. Accurate alignment between axes of shaft and the housing bore is required.
ii. Deep groove ball bearing has poor rigidity compared with roller bearing. This is due to the point contact compared with line contact in case of roller bearing. It is unsuitable for machine tool where rigidity is important consideration.

1.2.4 Types of Maintenance

Over the years maintenance practices followed in the industry have changed. With increase in demand for higher quality products and for environmental safety, the industries are nowadays adapting to different kinds of maintenance activities. These include:

Breakdown Maintenance: In this type of maintenance, the machine is allowed to run without maintenance until it completely fails or when the machine becomes unproductive. But this kind of maintenance leads to ultimate failure of machine which results in increase in production time and also the cost. The repair costs are also more in this type of maintenance.

Preventive Maintenance: In this type of maintenance, activities are carried out as per the planned schedule prepared and based on the importance of the equipment. The main activities involved are Inspection of the equipment, regular maintenance activities like changing of lubricants, tightening of bolts including base bolts, arresting of oil leakages etc.

This approach to machinery has its own kind of disadvantages. Firstly, periodically dismantling critical equipment in the plant is expensive and time-consuming. Second, the probability of failure of the machine cannot be reduced by replacing it with a new one. Third, a machine which is operating satisfactorily may actually be degraded by frequent disassembly. There is always a chance that a gasket or seal might not be properly installed, bolts not tightened properly, or the original alignment or balance of the machine disturbed during reassembly. In addition, some machine problems such as unbalance are evident only during operation.

Condition based Maintenance (Predictive Maintenance): To overcome the above Condition Based Maintenance came in to practice to avoid unnecessary over hauling and Maintenance activities. Condition Monitoring is an advanced and very useful tool of predictive maintenance techniques. It involves regular inspection of equipment and sophisticated instruments to assess the health of the machine. Most of the maintenance activities can be preferably done while equipment is in operation. Also, shutdown for repairs can be scheduled conveniently. Moreover, repair time can be kept to minimum that results in reducing the downtime which is a limiting factor in time-based preventive maintenance.

1.2.5 Techniques in Condition Monitoring

Visual monitoring: Visual examination involves assessing the performance of the machine using human senses of observation, smell, and sound. It sometimes reveals the tell-tale signs of failure. Simple aids like microscopes, bore scopes, stroboscopes, photographs, dye penetrates etc. can through light on types and nature of defects developing in components.

Performance monitoring: Machines operating conditions can sometime be assessed be performance assessment by comparing inputs and outputs. The component behaviour can also be assessed depending upon the type of components.

Vibration monitoring: All machines which contain moving components vibrate. The nature and magnitude of vibration of a particular component of a machine can provide information about its mechanical condition. Vibrations arise from cyclic excitation forces with in the machine. These forces can be inherent of the machine or can be due to propagation of some defect. The following list clearly depicts machine defects which can be easily detected, diagnosed using vibration monitoring.

Shafts and rotors	:	Unbalanced, bent shafts, Miss Alignment, eccentric journals, critical speeds
Journal Bearing	:	Oil whirl, Oval journals
Rolling element bearings	:	Race and element Pitting, distortion, loss of lubricant
Electrical Machines	:	Unbalanced Magnetic Pull
Miscellaneous	:	Structural Faults, Foundation Faults, fault combustion in diesel engines, structural resonance, piping faults and resonance
Flexible Couplings	:	Unbalance, Miss-Alignment.
Gears	:	Tooth meshing faults, worn teeth Miss Alignment, damaged pulleys; belt and groove wear eccentric pulleys.
Belt drives	:	Mismatched Belts, Miss Alignment, damaged pulleys, belt and groove wear, and eccentric pulley.

Shock Pulse Monitoring (SPM): This is a reliable method more commonly known as SPM for monitoring the condition of anti-friction bearings. In this technique the shock impulses produced by the impact between the rolling elements and surface defects either on race ways or rolling elements are measured. This technique has distinct advantage over the vibration monitoring techniques. The vibration Amplitudes produced is unsteady and the frequency is very high. Unless the degree of damage is high, vibration analysis will not detect failing anti-friction bearings whereas SPM can detect the defective bearing early.

Temperature Monitoring: Measuring temperature yields substantial information about machinery condition. Simple aids like temperature crayons and temperature tapes prove handy in monitoring temperature of bearings, motors etc. But for more complex measurements thermograph is used. Thermograph is based on the principal of extending human vision into infrared zone. Infra-red sensitive equipment and instrumentation is used for this purpose. The temperatures of hot objects and thermal profile of hot surfaces is obtained for comparison with acceptable standards for purposes of trouble shooting. Thermograph is a non-contact technique and involves measurements of infra-red radiations from hot objects. The undesirable hot spots are easily identified by taking their thermo grams and suitable remedial measures are taken.

Wear Debris Analysis: It involves the monitoring of lubricants for presence of wear particles. The relative between components parts give rise to various types of wear processes these wear processes generates typical wear particles which, after examination, can be correlated with the part which is wearing out as well as the type of wear taking place.

The foregoing paragraphs serve only to emphasize the gains to be had by adopting a condition-based-maintenance (CBM) practice. The general awareness the world over today is in favour of conserving scarce capital resources. It is particularly true of developing true of developing countries. With the advent of large, High-capacity, single-stream production facilities there is a growing need for this approach.

Benefits of CBM:

1. Prolongs machinery life: Expensive production machinery and plant support equipment can be maintained at a level where it will meet or even exceed its expected service life. This means your company can reduce its long-term capital investment in new machinery, while maintaining the same level and quality production.

2. Minimizes unscheduled downtime: Unexpected breakdown play havoc with production schedules and dramatically increases production cost. An effective CBM program lets you to detect a problem before it becomes critical. You can then schedule.

3. Eliminates unnecessary overhauls: Annual inspections and routine overhauls costs time and money. In order to prevent unexpected breakdown, machines are often taken off line and disassembled when there is actually nothing wrong with them. CBM allows a machine to run continuously until you detect the earliest stages of problem. This often means you can run the machine for much longer periods of time preventive maintenance schedule would allow.

4. Eliminates the requirement of standby equipment: Idle standby equipment is no longer a prudent investment for new or expanding facilities. Standby, or redundant, machinery is intended to maintain operations in the event of unexpected breakdown, allowing you to schedule a maintenance shutdown at a time when it will have minimal effect on normal operations.

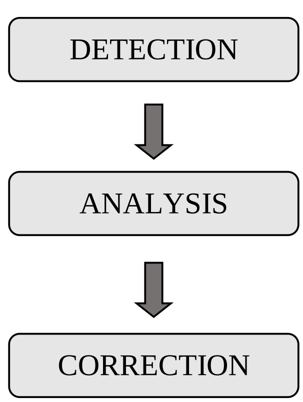
5. Provides more efficient operation: Under vibration and associated noise degrade working environments, causing needless employee fatigue, raising the potential for accidents, and generally lowering worker productivity. Although a certain amount of noise is inherent in the operation of machinery, a good CBM program can help keep machines running inherent noise levels.

6. Increases machinery safety: Certain classes of machinery defects pose serious safety hazards. The risk to personnel in the area rises as the defect reaches a critical point; and in the obvious signs of trouble appear only moments before a dangerous catastrophic breakdown occurs.

7. Improves customer satisfaction: Satisfied customers are the basis for profitable repeat business. Companies that produce rotating equipment can cause the techniques of CBM to delivery well-balanced and aligned equipment. This assures customer satisfaction during start-up in the field.

1.2.6 CBM Program

An effective CBM is a total program comprising the stages like 'Detection' , 'Analysis' and 'Correction'.



This is a logical sequence of steps. The program first helps you detect onset of problem. It then provides means for analysing the problem in order to determine its cause and finally it puts you in the position to correct the problem effectively and efficiently at a convenient time.

Detection: In this we keep track of a developing mechanical troubles which are at initial stage. All machines in this program should be tested in this fashion or monitored according to prescribed schedule depending on type of machine.

A data collector FFT (Fast Fourier Transformation) Analyzer is used to track and record vibration amplitude, spectrums and wave forms. Transducers of Accelerometer type are being used in collection of vibration data. The advantage of Accelerometer is that the measuring data can be converted in to velocity or displacement also. Later this collected data is fed in to computer by using software where the information is transferred and helpful in knowing the past data also by trends which helps in Analysing the problem easily.

Analysis: By using the data collected by FFT analyser now we should determine the nature of problem and to analyse the root cause of the problem in machinery by identifying its unique vibration characteristics.

Trouble can be identified by comparing these detailed reading with other information about the machine operating speeds, types of bearing and coupling past history of vibrations and if any maintenance work done in between. Once you have analyzed the cause of a vibration problem, preparing to take the corrective actions.

Correction: Now we schedule corrective action time which suits company’s operating schedule. Machinery faults such as bad bearing, faulty gears, looseness or misalignment can be corrected using maintenance procedures. However, correcting problems such as unbalance and resonance require special skills and knowledge.

1.3 Theory of vibrations

1.3.1 Vibration

Any motion that repeats itself after an interval of time is called vibration or oscillation. The simplest way to show vibration is to follow the motion of a weight suspended on the end of a spring as shown in fig. This is typical of all machines since they, too, have weight and spring like properties.

Basic theory of vibration

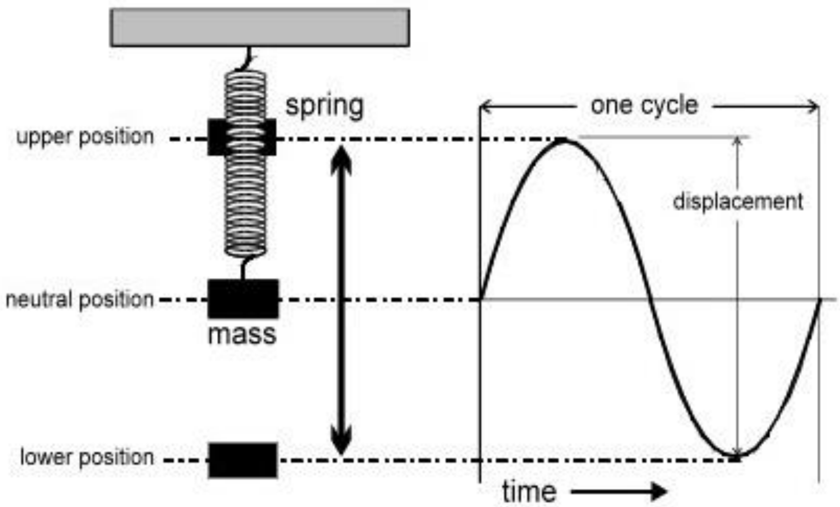


Fig:1.9 Basic theory of vibration

Until a force is applied to the weight to cause it to move, we have no vibration. By applying an upward to the weight to cause it to move we have no vibrations. By applying an upward force, the weight would move upward compressing the spring. If we release the weight it would drop below its neutral position to some limit of travel where the spring would stop the weight. The weight would then travel upward through the neutral position to the top limit of motion and back again through the neutral position. This motion will continue inexactly the same manner as the force is reapplied. Thus, vibrations is the response of a system to some internal or external (stimulus) or force applied to the system.

1.3.2 Classification of Vibration

a) Free and forced vibration
b) Undamped and damped vibration
c) Linear and nonlinear vibration
d) Deterministic and Random vibration

a) Free vibration And Forced Vibration

If a system after an initial disturbance is left to vibrate on its own the ensuing vibration is known as free vibration. No external force acts on the system. The oscillation of a simple pendulum is an example of free vibration.

If a system is subjected to an external force (often a repeating type of force), the resulting vibration is known as forced vibration. The oscillation that arises in machines such as diesel engines is an example of forced vibration. If the frequency of the external force coincides with one of the natural frequencies of the system, a condition known as resonance occurs and the system undergoes dangerously large oscillations. Failures of such structures as buildings, bridges, turbines, and airplane wings have been associated with the occurrence of resonance.

b) Undamped and Damped Vibration

If no energy is lost or dissipated in friction or other resistance during oscillation, the vibration is known as undamped vibration. If any energy is lost in this way, however it is called damped vibration. In many physical systems, the amount of damping is so small that it can be disregarded for most engineering purposes. However, consideration of damping becomes extremely important in analysing vibratory systems near resonance.

c) Linear and nonlinear vibration

If all the basic components of a vibratory system the spring, the mass, and the damper behave linearly the resulting vibration is known as linear vibration. If, however any of the basic components behaves nonlinearly the resulting vibration is known as nonlinear vibration. The differential equations that govern the behaviour the linear and the non-linear vibratory systems are linear and nonlinear respectively. If the vibration is linear the principle of superposition holds and the mathematical techniques of analysis are well developed. For nonlinear vibration the superposition principle is not valid and techniques of analysis are less well known. Since all vibratory systems tend to behave nonlinearly with increasing amplitude of oscillation knowledge of nonlinear vibration is desirable in dealing with practical vibratory systems.

d) Deterministic and random vibration

If the value of or magnitude of the excitation (force or motion) acting on a vibratory system is known at any given time the excitation is called deterministic. The resulting vibration is known as deterministic vibration.

In some cases, the excitation is non deterministic or random the value of excitation at a given time cannot be predicted. In these a large collection of records of the excitation may exhibit some statistical regularity. If it is possible to estimate averages such as mean and mean square values of the excitation. Examples of random excitation are wind velocity, road roughness, and ground motion during earthquakes. If the excitation is random the resulting vibration is called random vibration. In this case the vibratory response of the system is also random it can describe only in terms of statistical quantities.

1.3.3 Causes of Vibration in Machines

Almost all machine vibration due to one or more of these causes:

- Unbalance
- Misalignment
- Bearing problems
- Mechanical looseness
- Soft foot
- Resonance
- Belt – drive problems
- Eccentricity
- Gear problems
- Electrical motor problems

1.3.4 Characteristics of Vibrations

The amplitude of vibration is the magnitude of vibration. A machine with large vibration amplitude is one that experiences large, fast or forceful vibratory movements. The large the amplitude the more movement or stress is experienced by the machine and the more prone the machine is to damage. Vibration amplitude is thus an indication of the severity of vibration

In general, the severity or amplitude of the vibration relates to:

a) The size or amplitude of vibratory movement
b) The speed of the movement
c) The force associated with the movement

In most situations it is the speed or velocity amplitude of a machine gives the most useful information about the condition of the machine. A machine condition and mechanical problems are determined by measuring its vibration characteristics. The more important of these characteristics include:

• Frequency

• Displacement

• Velocity

• Acceleration

• Phase

Vibration frequency

The amount of time required to complete one full cycle of vibration pattern is called period of vibration. If a machine complete one full cycle of a vibration is said to be 1/60 th of a second. Vibration frequency is the measure of complete cycles that occur in a specified period of time. Frequency is the measure of the number of complete cycles that occur in a specified period of time. Frequency is related to the period of vibration pattern by the simple formula:

Frequency=1/period

Vibration 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). Under conditions of dynamic stress, displacement along may be a better indicator of severity. Consider a slow rotating machine such as mine hoist drum, rotating at 60rpm with vibration 20mils peak to peak displacement from rotor unbalance.

Vibration velocity

Since the vibrating weight is moving it must be moving with some speed. However, the speed of the weight 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. Since vibration velocity is directly related to vibration severity for most general-purpose vibration measurements it is the preferred parameter for measurements, as rule of thumb, vibration occurring in the 600-60000 CPM frequency range is generally best measured using vibration velocity.

Vibration acceleration

It is normally expressed in “g’s” peak, where one “g” is the acceleration produced by force of gravity at the surface of the earth. By international agreement, the value of 980.665 cm/sec2. As the velocity of the part increases the acceleration decreases. Acceleration is closely related to force and relatively large forces can occur at high frequencies even though the displacement and velocity may small. For high frequencies typically 60000(cycles/min) and up acceleration may be best indicator of vibration severity.

1.4 Vibration measurements

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 colour code, green, yellow 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 downloaded using Trend and Analysis software. The analyser setup can be to collect data in route mordent only vibration signature, but also bearing data with assigned fault conditions. Data after measurement superimposes assigned faults with fault frequencies to find out the abnormality. Residual bearing life can be calculated for bearings which are on regular trend most suitable for single speed and constant load applications.

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

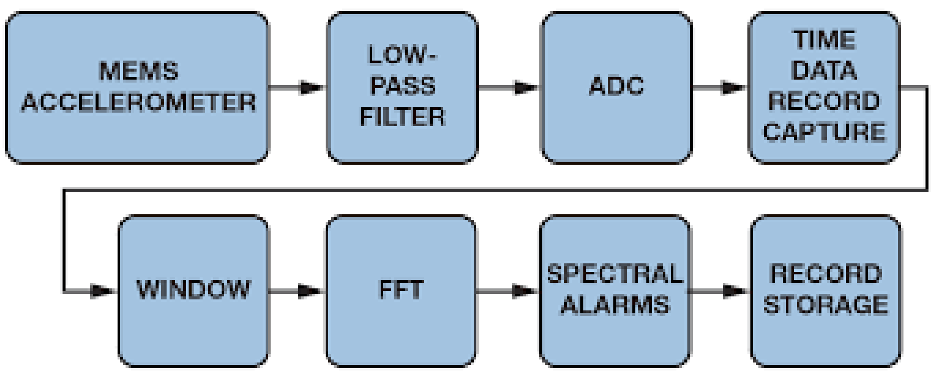


Fig:1.10 Vibration Measurement

1.4.1 Working of the measuring instrument

Before taking a vibration measurement you need to attach a sensor that can detect Vibration behaviour of 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 electric signal that is proportional to the acceleration of the vibrating component to which the accelerometer is attached. The piezo electric 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 either as velocity waveform or velocity spectrum.

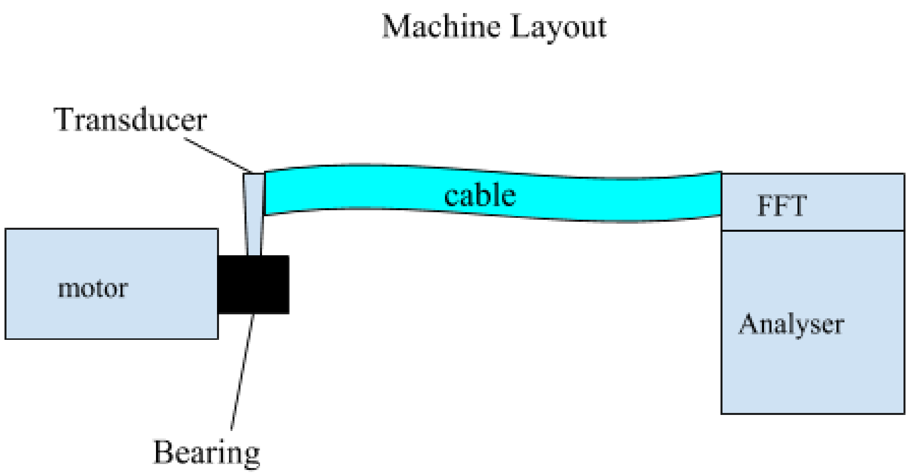


Fig:1.11 Machine Layout

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 simple explanation of how vibration data is acquired.

1.4.2 Data processing within the instrument

Triggering is 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 is detected in an input channel. For example, you can setup a trigger to capture a hammer impact. After your 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 increase the estimate of 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 a good example of repetitive signals. Both the force and acceleration signals are same for each measurement. This assumes that the trigger point is reliable. The pressure of high background noise may adversely affect the reliability of the trigger.

Windowing is technique used when computing FFTs. Theoretically the FFT can 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 at the end of the data block and have some special shaped in between. This function is then multiplied with the data block and this forces the signal to be periodic.

1.5 Different Analysis tools used for fault diagnosis in machines

1.5.1 Time Wave Form Analysis

One displacement 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 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.

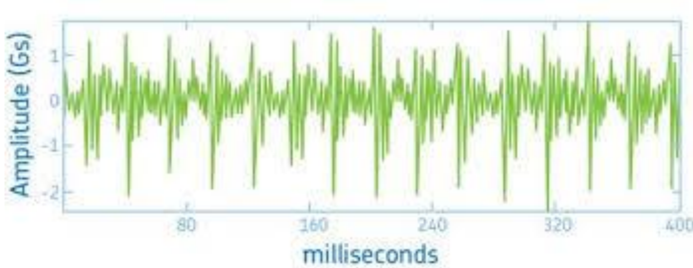


Fig:1.12 Time Waveform

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.

1.5.2 Spectrum analysis

Another kind of display commonly used by the 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.

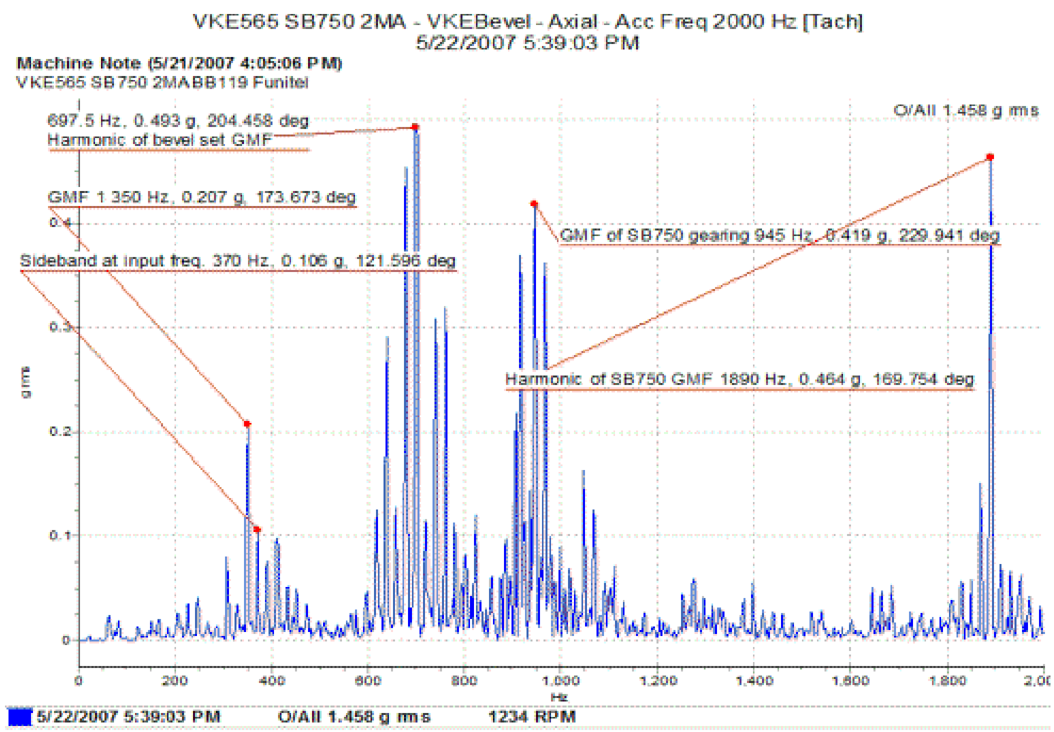


Fig:1.13 Spectrum Analysis

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 does 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.

1.6 Equipment used for Vibration analysis

1.6.1Vibxpert 2011

It is a dual channel vibration analyser frequency ranging from 10Hz to 10 KHz. It has wide range of features and capabilities all have the same basic common feature i.e. the data is processed and presented they include a computer chip programmed to perform the FFT (Fast Fourier Transformation) function. Software used for transferring data to computer is Omni Trend.

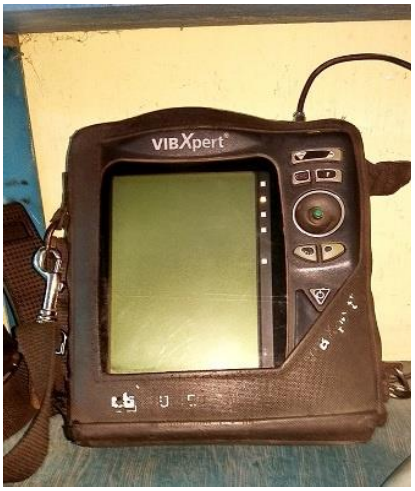


Fig:1.14 Vibxpert

Fig:1.15 CSI Analyzer

1.6.2 CSI 2117

It is a single channel vibration Analyzer frequency ranging from 10Hz to 10 KHz. It has wide range of features and capabilities all have the same basic common feature i.e. the data is processed and presented they include a computer chip programmed to perform the FFT (Fast Fourier Transformation) function. Software used for transferring data to computer is CSI Master Trend.

Technical data of instruments

Input Channels

Analog inputs for

- Voltage (AC/DC, ±30 V max)
- Current (AC/DC, ±30mA max)
- ICP® signal (2 mA,24 V max)
- Line Drive accelerometer (10 V , 10mA max)

Analog input for temperature measurement

- Thermocouple (type K)

1+1 pulse/ tachometer (RPM, Trigger, Key phasor)

- Accepts pulse & AC signals : 0V…. +26V or 0V
- Input parameters
- Analog channels
- Frequency range : 0.5HZ to 40 kHz
- Dynamic range : 96db /136 (means /total)
- Sampling frequency : up to 131 kHz per channel

Pulse/ Tachometer Channels

- Maximum input voltage : ±26V
- Switching threshold for
- 0V …. +26VSignals max. 2.5V rising,
- Min.0.6V falling
- -26V…. 0V signals min. -8V rising,
- Max. -10V falling
- Min Pulse length : 0.1ms.

Output Channels

- Stroboscope control
- Connection for stroboscope – TTL output

Signal Out

- Frequency range : 0.5Hz – 40 kHz
- Out impedance : 100 Ohm

Output parameters

Stroboscope control

- Frequency range : 0-500 Hz
- Resolution : 0.05 Hz

Signal-Out

- Frequency range : 0.5Hz - 40 kHz
- Output impedance : 100 Ohm

Mean. Range /accuracy* / filter (lower cut –off frequency)

- RPM
- 10…200000 min. -1/±1% or ±1min.-1 / ---

Temperature

- Type K: -50… +1000oC /± 1% or ±1oC /----

Vibration displacement

- 6000 µm (p-p)** / ±1%(±5%***) / 2Hz and 10Hz
- 1000 µm (p-p)*** / ±5% /0.5 Hz and 1Hz

Vibration velocity

- 6000 mm/s (p-p) ** / ±1% / 2Hz and 10Hz
- 1000 mm/s (p-p) *** / ±5% /0.5 Hz and 1Hz

Vibration acceleration

- 6000 mm/s2 (p-p) ** / ±1% / 2Hz and 10Hz
- 1000 mm/s2 (p-p) *** / ±5% /0.5 Hz and 1Hz

Shock pulse (bearing condition)

- Frequency response according to ISO 2954

1.6.3 Computer

Processor

- Intel Strong ARM 206 MHz

Keyboard

- 1 joystick & 6 keys (Intr.safe ver.: 2joysticks &12keys)

  (Zoom, Escape, Function, Help, Menu, On/Off)

Display

- LCD, 16 grey scales, 480x320 pixel (1/2 VGA)
- Pixel area 115x78 mm, backlit

Connectors

- Analog channels : Minisnap socket (Compatible to VIBSCANNER)
- Digital channel1 : Minisnap socket (RS232)
- Digital channel2 : Minisnap (Ethernet-10Mbit, USB)
- Thermocouple channel: QLA

Keyboard

- Material : Elastomer

Housing

- Material: ABS (intr.safe ver.: Aluminium)

Dimensions

- 180X160X50 mm

Weight

- 1.2kg

Environmental IP rating

- IP65, dust and splash –proofed

Temperature range

- -20 to +60o C (Storage)
- -10 to +60o C (Operating)
- -10 to +50o C (Operating, intr.safe device)

1.6.4 Accelerometer

Accelerometer is a transducer which converts mechanical acceleration in to electrical signals. It operates according to piezoelectric compression principle. Inside the sensor, a spring/mass damping system is formed by piezeo-ceramic disk and an internal sensor mass. When introducing vibrations in to this system, the mass exerts an alternating force on the ceramic disk and due to the piezoelectric effect charges are caused which are proportional to acceleration. An integrated charge amplifier increases the output signal to a usable signal level.

Type	Piezeo-electric acceleration sensor with integrated charge amplifier
Transformation factor	100 mV/g ±5% 10,2 mV/m/s^2 ±5%
Operating temperature range	-50^{o}C to +120^o C
Measuring range	± 80g (UB = -24V to -30V) ±40g (UB=-20V) ±20g (UB=-18V)
Linearity error	≤ 0,1% (0,1 g to 10g)
Transverse sensitivity (80 Hz)	≤7%
Strain Sensitivity	<0.00003 g/(μm/m)
Dielectric strength of Insulation	500 VRMS (>3min)
Over load capacity	Continuous 500g Shock 5000g (all directions) Fall from 1.5m on concrete without damage

1.6.5 Omnitrend Software

Condition monitoring and predictive maintenance software is deployed in predicting equipment maintenance needs. It monitors corrosion, oil condition, bearing wear, overheating, and other settings leading to potential breakdown. The goal of condition monitoring is to identify components for repair before they fail. The software's ability to monitor machinery permits plant personnel to pre-empt catastrophic failures. It also assists in advance parts ordering, scheduling of manpower, and facilitates the planning of repairs during downtime.

Condition monitoring focuses on numerous parameters to identify substantive changes indicating the development of a fault. This function extends the useful lifespan of equipment by identifying troublesome areas before they cause major issues. It is performed on rotating devices and machinery such as presses, pumps, electric motors, and internal combustion engines.

About sensors

Select functions of the program link to sensors supplying input data. These sensors include:

a) Accelerometers
b) tachometers
c) Proximity probes

Dynamic accelerometers measure vibrations. This enables the prediction of the lifespan of parts and the detection of machinery faults. An assortment of accelerometer solutions is engaged in situations, including piezoelectric, unbounded strain gage, vibrating element, and Hall effect models. Piezoelectric units are the most commonly used accelerometers for this purpose.

Tachometers measure a physical device's speed of rotation. Moreover, they measure its phase information, facilitating the matching of frequency components with the speed and position of a shaft. Proximity probes calculate physical device displacement. They monitor rotating shaft movement. They are found in 90° offset pairs supporting the mapping of shaft movement via an X-Y plot. Doing so allows for the detection of imperfections. The deficiencies include shaft misalignment, faulty bearing, or numerous other circumstances inhibiting proper rotation.

Benefits

The use of condition monitoring and predictive maintenance software has numerous advantages, including:

Predicting Equipment Failure: By predicting unplanned equipment failures, the technology reduces the occurrence of incidents. Given the potential for a tremendous cost associated with the breakdown of expensive capital assets, the capability to monitor these assets and predict when maintenance for avoiding catastrophic issues is required renders companies with a valuable service. Constant monitoring of equipment health executed by the system delivers more comprehensive coverage of such situations than traditional visual inspection methods.

Operating Condition: Solutions of this type let companies acquire a big picture view of the overall status of their equipment. If one piece of equipment exhibits signs of strain, other machinery can experience stress as well. In such cases, using plant downtime or shutting down the plant for a time to perform comprehensive equipment assessment and maintenance improves performance. This approach is more effective than a series of plant shutdowns to repair problems one by one.

Failure Prediction Accuracy: By integrating data from multiple sensors and indicators, the platform delivers a more comprehensive representation of equipment health. This integrated approach to data collection and analysis supports accurate evaluation to determine if extra maintenance is necessary. This process takes data from procedures, including vibration analysis, fault detection, and other disparate settings and considers them as a whole to generate a detailed report.

Reduced Condition Monitoring Costs: Traditional monitoring relied on highly trained analysts to determine if extra maintenance was warranted. Advanced applications incorporating "rule-based" analysis can reduce the dependence on constant human oversight of the activity. While human input is still required for high-level decision making, the systems present information related to remediation parameters, thereby reducing the labour costs traditionally associated with the activity.

Improving Equipment Reliability: The software aids in establishing the basis for systematic optimization of monitoring processes and procedures. This results in significant improvement in equipment reliability driven by lengthening mean times between failures for each piece of equipment. This is accomplished by taking steps to enhance the precision of maintenance tasks. The solutions assist in such endeavours by specifying actions allowing equipment to operate at optimal levels over its expected lifespan.

CHAPTER 02

LITERATURE REVIEW

2. LITERATURE REVIEW

Several authors have published their valuable research in the field of condition based maintenance, in particular about the vibration analysis and its applications and scope. The experimental and analytical work done in this field is quite prominently used in several industries for proactive maintenance and to prevent sudden breakdowns.

RavindraA.Tarle, et al (2015) had carried research on design, experimentation and validation analysis of fault diagnosis of ball bearing related to rotor system. Analysis using FFT methodology is done to find out possible faults and finally validated with MAT lab software. They have also done lubrication analysis for bearing with lack of lubrication and with lubrication.

SurojitPoddar, et al (2013) had presented paper on ball bearing fault detection using vibration parameters. Four faulty MB ER-10k bearings with inner race defect, outer race defect, ball defect and multiple defects were taken for experimentation. Vibxpert 2-channel FFT data collector and signal analyser are used for signal analysis. The corresponding FFT signals were plotted for four type of fault bearings and peak frequency is compared with calculated fault frequencies

H.Mohamadi, et al (2008) had presented paper on prediction of defects in roller bearings using vibration signal analysis. Time domain analysis, vibration spectrum analysis have been employed to identify defects. TMZ 6205-2RZ cylindrical roller bearing type is used. Time waveform indicates severity of vibrations for defective bearings and vibration spectrum identifies exact nature of defects.

G.Venkata Kishore RakshitRaju, et al (2018) carried his research on monitoring of bearing faults. After taking measurements at drive end and non-drive end side in running condition of 210 rpm and when compared ISO 10816 chart they concluded that it possesses inner race defect. The vibrational signal was collected by DC-12 and analysed in DREAM software

Rupendra Singh Tanwar, et al (2013) had carried work to predict defects in antifriction bearings. Two pedestal ball bearings, one healthy another faulty both are used for experimental analysis. Analogue to digital converter AD3525 was used to monitor vibration signals. Using MAT Lab and some commands graphs are drawn and faulty bearing values are compared with healthy one.

M. Amarnath, et al (2004) had the work on defects prediction in antifriction bearings. In experimental setup self-aligning double row ball bearing is mounted at driver end and cylindrical roller bearing is mounted at free end. Cylindrical roller bearing NRB NU-305 with outer race and roller defects, HMT E-245 with inner race defect have been used for analysis. IRD mechanalysis model 880-spectrum analyser was used to monitor spike energy pulses. The peak to peak time response of good bearing and defective bearings are compared.

Syed Zeeshan, et al (2016) had done a case study on antifriction bearing diagnostics in a manufacturing industry. The experiment is carried on machine MAZAK FH 6800.the bearing vibration analysis is conducted on instrument smart balancer. For different speeds vibration is noted in mm/sec in both clockwise and anticlockwise directions. Using formulas damage frequencies in rolling element bearings are calculated. A graph of mm/sec vs. harmonics is plotted at end to test vibration levels.

P. Venkata Vara Prasad, et al (2015) had carried work on Condition monitoring and vibration analysis of two different rotating machines pumps and fans. He measured the vibration using FFT and accelerometer for offline measurement. With significant peaks at 1X and high axial vibration the error is observed as misalignment.

H.Saruhan, et al (2014) had presented the work on vibration analysis of rolling element bearings and defects. In this study different types of rolling element bearings defects with respect to two different load level is taken since load affects the signature magnitude. MB ER-12K type of bearing is used. With help of vibration spectrum analysis normal state condition bearing and deliberately defected bearings were tested under different shaft running speeds.

2.1 Scope of Work

In the light of all this literature on CBM, it is clearly evident that there is significant reliance on vibration analysis in maintaining the health of a machine. The present work focuses on analysing the vibrations of an Industrial fan to ensure its uninterrupted operation in meeting the cooling requirements of a critical equipment. Thus, experimentation on industrial fan for the collection of vibration signal is proposed in Steel plant and the analysis aspects demanded by the CBM were carried out.

CHAPTER 03

EXPERIMENTATION

3. EXPERIMENTATION

The experiment is carried out on industrial fan at Coke dry cooling plant on motor and fan drive end and non-drive end bearings in Coke Oven and Coal Chemical Plant department. This department has been designed to produce coke by processing the Coal to supply Blast Furnace for Metallurgical applications. The main equipment of this department comprises 4 batteries (each 7 meters high with 67 ovens). Each battery is associated with Coke Dry cooling Plant to improve the coke quality. During dry cooling process the coke is cooled by circulating nitrogen gas through Industrial fan. The heat from nitrogen gas is recovered by waste heat boiler.

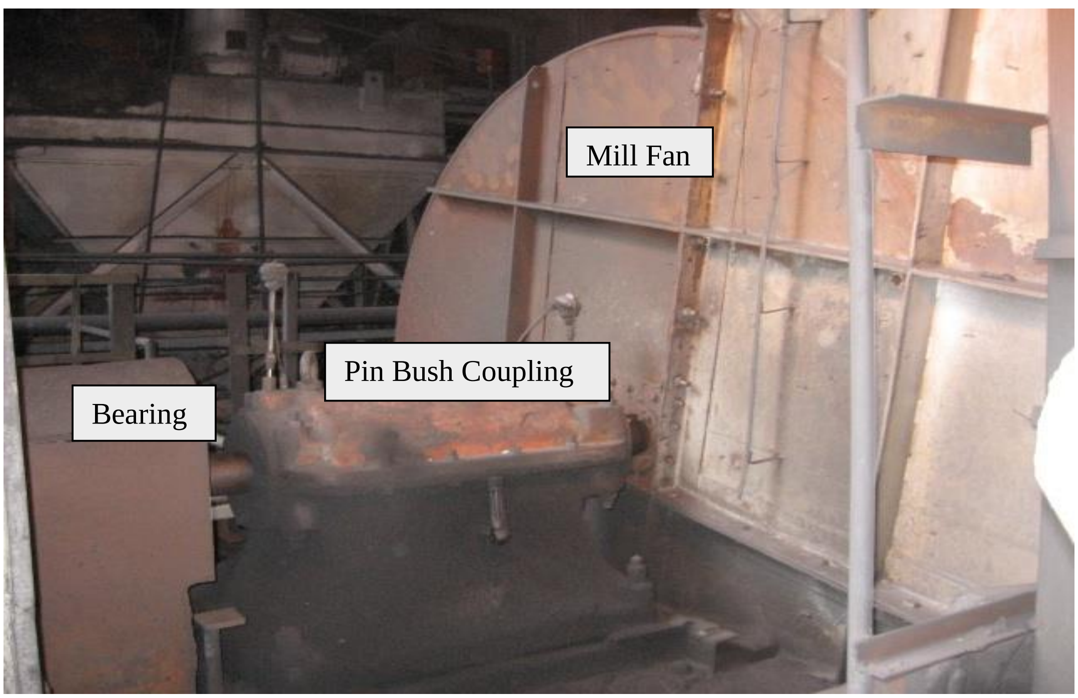


Fig:3.1 Mill Fan Equipment

Equipment Details

- Equipment type : Single suction over hung rotor type
- Location : Coke oven
- Pressure : 800 mmWC (or mm of water)

- Impeller diameter : 2600 mm
- Motor type : 3-Phase Induction Motor
- Rating : 630 Kw
- Operating voltage : 6600 V
- Full load current : 69 Amp
- Motor speed : 1000 rpm
- Handling medium : Nitrogen
- Coupling type : Pin bush
- Foundation type : Concrete
- Motor bearing : Double row spherical roller bearing (6228)

LAYOUT:

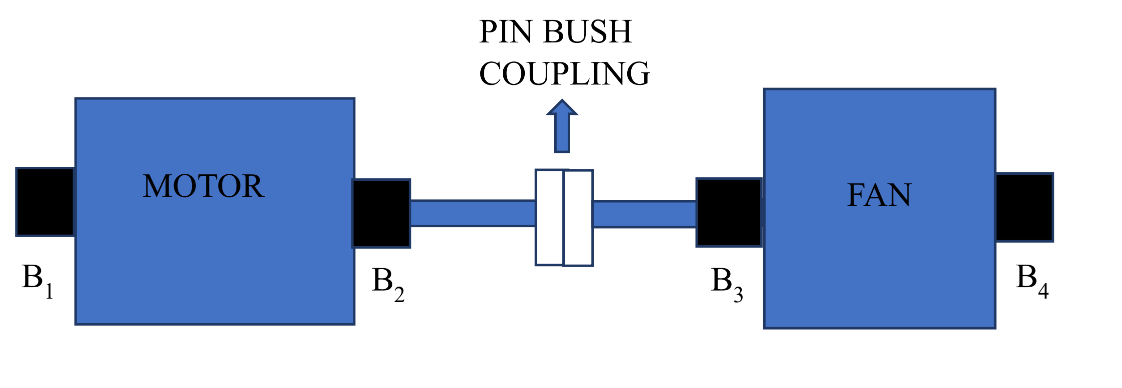


Fig:3.2 Machine Layout

B_1	-	MNDE Bearing
B_2	-	MDE Bearing
B_3	-	FDE Bearing
B_4	-	FNDE Bearing
MNDE	-	Motor Non-Drive End
MDE	-	Motor Drive End
FDE	-	Fan Drive End
FNDE	-	Fan Non-Drive End

3.1 Experimental Procedure

In many cases the analysis steps carried out by us may be sufficient to pinpoint the specific defect causing excessive vibration. If not, the next step is to obtain complete set of amplitude versus frequency spectrums of FFTs at each bearing of the machine train. For a proper analysis the machine should be operating under normal conditions of load, speed, temperature etc.

Condition Monitoring technique is done only on critical components of the plant and industrial fan is one such component whose health is periodically monitored using vibrational analysis. The experiment is conducted on a cooling equipment i.e., a fan and a motor arrangement. Using vibration analysers and accelerometers, the vibration readings are noted down periodically in axial, vertical, and horizontal directions at both motor and fan's drive and non-drive end bearings. Once, vibration data is obtained then using omni trend software the frequency spectrums and time waveforms are plotted. Any dominant peaks or repeated patterns in the vibrations helps us in identifying the defects. Thus, higher amplitude is not desirable and it is a sign of fault in the equipment. For bearing, the fault frequencies are calculated and if any of its frequency matches with the fault frequencies provided by ISO then it indicates the presence of defect. The fault frequency table is provided below.

In order to ensure that the analysis data taken includes all the problem related vibration characteristic and yet is easy to evaluate and interpret the following recommendations is offered.

Fig:3.3 Data Collection

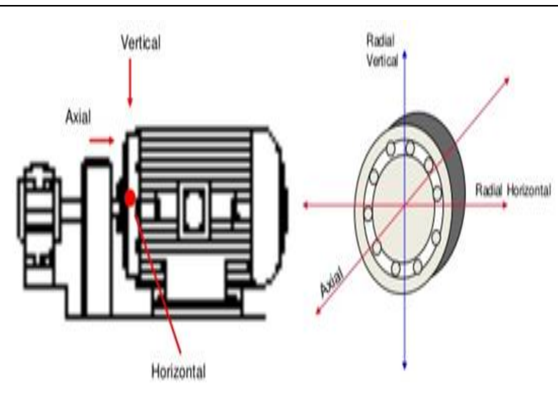


Fig:3.4 Axial, Horizontal, Vertical

Deep Groove Ball Bearing Fault Frequencies as per ISO

Bearing number: 6228

Fault frequencies	Multiplication Factors
FTF	0.42
BPFO	4.19
BPFI	5.81
BSF	2.99

Measurement Specifications

- Data collected in terms of waveforms and spectrums
- Amplitude is measured in mm/sec velocity (RMS)
- Frequency range 0 to 60000 cpm
- Sampling time for wave form-4sec
- Resolution varies from 100 to 6400 lines in FFT spectra.
- Data storage capacity-1000kb
- Number of averages -1 to 9999
- After data is recorded at the site from analyser at is dumped into host computer for further analysis

NOTE: Industrial Fan is running with (100%) full load

DIRECTION	**MNDE (mm/sec)**	**MDE (mm/sec)**	**FDE (mm/sec)**	**FNDE (mm/sec)**
VERTICAL	1.93	5.5	3.37	1.85
AXIAL	2.76	3.49	2.95	2.87
HORIZONTAL	2.59	1.84	2.48	2.54

Table: Overall value Readings

The band width of 0 to 60000 is recorded in the FFT analysers and an overall reading of 5.5 mm/sec is obtained at motor drive end in vertical direction which is the integration of amplitudes in that band width. As per ISO 2372 this equipment belongs to class-3 and the maximum vibration limit for this equipment is 4.5 mm/sec. So the above readings are not within the limits in vertical direction.

CHAPTER 04

CALCULATIONS & ANALYSIS

4. CALCULATIONS AND ANALYSIS

The calculations in this analysis involve finding the frequencies of various components in the equipment and then analysing the vibration signal wave through Fast Fourier Transformation to find the frequencies corresponding to the fault. These frequencies should then be verified with component frequency to figure out the faulty component from within the equipment.

4.1 Bearing Fault Frequencies Calculations

Inner race rotating and outer race stationary

$$FTF = \frac{S}{2}\left(1 - \frac{B_d}{P_d}\cos\phi\right)$$

$$BPFO = \frac{N_b}{2} \times S\left(1 - \frac{B_d}{P_d}\cos\phi\right)$$

$$BPFI = \frac{N_b}{2} \times S\left(1 + \frac{B_d}{P_d}\cos\phi\right)$$

$$BSF = \frac{P_d}{2B_d} \times S\left(1 - \left(\frac{B_d}{P_d}\right)^2 \cos^2\phi\right)$$

S - Speed (Revolutions per Minute)	:	996 rpm
B_d - Ball or roller diameter	:	1.25 inches
N_b - Number of balls or rollers	:	10
P_d - Pitch diameter	:	7.67 inches
ϕ - Contact angle	:	8.1

FTF - Fundamental Train Frequency

BPFI - Ball Pass Frequency of Inner race

BPFO - Ball Pass Frequency of outer race

BSF - Ball Spin Frequency

$$FTF = \frac{S}{2}\left(1 - \frac{B_d}{P_d}\cos\phi\right)$$

$$= \frac{996}{2}\left(1 - \frac{1.25}{7.67}\cos 8.1\right)$$

$$= 417.398 \text{ cpm}$$

$$BPFO = \frac{N_b}{2} \times S\left(1 - \frac{B_d}{P_d}\cos\phi\right)$$

$$= \frac{10}{2} \times 996\left(1 - \frac{1.25}{7.677}\cos 8.1\right)$$

$$= 5248 \text{ cpm}$$

$$BPFI = \frac{N_b}{2} \times S\left(1 + \frac{B_d}{P_d}\cos\phi\right)$$

$$= \frac{10}{2} \times 996\left(1 + \frac{1.25}{7.677}\cos 8.1\right)$$

$$= 5786 \text{ cpm}$$

$$BSF = \frac{P_d}{2B_d} \times S\left(1 - \left(\frac{B_d}{P_d}\right)^2 \cos^2\phi\right)$$

$$= \frac{7.677}{2 \times 1.25} 996\left(1 - \left(\frac{1.25}{7.677}\right)^2 \cos^2 8.1\right)$$

$$= 2978 \text{ cpm}$$

4.2 Determination of Bearing Defects:

Rolling element bearing having flaws in raceways, rolling elements, or cage will usually cause a high frequency of vibration. Actually, defective bearing will not generally cause a single discrete frequency of vibration, but instead may generate several frequencies simultaneously the spectrum taken out from fault bearing machine.

We can see that, there are several high frequencies, generated by the faulty bearing. The vibration signature further suggests that, vibration is somewhat random and unsteady. Thus, observing the rotating shaft with stroboscopic light with probably not show a stationary image as it would for vibration caused by unbalance, misalignment of gears which occurs at higher multiples of shaft RPM. In most cases the bearing vibration is not steady and the frequency meter and the amplitude mater can be observed to twitch fluctuate slightly. To assist in determining the machine problem including a faulty bearing the defect frequencies of the bearing can be calculated and over laid on the vibration spectra. The general rolling element bearing frequencies are,

1. Bearing pass frequency outer race (BPFO)
2. Bearing pass frequency inner race (BPFI)
3. Ball spin frequency (BSF)
4. Fault train frequency (FTF)

As a rule of thumb, the ball passing frequencies for the inner race of the bearing will be around 60% of the no. of rolling elements multiplied by the shaft RPM. The ball pass frequency for the outer race will be 40% of the no. of rolling elements multiplied by the shaft RPM.

Steps to diagnose the defect in the equipment

Know the equipment history and analyse the problem by knowing what all recent maintenance that the equipment underwent. In many cases, the analysis steps carried out thus far may be sufficient to pinpoint the specific problem causing excessive vibration, if not the next step is to obtain complete set of amplitude versus frequency spectrums from FFT analyser at each bearing of the machine train. For a proper analysis, the machine should be operating under normal conditions of load, speed, temperature etc.

With FFT analyser collect the data in X, Y AND Axial direction on bearing to be taken and we should tabulate the data on MOTOR DRIVE END (MDE), MOTOR NON-DRIVE END (MNDE), FAN DRIVE END (FDE) and FAN NON-DRIVE END (FNDE). From the table we can clearly spot by knowing the highest Amplitude reading that is noted and by taking that data we decide at what end we are getting more amplitude and we concentrate on that side only.

In order to ensure that the analysis data taken includes all the problem related vibration characteristics and yet, is easy to evaluate and interpret the following recommendation is offered

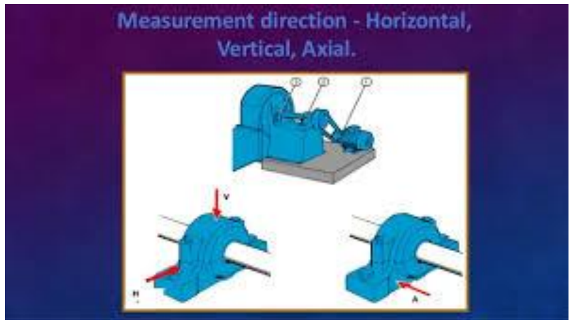


Fig:3.4 Horizontal, Vertical and Axial direction

Use the same amplitude range (scale) for all FFT's

Since the machine vibration amplitude-versus-frequency Characteristics will be presented in the form of graphics plots or FFTs, it is most important to use the same amplitude range for each FFTs to simply the comparison of the data obtained at each bearing and measurement direction. If the data is presented with different amplitude scales, the interpretation and the evaluation of the data becomes an extremely tedious, time consuming and confusing task. The importance of using the same full-scale amplitude range for each plot can best be illustrate by examining comparative horizontal, vertical and axial FFTs. This data was taken on outboard bearing.

For routine periodic checks, most FFTs data collector are used in an auto ranging mode which means that the instruments automatically selects the most appropriate full scale range for each overall measurements and FFT taken .While this is a great time saver when collecting routine data on many machines, when the data collector is being used to collect FFTs as a part of a detailed vibration analysis overriding the auto-ranging features to a "fixes" fill-scale range, simply taken and record overall amplitudes at each measurements point and a transducer direction to determine the highest amplitudes reading. Then simply select lowest full-scale amplitude that will accommodate the highest reading recording and leave the instruction set to this range for all FFTs. By doing this, all FFTs observed on the instrument display screen will be directly comparable in the field.

4.3 Identifying the problem component based on frequency:

Most problems generate vibration with frequencies that are exactly related to the rotating speed of the part in trouble. Thus, frequencies that are exactly related to the rotating speed of the part in trouble. Thus, frequencies that are exactly 1xRPM or multiplies(harmonics) of 1 RPM such as 2X,3X,4X etc. in addition, same problem may cause vibration frequencies that are exact sub harmonics of 1xRPM such as 1/2x,1/3x,1/4xRPM. In any event, the FFT analysis data cum relationship between the measured vibration frequency and the rotating speed of the various machine elements.

In addition to identifying the problem machine components based on frequency, the second purpose of FFT analysis data is to reduce the list of possible problems based on the measured vibration frequencies. Operation problem generates its own unique vibration frequency, a list of the problems that causes or generate that particular frequency can be made, which greatly reduces the long list of possibilities.

A little common sense can reduce this list even further by relating vibration frequency with rotating speed (RPM).

4.4 ANALYSIS

The vibrations are recorded from the Mill Fan equipment in three different directions i.e., axial, vertical and horizontal using Vibxpert and accelerometer at regular intervals of time.

Using OMNITREND software the readings are analysed through time wave form analysis. A sudden increase in amplitude led to the identification of defect in the bearing.

- In the spectrum, predominant peak is observed at 3x frequency i.e., three times of fundamental frequency. There a periodic increase in the amplitude due to defect in the rolling elements
- The calculated ball spin frequency is matching with the standard fault frequency of the ball bearing.

Physical Observations:

- Abnormal and rhythmic knocking sounds from the motor is high at bearing points as compared to Motor Body.

- Fan side readings are more or less at moderate level.

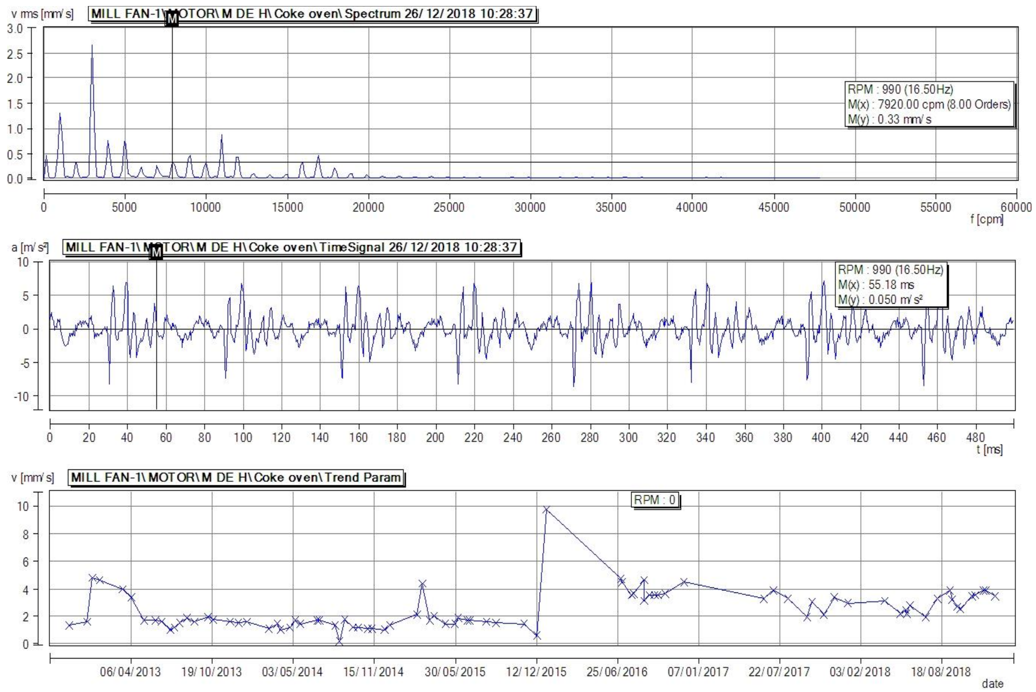
- Lubrication condition also appears to be dry.

- Motor drive end vibrations readings are high in vertical direction.

- The time wave form is also appeared like amplitude modulation patteren in the axial direction readings of MDE bearing.

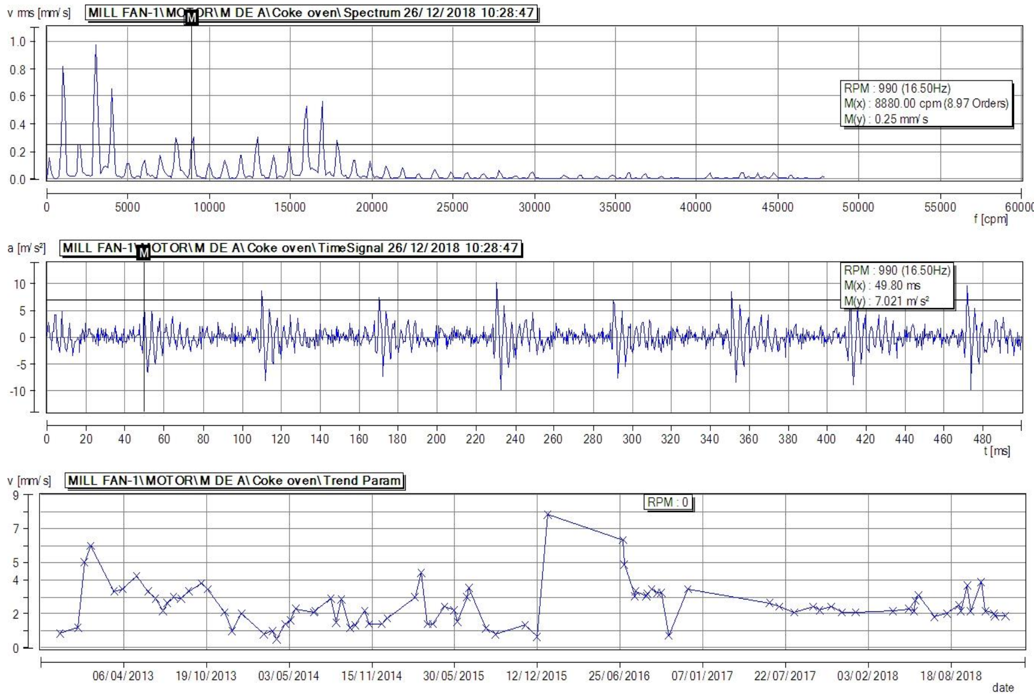
The above observations, conditions and predominant frequencies appeared in the spectrums directed this analysis towards suspicion of bearing condition.

MOTOR DRIVE END (MDE) Horizontal



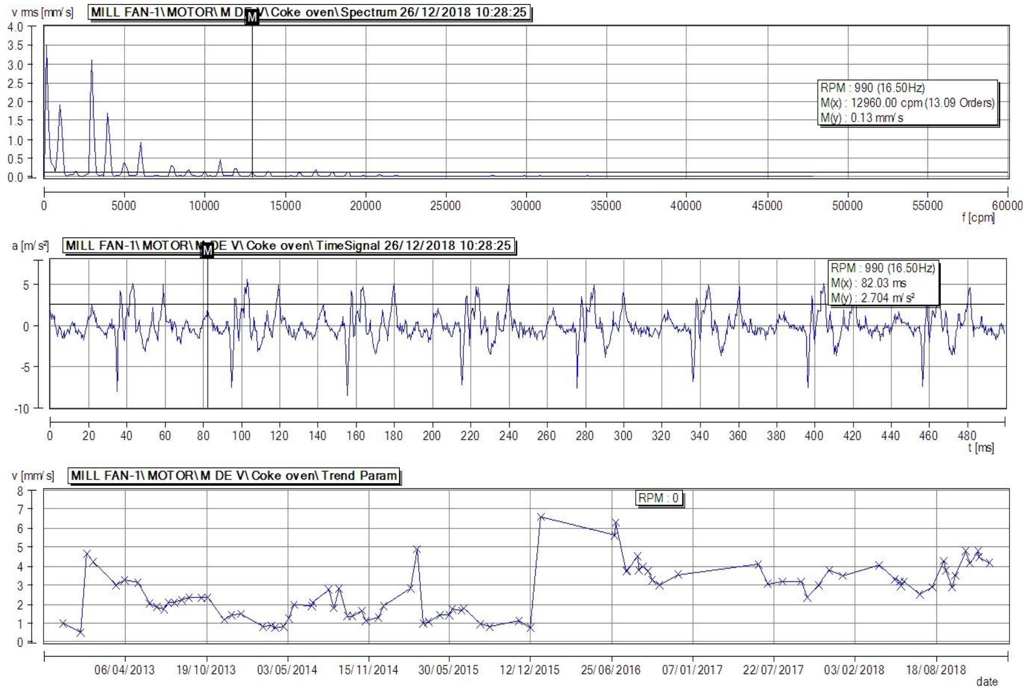
The graph drawn between velocity and frequency is the spectrum graph. The overall amplitude is 3.49 which is less than 4.5 that a class 3 equipment can withstand. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month overall amplitude and increase or decrease in amplitude after the action has taken.

MOTOR DRIVE END (MDE) Axial



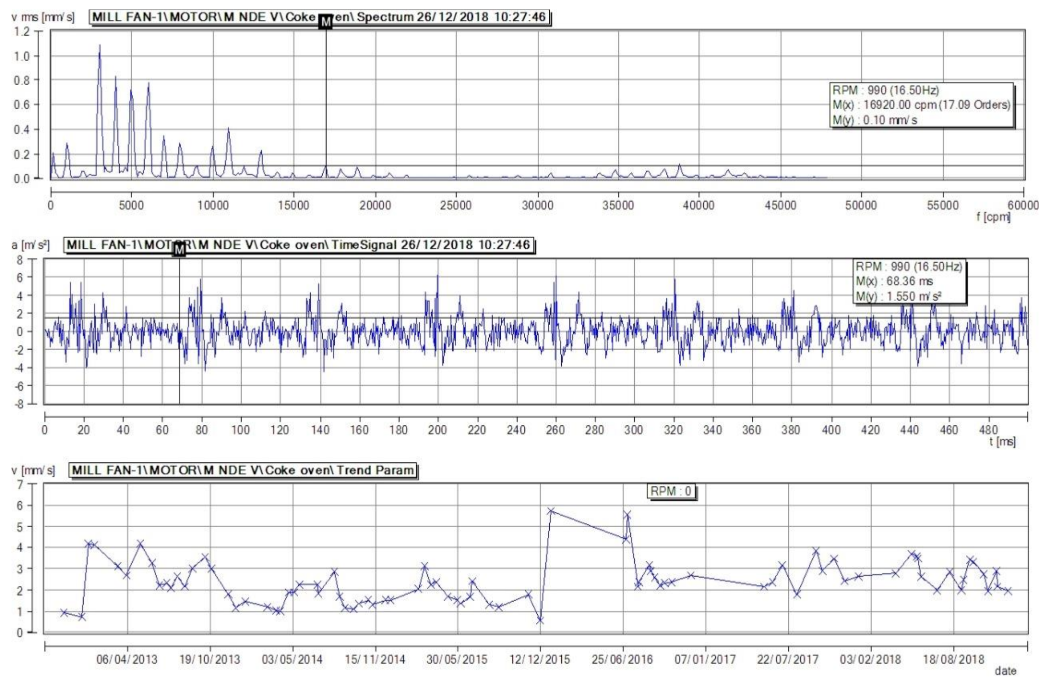
The graph drawn between velocity and frequency is the spectrum graph. The overall amplitude is 1.84 which is less than 4.5 that a class 3 equipment can withstand. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month. Overall amplitude and increase or decrease in amplitude after the action has taken.

MOTOR DRIVE END (MDE) Vertical



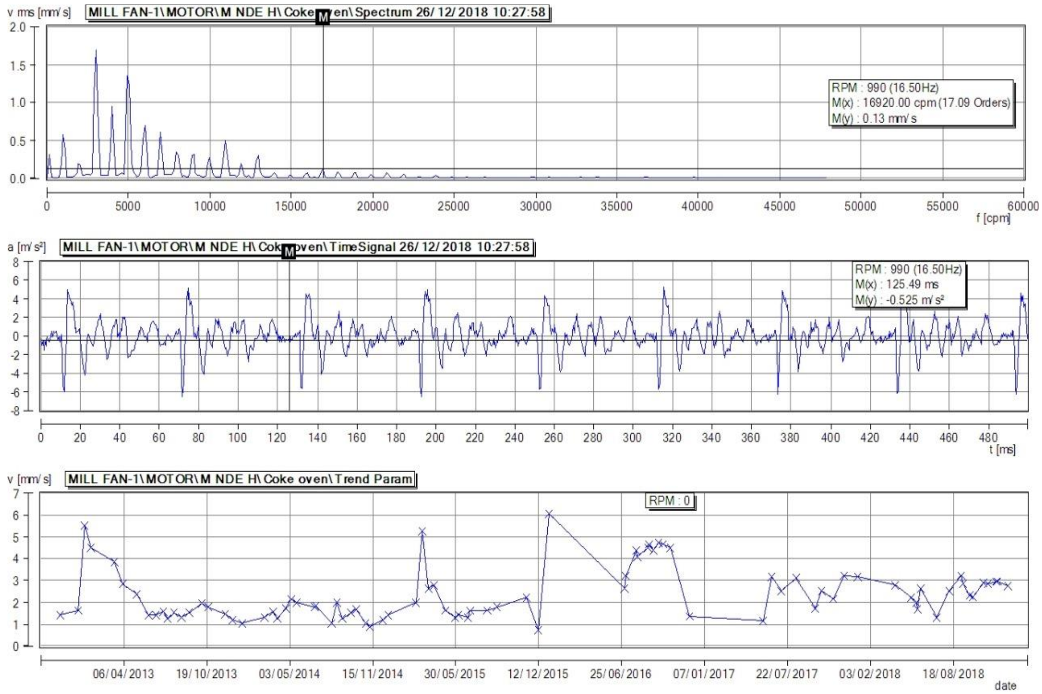
The graph drawn between velocity and frequency is the spectrum graph. Out of total amplitude which is 5.5 seventy percent is concentrated below 3000 cpm. The overall amplitude of the class 3 equipment should be less than 4.5, this made us to suspect the fault in the industrial fan. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month overall amplitude and increase or decrease in amplitude after the action has taken.

MOTOR NON-DRIVE END (MNDE) Vertical



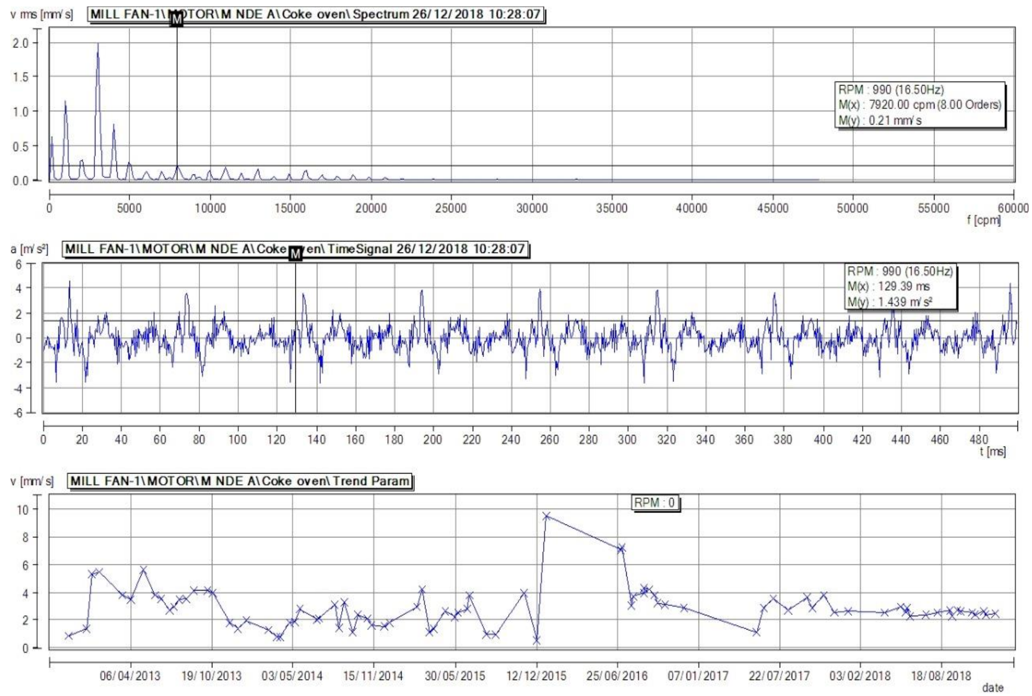
The graph drawn between velocity and frequency is the spectrum graph. The overall amplitude is i.93 which is less than 4.5 that a class 3 equipment can withstand. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month overall amplitude and increase or decrease in amplitude after the action has taken.

MOTOR NON-DRIVE END (MNDE) Horizontal



The graph drawn between velocity and frequency is the spectrum graph. The overall amplitude is 2.59 which is less than 4.5 that a class 3 equipment can withstand. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month overall amplitude and increase or decrease in amplitude after the action has taken.

MOTOR NON-DRIVE END (MNDE) Axial



The graph drawn between velocity and frequency is the spectrum graph. The overall amplitude is 2.76 which is less than 4.5 that a class 3 equipment can withstand. The second graph is drawn between acceleration and time period is time signal which is combination of all the waves produced in the equipment. The third graph is trend param which indicates amplitude of the equipment in the particular direction on a particular day, here we can also previous days/month overall amplitude and increase or decrease in amplitude after the action has taken.

CHAPTER 05

RESULTS & DISCUSSIONS

5. RESULTS AND DISCUSSIONS

From the analysis on the Industrial fan, the vibrations were recorded and the vibration signal wave is analysed with FFT to understand what all frequencies are contributing towards the vibrations and which frequency could possibly pose the fault in the equipment. Of all the reading of vibrations taken along various directions at different locations on the equipment, it is observed that the reading were showing permissible vibration levels in most of the locations and directions except at the Motor Drive end bearing mount along vertical direction.

DIRECTION	**MNDE (mm/sec)**	**MDE (mm/sec)**	**FDE (mm/sec)**	**FNDE (mm/sec)**
VERTICAL	1.93	5.5	3.37	1.85
AXIAL	2.76	3.49	2.95	2.87
HORIZONTAL	2.59	1.84	2.48	2.54

Table: Overall value Readings of Vibration signal

Based on the frequency spectrum of the vibration signal, the location of error could possibly at the site of motor drive end bearing. Upon considerate observation and calculations, the fault frequencies from the analysis were found to be at around 3000 cpm which corresponds to 3X times of the fans' running speed. Since this 3X frequency closely corresponds to Ball Spin Frequency (BSF).

With this suspicion, the trend of the bearing health over the past few years were verified and the present readings of vibration analysis were compared with past history. Upon comparison, the earlier faults indicated by this 3X frequency were associated with the fault bearings and thus the suspicion got strengthened.

The industry maintenance personnel attended this fan and overhauled few components of the equipment and replaced the faulty ball elements of the bearing, thus restoring the health of the equipment overall.

From this work it can be reaffirmed that relying on vibration analysis for fault diagnosis of industrial equipment is one of the best choices available at hand. However, to confirm the diagnosis and to check the actual problem with in the component, the equipment needs to be disassembled and investigated.

CHAPTER 06

CONCLUSIONS

6. CONCLUSIONS

Premature failure of bearing will happen only if any manufacturing defects are developed during the process of manufacturing. After putting in the operation of any bearing it may fail due to Normal aging Effects. Early failure of bearing after taking in to operation is not the problem of bearing but some external forces are responsible for their failure. Identification of failures in bearings can be detected through different techniques like Shock Pulse Monitoring (SPM), Acoustic Emission Analysis (AE). These techniques can help in finding out condition of the bearing but it is not possible to find out the root cause of the failure.

Early and Efficient fault detection is very important in process industries, Failure of any machine leads to huge production loss. Vibration Analysis is the versatile tool in identification of bearing failures at an early stage and also helps in identification of root cause like Misalignment in the system, Misalignment of bearing with its shaft or in the housing, Unbalance in the rotors, and resonant conditions in the surrounding supporting structures

1. With the help of Vibxpert analyzer and omni trend software, condition based monitoring of industrial equipment was performed.
2. Bearing spin frequency matches with fault spin frequency which indicates the function of defective bearing.
3. The root cause has been identified that the balls got worn out due to external force acting on bearing.
4. The defective bearing has been replaced.
5. Condition monitoring as a maintenance tool has played an important role in early identification and fixation of a problem that could have turn into a major one adversely effective for the production of plant.
6. It has been suggested to the plant ensure that CBM can be further extended to all such rotary equipment to excess vibrations due to aging.

REFERENCES AND BIBLIOGRAPHY

REFERENCES

[1] G Venkata Kishore Rakshit Raju, M Sree Veena, M C S Reddy, "Condition Monitoring of Ball Bearings", Internation journal of Advanced Research, Ideas and Innovations in Technology, vol. 4, issue 2, (2018), pp. 54-59.

[2] H. MohamadiMonavar, H. Ahmadi and S.S. Mohtasebi, "Prediction of Defects in Roller Bearings Using Vibration Signal Analysis", World Applied Sciences Journal, vol.4 (1), (2008), pp. 150-154.

[3] H. Saruhan*, S. Saridemir, A. Cicek and I. Uygur, "Vibration Analysis of Rolling Element Bearings Defects", Journal of Applied Research and Technology., vol.12, (2014), pp. 384-395.

[4] M Amarnath, R Shrinidhi, A Ramachandra and S B kandagal, "Prediction of Defects in Antifriction Bearings using Vibration Signal Analysis", IE(I) Journal- MC, vol 85 (2004), pp. 88-92.

[5] P. Venkata Prasad and V.Ranjith Kumar, "Detection of Bearing Fault using Vibration Analysis and Controlling the Vibrations", International Journal of Engineering Sciences & Research Technology., 4.(10), (2015), pp. 539-550.

[6] Ravindra A.Tarle, Nilesh K.Kharate and Shyam P. Mogal, "Vibration Analysis of Ball Bearing", International Journal of Science and Research., vol.4,(2015), pp. 2655-2665.

[7] Rupendra Singh Tanwar, Shri Ram Dravid and Pradeep Patil, "Fault Diagnosis of ball Bearing through Vibration Analysis", International Journal of Latest Trends in Engineering and Technology., vol. 1, issue 1, (2013), pp. 200-204.

[8] Surojit Poddar and Madan Lal Chandravanshi, "Ball Bearing Fault Detection Using Vibration Parameters", International Journal of Engineering Research & Technology., vol. 2, issue 12, (2013), pp. 1239-1244.

[9] Syed Zeashan, Subhan Ali and Prashanth Pai M, "Antifriction Bearing Diagnostics in a Manufacturing Industry", Journal of Mechanical Engineering and Automation., vol. 6(5A), (2016), pp. 58-62.

BIBLIOGRAPHY

- Steel plant training – by RINL Visakhapatnam
- Vibrational analysis – study material
- Hand book of conditional monitoring - edited by BKN Rao

GLOSSARY OF TERMS

Accelerometer: A transducer is a device with an electric output directly proportional to the acceleration of the vibrating point in the direction in which the transducer is attached. The acceleration of a vibrating component is usually measured using an accelerometer.

Amplitude modulation: In machine system the fluctuation and the amplitude of a signal due to the influence of another signal that is of a different frequency. In rotating machinery, high frequency signals, such as bearing inner race defect signals, are often amplitude-modulated by the lower frequency signal of the rotating shaft, due to the defect passing in and out of the load zone once every revolution. The spectrum corresponding to a sinusoidal, amplitude-modulated by another is characterized by a peak located at the frequency of the sinusoid, and a sideband on either side of the peak, each sideband distanced from the peak by the frequency of the modulating sinusoid.

Angle contact bearing: A bearing that supports both radial and axial shafts loads. The rolling elements in an angular contact bearing are usually oriented at an angle to the shaft axis.

Axial Vibration: Vibration is in the direction of the centreline of a shaft or rotor. Arial Vibration is seen in overhung rotors.

Balancing: The adjustment in the mass distribution in a rotating part so the axis of rotation and mass centreline of the rotating part are coincident.

Ball pass frequency: The frequency corresponding to the rate at which balls or rollers in a bearing pass a particular location on one or other of the races. The inner race and outer race ball pass frequencies are different from each other and are dependent on the geometry of the bearing and the rotation speed of the bearing. The term Ball Pass Frequency is often abbreviated as BPF

Bode plot: A Set of two graphs, one showing how amplitude varies with frequency and the other graph showing how phase varies with frequency. A bode plot is used to show the frequency response of the system.

Brinelling: Identification of the races of a bearing by its rolling elements. The indentation is usually caused by vibration of the shaft while it is not rotating. The identification could also be due to large static forces being applied to the shaft while it is not rotating. Brinelling causes spectral peaks at the ball pass frequencies.

Cpm: A measurement unit for the frequency of periodic motion, cpm stands for 'cycles per minute'. One cpm is equal to one sixty of hertz (1/60Hz)

Fast Fourier Transform: An algorithm for performing the DFT operation efficiently i.e. an algorithm for calculating a discrete spectrum from a discrete waveform. The term 'Fast Fourier Transform' is often abbreviated as FFT. The FFT algorithm determines the frequencies and the amplitudes corresponding to the frequencies that are present in the wave form

FFT analyser: The Spectrum analyzer uses the FFT algorithm to calculate spectra from waveforms. Most spectrum analysers are FFT analysers.

Fourier transform: A mathematical operation that transforms a time domain functions into an equivalent frequency domain function. The Fast Fourier Transform, a computational version of the Fourier transform, is used to calculate discrete frequency domain spectra from discrete time domain waveforms.

Harmonic: Spectra peak at a frequency that is whole number multiple of the fundamental frequency or the frequency of an excitation force present. Single harmonic frequency is 'n' times of the fundamental frequency is called 'nX'.

Modulation: The varying or fluctuation of a signal due to the influence of another signal. The signal that is being modulated is called the carrier and the signal causing the modulation of the carrier is called the 'Modulating Signal'.

Natural Frequency: The frequency at which a system will vibrate when it is vibrating freely by itself without the influence of an excitation force. An n degree of freedom system has n frequencies.

Phase: It is the angle of lead or lag between two vibration peaks or with respect to reference points.

Side Bands: Minor peaks, caused by amplitude or frequency or frequency modulation, located symmetrically on either side of spectra peaks. The distance between adjacent sidebands is equal to the frequency of the modulating signal.

ACRONYMS

CBM	-	Condition Based Maintenance
MNDE	-	Motor Non-Drive End
MDE	-	Motor Drive End
FNDE	-	Fan Non-Drive End
FDE	-	Fan Drive End
FFT	-	Fast Fourier Transformers
RINL	-	Rastriya Ispat Nigam Limited
SPM	-	Shock Pulse Monitoring
SMS	-	Steel Melt Shop
LMMM	-	Light & Medium Merchant Mills
WRM	-	Wire Rod Mill
MMSM	-	Medium Merchant & Structure Mill
rms	-	Root Mean Square
ISO	-	International Organization for Standardization
CSI	-	Condition Sensor Interface
RPM	-	Rotation Per Minute
USB	-	Universal Serial Bus
CDCP	-	Coke Dry Cooling Plant
COCCP	-	Coke Oven & Coal Chemical Plant
Cpm	-	Cycles per Minute
mmWC	-	Millimetres per Water Column
BPFO	-	Ball Pass Frequency Outer race
BPFI	-	Ball Pass Frequency Inner race
BSF	-	Ball Spin Frequency
FTF	-	Fault Train Frequency

APPENDIX

Appendix-I : Table of Vibration frequencies and their likely causes

FREQUENCY IN TERMS OF RPM	MOST LIKELY CAUSES	OTHER POSSIBLE CAUSES & REMARKS
1X RPM	Unbalance	Eccentric journals, gears or pulleys. Misalignment if high axial vibration Bad belts Resonance Reciprocating forces Electrical problems
2XRPM	Mechanical Looseness	Misalignment if high axial vibration Reciprocating forces Resonance Bad belts if 2XRPM of belt
3XRPM	Misalignment looseness	Usually a combination of misalignment and excessive axial clearance (looseness)
Less than 1X RPM	Oil Whirl (less than 0.5X RPM)	Bad drive belts background vibration Resonance ” Beat” vibration
Synchronous (A.C line frequency)	Electrical Problems	Common electrical problems include broken rotor bars, eccentric rotor, unbalanced phase in poly-phase system unequal air gap
2X synch. Frequency	Torque pulses	Rare as problem unless resonance is excited

Appendix-II : Bearing frequency table

Bearing Number	NB	BD	PD	PHI	BPFO	BPFI	FTF	BSF
6080	13	2.5	19.685	0	5.67	7.33	0.44	3.87
6084	14	2.5	20.472	0	6.15	7.85	0.44	4.03
6200	8	0.187	0.807	0	3.07	4.93	0.38	2.04
6201	7	0.218	0.866	0	2.62	4.38	0.37	1.86
6202	7	0.25	0.984	0	2.61	4.39	0.37	1.84
6203	7	0.281	1.133	0	2.63	4.37	0.38	1.89
6204	8	0.312	1.358	0	3.08	4.92	0.39	2.06
62/22	8	0.312	1.417	0	3.12	4.88	0.39	2.16
6205	9	0.312	1.535	0	3.59	5.41	0.40	2.36
62/78	8	0.375	1.692	0	3.11	4.89	0.39	2.15
6206	9	0.375	1.83	0	3.58	5.42	0.40	2.34
62/32	8	0.406	1.909	0	3.15	4.85	0.39	2.24
6207	9	0.437	2.106	0	3.57	5.43	0.40	2.31
6208	9	0.468	2.362	0	3.61	5.39	0.4	2.42
6209	9	0.5	2.559	0	3.62	5.38	0.40	2.46
6210	10	0.5	2.755	0	4.09	5.91	0.41	2.66
6211	10	0.562	3.051	0	4.08	5.92	0.41	2.62
6212	10	0.625	3.405	0	4.08	5.92	0.41	2.63
6213	10	0.656	3.641	0	4.1	5.9	0.41	2.69
6214	10	0.687	3.838	0	4.11	5.89	0.41	2.7
6215	11	0.687	4.074	0	4.57	6.43	0.42	2.88
6216	10	0.749	4.33	0	4.14	5.86	0.41	2.8
6217	11	0.781	4.645	0	4.58	6.42	0.42	2.89
6218	10	0.874	4.921	0	4.11	5.89	0.41	2.73
6219	10	0.937	5.216	0	4.1	5.9	0.41	2.69
6220	10	1	5.511	0	4.09	5.91	0.41	2.66
6221	10	1.062	5.807	0	4.09	5.91	0.41	2.64
6222	10	1.125	6.102	0	4.08	5.92	0.41	2.62
6224	10	1.187	6.594	0	4.1	5.9	0.41	2.69
6226	10	1.25	7.086	0	4.12	5.88	0.41	2.75
6228	10	1.25	7.677	0	4.19	5.81	0.42	2.99
6230	11	1.25	8.267	0	4.67	6.33	0.42	3.23
6230	12	1.25	8.858	0	5.15	6.85	0.43	3.47
6234	12	1.374	9.448	0	5.13	6.87	0.43	3.37
6236	11	1.5	9.842	0	4.66	6.34	0.42	3.2
6238	11	1.625	10.433	0	4.64	6.36	0.42	3.13
6240	12	1.625	11.023	0	5.12	6.88	0.43	3.32
6244	12	1.75	12.204	0	5.14	6.86	0.43	3.42
63200	8	0.187	0.807	0	3.07	4.93	0.38	2.04
63201	7	0.218	0.866	0	2.62	4.38	0.37	1.86
63202	7	0.25	0.984	0	2.61	4.39	0.37	1.84
63203	7	0.281	1.133	0	2.63	4.37	0.38	1.89

Excerpt from NTN Bearing manufactures hand book (Pg-4)