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DETECTION OF BEARING FAULT USING VIBRATION ANALYSIS AND CONTROLLING THE VIBRATIONS

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ABSTRACT

In today's world we were more concerned with reducing the cost of failure and maintenance in any industry as per schedules of each machine and determined by the exact running condition of each major machinery components used in industries like power plants, chemical plants and automotive industries that require precise and efficient performance. Condition monitoring of these machine components like bearings, shafts and shaft mountings and installation of machine was important to avoid failures. Several techniques were available and vibration monitoring was one of them. Vibration monitoring and analysis was one such tool that can be used for determining the condition of a rotating machine and its analysis. Vibration analysis gets much advantage in factories as a predictive maintenance technique.

In this study, vibration response of the rolling bearings to the defects on outer race, inner race and the rolling elements is obtained and analyzed. It shows that every defect excites the system at its characteristic frequency. The location of the faults is indicated by the FFT spectrum. Defects are indicated at motor and fan both bearings in horizontal direction. In situ dynamic balance was implemented by adding weight to reduce rate of vibrations.

The results reveal that vibration based monitoring method is successful in detecting the faults in the bearing.

KEYWORDS: FFT, spectrum.

INTRODUCTION

Industrialization brought revolution in production that means by using low cost and less time rate of production high. This was due to introduction of machinery in field of production. Each and every machine had certain life span; if there were properly installed and regulated for this to reach its rated life was done by proper supervision on regular intervals. For maintains purpose expertise man power was utilized but rate of failure was more instead of man power, many techniques were implemented through which rate of failure was minimize and optimizing the resources like men, machines, materials & money and then ensuring the health of assets.

In early days, equipment maintenance was conducted only when equipment actually failed. Shortly thereafter, came to the necessity of performing regular maintenance on the equipment, could keep the equipment to operate longer between failures. This type of regular maintenance can be done by periodic maintenance and preventive maintenance, help to determine the condition of the equipment which is in operating condition. For this reason maintenance schedules of each machine are more and more determined by the exact running condition of each machine. To understand the running condition of the machine detailed condition monitoring activities are to be undertaken. If done properly, condition monitoring also helps in predicting the residual time before a particular machine needs overhaul. Vibration monitoring and analysis is one such tool that can be used for determining the condition of a rotating machine and its analysis gives a clear picture of the any fault that there may be.

The main objective of the project is to utilize the vibration analysis utilize the vibration analysis techniques to identify the faults of certain rotating machines like pump and fan.

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LITERATURE REVIEW

N. Tandon et.al, (ref 1), had carried out their work on condition monitoring of different machines. The techniques covered in their work were performance, vibration, motor stator current, shock pulse, acoustic emission, and thermography and wear debris monitoring. Signal processing techniques to gain more benefits of vibration monitoring were covered. Later **Dr.M.R.S satyanarayana et.al, (ref 2)** had presented on condition monitoring and vibration analysis of boiler feed pump. The implementation of condition based maintenance on boiler feed pump critical machine used in the thermal power plant, by adopting vibration spectrum analysis which is a predictive maintenance technology. The application of computer and electronic measuring and detecting systems had provided a new improvement for condition monitoring a particular relevance for plant engineers in utilities and service departments. **Schoen et.al; (ref 3)** had stated on vibration monitoring of a machine element and addressed the application of motor current spectral analysis for the detection of rolling-element bearing damage in induction machines. This study takes the initial step of investigating the efficacy of current monitoring for bearing fault detection by correlating the relationship between vibration and current frequencies caused by incipient bearing failures. The bearing failure modes are reviewed and the characteristic bearing frequencies associated with the physical construction of the bearings are defined. **Ilya Mokhov and Alexey Minin (ref 4)** observed new forecasting and classification technique for particular vibration signal characteristics and suggested approaches allow creating a part of control system responsible for early fault detection, which could be used for preventive maintenance of industrial equipment. Presented approach can be extended to high frequency financial data for the prediction of “faults” on the market. **Sadettin Orhan et.al; (ref 5)** worked on “Vibration monitoring for defect diagnosis of rolling element bearings as a predictive maintenance tool Comprehensive case studies”. In this study, the vibration monitoring and analysis were studies, examined and presented in machineries that were running in real operating conditions. Failures formed on the machineries in the course of time were determined in its early stage by the spectral analysis. It was shown that the vibration analysis gets much advantage in factories as a predictive maintenance technique. **Surendra & Richardson (ref 6)** demonstrate the effects of rotating machinery shaft misalignment on its dynamic behavior which is characterized in the form of an Operational Deflection Shape (ODS). Tests are performed on a machinery fault simulator under various operating conditions. Since misalignment produces dominant motion at the rotor running speed and its harmonics, this data was used to construct an ODS. The emphasis was on correlating the ODS of the machine when properly aligned with its ODS following induced shaft misalignment, which results in providing a new perspective of machinery fault detection. **Abhinay et.al;** (ref 7) studied on Vibration Based Condition Assessment of Rolling element Bearings with Localized Defects. In their study, vibration response of the rolling bearings to the defects on outer race, inner race and the rolling elements was obtained and analyzed. It shows that every defect excites the system at its characteristic frequency. The location of the faults is indicated by the FFT spectrum. The results reveal that vibration based monitoring method is successful in detecting the faults in the bearing. **Milind Natu (ref 8)** had presented on Bearing Fault Analysis Using Frequency Analysis. Bearing fault diagnosis is important in condition monitoring of any rotating machine. Early fault detection in machineries can save millions of rupee in emergency maintenance cost. In their Paper, they explains the procedure for detecting bearing faults using FFT and by using Wavelet analysis more specifically HAAR wavelet up to two levels of approximations and detail components. The analysis is carried out offline in MATLAB. **Pravesh Durkhure and Akhilesh Lodwal (ref 9)** observed Fault diagnosis of Ball bearings by statistical analysis under various time domain parameters and investigates the correlation between time domain and frequency domain analysis of vibration signature to judge and find the fault in bearing. This is achieved by vibration analysis and investigating different time domain parameter like Kurtosis, Skewness, Crest factor, RMS Value. Vibration data of healthy bearing are used as a standard for the analysis of vibration spectra of faulty bearing. The result shows that the statistical analysis through different time domain parameters and its fast Fourier transformation provides efficient representation of fault detection in rolling element bearings, and they also get exact fault position for defective bearing by its frequency domain analysis. **Lakshmi Pratyusha et.al; (ref 10)** had presented on Bearing Health Condition Monitoring Time Domain Analysis. The current work focuses on the Time Domain Analysis in Vibration Monitoring of a rolling element bearing. This type of analysis depends on several statistical features which are used to identify the defects in the bearing done by a method called feature extraction. It involves calculating features using the raw vibration data and also finding the features using time derivative and time integral of the vibration data. **G. Suresh Babu and Dr. V. Chittaranjan Das (ref 11)** Studied on implementation of condition based maintenance on BOILER FEED pump critical Machine used in the thermal plant, by adopting Vibration spectrum analysis which is a predictive maintenance technology. For the BOILER FEED pump the vibration readings show that values are more than normal readings. Spectrum analysis was done on readings and found that mass unbalance in vanes. It was corrected based on phase analysis and vibration readings were observed after modification which gives the values within normal range. It eliminates unnecessary opening of equipment with considerable savings in personnel resources.

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Definition of vibration

Any motion that repeat itself after an interval of time is called vibration or oscillation .**Vibration** refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road.

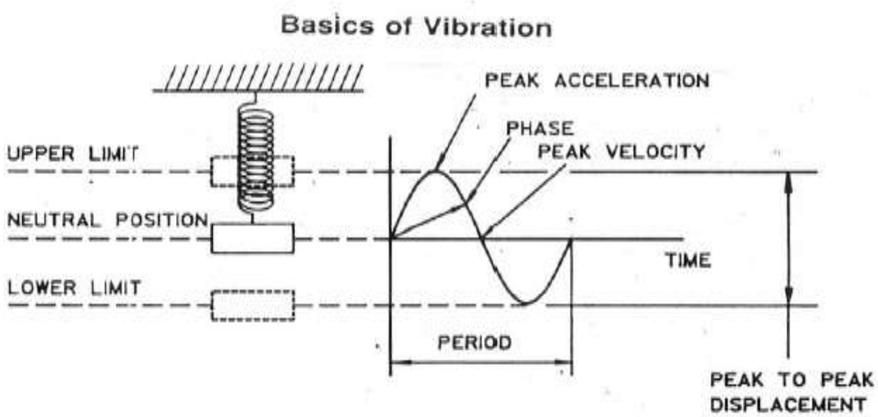

Figure 3.1 Basic vibration representations

More often, vibration is undesirable, wasting energy and creating unwanted sound – noise. For example, the vibration motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations can be caused by imbalances in the rotating parts, uneven friction, the meshing of gear teeth, etc. Careful designs usually minimize unwanted vibrations.

Sources of vibration in Rotating Machine element

1. Misalignment of couplings, bearings and gears.
2. Unbalance of rotating components.
3. Looseness
4. Deterioration of rolling –element bearings
5. Gear wear
6. Eccentricity of rotating components such as “v” belt pulleys or gears.
7. Aerodynamic /hydraulic problems in fans, blowers and pumps.
8. Bent shaft
9. Resonance
10. Electrical problems in motors.

Characteristics of vibration Machine element

Whenever vibration occurs, there are actually four forces involved that determine the characteristics of the vibration. These forces are:

- ❖ The exciting force, such as unbalance or misalignment.
- ❖ The mass of the vibrating system, denoted by M.
- ❖ The stiffness of the vibrating system, denoted by the symbol K.
- ❖ The damping characteristics(C) of the vibrating system

The exiting force is trying to cause vibration, whereas the stiffness, mass and damping forces are trying to oppose the exiting force and control or minimize the vibration.

The characteristics needed to define the vibration include:

- ❖ Frequency
- ❖ Displacement
- ❖ Velocity
- ❖ Acceleration

INSTUMENT UED FOR VIBRATION ANALYSIS AND DETECTION:

Digital or FFT frequency analyzer

The term "FFT" stands for "Fast Fourier Transform". Nearly 200 years ago, French mathematician, Baron Jean Baptist Joseph Fourier established that any periodic function (which includes machinery vibration signals) can be represented mathematically as a series of sines and cosines. In other words, it is possible to take a vibration time waveform, whether simple or complex, and mathematically calculate the vibration frequencies present along with their amplitudes this process is called a "Fourier Transform". Although a Fourier Transform can be done manually, the process is extremely time consuming. However, with the introduction of digital technology, the process can be carried out very fast. Hence the term Fast Fourier Transform or FFT. Digital vibration analyzers and data collectors actually include a computer chip programmed to perform the FFT function.

Fig: 4.1 Fast Fourier Transformers

Fig: 4.2 FFT cable and probe

Input

Since a vibration accelerometer is normally used for vibration detection and Analysis, it may be necessary to convert the acceleration signal to velocity by "single integration" or to displacement by "double integration". These functions are carried out at the input section. Calibration of the analog signal, based on transducer sensitivity, is also performed at the input.

Vibration monitoring systems are usually equipped with some contact piezoelectric probes. Absolute vibrations in mm/s RMS are measured. The absolute and relative vibration data are compared. Fake trips are distinguished easily by this method. Probe installation mistakes are usually caused such fake trips. These indicators are usually installed in main board substations. The absolute and relative vibration data and trends are presented. Besides, the basic principles of piezoelectric probes discussed. Misalignment and unbalance is the most cause of machine vibration. An unbalanced rotor always cause more vibration and generates excessive force in the bearing area and reduces the life of the machine. Understanding and practicing the fundamentals of rotating shaft parameters is the first step in reducing unnecessary vibration, reducing maintenance costs and increasing machine uptime. Misalignment and unbalance have unique characteristics in FFT, TWF or phase behavior of machine. Vibration analysis could predict unexpected shut down in industrial plants.

Specifications

Parameter	**Maximum Measurement Range**	**Maximum Resolution**	**Frequency Range**
Displacement Peak-Peak value	5mm	1 micrometer	10-500Hz
Velocity RMS value	200mm/s	0.1mm/s	10-1kHz
Acceleration Peak value	250m/s^2	0.1 m/s^2	20-10kHz
High Frequency Acceleration Envelope RMS value	20unit	0.1unit	5-1kHz. Demodulated from 15-40kHz acceleration

Maximum measurement range/ frequency range when the sensitivity of the sensor is 5pC/ms^{-2}

- Measurement accuracy ±5%.
- Type of sensors **:** Piezoelectric accelerometer.
- Range of frequency analysis **:** 100, 200, 500, 1k, 2k, 5k, 10k (Hz).
- The sampling frequency is 2.56 times of the analysis frequency range.
- 2Anti-aliasing filter:8-order ellipse.
- Power supply: Nickel-Hydrogen battery. Work for at least 8 hours continuously after fully charged. Storage capacity for 320sets of data (including sequential number, peak of acceleration, RMS of velocity, peak-peak of displacement, and RMS of envelope) and 48 × 1024 points of vibration waveforms.
- Dimensions **:** 196 × 101 × 45 (mm).
- Weight **:** 1100 grams (including battery).

Operational Environment

- Environmental temperature **:** 5-40 (degrees Celsius).
- Relative Humidity **:** ≤85 % (non-saturated).
- No corrosive gas.
- No strong electromagnetic magnetic field interference and no strong vibration and shock.

Safety

Model-911 data collector and its sensor should not be in direct contact with moving parts of the machinery. You should also observe the safety regulations of the workshop during the operation.

Where to Take the Readings:

Since vibratory forces generated by the rotating components of a machine are passed through the bearings, vibration readings for both detection and analysis should be taken directly on the bearings whenever possible. The readings will be taken on any machine in the horizontal, vertical and axial directions.

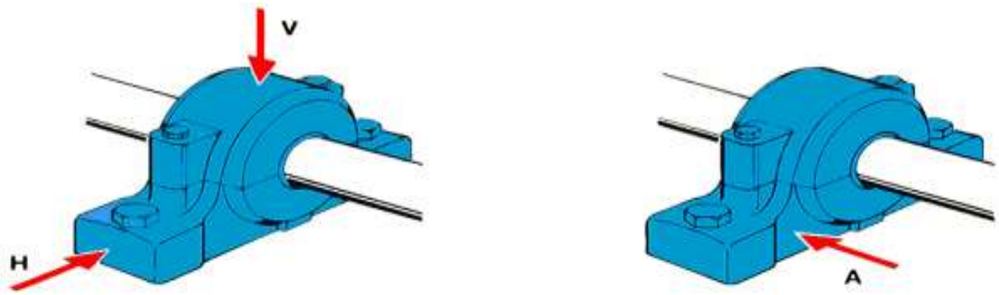

Figure 4.21 directions of taking the vibration readings

VIBRATION ANALYSISOFDIFFERENT ROTATING MACHINES

For analyzing vibration signature and learning how to detect fault using vibration analysis we chose 2 rotating machine with different construction and different speed. The machines comprised of, pumps, fans. We have measured the vibration using vibration measuring instrument FFT. I have used an accelerometer for this offline measurement. I analyzed the readings using Machine Analyst software. The FFT and Time waveform of each machine and their analysis follows.

SEAL AIR FAN

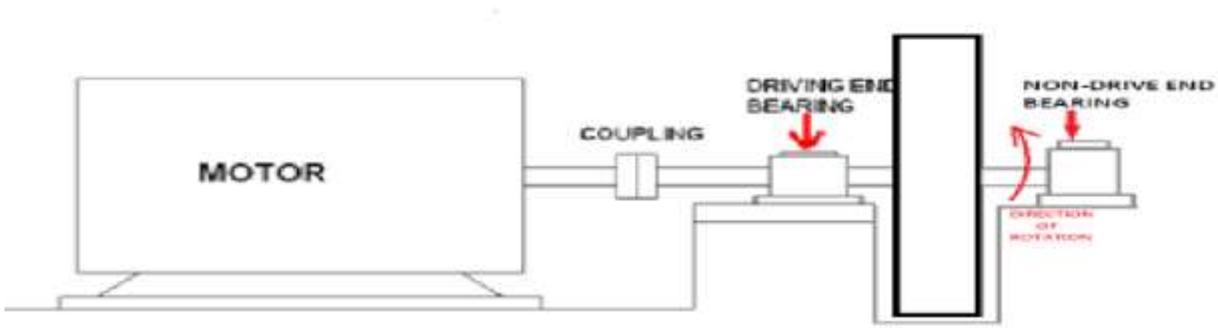

Fig: 5.1 SCHEMATIC DRAWING OF SEAL AIR FAN

SPECIFICATION:

Rating	: 83.5 KW
PUMP RPM	: 3000
MOTOR RPM	: 3000
NATURE OF COUPLING	: FLEXIBLE
BEARING: TAPER ROLLER BEARING	: DIA 65 mm
TYPE OF LUBRICANT	: ISO VG 32 (AS PER DRAWING)

As the fan is horizontal with rated power with more than 15 KW but less than 300 KW with flexible drive, it falls under Part 10816 Part 3 for a machine having continuous running condition the alarm setting is 4.5 mm/s and the ad vice trip setting is 7.1 mm/s.

VIBRATION DATA TAKEN WITH: Co Co-80 MODEL No: 55836

Fig: 6.1.2 Vibration Readings of Pump Vertical at NDE

LOCATION	Vibration Limit As Per ISO 10816	Direction	Visited on 13.03.15 Rpm:910 (Before Balancing)	Visited on 13.03.15 Rpm: 910 (After Balancing)	Visited on 14.03.2015 Rpm:726
MOTOR NDE	11.2 mm/sec. (RMS)	H	***10.7***	***4.2***	***2.2***
		V	***2.1***	***1.3***	***0.8***
		A	***1.6***	***0.8***	***0.5***
MOTOR DE		H	***8.3***	***2.6***	***2.1***
		V	***2.4***	***1.2***	***0.7***
		A	***1.9***	***0.9***	***0.4***
FAN DE		H	***6.5***	***3.6***	***1.7***
		V	***1.5***	***0.9***	***0.6***
		A	***3.7***	***2.4***	***1.6***
FAN NDE		H	***10.7***	***5.6***	***2.3***
		V	***3.2***	***1.8***	***1.0***
		A	***7.8***	***5.6***	***1.0***

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Observations & Analysis :

- Defects are indicated at motor and fan both bearings in horizontal direction.
- In situ dynamic balance was implemented on 13.03.2015 by adding 5kg weight.
- After balancing fan vibrations decreased from 10.7 mm/sec to 4.2 mm/sec.
- Still minor unbalance indicated at fan impeller.
- Axial vibration observed at fan NDE bearing.

SPECTRUMS:

From the FFT, we can see high amplitude of 4.46 mm/s at 1X of the rotating speed. The peak is only at 1X, there is no other significant peak

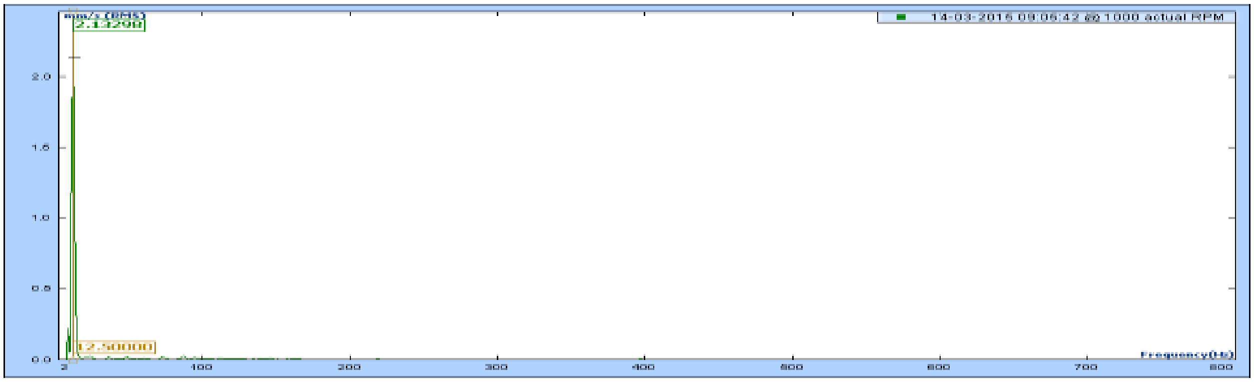

Fig: 5.1 Spectrum of MOTOR NDE H

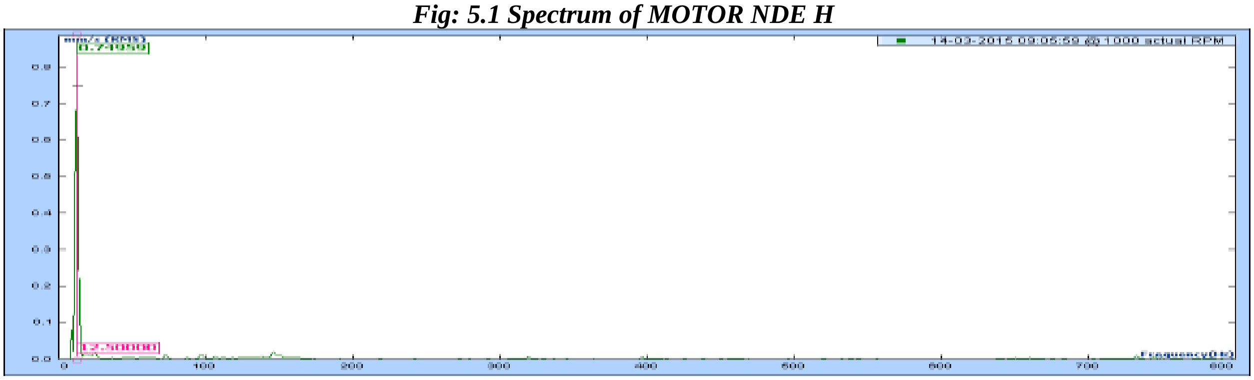

Fig: 5.2 Spectrum of MOTOR NDE V

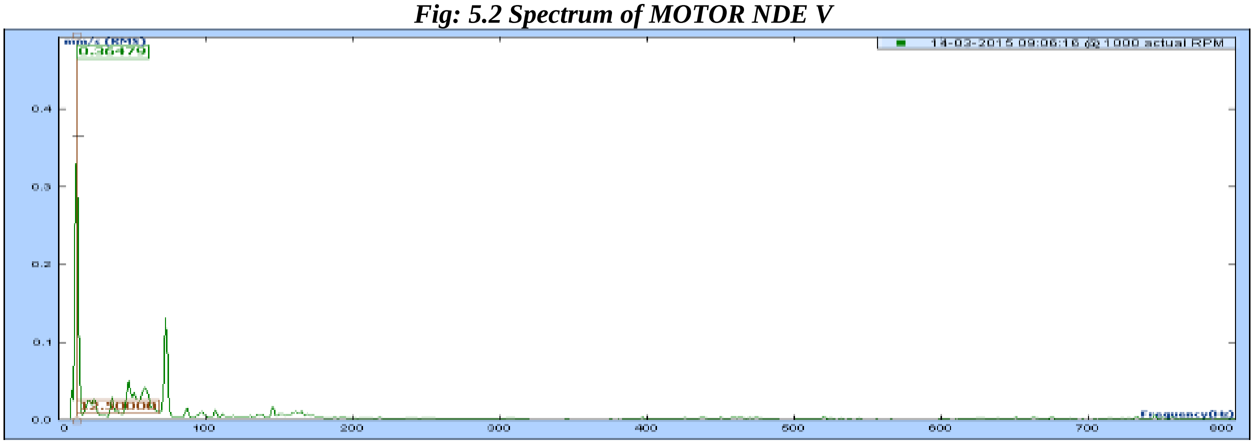

Fig: 5.3 Spectrum of MOTOR NDE A

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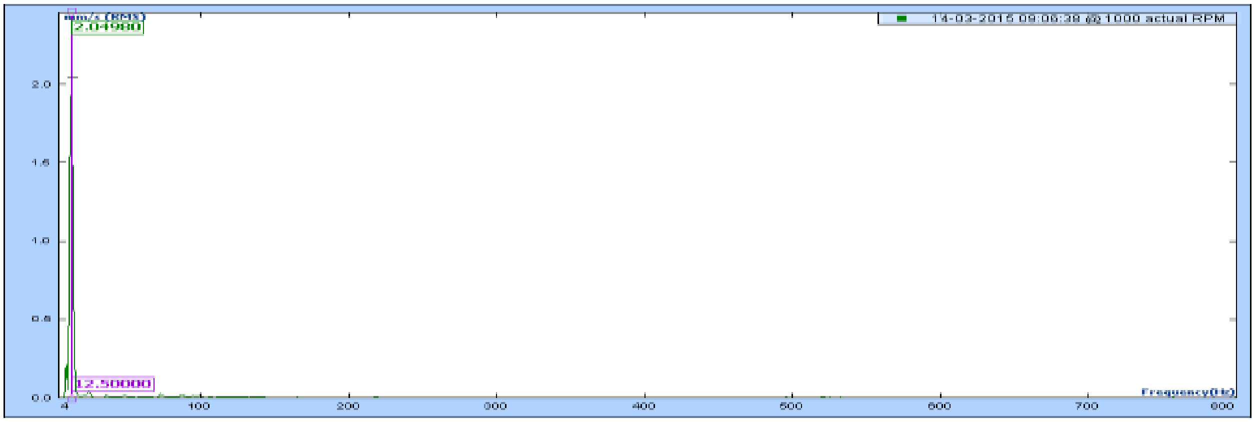

Fig: 5.4 Spectrum of MOTOR DE H

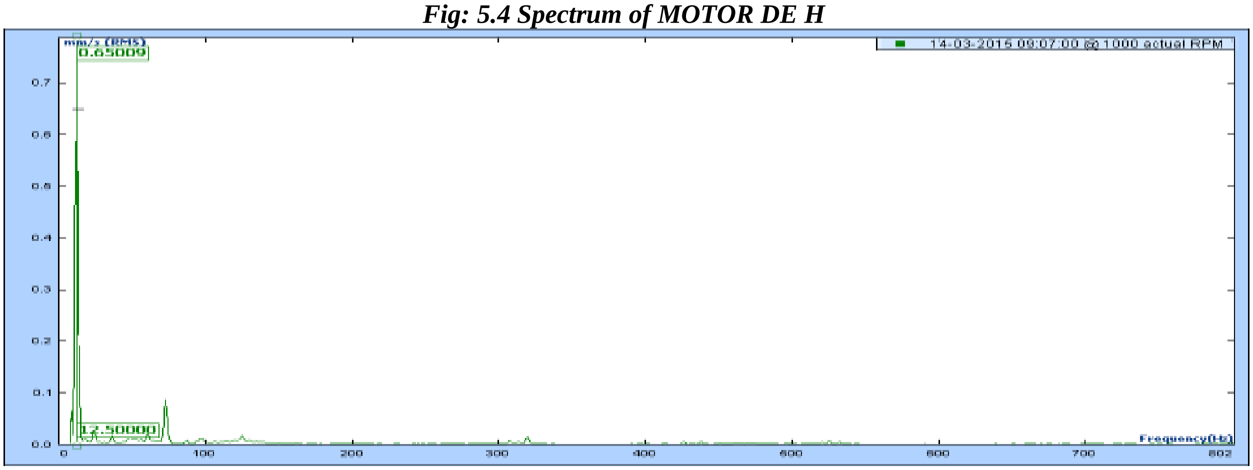

Fig: 5.5 Spectrum of MOTOR DE V

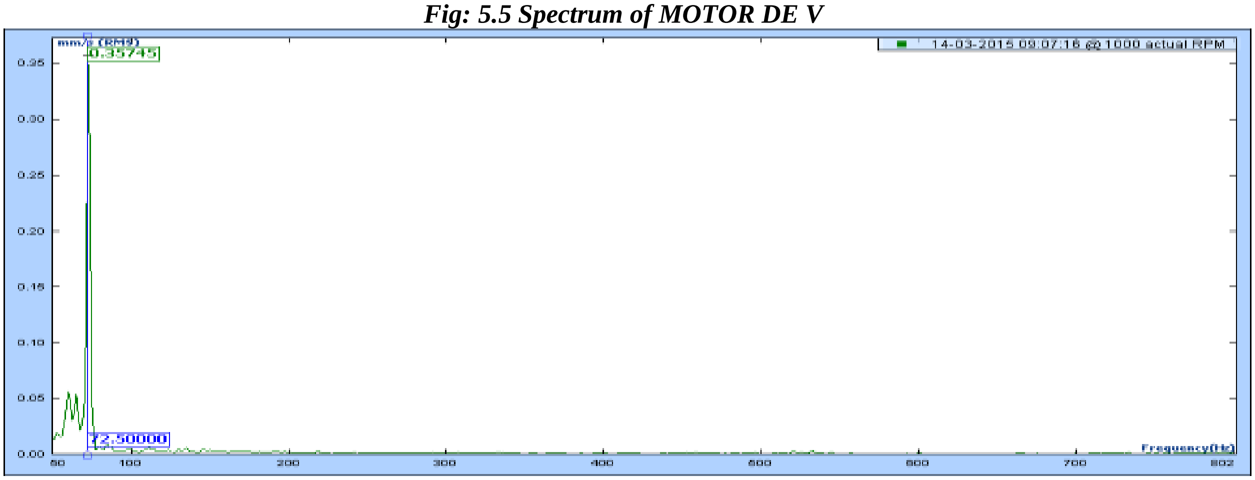

Fig: 5.6 Spectrum of MOTOR DE A

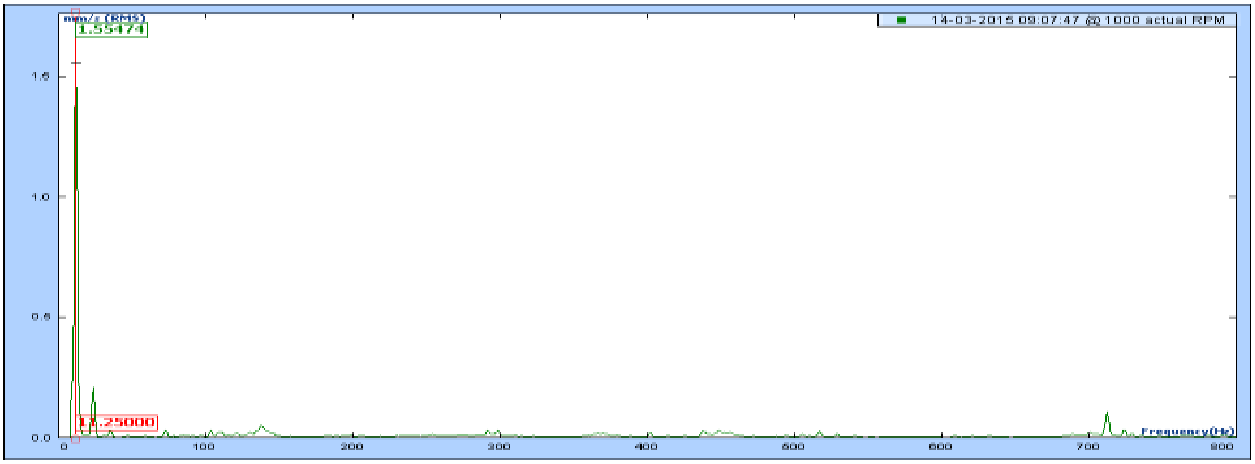

Fig: 5.7 Spectrum of FAN DE H

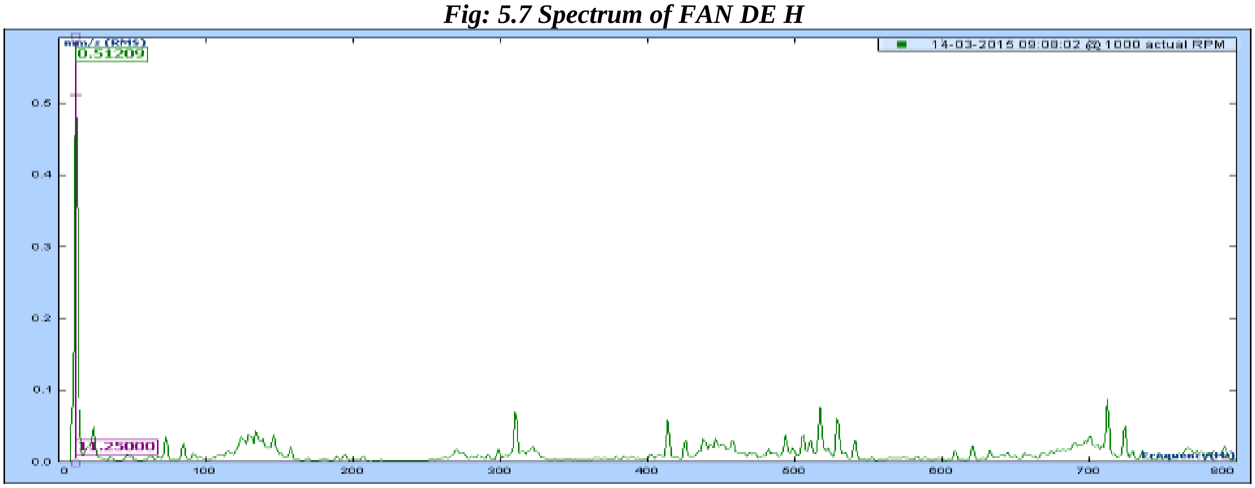

Fig: 5.8 Spectrum of FAN DE V

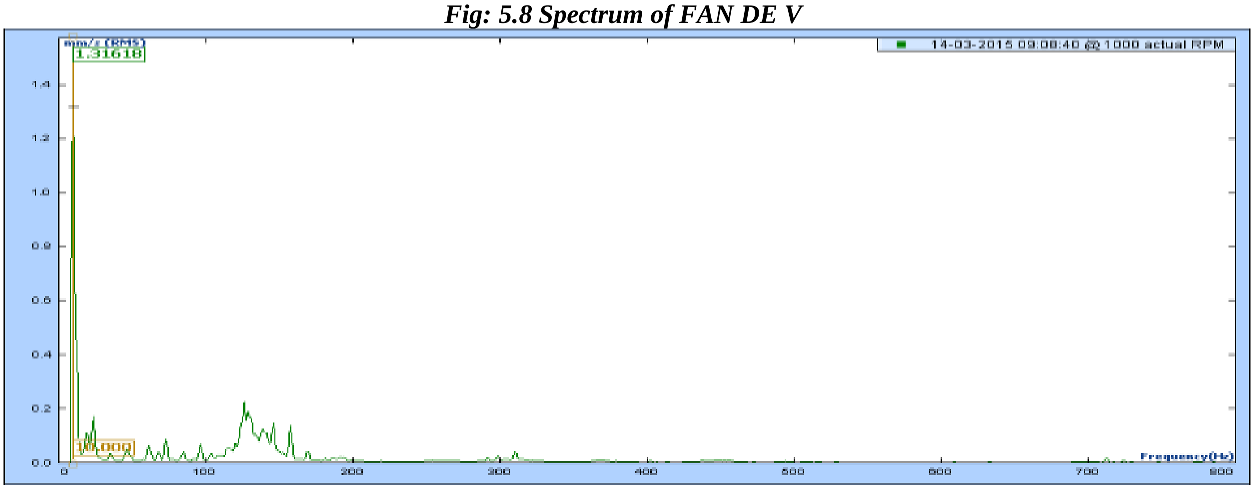

Fig: 5.9 Spectrum of FAN DE A

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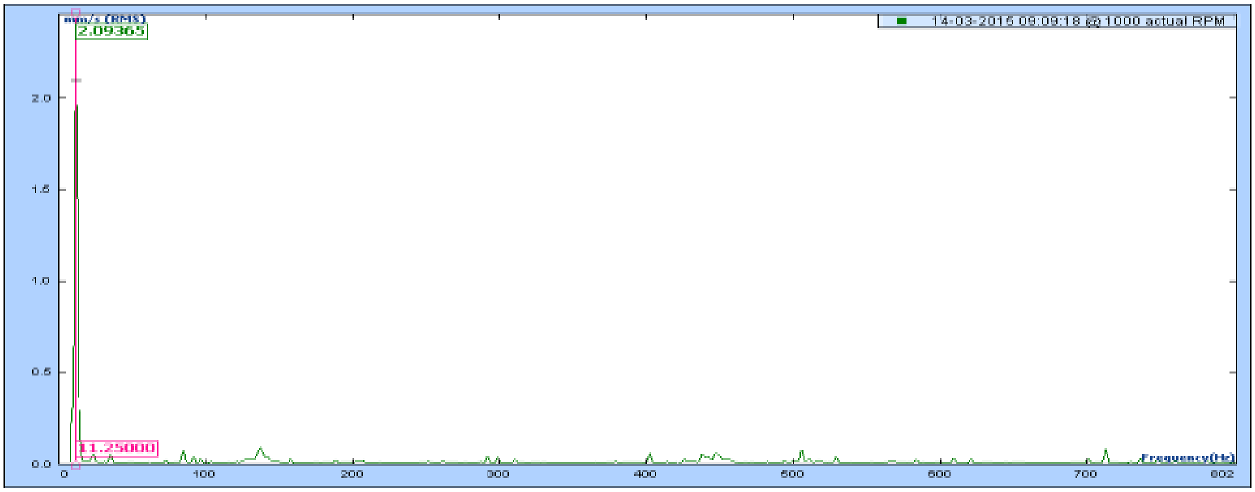

Fig: 5.10 Spectrum of FAN NDE H

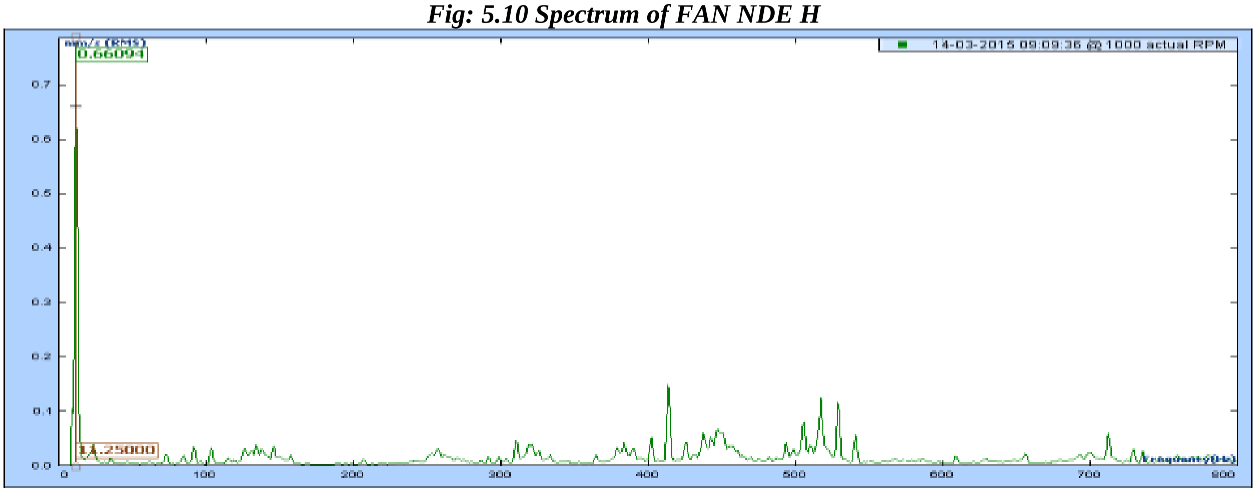

Fig: 5.11 Spectrum of FAN NDE V

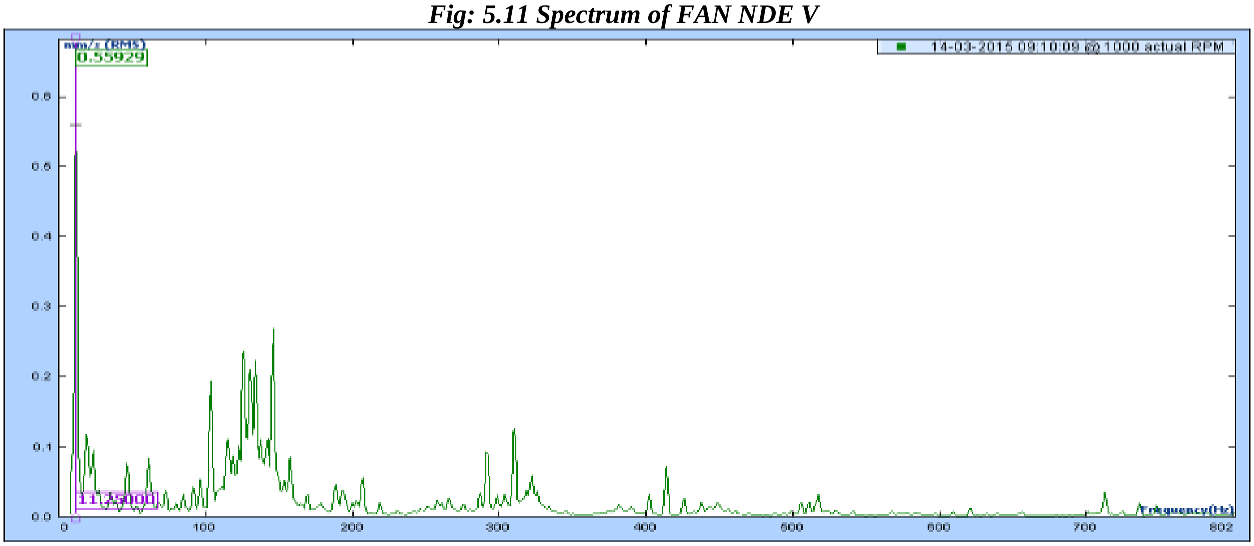

Fig: 5.12 Spectrum of FAN NDE A

From the above FFTs of the drive end of the pump also show significant amplitude at 1x. And the peak for axial direction is well under the alarm settings. So we are concerned with only vertical and horizontal direction

Analysis:
- ✓ The FFT shows high peaks only at 1x.
- ✓ To pin point the cause of the vibration the vibration reading at different positions of the non-drive end were taken.
- ✓ Also if there was a bent shaft the vibration amplitude would have been equal in both horizontal and vertical direction. So the shaft is not bent.
- ✓ We can say that there may be a slight misalignment in the vertical direction but is well below alarm condition

CAUSE	POSSIBILITY	REMARKS
1.Unbalance	NO	Huge difference between horizontal and vertical vibrational amplitude
2.Eccentric Shaft	NO	Phase difference between vertical and horizontal is 90^0
3.Misalignment	YES	Only high vertical vibration at 1X, no other significant peak
4.Bent Shaft	NO	Huge difference between horizontal and vertical vibration amplitude
5.Looseness	NO	Little difference in values above and below parting plane

Table 5.1 Identifying the problem

From the FFTS of the horizontal and axial direction at the drive end of the fan, there are significant peaks at 2X. The vibration at 2X is about 60% of the overall vibration amplitude. Analyzing the FFTs it can be said that the shaft may have radial misalignment. There is a high amplitude in axial direction also, which may be due to slight axial misalignment but that is within limit.

CONCLUSIONS

- ❖The vibration condition monitoring groups should have provide good trends of different vibration data and graphs like absolute and relative over all vibrations, FFT, TWF and phase characteristics in different points and directions.
- ❖Furthermore, vibration analysts should have good understanding and back ground about machinery characteristics of machinery.
- ❖After comparing the vibration trends and data with machinery and process evidences for different main machine faults like wear, misalignment, Oil whip/whirl, shaft crack, looseness and unbalance, the vibration analysts could recommend optimal maintenance action on most critical equipment.
- ❖Changing in load and RPM should be monitored accurately. These kinds of process abnormalities sometime cause serious mechanical problems
- ❖A method for continuously monitoring the condition of a motor and which interprets condition of faulty and healthy
- ❖Very small defects can be detected by using FFT Technique, The defects can be finding before breaking and Repairs, maintained and replacements can be reduced

SCOPE OF FEATURES

Condition monitoring is regular monitoring of machineries and predicting failure. The main benefits of this are

- ❖Predicting failure
- ❖Planned outage
- ❖Cost saving due to reduction in sudden failure and unwanted repairs
- ❖The project covers the theory and practical application of all the state-of-the-art analysis techniques for condition monitoring by vibration analysis.
- ❖The report also covers the analysis of vibration of different rotating machines.
- ❖The problem of a journal bearing is also monitored and analysed. Certain proactive measures for the journal bearing is also advised which may decrease the vibration of the shaft for the time being so that unplanned shutdown can be avoided.
- ❖From the cost effectiveness point of view, if a journal bearing fails suddenly there will be severe losses
- ❖Minimum 4 days downtime for maintenance which is huge
    - ➢ Cost of a bearing Rs. 2 lakhs.
    - ➢ Huge losses if the blades or other parts are affected

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❖If the bearing clearance problem is detected early we can take certain proactive actions to retard the deterioration process. Thus unplanned shut-down can be avoided and huge cost can be saved.

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