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International Journal of Recent Scientific Research
Vol. 6, Issue, 8, pp.5796-5800, August, 2015

ISSN: 0976-3031

International Journal of Recent Scientific Research

RESEARCH ARTICLE

CONDITION MONITORING AND DETECTION OF UNBALANCE USING VIBRATION SIGNATURE ANALYSIS

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ARTICLE INFO

Article History:

Received 14th, July, 2015
Received in revised form 23th, July, 2015
Accepted 13th, August, 2015
Published online 28th, August, 2015

Key words:

Condition monitoring, vibration analysis, unbalance, rotor.

ABSTRACT

Condition monitoring is an important machine maintenance technique which predicts the condition of machine for preventing the unexpected failure. It involves with continuous analysis of operational equipment and the identification of problem before component breakage or machine failure. High level of structural reliability is achieved with minimum maintenance cost with condition monitoring. Unbalance is a common source of vibration, unequal distribution of weight of a rotor about its rotating centerline is unbalance. Experimental procedure was carried out for determining the intensity of vibration and its source, using vibration analyzers and trending software. The experimental readings were taken periodically. Variations of these readings were used to determine the amount of balancing to be provided.

INTRODUCTION

An effective predictive maintenance programme is a total programme of detection, analysis and correction. All machines in this program should be monitored according to a prescribed schedule i.e., weekly or monthly according to criticality of equipment. Predictive maintenance of rotating machinery is done to increase the production time whereby reduces down time. Vibration analysis detects the problem early, when defects are minor and do not effect machine operation. If we can diagnose the nature of the problem, necessary repairs can be scheduled at convenient time, minimizing extensive damage to the machine resulting from forced failure. Machine in good condition can continue to run as long as no problems are developed. Time and money are not wasted, dismantling the machine which is already operating smoothly. A vibration pick up device was held against the machine surface and in turn attached to a data collector to read the vibrations. The vibration levels are automatically read into the data collector memory and returned to a central computer to which the information is transferred. The computerized system handles all figures, graphs and data electronically. Problems are detected by studying graph trends by identifying their unique vibration characteristics specific to an equipment. After identification of problem, necessary for a preventive maintenance, plans are made that best suits for a company`s operating schedule. Machinery faults such as bad bearings, worn out gears or mechanical looseness or misalignment can be corrected. The rotary equipment in the plant is divided into three categories. Extremely critical equipment, Critical equipment and Semi critical equipment. Daily vibration analysis is done on all these 3 categories of equipment unit wise. Around 70 to 80 equipments are taken daily and these are analyzed through vibration analysis software loaded in a computer. For some equipment monitoring is done daily or even twice a day if the equipment condition is alarming. The whole equipment in the refinery will be covered in one week i.e. monitoring analysis, detection of fault and schedule for rectification is necessary.

Condition Monitoring is an advanced and very useful tool of predictive maintenance techniques. It has made good progress in recent years in identifying many types of deterioration in plant machinery, so that pro-active maintenance can be performed, improving overall plant productivity. There is a wide variety of condition monitoring techniques currently in use for the diagnosis and prediction of machinery faults, but little attention has been paid to the occurrence and detection of vibration analysis of rotating equipments. (G.SureshBabu *et al*, 2005) aims at the 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

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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. (N. Dileep, *et al*. 2013) is primarily focused on the implementation of vibration based maintenance on critical rotating machines namely forced draft fan (f.d. fan 6b) which is one of the boilers auxiliary. FD fans for boilers force ambient air into the boiler, typically through a preheater to increase overall boiler efficiency. The required vibration readings were taken. The levels of vibration of the fan driving end (hub1) are beyond the safe limits of desired velocity and displacement limit values. These further may cause to failure of the fan. This paper also explains about the Spike energy readings which were calculated and explained. After reading are taken it was noticed that fan driving end bearing was failed due to long life time of bearing, which is one of the cause for the increase of vibrations. This problem was rectified by replacing the new bearing and again vibration readings are noted found to be in safe limits of velocity. (A.Alwodai, *et al* 2012), focused on the problem of failures in induction motors is a large concern due to its significant influence over industrial production. Therefore a large number of detection techniques were presented to avoid this problem. This paper presents the comparison results of induction motor rotor fault detection using three methods: motor current signature analysis (MCSA), surface vibration (SV), and instantaneous angular speed (IAS). These three measurements were performed under different loads with three rotor conditions: baseline, one rotor bar broken and two rotor bar broken. The faults can be detected and diagnosed based on the amplitude difference of the characteristic frequency components of power spectrum. However IAS may be the best technique because it gives the clearest spectrum representation in which the largest amplitude change is observed due to the faults.(R.K Biswas *et al* 2011) this paper highlights both vibration and oil analysis by ferrography for condition monitoring of the turbo generator set bearings after over hauling the machine i.e. at the start of the machine running or in case of new machine the vibration do not give a true picture of the machine condition. Oil analysis by ferrography gives better idea of the machine deteriotion. Specially at the early stage of machine running in this paper vibration analysis Fourier transform infrared technique and image processing of the Ferro gram has been done for quantitative assessment of the deterioration., a real life case has been discussed in this paper.

Condition Monitoring Techniques

The different condition monitoring techniques are visual, performance, vibration, shock pulse, temperature and wear debris monitoring. Visual monitoring involves assessing the performance of the machine using human senses of observation, smell, and sound. It sometimes reveals tell-tale signs of failures. Simple aids like microscope, photographs, horoscope, stroboscopes, dye penetrants etc can qualitatively throw much light on types and nature of defects developing in components. By adopting performance monitoring, machine's operating condition can be assessed by comparing inputs and outputs. The component behavior can also be assessed depending upon the type of components.

In vibration monitoring, all machines which contain moving components, vibrate. The nature and magnitude of vibration of a particular component of a machine can provide valuable information about its mechanical conditions. Vibrations arise from cyclic excitation forces with in the machine. These forces can be inherent in the design of the machine, or can be due to the propagation of some defect. A wide range of electronic equipment like for vibrations monitoring are available now a days, which are easy to operate, can extract the required overall and spectrum information from the vibration of machines. The shock pulse monitoring is a reliable method for monitoring the condition of anti-friction (rolling elements) bearings. In this technique the shock impulses produced by the impact between the rolling elements and surface defects, either on raceways or rolling elements are measured.

Temperature monitoring involves thermography, is a non-contact technique which involves measurement of infra-red radiations from hot objects. Simple aids like infra-red instruments and temperature tapes are handy in monitoring temperature of bearings, motors etc. Wear debris monitoring involves the monitoring of lubricants in the bearings and gear boxes for presence of wear particles. The relative movement between component parts gives rise to various types of wear processes. These wear processes generate 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.

Vibration Analysis And Diagnostic Tools

Vibration Analysis **is** used 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 In order to insure that the analysis data taken includes all the problem-related vibration characteristics and yet, is easy to evaluate and interpret the causes of vibration in machines. Almost all machine vibration are due to one or more reasons like unbalance, misalignment, bearing problems, mechanical looseness, soft foot, resonance, belt-drive problems, eccentricity, gear problems, electrical motor problems. Unbalance is due to unequal distributions of the weight of a rotor about its rotating center line. According to the international standards organization (ISO), "the condition which exits in a rotor when the vibratory force or motion is imparted to its bearings as a result of centrifugal forces". Also, over half of all machinery problems are caused by misalignment. Misalignment is created when shafts, couplings and bearings are not properly aligned along their centrelines. The types of misalignment are angular and parallel or a combination of both.

Tools For Fault Diagnosis In Machines

Time Waveform Analysis: A waveform is a graphical representation of how the vibration level changes with time. A velocity waveform is simply a chart that shows how the velocity of a vibrating component changes with time. The amount of information a wave contains depends on the duration and resolution of the waveform. The duration of a waveform is the total time period over which information may be obtained from the waveform. In most cases, a few seconds are sufficient. 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 waveform is detailed if there are more samples.

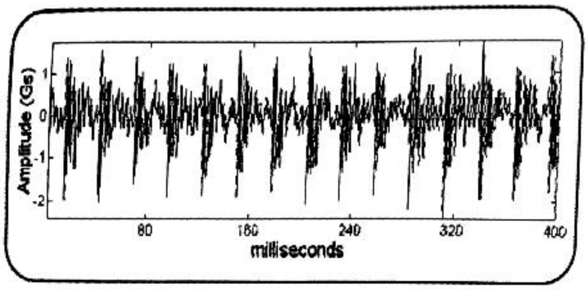

Figure 1 Velocity wave form

Spectrum Analysis: Another kind of display used by vibration analysis 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.

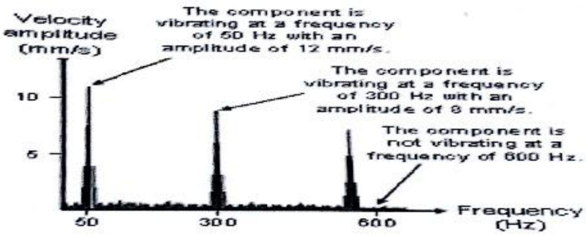

Figure 2 Spectrum analysis

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.

***Phase Analysis*:** Phase, the time relation of a signal to another signal of the same frequency, or the time relation of a vibrating object to another object vibrating at the same frequency. The vibratory motion of an object is 'in phase' with that of another object if they oscillate at the same frequency in a synchronized manner

Phase angle: A quantity that indicates the phase of a waveform or vibration motion in relation to another waveform or vibratory motion. Phase angle can be expressed in degrees or radians. In Phase analysis a reflecting tape is placed on the rotating shaft and a photo tacho which generates pulses is focused on the reflecting tape. Whenever the reflecting tape passes through the photo tacho a pulse is generated. Photo tacho is connected to the analyzer which records the pulses generated by it. Phase analysis gives us a clear idea of the transmission of vibration through the machines and the exact location of the fault. It is of great help while confirming the problems of unbalance, misalignment, bent shaft, which cannot be easily done through spectrum analysis.

***Orbit Analysis*:** Is based on the path of the enter line of rotating shaft within the clearance of the bearing different faults are being detected and analyzed. This analysis is valid for the machines having journal bearings. Different orbit plots indicate different machine faults.

Table 1 Orbit Analysis

Orbit Shape	Problem
Ellipse, Circle	Unbalance
Banana, horizontal, 8 shaped loop	Misalignment
Double loop	Oil Whirl
Erratic	Rubbing

Spectrum Analysis of Machine Faults

Unbalance:

It is identified when the radial measurements 1x amplitude is high, and harmonics (except vane passing) are less than 15% of the 1x, also, If the majority of vibration is in the radial plane, and the 1x amplitude is medium to high in amplitude, and the phases from the vertical and horizontal measurements differ by 90^0, $\pm 30^0$ there may be imbalance

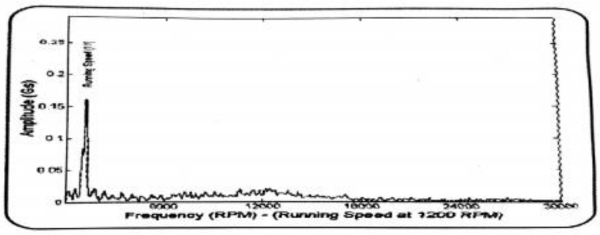

Figure 3 A FFT Spectrum Showing Unbalance

If there is a non-synchronous peak corresponding to the 1x running speed of a coupled machine, then there may be imbalance on the other machine. If the primary vibration plane is both axial and radial, and the machine has an overhung mass, and the axial phase measurements across the machine are in phase, then there may be imbalance. The modern balancing instruments, including vibration analyzers like Scheck analyzer and data collectors take the original unbalance data, trail weight information and unbalance data resultant from the addition of trail weight information and unbalance data resultant from the addition of trail weights to calculate the needed balance corrections and will be displayed on screen. Despite all the automation, sometimes the calculated solution doesn't always solve the problem and computer controlled automobiles doesn't always run.

Fault Diagnoses

The equipment is b-1 conveyor (drive 542) and the problem as per ISO 2372 this equipment belongs to class-3 and the vibration limit is 4.5 mm/sec**.** The present vibration level is 7.9 mm/sec, on motor bearings.

Equipment Layout

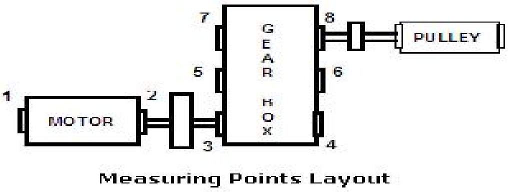

Figure 4 Conveyor Drive

Table 1 Details of Conveyor Drive

Equipment Type & Handling medium	Belt conveyor drive & Burden (iron ore , sinter, coke)
Location	Burden handling station in BF-1
Motor type , speed & power	Three phase induction motor , 990rpm & 200 KW
Gear box bearing type	spherical rollers
Type of bearing cooling	oil lubricated
Type of coupling & mounting	pin bush and gear coupling & Steel frame on concrete
Belt type & Width	Rubber & 1.2 m
Idlers	Truffing, Impact
Belt cleaning	Scrappers cleaning

Monitoring Points

Vibration readings are taken and respective spectrums , time waves and overall values are collected in vertical, horizontal and axial directions at Motor non drive end bearing (MNDE) and Motor drive end bearing (MDE) Total bearing points are 8 nos. The data is collected using , Single channel vibration analyzer CSI 2117 having frequency range of 10 Hz to 10 KHz using CSI Master Trend. Also , Dual channel vibration Vibxpert 2011 analyzer having frequency range of 10 Hz to 10 KHz using omnitrend are used.

Figure 2 Vibration analyser

Data is collected in terms of waveforms and spectrums, Amplitude is measured in mm/sec velocity (RMS), Frequency measured in terms of cycles/min, Frequency range 0 to 160000cpm, Sampling time for waveform – 4 sec, 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 analyzer at is dumped into host computer for further analysis.

Table 4 Vibration readings (mm/sec) Conveyor running with (100%) full load at MNDE

Direction / Period	Vertical	Horizontal	Axial
Day 1 (25-02-15)	0.8	1.2	1.7
Day 2 (01-03-15)	0.9	1.5	1.6
Day 3 (07-03-15)	2.1	6.3	1.3
Day 4 (09-03-15)	2.2	7.9	2.7
Day 5 (12-03-15)	1.6	2.8	1.2
Day 6 (13-03-15)	1.2	2.2	1.5

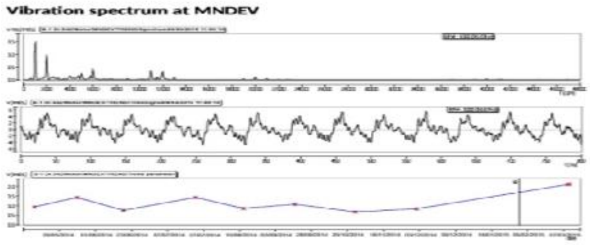

Figure 4 Vibration spectrum taken at Motor non drive end bearing (MNDE)

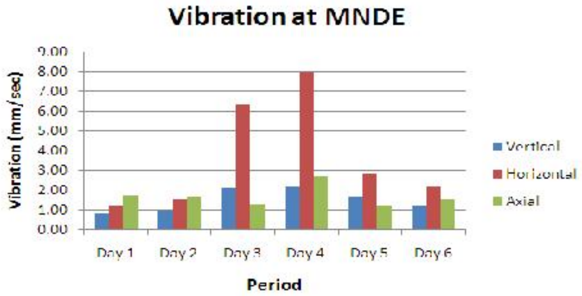

Figure 3Vibration spectrum taken at Motor non drive end bearing (MNDE)

Table 4 Vibration readings (mm/sec) Conveyor running with (100%) full load at MDE

Direction Period	Vertical	Horizontal	Axial
Day 1 (25-02-15)	0.7	1.4	1.6
Day 2 (01-03-15)	0.8	1.3	1.7
Day 3 (07-03-15)	3.7	6.8	1.7
Day 4 (09-03-15)	3.8	7.1	1.8
Day 5 (12-03-15)	1.2	3.4	1.6
Day 6 (13-03-15)	1.4	2.4	1.8

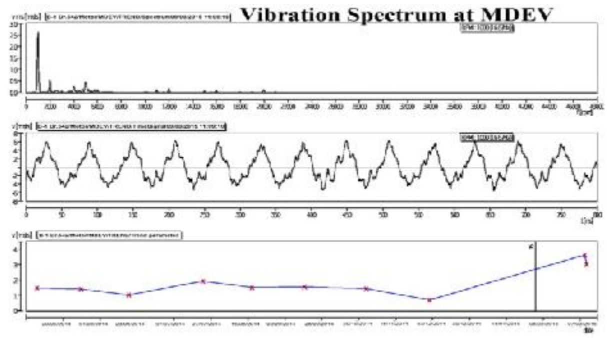

Figure 5Vibration spectrum taken at Motor drive end bearing (MDE)

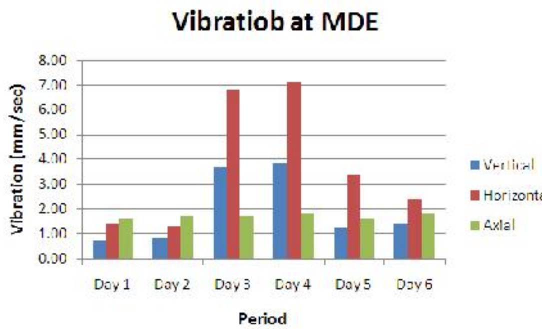

Figure 6 Vibration spectrum taken at Motor drive end bearing (MDE)

DISCUSSION

1. From the above data it is noticed that Motor both DE and NDE bearing vibrations increased suddenly.

2. Phase readings reveals that the phase shift between vertical to horizontal direction at motor both bearings is 90 degrees (approximately) and on the structure also same difference is noticed.
3. In the coast down test it is noticed that the vibration amplitude is decreased with the corresponding decrease in the speed and the phase is almost stable.
4. In the solo run test also same phenomena is observed with low level of vibration amplitude.

RESULTS AND ANALYSIS

1. In the spectrums predominant peak is observed at 1xrpm frequency (ie. fundamental frequency.
2. The phase difference between vertical to horizontal direction at motor both bearings is 90 degrees.
3. Decrease in vibration amplitude with the corresponding decrease in the speed and almost stable phase readings.
4. The above three points and observations indicating that the motor rotor was unbalanced and there is no structural weakness.

Table 5 Vibration readings (mm/sec) running with (100%) full load at MNDE & MDE

DIRECTION	MNDE (mm/sec)	MDE (mm/sec)
VERTICAL	1.2	1.4
HORIZONTAL	2.2	2.4
AXIAL	1.5	1.8

CONCLUSIONS

1. With the aid of vibxpert analyzer and omnitrend software, condition based monitoring of motor rotor was performed.
2. The motor rotor was balanced, by approximately adding 50 grams of weight to the rotor.
3. After placing the motor on the bed, alignment was done and trail run was taken. It is found that vibrations have decreased. The equipment is finally given for operation.
4. The reliability of the motor has been increased after these diagnostics.
5. Condition monitoring has played an important part as a maintenance tool. It has played an important role in early identification and fixation of a problem that could have turn into a major one adversely effective the production of plant.

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How to cite this article:

K.Satyanarayana *et al*., Condition Monitoring And Detection Of Unbalance Using Vibration Signature Analysis. *International Journal of Recent Scientific Research Vol. 6, Issue, 8, pp.5796-5800, August, 2015*

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