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Condition monitoring of systems in thermal power plant for vibration, motor signature, noise and wear debris analysis

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ABSTRACT

Condition monitoring is technique used to monitor the condition of an equipment or machinery without interrupting it working. Condition monitoring techniques are carried out when the machine is in operation. Most widely used condition monitoring techniques include vibration monitoring, motor current signature analysis, noise monitoring and wear debris analysis. Vibration monitoring detects the presence of unbalanced forces generated due to misalignment, damaged bearing, electrical defects and resonance. Motor current signature analysis is used to determine the defects in motor by analyzing the spectrum generated by the tongue tester. Noise monitoring is performed with the help of acoustic noise meter and wear debris is done to determine the contamination level of lubrication oil in various engines. These techniques are found to be highly efficient in determining the defects of the systems like pump at an early stage. A detailed study on these condition monitoring techniques has been carried out in this paper and also the methods for analysis of the results obtained from these tests are also discussed.

***Keywords*:** Analysis, current signature, monitoring, noise, vibration, wear debris

1. INTRODUCTION

Condition monitoring is defined as the continuous evaluation of the health of the plant and the equipment throughout its service life [1]. It is able to be detect faults while they are

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still developing. This is called incipient failure detection. Condition monitoring is technique used to monitor the condition of an equipment or machinery without interrupting it working [2]. Condition monitoring techniques are carried out when the machine is in operation. Various instruments are used for collecting data required for analyzing the condition of the machines. After collecting data using these instruments, the analysis is carried out by condition monitoring analyst [3]. Main objectives of condition monitoring are:

1. Reduce chances of breakdown
2. Take timely action before machinery undergoes catastrophic failure
3. Avoid secondary damage. Secondary damages are caused in one part of a machinery when damages in some other parts goes unnoticed (Ex: Misalignment of shafts if not rectified leads to bearing failure)
4. To detect the flaws in equipments at early stage and order for spare parts. Since spares are manufactured by Original Equipment Manufacturer, It would require some time for spare production. By early detection of failure the shutdown time can be greatly reduced.
5. To plan and schedule the maintenance activity.
6. To identify the exact location and reason of fault so that there won't be any unnecessary maintenance activity.
7. To increase the life of the plant.

Various condition monitoring techniques used are vibration monitoring, noise monitoring, motor current signature analysis, wear debris analysis, dissolve gas analysis, Thermo vision scanning, magnetic particle inspection, ELCID test and sweep frequency response analysis [4]. This project was concentrated mainly on first four condition monitoring techniques listed above.. All these four condition monitoring techniques has been explained in detail below.

2. VIBRATION MONITORING

Vibration is to and fro motion of a body from its original position of rest. It may be also called as oscillating motion of a machinery under operation due to external excitation forces or due to forces generated within the machine like unbalanced electrical force in motors, impact forces due to rolling element contact and hydraulic forces in pumps [5].

All machines generate vibrations and the analysis of the produced vibration can be used to give information on the condition of the machine [6]. Even very small amplitude of vibration of machine frame can produce high noise. Noise and vibration in machines are caused by forces which are magnetic, mechanical and aerodynamic origin. Characteristics of vibration in a machinery is determined by following properties like Exciting force, Mass of vibrating system, Stiffness of vibrating system and Damping properties of vibrating system [7]. Among these properties specified above, only exciting forces supports vibration and all other properties oppose vibration. The machine defects that mostly causes vibrations include unbalance in rotors, misalignment, looseness of rotating parts, damaged bearing, rubbing of rotating parts, hydraulic defects, electrical defects and resonance. A body may vibrate in three directions namely axial, vertical and horizontal [8].

Therefore the vibration readings are taken in all these three directions at each point. Amplitude is the amount of vibration present in the measured signal and it is expressed in displacement, velocity and acceleration. Conditions where these parameters are used for expressing vibrations are discussed below:

1. Displacement (d): It is the distance of the object from position of rest (Unit: mils or microns). It is used under conditions of dynamic stress. It can be used for speeds upto 600rpm, where it is more sensitive.
2. Velocity (v): It is the rate of change of displacement (Unit: inch/sec or mm/sec). It is used under conditions of fatigue and for operating speeds in the range of 600 to 60000 rpm.
3. Acceleration (a): It is the rate of change of velocity (unit: g or mm/sq. sec). It is closely related with forces and large forces occurs at larger frequencies and at speeds above 60000 rpm.

2. 1. Vibration Analyzer

Each machine generates its own characteristic vibration spectrum. Vibration is a combination of different waveforms each of which corresponds to invidual frequent. Basic spectrum obtained from any vibration pick up is time waveform combination of different characteristic waveforms. Interpretation of time representation of a sine wave is very difficult. Using Fast Fourier transformation technique, vibration analyzer calculates and gives frequency domain spectrum. Fast Fourier transformation helps to transform the original time signal to a form that can be easily understood.

Emerson's 2130 FFT analyzer is developed to provide quick information about machinery for taking immediate maintenance action. Some advantages of this analyzer are:

1. More machines monitored in lesser time. It provides faster data collection which increases the number of machines being monitored in short duration.
2. Portable and durable: It is very light weight and also portable. It develops reports in field at each point.
3. Dual channel option: It enables to attach two sensor cables at a time which facilitate the measurement of vibration at two points at a time. Dual channel reduces the monitoring time and improves efficiency.
4. Easy operation: It is very easy to operate and one requires minimal training to work with this. Spectrum generated by analyzer specifies the type of fault (Ex: imbalance, bearing failure etc.)
5. Embedded intelligence: It enables the user to conduct additional diagnostic tests at machine site.
6. Detect wear at its early stage: It detects stress waves generated at the earliest stages when bearing and gear wear begins. It also specifies the severity of the detected wear so that the maintenance can be scheduled effectively.
7. Full spectrum of measurement: It has slow speed technology which helps in measurement of vibration of machines running at very slow speed. It also measures high speed vibration of signals upto 80000 Hz.
8. In field analysis: It has advanced infield analysis tools like waveform auto co-relation, fault frequency overlays, fourteen pre-defined analysis experts and quad plotting.

9. Variable speed analysis: Analysis at varying speeds is important since most of equipments works at varying speeds in order to meet the production demands. This supports the operator to evaluate the developing faults in the field.
10. Predict catastrophic failure: It develops orbit faults to identify problems like misalignment and shaft rubs.

Figure 1. Vibration readings taken using analyzer

Waveform is a graphical representation of how vibration level changes with time. Spectrum is a graphical display of frequencies at which machine component is vibrating together with amplitudes of the component at these frequencies [9]. This spectrum is generated by the analyzer and the corresponding vibration data for developing this spectrum is captured and send to the analyzer by the sensors. The defects in the machine can be identified from the vibration spectrum by analyzing following

1. If there is increase in multiples of running speed harmonics from 1x, 2x, 3x upto 10x frequency, then the looseness of motor bearing can be suspected.
2. If there is predominant frequency of vibrations in 1x rpm then existence of resonance problem can be suspected and bump test may be recommended to confirm it.
3. If there is predominant frequency of vibrations in 1x rpm then the existence of misalignment can be suspected and phase analysis it may be recommended to confirm it.
4. If there is increase in higher frequencies and contribution of non-synchronous energy (i.e. any vibration greater than 1x frequency but is not a whole multiple of it) in the

acceleration spectrum then the defects in bearing can be suspected and distress level measurement is recommended to give indication of the state of bearings health.

5. If there is increase in 1x frequency only in horizontal direction then it may be due to misalignment or foundation problem.
6. If the foundation problem is suspected then the vibration readings are taken in foots and uneven readings indicate the chances of foundation problem and further confirmation of exact root cause is done by ultrasonic pulse velocity test and rebound hammer test.

The sensors are attached to the bearing of the rotating parts since bearing is that part of the machinery which supports the weight of parts and forces associated with rotary motion and vibration. Sensors are provided with magnets which helps to attach these to the bearings and vibration readings are collected by attaching these sensors in three directions (horizontal, vertical and axial) at each bearing [10]. It is very important to know the directions in which reading has to be taken since each has its relevance.

Axial direction is always parallel to the shaft in both horizontal and vertical machines. In horizontally mounted machines the vertical direction is the shortest line possible connecting the machine shaft & machine base and horizontal direction is a line drawn out from the machine shaft that runs exactly parallel to the ground [11]. In vertically mounted machines, the vertical direction is in the direction of discharge and horizontal direction is perpendicular to vertical direction. Acceleration reading are only measured in horizontal direction and velocity readings are measured in all three directions. There are three types of sensors used by these analyzers, namely displacement sensors, velocity sensor and acceleration sensor.

2. 2. Displacement Sensor

Eddy current probes are non-contact sensors primarily used to measure displacement that reflects shaft radial vibration, shaft/rotor position and clearance and rotational speed. Also referred to as “proximity probes” or “displacement probes”, eddy current probes are typically applied on machines utilizing sleeve/journal bearings. They have excellent frequency response with no lower frequency limit and can also be used to provide a trigger input for phase-related measurements. Eddy current probe systems are the best solution for shaft position measurements in sleeve bearing equipment .

2. 3. Velocity Sensor

Velocity sensors are used for low to medium frequency measurements. They are useful for vibration monitoring and balancing operations on rotating machinery. As compared to accelerometers, velocity sensors have lower sensitivity to high frequency vibrations. There are two types. Traditional, “self-generating” velocity sensors or “velocity pickups”. These are of a mechanical design that use an electromagnetic (coil and magnet) system to generate the velocity signal. Their advantage is a direct measurement of velocity. Their disadvantages are that they wear out over time, owing to the moving parts, and are sensitive to mounting orientation. Piezoelectric velocity sensors (internally integrated accelerometers). These are more common today, as they have improved capabilities over self-generating types and are a more rugged and smaller size design.

2. 4. Acceleration Sensors

The acceleration sensor is versatile, reliable and the most popular vibration sensor for machinery monitoring. For a given mechanical acceleration level, piezoelectric accelerometers have a constant signal over a wide frequency range, typically up to 20 kHz, and are very useful for all types of vibration measurements. Acceleration integrated to velocity can be used for low frequency measurements. Acceleration signals in the high frequency range added with various signal processing techniques like Acceleration Enveloping are very useful for bearing and gear measurements. The basic acceleration sensor has a good signal to noise ratio over a wide dynamic range. They are useful for measuring low to very high frequencies and are available in a wide variety of general purpose and application specific designs. When combined with vibration monitors capable of integrating from acceleration to velocity, accelerometers can be useful components in a multi-parameter monitoring program.

Figure 2. SKF acceleration Sensors

3. MOTOR CURRENT SIGNATURE ANALYSIS

Motor Current Signature Analysis (MCSA) is based on current monitoring of induction motor therefore it is not very expensive. The MCSA uses the current spectrum of the machine for locating characteristic fault frequencies [12]. When a fault is present, the frequency spectrum of the line current becomes different from healthy motor. Such a fault modulates the air-gap and produces rotating frequency harmonics in the self and mutual inductances of the machine. It depends upon locating specific harmonic component in the line current.

When there is a high resistance spot (Eg: due to broken bar) harmonic fluxes are produced in air gap. These harmonic fluxes induce a current component in stator winding which causes modulation of supply current at pole pass frequency [13]. Hall Effect current sensor (tongue tester) clamped to primary or secondary circuit and output is fed to FFT analyzer. The current component in the stator winding causes modulation or fluctuation of the supply current at positive or negative pole pass frequency [14]. Pole pass frequency is the product of motor slip and number of poles. Motor Current Signature Analysis (MCSA) based methods are used to diagnose the common faults of induction motor such as broken bar fault, short winding fault, bearing fault, air gap eccentricity fault, and load faults .

3. 1. Current Clamps (Tongue tester)

Current clamps are used for collecting data for Motor current signature Analysis. It uses electric motor as transducer, allowing the user to evaluate the electrical and mechanical condition from motor control Centre (MCC) enabling easy testing of motor located at remote inaccessible or hazardous area. The current clamp meter has two features. It creates an air gap in the magnetic circuit. The air gap limits the magnetic flux so that core cannot saturate. The Hall Effect current sensor is introduced into the air gap to measure the magnetic flux directly [5]. The output voltage from the sensor is then amplified and scaled to represent the current flowing in a conductor placed in the jaws of the clamp.

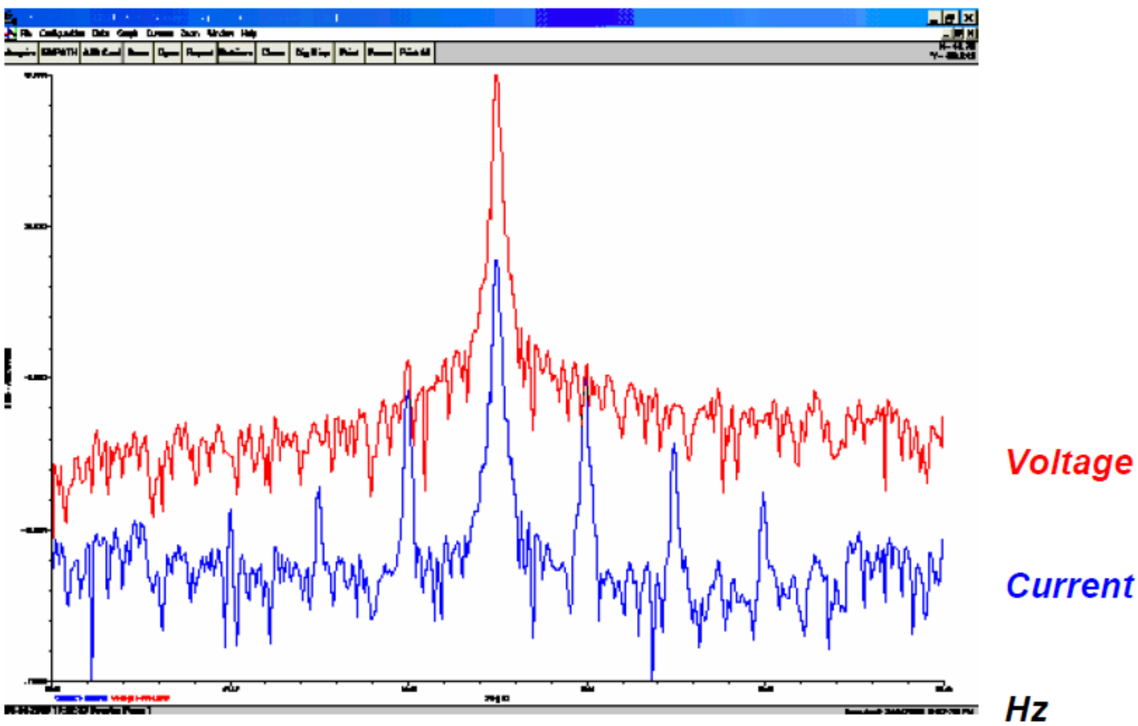

Figure 3. Spectrum of severely damaged rotor

The current values read by the clamp meter is recorded in the analyzer which develops a raw spectrum of frequency vs voltage. This generated spectrum is analyzed by amplifying the raw spectrum into more detailed one by changing the scale. Then the calculation of motor current index is carried out by noting the values of line frequency and pole pass frequency. Spectrum of severely damaged and good rotor is as shown in figure no 3 and 4.

Motor current index = 20 Log (Line frequency/pole pass frequency) ----------- (1)

In the spectrum generated by analyzer for the broken rotor bar it can be observed that the side bands are on the higher on both sides of the pole band. The condition of motor rotor bars can be predicted from the value of motor current index. Rotor bar severity level chart has been given below.

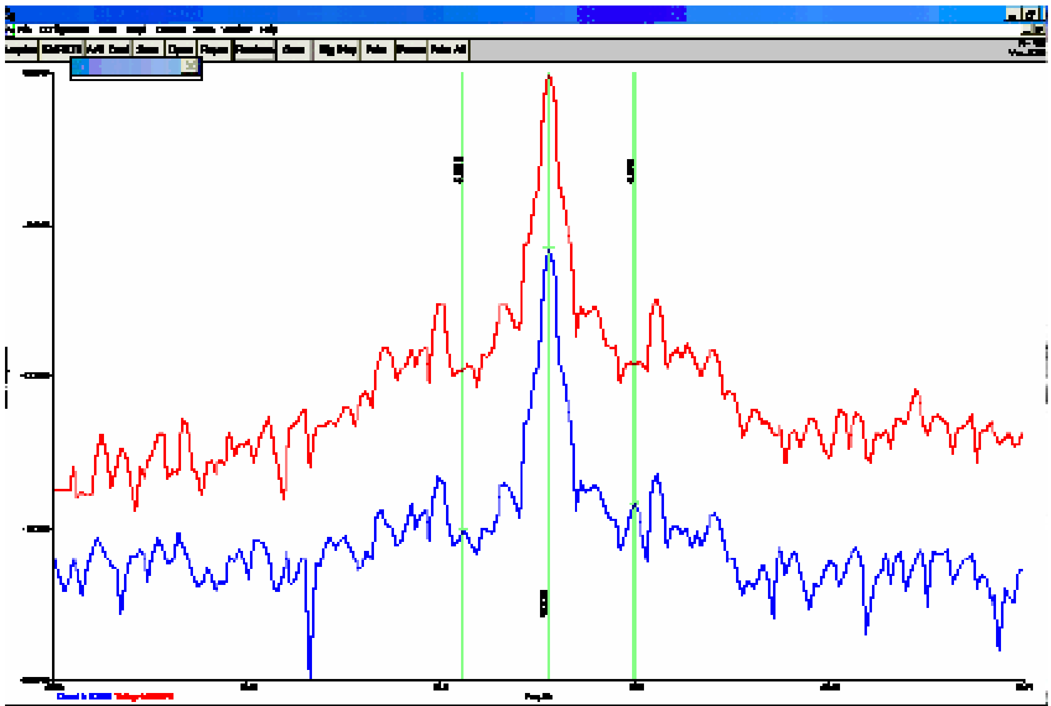

Figure 4. Spectrum of good rotor

Table 1. Corrective action based on MCI value.

Severity Level	MCI (db)	Rotor condition assessment	Corrective action
1	> 60	Excellent	None
2	54 - 60	Good	None
3	48 - 54	Moderate	Trend data
4	42 - 48	Rotor bar crack may be developing or problems with high resistance joints	Increase trending frequency
5	36 - 42	One or two rotor bars likely cracked or broken	Perform vibration test to confirm source of severity
6	30 - 36	Multiple cracked or broken rotor bars	Repair ASAP
7	< 30	Multiple cracked or broken rotor bars and end rings	Repair or replace ASAP

4. NOISE MONITORING

The noise levels in industries must be continuously monitored since the prevailing noise levels in the neighborhood may have adverse effect on workers working in that area and also on the scope of future expansion or modification may be limited [15]. Noisy workings will lead to violation of environmental guidelines, industrial disputes and compensation claims.

The control of Pollution act, 1974 authorizes the local authorities to inspect and abate nuisances with the establishment of a "noise abatement zone" and entertain complaints if industrial noise levels exceed the standard background noise level by 10 db. The social security amendment No.4, Regulations 1979 necessitates more measures of noise pollution in industry. International standards organization (ISO) standards 1999, 3744, 3746, 3891 and 1996 give procedures and guidelines for noise measurement. However application of the methods described in the standards to a particular situation requires careful observations of the influences of conditions pertaining to the site.

According Occupational Safety and Health Administration (OSHA) standard 29 CFR 1910.95, "Occupational Noise Exposure" which is designed to protect general industry workers, such as those working in the manufacturing, utilities, and service sectors. The General Industry standard establishes permissible noise exposures, requires the use of engineering and administrative controls, and sets out the requirements of a hearing conservation program. The general industry noise standard contains two noise exposure limit tables. Each table serves a different purpose:

1. Table G-16: This table applies to the engineering and administrative controls section, which provides a 90 dB criterion for an 8-hour TWA PEL and is measured using a 90-dB threshold (i.e., noise below 90 dB is not integrated into the TWA). This table limits short-term noise exposure to a level not greater than 115 dB (for up to 15 minutes).
2. Table G-16A provides information (e.g. reference durations) useful for calculating TWA exposures when the work shift noise exposure is composed of two or more periods of noise at different levels. Although this table lists noise levels exceeding 115 dB, these listings are only intended as aids in calculating TWA exposure levels the listings for higher noise exposure levels do not imply that these noise levels are acceptable.

4. 1. Acoustic Noise Monitoring

Noise monitoring is done by measuring and analyzing the acoustic noise spectrum. Acoustic noise from air gap eccentricity in induction motors can be used for fault detection [16]. Acoustic noise from air gap eccentricity in induction motors can be used for fault detection. However the application of noise measurements in a plant is not practical because of the noisy background from other machines operating in the vicinity. Acoustic noise meters are used to measure the overall noise in the area of the machinery [17]. Noise level readings are taken every month. At manned locations the noise limits is 75 db. At unmanned locations, noise level trending is done and abnormal rising trend noticed will be investigated.

Figure 5. Acoustic noise meter

4. 2. Ultrasonic Noise Meter

Ultrasonic noise meter involves the application of ultrasound which is used for detection and measurement. Ultrasound is an oscillating sound pressure wave with a high frequency (20 to 100 kHz and beyond range of human beings) Ultrasonic instruments receive high frequency sounds produced by operating equipment, electrical emission and leaks [18]. It then electronically translate ultrasound frequencies down into audible range which can be heard through headphones and observed as intensity on display panel. Ultrasonic noise meter has a gun like structure and it is pointed to the bearing or gear where defects or faults has been suspected. Sounds of meshing of gears and also movement of bearing can be clearly heard through the microphone of the noise meter. Display panel of the meter gives the amplitude reading and also there are 9 LEDs in the meter. Defect severity is determined by the number of LEDs glowing and if there are more than 5 LEDs glowing then there are higher chances of failures or defects in the corresponding bearing or gear.

5. WEAR DEBRIS ANALYSIS

Lubrication of machines are done to reduce friction, remove heat, prevent corrosion and to provide effective sealing against dirt. It is necessary to check the lubricating oil in order to monitor the condition of oil by measuring the contamination level of the oil and use these results to monitor the condition of machine [19]. So a sample of lubricating oil is collected from the machinery using a vacuum pump without interrupting its operation and various properties of the oil is checked. Particles present in lube oil may be ferrous, non-ferrous or contaminant [20]. Properties of the oil which determines its condition are viscosity, water contamination level, Total Acid/Base Number, flash point, pour point, foaming characteristic and emulsion characteristic.

Wear debris analysis involves the determination of wear particle concentration and it is achieved by using ferrography to separate wear debris and contaminate particles from lube oil and arrange them on transparent substrate for microscopic examination [21]. Ferrography analysis involves Quantitative measurement of Wear Particle Concentration (WPC) and Percentage of Large Particle (PLP) and qualitative or analytical ferrography for microscopic analysis of wear particle & contaminants and address source & cause of wear particles. Presence of wear debris in the lube oil also leads to corrosion of the system components [22].

Contamination analysis of lube oil is done by particle count test which uses laser technology for counting the number of particles in different size ranges [23]. Particle count test is very much useful to access the contamination levels in critical equipments like hydraulic based equipments and servo drives which fails mostly by contamination related problems [24]. Types of wear particles which can be detected using ferrography and particle count test are normal rubbing wear, cutting wear, bearing wear, severe sliding wear, gear wear, non-corrosive wear, corrosive wear, black oxides, red oxides, spheres, sand and dirt, friction polymers, contaminant spheres and fibers.Increase in contamination of lubrication oil also leads to higher emission from engine which brings out the need for renewable and alternate energy sources [25].

6. CONCLUSIONS

A detailed study on condition monitoring techniques like vibration analysis using FFT analyzers, Motor current signature analysis, noise monitoring and wear debris analysis, which are carried out in various pumps and compressors in thermal power plants has been carried out. Methods for analysis on the data collected by instruments is done and spectrum analysis has been briefed in the paper. Condition monitoring techniques was found to be very much effective in maintaining the equipments in healthy condition and also detecting the flaws at early stage so that secondary damages can be avoided.

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