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Condition Monitoring as a Critical Decision Strategy for Power Plants Maintenance

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Abstract

Condition monitoring of electrical power plant items can ensure significant savings in both maintenance and operational costs, hence increase availability and reliability. Condition monitoring can be used as a maintenance management strategy. In doing this, the right and appropriate monitoring techniques with the required experience to optimize maintenance is a necessity. Hence, reliable performance of power plant can be achieved through diligence and dedicated attention to a broad range of activities that encompass life cycle of the plants and equipment. The first phase of these activities entails engineering specification and manufacturing through installation, the second covers from startup through operation, mechanical performance monitoring, and maintenance. Condition monitoring is a procedure available to the maintenance engineer, whereby various diagnostic techniques are used to obtain advanced warning of the need to repair plant, and to determine the nature of the repair. The method is playing an increasingly important role in maintenance strategy mainly because of the need to reduce costs, increase safety, availability, and reliability. Therefore, this paper considers the techniques, costs, strategies, and future use of condition monitoring in power plant maintenance.

Keywords: *Condition monitoring, Diagnostic, Maintenance, Performance, Power plants, Strategic decision.*

1.0.Introduction

The maintenance of electric-generating power plant involves a very huge annual expenditure running up to millions of dollars. It is, therefore, necessary to establish cost effectiveness of the present maintenance policies. The general problems in this evaluation are lack of information and lack of suitable techniques to analyze the information. Most items of power plants are complex mechanical components and as such, it is very difficult to predict their failures without condition monitoring techniques. Condition monitoring must be considered in the context of plant maintenance strategies which involve varieties of maintenance actions, according to functions and nature of each main plant items. When used in the right circumstance with appropriate monitoring devices, condition monitoring can give a reasonable potential maintenance cost savings. Condition monitoring offers most benefit when production demands are close to plant theoretical maximum capacity. Other benefits include safety, especially in hazardous environments and critical plant items.

Condition monitoring is therefore a timely introduction of techniques of modern maintenance management that easily relate to today's power production productivity. An integral part of any engineering or manufacturing process is a continuous process of assessing performance/productivity, safety, and reliability. It reduces the high cost of using the traditional methods by sing the advanced technology of common mode failure analysis and modeling, with potential savings on system capital costs. Condition monitoring is a power tool for maintenance improvement. It is one of the fastest-growing techniques for quality and performance improvement. Now, more than ever, there is a clear need for straightforward guidelines for condition monitoring in power plants. Power system availability is of fundamental importance to efficient operation of other sectors. Current ideas on maintenance are quite different from the out-of-date traditional approach of fire-fighting breakdown. Efficient engineering and production facilities now adopt continuous assessment of its safety reliability and maintenance based on individual machine condition and deterioration trend. It has proven to be the most efficient and available approach to the care of plant and machinery as far as condition-based maintenance is concerned before breakdown so as to reduce production loss and machine downtime, cut maintenance costs, and improve morale, thereby leading to improved operations and increased profitability.

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2.0 Materials and Methods

Materials and methods are presented in terms of commonly monitored variables of rotating equipment, process variables, surveillance and diagnosis as well as vibration analysis. [1] illustrated this general process, from where failure starts, to when it is noticed and finally where the system fails. The region before degradation starts is therefore classified as a normal state, and where degradation begins is the degradable state and where failure is initiated is the failed state. A typical failure pattern for a degradable component is presented in Figure 1.

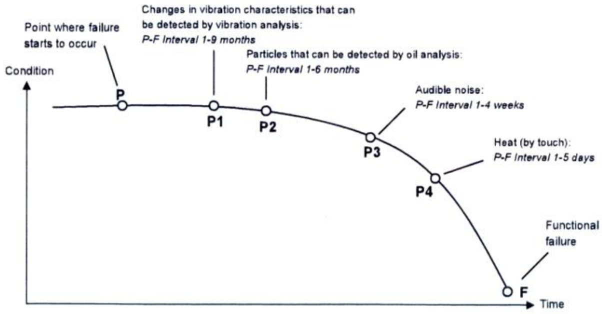

Figure 1: Degradation Process of an Item by Condition Monitoring[1]

Failure is the termination of the ability of an item to perform a required function [2],[3] described functional failure as the inability of an item to meet a specified standard. Degradation leads to loss of physical, functional, and economic value of component/asset. Physical degradation is due to the using up or expiration of the useful life of a component/system. This is caused by wear and tear, exposure to stress, fatigue, creep, corrosion, erosion, and similar factors. This will result in functional obsolescence of the component/system. It will manifest in the form of inefficiencies and inadequacies or low performance of the component/system compared to its normal state [1]. It is inevitably that the component/system if evaluated in economic terms will have low economic value. Methods of determining degradation include use and age analysis, observation, and direct measurement.

If the degradation process is allowed to continue indefinitely the component/system at some point will fail. A degradation model normally contains two important components, namely the degradation processes of the indicators and the relationship between indicators and the failure events. There are different ways to describe the relationship between degradation indicators and the failure events. Commonly used degradation models can be classified into three types. There are threshold crossing models, hazard rate process models, and state space models [4],[5],[6],[7],[8],[9][10],[11].

2.1 Commonly Monitored Variables of Rotating Equipment

Commonly monitored variables of rotating equipment are:

Mechanical and electrical variables – rotating speeds, bearing temperatures, metal and exit oil, rotor axial position, rotor radial vibrations, balance piston pressures, steam turbine stage pressures, electric motor power consumption and winding temperatures, gas acoustics, etc.

Process variables – suction and discharge pressures, process flows, suction and inter-stage drum liquid levels, fuel, and gas or steam flow, inlet and exhaust conditions, etc.

Auxiliary conditions – lube and seal pressure and temperature drops, lube and seal oil tank levels, oil drain trap levels, strainer differential pressures.

Typical faults – shaft flaw, steam turbine casing joint leakages and labyrinth seal rub, bearing misalignment, wiped journal bearings, etc. Failure may equally result from deficiencies in specification, design and fabrication, storage and handling installation, operating practices, and/or maintenance. Most of these failures are evident during commissioning or subsequent operation, whereas others may be detected with online mechanical monitoring of bearing metal temperature, rotor vibration, and rotor axial position.

Apart from commonly monitored variables, process variables, auxiliary conditions, and typical failures are included to emphasize the impact of process and other conditions on the mechanical security of rotating machinery. These include system failure, excessive gas temperatures, and off-specification steam condition, but could be identifiable with reliable operating instrumentation. Other process variables such as excessive compressor suction throttling and turbulence are avoidable through diligent attention to system process design and piping layout. Mechanical monitoring is equally important, through which an immediate and continuing knowledge of the behaviour and condition of bearing and rotating elements is gained. This knowledge permits the user to achieve the following;

i. Detect distress before major damage occurs
ii. Improve predictive and preventive maintenance
iii. Minimize spare part inventory and usage
iv. Prolong periods between major overhauls
v. Develop information for identification and correction of deficiencies in mechanical design and fabrication.

2.2 Surveillance and Diagnosis

Condition monitoring utilizes non-destructive techniques (NDT) and other techniques which have become available over three decades now. The techniques include vibration and frequency analysis, acoustic emission, corrosion monitoring, and analysis, as well as thermography and optical monitoring. Condition monitoring becomes increasingly attractive particularly where breakdown can be catastrophic for example in nuclear power plant. It was these high sensitive and technology plants that first accepted the condition monitoring methodology. With condition monitoring, it is necessary to identify data so that an indicator or indicators of approaching failure are pinpointed. It is usually necessary to predict how component or item is likely to fail. Line-dependent failure is typical of corrosion and vibration, for example, heat exchanger fouling, oil degradation, etc. However, the more complex and/or older an item becomes, so are more components likely to fail in a greater variety of ways each to a different time-scale. The failure mode of the plant item is then at random, and random failure also arises from damages

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caused by process malfunction. It then becomes pertinent for the maintenance engineer to apply experience, historical data, and analysis of the plant/equipment and process conditions to judge how an item might fail as well as the time relationship of failure. Based on these, appropriate monitoring techniques and frequency of application on items which will justify condition monitoring, and the costs are appraised. Reliable performance of plant and equipment can be achieved through; first, engineering specifications and manufacturing through installation; secondly, from start-up through operation, mechanical performance monitoring and maintenance.

Power plant uses cannot afford to remain aloof from enforcement of specification requirement and manufacturing quality standards for critical machinery. The importance of such machinery, coupled with dearth of experienced operators and maintenance workforce, demands close surveillance. The surveillance requires extensive inspection which is costly together with scarce talents. Surveillance must begin early and cover selected components in addition to the overall assembly and tests. Typical considerations demanding special attention prior to final assembly and tests include casing casting quality, shaft ultrasonic inspection quality and finish of wheel welding, component balancing of wheel and balance pistons, fit and concentricity of wheels and shaft sleeves to shafts, and rotor balancing. A "Vendor Quality Assurance Documentation Program" will simulate manufacturer's commitment to high-quality of critical machinery and simultaneously obtain "as-built" data of the plant and equipment. Certified records are required for critical materials, non-destructive tests, balancing, and running tests. Non-certified records are required for less critical materials, selected "as-built" dimensions, fits, and finishes of shafts, shaft sleeves and wheel hubs, and bearing bores and contact areas. Basic engineering design dimensions and maximum and minimum standard deviations are required for comparison with the "as-built" data. User and manufacturer negotiation relative to quality assurance must be conducted early and in-depth. Areas of concern and deficiencies are reconciled early enough. Shop mechanical testing of rotating plant and equipment will identify plant and equipment design and fabrication deficiencies. The value of the tests is significantly enhanced if test objectives and procedures are clearly defined, thoroughly understood, and diligently enforced.

2.2.1 Corrosion and Erosion Monitoring

Corrosion and erosion of inner surfaces are the most insidious types of plant deterioration[12]. Casing thickness should always be monitored in order to avoid sudden and inadequate warning failures. The simplest method of casing thickness monitoring is to drill very small diameter holes to a predetermined distance from the inner surface. When corrosion has reached the end of the holes the liquid contained in the casing will then escape indicating the eminence of failure. For the integrity of the plant to be ensured, regular monitoring of the telltale holes must be carried out. The existence of the telltale hole in the casing being monitored will raise the stress locally.

2.2.2 Lubricant Analysis

The condition of the lubricant can be used to detect the damage at the interface between parts with relative movement. The simplest techniques are the mass use of filters and magnetic plugs. The filters and magnetic plugs meet all the requirement of the ideal condition monitoring technique. The simplest method of lubricant analysis is the examination of the filter placed to protect the system. Certainly, filters placed in the separate return line will give maximum information. An alternative method of lubricant analysis involved the use of magnetic plugs, which can be fitted in the return lines from the oil tank near the return flow. It is important that the returning oil should flow around the magnetic plug and that the magnetic plug should be easy to remove. Units incorporating a self-closing valve to seal the system whilst the magnetic probe removed are available. During examination of the filter or plug, the total mass of the debris accumulation should be recorded. Before examination under a binocular microscope with magnification of about 200, the debris should be washed and then dried out on filter paper or attached to cello tape. The essence of this examination is to find and categorize the larger particles. The larger particles are indicative of failure of a washed surface rather than an acceptable wear [12]. Lubricant analysis has been developed to provide detail diagnostic information, for example the type of component that is filing can be determined after categorizing the size, shape, and general appearance of the larger particles.

2.2.3 Motor Flux Leakage

The most common source of movement in the industry is the electric motors which drive conveyors, machines, pumps, etc. Electric motors are the most common cause of plant shutdown. Failure in an electric motor can be classified under two broad categories, namely mechanical deterioration and electrical malfunction, Mechanical deterioration includes bearing degradation and motor distortion while electrical malfunction includes phase failures and short-circuiting. Both mechanical distortion and electrical malfunction can be easily detected by monitoring the flux leakage from gap between the motor and the stator windings. It can be monitored by attaching search oil permanently to the motor [13]. This does not require major disassembly but may result in the removal of the motor and covers. In this condition monitoring technique, a meter is available to be plugged into the search oil terminals giving two readings - one sensitive to electrical faults and the other indicative of any other likely faults. Researches on motor flus leakage have been conducted by [14],[15].

2.2.4 Vibration Analysis

Vibration monitoring is well proven and cost-effective approach to maintenance on condition, enabling many plants/equipment to run for periods in excess of 50,000 hours without interruption for scheduled maintenance. This cuts maintenance costs and avoids unnecessary downtime.

Vibration analysis measure the changes in the extent of vibration of rotating plants/equipment. This measurement gives warning on impending failure or damage to equipment widely used in electric power plants, such as pumps,

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compressors, boilers, fans, bearing, etc., and most methods of examining vibration data involve some forms of frequency analysis. Imbalance, misalignment, unstable foundations, fittings, and some types of bearing failures can easily be detected by vibration analysis, usually measured below $2KHz$, utilizing portable instrumentation mainly velocity transducers and frequency scanner of ¼ octave band. At higher frequencies, acceleration and other analytical equipment such as fast Fourier Transform Systems and real-time spectral analyzers are used to produce power spectral densities. In addition, extensive background knowledge of plants and machinery specifications and actual operating conditions are obtained from field results, or laboratory/simulation tests. Vibration monitoring method has the potential to uncover over 70% of mechanical faults in equipment[16]. Vibration severity chart for machineries is available at [17].

A summary of machinery "saves" with temperature and vibration monitors is presented in Table 1.

Table 1: Machinery "Saves" with Temperature and Vibration Monitors

Machine service	Monitor type	Alarm (A) Shutdown (S)	Problem	Potential Damage	Actual Damage
				Total wreck	None
Hot gas expander	Radial vibration	(A)	Internal shaft flaw	Rotor wreck	None
	Axial disp. and thrust temp.	(A)	Blocked oil line	Diaphragm wreck	
Gas compressor	Journal temp.	(A)	Cracked bearing housing	Bearing failure, rotor wreck	Scored bearing
Gas turbine	Radial vibration	(S)	Bearing housing failure	Gas turbine rotor wreck	Shaft coupling failure
Steam turbine babbitt	Radial vibration	(S)	Journal babbitt failure	Scored journal, rotor wreck	Bearing
Steam turbine	Axial displacement	(A)	Turbine "salting" excess thrust load	Failed thrust bearing, rotor and displ. wreck	None*
Gas compressor	Radial vibration	(A)	Misaligned casing bore	Bearing failure, scored journal or rotor wreck	None, corrected
Hot gas expander	Radial vibration	(S)	Rotor instability	Labyrinth and rotor wreck	Minimal; bearing preload increased
Air compressor	Axial displacement	(A)	Thrust collar turn out	Thrust bearing failure, rotor and displ. Wreck	None*; corrected

N/B: *corrected by turbine wash and displ. represents displacement

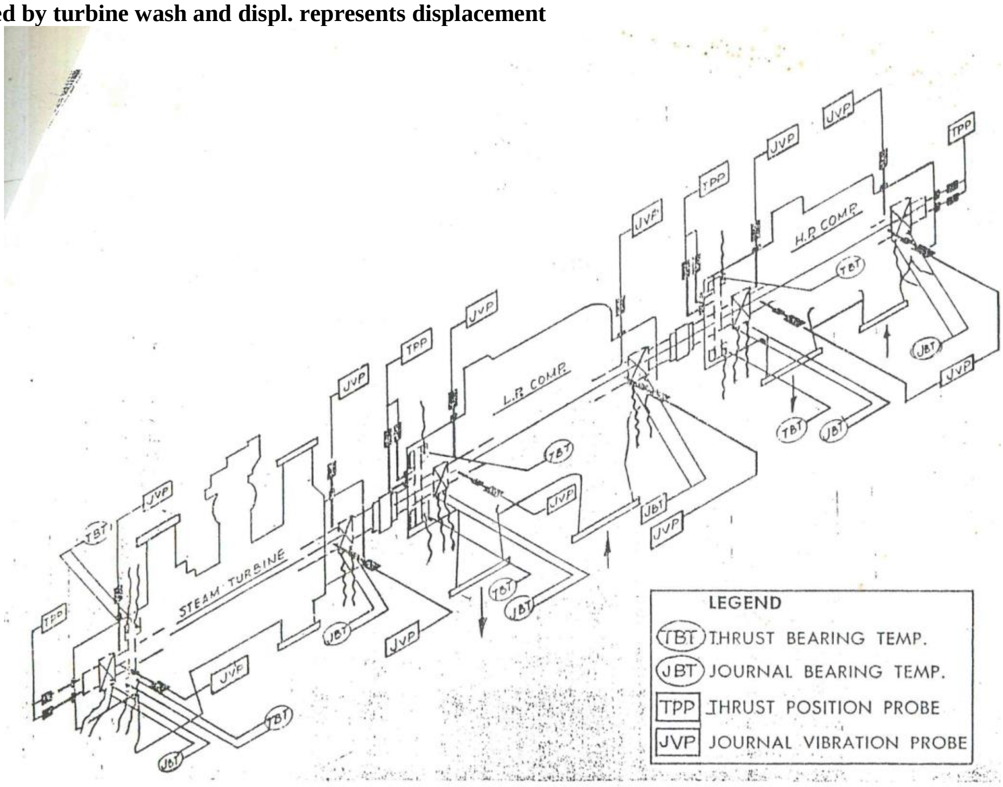

Figure 1: Bearing temperature and shaft monitoring systems for a steam turbine-driven, two-compressor train

A typical guide for selection of monitored as far as temperature and vibration monitoring is presented in Table 2 for more clarification.

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Table 2: Temperature and Vibration Monitoring – Guides for Selection of Monitored

S/N	Priority	Monitored Variables	Response Mode
1	(Basic Installation)	Thrust bearing temperature. Gear journal bearing temperature.	Alarm
2		(1)Plus journal bearing temperature. Motor bearing velocity pick up.	Alarm
3		(1)Plus shaft axial position probe	Alarm
4		(1)Thrust (3) plus second shaft axial position probe, key phasor, motor winding temperatures	Alarm
5		(1)Thrust (4) plus horizontal radial vibration probe (for diagnosis)	Alarm (and optimal shutdown on shaft axial position and radial vibration
6	("Complete System")	(1)Thrust (5) plus redundant sensors, and/or probes	Alarms and shutdown

Pressure by stages and lube oil analysis are recorded monthly or quarterly. Bearing cap on other casing movements are frequently determined with hand-held vibration meters.

The fourth category of data is for problem diagnosis.

2.2.5 Acoustic Emission

Acoustic emission is the stress wave generated when a material is under stress, whether by deformation, or growth defects. The driving force is the elastic strain energy (residual, thermal, applied) stored in the material. As faults occur in the material, they generate acoustic stress waves, the significance of which is associated only with deformation or fracture process. Transducers detect the sound as it occurs. By comparing the arrival times of the signals at two or more transcoders it is possible to detect the area of fault origin. Each type of detect generate a specific acoustic signal with recognizable characteristics. Continuous monitoring systems can chart the growth of a detect giving a good indication of its size and severity hence can be located and assessed simultaneously. Acoustic surveillance can be used in every structure pressure system or high-pressure vessels where integrity is highly needed. The use of acoustic surveillance was first applied in high technology and high-risk areas particularly, aerospace and aircraft industries. The use of acoustic surveillance has extended to electric power industry as well where proof testing of high-pressure vessels, pipework systems, compressors, pumps, etc. are needed. Basic instrumentation comprises; a transducer (normally a sensitive piezoelectric ceramic element between 100 and 300KHz) and a preamplifier there are the usual, amplifier filters and digital electronics for further signal processing and data analysis.

2.2.6 Thermography

Thermography is a temperature-based condition monitoring, using the infrared region of the electromagnetic spectrum. A stationary or moving object can be examined at any distant without influencing the temperature of the object. There is no contact or linkage with the object. The range of measurement is from $-20℃$ - $+2000℃$. The components of a modern portable thermographic system include a camera unit (comprising an infra-red detector element, processing front lenses, prism scanning, mechanism, and infra-red detector-video signal converter, colour monitor, and profile adaptor. Thermography is a temperature surveillance techniques popularly used in power plants. The availability or real-time thermal surveillance has a powerful dimension in condition monitoring in operation and maintenance departments. [18] label has up to eight indicators, which change irreversibly from pearl grey to black when its critical temperature is reached.

3. Discussion

An interesting experiment involving a shaft system with good and defective bearing is illustrated in Figure 3. The vibration signature of bad and good bearing can easily be compared as in Figure 3. This can serve as a simple guide to take maintenance decisions. Thresholds should be established, beyond this that the component is considered failed. The concept of envelope detection is illustrated in Figure 4 which depicts amplitude versus time traces on oscilloscope screen. It is demodulated to extract the necessary of amplitude, voltage against time and displayed.

Although acoustic high frequency signal generally show an upward trend long before low frequency signal, acoustic high frequency signal often decrease when antifriction bearing defects have progressed to the point of near-destruction. Figure 5 is very typical of this observation.

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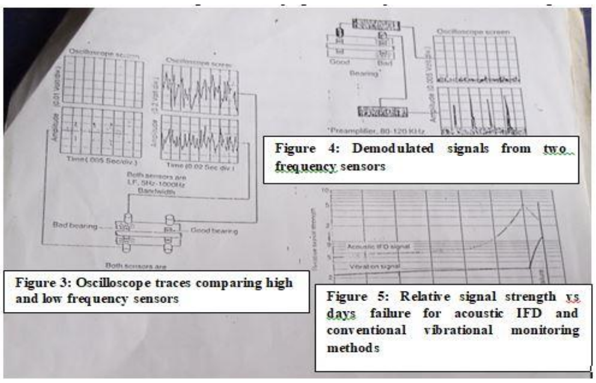

Figure 3: Oscilloscope traces comparing high and low frequency sensors

Figure 4: Demodulated signals from two frequency sensors

Figure 5: Relative signal strength vs days failure for acoustic IFD and conventional vibrational monitoring methods

4. Conclusion

Condition monitoring is a very effective method to apply in power plant assessment and maintenance planning. For critical equipment as this, no good other option exist other than using condition monitoring to monitor and assess the health of the plants to know if they are working in normal condition. Vibration signature using amplitude vs time or velocity vs time are very effective to reveal the condition of the plant. Peaks will show the normal or abnormal working of the components of the plant such as the bearing. Condition monitoring is vital to maintenance department to take appropriate actions and safe the plant from unpredictable power plant failure.

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