Condition Based Diagnostic Techniques for Predictive Maintenance- A Key of Success to Paper Industry

Tyagi Sanjay,* Thapliyal B.P.,* Mathur R.M.* & Ray A.K.**

ABSTRACT

Condition monitoring of the plants and machines in process industry like paper has acquired a considerable importance as a useful tool for predictive or condition based maintenance. It is the scientific approach that can be employed to detect potential failures that are not evident through any preventive maintenance program. The increasing competitiveness in paper industry makes the use of predictive maintenance strategy essential for achieving high industrial productivities and low energy expenditure. To ensure plant reliability and equipment availability techniques like vibration analysis, oil analysis, thermography, ultrasonic measurement and acoustic emission monitoring are available and are used widely in process industries abroad. As far as, Indian paper industry is concerned, only few plants have adopted his predictive maintenance techniques and a lot of industry still follows the conventional maintenance strategies that are not always economical. In the present work different techniques for condition based predictive maintenance are discussed with few case studies related to paper industry.

Key Word: *Predictive Maintenance, Vibrational analysis, Lubricating oils, Condition Monitoring, Thermography, Rotating machines.*

Introduction

The fundamental purpose of maintenance in any process industry is to provide the required capacity for production at the lowest cost. It is the management, control, execution and quality of those activities which will ensure that optimum levels of availability and overall performance of plant are achieved in order to meet business objectives (1).

A survey in Indian Industry indicates that 1/3 rd of all maintenance cost is wasted as a result of unnecessary or unplanned carried out maintenance. In the last few years, with the ever increasing quest for production, almost all paper industries of India have gone for expansion plans but these expansions showed an under utilization of capacity due to inadequate infrastructure particularly maintenance. There appears to be considerable scope to modernize the existing maintenance procedures of Indian Paper Industry and keep pace with the awareness and development taking place elsewhere.

Literature Review

Fundamentally, maintenance strategies may be classified as
(a) Corrective or breakdown maintenance
(b) Preventive maintenance

(a) Corrective or break down maintenance:

This is also known as operate to failure and is required when machine is at failure or run to failure. Since, maintenance costs being a major part of total operating cost of all manufacturing and production plants (between 5 – 40% of costs of goods produced depending on type of industry), considerable saving can be achieved if proper attention is paid to maintenance procedures. Table 1 gives the glimpses of maintenance cost of few industries.

Table 1: Maintenance cost in few Industries

S.No	Industries	Maintenance cost(% of total sales)
1.	Pharmaceuticals Industry	16%
2.	Car manufacturing	4%
3.	Chemical Industry	6%
4.	Engine manufacturing	7%
5.	Casting/Forging	8%
6.	Paper Manufacturing	10%
7.	Steel Industry	15%
8.	Electronics	2%

With most paper mills moving towards 24 x 7 production schedule, there is a need that supporting equipments and systems availability to be always in running condition. The maintenance departments have no longer freedom to extend periods of available equipment downtime in order to carry out maintenance. Instead, the maintenance function is moving towards a more predictive approach. This is where the modern technologies of predictive maintenance are now pre dominantly being used to effectively monitor the performance of equipment and plan maintenance interventions in timely manner.(1,2)

In any Industry, running many inexpensive machines and having each important process duplicated, machines can usually be run to breakdown. Here, loss of production is not as significant as spare

*Central Pulp & Paper Research Institute, Saharanpur-247001 (U.P.)
Emeritus Fellow, Dept. of Paper Technology, IIT Roorkee, (SRE Campus), Saharanpur - 247001 (U.P.)

machine can take over and consequently there is not always an advantage in economy or safety using more sophisticated maintenance methods. However, in cases like process industry, where large unduplicated process machine run to breakdown, it become necessary to look after the root cause of the problem and with this information, maintenance engineer can order necessary spares ahead of expected breakdown.(3)

(b). Preventive Maintenance:
This is time based maintenance where plant management decides to take some actions with the aim of preventing failure occurring or at least reducing the chance of failure. They can be classified as (1)

- **Maintenance on fixed or duty basis**:
  This is a better way than allowing machine to fail, but what is the optimum interval to do the maintenance job is not clear. The challenge is to find the correct time interval. Some machines will be dismantled unnecessarily, while other fails due to lack of inspection. Fixed time maintenance is effective if there is a strongly age dependent failure mode which is revealed by experience.

- **Opportunity Maintenance:**
  Opportunity maintenance takes advantage of a plant shutdown from some other cause than from the machine to be worked on. This means that no production will be lost due to this machine. (unless it is critical and work goes beyond the initial time period).

- **Design out maintenance**:
  This is an improved strategy where component or machine is redesigned to improve performance or maintainability after the root cause of poor performance has been identified.

- **Management Policy**:
  Here maintenance work is performed for reasons like environmental/social responsibility, corporate image, industrial relations and local community relations.

Experience has shown that in a vast majority of cases, above time based maintenance is uneconomical. A significant fact is that instead of the failure rate of the machine improving by replacing wear parts regularly, the opposite often happens and the reliability of newly serviced machine is reduced temporarily by the interference. As the actual failure pattern for each individual machine cannot be predicted, an individual approach is therefore needed and this is the possibility which on-condition maintenance offers.

(c). On Condition Maintenance:
With this method, each machine is considered individually by making fixed interval condition measurement to obtain a quantitative value of the 'health' of the machine. Maintenance is scheduled as a result of some regular measurement or assessment of plant condition, usually trending the parameter and prediction of lead time to failure. The basis is that most mechanical components give some warning of their impending failure. Electronic items do however often fail suddenly.

(d). Predictive Maintenance:
Predictive maintenance belongs to scientific technologies that can be employed to detect potential failures that are not evident through any preventive maintenance programme. If one is able to judge the failure pattern of the equipment, its failure can be detected well in advance using Predictive Maintenance programme and appropriate actions can be taken in a planned manner. The use of condition based maintenance has dramatically reduced non- value added maintenance by eliminating the need of unnecessarily shutdown of the equipment for maintenance checks [2,4] Some of the main technologies current in practice in industry are

- Thermography: infrared imaging to detect abnormal temperature or hot spots.
- Vibrational monitoring: accelerometer instruments can be used to detect abnormal or high vibration particularly in bearings.
- Oil Analysis: Analysis of oil can detect the deterioration or breaking down of an internal equipment part.
- Ultrasonic measurement: Use of ultrasonic technologies to detect leaks or blockages on utility system.

Principle of Condition Monitoring:
Condition monitoring is a relatively new science and has clear benefits to the industry. It has become a key part of the modern maintenance department and more and more companies are taking on board these technologies in order to maximize the reliability of their equipment by detecting failures well in advance. Figure 1 shows the basic principle on which condition monitoring works. For particular equipment a suitable parameter is chosen that

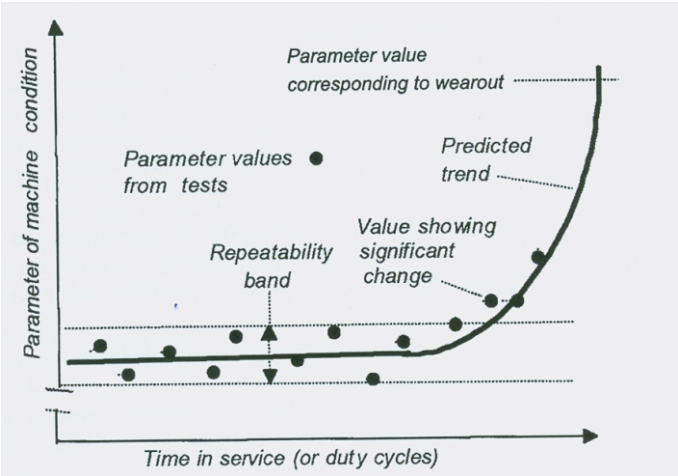

Figure 1: Principle of Condition Monitoring: trending

indicates the internal condition of the plant item. i.e. in rotating machinery, the vibration level is commonly used. Initial samples are used to establish by experience the repeatability band that is obtainable in normal operating circumstances when the equipment is considered to be running in good condition. With new and over hauled equipments, these values may be changed until the wearing- in period (infant mortality) has passed. (5)

Routine readings are taken at suitable intervals (may be continuous, monthly, quarterly or yearly), depending on issues such as access, size of plant and convenience of setting up routes for data collections or testing. When degradation occurs, the parameter falls outside the repeatability band and the frequency of reading often increased to enable prediction of remaining time to

failure is not easy to tell, but it is usually of sufficient accuracy to meet the needs of maintenance. Now a days the development and application of computers and mathematical tools assist maintenance decision making and is becoming powerful tool in the hand of maintenance engineers.(3,5)

An overview of application and benefits of Conditioned Predictive Maintenance

Some failure modes cannot be designed out i.e. mechanical bearing or electric panels, but if failure can be detected early, the maintenance department can plan the work in much organized manner. Unplanned breakdown maintenance can cost as much as three times that of planned maintenance so predictive maintenance is of significant benefit. Detecting a failure early means that the level of damage that can follow an actual failure also can be avoided or reduced (6). Given below the overview of some techniques for condition based predictive maintenance.

1. Vibration monitoring and Analysis:

Vibration monitoring and analysis is probably the best known technique for rotating machines such as pumps, air compressor steam turbine etc. Vibration can be defined as simply the cyclic or oscillating motion of a machine or machine component from its position of rest. It is normal for all machines to have some level of small vibration, however when this vibration increase or become excessive, it indicates the mechanical fault of some type. Vibration analysis uses accelerometer instruments to detect these vibration movements and results of these vibration readings can be plotted (magnitude v/s frequency) using a mathematical representation called Fast Fouriers Transform (FFT). The FFT plot will highlight the level of vibration and identifies which frequencies they are present in . The frequencies present are related to the machine cyclic movement, such as rpm and by using this data the origin of fault can be determined. (2, 7,8)

Figure 2 shows a typical vibration plot for a motor drive unit. Each element in the drive system operates at different frequencies and the magnitude of the vibration is used to determine if any fault exist. The vibration levels or magnitude level will also tell the severity of vibration and whether any action is needed or not. The procedure is to take some baseline readings when the equipment is first installed and with the passage of time, the equipments is trended and areas of deterioration can be identified.

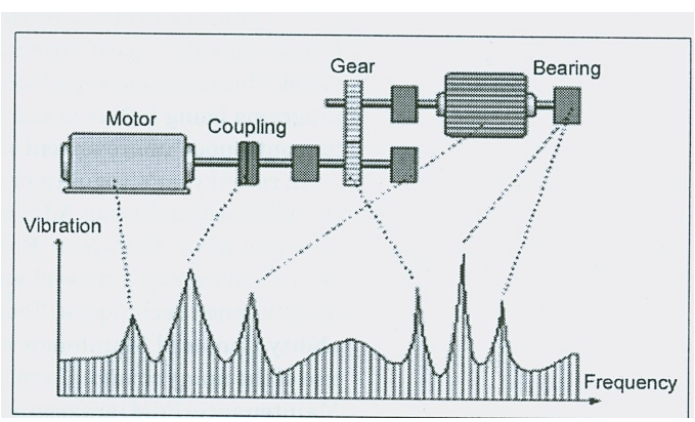

Figure 2: Typical vibration analysis FFT plot (magnitude vs. frequency)

The vibration analysis plot offer contain multiple fault frequencies where analyst needs a detailed knowledge of the operating characteristics of the equipment (such as number of fan blades , RPMs, pulley ratios, bearing types etc) For this reason vibration analysis takes a lot of mechanical expertise and training in order to become proficient. Any false diagnosis can sometimes be a problem with correct training and mechanical proficiency. The following type of problems can be determined using vibration analysis

- Unbalance of rotary components
- Mechanical looseness
- Misalignment of drive system , shafts etc.
- Belt deflection
- Bearing deterioration and gear wear

The vibration analysis can be formed using accelerometer instruments (Fig 3) which detect vibration levels.

2. Thermal Imaging or Thermography

Principle of Thermography:

As the name suggest, infrared thermography is based on infrared (IR) technique. It is based on the principle that every object emits certain amount of IR energy and the intensity of this IR radiation is a function of temperature. In an electromagnetic spectrum, the IR region appears between 0.8 µm to 1000µ m wavelength. This wave length of IR spectrum is more than that of a visible spectrum. The IR energy which can directly represent the surface temperature can be detected and quantified by the help of IR scanning system. (2,9,10,11)

Thermography is a temperature profiling of surface or point. Thermal imaging is used primarily on electrical panels to identify loose connection but now it is used in other applications such as checking for blockages in pipes, carrying out heat survey in plants, mill drive train misalignment, leakages from steam traps, misaligned pumps.

Thermograpy instruments generally used are infrared cameras which contains infrared detector that converts IR software package to load, store and compile results . Use of infrared camera requires specific training as setting up of camera and interpretation of results require a level of expertise. Thermography or infrared imaging requires a direct exposure to the surface being measured as infrared cannot penetrate through surfaces such as glass or plastic, unless specifically designed IR windows are installed. Emissivity factor (ε) is an important parameter in IR cameras. Emissivity is a heat factor which depends on the material type being scanned, its color and angle of heat being radiated for a true black body emissivity (ε) = 1 while for other surface it is less than 1. Its value become important because if not set correctly the true temperature reading could be offset

Advantage of Thermography

- It is non destructive and non contact type technique
- It gives fast, reliable and accurate measurements.
- Capable of catching moving targets in real time
- Large surface area can be scanned
- Measurement in areas inaccessible for hazardous for other methods

Disadvantages

- Duality cameras are expensive having ± 2 or worsen accuracy
- Ability to only measure surface areas. Unable to detect the inside temperature

Application of IR Thermography

Application of IR Thermal imaging extends from micro electronics level to scanning wide areas of all fields like medicine, environment, agriculture, thermo fluid dynamics and maintenance

Use of Thermography in Maintenance

Thermography images help maintenance crew to predict equipment failure and to plan corrective action before a costly shut down so In order to reduce the maintenance cost of mechanical equipment IR Thermography allows for inspection of power plants, as well as, for monitoring of temperature and thermal patterns on pumps, motors, bearings, pulleys, fans, drives , conveyors etc while equipment is on line and running under full load.

Application of Thermography to paper industry

The thermal imaging can be used in paper industry both in the field of maintenance as well as in trouble shooting. Given below few areas of use of thermography

Steam Traps: -

Defective steam traps are quite common in paper industry especially in the area of paper machine dryers and recovery evaporators causing lot of energy loss. IR Thermography can be very easily used to identify the detective steam trap by simply taking thermal image of inlet and outlet of the trap and noting down their temperature difference. It there is not a proper temperature difference, then trap is not working properly (Fig. 3)

Insulation: -

IR Thermography can be effectively utilized in checking the surface insulation of steam / condensate pipe lines, boiler surface, digesters, pre-heaters and recovery evaporators. The national bureau of standards in Washington has found benefit of 30% reduction in energy loss in medium size industrial furnace by applying thermography for its insulation checkup.

Motor coupling: -

All motors have a maximum operating temperature and thermal pattern which plays vital role in motor maintenance programme. Condition such as inadequate air flow, unbalance voltage . bearing failure , loose foundation bolts , degradation of rotor or stator all responsible for rize in temperature of motor which can be imagine

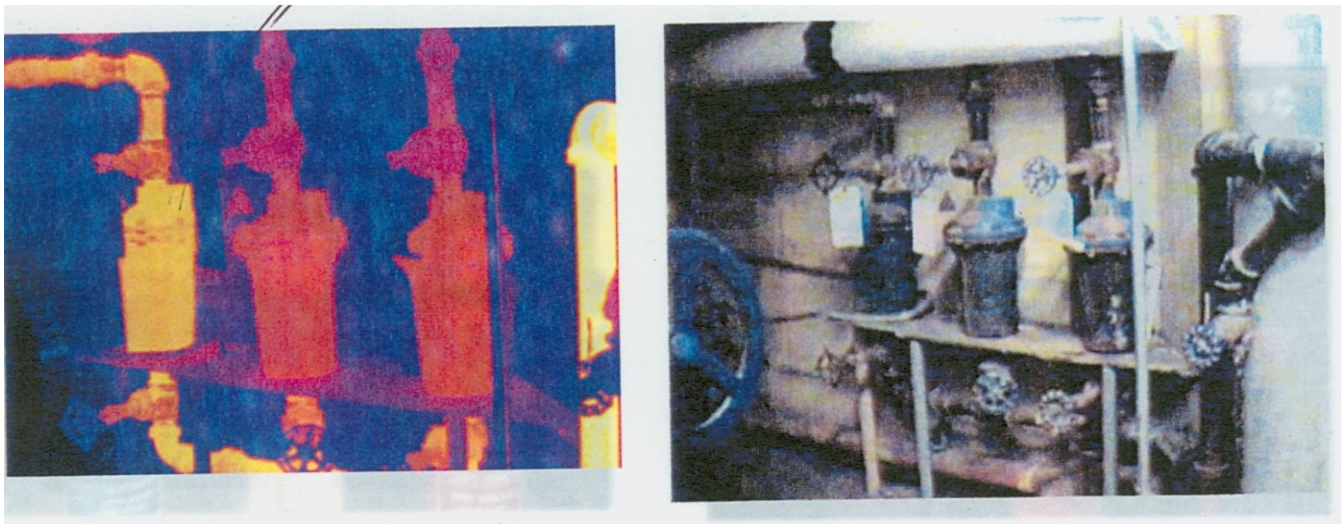

Figure 3: Thermography image of steam traps having steam leakage

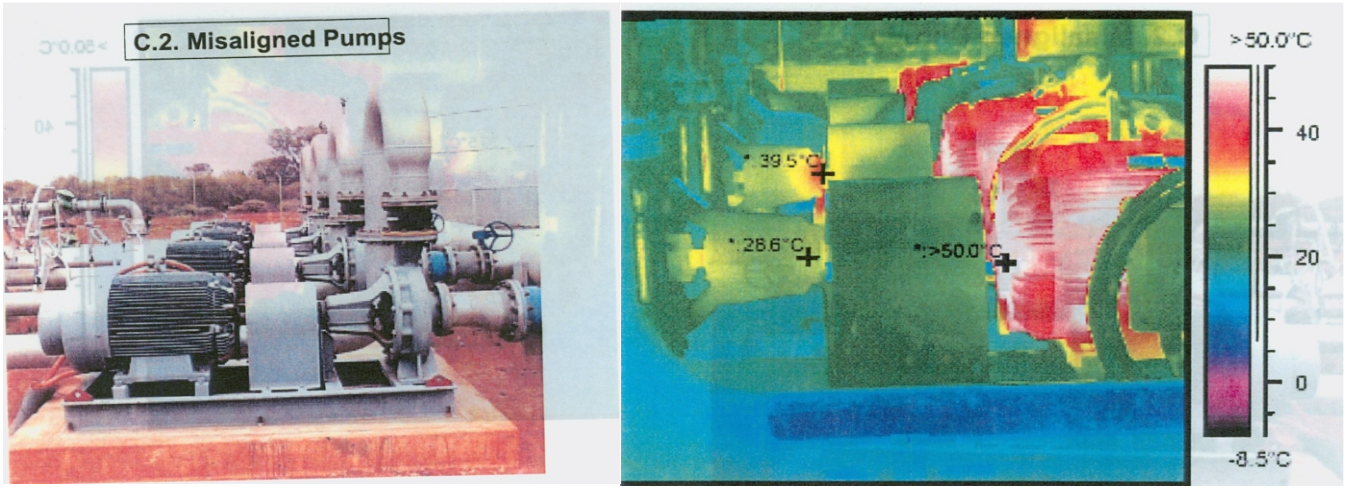

Figure 4: Threrm al image showing high temperature rise in motor bearing due to misaligned pump

by IR thermography and any maintenance can be carried out well in advance (Fig 4)

Lime kiln:-

The lime klin often faces the problem of refractory bricks/lines fall causing huge energy loss in terms of radiation. Thermography proved to be an efficient tool for the monitoring of lime kiln insulation lines.

Paper Roll :-

Thermography can be used in determining the moisture variation in CD direction of paper web at pope reel. The temperature difference in CD profile of paper can be correlated with moisture variation, grammage variation and thickness variation and corrective action can be taken by paper maker. (Fig. 5)

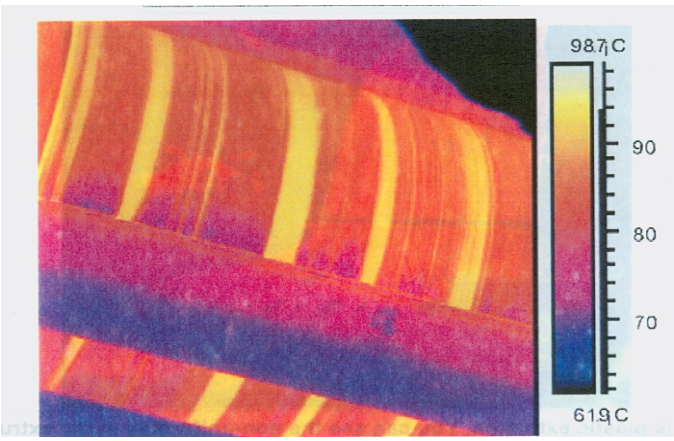

Figure 5: Thermal image of paper roll showing moisture variation

Paper Machine dryers:

IR Thermography can be used as a tool for the maintenance of Yankee Dryer of paper machine. It can be used to evaluate the performance of the condensate removal siphons of dryers. It is also useful for the diagnosis of other problems like excessive edge wear, repetitive surface wear, out of round dryer, shipped creeps , excessive doctor blade loading sheet plugging , uneven dryer coating , steam leaks and many more.

Tribology based Diagnosis Technology (Lubricant Analysis):

Oil greases and other lubricants are commonly used in equipments with moving parts such as gears and bearing for different applications , different grades of oils and lubricants are recommended and based on type of oil grade , chemical properties of lubricant can be tested . Using oil analysis, the quality of lubricant and material constituents can be tested and compared against he original specification. Lubricant analysis can be used to determine when an lubricant change out is required. This also helps in detecting wear of internal components. Given below, few examples where the lubricant change would supercede the change frequency based on running hours.

- High Iron content indicating wear and tear (may require further investigation of equipment)
- Breakdown in oil additives
- High water content
- Change in viscosity levels.

e.g. if the gears inside a machine are wearing fragments of metal are deposited in the oil. When oil is tested, traces of this metal debris will give the maintenance from prior warning of the potential failure. The type of metal detected will also give useful information regarding its origin (i.e. bearing or gears, etc)

Oil or lubricant analysis programmes allow a condition based approach to lubricant change rather than a fixed internal or by equipment run hours . Tribology based diagnosis technique give prediction regarding machine wear out much earlier as compared to other predictive maintenance techniques. it is well evident from Fig(6)

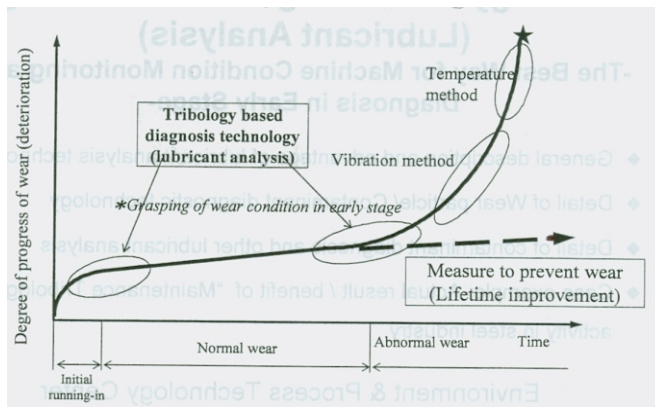

Figure 6: Damage process of machine and lubrication system diagnosis

Ultra sonic Measurement:

Ultrasonic measurement is primarily used for leak detection on steam and air system. They are also useful to detect leaking values.

Principle of Ultrasonic Measurement

Ultrasonic measurement instruments translet high frequency sounds produced by steam or air leaks into the audible range which can be heard through headphones and can be visualized on meter on display. The high frequency ultrasonic components of these sounds are extremely short wave signal. These signals can be isolated from background plant noise to detect their exact location.

Use of Ultrasonic testing for steam traps:-

The ultrasonic testing can be effectively used for the testing of the steam traps . Steam traps are used on steam distribution lines (e.g in dryer section of paper machine or in evaporators in recovery section) to remove unwanted condensate build up when steam traps foils , the build up of condensate dramatically increases due to passage of line steam in condensate . This will result in increased consumption in steam, poor efficiency of steam coils or heat exchangers, increased water hammering in steam pipe work and an overall inefficient steam system.

Steam traps are temperature and condensate sensitive devices that open or closes automatically to allow condensate passes to drain. Steam traps can fail open (In which case both steam and condensate passes to drain) and fail closed (which allows an internal build up of condensate in steam line). The fail open steam trap can be detected by the ultrasonic frequencies present from the steam and condensate continuously leaking through the trap. A failed closed trap can be detected by the absence of ultrasonic frequencies at the trap. Periodic steam trap surveys using

ultrasonic measurement to identify fault is not only useful from maintenance point of view but also bring significant cost savings by increasing the efficiency of steam system.

Acoustic Emission: -

This is relatively new technique for the detecting the initiation of cracks in machine structures. As crack is initiated propagated through material, a stress pulse is generated and transmitted through the material as stress wave. A transducer mounted on the surface, will detect the disturbance and produce on electric out put.

The source of the wave or location of the crack can be found by using three or more transducers. The transducers detect high frequencies of 200 kHZ or more. Counters with a threshold limit register a count each time the signal level exceeds the threshold values. Several other parameters like rise time, event duration etc. are also used for analysis

Acoustic emission has been successfully used in a number of applications testing of pressure vessels, detection of leaks, cavitations detection, corrosion fatigue crack detection, seal failure detection , detection of damage in rolling .

Conclusions

A diagnostic condition based model can be used for predictive maintenance of equipments and plants in paper industry

Condition monitoring based maintenance may be component of total maintenance system,, involving use of other maintenance strategies as well. It is also to be a part of manufacturing system for machine and production control

PDM is widely accepted approach to the maintenance strategy for paper mills. The benefits of PdM can be extended to promote a proactive approach to maintenance. Not only in maintenance, this approach is also useful as energy conservation measure for plants. The above strategy would lead to economic benefits and avoidance of unscheduled breakdowns and safety especially for large capacity high speed machines.

References:

1. Raymond S. Beebe, “Predictive Maintenance of Pumps using condition Monitoring”, book published by Elsevier Science & Technology Books, (April 2004)
2. Liggan & David Lyons, “Applying Predictive maintenance Techniques to utility system”, Pharmaceutical Engineering, Nov/Dec. 2011, Vol. 31, No. 06, pp- 1- 7.
3. Course notes of “Energy Conservation Techniques for India”, Course JFY 2009 (1), Aug 30, 2009 to Sept, 19, 2009, Japan International Cooperation Agency, Kitakyshu, Japan.
4. Ugechi, C. I., Ugbonnaya, E. A., Lilly,M. T., Ogaji, S. O. T. and Probert, S. D., “Condition based diagnostic approach for predicting the maintenance requirements of machinery”, Engineering 2009, 1 177 187.
5. Higgins L. R., “Maintenance Engineering Handbook”, McGraw-Hill Book Company, New York, USA, 1995.
6. Nakra, B. C., “Condition monitoring, fault diagnosis and Predictive maintenance of Mechanical systems”, , Impulse, ITM, Vol. 2, 2006.
7. Toshio Toyota, “Condition diagnosis Technology for Energy Conservation”, Professor Emeritus, Kyushu Institute of Technology, 'Energy Conservation Techniques for India”, Course JFY 2009 (II), Aug 30, 2009 to Sept, 19, 2009, Japan International Cooperation Agency, Kitakyshu, Japan.
8. Broch, J. T., “Mechanical vibration and shock measurement”, 2nd edition, K. Larsen & Sons, A/S, Denmak, 1980.
9. Smith, B. M., “Condition monitoring by Thermography”, NDT Int. Vol. 11, 1978.
10. Garnaik, S. P., “Infrared Thermography: A versatile Technology for Condition Monitoring and Energy Conservation”, , www.reliabilityweb.com.
11. Meola, C., Carlomagno, G. M., “Recent advances in the use of infrared thermography”, Meas. Sci. Technology, P2-3 (2004).
12. Yoshiaki Shia, “Tribology based diagnosis Technology (lubricant analysis)”, Nippo Steel Corporation, “Energy Conservation Techniques for India”, Course JFY 2009 (1), Aug 30, 2009 to Sept, 19, 2009, Japan International Cooperation Agency, Kitakyshu, Japan.
13. Bandes, A. S., “Ultrasound simplifies steam trap inspection”, Plant Engineering, (2003), Feb. pp. 62- 64.
14. “Acoustic emission monitoring of corrosion fatigue crack growth in offshore steel”, NDT Intl., Vol. 17, PP 147 , 1984.
15. Bor, P., “Detect incipient failure by monitoring acoustic emission” Power, p 69, Dec. 1982.
16. Verma Anuj Kumar, Ray A.K., Singh S.P., and Banerjee Debasis and Schabel Samuel-Active Thermography in Paper Industry-A review- IPPTA,Vol.21, No.2,April-June,(2009), pp 55-58 .