

A Review on Condition Based Monitoring Techniques for Mechanical and Electrical Equipments

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ABSTRACT: Machines or equipments are widely used in industries either directly or indirectly for the production of goods and services. The availability of such equipments becomes very important because these equipments work under different environments, run invariably continuously in the field and their maintenance requirements vary from case to case. So an efficient maintenance plan based on condition monitoring is required for their smooth functioning. A wide range of condition based monitoring (CBM) techniques are available in the industries over the world and some of them have become a standard practice in the industry. This paper presents the various condition monitoring techniques being practiced in the industry, its applications, advantages, disadvantages, method of fault diagnosis and recent advancements associated with remote condition monitoring of mechanical and electrical equipments.

KEYWORDS: Condition based monitoring (CBM), Maintenance, Remote Condition Monitoring, Fault Diagnosis.

I. INTRODUCTION

These days machines are expensive and breakdowns results in huge time loss and incurs too much cost. So the maintenance approaches are becoming more inclined towards putting actions into force which ensures the availability of machine. The main goal of maintenance is to prevent the breakdowns to occur thereby saving costs related to it. The maintenance is broadly classified into corrective (failure has already occurred), preventive or condition based maintenance (to prevent failure to occur) and reliability centered maintenance (scheduled plan that provides acceptable level of operability) [1]. There are different tools which are part of the maintenance activities and condition based monitoring (CBM) is one among them. CBM is a maintenance technique that monitors the condition of equipment by systematic collection of data with the help of instruments or sensors and processing of data into a meaningful information in order to take a call on maintenance actions which are yet to be taken [7] CBM helps in indentifying time left to failure by monitoring the condition of the equipments while it is in operation. The need to stop the machine to check the health status of it is mostly not required in case of CBM which helps in preventing the idle situation of machine. CBM is helpful in providing the set of data which is beneficial for the planning of maintenance schedules [2]. Following are the main steps of adopted in CBM [6]:



Fig. 1 Steps of CBM

From Fig. 1, the main steps involved while conducting the condition monitoring of any equipment mainly involves the capturing of signal by using some CBM technique. The various signatures shown by the signal are then processed or analysed with the help of suitable tools like software, human experience, mathematical tools, etc. The outcome of the analysis is then interpreted in quantitative data which is easy to understand for further decision making. Condition based monitoring mainly includes two approaches for checking the health status of equipments: these are trend monitoring and condition checking. Trend monitoring mainly involves the continuous recording of data during machine run and its interpretation in order to detect any abnormalities in the condition of the equipment(s). Condition checking is done for a particular parameter like vibration, temperature, oil, etc. for which measurement is taken by the CBM expert with the help of certain instrument over a fixed interval of time. Condition checking requires expertise in terms of machine knowledge which makes the method less flexible than trend monitoring [31].

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In general, CBM system includes detection of faults, anticipating any favourable situation for breakdowns, and diagnosis of faults in the machine. The traces of CBM are widely found in industries with applications in power plants, manufacturing units, automobile industry, etc. [8]. Elanien et.al. [13] presented different approaches for monitoring the condition of power transformer. These CBM approaches were classified into 5 different domains related to the type of fault: temperature monitoring, vibration monitoring, dissolved gas analysis (DGA), partial discharge (PD) monitoring and sweep frequency response analysis (SFRA). The most widely used techniques available for monitoring the mechanical and electrical equipments are presented in Table 1 below:

TABLE NO.1 CBM TECHNIQUES

Type of Equipment	CBM Techniques	Type of Equipment	CBM Techniques	
Mechanical	Temperature Monitoring	Electrical	Temperature Monitoring	Turns Ratio measurement
	Vibration Monitoring		Oil Testing	Dissolved Gas Analysis
	Pressure Monitoring		Capacitance & Tan Delta Test	IR & PI measurement
	Wear/Corrosion Monitoring		Magnetic Balance Test	Winding Resistance Test
	Chemical Analysis		Sweep Frequency Response Analysis	Moisture monitoring

Lord and Hodge [19] study was more focussed on monitoring of component or part of an equipment, e.g., monitoring the condition of transformer oil tank was mainly focussed on following key parameters:

- Moisture
- Winding insulation degradation
- Wear Debris
- Geometry of winding and core
- Winding temperature
- Main tank electrical and acoustic partial discharge (PD)

Every machine system gives some form of signal or symptoms in regard to its abnormal functioning. This is called signatures which are used as key parameters for checking the health status of equipments. These signatures helped in information extraction of system in the form of electrical, vibration, thermal, environmental, results from oil analysis, etc [7]. The multiple set of data provided by the various signatures helps in building a systematic relationship among them which is helpful in diagnosis of fault [9]. According to Sheng et.al. [5] the diagnosis of fault found in a equipment is mainly done in two ways either by portable monitoring system based on data collection device or by on-line condition monitoring system based on sensors. Higgs et.al [6] recognised the deployment of CBM in field in two ways either localized CBM (manual and schedule based monitoring) or remote CBM (automatic and continuous sensor based monitoring). The most preferred way of monitoring the equipment is periodic schedule based intervals owing to its lesser cost compared to continuous sensor based monitoring. [10]. Hence CBM becomes important part of the maintenance system in order to increase the availability of equipment.

II. RELATED WORK

Some of the investigations and different techniques used by researchers for monitoring the health of machine parts and components are described below:

Mortazavizadeh and Mousavi [11] presented the study of various CBM techniques of rotating electrical equipments. Various signatures were identified by conducting electrical analysis, mechanical analysis, chemical analysis and thermal analysis. The signatures identified by electrical analysis includes: flux, motor power, torque, voltage and partial discharge. For mechanical analysis it includes: vibration, noise and torque, for chemical analysis it involves: infrared, ferrography and image processing and for thermal analysis it includes: measurement of temperature and its modelling in FEM.

Spare [12] presented a business case study on maintenance of electrical equipments based on condition monitoring. Then various benefits from CBM were identified like lesser maintenance costs, reduction in breakdowns, increase in operational life of an equipment, higher reliability and availability of equipment and improve worker safety and prevent environmental hazards. Elanien et.al. [14] also backed this view while conducting CBM of transformer. The major aims of CBM are clearly stated in [15] which include preventing any kind of breakdown, to increase machine utilization, optimization of maintenance schedules and to stretch the working life of equipment.

Tandon [15] detected the faults in roller bearing by studying different vibration parameters. The different parameters involved were overall RMS, peak, crest factor, power and cepstrum. The vibration signals of faulty bearings were

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measured and compared with those of good bearings. It was then observed that power parameter outperformed other parameters in fault detection followed by peak and RMS measurements.

Trendafilova and Brussel [20] proposed a method for defect detection in robot joints from their measured vibration signals. It employed a pattern recognition principle with nonlinear autoregressive modelling. A reference database was created from signals that came from known conditions. The method used the nearest neighbour principle and assigned a new signal to the category to which its nearest neighbour from the reference database belongs. The nearest neighbour was chosen on the minimum Euclidean distance basis. The coefficients of a nonlinear AR model were used as features of each signal. The method showed very good performance with signal blocks drawn from the measured acceleration signals.

Hansen and Gao [16] studied the vibration behavior of a deep groove ball bearing with the help of force sensor integrated structurally to it. Modeling was done with the help of FEM in order to predict the output of sensor by varying load and rotational speed. The defects on the bearing were detected by series of signals which were not repeated between consecutive revolutions of the bearing.

A survey was conducted which reported the major reasons of failure of power transformers (approx. 51%). The reasons involved were high moisture presence, presence of foreign particles, ageing that leads to reduction in dielectric strength of the transformer. The other reason mentioned were winding damage due to short circuit forces and bushing damage due to change in insulation dielectric strength [18].

Sameh et.al. [21] found another method of condition monitoring in rotating electrical machinery by measuring and analysing the acoustic noise spectrum. These acoustic noise emissions from air gap were held responsible for causing eccentricity in the induction motor. But, the application of noise measurement in a noisy environment like a plant is not so efficient. However, Ellison and Yang [22] presented a different approach for air gap eccentricity detection by carrying out a test in an anechoic chamber. Slot harmonics in the acoustic noise spectra were introduced as an indicator of static eccentricity.

Millar and Lehtonen [17] presented a study on condition monitoring of power cables by measuring the current signals. A mathematical model based on FEM simulations was developed to detect any temperature rise in the cable. The different algorithms used were based on exponential function because these are mathematically compatible to give numerically simulated results. The results had shown the variations in temperature characteristics of cable in the form of exponential expressions.

Chemical analysis is another CBM technique which helps in detecting any changes in the chemistry of the part of equipment. The monitoring of insulation of a transformer can be done chemically by the detecting the presence of any foreign agent in the coolant gas or by detecting the gases which are produced as result of degradation of insulation such as hydrogen, methane, ethane or hydrocarbons, like acetylene, etc. [23]. Carson et.al. [24] conducted chemical analysis of large turbogenerator by designing an ion chamber which was used to detect any gases formed as result of heated insulation. In order to detect the presence of various gases in transformer oil, dissolved gas analysis is mainly preferred [42].

Hongbo et.al [25] studied the impact of solid wear debris on the performance of transformer. It was found that the presence of these metal impurities in the transformer oil leads to change in magnetic field distribution and equivalent inductance of the coil. The technique of monitoring the wear debris is of non-contact type, i.e., it can be done in both off-line and on-line mode.

Tavner [23] presented three different methods of thermal analysis of electrical equipments: 1) Temperature measurement with help of sensors like resistance temperature detectors (RTD); 2) Measuring of temperature with the help of infra red thermal camera which also locates the hot spot inside and over the surface, if any; 3) Measuring temperature of the coolant fluid in bulk in systematic distributed patterns. Milic and Srechovic [26] presented a new non-contact measurement system for hotspot and bearing fault detection in railway traction system (RTS).

Boglietti et.al. [27] presented the two thermal models for electric equipment condition monitoring. These models were divided into: Finite Element Analysis (FEA) and Lumped Parameter (LP) thermal model. In order to model the thermal behaviour of equipment FEA was used. It was observed that the applications of FEA have been limited to small components like stator and rotor and find difficulty in simulations for motors with complicated geometry. The accuracy of model is generally dependent on the number of thermally homogenous bodies used in model [28, 29]. On contrary to this, lumped parameter gives best solution for different parts of the equipment and moreover much easy to solve. A better overall view of temperature variations in different parts of equipments along with less computing time was observed in lumped parameters [30]. Chowdhury [31] supported this view by claiming easy visualization of

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machine geometry parameters with the help of LP thermal circuit. Boglietti et al. [27] compared the LP and FEA for thermal modelling of electrical machines.

Babu and Das [33] presented the condition monitoring technique for boiler feed pump by using vibration spectrum analysis. A data recording system, namely, Data PAC 1500 was used and mounted on the four supports of bearing along horizontal (H), vertical (V), and axial (A) directions and recorded data in displacement and velocity modes. Vibration readings showed normal behaviour of the pump. However the spectrum analysis revealed presence of unbalanced mass in vanes. On the basis of phase analysis it was then corrected and vibration readings were again checked after it and found the values within control limits. Heng and Nor [32] used statistical analysis method to find faults in a roller bearing by using the sound pressure and vibration signals. It was reported that under ideal conditions, the statistical method can be used to identify the different types of defect present in the bearing.

Plapper and Weck [34] presented an approach for condition monitoring of components of mechanical NC machine by measuring the drive and controller signals. The main target was to detect backlash and pitting on guide ways. The findings reported that drive signals proved beneficial in terms of lesser cost for signal logging and availability of reliable signals from sensors employed. The information provided by the digital drive signals for detecting the said faults was found reasonable for the CBM of NC machine tool.

Ma and Yang [35] presented a methodology for detection of fault in actuators and sensors of manipulators by developing an adaptive observation systems based on mathematical model of manipulator. The residual signals were generated and the diagnosis system for fault detection was developed to detect the multiple faults at single interval of time. The need for assuming any assumptions on the system was not required to check the stability of overall fault detection system. The fault diagnosis and detection system was verified on an IMI robot manipulator. The results showed that the proposed fault detection system was efficient enough to detect faults of sensor and actuator simultaneously.

Jaber and Bicker [36] developed an intelligent fault monitoring diagnosis system to check the health condition of industrial gears for robot joints, such as gear tooth wear. In order to extract the relevant features of faults concept of discrete wavelet transform (DWT) was used. The time frequency signal analysis based on DWT helped in detection of various fault features present in the gear. These features were further classified with the help of artificial neural network (ANN). A PUMA 560 robot was used for vibration monitoring of gear and a software-hardware integration of National Instruments was used for recording the data (DAQ). The movement of gear joint was cyclic during the features were extracted. The algorithm and programming for whole monitoring system was done on Labview and Matlab. The various signatures recorded by DAQ were further decomposed into multi band frequency levels. For each level of frequencies obtained the standard deviation was calculated and was used to design and train the proposed ANN. Elanien [13] claimed that in order to detect the temperature variations in transformers ANN performed effectively.

Hameed and Shameer [37] presented the methodology for condition monitoring of turbine and generator. The reciprocating part produced various vibrations which in turn produces the acoustic noise signals. These signals were initially not detectable because they are dumped in the surrounding noisy environment and posed a major challenge to detect them earlier in order to prevent any breakdown in future. These signals of very small amplitude, during their initial stage were collected with the help of digital signal processing source separation technique and then they were compared with pre-recorded data to detect any variations in the system. The simulated results for the acoustic data collected were then presented with the help of Matlab.

Elhaj [38] presented condition monitoring approach for detecting the valve faults in reciprocating compressors by using instantaneous angular speed (IAS) and dynamic pressure techniques. For experimentation a leakage was introduced intentionally in the compressor in order for it to get it detected by IAS and dynamic pressure methods. The effect of leakage on the performance of compressor was monitored critically and its subsequent comparison with the normal one was done in order to detect any variations form the healthy performance. The variations in terms of fault signatures were noted for further fault diagnosis. For each of the technique truth table was made based on the signature related to valve opening and closing. These truth tables pointed out the situation in which each of the techniques can be used for fault detection. The two tables were then combined to form a single decision table to provide more reliable method for detecting the individual faults occurring in the compressor. The results revealed how the variation in pressure and valve opening and closing angle helped in detecting the various faults. The truth tables justified the use of IAS and dynamic pressure technique as a novel method of fault detection and diagnosis in compressor.

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Samhoury et.al. [39] introduced an intelligent condition monitoring system for the machines in the potash industry by using the applications of adaptive neuro-fuzzy inference system (ANFIS) and a neural network system (NN). The type of sensor used to collect the fault information was piezoelectric accelerometer. The vibration signals were collected by the sensor and relevant features related to the signal like RMS, variance, skewness, etc. were then fed as inputs to ANFIS and NN systems and these in turn gave the output value for a particular type of fault. The comparison between the outputs of two systems revealed that RMS and variance features gave accurate results in predicting the fault with minimum prediction error. ANNs also found applications in fault detection and diagnosis for rotating machines [40]. Another paper introduced the integration of ANNs with fuzzy logic for fault diagnosis. The applications for ANNs were studied in the medical and chemical fields [41].

III. SUMMARY OF REVIEWED PAPER

Prediction of faults well before the failure or breakdown of equipment proved beneficial for industries from any sort of capital loss. Condition based monitoring (CBM) is playing vital role in this direction by mainly focussing on reduction in unexpected breakdowns and maintenance costs and improves operator safety and life of equipment. Variety of CBM techniques are available world over which are mainly used according to the application of equipment and as per need of customer. The use of sensor-software integration proved beneficial for remote monitoring of the machine system. The temperature and vibration monitoring are most widely used CBM techniques among both mechanical and electrical equipments. The oil analysis is another one such technique which is widely and frequently used to check any changes in the chemistry of lubricants. In rotating machines, the key component is bearing for which vibration and temperature monitoring is done. The presence of gases inside the transformers is mainly due to the degradation of insulation thus the need of dissolved gas analysis is observed. The modelling of various findings of a CBM technique helps in providing the in-depth analysis and more quantitative data related to the health of equipment. The use of non contact type monitoring like thermo vision camera helps in monitoring the condition of equipment while in operation. The intelligent condition monitoring makes use of advance software techniques like FEM, DWT, ANN, LP, Matlab, Labview, etc. to mathematically model the system for fault diagnosis.

IV. CONCLUSION

This paper shows the effectiveness of CBM technique(s) in finding the various faults for mechanical and electrical equipments. The use of CBM in industry helps in predicting the health and detecting the faults for equipment at a much faster rate than the traditional approach and that too well in advance. This in turn helps in reduction of downtime and increases the availability of the equipment. Due to its various advantages, CBM is most widely used and acceptable technique of maintenance in industry.

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