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Condition Monitoring of Rotating Machines: A Review

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ABSTRACT

An uninterrupted health monitoring of machine is essential in various applications where failure of machine leads to loss of quality control, productivity and safety against catastrophic failure. Condition monitoring of machine involves continuous assessment on the performance of rotating components i.e. bearings, gears and motors and anticipating the faults before it cause any adversity. Rotating machines are commonly used in the industry for different applications such as railways, pumps, conveyors, blowers, elevator, mining industry, etc. Condition monitoring of rotating machines has been an important task for technicians, engineers, and researchers mainly to enhance structural reliability in a real time. This paper presents an enlarged survey on the expansion and the recent approaches in the condition monitoring of rotating machines. In current scenario, condition monitoring has proved their ability for fault detection of incipient faults in mechanical machines and equipments. Several techniques such as vibration monitoring, acoustic emission monitoring, invasive monitoring, oil monitoring are available for determining the health of rotating machines but all these monitoring methods needs expensive transducers and sensors.

Keywords: Condition monitoring, fault detection, wireless monitoring, motor current signature analysis

1. INTRODUCTION

Condition monitoring (CM) of a system has become an important to ensure the machine availability by timely maintenance procedures. Especially unanticipated faults of rotating elements can lead to expensive machine downtime due to restricted machine availability [1], therefore it is required to monitor the health of the machine in order to reduce breakdown maintenance and thus operating costs. Typically, the traditional CM schemes need to acquire and analyze the large amount of information about the system to be monitored. However, this scheme is very cumbersome and approachability to this data is challenging and often does not exist. Modeling of a system physically, with high accuracy due to its intricate interaction among numerous dynamical subsystems, for monitoring its health and anticipate failures can intermittently be constructed [2-4].

A conventional maintenance technique in the industry has taken two types, based on fixed time interval maintenance and failure of plant as and when it happens. However, to improving the CM of system using today's technology, the selection of sensors are of core importance for providing better data acquisition system. The key elements of this new technique is condition based CM, which depends upon the parameter of the induction motor in industry [5-6]. The CM is used to enhance the performance of the rotating machines, increasing machine life, reducing internal and external damages [7].

Condition monitoring of rotating machines has become necessary to stop the unexpected machine shutdown. Several techniques are used for CM of rotating machines such as vibration signature analysis, acoustic emission monitoring, motor current signature analysis (MCSA), but these monitoring techniques are complex and require expensive sensors [8-10]. An effective and efficient CM scheme is capable to give an early warning or predictive fault information at early stages. The CM collects primitive data information about the machine using signal processing or data analysis techniques. The major problem of this type of approach requires human interpretation [11].

The automation of the CM is the process is a logical progression of the parameter based monitoring technologies [12]. The automate fault detection and diagnostic process require an intelligent system such as fuzzy logic, genetic algorithm, artificial neural network and expert system [13]. In present days, it has become necessary to monitor the machine parameters and detection of predictive failures at their inception, otherwise it may lead to unexpected machine downtime which cause big financial loss [14]. The various CM indicators for fault diagnosis of dynamic machines has been discussed [15].

2. CONDITION MONITORING TECHNIQUES

In CM, complexity and cost of a monitoring system surge with number of times the data acquire, so panoptic monitoring is mainly confined to the conditions where the consequences of the quality, poor availability or yield are so severe that they noticeably validate the investment in CM. Han et al conducted a survey and reported the state-of-the-art development in the CM and fault diagnosis [16]. Survey points out the most important benefits using intelligence and advanced signal processing techniques in development of CM schemes. Induction motor is most important prime mover in industrial application due to their high efficiency, low cost, ruggedness, high reliability. Induction machine fault detection of the

induction motor based on thermal images is reported in [17]. In operating conditions, induction motor faces some limitations, however if operating parameters are exceeded then some mechanical or electrical failure will be occur in the induction motor which results in shut down, even, face a large economic loss as shown in Fig. 1. Hence, it is most important to monitor the cause of failure of induction motor [18]. Therefore, various monitoring techniques for induction motor have been developed to diagnose faults. In this section, various CM techniques for rotating machines have been discussed [19-21]. Several organizations and research institutes have already matured smart CM for the entire fleet of machines for industrial applications.

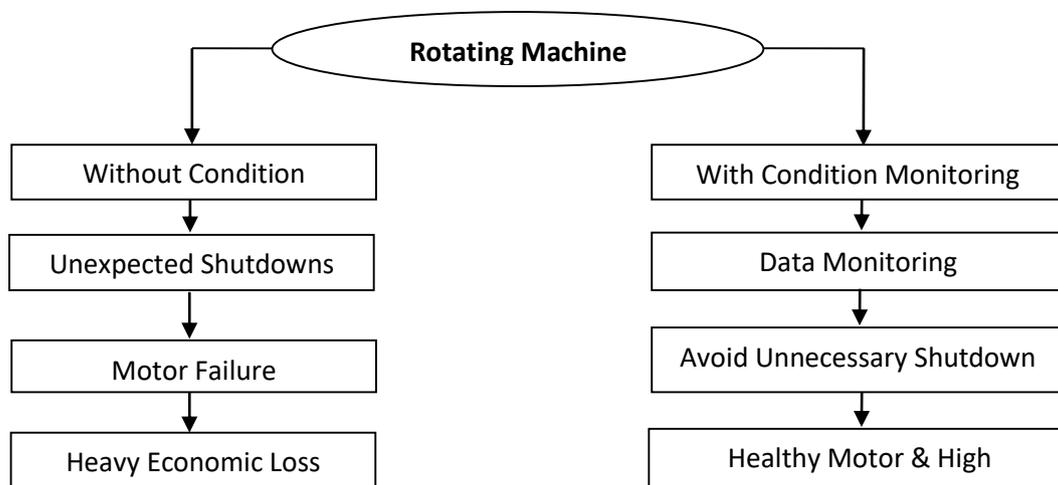


Figure 1. Need of Condition Monitoring

2. 1. Vibration monitoring

Acquisition and subsequent processing of vibration data for rotating machinery fault diagnosis can be quite intricate; as data are usually required in three mutually perpendicular directions for accurate fault diagnosis. Several vibration monitoring approaches and data processing techniques for condition monitoring have been explored [22-25]. In healthy conditions, induction motor produces a little vibration signal. Health monitoring of induction motor using vibration signatures has been presented [26]. Shnibha et al. presented a more reliable method for CM using vibration signatures. When a fault occurs in internal part of induction motor it generates large vibration signals [27]. Vibration signals can be detected in the term of velocity or acceleration or displacement in relative or absolute value. The survey story of fault detection in IM has been presented with different bearing faults using vibration and acoustic signals. Vibration of either the motor stator core or end caps can be easily monitored by an accelerometer which is usually directly mounted on the motor. Analysing the measured signal using traditional signal processing techniques viz. Fast Fourier Transform (FFT) does not always achieve adequate results. In Fourier transforms of a signal, it is impossible to tell when a particular event took place. An effort has been made to determine when and at what frequencies a signal event occurred [28].

2. 2. Noise monitoring

Noise monitoring works with ultrasonic and audible frequencies monitoring techniques. The method can be implemented for bearing and rotor related defects. Bearing faults, gear faults and motor faults can be detected using acoustic sensors. When working with ultrasonic wave, it has ability to monitor the stator related faults [29]. However, in all CM techniques, various actuators and sensors are used to gather vibration data from the machine. Van Hecke et al. presented a fault diagnostics of low speed bearing with a new acoustic emission based techniques that allows noise signals to be the acquired sampled at a rate comparable to vibration based CM [30]. From the literature, it has been observed that the acoustic emission based monitoring techniques is less efficient with compare to other CM techniques [31].

2. 3. Air gap torque monitoring

In Induction motor, the production of air gap torque depends on the current and flux linkages. The air-gap torque can be measured, while the induction motor in running condition. It is laborious to measure the air-gap torque directly [32]. Kumar et al. presented a Finite Element Analysis (FEA) in the estimation of air- gap torque observation of the induction motor under standard supply systems at different frequencies [33]. The analysis of air gap torque can be done, if differentiated the faults of unbalance stator winding and rotor bar. This can be economically attractive to industrial application, where an unwanted shut down, even facing a heavy economic loss in production of plant.

2. 4. Motor current signature analysis (MCSA)

MCSA technique works by acquiring current and voltage signals from the induction motor. As a complement for MCSA, a thermal imaging technique has been used for fault detection of induction motor [34]. The signal processing techniques have been applied to the acquired current signals to produce their power spectrum profile [35]. Park et al. presented the influence of blade pass frequency (BPF) vibration in induction motor on MCSA-based RF detection [36]. The power spectrum profiles are useful in the detection of different kind of faults in the induction motor. Such current and voltage signals are measured through current and voltage sensors followed by utilizing the advance tools such as artificial neural network, fuzzy logic, digital signal processing tools, etc. MCSA technique is highly versatile for CM of the induction motors. It can easily detect these faults at an early stage and provide predictive information about the machine failure [37].

2. 5. Temperature monitoring

The condition monitoring is to check the variables with regard to tolerances, and alarms, after an alarm is triggered the operator then has to take the appropriate actions. One of the most important advantages of the temperature monitoring, it need less instrumentations [38]. The temperature monitoring technique is widely in use in electrical and mechanical maintenance, agriculture, military, navy, aviation, geological survey, automotive, fault detection and it is also used in industry to detect serious faults in equipment, quality control and process control [39]. The temperature monitoring technique is also used in civil structures, water leakage, corrosion damages and welding processes, electrical installations, machineries and equipment, aerospace, food, paper mills, nuclear plant and plastic industries. A new technique of temperature

monitoring technique as a non-invasive and non-contact CM & fault detection tool for Induction motor has been successfully implemented [40].

2. 6. Speed fluctuations monitoring

The speed fluctuations monitoring is a technique that can detect failure or defects using speed fluctuations in the operational period of the rotating machines. This technique can be utilized for detecting the rotor faults in induction motor [41]. Traditionally used techniques are air-gap eccentricity, vibrations, rotor asymmetry, misalignment and damaged bearings. In normal rotor bar, current fluctuates sinusoidally with the slip frequency, provide a contribution to developing the torque that will vary sinusoidally with twice the slip frequency [42]. A defected rotor bar will not contribute to the shaft torque. For the rotor, the resulting torque can be divided into two components in which one is constant and other is which varies with twice slip frequency. Mostly, the induction motor has variable load torque, the used instruments are capable of distinguishing between load fluctuations and fluctuations of twice slip frequency indicating rotor faults in induction motor [43].

2. 7. Induced voltage

The important reasons behind the failures of rotating machines are manufacturing tolerance, their origin in design, assembly, and schedule of maintenance working environment, installation, and nature of the load on rotating machine. Induction motor, similar as other electrical rotating machines are subjected to both mechanical and electromagnetic forces [44]. So, the design and development of the induction motor is such that the interaction between these forces under equilibrium leads to silent operation wherever in case of fault, the equilibrium is lost hence leads to further enhancement of the fault [45]. The voltage induced along the healthy condition leads to minimum noise and vibrations with a stable operation of the induction motor. When any failure or fault occurs in induction motor, the rotating shaft of the motor provides an indication to the winding or stator core [46]. The induced rotor voltage has not yet proved to be a most useful parameter for CM due to its complexity and non-reliability.

2. 8. Magnetic flux monitoring

In induction motors, the magnetic flux in the air-gap during healthy conditions varies sinusoidally with space or time. Related problems to rotor and stator faults cause deviations from the sinusoidal variations [47]. The rotor faults can be easily identified using a search coil fixed to its stator part. The changes in the air-gap flux density caused by the stator or rotor will produce an axial flux that can be easily detected by a measuring coil around the rotating shaft or other sensors [48]. Failures are directly revealed to the analysis of the frequency spectrum of the machine or motor signal that can be acquired by the different acquisition techniques. The monitoring of the axial leakage fluxes is possible to detect the various asymmetries and abnormalities such as stator inter-tum failure, broken rotor bars, bearing related problems, eccentricity faults, misalignment and so on [49].

2. 9. Oil monitoring technique

The key to the health of the ship and its machinery lies to the effective CM, which ultimately will help to increase reliability and reduce cost of ownership. As part of such routine programmes, the monitoring of the lubricant vessels will assist operators and maintenance workers in making timely decisions relating to the servicing of equipment, maximizing the lifespan of rotating parts of the machinery. The oil monitoring technique is not widely used techniques for motors. But in useful manner, the circulatory lubricant system it may be a valuable tool. Some machines include a unit of the industrial motors and a pump immersed in the pumped medium [50-51].

The power supply to these units is provided through an umbilical system which provides wires for electric supply and control, and oil that provides lubrication, cooling and insulation. In such type of industrial systems oil monitoring is a tool in point, that analysis and examine the oil particles of metal and fibres. Most of the causes of these particles may be bearing wear and tear, friction of streaming oil, partial discharges and they can originate from chemical impurities like oxides or water.

The detection of these particles or impurities is realized in following ways:

- A magnetic plug attracts ferromagnetic particles in lubricating and hydraulic oils.
- Mobile field equipment to collecting the particles from filters for later analysis.
- Spectrometry for analysing what elements the particles contain.
- Particle counting and analysing to reveal particle size and concentration.
- Ferrography deposits the ferromagnetic particles by magnetism.

Table 1. Comparison of Different CM Techniques.

Techniques	Insulation	Stator Windin	Rotor winding	Eccentricity	Bearing Damage
Vibration	-	-	✓	✓	✓
Noise Monitoring	-	-	✓	✓	✓
Air-Gap Monitoring	-	-	-	✓	✓
MCSA	-	✓	✓	✓	✓
Temperature Monitoring	✓	✓	✓	✓	✓
Speed Fluctuations Monitoring	-	✓	✓	✓	✓
Induced Voltage	✓	✓	✓	✓	✓
Magnetic Flux Monitoring	-	✓	✓	✓	-
Oil- Monitoring Techniques	-	-	-	✓	✓

3. CONCLUSIONS

CM of rotating machines has evolved with the advent of sensing data analytics platforms, machine diagnostic methods, and information management. The developments of the monitoring technologies enhance to obtain the automation monitoring systems for the overall deployment of the industrial plant. In this paper, the state-of-the-art-review on condition monitoring of rotating machines has been reviewed which is useful for orienting new research in the field of condition based monitoring of induction motor and other electrical rotating machines.

MCSA, the most popular technique, provides sensor less diagnosis of some motor problems but it's not so effective for the industrial applications where the load will constantly change on rotating machine. Time-frequency analysis has been investigated vastly in recent years but its heavy hardware requirements and high complexity are limitations for the low-cost monitoring systems.

Motor power analysis because of need to both currents and voltages simultaneously and dependence on the drive inertia has some limitation. Most of recurring problems in rotating machinery like misalignments can be identified by vibration analysis. The measured vibration and associated current harmonics are closely correlated. By detection ozone, carbon monoxide and others in the coolant oil monitoring technique, some faults like insulation degradation can be detected easily. Also, temperature monitoring is introduced as efficient tools for condition monitoring of motors.

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