ENHANCEMENT OF ELECTRIC MOTOR RELIABILITY THROUGH CONDITION MONITORING

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Abstract: Diagnostic service offerings, such as condition monitoring (CM) of electric motors, for industrial customers are a potential market for electric utilities. This paper reviews the mechanisms of major motor component failures along with the existing techniques for detecting these defects. Whereas other researchers have focused on singular methods for fault diagnosis, we seek to develop an integrated CM system for induction motors. Our approach combines the diverse information from motor magnetic fields, vibration signals, and acoustic emissions into a more robust and comprehensive CM approach. Such a multi-faceted methodology using diverse measurement signals will allow inter comparisons of diagnostic information.

Keywords: condition monitoring, failure detection, electric motors, motor bearing failure, predictive maintenance, online equipment health monitoring.

1. INTRODUCTION

In the competitive, deregulated environment, electric utilities are continuing to expand their product line by offering value-added services to customers. For example, utilities are providing power quality monitoring for commercial customers and telecommunication services for residential consumers (Newbury, 1996). One potential market is diagnostic services for industrial customers. Such diagnostics could include condition monitoring (CM) of electrical equipment such as motors.

A CM program can reduce both costs and equipment downtime, primarily by eliminating unnecessary maintenance and refurbishment actions. CM can also provide a technical basis for extending a motor's qualified life, an advantage that can provide very significant cost savings. Finally, CM can allow the utility to selectively focus attention on motors that, for reasons of loading conditions, operating patterns (i.e., on/off cycles, run time), or environmental considerations, are more susceptible to degradation.

Scientific literature is ripe with instances in which CM has been applied to equipment within power plants and systems (McGrail, 1998) and other significant infrastructures (e.g., bridges). For example, Birlasekaran *et al.* (1998) review examples of condition monitoring applied to transformers, power cables, switchgear, bushings and insulators.

Over the past 10 years, sophisticated online monitors, which are sensitive to many motor problems that can occur, have been developed. In particular, these methods include (Stone and Kapler, 1997):

- vibration monitoring to detect bearing problems,
- stator current harmonic analysis to detect induction rotor problems, and
- flux probes to detect synchronous rotor problems.

These techniques have been applied to find various problems before catastrophic failure occurs, thereby enabling repairs to be made, often at a fraction of the cost that would be incurred if failure did happen. In one case, electric power plant operators reported avoided costs of $1.2 million over three years for ~30 motors using predictive maintenance techniques (EPRI, 1999a); in another plant, a cost savings of $182,000 was realized with four electric motors (EPRI, 1999b).

2. TYPES OF ELETRIC MOTOR FAULTS AND THEIR DETECTION TECHNIQUES

The major faults of electrical machines can be broadly classified as (Nandi and Toliyat, 1999):

- stator faults resulting in the opening or shorting of one or more of the stator phase windings;
- abnormal connection of the stator windings;
- broken rotor bar or cracked rotor end-rings;
- static and/or dynamic air-gap irregularities;
- bent shaft (akin to dynamic eccentricity) which can result in rubbing between the rotor and stator, causing serious damage to the stator core and windings;
- shorted rotor field winding; and
- bearing and gearbox failures.

Industry reliability surveys suggest that ac motor failures may be divided into five categories, including (IEEE, 1997):

- bearing: 44%;
- stator winding: 26%;
- rotor: 3%;
- shaft: 5%; and
- others: 22%.

Because bearing, stator, and rotor failure account for over 70% of all motor failures, much work has been done to identify ways to reduce operational conditions that may cause failure of these components. For instance, motor bearing failures would be significantly diminished if the driven equipment was properly aligned when installed and remained aligned regardless of changes in operating conditions. A motor coupled to a misaligned pump load, or a load with rotational unbalance, will likely fail prematurely due to stresses imparted upon the bearings.

Based upon the above information, bearing, stator turn, and rotor bar failures are the most prevalent ones and thus demand special attention. These faults and their diagnosis are briefly discussed below. Subsequently, Table 1 provides a comprehensive comparison of the induction motor failure types and the existing techniques for their detection.

2.1 Bearing faults.

The majority of the electrical machines use ball or rolling element bearings. The main components of rolling bearings are the inner ring, the outer ring, and the rolling elements (see Fig. 1). Typically, the inner ring of the bearing is mounted on a rotating shaft, and the outer ring is mounted to a stationary housing. The rolling elements may be balls or rollers. The balls in a ball bearing transfer the load over a very small surface (ideally, point contact) on the raceways.

Radial ball bearings are simple in design, suitable for high and even very high speeds, and robust in operation and require little maintenance. Angular-contact ball bearings have an angle between the inner and outer rings, as shown in Fig. 1, which enables them to support both radial and axial loads.

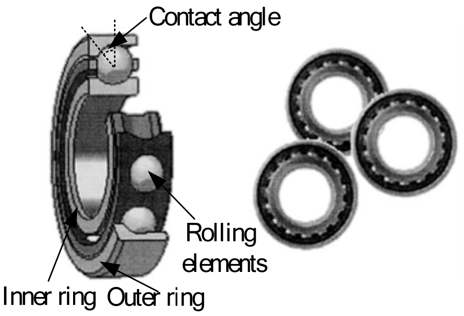

Fig. 1 Angular contact ball bearings (McInerny and Dai, 2003).

There are a number of mechanisms that can lead to bearing failure, including mechanical damage, crack damage, wear damage, lubricant deficiency, and corrosion. Abusive handling can induce nicks and dents, which are especially harmful when located in areas tracked by the rolling elements. Even under normal operating conditions with balanced load and good alignment, fatigue failures may take place. These faults may lead to increased vibration and noise levels. Flaking or spalling of bearings might occur when fatigue causes small pieces to break loose from the bearing.

Though almost 40%-50% of all motor failures are bearing related, very little has been reported in literature regarding bearing related fault detection. Bearing faults might manifest themselves as rotor asymmetry faults (Kliman and Stein, 1990), which are usually covered under the category of eccentricity related faults. Otherwise, the ball bearing related defects can be categorized as (Devaney and Eren, 2004) outer bearing race, inner bearing race, ball, and train defects. The vibration frequencies to detect these faults are given by analytical expressions.

Although bearing faults account for nearly half of all induction motor failures, Kliman *et al.* (1997) noted that a review of scientific literature reveals dozens of papers addressing rotor bars but only a few papers employing motor current signature analysis to detect bearing faults.

Motor bearing damage detection using a stator current signal is a useful application area (Schoen *et al.*, 1995; Yazici and Kliman, 1999; Lindh *et al.*, 2002). In stator current monitoring, the condition is often scrutinized at pre-calculated characteristic frequencies at which faults are likely to cause changes. However, such information is not necessarily available or easily discovered and, thus, a generic method which can determine the significant frequencies of interest would be of considerable value.

Ilonen *et al.* (2005) have proposed a method and a general diagnosis tool. The method can discriminate between two classes of signals using statistical discrimination measures for time-frequency features, *i.e.*, Gabor filter responses. The method utilizes