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Misalignment detection in induction motors with flexible coupling by means of estimated torque analysis and MCSA

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A B S T R A C T

In recent years, progress has been made in developing techniques to detect mechanical faults in actuators driven by induction motors. The latest developments show their capability to detect faults from the analysis of the motor electrical variables. The techniques are based on the analysis of the Motor Current Signature Analysis (MCSA) and the Load Torque Signature Analysis (LTSA), among others. Thus, failures such as misalignment between the motor and load, progressive gear teeth wear, and mass imbalances have been successfully detected. In case of misalignment between the motor and load, both angular and radial misalignment, the results presented in literature do not consider the characteristics of the coupling device. In this work, it is studied a mechanism in which the power transmission between the motor and load is performed by means of different types of couplings, mainly those most frequently used in industry. Results show that the conclusions drawn for a particular coupling are not necessarily applicable to others. Finally, this paper presents data of interest for the development of algorithms or expert systems for fault detection and diagnosis.

1. Introduction

Induction motors have become an almost exclusive alternative for developing mechanical power for industrial applications. Given their importance, a major effort has been made in recent decades to develop fault detection techniques. The non-invasive techniques based on monitoring the electrical variables (stator voltage and currents) present the main advantage of their on-line implementation [1–3]. Thus, several techniques have been developed to diagnose stator short circuits, rotor broken bars or end rings, and air gap eccentricity, among others [4].

One possibility to detect and diagnose faults in induction motors consists in analyzing the stator current spectrum (MCSA: Motor current signature analysis) [5,6]. This technique allows the motor diagnosis from sensing the stator currents and therefore its application is fast and economical. A variation of this technique, known as Park's Vector Approach [7], consists in tracking the Vector de Park module. The most important advantages of these techniques are that they are non-invasive and their implementation does not require expensive sensors and data acquisition processes (measurement systems). Load Torque Signature Analysis (LTSA) is an alternative to MCSA [8]. Though this technique requires not only sensing the stator currents but also the applied voltages, the frequency components are more likely to be associated with a

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particular fault, which in some cases can be more clearly identified than when using the MCSA.

Progress in the implementation of non-invasive techniques has made it possible to extend the diagnosis of faults to the kinematic chain between the motor and load, even to the load. In [9–11], different techniques for fault detection in gear box driven by induction motors are proposed. In such cases, it is possible to detect gear-teeth wear or breakage from the analysis of the frequency spectrum of the stator currents or the estimated electric torque.

Regarding the driven load, literature presents background on the detection of anomalies from the analysis of electrical variables. For instance, the detection of anomalies in the table of a coal mill is presented in [11]; in [13], the detection of anomalies in an air compressor from the motor variables are shown, and, the detection of cavitation in hydraulic systems with identical strategy is studied in [14].

A study based on the tracking of the stator current and of the active power consumed by the motor to detect misalignment between the motor axes and load is presented in [15]. This paper presents a model that determines the frequencies associated with fault and through experimental tests the feasibility of the proposed method is demonstrated. These tests however are limited to elastic couplings (Rubber Tire-type Couplings) and misalignment on the coupling system may be of great consideration. Results show for example angular misalignment of about 1 to 3 degrees. Though these misalignment angles are within admissible values for elastic couplings, it is important to highlight the capability of the technique for detecting minor misalignments, as they can raise the level of vibration to dangerous levels. A comparison between the MCSA and the vibration analysis can be observed in [16]. This comparison demonstrates that the ability to detect misalignment of MCSA and traditional techniques based on vibration analysis is similar. In addition, [17] also proposes an algorithm able to diagnose faults due to misalignment and mass imbalance for different load conditions. This algorithm compares the fault frequencies of the stator currents with a predetermined admissible value. However, this comparison does not provide criteria to determine failure thresholds. It does not establish differences between different types of couplings either.

This work focuses on misalignment detection. Unlike other works related to the subject, it includes the coupling parameters as variables. In fact, given that there are different choices for power transmission, their comparison is carried out to show the proposed detection technique effectiveness for the most common couplings. Then, it becomes important to establish the criteria to relate the most commonly used fault indicators and angular and radial misalignments.

The theoretical bases that allow to deduce how misalignment events occur on the electric motor torque and the stator current are also presented. Then, experimental results are presented for different types of couplings, and finally conclusions are drawn.

2. Misaligned drives model

It is important to distinguish two types of potential misalignment: angular misalignment and radial misalignment. *Angular misalignment* occurs when there is an angular deviation between the motor shaft and load. This situation is illustrated in Fig. 1a. The degree of misalignment is represented by angle α between the two shafts. When the shafts are perfectly parallel to each other, but not on the same line, *radial misalignment* occurs. This situation can be observed in Fig. 1b. Radial misalignment is more severe as the distance between the two axes of rotation becomes greater. Such distance is indicated as d in Fig. 1b and it will be taken as a reference value to indicate degrees of radial misalignment in experimental tests.

Misalignment situations are very common in industrial applications. They usually arise during the assembly process and can be associated to the motor fasteners, the gearbox or other drive components. They can be also due to the preloads produced in pipes or any other components associated with the load. Misalignment can not only occur as the two types described in Fig. 1 but also as a combination of them.

Mostly elastic couplings are used in these applications. These couplings allow dampening sudden load torque disturbances, avoiding knocks on the wheels of the gearboxes, and reducing vibrations during load transmission. All elastic couplings are able to bear small levels of misalignment. The main purpose of the flexible couplings is to allow misalignment due to the assembly of connected rotors and due to the changes of temperature and operation. In addition, the flexible couplings separate mechanically the rotors so that the rotodynamic design of individual rotors can be carried out separately. However, misalignments of any degree reduce couplings lifetime, increase losses [15], and generate mechanical vibrations and bending stress on axes, which may affect the bearing system severely.

Fig. 2 shows the four different elastic couplings evaluated in this work, mostly used in industrial applications [18]. Jaw Couplings (Fig. 2a) are an inexpensive and easy to mount option for standard power applications. They are able to dampen moderate-impact low-vibration loads. Couplings of this type are not torsionally rigid and can bear some degree of radial and angular misalignment as well as axial movement on the shaft. Gear Couplings (Fig. 2b), on the other hand, show torque high density and are torsionally rigid. They can be either flexible or flexible-rigid couplings. Flexible couplings are able to bear radial and angular misalignment. Metal Ribbon Couplings (Fig. 2c) allow torsion as well as angular and radial misalignment. They require lubrication and have certain limitations of temperature and speed. Finally, Rubber-type Couplings, (Fig. 2d), are able to bear some degree of misalignment at all levels without imposing excessing loads on the bearing system. Their damping properties allow reducing torsion vibrations and oscillations.

As it is shown in [14], misalignment modifies the motor torque according to the following equation: