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Classification of unbalance and misalignment in induction motors using orbital analysis and associative memories

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ABSTRACT

Fault detection in induction motors is an important task in industry when production greatly depends of the functioning of the machine. This paper presents a new computational model for detecting misalignment and unbalance problems in electrical induction motors. Through orbital analysis and signal vibrations, unbalance and misalignment motor faults can be mapped into patterns, which are processed by a classifier: the Steinbuch Lernmatrix. This associative memory has been widely used as classifier in the pattern recognition field. A modification of the Lernmatrix is proposed in order to process real valued data and improve the efficiency and performance of the classifier. Experimental patterns obtained from induction motors in real situations and with a certain level of unbalance or misalignment were processed by the proposed model. Classification results obtained in an experimental phase indicate a good performance of the associative memory, providing an alternative way for recognizing induction motor faults.

1. Introduction

Nowadays, induction motors are used widely in industry, where exposure to hard environments and conditions affects the optimal functioning, making them more vulnerable to electrical or mechanical faults. Those faults should be detected early in order to avoid degradation or failures on critical electro-mechanical engine parts. Most electric motor failures interrupt processes, reduce production and may damage other related machinery. In some factories, a very expensive scheduled maintenance is performed in order to prevent sudden motor failures. Normal operation of motors is extremely significant due to it ensuring precision equipment and manufacture process safety [35,37]. An appropriated supervision and monitoring for motor faults can be helpful for detecting bad performance in its operation. In this sense, several analyses have been studied by using some characteristic behaviors produced by the induction motor; e.g. acoustic analysis [17], electrical problems [57], orbital electro-magnetic analysis [19] or motor vibrations [24].

In literature, several models for analyzing electro-mechanical faults have been helpful in the decision making of expert criteria. Those works have been implemented using different mathematical theories such as spectral analyses, wavelet analysis, time warping, time frequency analysis, Wigner–Ville distribution, stator current analysis, etc. [10,28,29,35,38,58,59]. Those models allow determining useful characteristics for preventing and detecting possible failures in induction motors. Other models based in artificial intelligence have been proposed in order to complement this area, providing a strong base for developing more complemented systems in this field; e.g. artificial neural networks [14,16,34,51,7], Bayesian networks [33], support vector machine [4], fuzzy logic [15,61], entropy and optimization methods [53] among others. Moreover, analyses of incipient motor faults can be made using electrical signals that include features that are useful for identifying certain motor faults. Those features can be studied and explored using the pattern recognition theory, which has proved extremely useful for motor fault identification. Lately, several works using pattern processing have been proposed. In those models, incipient motor fault signals must be correctly preprocessed and transformed into patterns in order to correctly identify different motor fault states ([21,43,48,62]). On the other hand, using associative memories is considered, because they have demonstrated to be very efficient algorithms for pattern classification, providing good performance and efficiency. In literature, several types of associative memories have been developed, trying to increase their

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classification capabilities or their implementation z [1,2,22,27,30,31,40,45,46,49,52,56]. The first associative memories was created by karl [49], where his Lernmatrix is a crucial precedent in the development of current associative memory models and is one of the first successful attempts to encode information in an arrangement, known as crossbar grids. In general, a particular drawback in associative memories is that data information is based on processing binary patterns; it means, real values ($\Re$) must be binarized, which implies information loss or large vector sizes in order to save as much information as possible. In order to resolve this gap, actual improvements consider the use of real data information trying to avoid this problem using new or classical models as those proposed by Esmi et al. [13], Salavati et al. [47] and Zheng [60]. The Lernmatrix has been a widely studied architecture and its recognition capabilities can be increased if a new algorithm for storing and recovering real valued patterns is adapted as a new extension. In this way, associative memories have considerable importance in pattern recognition applications, and their characteristics provide a good solution for incipient motor faults in pattern classification. Therefore, this work proposes a different way for induction motor fault pattern recognition. The importance of using orbital analyses is that no spectral analyses are needed in the developing of this research, avoiding the developing of too complex models as those proposed by the literature. In this sense, we have hypothesized that unbalance and misalignment motor faults can be modeled using orbits, where amplitude vibrations measured, surely will define a characteristic orbit shape; this behavior is used for recognizing the motor fault using the Lernmatrix. Hence, the core of this work is based on two contributions: (a) the feature extraction of vibration signals for building orbital patterns and (b) the modification of a binary classifier (Lernmatrix) for real-value data processing.

The rest of the paper is organized as follows: Section 2 presents some concepts about incipient faults in induction motors and the main characteristics of each one. In Section 3, orbital vibration pattern analysis is developed, remaking the behaviors of the orbital signal when a motor fault is present. Also, pattern construction methodology is described in this section using the digitalized electrical signals. In Section 4, the Lernmatrix associative memory is used for pattern classification, explaining the architecture of the Lernmatrix core and the proposed modification. In Section 5, experimental patterns of motor faults obtained from real situations are used for testing the proposed model. Finally, Section 6 discusses the results obtained and gives some conclusions and future research directions.

2. Induction motor faults measurement

2.1. Definitions

Motor vibrations can cause motor wearing, fissuring by fatigue, loss of effectiveness, breakage of seals, noise, etc. Vibrations are good indicators about mechanical motor conditions and they can be a suitable way for diagnosing fault evolutions. According to this, catastrophic motor failures can be predicted if behavior changes of motor vibrations are studied and interpreted.

Failures in motors may occur frequently in three main components: rotor, stator and bearings [3,36,41,6,7,50,55]. Faults in electric machines can be classified in mechanical or electrical faults. This work is mainly interested in studying three types of motor fault due to being the most commonly presented faults: rotor unbalance, shaft misalignment and extremely shaft misalignment. These motor faults are described as follows:

1. *Rotor unbalance* can be defined as the unequal mass distribution on the motor rotation center and this is the most common problem in induction motors (Fig. 1a). In this case, the main harmonic presents amplitudes higher than normal [3].
2. *Shaft misalignment* is the most common cause of machine vibration after imbalance, which leads additional dynamic load and accelerate machine deterioration (Fig. 1b). This type of vibration is often from reactive forces in the couplings between two rotating shafts. Generally, a misalignment presents the fundamental harmonic at 2x rpm.
3. *Extremely shaft misalignment* occurs when slight shaft misalignments are not corrected and the evolution increases. In an extreme misalignment the range can vary from 4x to 8x rpm [18,26,32].

2.2. Signal acquisition

Vibration is a common symptom derived from mechanical faults in induction motors. Such vibrations can be measured using a piezo-electric accelerometer sensor, which generates an electrical signal that is proportional to the acceleration vibration of a seismic mass [20]. As each motor has a different rotation speed, standards such as ISO 10816 [25] and VDI 2056 [54] have established sampling frequency rates for motor measuring. According to them, this work used a sampling frequency of 50 kHz, being large enough to obtain a good quality signal and avoid aliasing over tested induction motors. In this work, induction motors with ½ to 1 HP and from 1000 to 2000 rpm were used for measuring vibration signals.

Signal vibrations produced by an accelerometer depend of its orientation. In order to measure orbital patterns, two piezo-electric accelerometers were placed in the motor chassis near each axis (x, y). A rotor orbital vibration can be measured if the accelerometers are placed orthogonally (Fig. 2).

Once the accelerometers were placed correctly, the vibration signals were obtained. Those signals are contaminated with other undesirable signals (Fig.3) and must be removed in order to extract the orbit to be used; the following section explains this important process.

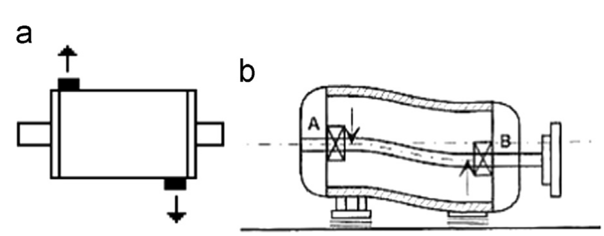

Fig. 1. Different Motor fault illustrations: (a) rotor unbalance and (b) shaft misalignment.

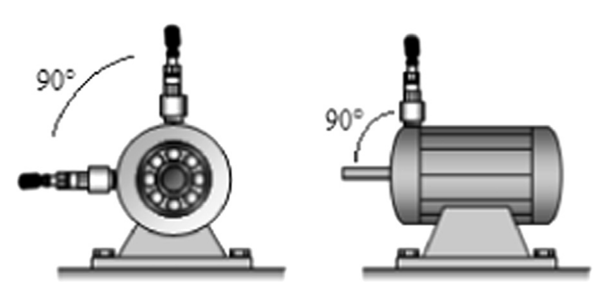

Fig. 2. Accelerometers placement at 90° over the chassis and between sensors.