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Acoustic based fault diagnosis of three-phase induction motor

Adam Glowacz

AGH University of Science and Technology, Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering, Department of Automatic Control and Robotics, Al. A. Mickiewicza 30, 30-059 Kraków, Poland

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ABSTRACT

The article describes acoustic based fault diagnosis techniques of a three-phase induction motor. Four real states of the three-phase induction motor were analysed: healthy three-phase induction motor, three-phase induction motor with broken rotor bar, three-phase induction motor with 2 broken rotor bars, three-phase induction motor with faulty ring of squirrel-cage. Two feature extraction methods of acoustic signals of the induction motor - SMOFS-32-MULTIEXPANDED-2-GROUPS (Shortened Method of Frequencies Selection Multiexpanded 2 Groups) and SMOFS-32-MULTIEXPANDED-1-GROUP were described. The Nearest Neighbour classifier, backpropagation neural network and modified classifier based on words coding were used for recognition of acoustic signals. Results of recognition were very good for the real data and developed fault diagnosis techniques based on acoustic signals. The described fault diagnosis approach can find applications in the industry.

1. Introduction

Electrical motors play an important role in industry and home appliances. They are used in many industrial plants such as: refineries, mines, factories, and ironworks. High reliability and cost reductions are essential for mentioned industrial plants. Each year the number of electrical motors is increased. Induction motor is a widely used electrical motor. Induction motors are inexpensive and have high reliability. They are also easy to maintain. Any electrical motor failure causes loss of production. It may also cause permanent failure of electrical motor. Operators of electrical motor can prevent unexpected failure if they use early fault diagnosis system [1]. It is a reason to develop such fault diagnosis system.

Diagnosis of electrical motors is discussed in many scientific articles [2,3]. Mechanical faults (mechanical unbalance, bearing failures, shaft misalignment, air-gap deformation) and electrical faults (rotor and stator faults) of induction motors were analysed [4–8]. Vibration, electrical and thermal analyses were used for fault diagnosis of electrical machines [9–19]. Acoustic signals were also analysed [20–28]. Techniques based on thermal and acoustic signals are called non-invasive fault diagnosis techniques (we do not need to connect anything).

Techniques based on electrical signals are usually invasive fault diagnosis techniques. Each of technique has advantages and disadvantages. Advantages of analysis of vibration signals are: low cost and instant measurement of vibrations [29–39]. Vibration signals can be used for mechanical and electrical faults of the motor. The problem for vibration analysis is set of accelerometer/data logger. It is required to put the device in the same way. Moreover the location of the fault cannot be exactly determined.

In the literature thermal imaging was used for fault diagnosis of induction motors [40–42]. Advantages of analysis of thermal images are: non-invasive measurement and proper detection of the location of the fault. However this technique has some disadvantages: high cost as well as time to heat up motor, slower processing of the data (images). It is also required to put the thermal camera in the same way and use proper methods of image processing [40–43].

In the literature fault diagnosis techniques based on the analysis of electric currents were described [2–6]. Advantages of analysis of electrical current are: low cost, high recognition efficiency, signal is not mixed. However this technique has some disadvantages: invasive technique, limited faulty states - electrical faults.

Descriptions of acoustic based fault diagnosis techniques are also available in the literature [44–50]. Advantages of acoustic based fault diagnosis are: non-invasive technique, low cost and instant measurement of acoustic signals. Acoustic signals can be used for mechanical and electrical faults of the motor. The problem for acoustic analysis is set of microphone. It is required to put the device in the same way. Moreover the location of the fault cannot be exactly determined (similar to vibration signals). Acoustic signals are mixed by other signals (reflected waves). They are mixed more than vibration and electrical current signals.

In this paper acoustic based fault diagnosis technique of a three-phase induction motor was described. Four states of the three-phase induction motor were analysed (Fig. 1): healthy three-phase induction

E-mail address: adglow@agh.edu.pl.

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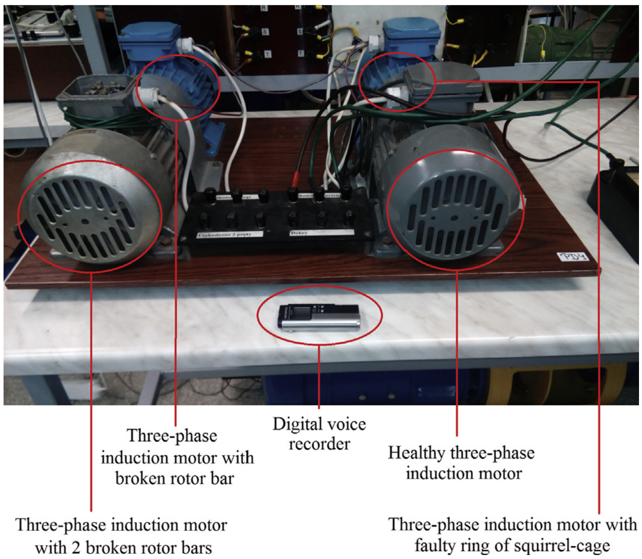

Fig. 1. Experimental setup of analysis of acoustic signals of analysed three phase induction motors.

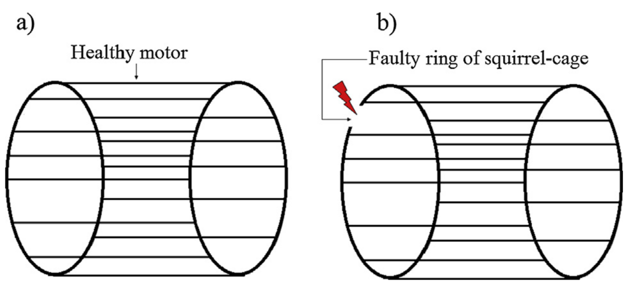

Fig. 2. (a) Rotor of the healthy three-phase induction motor. (b) Rotor of the three-phase induction motor with faulty ring of squirrel-cage.

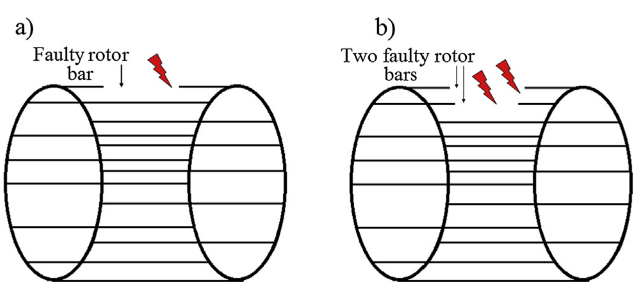

Fig. 3. (a) Rotor of the three-phase induction motor with broken rotor bar. (b) Rotor of the three-phase induction motor with 2 broken rotor bars.

motor (Fig. 2a), three-phase induction motor with faulty ring of squirrel-cage (Fig. 2b), three-phase induction motor with broken rotor bar (Fig. 3a), three-phase induction motor with 2 broken rotor bars (Fig. 3b). The proposed fault diagnosis techniques consist of signal processing methods: preprocessing, feature extraction, classification. Two feature extraction methods of acoustic signals - SMOFS-32-MULTIEXPANDED-2-GROUPS (Shortened Method of Frequencies Selection Multiexpanded 2 Groups) and SMOFS-32-MULTIEXPANDED-1-GROUP were developed. The classification step was performed using the Nearest Neighbour classifier, backpropagation neural network and modified classifier based on words coding.

2. Acoustic based fault diagnosis technique

The proposed acoustic based fault diagnosis techniques consist of signal processing methods, such as: preprocessing, feature extraction, classification (Fig. 4). The first step of signal processing is recording of acoustic signal of the three-phase induction motor. For this purpose low-cost capacity microphone with computer or digital voice recorder can be used. Low-cost capacity microphone with computer can be used for online condition monitoring. It has frequency range 20–20,000 Hz. Dynamic microphone has frequency range 100–5000 Hz. Lower frequency (< 100 Hz) are essential for condition monitoring. The author analysed three-phase induction motor using digital voice recorder (format: WAVE, sampling frequency 44,100 Hz, 16 bits, mono channel, omnidirectional). The second step of signal processing is split of soundtrack into smaller audio files.

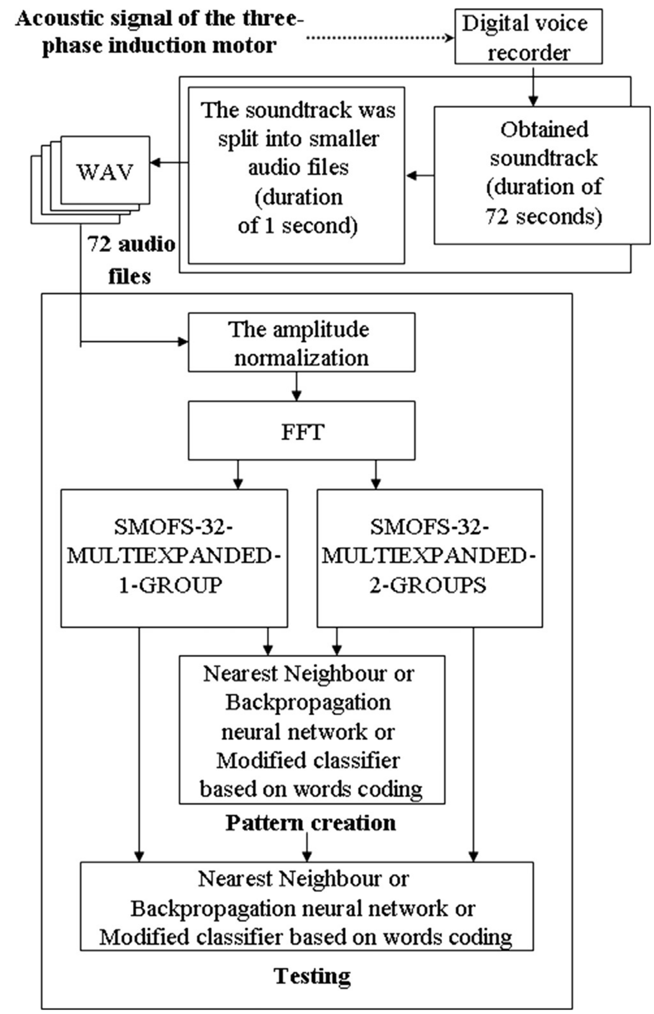

Fig. 4. Proposed acoustic based fault diagnosis techniques of the three-phase induction motor using SMOFS-32-MULTIEXPANDED-2-GROUPS and SMOFS-32-MULTIEXPANDED-1-GROUP.

Next the acoustic data were split into 1-second data files. After that signal was normalized in the range $[-1, 1]$. Normalized signals were processed by the Hamming window, the FFT method (16384 frequency components) and the SMOFS-32-MULTIEXPANDED-2-GROUPS, SMOFS-32- MULTIEXPANDED-1-GROUP. Feature extraction methods computed training and test feature vectors (Fig. 4). The last step of signal processing was classification of feature vectors. Classification of feature vectors was based on the Nearest Neighbour classifier, backpropagation neural network and modified classifier based on words coding.

2.1. *Shortened Method of Frequencies Selection Multiexpanded 2 Groups and 1 Group*

The Shortened Method of Frequencies Selection Multiexpanded 2