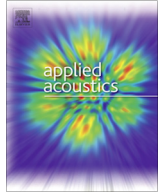




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Diagnosis of stator faults of the single-phase induction motor using acoustic signals

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ABSTRACT

An early diagnosis of faults prevents financial loss and downtimes in the industry. In this paper the authors presented the early fault diagnostic technique of stator faults of the single-phase induction motor. The proposed technique was based on recognition of acoustic signals. The authors measured and analysed 3 states of the single-phase induction motor: a healthy single-phase induction motor, a single-phase induction motor with shorted coils of auxiliary winding, a single-phase induction motor with shorted coils of auxiliary winding and main winding. In this paper an original method of feature extraction called MSAF-RATIO30-MULTIEXPANDED (Method of Selection of Amplitudes of Frequency - Ratio 30% of maximum of amplitude Multiexpanded) was described. This method was used to form feature vectors. A classification of obtained vectors was performed by the KNN (K-Nearest Neighbour classifier), the K-Means clustering and the Linear Perceptron. The early fault diagnostic technique can find application for protection of the single-phase induction motors. It can be also used for other rotating electrical machines.

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1. Introduction

A number of electric rotating motor has greatly increased in recent years [1]. The induction motors are the most widely used electrical rotating motor in the industry. One of the type of induction motor is a single-phase induction motor (Fig. 1). It finds extensive applications in home appliances and industrial machines [2,3].

A degradation of electrical rotating motors is normal process depended on operation process time. The early diagnosis of faults prevents financial loss and unscheduled downtimes in the industry. It also prevent the harmful accidents. The different types of faults of electrical rotating motors were described in the literature [1,2]. These faults can be listed as: stator faults (stator open phase, short circuits of winding - Figs.2 and 3, increased resistance of connections), rotor electrical faults (rotor open phase, short circuits of winding, broken bars, faulty ring of squirrel-cage, increased resistance of connections), rotor mechanical faults (bearings damage, shaft misalignment, bent shaft, rotor eccentricity). In the literature there are a lot of published works about diagnostic techniques of

electrical rotating motor. The analyses of electric currents of electrical motors were described in the literature [4–7]. The method of current measurement in the rotor cage bars of prototype induction motor was described [5]. Two diagnostic methods for the detection of broken bars in induction motors with squirrel-cage type rotors were developed [6]. A condition monitoring system for the motor bearing faults identification, utilizing the motor stator current and voltage was presented [7]. The diagnostic model for longwall conveyor engines was developed in the literature [8]. The analyses of vibration signals of induction motor [3,9,10] and bearings [11,12] were described. The vibration signals were also used for many similar applications such as: evaluation of wear of friction pads rail brake disc [13], vibration level of the chipper during operations [14], diagnosis of hybrid failures in gear transmission systems [15], evaluation of state of rolling bearings mounted in vehicles [16,17]. The articles about noninvasive techniques of fault diagnosis based on: thermal imaging and acoustic signal were also presented. The investigations of thermal imaging of electric rotating motor were discussed in the literature [18–22].

Acoustic signals were also used for fault diagnosis of machines [23–33]. The result of a study of the acoustic quality of noise emitted by a three-phase, induction motor fed with various modulation techniques was described [23]. A signal processing approach to

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Fig. 1. Healthy single-phase induction motors.

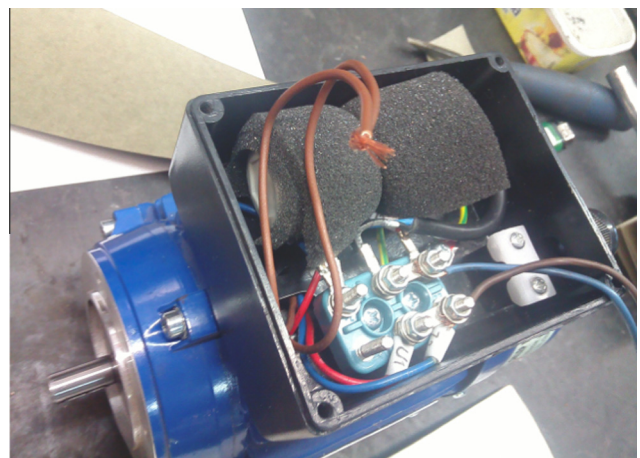


Fig. 2. Single-phase induction motor with shorted coils of auxiliary winding.

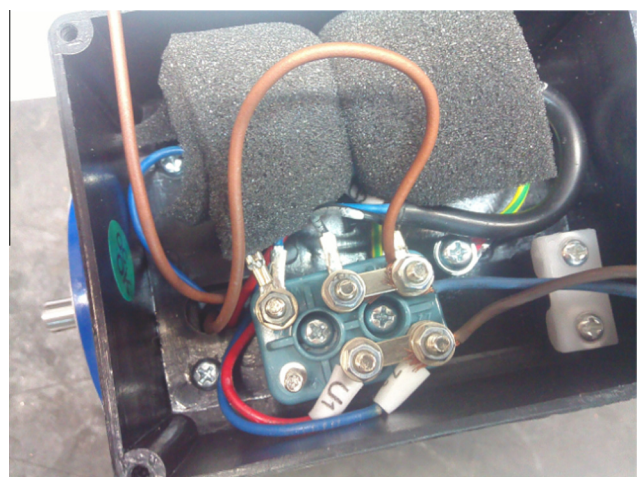


Fig. 3. Single-phase induction motor with shorted coils of auxiliary winding and main winding.

bearing fault detection with the use of a mobile phone was presented [24]. The analysis of sound field emitted by selected CNC machine tools was carried out [25]. Vibroacoustic measurements applied to external gear pumps were presented [26]. The acoustic signals were also analysed for tool wear monitoring [27]. The scientists also presented the possible applications of using acoustic diagnostics in inspecting the technical condition of a combustion engine [28,29]. The acoustic emission-based method for the condition monitoring of low speed reversible slew bearings was discussed [30]. Automatic gear and bearing fault localization using vibration and acoustic signals was also presented [31]. Diagnosis of three-phase induction motor and synchronous motor using acoustic signals was also developed [32–34].

The recognition of acoustic signals was not an easy task. The first problem was a microphone. It recorded many sounds from environment. Next problems were various parameters such as: rotor speed, power and size. It was a problem because we needed a lot of samples of acoustic signals from many electric rotating motors. It required strict cooperation with industry and motor operators. It should be also defined what faults to look for after access to a motor is granted. For these reasons, the authors decided to solve this problem.

In this paper the authors proposed efficient technique of early fault diagnosis. This technique was a variant of signal processing methods: preprocessing, feature extraction and classification. A feature extraction was based on original method called MSAF-RATIO30-MULTIEXPANDED. The three acoustic signals of states of the single-phase induction motor were analysed by the authors.

2. Proposed technique of fault diagnosis

The presented technique of fault diagnosis was based on the recognition of acoustic signals. This technique was the variant of signal processing methods: preprocessing, feature extraction and classification. The classification step was divided into pattern creation and testing (identification).

At the beginning the audio data were recorded by a capacitor microphone. The authors used ZALMAN ZM-MIC1 and OLYMPUS TP-7 microphones. Other capacitor microphones can be also used. The recorded data were split and processed by amplitude normalization and windowing (window size 32768). Next normalized signal was processed by the FFT and MSAF-RATIO30-MULTIEXPANDED. MSAF-RATIO30-MULTIEXPANDED created feature vectors. The last step of the pattern creation was creation of patterns - feature vectors. It was dependent on the selected classifier.

The method MSAF-RATIO30-MULTIEXPANDED was not necessary for testing (all frequencies were found in the pattern creation). Test and training samples were processed similarly. Next obtained test feature vectors were classified by the K-Nearest Neighbour classifier, the K-Means clustering and the Linear Perceptron (Fig. 4).

2.1. Method of Selection of Amplitudes of Frequency - Ratio 30% of maximum of amplitude Multiexpanded

The original method of feature extraction MSAF-RATIO30-MULTIEXPANDED (Method of Selection of Amplitudes of Frequency - Ratio 30% of maximum of amplitude Multiexpanded) was presented in Fig. 5.

The steps of MSAF-RATIO30-MULTIEXPANDED can be described in the following way:

- (1) Calculate the frequency spectrum of acoustic signal for each state of the single-phase induction motor (from several training sets, so we can use for example 5 training samples

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