Mechanical Systems and Signal Processing 46 (2014) 45–58

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Sound based induction motor fault diagnosis using Kohonen self-organizing map

Emin Germen, Murat Başaran *, Mehmet Fidan

Department of Electrical and Electronics Engineering, Anadolu University, Eskisehir, Turkey

ARTICLE INFO

Article history:
Received 30 January 2013
Received in revised form
19 June 2013
Accepted 2 December 2013
Available online 31 January 2014

Keywords:
Induction motors
Fault detection
Kohonen SOM
Acoustic signal processing

ABSTRACT

The induction motors, which have simple structures and design, are the essential elements of the industry. Their long-lasting utilization in critical processes possibly causes unavoidable mechanical and electrical defects that can deteriorate the production. The early diagnosis of the defects in induction motors is crucial in order to avoid interruption of manufacturing. In this work, the mechanical and the electrical faults which can be observed frequently on the induction motors are classified by means of analysis of the acoustic data of squirrel cage induction motors recorded by using several microphones simultaneously since the true nature of propagation of sound around the running motor provides specific clues about the types of the faults. In order to reveal the traces of the faults, multiple microphones are placed in a hemispherical shape around the motor. Correlation and wavelet-based analyses are applied for extracting necessary features from the recorded data. The features obtained from same types of motors with different kind of faults are used for the classification using the Self-Organizing Maps method. As it is described in this paper, highly motivating results are obtained both on the separation of healthy motor and faulty one and on the classification of fault types.

1. Introduction

Due to their simple construction, cost effectiveness and easy maintenance, the squirrel cage induction motors are the most preferable electrical motors in the industry. In order not to interrupt the industrial processes caused by unexpected failures of induction motors, preventive maintenance strategies are essential. Early diagnostics of incipient faults in induction motors are important to ensure safe operation and help to recognize and fix the problems with low costs and time.

Significant amount of research have been focused on the methods for the early detection of the mechanical and electrical faults in induction motors [1]. Among all the methods in literature, motor current signature analysis (MCSA) is one of the most popular ones, which provides an effective way to detect incipient faults. MCSA mainly focuses on the analysis of the current data that is supplied from the ac network to the induction motor with time–frequency analysis techniques like Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT), Wavelet Transform or Wavelet Packet Transform [2]. However there is a bottleneck to apply this technique to induction motors in their working environment since in most cases obtaining data is a cumbersome process because of the additional circuitry like isolators or data acquisition cards and interface that should be added between the supply and the test motors. Also it may not be possible to detach load from motor and run motor under no load condition. In order to get rid of disadvantages of current based techniques like MCSA, the acoustic and

* Corresponding author.
E-mail addresses: egermen@anadolu.edu.tr (E. Germen), muratb@anadolu.edu.tr (M. Başaran), mfidan@anadolu.edu.tr (M. Fidan).

0888-3270/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ymssp.2013.12.002

vibrational methods are getting popular since those approaches do not require detaching motors from their working environment. Fault diagnosis methods based on vibration analysis have been applied for many years using the methods such as Fourier and Wavelet Transforms, and have shown significant success especially on detecting faulty bearing detection [3].

Vibration signal can be obtained via a contact device such as accelerometer; however in some special cases it may be problematic. For example the surface of the test motor may be irregular and the device could not be located properly on the test motors. Also the surface may be greasy or slippery due to the hard operating conditions like high temperature and humidity [4]. On the other hand, sound based fault diagnosis of motors offers a great advantage that solves many of these problems since it offers a contactless solution to obtain data. Only external microphones located around the operating motor are enough to record the information. Unlike vibration-based analysis, there is a very limited literature on fault diagnosis of induction motors, which are based on techniques of sound analysis. In Ref. [5] stator current, vibration and acoustic methods are compared and very detailed results for different types of faults in different load conditions have been introduced. It is worth to note that in this work, the acoustic methods are quite effective in order to capture the signatures of bearing faults. Previous work on acoustic analysis of induction motors also has promising results. In Ref. [6], compressor motor faults were successfully identified inside a semi-anechoic chamber environment. In Ref. [7] the effects of localization of multiple microphones have been scrutinized and their effects on results have been investigated. It is worth to mention the work [8], where a detailed sound based approach has been applied in order to make fault detection in high-speed motors. There, the vacuum cleaner motor experiments have been carried out in echo-free silent environment that provide significant results on detection of faults. However the real life applications in industry always introduce ambient noise.

In this work, the acoustic data are collected from the same type of five different induction motors located in an environment with ambient noise, where four of them have specific incipient mechanical or electrical faults, via five microphones surrounding the test rig. These data can be analyzed like current or vibration data and can possibly contain many fault related information for diagnosis. Therefore this paper aims to scrutinize the suitable information hidden in acoustic data, which can distinguish the healthy motor from the faulty ones, and classify the fault types. Here the first strategy, features are obtained directly by calculating the cross correlation coefficients of the sound data recorded by the microphone pairs. For each experimental trial, 10 different correlation coefficients are calculated for each motor using 5 different microphones. In the second strategy, additional features are extracted by using 2D wavelet decomposition of the grayscale images, which are obtained by converting one-dimensional sound data, which are recorded by each separate microphone, to 2D grayscale images. As it has been described in Ref. [9], the 2D representation has many advantages over the regular one-dimensional data since it provides many additional information and possible usage of image processing tools. These two dimensional images are expected to show different type of textures and in former works for texture analysis, basically wavelet based methods were used [10–21]. These wavelet based texture analysis methods are applied on different kind of research areas including classification of tomography images [10,11], fingerprint classification [12], analysis of SAR images [13], power quality analysis from 2D represented power quality event data [14,15] and fault analysis of rotating machinery by using data obtained from infrared thermography [16].

The detection of faulty motor is a classification problem. Here it is reasonable to use neural network techniques, especially Kohonen Self-Organizing Map (SOM), in order to discriminate a faulty motor from a healthy one [22]. The idea behind the SOM is finding a projection of multi-dimensional vector space into two-dimensional lattices. While scattering the input vectors to the two-dimensional lattice, SOM also provides information about the possible similarities and resemblances of input vectors and it presents a visual representation of possible clusters in data set. In order to get the benefits of SOM, the feature vectors, which are used to identify the nature of the fault, should have to be designated in proper fashion. This paper also focuses on definition of those feature vectors obtained from acoustic data, which are used in SOM.

This article continues with Section 2, which contains the explanation of motor fault types and detailed information of the experimental setup constructed by induction motors and microphones. Afterwards in Section 3, the features obtained from the sound data of the healthy and faulty motors to classify the fault types are expressed. Furthermore, Self-Organizing Maps (SOMs) and Learning Vector Quantization (LVQ) methods applied on the obtained features to classify the fault types are explained and the classification results are presented in details, in Section 4. Finally Section 5 concludes the paper.

2. Fault types and experimental setup

In this work, five induction motors are used in order to obtain the acoustic data. Motors are driven directly from AC network. A 3-phase, 25 kVA, Δ-ϒ connected isolation transformer is located between laboratory setup and the network where the motors are supplied with the output of this transformer. Test motors are 3-phase and 2-pole squirrel cage induction motors rated at 2.2 kW and 380-V line to line.

Some commonly encountered mechanical and electrical faults are created synthetically on four of these motors. One of these identical motors is left untouched in order to get the healthy motor data. The faults are chosen and created such that those are the most encountered incipient faults in industry. The broken rotor bar fault is realized by drilling holes to 3 bars respectively over 18 bars as illustrated in left side of Fig. 1. This type of faults cause a rise in magnitude at adjacent side band frequency components of the motor current located symmetrically around the main frequency which the stator coils are supplied by Ref. [5]. However, monitoring the increase in magnitude at the predicted sideband frequencies alone may mislead the classification since different types of faults may have same frequency components. Also when the amount of slip