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FAULT DIAGNOSIS OF THREE-PHASE INDUCTION MOTORS BASED ON VIBRATION AND ELECTRICAL CURRENT SIGNALS

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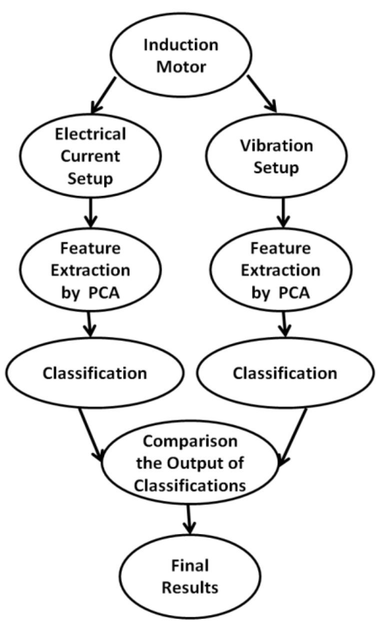
Graphical abstract



Fault detection method

Abstract

Induction motors (IM) as a critical component of many industrial processes are subjected to issues such as aging motors, high reliability requirements, and cost competitiveness. Therefore, many research efforts have been focused on fault detection in IMs. The main specification of this paper involves fault detection of three phase IMs using vibration and electrical current setup. This paper compares the results obtained by vibration and electrical current setup in order to a better understanding of fault detection setups' operation in induction machines. The experimentation was performed on two faulty and one healthy squirrel cage motor. A number of data was captured through the labVIEW software. Principal Component Analysis (PCA) was employed for feature extraction to classify the faults of IMs. Most vibration hardware systems are relatively costly and difficult to set up, but they resulted in significantly higher accurate and classified data in comparison to the results of current setup.

Keywords: Induction motor (IM), fault diagnosis, electrical current setup, vibration setup

Motor aruhan adalah satu komponen penting di dalam proses industri yang mempunyai beberapa masalah antaranya seperti motor penuaan, keperluan kebolehpercayaan yang tinggi, dan persaingan harga di pasaran. Sehubungan dengan itu, pelbagai kajian telah memberi tumpuan kepada pengesanan kekurangan yang dihasilkan pada motor aruhan. Tujuan utama artikel ini adalah mengenalpasti kerosakan bagi motor aruhan tiga fasa dengan menggunakan getaran dan sistem arus elektrik. Artikel ini telah membandingkan hasil keputusan yang diperolehi dari getaran dan sistem arus elektrik untuk pemahaman yang lebih jelas bagi operasi pengesanan kekurangan yang dihasilkan di dalam motor aruhan. Eksperimen telah dijalankan ke atas dua jenis kerosakan dan satu motor sangkar tupai yang baik. Nilai tersebut telah direkodkan dengan menggunakan perisian LabVIEW. Analisis Komponen Prinsipal (PCA) telah digunakan untuk mengklasifikasikan jenis kekurangan yang terdapat di dalam motor aruhan.

Kata kunci: Motor aruhan, pengesanan kekurangan, sistem arus elektrik, sistem getaran

1.0 INTRODUCTION

Induction motors (IM) are most commonly used electrical machines in industry with a wide variety of industrial applications [1]. The possibility of the faults in IMs is unavoidable despite of their high reliability [1, 2]. There are variety of faults in IMs such as 1) stator faults leading to the opening or shorting of one or more of the stator phase winding 2) abnormal connection of the stator windings 3) broken rotor bar or cracked rotor end rings 4) static and dynamic air gap irregularities 5) bent shaft 6) shorted rotor field winding 7) bearing & gearbox failures [3-6].

Numerous methods have been proposed for induction motor faults diagnosis such as vibration analysis, motor current signature analysis (MCSA) [7-9], electromagnetic field monitoring [10], chemical analysis, temperature measurability [11], infrared measurement, acoustic noise analysis [12], stray flux, and partial discharge measurement [13].

Electrical and mechanical data are frequently used in fault diagnosis methods [14]. Current and vibration signals, which are provided by inventors and accelerometer sensors respectively, have specific characteristic behaviors for each kind of main motor faults. Thus, it is practical to detect and diagnose faults based on current and vibration measurements [15, 16]. In lots of situations, vibration analysis is known as an effective method to detect the presence of faults in IMs. However, most expensive and load-critical machines should be used for vibration sensors' installation generally. Furthermore, unreliable readings can be resulted due to the sensitivity of these sensors to environmental factors. Additionally, mechanical sensors in most cases are not capable to detect electrical faults, such as stator faults.

Fault diagnosis of induction machine can be also achieved through MCSA [7]. Current monitoring can overcome these shortcomings of vibration monitoring. It can be installed inexpensively on most machines by using the current transforms, placing on the motor control centers or switchgear. Recently MCSA has received much attention as a result of convenience in monitoring large numbers of motors remotely from one location. In addition, working environments cannot influence on the fault patterns in the current signal [17-19]. This paper aims to discriminate between vibration and electrical current setup for detection of faults in three-phase induction machines. Advantages and disadvantages of the proposed motor fault detection systems is also stressed.

2.0 METHODOLOGY

Two faulty IMs with stator winding fault and broken rotor bar fault, and one healthy motor were used in the lab. The physical parameters of the IMs under test have been depicted in Table 1.

Table 1 Physical data of three-phase IM

Symbol	Description	Value
f_s	Input stator frequency	60 Hz
V_s	Input stator phase voltage	230 V
N_s	Number of stator winding turns	150
p	Number of pole pairs	4
R_s	Stator winding electrical resistance	1.4 Ω
r_{ag}	Air-gap average radius	64 mm
l_{ag}	Air-gap length	0.24 mm
L_{rb}	Rotor bar self-inductance	0.26 μH
R_{rb}	Rotor bar resistance	92.33 μΩ

Two different setup including i) Vibration setup consisted NI PCI- 4474 DAQ card and accelerometers; ii) Current setup included NI 9234 and NI 9174 CDAQ cards, and current clipping sensor have been utilized for data acquisition. Details of these two cards has been tabulated in Table 2.

Table 2 Details of data acquisition cards

NI PCI-4474 CARD	NI 9234 CARD
24-bit Resolution	24-bit Resolution
110 dB Dynamic range	120 dB Dynamic range
102.4 KS/s Maximum Sampling Rate	51.2 KS/s Maximum Sampling Rate
45 KHz alias-free bandwidth	1 KHz alias-free bandwidth
AC/DC Coupling	AC/DC Coupling
±10V range	±5V range

NI PCI- 4474 DAQ and NI9234 cards were used for vibration and electrical current setup respectively in order to import the captured data into LabView software. Vibration and electrical current data should be captured from healthy and faulty motors to apply in fault detection analysis in numerical form.

Numerous data has been captured from faulty and healthy IMs. Therefore, feature extraction has been used to reduce the large number of captured data. Various features such as mean value, root mean square (RMS), skewness, kurtosis and crest factor presented in the following equations was extracted:

$$\text{Mean Value } (\mu) = \frac{\sum_{t=1}^{n} y(t)}{n} \quad (1)$$

$$\text{Root Mean Square } (\sigma) = \sqrt{\frac{\sum_{t=1}^{n} (y(t) - \mu)}{n}} \quad (2)$$

$$\text{Skewness} = \frac{\sum_{t=1}^{n} (y(t) - \mu)^2}{n\sigma^3} \quad (3)$$

$$\text{Kurtosis} = \frac{\sum_{t=1}^{n} (y(t) - \mu)^4}{n\sigma^4} - 3 \quad (4)$$

$$\text{Crest factor} = \frac{|Y|_{peak}}{Y_{rms}} \quad (5)$$

Reduce the dimension of the extracted features was done by using Principal Component Analysis (PCA) method.

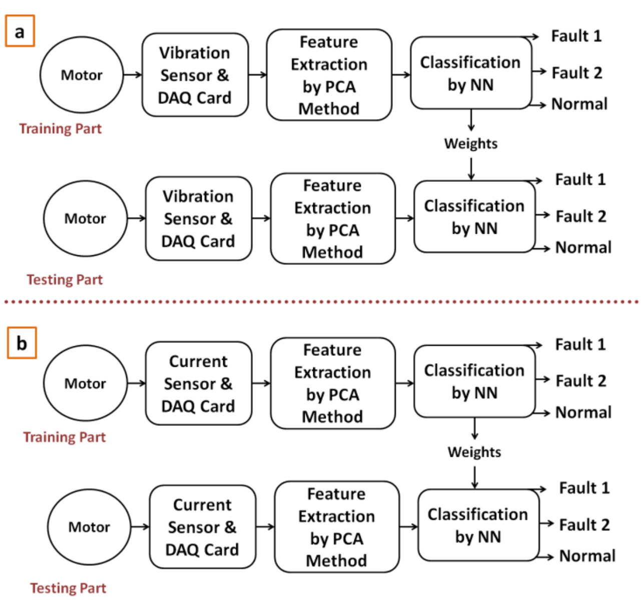


Figure 1 Fault detection block diagram of a) vibration setup and b) electrical current setup

As it depicted in Figure 1 the output of PCA has been classified by using a neural network (NN) classifier. The outputs of NN classifier has clearly displayed three separate classes; Fault 1 (broken rotor fault class), Fault 2 (winding fault class), and Normal (normal condition class). Diagnostic and monitoring techniques are based on machine learning approaches containing of training stage and testing stage. In the training stage classification algorithm is trained by using the training dataset. In testing stage, the testing dataset is used in order to corroborate the classification accuracy of the algorithm. A signature is generated from faulty and healthy motors during the training stage of the diagnostic and monitoring systems, and results obtained from the trained algorithm is tested on the so-called "unseen signals" in testing stage. Data were captured from healthy and faulty motors by vibration and current sensors in training part. In testing part, the trained algorithm in previous part was tested, and then data with the same weights obtained from training stage were classified by using NN classifier.

3.0 RESULTS AND DISCUSSION

The data was captured for vibration and stator current at the same time. Vibration and stator current data were taken by accelerometer sensors and normal clipping electrical current signal sensor respectively.

PCA was used based on the features stated in equations 1 to 5 for data classification. Results of PCA classification for vibration and current sensor data by using NN classifier have been depicted in Figure 2 and Figure 3.

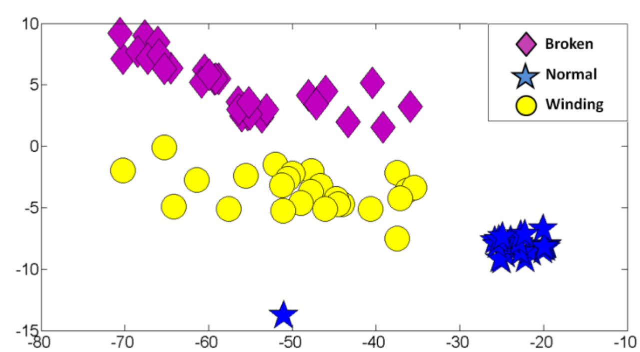


Figure 2 PCA classified results by vibration sensor

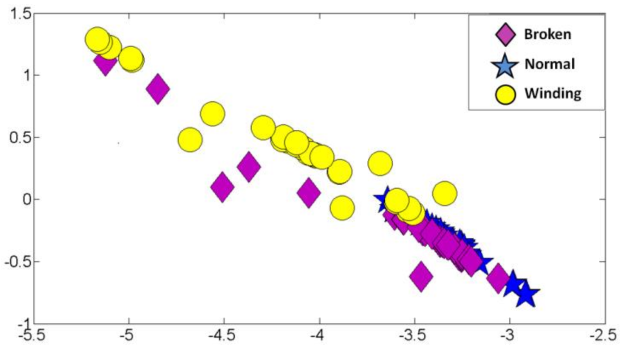


Figure 3 PCA classified results by electrical current sensor

As depicted in Figure 2, vibration data were clearly classified and features related to each fault were surrounded in their own specific area. Whilst, the data taken by electrical current sensors (Figure 3) showed some errors and overlapping. In the case of electrical current setup, results do not have any levels of dissociation. Broken rotor, winding faults and normal features cannot be easily distinguished from each other in the electrical current system (Figure 3).

The mean square error (MSE) versus number of layers was plotted in order to find the optimum number of layers in NNs. Firstly the NN was trained 10 times with different number of layers from 3 to 20 layers. Then the average of MSE for each number of layers was calculated. As it has been shown in Figure 4 the minimum average of MSE was obtained for 6 layers. Therefore, NN was trained for 6 layers.

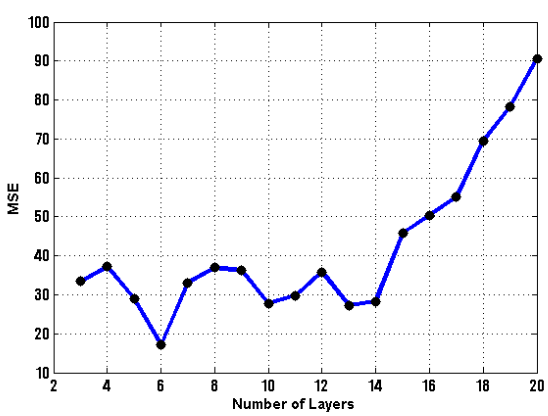


Figure 4 Statistical diagram of MSE versus number of layers

Vibration data capturing setup gives more accurate and reliable results than electrical current setup, but it is costly, sensitive and fragile in maintenance. Furthermore, this setup requests expert operator with a great knowledge about installation and operation. General information of advantages and drawbacks of two tested fault detection setups in this study have been tabulated in Table 3.

Table 3 Advantages and disadvantages of vibration and electrical current setups in fault detection

Fault detection setup	Advantages	Disadvantages
Vibration	Classified results, Accurate, Reliable	High cost, Technical difficulties of access to the machine, Influence of the transmission path, Sensitivity to the sensor position, Sensitivity to the environmental factors, Damaged easily
Current	Inexpensive, Insensitive to working environments, convenience in monitoring large numbers of motors remotely from one location	Unclassified results, Low- accurate

4.0 CONCLUSION

In this study two faulty and one healthy IMs have been tested by vibration and electrical current setup in order to provide a comparison between these two experimental setups' operation in fault detection. Informative features (represent characteristics of the whole samples) have been used due to the huge volume of data in data capturing. Feature extraction was carried out by using PCA method to reduce the features dimensions. Vibration hardware setup showed significantly higher levels of accuracy in comparison to the electrical current setup. However, high cost of vibration sensors owing to maintenance and technical assistant makes them improper as a suitable fault detection system. In contrast, fault detection based on electrical current setup is inexpensive, but the results are not very clear and accurate. Although, the vibration and current systems have their own advantages for fault detection in industrial area, but development of these fault detection systems seems to be necessary.

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