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Measurement of Current Signature in Three-Phase Induction Motor to Detection of Bearing Failure

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Abstract: Three-phase induction motor is the type of motor that is commonly used in many industries. Due to this heavily used type of motor in the industry, the probability of this machine experiencing bearing failure is high. The main aim of this study is to compare the current signature of the three-phase induction motor during normal condition and during bearing failure with varying the torque from 0%, 20%, 40%, 60%, 80%, and 100%. The material used to perform this study was a three-phase induction motor, current clamp, oscilloscope, normal and faulty bearings (outer, inner, and cage failures). As for the method, motor current signature analysis (MCSA) was used to detect the current signature since each failure has its own unique signature. The current clamp was clamped at one of the phases (R-Y-B) and connected to the oscilloscope to perform the MCSA. After conducting the study, the amplitude (dBV) up to 10 kHz high-frequency domain increased when the torque was varied from 0% to 100% for normal conditions, while the amplitude value (dBV) shows increment and decrement for outer, inner and cage failures at both drive end and non-drive ends. In conclusion, the study successfully used MCSA to differentiate the amplitude value for normal and bearing failure conditions for 0% until 100% torque but it was difficult to detect the changes in sideband frequency for bearing failure conditions. Last but not least, using a high-resolution of data acquisition system was suggested to obtain more accurate results.

Keywords: Motor Current Signature Analysis (MCSA), Decibel Volt (dBV), Torque

1. Introduction

A three-phase induction motor is a type of electrical motor that converts electrical energy to mechanical energy and is widely used in industry for controlling various components such as conveyors, pumps, and compressors. Due to its widespread use, the probability of various faults occurring internally and externally is high, including issues with the rotor or stator, air gap, stator coil, shaft, rotor bar, and bearing failure [1].

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Bearing failure is a common problem that three-phase induction motors faced, with studies showing that 40% of failures are caused by damaged or broken bearings [1]. This type of motor is a high voltage, with costs reaching over RM 1 million. Bearing failure affects the operation of the motor and can lead to production losses. When the bearing failure occurs, the mechanical part inside the induction motor will affect the current signature [2]. Motor Current Signature Analysis (MCSA) is a method that can be used to detect slight changes in the induction motor current caused by bearing failure. When the MCSA method is applied, the current signature of the induction motor will change which indicates that a fault has occurred in the induction motor [3]. One advantage of MCSA is that it can be done online, without interrupting the operation of the motor.

The objectives of this study are to measure and compare the current signature of a normal three-phase induction motor with varying torque, and a three-phase induction motor with bearing failure with varying torque and focus on analyzing the current signature of a normal induction motor and comparing it to the current signature of the three-phase induction motor with a bearing failure.

2. Materials and Methods

This part briefly overviews the project workflow as well as the development of the process of the research.

2.1 Materials

Each of the equipment listed in Table 1 used in this study has its own features and combining this equipment leads to completing the Motor Current Signature Analysis (MCSA) to detect bearing failure for normal conditions and bearing failure conditions from 0% to 100% torque.

Table 1: List and Function of Equipment Used in the Study

Equipment	Functions
Three-phase induction motor	The motor is used to perform the MCSA method to monitor the current signature for healthy and bearing failure condition
Lucas-Nuelle Servo Drive	Act as load simulator connected to the induction motor shaft
Lucas-Nuelle Digital Control Unit for Servo Drive	Torque control is used since the study is done by varying the torque.
HANTEK AC/DC Current Clamp	To measure the current of the induction motor at 1 phase and be compatible with an oscilloscope in order to monitor the frequency spectrum.
KEYSIGHT DSOXI202G Oscilloscope	To display time domain waveform and frequency domain waveform using Fast Fourier Transform (FFT)
Matlab Software	To do the coding to produce the graph based on the data obtained and ease the analysis process
Portable Thermal Camera	To capture the thermal imaging and temperature value of the induction motor

2.2 Methods

In this section, the process of how to do the measurement of the current signature using Motor Current Signature Analysis. Motor Current Signature Analysis is a method used to analyze the current of the stator winding in a three-phase induction motor [5]. By obtaining data from the stator winding current, abnormal conditions in the induction motor can be detected. Therefore, the stator winding current can be represented in both the time domain and frequency domain as shown in Figure 1.

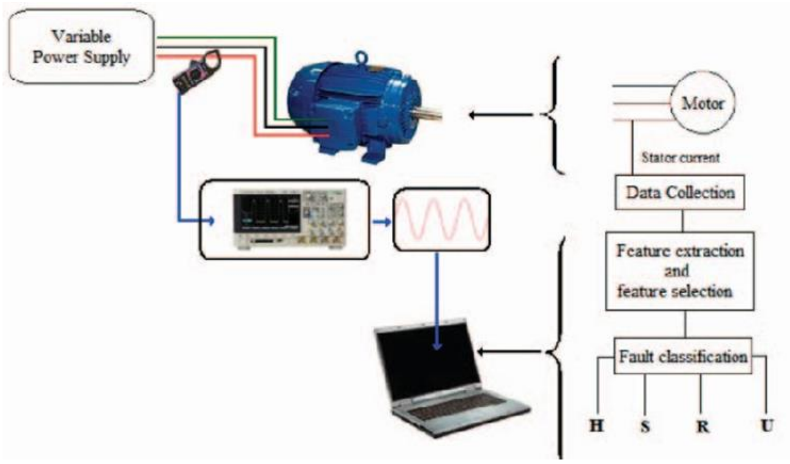


Figure 1: Process of Current Monitoring using MCSA Method [5]

Figure 1 shows the MCSA method is a procedure for monitoring current in an induction motor. It involves three main steps: collecting data, selecting features, and classifying failures. Data is collected by measuring the current of the stator winding using a transducer. The selected features are obtained by converting the time-domain signal to the frequency-domain using FFT, which is used to monitor the sideband peaks generated by motor failure. The final step is classification of failure, which involves comparing the frequency spectrum of a normal motor to one experiencing failure.

2.3 Equations

Bearing failure in the induction motor can be determined by the frequency spectrum of $f0$ and $f1$ for the bearing that has six to twelve ball bearings. Equations (1) and (2) below are the formula used to calculate the frequency spectrum [1]:

$$f_0 = 0.4nf_{rm} \quad Eq. 1$$

$$f_1 = 0.6nf_r \quad Eq. 2$$

Where $f0$ is the lower frequency side band, $f1$ is the upper-frequency sideband, n is the total number of balls bearing and frm is the frequency of the mechanical rotor [2]. To determine the frequency of the mechanical al rotor frm, it can be calculated by using Equation (3) [4].

$$f_{rm} = \frac{1-s}{p/_2} f_s \quad Eq. 3$$

Where fs is the supply frequency, p is the number of poles and s is the slip of the motor.

3. Results and Discussion

This section will present the data obtained after conducting the study for measuring the current signature of the induction motor for normal and bearing failure conditions for 0% to 100% torque. In addition, thermal imaging analysis has also been added in order to prove that the modified bearing fault can be detected.

3.1 Results for Data 0% and 100% Torque for Normal condition

In this part, the amplitude (dBV) parameters was analyzed based on the harmonic signal that appeared on the high-frequency domain 10kHz for normal conditions after performing the Motor Current Signature Analysis (MCSA). Table 2 shows the amplitude values in dBV for data of varied torque of a motor in the high-frequency domain of 10 kHz. The maximum amplitude value for the fundamental frequency of 50 Hz was -10 dBV when 100% torque was applied and the minimum was -

16.5 dBV when no torque was applied. At 1st harmonic 150 Hz, the maximum amplitude value was -48.1 dBV at 100% torque and the minimum was -56.4 dBV at 80% torque. For the 3rd harmonic 250 Hz, the maximum amplitude was -55.0 dBV at 100% torque and the minimum was -75.2 dBV at 80% torque. At 5th harmonic 350 Hz, the maximum amplitude was -70.3 dBV at 20% torque and the minimum was -75.1 dBV at 40% torque.

Figure 2 presents the graph of amplitude versus torque for the 1st, 3rd, and 5th harmonics. The amplitude increases as torque increase for the fundamental frequency of 50 Hz. For the 1st harmonic, amplitude increases with torque but decreases to -56.4 dBV at 80% applied torque. Similarly, for the 3rd harmonic, amplitude increases with torque but decreases to -75.2 dBV at 80% applied torque. For the 5th harmonic, the graph is not stable as the amplitude increases and decreases with the increment of torque.

Table 2: Amplitude (dBV) parameters at normal condition

Torque (%)	Amplitude (dBV)			
	50Hz	150Hz	250Hz	350Hz
0	-16.5	-51.1	-71.9	-
20	-16.2	-48.8	-62.7	-70.3
40	-14.9	-49.1	-60.9	-75.1
60	-13.7	-48.1	-57.3	-71.0
80	-13.0	-56.4	-75.2	-
100	-10.3	-48.1	-55.0	-71

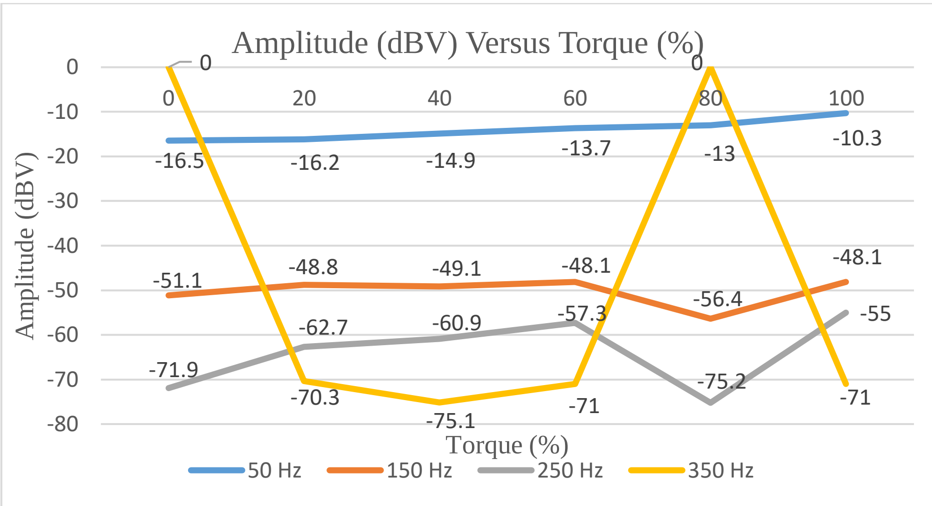
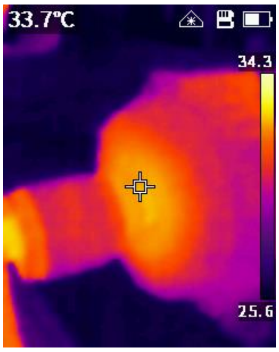


Figure 2: Graph Amplitude (dBV) versus Torque (%)

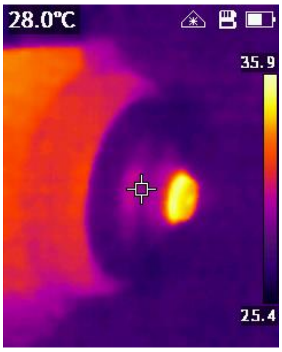
3.2 Result for Normal Condition at Drive End and Non-Drive End for 0% and 100% Torque

A thermal imaging process was done using a portable thermal camera on a three-phase induction motor. The temperature of both drive ends was recorded after 5 minutes of operation while varying the torque. The results were shown in the form of thermal images.

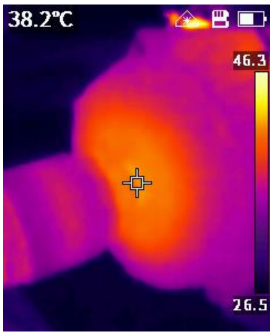
Figure 3 shows thermal images of a three-phase induction motor at the drive end and non-drive end for 0% and 100% torque. The temperature at the drive end was 33.7°C and 28.0°C at the non-drive end under normal conditions of 0% torque. At 100% torque, the temperature at the drive end was 38.2°C and 28.3°C at the non-drive end. Table 3 shows the temperature of the bearing went up after the motor was turned on for 5 minutes. When the torque increased from 0% to 100%, the temperature at the drive end increased from 33.7°C to 38.2°C (by 4.5°C). The temperature at the non-drive end increased from 28.0°C to 28.3°C (by 0.3°C).



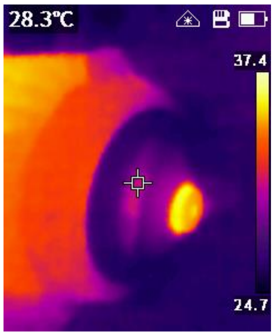
(a) 0% Torque at the Drive End



(b) 0% Torque at the Non-Drive End



(c) 100% Torque at the Drive End



(d) 100% Torque at the Non-Drive End

Figure 3: Thermal Imaging for Normal condition at Drive and Non-Drive End for 0% and 100% Torque

Table 3: Comparison of Temperature Value for Normal Conditions at 0% and 100% Torque

Torque (%)	Temperature of Bearing (°C)	
	Drive End	Non-Drive End
0	33.7	28.0
100	38.2	28.3
Difference between temperature	4.5	0.3

3.3 Summary of Research Findings

In this section, the summary of the research was presented after performing the data measurement using MCSA and Thermal Analysis for normal and bearing failure conditions which consist of outer race fault, inner race fault, and cage fault for 0% and 100% torque applied. The data observation was made to see the changes in harmonic for the three-bearing failure. From Table 4, it can be concluded that there were significant decreases and increases in amplitude (dBV) at certain harmonics for bearing faults at 0% torque. For an outer race fault, a significant decrease in amplitude (dBV) is observed at 150Hz (drive end) and at 350Hz (other ends). For an inner race fault, both ends experience a significant increase in amplitude (dBV) at 250Hz. Lastly, for cage failure, the drive end experiences a significant decrease in amplitude (dBV) at 150Hz, while the other end experiences a significant increase in amplitude (dBV) at 250Hz.

Table 4: Summary of Research Finding at 0% Torque using MCSA Method

Fault	Location	Torque	Observation
Outer race fault	Drive end	0%	Significant decrease of dBV at 150Hz
Outer race fault	Non-drive end	0%	Significant decrease of dBV at 350Hz
Inner race fault	Drive end	0%	Significant increase of dBV at 250Hz
Inner race fault	Non-drive end	0%	Significant increase of dBV at 250Hz
Cage Fault	Drive end	0%	Significant decrease of dBV at 150Hz
Cage Fault	Non-drive end	0%	Significant increase of dBV at 250Hz

From Table 5, it can be concluded that there were significant decreases and increases in amplitude (dBV) at certain harmonics for bearing faults at 100% torque. For an outer race fault, a significant increase in amplitude (dBV) is observed at 350Hz (drive end) and at 250Hz (non-drive end). For an inner race fault, the drive end experiences a significant decrease in amplitude (dBV) at 250Hz, while the other end experiences a significant increase at 350Hz. Lastly, for cage failure, both ends experience a significant increase in amplitude value at 350Hz.

Table 5: Summary of Research Finding at 100% Torque using MCSA Method

Fault	Location	Torque	Observation
Outer race fault	Drive end	100%	Significant increase of dBV at 350Hz
Outer race fault	Non-drive end	100%	Significant decrease of dBV at 250Hz
Inner race fault	Drive end	100%	Significant decrease of dBV at 250Hz
Inner race fault	Non-drive end	100%	Significant increase of dBV at 350Hz
Cage Fault	Drive end	100%	Significant increase of dBV at 350Hz
Cage Fault	Non-drive end	100%	Significant increase of dBV at 350Hz

From Table 6, when there was no torque applied to the motor, there was a significant increase in temperature at the non-drive end for the outer race fault bearing. For the inner race fault and cage fault, a significant increase in temperature can be seen at the drive end of the induction motor. This significant can be seen when the thermal camera shows the hottest region of the measured part.

Table 6: Summary of Research Finding at 0% Torque using Thermal Analysis

Fault	Torque	Observation
Outer race fault	0%	Significant increase in temperature at the non-drive end
Inner race fault	0%	Significant increase in temperature at the drive end
Cage Fault	0%	Significant increase in temperature at the drive end

From Table 7, when there was 100% torque applied to the motor, there was a significant increase in temperature at the non-drive end for the outer race fault bearing. For the inner race fault and cage fault, a significant increase in temperature can be seen at the drive end of the induction motor. This sign can be seen when the thermal camera shows the hottest region of the measured part.

Table 7: Summary of Research Finding at 100% Torque using Thermal Analysis

Fault	Torque	Observation
Outer race fault	100%	Significant increase in temperature at the non-drive end
Inner race fault	100%	Significant increase in temperature at the drive end
Cage Fault	100%	Significant increase in temperature at the drive end

4. Conclusion

Motor Current Signature Analysis (MCSA) is a method used to detect the failure in induction motors. It can detect small changes in current frequency to indicate a motor failure. One advantage of MCSA is that it can be performed online without interrupting the operation of the motor. In the experiment, the current signature of a three-phase induction motor was measured under normal conditions with varying torque. The data showed that amplitude values increase as torque increases and harmonic signals decrease from the fundamental frequency to the 5th harmonic. In the second and third objectives of the experiment, the bearing was modified to create outer, inner, and cage faults to measure the current signature and detect bearing failure. The torque was also varied from 0% to 100% for comparison to the normal condition. The data shows that it is hard to detect sideband frequency and that amplitude values increase for outer and inner race faults at the drive end, and decrease at the non-drive end. For cage faults, amplitude values increase at both the drive and non-drive ends. The recommendation for future improvement of this project is to use high-resolution data acquisition systems to capture a more detailed current signature, which can be used to more accurately identify bearing failure.

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