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Three-Phase Induction Motor Noise Analysis and Fault Detection

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Abstract— **The aim of this study is to mitigate the noise and identify the origins of electrical motor malfunction through the analysis of noise signals. At four different rpm ranges with audible noise, i.e., 1470, 1998, 2015, 2650, and 2890 rpm; motor vibration signals were recorded. Each of the three phases will have its own set of measurements taken in two different modes from the current transformer: forward and reverse. Three Digital-to-Analogue Converters (DACs) connect LabVIEW to the motor, which makes data collecting easier. For precise data gathering, three separate apps were created. The MATLAB/SIMULINK filters out the flaws that were found by comparing the FFTs of the noise signals. Various measuring instruments were employed, and their outputs were compared to determine that the results were consistent. As part of this, there were two frequency analyzers—one for more precise measurements and another with a smaller range—and two current transformers with varying ranges. Data analysis from experimental testing was the backbone of the study, and the results were promising.**

Keywords— Current transformers, CT, Data Acquisition (DAQ), fault detection, FFT, frequency analyzer, induction motor, LABVIEW, MATLAB/Simulink, noise analysis, VFD.

I. Introduction

Induction machines are used everywhere in the world, from factories to our homes [1-3]. However, understanding the problems with these machines can be challenging at times for a variety of reasons, such as the machine being in a critical state in which we are unable to stop it or being too far away for us to access. However, by identifying the source of the noise in the machine which can be caused by several mechanical or electrical problems we can learn more about the issues [4]. Many attempts have been studied to estimate the noise in electrical machines [5-7]. Acoustics modelling were done and found that is contributed by the electromagnetic force and resonance with natural frequencies of the motor.

In this study, an attempt to identify the machine's fault, or the source of the noise, by analysing the vibration and the current supply waveforms of the induction machine using various devices at various ranges. The quicker the source of noise is predicted, the quicker the fault in the machine will be detected, and therefore that will save repair time and cost. An induction machine is a rotatory machine, which means that any mechanical fault will cause it to vibrate at a specific frequency. Once the frequencies are defined, faults can be identified and to be certain, the spectra of the supply currents should be analysed because, as the fault occurs with a specific rotatory movement, it will be reflected on the magnetic flux in the machine and therefore the radial forces and thus on the frequency components of the current waveforms.

Fig. 1 summaries the vibration effect on the input current. The vibration frequencies can be compared with the present frequencies. Research has shown that each fault has a specific purpose that determines the severity and the location of the fault [7-8]. Two vibration sensors and two different current transformers are used, with low and high ranges to analyse and validate the mechanical vibrations with the consequent resulted injected harmonics in the currents by motor current structure analysis (MCSA); and by connecting them to data acquisition (DAQ) [9-10], data can be read in LabVIEW software [11]. Through which the current waveforms and vibration signals are read, and Fast Fourier Transform (FFT) [12] are conducted to transform the waveforms from time domain to frequency domain as illustrated in Fig. 2.

To obtain the effect under load conditions, the motor is connected to a load to observe any effects of the load during the fault. Variable Frequency Drive (VFD) is used to control the speed in the study [13-16].

Moreover, knowing the natural frequencies [17-20], which is the frequencies at which the material vibrate will allow as to know which frequency cause the vibration by comparing the natural frequencies and what we get from the sensors, and for this reason we had to use a mechanical engineering software to simulate the machine and using finite element software [21] estimate the natural frequencies of the motor structure.

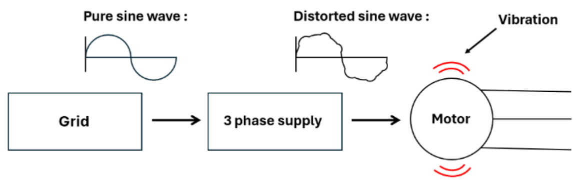

Fig. 1. Vibration effect on the input current

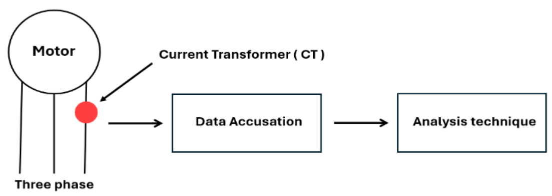

Fig. 2. Taking the data of the current transformer (CT)

II. Design Implementation

A. Flow of Analysis

The block diagram of the complete design is illustrated in Fig. 3 and the flow of the analysis is explained in detail in the flowchart shown in Fig. 4. A dual speed three-phase induction motor of rating 1 kW is used to check the analysis with and without load. The three-phase motor is supplied via a VFD to control the speed via V/f technique. SKF microloge analysis [22-23] is used to directly provide the noise signal with its spectrum. The acceleration sensors were interfaced to LabVIEW through the DAQ cards [10]. The three-phase currents waveforms were measured by current transformers.

B. Setup of Hardware

The motor was chosen based on the nominal value that the machines were designed to operate at, and its ability to work with different winding and loads, which helps to get in depth and more accurate results when it comes to the analysing part. A Variable Frequency Drive (VFD) [16] is a type of motor controller that adjusts the frequency and voltage supplied to an electric motor to control its speed and torque. In simpler terms, it is like a dimmer switch for electric motors. By changing the frequency of the electrical power supplied to the motor.

DAQ is implemented, which is the process of gathering and collecting real-world data from sensors and instruments into a computer for analysis and storage. In the setup, NI-USB 6215, NI-USB 6008 and NI-USB 6009 [24-25] were used.

Selecting the right current transformers (CT's) is very crucial to analyse the current waveforms, two ranges were selected, high and low to detect respectively, the low and high frequency faults. Table I shows a comparison of the two CT's.

Several vibration sensors were glued around on the motor housing to get the average vibration of the motor, where the vibration sensors of brand ADXL335 for low range vibration were used. For high range vibrations, SKF Microlog frequency analyser [23] is used, which is positioned on the center of the machine. Fig. 5 shows the location of the vibration sensors on the induction motor. A relay module [26] used to switch the VFD and to control the direction of rotation of the three-phase induction motor.

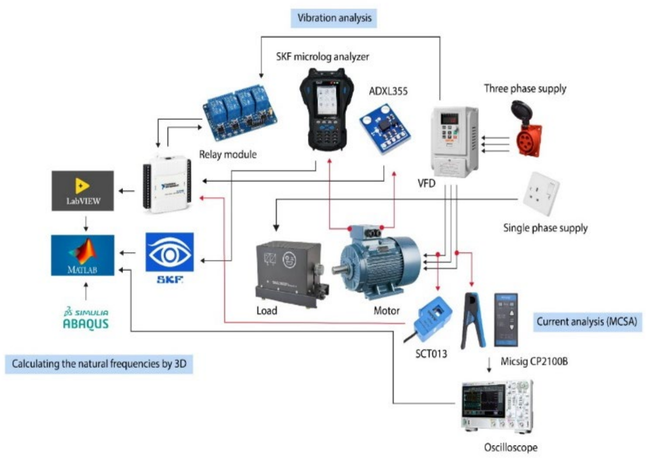

Fig. 3. Block diagram of noise analysis and fault detection

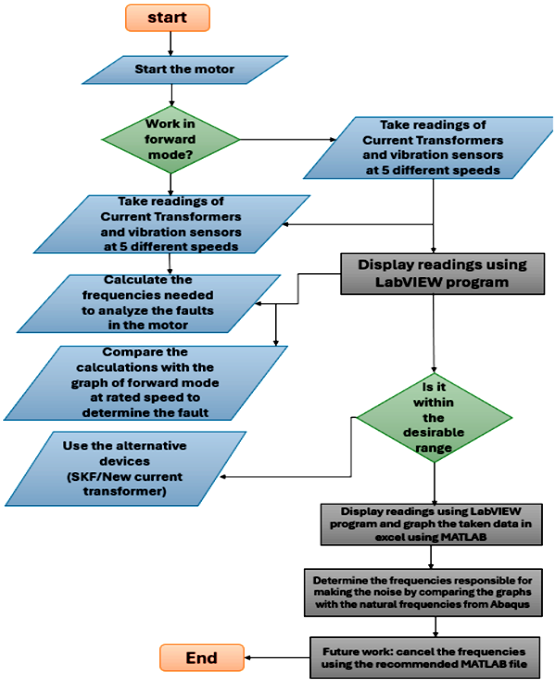

Fig. 4. Flowchart of the designed system

TABLE I. Comparson of the Utilized Current Transformers

Name of sensor	Micsig CP2100B	SCT013
Price	High price	Low price
Working Frequency	High frequency	Low frequency
Availability	Limited	Available
Usage	Needs an oscilloscope	Direct usage

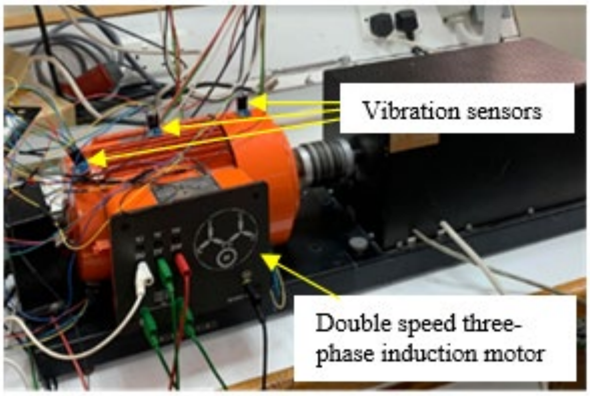

Fig. 5. Positions of vibration sensors

C. Software and Coding

Several software's were used in the analysis and can be summarized as follows:

LabVIEW: The most widely used test and measurement development software for scientists and engineers has been LabVIEW for more than 30 years. There is no program that boosts productivity more than LabVIEW. Its user-friendly graphical programming language allows to concentrate less on creating software and more on addressing technical problems. You may now utilize the industry-standard for test and measurement development for your own non-commercial projects thanks to the release of the LabVIEW Community version. Taking the data from the data acquisition needed to have a flexible software like LabVIEW, we used it because it is simple and easy to use specially on processing and handling the analogue signals, also it just needs the understanding of the main block for programming. Fig. 6 shows the LabVIEW simulated model.

MATLAB: The extracted data from LabVIEW was in Excel format, and by using MATLAB to plot the waves, in which the waveforms can be displayed in a clear view. Fig. 7 presents the flowchart of the implemented code.

Simulation with Finite Element Method (FEM) via Abaqus: Noise is created by a combination of mechanical and electrical causes; hence, estimating the inherent frequencies (natural frequencies) of the motor is required to determine if they were activated by the frequency components of the currents. This is done using Abaqus. Abaqus is a software suite designed for finite element analysis and computer-aided engineering jobs. It is often used to simulate and analyse the behaviour of structures, components, and materials under a variety of situations, including stress, heat, and other physical influences. Using the finite element approach the natural frequencies of the stator with the windings could be calculated. Fig. 8 shows the flowchart of Abaqus model. To simulate the stator in Abaqus, the stator is modelled using real dimensions as illustrated in Fig. 9.

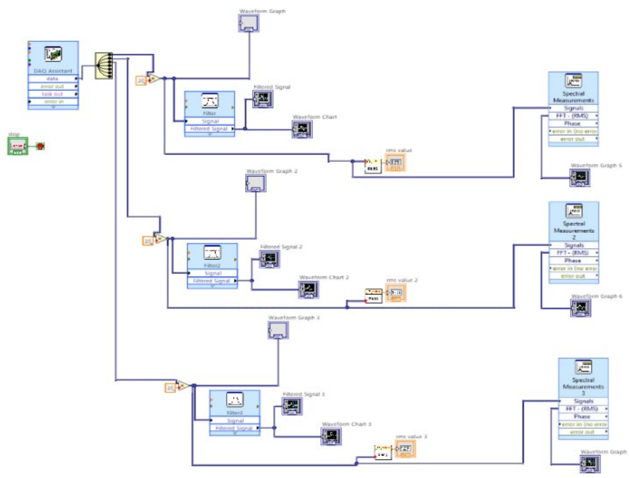

Fig. 6. LabVIEW simulated model

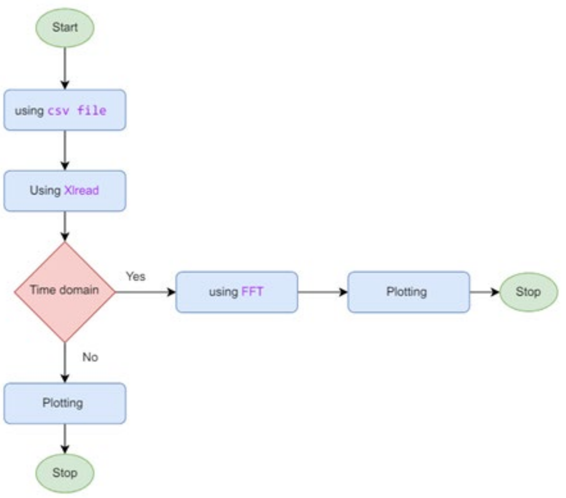

Fig. 7. Flowchart of the code

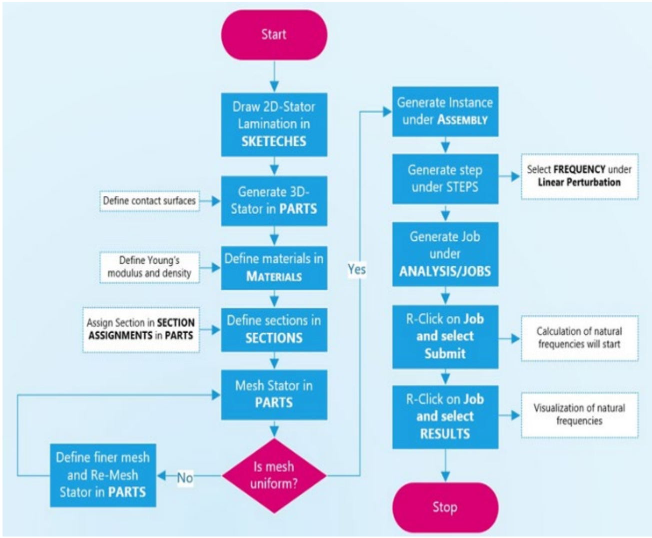

Fig. 8. Flowchart for Abaqus simulation

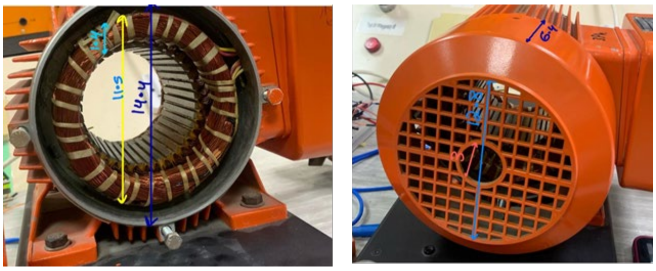

Fig. 9. Machine dimensions for Abaqus simulation

III. REULTS AND DUSCUSSIONS

The investigation comprised five constant speeds: 1740, 1998, 2015, 2560, and 2890 rpm, at which the noise is audible, and the results were consistent across all observed speeds. To compute the appropriate frequencies, several formulae will be utilized based on the kind of fault to be identified, with two fault categories discussed in this study.

a) Rotor Broken Bars:

For the case of broken bars, the equation is the following:

$$F_c = F_1 (1 \pm 2s) \quad (1)$$

Where: f_c is broken bars frequency, F_1 represents the supply frequency and s is the slip frequency. Calculating the slip, s by equation (2), where n_s is the synchronous speed:

$$s = (n_s - n)/n_s \quad (2)$$

$F_{c+} = 53.667$ Hz and $F_{c-} = 46.333$ Hz

Fig.10 shows fault analysis for broken bars using the reading from current transformers. From Fig. 10, a conclusion can be reached that the induction motor under test has broken bar's fault. The difference in the calculated frequencies and the experimental ones are due to the analysis taken in a not very isolated environment which can lead to a little bit of shift in the frequency.

b) Bearing Failures

The equations used for the case of bearing failures are given as following:

$$f_0 = 0.4{*}n{*}f_{rm} \quad (3)$$

$$f_1 = 0.6{*}n{*}f_{rm} \quad (4)$$

where, f_0=lower frequency, f_1=upper frequency, n = balls number in the bearing = 9.

Note that f_{rm} is the rotor mechanical frequency, 50 Hz, which will give us f_0 = 180 Hz and f_1= 270 Hz.

Based on these calculations and the measured data from the current transformers and then graphing it using MATLAB, it can be concluded that the induction motor does not have any bearing failure, because there was not any sudden change in the amplitude at the calculated frequencies. Fig. 11 illustrates the fault analysis for bearing failures via utilization of current transformers readings. The materials used to model the stator and the windings of the stator [27] are shown in Table II. Some of the natural frequencies of the stator with the windings [28-29] are shown in Fig. 12.

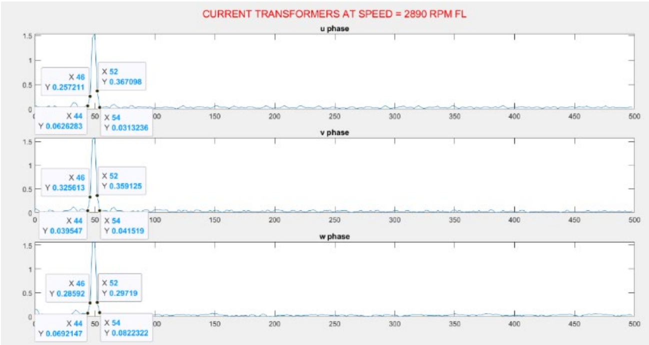

Fig.10. Fault analysis for broken bars via current transformers readings

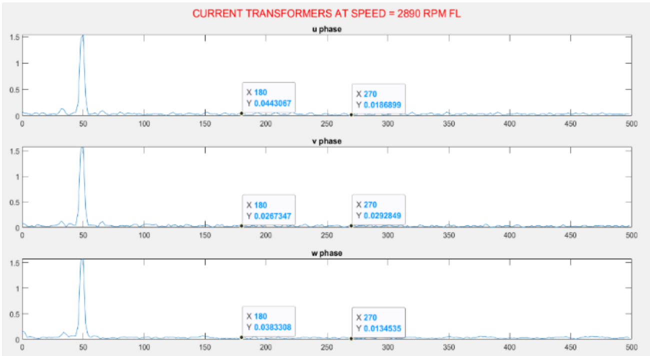

Fig. 11. Fault analysis for bearing failures using current transformers readings

TABLE II. MATERIAL CHARACHTERISTICS IS ABAQUS SIMULATION

Component	**Material**	**Density (kg/m^3)**	**Elastic: Isotropic**	
			Young's Modulus (N/mm^2)	**Poisson's Ratio**
Stator	Electric Steel	7850	210000	0.30
Windings	Copper	4827	210000	0.35
End-turn	Copper	8930	6200	0.35
Housing	Aluminium	2700	69000	0.33

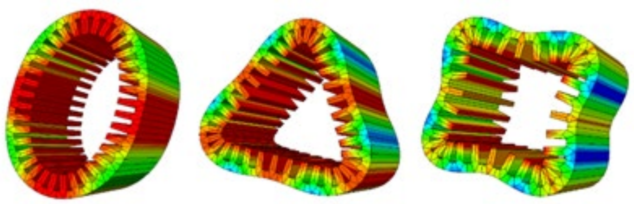

Fig.12. Natural modes of stator obtained via Abaqus (Frequencies: oval mode 98.25 Hz, triangle mode 264.92 Hz and square mode 481.51 Hz, respectively)

An estimation of the cost of the total elements is given in Table III as $334.56. The price would be different depending on the type of motor the tests will be done on.

TABLE III. MATECOST OF THE DESIGNED SYSTEM

ITEM	DESCRIPTION	QUANTITY	Price	TOTAL (with shipment)
40 Pin Breadboard Jumper Cable Wire	- Male to Male/Female to Female/Male to Female, 20CM - Male to Male, 20CM: - Female to Male, 20CM	2 2 2	$0.97 $1.39 $1.27	$5.46
140Pcs Preformed Breadboard Jumper Wire Kit	140pcs	1	$1.37	$2.09
diymore ADXL335 Tri-axis Accelerometer Sensor Module	Module	8	$2.76	$22.08
Micsig Oscilloscope Probe CP2100A AC/DC Current Probe	Probe	1	$259	$259
6mm Scotch 3m Double Sided Tape Adhesive	20mm	1	$2.25	$2.25
Digital Multimeter ZT100 4000 counts DC/AC	ZT100 with T1101	1	$8.68	$8.68
Current transformer	SCT013	7	$5	$35

IV. CONCLUSIONS

The investigations in this paper focus on two key areas aimed at reducing noise: electrical and mechanical. The mechanical component is vital for noise mitigation, as demonstrated through extensive testing of the motor to identify potential faults using various tools detailed in the accompanying report. Specific programs were also developed to accurately capture readings and frequencies at different speeds. The primary goal was to identify motor defects and effectively reduce the noise generated by the motor. It is recommended to use multiple vibration sensors to enhance the accuracy of the results, ensuring rigorous testing to validate the results integrity.

Future research can use MATLAB/SIMULINK to cancel noise frequencies. Noise will be reduced via utility of vibration sensor analysis, SKF, current transformers, and FEM software for modes estimation. Noise can be eliminated by targeting frequencies in the current waveforms that occur due to mechanical or electrical problems.

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