26th IMEKO TC4 International Symposium
24th International Workshop on ADC and DAC Modelling and Testing
IMEKO TC-4 2023
Pordenone, Italy / September 20-21, 2023

Current Measurements for Fault Diagnosis in Induction Motors

Simone Mari, Andrea Credo, Giovanni Bucci, Fabrizio Ciancetta, Edoardo Fiorucci, Andrea Fioravanti

University of L'Aquila, Dept. of Industrial and Information Engineering and Economics, Monteluco di Roio, 67100, L'Aquila (AQ), Italy
Correspondence: simone.mari@graduate.univaq.it

Abstract **– Predictive maintenance has become increasingly important in modern industry as it can prevent unplanned production interruptions and reduce maintenance costs. This is especially important for companies working with expensive and complex machinery, such as those used in manufacturing, transportation, and energy. Predictive maintenance uses sensors and data analytics to monitor equipment performance and predict when a failure or breakdown might occur. This paper presents a preliminary study on the use of absorbed currents measurement of a three-phase induction motor aimed at electrical fault diagnostics. In detail, a 4-pole high efficiency induction motor with 3kW of rated power was simulated in the Ansys Electronic Desktop environment. The simulated operation is with direct mains power supply. The motor was simulated initially at no load, then load torque values of 20%, 40%, 60%, 80% and 100% of rated value were evaluated. The currents drawn on the three phases were evaluated with a computational step of 500 µs, corresponding to a sampling rate of 2 kHz. The same simulations were subsequently repeated by reproducing five different fault conditions in the motor. Therefore, an analysis of the waveforms of the absorbed currents is provided and a diagnostic system based on their analysis is proposed.**

I. INTRODUCTION

With the development of Industry 4.0, there has been a significant increase in the complexity and efficiency of systems in the industrial sector. Electric motors provide the main source of energy for machinery and must be in excellent condition over time to maintain high levels of productivity. The various components in the motor may be subject to both electrical and mechanical failures, causing slowdowns in the company's production process and significant economic losses. To verify the correct functioning of the motor and the condition of the components, various maintenance strategies are implemented, which differ in machine downtime and cost [1],[2]. By using the correct maintenance strategy and intervening only when necessary, machine productivity time can be optimized, costs can be reduced for the company, and operational safety can also be improved [3],[4].

The literature proposes numerous systems for fault detection on induction motors, utilizing measurements of both current and vibration and acoustic emission. However, these methods primarily focus on detecting mechanical faults such as damaged bearings or misalignment. The potential of using current measurement as a diagnostic system for electrical faults has not been extensively explored, leaving a gap in the literature. To address this, this paper presents a novel approach for diagnosing electrical faults by measuring phase currents. A 4-pole high efficiency induction motor with 3kW of rated power was simulated under varying load conditions, and different electrical fault conditions on both the stator and rotor were analyzed in the simulations. The waveforms of the absorbed currents were thoroughly examined and compared across all conditions. This enabled the creation of a diagnostic system that can effectively indicate the presence of faults. The proposed method has the potential to provide valuable insights into the detection and diagnosis of electrical faults in induction motors, which can improve the overall efficiency and reliability of the system. By identifying faults early on, necessary repairs can be made before they escalate, reducing downtime and maintenance costs. Overall, this research contributes to the development of more comprehensive and effective fault detection systems for induction motors.

II. ELECTROMAGNETIC SIMULATION

The validation of the proposed method is based on Finite Element Analysis (FEA) which simulates an electromechanical transient of the induction motor.

The electromechanical transient simulation considers the computation of the torque with FEA and the speed is computed considering the differential equation of the mechanical rotational speed considering the rotor and possible load inertia, the initial speed, and the damping coefficient. The considered motor is a 4-pole high-efficiency induction motor with 3kW of rated power. The main parameters of the motor are reported in Table I.

The adopted mesh and the geometry of the motor are shown in Fig. 1. The element size has been selected in order to speed up the burden of computational time maintaining a good approximation in the results. This is necessary because, in order to evaluate all phenomena correctly, it is necessary to have a big simulation time with a reduced time step.

Table 1. Main Induction Motor Parameters.

Parameters	**Unit**	**Value**
Phase voltage (rms)	*Vrms*	240
Phase Current	*Irms*	7.7
Number of poles		4
Stack length	*mm*	130
Outer Stator Diameter	*mm*	240
Inner Stator Diameter	*mm*	7.7
Wire Size	*mm*^{2}	240
Number of turns per phase		198
Number of Stator Slots		36
Number of Rotor Slots		28

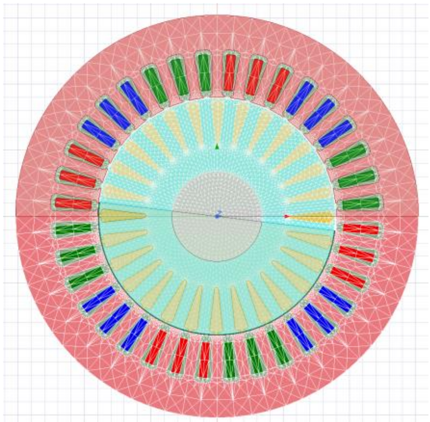

Fig. 1. Model and mesh of the simulated Induction Motor

The simulations include a first period in which the motor reaches its steady state at no load conditions; after that, it has been introduced a first torque step of 20% of rated torque (4 Nm). This torque value is maintained for 4s in order to reach the steady state; therefore, further torque steps with the needed time for obtaining the steady state. The values for the torque steps are 40% (8 Nm), 60% (12 Nm), 80% (16 Nm), and 100% (20 Nm) and the time steps are 2s for the 40% of torque step and 1s for the others. In the final version this time step will be increased to better evaluate the results in steady state operation.

In Figure 2 it is reported the speed, the load and the electromagnetic torque of the simulated motor without faults.

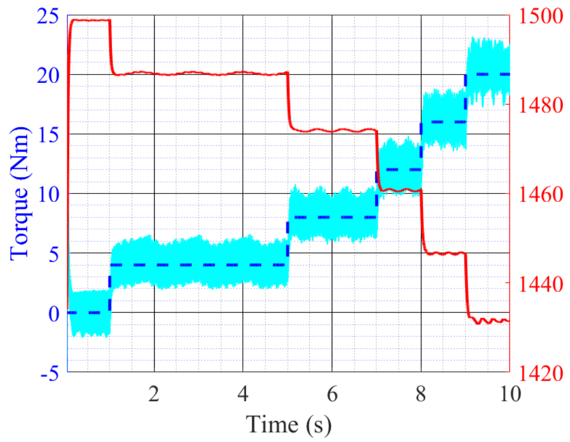

Fig. 2. Speed, load and torque without faults

From the simulation results it is possible to see a high-frequency torque oscillation and a little low-frequency speed oscillation, mainly due to the normal operation of the induction motor supplied with a constant frequency by the grid. With the FEA also some of the typical faults in the electrical machines have been simulated:

1) A short coil in the phase
2) Two short coils in two different phases
3) A no-filled rotor slot
4) A short coil in the phase with a no-filled rotor slot
5) Two short coils in two different phases with a no-filled rotor slot

In Figure 3 it is reported, as an example, the speed, the load and the electromagnetic torque of the simulated motor with one of the presented faults, in particular a no-filled rotor slot.

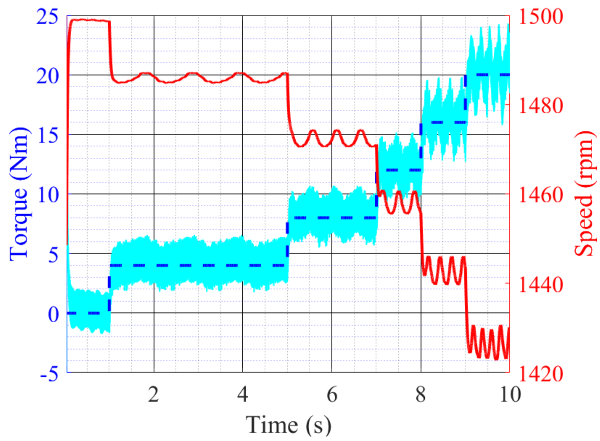

Fig. 3. Speed, load and torque with faults

It is clear from the figure that the fault introduces a higher distortion in the torque (in the high and low frequencies) and speed (in the low frequencies). To this further oscillations has to be associated with phase current oscillations which can be measured during the machine operation. The idea at the basis of this paper is to evaluate how much the faults impact the high and low frequencies oscillation in the phase currents and associate to these values the associated fault.

III. DATA ANALYSIS

To evaluate the results of the simulation described above in the first instance, transient states are filtered out and steady-state conditions are analyzed independently. The signals of the absorbed currents on the three phases were processed by Fast Fourier Transform (FFT) in order to evaluate their harmonic content. As shown in Fig. 4, the current drawn by the motor is predominantly a sine wave at 50 Hz, the harmonic content is definitely paltry to be appreciated for diagnostic purposes. The only effects reflected by faults on the spectrum of the absorbed current can be found in a harmonic cluster around the fundamental frequency at 50 Hz, in the case of a no-filled rotor slot, and an amplitude variation of the same 50 Hz, in the case of a short coil in the phase. In particular, note that the harmonic cluster present in the case of a no-filled rotor slot is due to an amplitude modulation of the current introduced by the fault. Fig. 5 shows the current drawn by Phase 1 of the motor when simulated with a no-filled rotor slot and load torque of 80 Nm. As a result of these evaluations, it was decided to implement a diagnostic system to detect faults and anomalies on induction motors by evaluating the relationship between the rms values of the different phases and the presence of a low-frequency modulating signal. In order to evaluate the modulating signal, the simulation was repeated to obtain steady states of 4 s each, which for a computational step of 500 μs corresponds to 8000 points. The simplest way to demodulate a signal is to obtain through a diode the absolute value of the received signal and then low-pass filter it, removing the high-frequency component. First, the diode is simulated by obtaining the absolute value of the current signal. Then, the output of the diode is filtered. For this purpose, a Butterworth filter is designed using Python's SciPy library. Finally, the signal mean is removed. Table 2 shows the frequency and amplitude values of the modulating signals obtained by demodulation of the absorbed current. Only the values for fault conditions 3), 4), 5) are reported since fault conditions 1) and 2) do not report any amplitude modulation. Fig. 6, on the other hand, shows a graphical indication of the phase-to-phase ratios of the rms values of the currents. it is evident that fault condition 3) has no discriminating factor compared with healthy motor conditions, while in all other cases the fault condition can be detected by imposing appropriate upper and lower limit values.

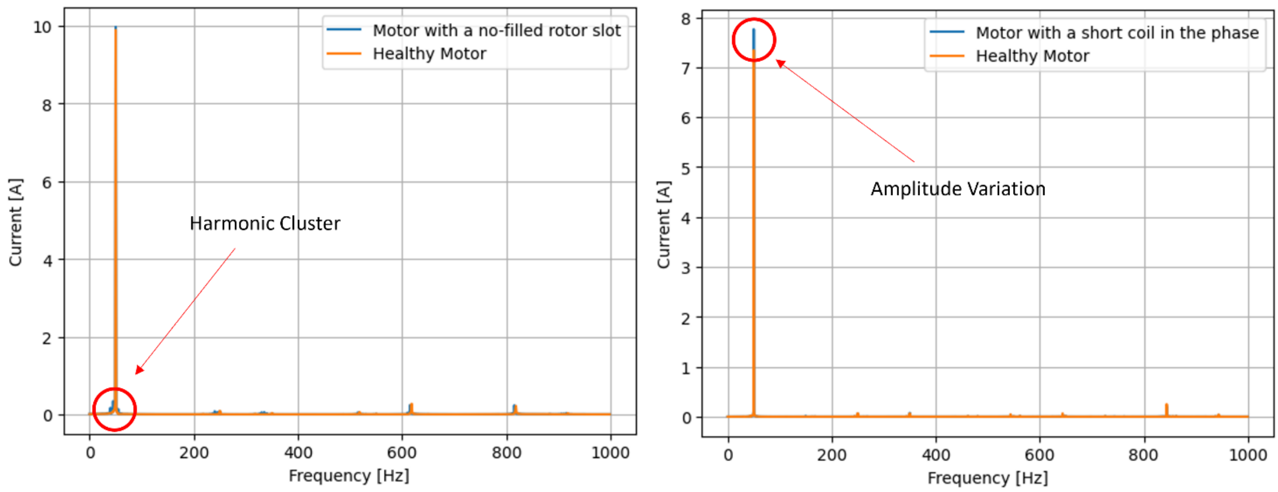

Fig. 4. Comparison of the harmonic contents of the absorbed current of the healthy motor compared with motors in which fault conditions were simulated.

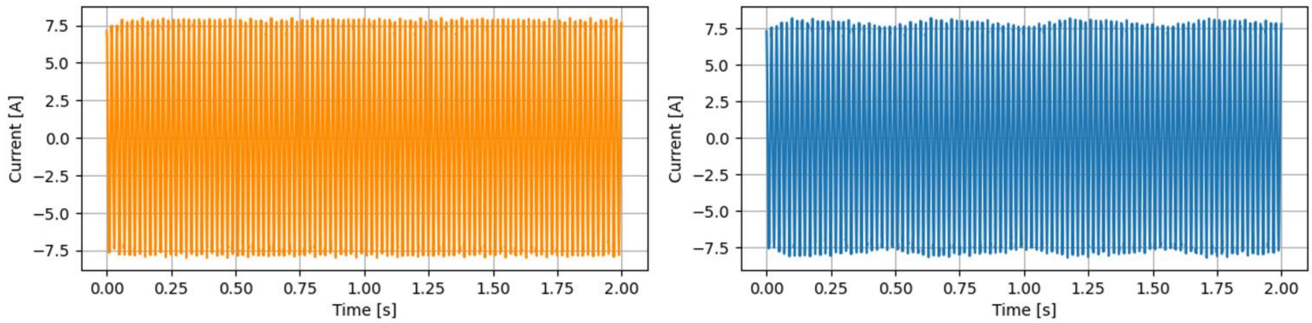

Fig. 5. Currents absorbed by the Phase 1 of the healthy motor (left) and the motor with a no-filled rotor slot (right).

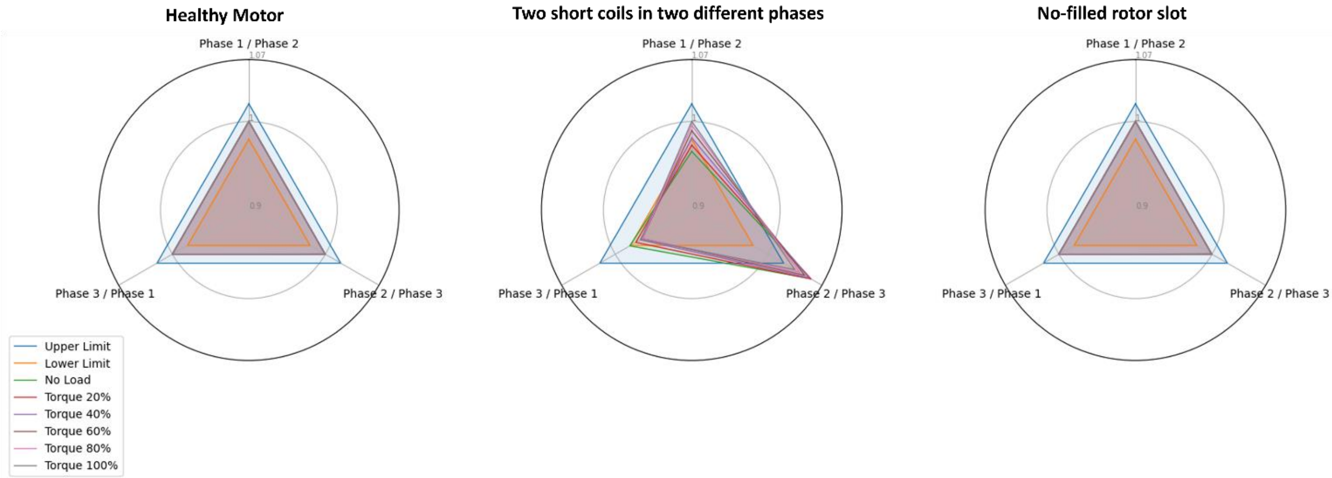

Fig. 6. Relationship between rms values of currents on different phases for healthy motor (left), motor with two short coils in two different phases (middle) and motor with no-filled rotor slot (right).

Table 2. Frequency and amplitude of the modulating signal extracted from the absorbed current.

		Fault Condition 3		Fault Condition 4		Fault Condition 5	
		f [Hz]	Amp. [A]	f [Hz]	Amp. [A]	f [Hz]	Amp. [A]
Torque	20%	0.93	1.20	0.93	1.20	0.93	1.20
	40%	1.95	0.79	1.95	0.76	2.00	0.73
	60%	2.98	1.01	2.98	0.95	2.98	0.86
	80%	3.61	0.64	3.61	0.63	3.61	0.62
	100%	5.19	1.15	5.19	1.28	5.19	1.19

IV. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this paper, a preliminary study was conducted to explore the potential of using the measurement of absorbed currents of a 3-phase induction motor for electrical fault diagnosis. The study involved simulating a high-efficiency 4-pole induction motor with a power rating of 3 kW in the Ansys Electronic Desktop environment. The motor was simulated under different load conditions, and the currents drawn on the three phases were evaluated with a high sampling rate of 2 kHz. The study also simulated five different fault conditions in the motor and analyzed the waveforms of the absorbed currents. The results showed that the rotor and stator faults are reflected differently on the current absorptions, and the relationship between the rms values of the different phases and the presence of a low-frequency modulating signal was evaluated. The study successfully developed a system that allowed all five simulated fault situations to be discriminated. Future research will involve measuring currents on real induction motors and reproducing fault conditions to validate the proposed diagnostic system in real-world situations. The study has promising implications for the development of efficient and accurate electrical fault diagnosis systems for induction motors, which could improve maintenance practices and reduce downtime in various industries.

REFERENCES

[1] H. Henao et al., "Trends in fault diagnosis for electrical machines: A review of diagnostic techniques," IEEE Ind. Electron. Mag., vol. 8, no. 2, pp. 31–42, Jun. 2014.

[2] F. C. Trutt, J. Sottile, and J. L. Kohler, "Detection of AC machine winding deterioration using electrically excited vibrations," IEEE Trans. Ind. Appl., vol. 37, no. 1, pp. 10–14, Jan. 2001.

[3] G. Bucci, F. Ciancetta, A. Fioravanti, E. Fiorucci, S Mari, A. Silvestri, "Online SFRA for Reliability of Power Systems: Characterization of a Batch of Healthy and Damaged Induction Motors for Predictive Maintenance". Sensors 2023, 23, 2583,

[4] D. Siyambalapitiya, P. McLaren, "Reliability improvement and economic benefits of online monitoring system for large induction machines". IEEE Trans. Ind. Applicat. 1990, 26, 1018–1025.