Finite Element Analysis of Magnetic Flux Density in Digital Twin of Electric Motor with Rotor Fault

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***Abstract*— This paper presents the effects analysis of the fault evolution of broken rotor bars on the magnetic flux density of an induction motor. For this, finite element analysis of the commercial motor digital twin, operating in four different faulty conditions, is used to evaluate the spatial distribution of the flux density.**

Keywords—broken bars fault; digital twin; finite element method; induction motor; magnetic flux

I. Introduction

Most industrial processes depend on an electric motor. Among all the types available on the market, the most popular is the three-phase induction for having characteristics such as: high efficiency, simple construction, robustness, high starting torque, low maintenance and convenient power-volume ratio. However, these motors are subject to malfunction and unexpectedly stop working. These faults, directly or indirectly, cause loss in the most diverse sectors [1].

Currently, reducing downtime and reliable operation of electric motors is strategically very important, and for that, early diagnosis of motor faults is highly demanded. In this sense, with the implementation of Industry 4.0, automated predictive maintenance has proved to be an essential component in the consolidation of this new industrial revolution.

Broken Rotor Bars (BRBs) are responsible for about 10% of induction motor faults. Usually, this type of failure is caused by high mechanical stresses, high temperatures, problems in the casting or during the manufacturing process. Commonly, this fault starts as a high resistance that causes temperature increase, progresses to cracks or small holes in the rotor bars, which evolve to a complete rupture of the bar [2].

Many fault diagnosis methodologies are based on changing the operating behavior of induction motors. For this, it is necessary to monitor one or more machine variables, the main ones being: mechanical vibration, temperature, torque, output power, acoustic noise, voltage, current, magnetic flux in the air gap, stray flux, electromagnetic field and speed. [3].

Studies using magnetic flux monitoring, either in the air gap or external to the motor, have been proposed and shown to be effective in fault diagnosis [4]. For this, researchers usually use different methodologies for diagnosis, such as: tools for signal analysis in the frequency domain, data processing algorithms, artificial intelligence, and machine learning [2]. However, regardless of the technique used, in order to obtain a correct and effective fault diagnosis, signals of the same healthy and faulty motor are required.

These signals are basically obtained in two ways: collecting signals from machines operating in the industry or in the laboratory. Both strategies have limitations and/or drawbacks, have high costs and require destructive testing. In this sense, the possibility of computer simulation of faulty machines appears as an alternative to traditional experimentation methods. Among the simulation techniques, the Finite Element Method (FEM) has been consolidated as an important tool for the electrical machines analysis, as it can provide accurate modeling for various conditions of the machine [1], [2], [3], [4], [5].

In this context, the present work presents the magnetic flux density analysis of the detailed FEM model of an induction motor, called digital twin. Simulation results from four different conditions (healthy, 1, 2 and 4 BRBs) are analyzed to demonstrate the effects caused by the evolution of broken rotor bars fault severity.

II. Methodology

Using the FEM, the digital twin of a commercial three-phase induction motor was implemented, with 750 W (1 hp) power, 60 Hz and rated speed of 1730 rpm. The motor in question was modeled in detail in two-dimensions, that is, all its parts were designed and characterized according to their real characteristics.

The complete model, without divisions into symmetry axes, was implemented in order to enable testing for all types of faults. It should be noted that the model under discussion considers the rotor bars inclination present in the real motor.

To represent the skew of a slot, present in the real motor, the model was divided into slices. More specifically, five slices were considered along the model depth.

The boundary condition used in the simulations assumes that the fields will only disappear at points far from the stator. This fact makes it possible to carry out fault studies based on measurements of fields external to the motor.

To implement the defect of broken bars in the rotor, the geometries, which represent the bars where the breakage will be simulated, had the material that composes them changed from aluminum to vacuum. Thereby, reproduction of the effects that occur in real situations is ensured as the current circulation through these bars is blocked.

Furthermore, the digital twin presented in this study considers effects of the motor real operating temperature on the most affected elements, such as the stator windings, the rotor bars, and end rings.

III. Results and discussion

In this section, the results presented are of the simulation of digital twins modeled in finite elements, described above, operating in steady state with nominal load torque.

Fig. 1 shows the spatial distribution of the magnetic flux density in 4 different conditions (healthy, 1, 2 and 4 BRBs) at the same instant of time. Broken bars are indicated by black arrows in the figure.

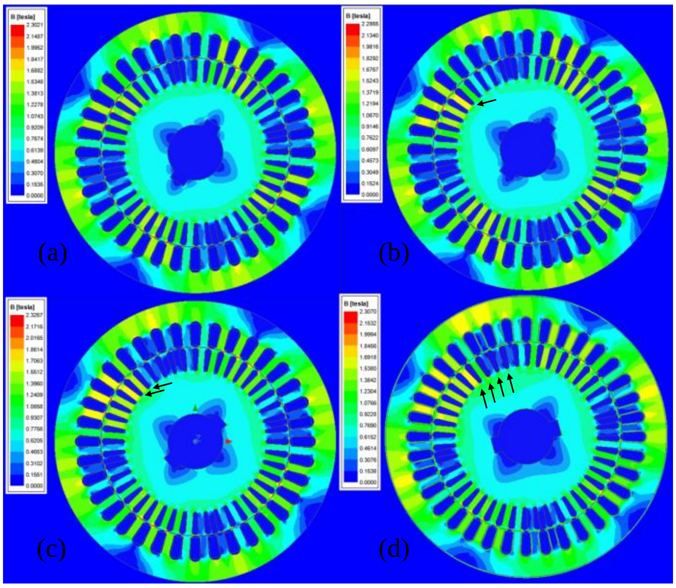

Fig. 1. Spatial distribution of magnetic flux density for (a) healthy condition, (b) with 1 BRB, (c) 2 BRBs and (d) 4 consecutive BRBs.

It can be seen in Fig. 1 (a), in the healthy condition of the motor, the spatial distribution of the magnetic flux density is symmetrical. However, with an initial failure of only one broken rotor bar (Fig. 1 (b)), the distribution already becomes asymmetrical. Still, observing the conditions of 2 BRBs and 4 BRBs, respectively in Fig. 1 (c) and (d), it is noticed that the increase in the fault severity makes the asymmetry in the flux distribution even greater.

For the rotor fault cases presented in Fig. 1, it is possible to verify the greater saturation of the magnetic flux density in the stator and rotor teeth in places close to the broken bars, and that this phenomenon is aggravated with the increase in the severity of the fault. This is in agreement with the observations established in the technical literature [2], [3] e [5].

When a motor has a broken rotor bar fault, It is observed excessive current flow concentrated in the adjacent bars instead of the broken bar, consequently, the magnetic field pattern is distorted. These adjacent bars become more susceptible to thermal stress due to overheating causing additional bar breakage.

In regions where the flux density is increased, the core loss density is higher compared to other regions of the machine. These factors result in a degradation in the induction motor mechanical performance, causing vibration, oscillation in torque and speed.

If the motor continues to operate under these conditions, the severity of the BRBs fault increases and the damage can spread to other faults. This can lead to an unexpected machine shutdown, causing significant revenue loss during downtime, as well as in repair or replacement costs.

IV. Conclusion

This work presented the effects evolution analysis of the broken rotor bars fault on the magnetic flux density of a three-phase induction motor. For this, the digital twin of a commercial motor was used. The digital twin is a complete and detailed FEM model, which considers the effect of temperature on its components and the skew of the rotor bars.

The digital twin simulation results showed the asymmetry caused in the spatial distribution of the magnetic flux density because of the broken rotor bars fault. Also, the saturation of the magnetic flux density in the stator and rotor teeth was observed in places close to the broken bars. Still, it was found that these phenomena are aggravated with the evolution of the BRBs fault severity.

Finally, the possibility of using the digital twin for fault diagnosis based on magnetic flux monitoring through simulation data is suggested. In this way, it is possible to analyze the most diverse types and severities of failures, without the need for destructive tests, high financial cost with bench, equipment, sensors, and motors.

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