ONLINE DETECTION OF ROTOR ECCENTRICITY IN SQUIRREL CAGE INDUNCTION MOTORS

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Abstract: Squirrel cage induction motors are the most common electric machines employed in industrial environments. Periodic online condition monitoring should be performed for early electrical and mechanical fault detection, thus preventing further deterioration of the machine in case a fault is present. Motor current signature analysis is usually used for online fault detection and different algorithms that fall in this category have recently been proposed. In this paper, the spectrum of the RMS value of the stator current is used to detect the presence of rotor static eccentricity.

Key words: Induction motors, condition monitoring, online fault detection, rotor eccentricity

1. INTRODUCTION

In industry the most common electric machine is the squirrel cage induction motor, due to its robustness and simplicity. Despite their robustness, faults occur, with broken bars and rotor eccentricity being most common. If these faults are detected in an early stage, it is possible to prevent further deterioration of the machine thus saving running costs by increasing the life-span of the machine and reducing its offline time. To achieve this, periodic condition monitoring should be performed, but to avoid having to remove the machine from its working place, monitoring should be done online.

In general, condition monitoring schemes have concentrated on sensing specific failures modes in one of three induction motor components: the stator winding, the rotor winding, or the bearings. Thermal and vibration monitoring have been used for decades [1]. However, vibration transducers are expensive and care should be taken into account for mechanical installation and signal transmission. Similar problems exist while working with other sensors, like speed and temperature sensors. Therefore, most of the recent research has been directed toward electrical monitoring of the motor with emphasis on inspecting the stator current of the motor [2].

A wide variety of non intruding condition monitoring techniques has been introduced over the last decade. Online diagnostic tools based on the motor current signature analysis (MCSA) have been developed [2-8]. This technique has several advantages since it is usually cheaper and easier to implement than other known techniques. Other methods have been proposed, but their computational complexity is a major drawback. Different algorithms to analyze the stator currents such as principal component analysis [9] and Park's vector approach [10] have also been proposed. Most of the present techniques require the user to have some degree of expertise in order to distinguish a normal operation condition from a potential failure. Some authors propose the use of soft computing tools [11-16]. However, many of these tools require a prior identification of the system, and only then they are able to identify some faulty situation. Recently, an approach based on the spectrum analysis of the stator currents RMS value was proposed as a method for early detection of broken bars [17]. The previous method is easy to implement and achieved good detection results.

Rotor broken bars and eccentricity often show up simultaneously, therefore it is important to evaluate how a given algorithm performs in the presence of these types of faults. In this paper, the method proposed in [17] is tested on a machine with rotor eccentricity. Although, static and dynamic eccentricity can occur, in this paper the focus is in the effects of static eccentricity. Experimental results are used to analyze the proposed method.

This paper is organized as follows. Section 2 describes the proposed on-line algorithm detection. Section 3 reports on the experimental results of the proposed approach. Conclusions are presented in section 4.

2. ONLINE DETECTION ALGORITHM

The algorithm used to detect an eccentricity fault is based on the monitoring and analysis of the stator currents. In a healthy induction motor, the stator currents will be composed of a single frequency component that is equal to the electrical network supplied current frequency *f*. However, when faults are present, characteristic frequencies appear on the currents spectra. For rotor eccentricity, these frequencies appear at [18]

$$f_{ec} = f \pm m f_r , \quad m \in 1,2,3,\ldots \tag{1}$$

where f_r is the rotational frequency of the machine, which is highly dependent on the number of poles. The rotational frequency is also slightly dependent on the loading conditions, due to the load dependent rotor slip.

The proposed algorithm for the processing of the stator currents is based on obtaining the RMS values of the currents and then analyzing its spectral content. When the motor is healthy, the RMS value of the stator current is constant and its spectrum only contains a DC component. However, when eccentricity exists, the stator currents present a high amplitude frequency component at the supply frequency which may drown the small amplitude frequency components at frequencies given by (1). The motor rotational speed needs to be measured to find the exact location of these components, which can be avoided by applying the proposed algorithm. In fact, the RMS value will no longer be constant, but will have small oscillations related to the rotor eccentricity characteristic frequencies, which will clearly appear on its spectrum.

The algorithm is schematically shown in Figure 1.

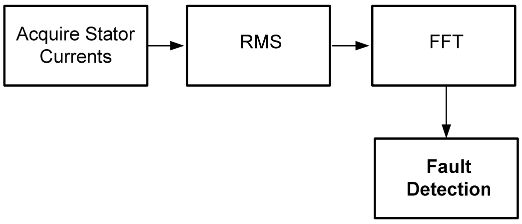

Fig. 1. Method used to detect rotor eccentricity faults.

3. EXPERIMENTAL RESULTS

In this section, the proposed algorithm is applied to an induction motor with an adjustable shaft that can be used to impose different levels of eccentricity. The 0.75 kW, 230/400 V, 50 Hz induction motor has 4 poles resulting in a rotational frequency $f_r \approx 25\,\text{Hz}$. The induction motor is attached to a shaft by a drive shaft as shown in Figure 2. The shaft is supported by two bearings and the bearing farthest from the engine can slide on a ruler imposing rotor eccentricity.

Fig. 2. Induction motor and adjustable shaft used to test rotor eccentricity faults.

The stator current is acquired using the current transducers LEM LA25-NP and a data acquisition board NI USB-9215, with sampling frequency $f_s = 50\,\text{kS/s}$, connected to a computer. The current transducer sensors are shown in Figure 3.

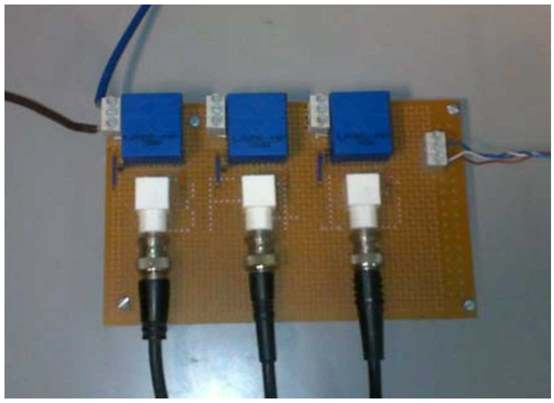

Fig. 3. Stator current measurement sensors.

This setup was used to measure the stator currents of the motor with a deviation, from the center, of 0.4 mm in the bearing that is farthest from the motor. Also, for comparison terms, measurements were performed without shaft deviation, corresponding to an healthy motor. Figure 4 presents the acquired current of a single phase when there is no rotor eccentricity, while Figure 5 shows the same stator current when there is rotor eccentricity. By comparing the time domain Figures 4 and 5 there is no evidence of rotor eccentricity faults.

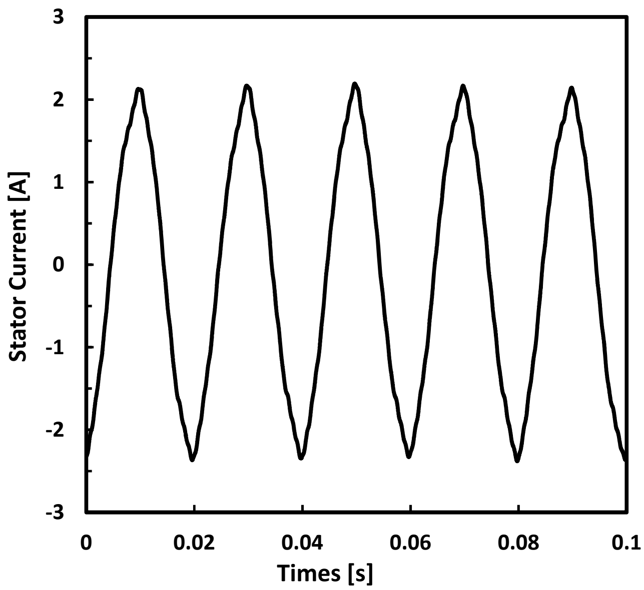

Fig. 4. Experimental stator current of the machine without rotor eccentricity.

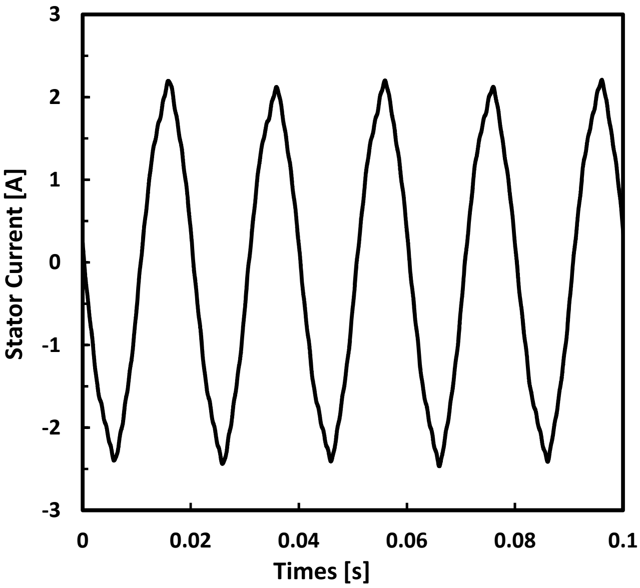

Fig. 5. Experimental stator current of the machine with rotor eccentricity.

The application of the Fast Fourier Transform (FFT) to the acquired currents yield the results presented in Figures 6 and 7. In either case, the 50 Hz component of the supply frequency is clearly seen in the current spectrum. However, in the case of rotor eccentricity it is not clear that eccentricity characteristic frequencies are present close to 25 Hz, 75 Hz, 100 Hz, etc.

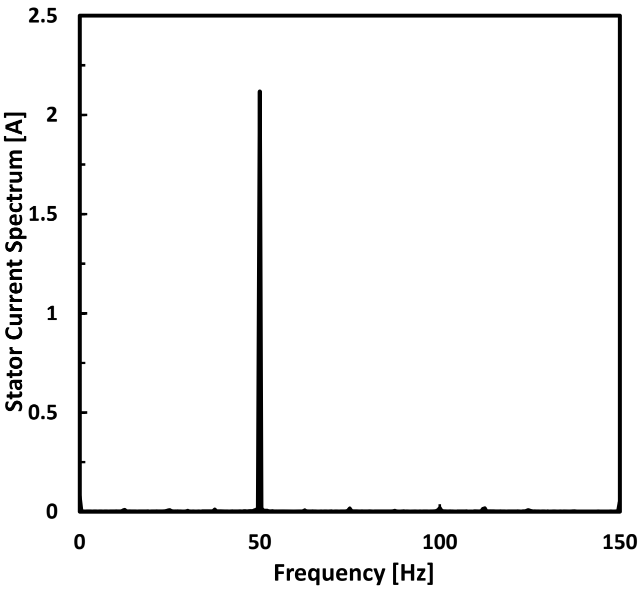

Fig. 6 Amplitude spectrum of the acquired stator current of the machine without rotor eccentricity.

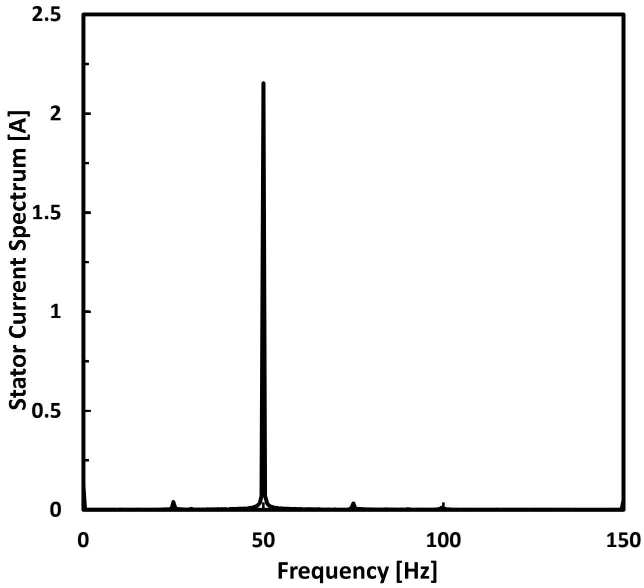

Fig. 7 Amplitude spectrum of the acquired stator current of the machine with rotor eccentricity.

The RMS value of the acquired stator current was computed for both cases. For the case without rotor eccentricity, shown in Figure 8, there are small oscillations of the RMS value. Small oscillations also appear when there is rotor eccentricity, as presented in Figure 9. Although it is apparent that, in the last case, the plotted wave has a period of roughly 40 ms, corresponding to a frequency of 25 Hz, this analysis is best performed in the frequency domain. Thus, the spectrum of the RMS value of the stator current is shown in Figure 10 for the case without rotor eccentricity, and in Figure 11 for the case with rotor eccentricity. The supply frequency was converted into a DC component that was removed from the plot, remaining only the oscillations possibly due to motor faults.

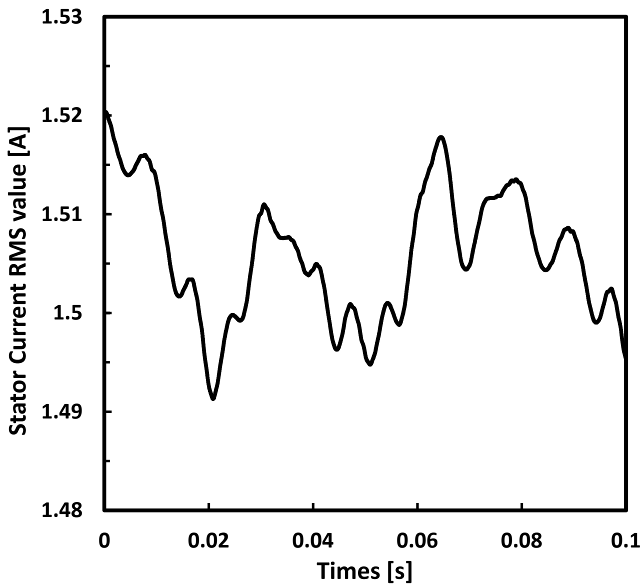

Fig. 8 RMS value of the stator current a motor without rotor eccentricity.

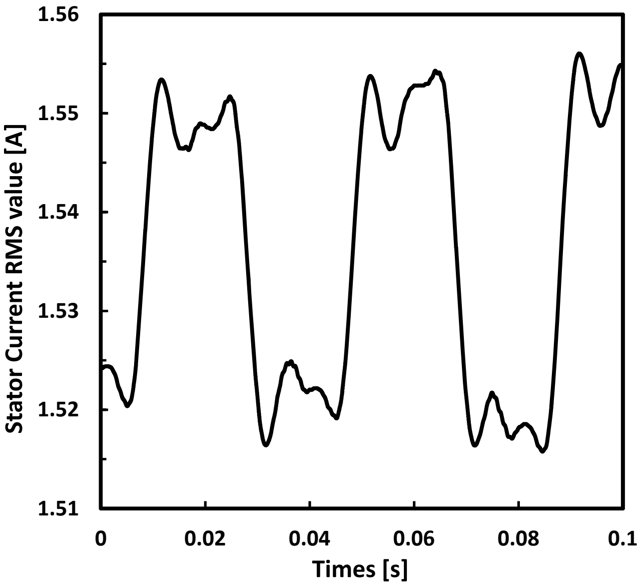

Fig. 9 RMS value of the stator current of a motor with rotor eccentricity.

In Figure 10, although there was no visible rotor eccentricity, a small frequency component at 25 Hz is present along other perturbations, implying that the rotor is not perfectly aligned. However, Figure 11 which corresponds to an imposed rotor eccentricity presents a higher amplitude frequency component at around 25 Hz. Frequency components at 75 Hz and 125 Hz are also present, clearly showing the existence of rotor eccentricity. These components were hidden by the high amplitude of the current's supply frequency. It is clear that the severity of the eccentricity can be assessed by the amplitude of the frequency component close to 25 Hz.

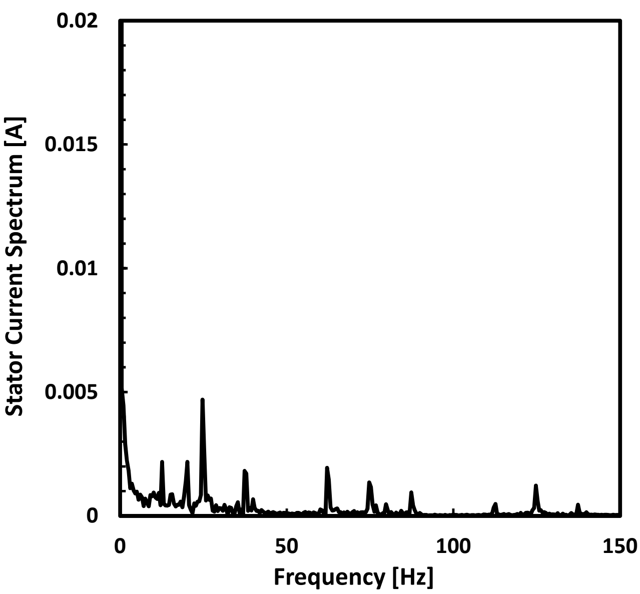

Fig. 10. Amplitude spectrum of RMS value of the stator current the machine without rotor eccentricity.

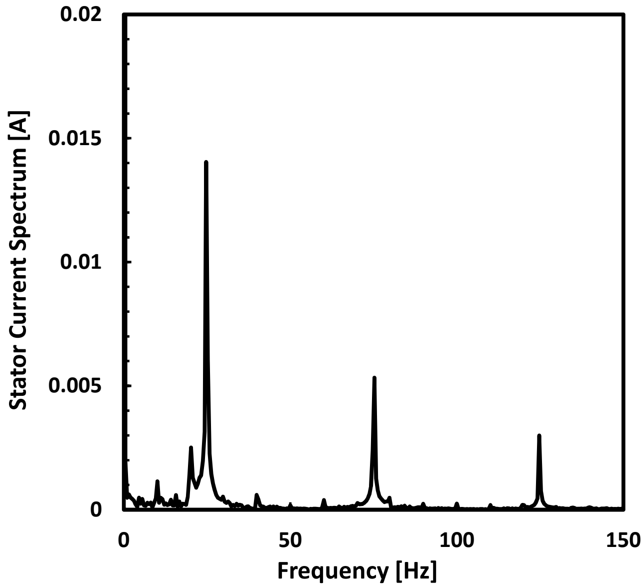

Fig. 11. Amplitude spectrum of RMS value of the stator current the machine with rotor eccentricity.

4. CONCLUSION

In this paper, the performance of an induction motor online fault detection system is analyzed. The algorithm used is based on the spectral analysis of the RMS value of the stator currents. This algorithm had been previously tested for rotor broken bars, and is used here to detect rotor eccentricity which usually appears simultaneously with rotor broken bars. Although different methods can be used to detect rotor eccentricity, this algorithm should also be tested in this case. It was shown that the algorithm can be used to detect rotor eccentricity.

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