DETECTION OF ECCENTICITY AND BROKEN ROTOR BAR FAULTS BY MEANS OF MONITORING OF CURRENT AND MAGNETIC FLUX DENSITY SPECTRUMS

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Abstract: In this paper, faults detection and classification using motor current signature analysis (MCSA) and monitoring of magnetic flux density in air-gap of the machine is presented. A series of simulations using the models of three phase cage induction motor performed in different fault condition, such as static, dynamic and mixed eccentricity and broken rotor bars. Designed models were implemented with the help of finite element method to provide data that makes it possible to diagnose presence of any type of fault, as well as to analyze obtained and calculated results. Models were designed on the basis of characteristics and parameters of real motor. The results are illustrated in the form of graphs that makes visible illustration for effectiveness of the used diagnosis method.

Keywords: air-gap eccentricity, broken rotor bar, faults, induction motor, motor current signature analysis, harmonics, principal spot harmonics, characteristic frequencies, magnetic flux density

1. INTRODUCTION

Rotating electrical machines may be characterized by high importance for different industries in the whole world. Since the time of the first application they have become crucial for any industrial system in a wide range of power, starting from a few watts and up to several megawatts.

Early detection of incipient faults and their correct diagnosis allow avoiding harmful and wrecking outcome, and preventing losses on the financial side [2].

A significant part of the faults in induction machines is the eccentricity ones. Machine eccentricity is characterized by unequal air-gap that exists between the stator and rotor. In the case when eccentricity enlarges, unbalanced radial forces that also can be known as unbalanced magnetic pull or UMP, can cause stator to rotor rub. There exist two types of air-gap eccentricity: the static air-gap eccentricity and the dynamic one. On practice both static and dynamic eccentricities tend to coexist. An inherent level of static eccentricity exists even in newly manufactured machines due to manufacturing and assembly method [3]. A steady unbalanced magnetic pull (UMP) in one direction can be result of this. During the operation, this may lead to bent rotor shaft, bearing wear and tear etc, and can also result in some degree of dynamic eccentricity. In the case when these effects are not detected on early stage they can lead to rotor hub which in turn will cause major breakdown of the machine.

In the paper electrical condition monitoring using MCSA is chosen. As well as the current signal, the magnetic flux density in the air-gap were also examined.

2. FAULT EFFECT ON FREQUENCY SPECTRUM

2.1. AIR-GAP ECCENTRICITY

There exist two methods for the detection of air-gap eccentricity. In most cases it may be detected with the help of certain high frequency components in the stator line current. The first method allows to monitor behavior of the current at the sidebands of the slot frequencies. The sideband frequencies associated with an eccentricity are [1]

$$f_{slot+ecc} = f_s \left[(kR \pm n_d) \left(\frac{1-s}{p} \right) \pm n_\omega \right] \tag{1}$$

where $n_d = 0$ in case of static eccentricity, and $n_d = 1,2,3\ldots$ in case of dynamic eccentricity (n_d is known as eccentricity order), f_s is the fundamental supply frequency, R is the number of rotor slots, s is the slip, p is the number of pole pairs, k is any integer, and n_ω is the order of stator time harmonics that are present in the power supply driving the motor (n_ω = 1,3,5, etc).

The second method is based on the monitoring of the behavior of the current at the sidebands of the supply frequency and its odd multiples. These frequencies of interest are given by

$$f_{ecc} = k_1 \cdot f_s \pm m \cdot f_s \cdot \left(\frac{1-s}{p} \right) \tag{2}$$

where m = 1,2,3 ..., k_1 = 1,5,7.... Theoretically, frequencies multiple by 3 should not be present in the spectrums, but due to asymmetry of the machine and non-linearity of materials they can exit. Due to this method the knowledge of the construction of the machine is not required.

2.2. BROKEN ROTOR BARS

The broken rotor bar frequencies in the motor current are given by

$$f_{brb} = (1 \pm 2s)\, f_s\ . \tag{3}$$

3. MODELING AND SIMULATION RESULTS

The models of induction machine were prepared for two types of faults: air-gap eccentricity and broken rotor bars. The modeling of these effects allows investigation of its effect on the origination of characteristic frequencies and slot harmonics in the current spectrums and spectrums of magnetic flux.

Using finite element method there was implemented seven motor models that have been created based on the characteristics of a real induction motor. The time step used for all simulations is 0.0001 s. There are one healthy and three faulty models. Two models have different types of eccentricities – 20% dynamic eccentricity and mixed (ε_s = 20% and ε_d = 20%), and the last model has two broken rotor bars. The real motor is three-phase, four-pole, 400 V, 50 Hz, 1.1 kW squirrel-cage induction motor, that have 36 stator and 28 rotor slots. Modeling and FFT computation were carried out with the help of ANSYS Maxwell and MatLab software. All four motors have been simulated with operating speed 1440 rpm. This speed implies a slip s = 0.04.

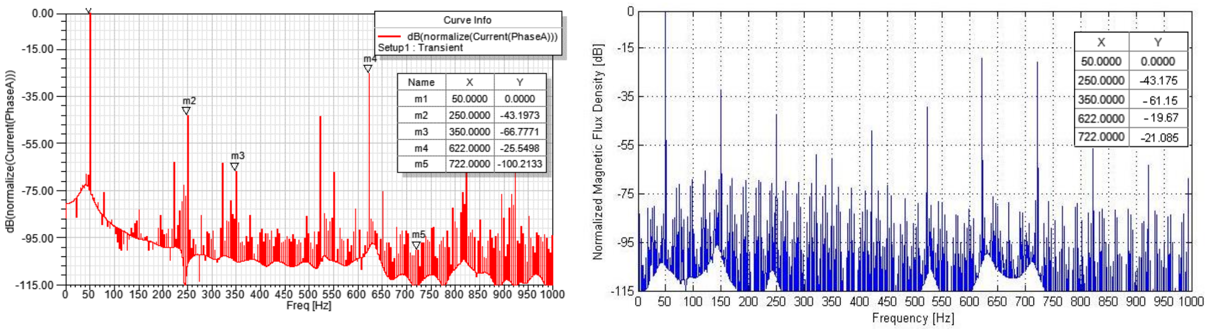
3.1. SIMULATION OF ECCENTRICITY-RELATED FAULTS

Machine eccentricity is characterized by unequal air-gap that occurs between the stator and rotor. Presence of this type of fault may result in a damage of the stator and rotor. Making the simulation and analyzing the obtained results, first of all it is needed to obtain eccentricity-related harmonics, based on (2). In this case $m = 1, s = 0.04, p = 2$. The resulting characteristic frequencies are 26, 74, 226, 274, 326, 374 Hz, etc.

Figure 1 shows the spectrums of current and magnetic flux density in the air-gap of the healthy machine. On Figure 1 (a) fundamental frequencies are pointed with markers. Figure 2 shows spectrums of current (a) and magnetic flux density in air-gap (b) of the machine having 20% of pure dynamic eccentricity. Spectrums of the machine with mixed eccentricity (20% static and 20% dynamic) are shown on Figure 3. Calculated by (2) characteristic and fundamental frequencies are pointed with the markers.

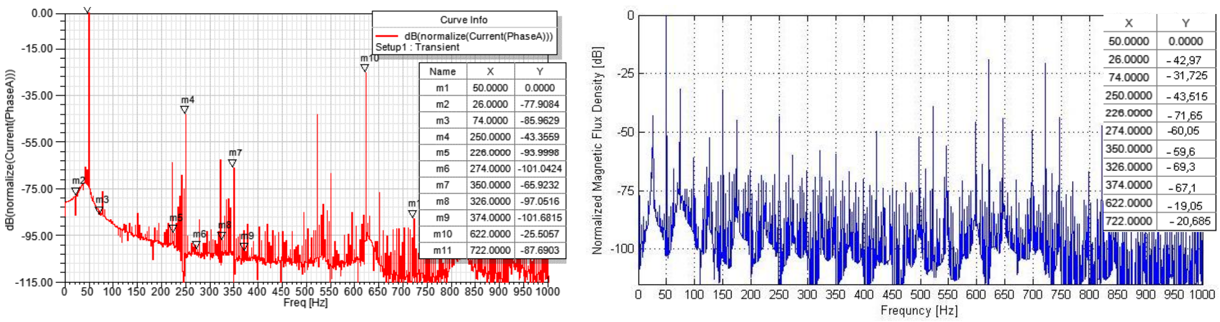
In these graphs it is clearly seen that characteristic frequencies that are located around fundamental frequencies have different amplitudes. It allows to recognize presence of faults in the machine. In all spectrums the peaks that are located at the frequencies of 622 Hz and 722 Hz may be recognized as a principle slot harmonics. Considering their origination in all machine models, it can be seen that the harmonic of 622 Hz is almost the same in the healthy machine as well as in the models with faults. Origination of this principle slot harmonic may be caused by slotting of the machine. Considering the spectrums of magnetic flux density in the air-gap, presence of the third harmonic that corresponds to frequency 150 Hz may be clearly seen. In the case of current spectrum this amplitude is very low due to symmetrical Y-connection of windings. The harmonic related to frequency 722 Hz in current spectrum increase with the severity of the fault, but in spectrum of magnetic flux density it is almost the same.

In the case of spectrum of magnetic flux density in the air-gap of the machine, the characteristic fequencies and sidebands around fundamental harmonics are also visible.



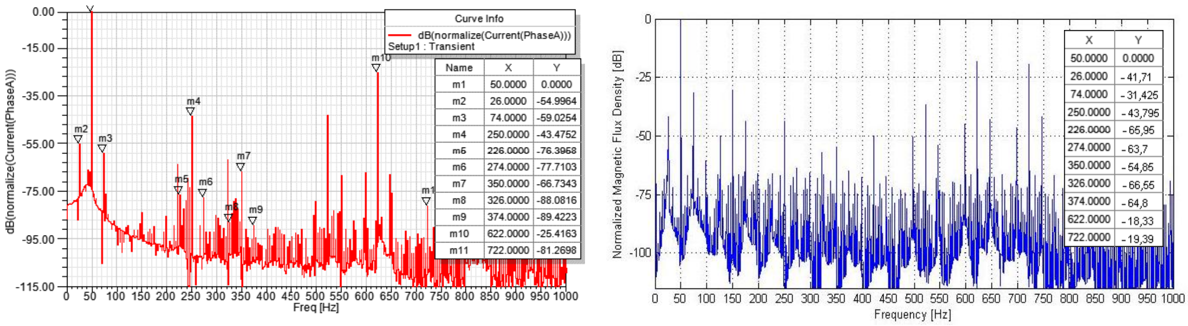
(a) (b)

Figure 1: Current spectrum (a) and spectrum of magnetic flux density (b) of healthy motor.



(a) (b)

Figure 2: Spectrums of current (a) and magnetic flux density in the air-gap (b) of motor with 20% dynamic eccentricity.



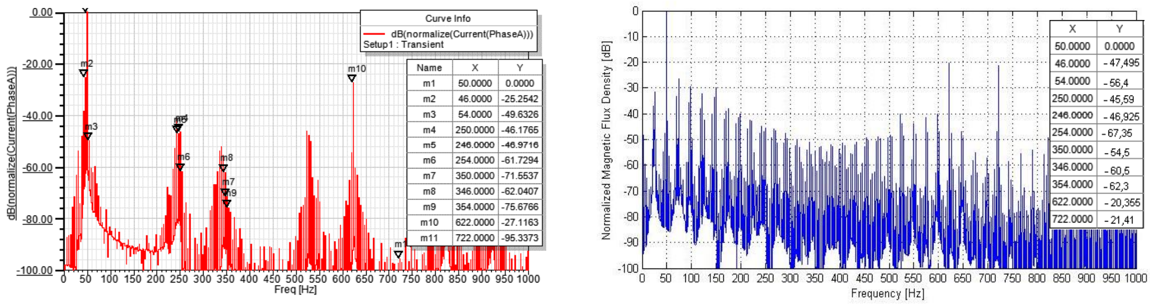
(a) (b)

Figure 3: Spectums of current (a) and magnetic flux density in the air-gap (b) of the motor with 20% static and 20 % dynamic eccentricity.

Considering and comparing obtained data from the current spectrum and spectrum of magnetic flux density in the air-gap of motor with pure dynamic eccentricity that are presented on Figure 2(a) and Figure 2(b), it is clearly seen that in the case of current spectrum, calculated characteristic frequencies are not visible. And vise versa, spectrum of magnetic flux density shows clear image of presence of this type of frequencies, especially around first harmonic (frequencies 26 Hz and 74 Hz). Examination of other comparison of these two type of spectrums on the example of presented figures shows that the amplitudes of the characteristic frequencies are much more higher that in the current spectrum. Hence, diagnosis of spectrum of magnetic flux in some cases may be more useful than the current one, but it is difficult in implementation.

3.2. SIMULATION OF BROKEN ROTOR BARS RELATED FAULTS

Considering the motor with two broken rotor bars, its characteristic frequencies are obtained due to (3). In this case the frequencies are 46, 54, 246, 254, 346, 354 Hz, etc. Figure 4 (a) shows current spectrum of machine with two broken rotor bars with pointed obtained characteristic and fundamental frequencies. Figure 4 (b) shows spectrum of the magnetic flux density in air-gap of this machine.



(a) (b)

Figure 4: Spectrums of current (a) and magnetic flux density in the air-gap (b) of motor with broken rotor bars.

The model with two broken rotor bars was examined for the presence of eccentricity-related harmonics in the spectrum of magnetic flux density that is shown on Figure 4 (b). This checkup allows to see that the flux in the spectrum of machine with two broken rotor bars contains also the eccentricity-related harmonics. It may be clearly seen in Figure 4 (b). Due to these results it is seen that there can be difficulties in the detection and diagnosis of these two faults.

As well as model with broken rotor bars, the models having eccentricity related faults were examined for the presence of frequencies that are characteristic for the motor with broken rotor bars. It was obtained that characteristic frequencies related to broken rotor bars are not influenced by the eccentricity.

4. CONCLUSION

In this paper the effects of motor eccentricity and broken rotor bars on the generation of characteristic frequencies and principal slot harmonics were investigated. The research was focused on MCSA and monitoring of magnetic flux density in the air-gap. It was carried out using ANSYS Maxwell and MatLab software. It was demonstrated that presence of the listed above faults results in the origination of the characteristic frequencies located around fundamental ones as well as rise of the principal slot harmonics. It is shown that spectrums of model with broken rotor bars contain frequencies related to eccentricity faults that creates the difficulties in recognition of these two faults. In the case of spectrum of magnetic flux density this problem is more significant. But in the case of the checkup of broken rotor bar related frequencies, it is seen that the spectrums of models that have eccentricity faults do not contain frequencies that are characteristic for broken rotor bar fault. Presented figures allows to see that diagnosis of magnetic flux density is useful in the case of monitoring the dynamic eccentricity. But it should be mentioned that this type of diagnosis is more difficult from the viewpoint of implementation.

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