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Research Article

An improved spectral analysis of the stray flux component for the detection of air-gap irregularities in squirrel cage motors

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ABSTRACT

For machines' monitoring purpose, the classical motor current signature analysis has shown its weakness in distinguishing the eccentricity occurrence in presence of others mechanical faults. Although Park's vector approach can cover this drawback, the high cost due to the requirement to use three current sensors associated with an advanced processing technique, makes it less desired by industrialists. In this paper, we suggest an alternative diagnosis method based on a suitable processing of the stray flux data. The experimental results have revealed the potential of a simple search coil for the detection and the distinction of the accurate eccentricity nature even in presence of similar mechanical faults.

1. Introduction

In industrial environment, a particular attention is given to the condition monitoring of squirrel-cage motors. In fact, despite their robustness, many failure sources related to the machine's power supply, the driven load, the mechanical coupling system or to the machine itself, can occur and affect the process efficiency.

Whereas power supply troubles are of electrical nature, faults related to the driven load and to the coupling system are of mechanical nature. For the machine itself, both electrical and mechanical troubles can occur. The most widespread faults of electrical nature concern the stator windings [1] and the rotor's broken bars [2]. The main mechanical defects are related to the rotor unbalance [3] and to the air-gap irregularities (eccentricities) [4].

Besides vibration techniques [5], eccentricity faults can be monitored by means of classical motor current signature analysis (MCSA). For a given p pole-pairs induction machine supplied by an equilibrate power system with fundamental frequency f_s and time harmonics $h = 1, 3, 5\ldots$, the frequencies characterizing the air-gap irregularities are given by [6]

$$f^{is}_{ecc} = [((kN_r \pm n_d)(1-s)/p) \pm h]f_s \quad (1)$$

where k is any positive integer, N_r is the number of the machine's rotor bars, n_d is the dynamic eccentricity order (static eccentricity is obtained for $n_d = 0$) and, s is the slip factor. Unfortunately, frequencies given by Eq. (1) cannot be observed for all combination $(p; N_r)$ [7]. Therefore, by monitoring f^{is}_{ecc}, the efficiency of MCSA technique is not always guaranteed.

On the other hand, for a mechanical rotation frequency f_r, mixed eccentricity leads to the apparition of additional sidebands around the main supply frequency [3,4,7,8]:

$$f^{is}_{mec} = f_s \pm k \cdot f_r \quad (2)$$

Unfortunately, these same sidebands can emerge in many others fault conditions (torque oscillation, rotor unbalance…). Consequently, the distinction of the cause failure is not always possible [8].

This weakness of the classical MCSA technique was extremely discussed in the scientific community and several alternative solutions were proposed. The applications of Wigner distribution [9], high-order harmonics analysis [10], Hilbert–Huang transform [11], space vector decomposition [12], instantaneous power components [13], and Vienna monitoring method (VMM) [14], are the main suggested techniques that we can be found in the literature.

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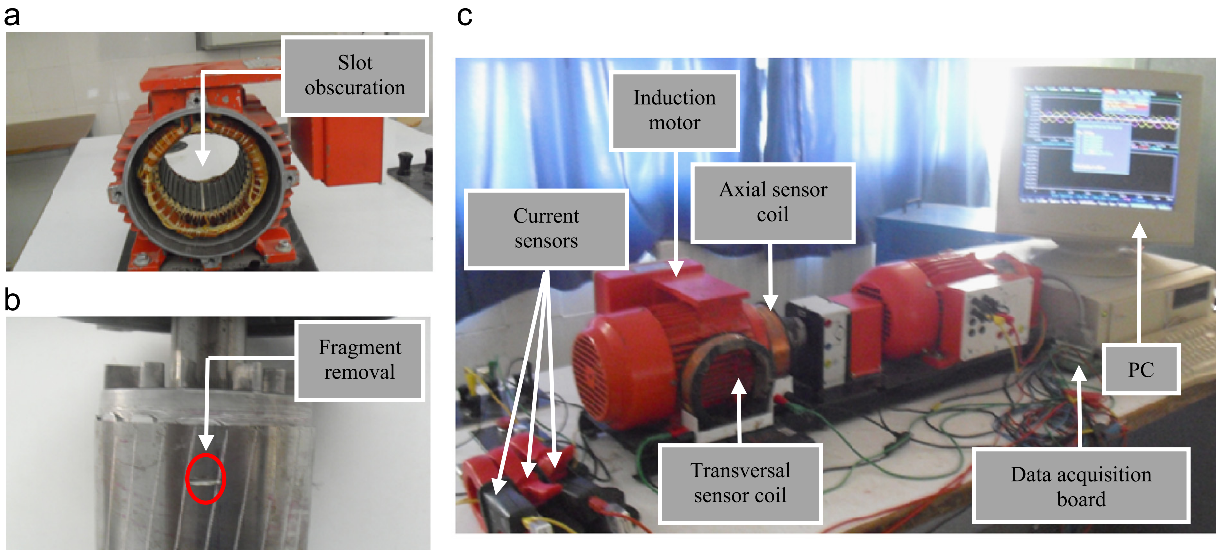

Fig. 1. Experimental setup.

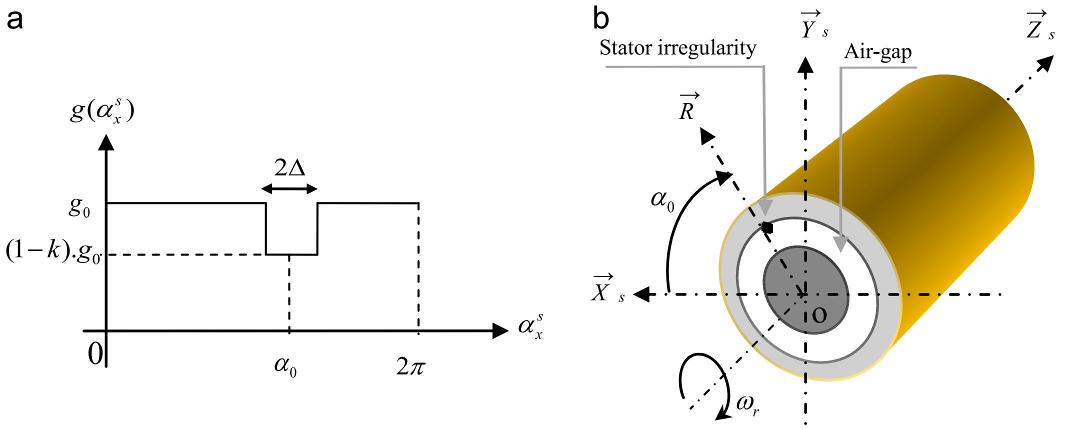

Fig. 2. Static eccentricity condition.

In this paper, we are going to evaluate the fault sensitivity of the MCSA and the Park's vector approaches for the detection of different eccentricity natures under various load levels. An alternative diagnosis method, based on an improved spectral analysis of the stray flux, will be suggested. The effectiveness of this proposed technique will be experimentally proven.

2. Material and methods

The machine under investigation is a three phases, 400 V, 50 Hz, and 1 kW 4 poles squirrel cage motor coupled to a dc shunt generator. Its rotor is a cast aluminum type with 28 bar. Static eccentricity (SEC) has been simulated by precisely placement of an obstruction (electric wire) into one stator slot (rotor rub is avoided) (Fig. 1a). For dynamic eccentricity (DEC) making, a small fragment has been removed from the rotor inter-bars (Fig. 1b).

Line currents were sensed via three clamps and, stray fluxes have been explored through two punt coils placed near the machine body for two positions: axially and transversally (Fig. 1c).

The motor was directly fed by the grid power supply and the stator windings were coupled in star without neutral point connection. By controlling the dc generator output current, various load torque levels can be applied to the motor's shaft.

In order to set the frequency bandwidth of the analyzed signals to a correct range, a low-pass anti-aliasing filter was implemented (cut frequency 1 KHz). All outputs were connected, in differential mode, to a data acquisition board (12 bits) and were performed using a sampling frequency of 5 kHz with a duration fixed at 10 s. In order to analyze data in the frequency domain, the used software was MATLAB™ (Blackman window).

3. Basic theory

In the following study, the considered machine is supposed to have $2p$ poles, N_s turns by stator coil, L coils per stator phase per pole and N_r rotor bars regularly spaced by $\alpha = 2\pi/N_r$. The lth stator coil pitch, the machine core length, the external rotor diameter, the air-gap length, and the air magnetic permeability will be respectively denoted as $\Delta\alpha_l$, l_c,D_r, g, and μ_0. The power supply is supposed to be equilibrated with main pulsation $\omega_s = 2\pi f_s$ and RMS line-to-line voltage $V_s\sqrt{3}$. The mechanical rotor speed will be denoted by $\omega_r = 2\pi f_r$ and, for any two positive integers $(m;n)$, we will denote $\Omega_n^m = [1 - m\cdot(1-s)]\omega_s - n\cdot\omega_r$. Each kth rotor mesh will be defined by its angular position$\alpha_k = (k-1)\alpha$. All saturation phenomena, time harmonics and slot effects will be neglected.

3.1. Rotor current frequencies

Due to the discrete nature of the stator winding distribution, three phases supply currents create a sum of forwards $(q = +1)$