Rotor Faults Detection Method for Squirrel Cage Induction Machines Based On the Park's Vector Approach

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Abstract ***– Due to their reliability, robustness and simple construction squirrel-cage induction motors are widely used in industry and are one of the most critical components in industrial processes. Any motor failure may yield an unexpected interruption at the industrial plant, with consequences in costs, product quality, and safety. Among several detection approaches proposed in the literature, those based on stator current monitoring are advantageous due to their non-invasive properties. One of these techniques is based on the spectrum analysis of machine line current. Another non-invasive technique is the Park's vector approach. In the literature this method is mainly used for detecting the stator winding faults of the induction machine***

In this paper the way how the Park's vector approach based method can be used for detecting the rotor faults of the squirrel cage induction machine is presented. After a short theoretical presentation results obtained by laboratory tests are given.

Keywords: ***induction machine, fault detection, condition monitoring, Park's vector approach.***

I. INTRODUCTION

Induction machines are critical components of many industrial processes and are frequently integrated in commercially available equipment and industrial processes. Motor-driven equipment often provide core capabilities essential to business success and to safety of equipment and personnel.

Unfortunately the electrical machines are not available at all times. Many components of the induction machine are susceptible to failures. For example, the stator windings are subject to insulation break-down caused by mechanical vibration, heat, age, damage during installation, and in special cases also by contamination by oil. The bars of the squirrel cage are subject to failures caused by a combination of various stresses that act on the rotor. Machine bearings are subject to excessive wear and damage caused by inadequate lubrication, asymmetric loading, or misalignment [1].

There are many published techniques and many commercially available tools to monitor induction motors to assure a high degree of reliability uptime [2], [3]:

- Electromagnetic field monitoring, search coils, coils wound around motor shafts (axial flux related detection),
- Temperature measurements,
- Infrared recognition,
- Radio frequency emissions monitoring,
- Noise and vibration monitoring,
- Speed and torque monitoring,
- Chemical analysis,
- Acoustic noise measurements,
- Motor current signature analysis,
- Model, artificial intelligence and neural network based techniques.

In spite of these tools, many companies are still faced with unexpected system failures and reduced motor lifetime. Environmental, duty, and installation issues may combine to accelerate motor failure far sooner than the designed motor lifetimes. Hence any new results in this field could be of real interest for all specialists involved [4], [5].

A special interest is focused on the on-line non-invasive approach of the fault detection of electrical machines, hence this can assure the best protection against machine downtimes and do not require stops of the industrial process just only for the machine testing [6].

The best method to fulfil the above requirements seems to be the motor current signature analysis (MCSA) [7]. This technique is based on the monitoring the machine's line current. Only a single current transducer is enough for this method, and it can be in any one of the three phases [8]. It can detect almost all of the above mentioned faults of any type of electrical machine at an early stage and thus avoid secondary damage and complete failure of the motor, and it can be also applied on-line [9].

There are several techniques in processing the measured line current. The most often used method is based on locating by spectrum analysis specific harmonic components in the line current produced of unique rotating flux components caused by faults such as broken rotor bars, air-gap eccentricity and shorted turns in stator windings, etc. [10], [11].

An other possibility is to apply the Park's vector approach [12]. The method is based on the visualisation of the motor current Park’s vector representation. If this is a perfect circle the machine can be considered as healthy. If an elliptical pattern is observed for this representation the machine is faulty. From the characteristics of the ellipse the fault's type can be established. Also the ellipticity increases with the severity of the fault [13].

II. THEORETICAL BACKGROUND

The analysis of the three-phase induction motor can be simplified using the Park transformation. The space phasor notation is used, which allows the transformation of the any instantaneous values of a three phase system onto a complex plane located in the cross section of the motor. In this plane, the space phasor rotate with an angular speed equal to the angular frequency of the three phase supply system.

A space phasor rotating with the same angular speed, for example, can describe the rotating magnetic field. Moreover, in the special case of the steady state, where the supply voltage is sinusoidal and symmetric, the space phasor become equal to three-phase voltage phasors, allowing the analysis in terms of complex algebra.

Practically this transformation allows the reduction of a three-phase system (*abc*) into a two-phase equivalent system with a zero sequence component (*dq*) as shown in Fig. 1.

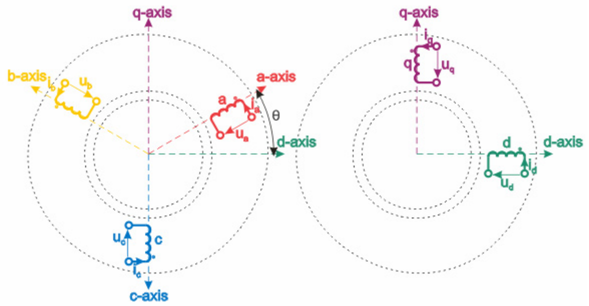

Fig. 1 The *abc* to *dq* system transformation

However, in three phase induction motors the connection to the mains usually does not considers the neutral. Therefore, the mains current has no homopolar component.

In order to transform the induction motor three-pahse quantities written in natural co-ordinates, into its equivalent space phasor form, the so-called 120º operator is introduced:

$$a = e^{\frac{2\pi}{3}j}, \qquad a^2 = e^{\frac{4\pi}{3}j} \tag{1}$$

Thus, the current stator space phasor can be expressed as follows:

$$\bar{i}_s = c\left(i_{s_A} + a i_{s_B} + a^2 i_{s_C}\right) \tag{2}$$

The factor *c*, takes usually one of two different values either $2/3$ or $\sqrt{2/3}$. The factor $2/3$ makes the amplitude of any space phasor, which represents a three phase balanced system, equal to the amplitudes of one phase of the three-phase system. The factor $\sqrt{2/3}$ may be used to define the power invariance of a three-phase system with its equivalent two-phase system.

If the first variant is selected for the c factor, equation (2) can be written as:

$$\bar{i}_s = \frac{2}{3}\left(i_{s_A} + a i_{s_B} + a^2 i_{s_C}\right) = \left|\bar{i}_s\right| e^{j\theta} \tag{3}$$

Expressed in the reference frame fixed to the stator, the real-axis of this reference frame is *d* and its imaginary-axis in quadrature is *q*.

The equivalence between the stator phasor and the *dq* two-axis components is the following:

$$\bar{i}_s = i_{s_d} + j \cdot i_{s_q} \tag{4}$$

or:

$$\begin{aligned} \operatorname{Re}\left(\bar{i}_s\right) &= \operatorname{Re}\left[\frac{2}{3}\left(i_{s_A} + a i_{s_B} + a^2 i_{s_C}\right)\right] = i_{s_d} \\ \operatorname{Im}\left(\bar{i}_s\right) &= \operatorname{Im}\left[\frac{2}{3}\left(i_{s_A} + a i_{s_B} + a^2 i_{s_C}\right)\right] = i_{s_q} \end{aligned} \tag{5}$$

The relationship between the real stator phase currents and the space phasor current can be expressed as follows:

$$\begin{aligned} i_{s_A} &= \operatorname{Re}\left(\bar{i}_s\right) \\ i_{s_B} &= \operatorname{Re}\left(a^2 \cdot \bar{i}_s\right) \\ i_{s_C} &= \operatorname{Re}\left(a \cdot \bar{i}_s\right) \end{aligned} \tag{6}$$

In a similar way can be written the space phasors of the stator voltage and flux, respectively of the rotor current, voltage and flux.

In the case of a healthy machine the three-phased system of the line currents is perfectly symmetrical:

$$\begin{aligned} i_{s_A} &= i_m \sin(\omega t) \\ i_{s_B} &= i_m \sin(\omega t + \frac{2\pi}{3}) \\ i_{s_C} &= i_m \sin(\omega t - \frac{2\pi}{3}) \end{aligned} \tag{7}$$

where i_m is the maximum value of the supply phase current, ω is the angular supply frequency and t is the time. The current phasor can be expressed as:

$$\bar{i}_s = i_m \sin(\omega t) + j \cdot i_m \cos(\omega t) \tag{8}$$

Hence from equation (4) the orthogonal components of the current phasor will be:

$$\begin{aligned} i_{s_d} &= i_m \sin(\omega t) \\ i_{s_q} &= i_m \cos(\omega t) \end{aligned} \tag{9}$$

The graphical representation of the current phasor is a circular locus centered at the origin of the coordinates. This is a very simple reference figure, which allows the detection of an abnormal condition due to any fault of the machine by observing the deviations of the acquired picture from the reference pattern.

When a fault occur equation (9) is no longer valid, because the line current will contain other components besides the positive-sequence component, leading to a representation different from the reference one. In these conditions, the current phasor modulus will contain a dominant dc level and an ac level, whose existence is directly related to the asymmetries either in the motor or in the voltage supply system [14].

III. LABORATORY TESTS

The tests were performed at the Department of Electrical and Electronic Engineering, University of Miskolc.

The test bench built up for these experiments is given in Fig. 2.

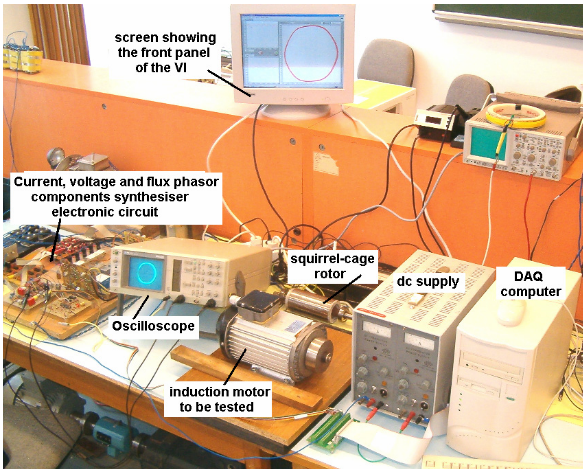

Fig. 2. The test bench

The induction machine under study had the following main data: P_N=1.5 kW, U_N=400/230 V (Y/Δ), f_N=50 Hz, I_N=4.2/7.3 A, n_N=1361 1/min, $cos\varphi_N$=0.69.

The squirrel cage induction machine was tested with two rotors, a healthy one, and one having broken rotor bars. The line currents of the motor were visualised on an oscilloscope using a special electronic circuit which was able to synthesise the two orthogonal components of the current, voltage and flux phasors. Beside this the line currents were acquired by a DAQ board from a PC. Using advanced virtual instruments (VIs) built up in LABView environment several characteristics of the motor under study were plotted.

The built up VI given in Fig. 3 plots based on the measured data several quantities: the torque, the line currents, the magnitude and the phase of the voltage, current and magnetic flux phasor, respectively draws in the complex plane the three phasors in discussion. This VI is an excellent instrument in studying the effects of faults on the components of the three phasors (voltage, current and flux).

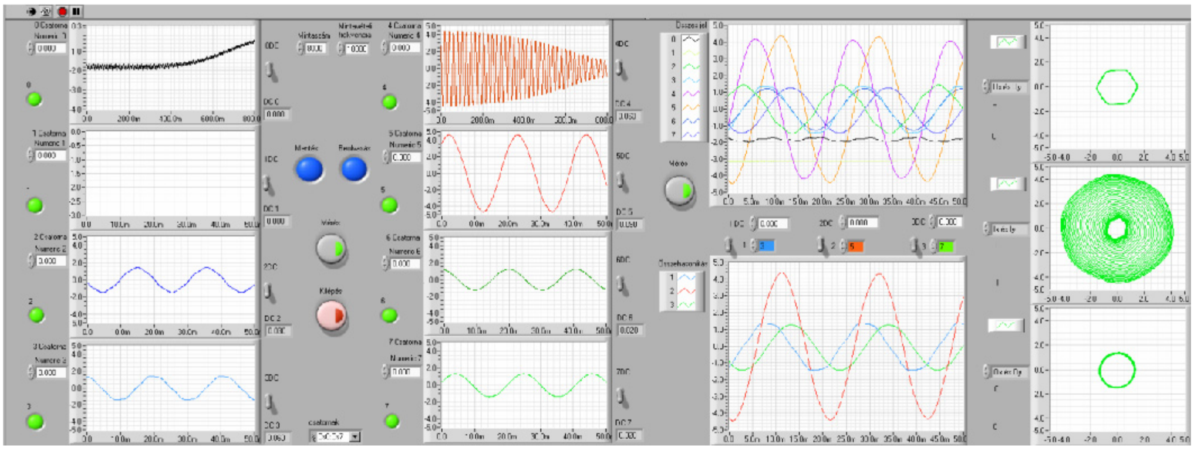

Fig. 3. The front panel of the virtual instrument used in data processing

Several measurements were performed both with the healthy squirrel cage induction machine and with that having broken rotor bars. Different loads and different regimes (starting and steady-state) has been studied.

Next only a part of the the most significant results obtained will be presented.

Studying the obtained results it was observed, that neither the phasor of the line voltage, nor of the magnetic flux do not suffer changes due to the faults in the rotor of the induction machines. Hence in all the cases only the following three plots will be given:

1. The torque (in Nm) versus time (ms)
2. One phase of the line current (in A) versus time (ms)
3. The phasor of the line current drawn in the complex plane

First the obtained results in the case of the healthy squirrel cage motor during starting will be given in Fig. 4.

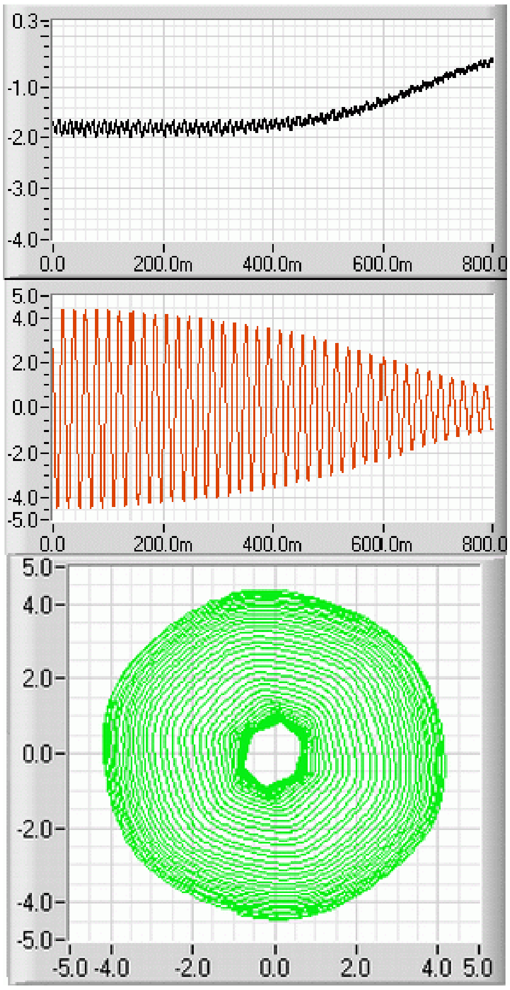

Fig. 4. Results in the case of healthy motor during starting

As it can be seen during the start-up the torque developed by the induction machine increases up to the load torque's value. The line current after the short starting period decreases in amplitude.

The most important issue in Fig. 4 is that the shape of the current phasor is very closed to the circle pattern, indicating that the motor is healthy.

Next, in Fig. 5, the same plots are given in the case of the squirrel cage induction machine in study having broken rotor bars. Also in this case the results are for the start-up of the induction machine.

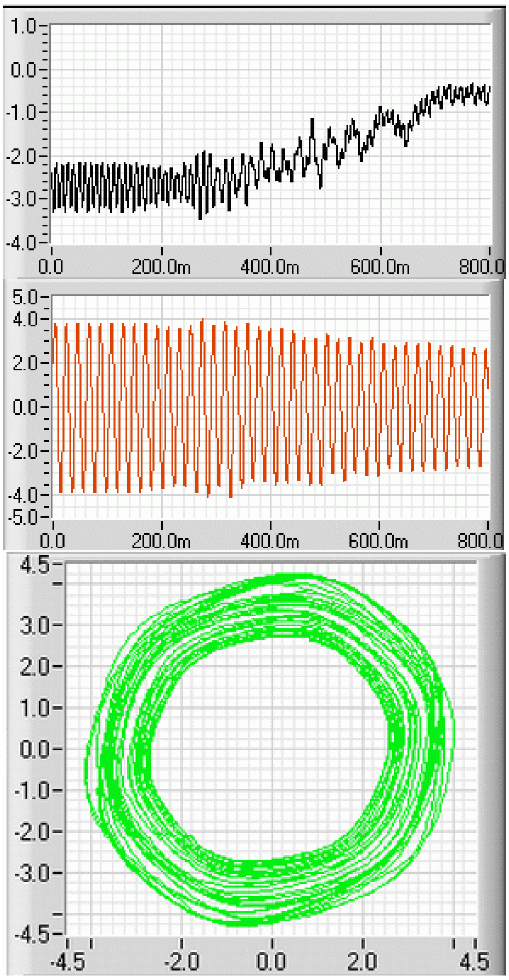

Fig. 5. Results in the case of faulty motor during starting

Due to the broken rotor bars the torque of the machine has significant fluctuations and the amplitude of the line current at the end of the starting period is quite high.

The shape of the current's phasor in Fig. 5 is not of perfect circular shape, which indicates a fault in the squirrel cage induction machine.

Finally it should be of real interest to see the three plots in the case of the faulty machine during the steady-state regime. These results are given in Fig. 6.

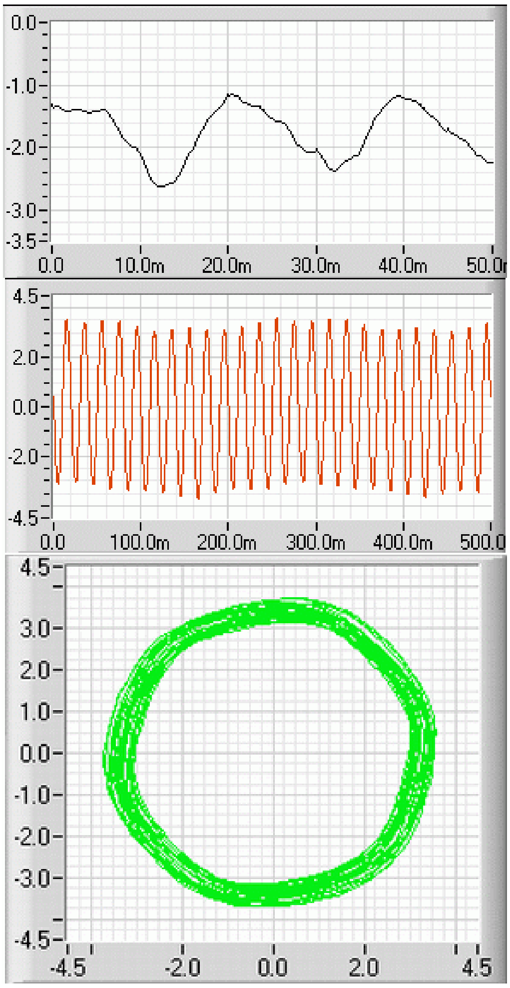

Fig. 6. Results in the case of faulty motor during steady-state regime

Also in this case the non-circular shape of the line current's phasor persists. From the same figure it can be observed as well the fluctuations of the developed torque and of the line current's amplitude, both evident signs of a fault in the induction machine.

IV. CONCLUSIONS

In this paper it was proved that the Park's vector approach can also be applied in the detection of broken rotor bars of the squirrel cage induction machines. By visualising the current phasor's shape the fault occurred in the machine can be easily observed.

A main advantage of this method is that the change in line current phasor's shape can be clearly observed also at much smaller loads than the rated one, the main disadvantage of the current signature analysis method combined with the spectral analysis.

Based on this approach different pattern recognition methods can be applied in order to automate the fault detection of the induction machine in order to be able to integrate it in advanced process condition monitoring systems.

The proposed method seems to be best suited for vector controlled induction machines, because in this case the orthogonal components of the line current are anyway computed.

Other further works are currently in progress concerning the use of this approach for diagnosing also other machine faults and a comparative study on this method and the harmonic content analyse of the line current's spectra.

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