ON THE ROTOR BAR FAULTS DETECTION IN INDUCTION MACHINES

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ABSTRACT

The monitoring of the condition of electrical machines can significantly reduce the costs of maintenance by allowing the early detection of faults, which could be expensive to repair. It is very advantageous to implement time and money saving condition based maintenance rather than periodic or failure based maintenance.

In this paper some results on detecting broken rotor bars in induction motors are presented. If there is any broken bar in the rotor it will directly affect the induced voltages in the stator windings and the waveform of the stator currents. Therefore the spectrum analysis of the line current (motor current signature analysis) is one of the best non-intrusive methods to be applied.

INTRODUCTION

Industry and government are both constantly under economic pressures to reduce costs while increasing service and productivity. To this endeavour, the condition monitoring of electrical machines is increasingly becoming important asset management tool. Consequently, electrical machine operators are looking for new and new motor faults detection systems having high performance predicting capabilities.

The main aims of condition monitoring are: shorting machine downtime, increasing machine life, availability and performance, reducing overall maintenance requirements, detecting all problems before they cause forced emergency shutdowns and lost production, reducing maintenance costs [1].

Squirrel-cage induction motors are ideal for most industrial applications because of their simple construction and robustness. This motor is the most widely used for industrial applications. Therefore the condition monitoring of this motor type is more important that of any other.

In recent years cage rotor design and manufacturing have undergone little change. As a result, rotor failures now account for a relatively large percentage of total induction motor failures [2].

Cage rotors are basically of two types: cast and fabricated. Previously, cast rotors were only used in small machines. However, with the advent of cast ducted rotors, casting technology can be used even for rotors of machines in the range of thousands kW. Cast rotors, although more rugged than the fabricated type, can almost never be repaired once faults like cracked or broken rotor bars develop in them.

The reasons for rotor bar and end-ring breakage are many. They can be caused by thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull, electromagnetic noise and vibration, residual stresses due to manufacturing problems, dynamic stresses arising from shaft torque, centrifugal forces and cyclic stresses, environmental stresses caused, for example, by contamination and abrasion of rotor material due to chemicals or moisture, mechanical stresses due to loose laminations, fatigued parts, bearing failure, etc.

To date, different methods have been used for rotor fault detection [1, 2]. One of the most well-known approaches for diagnosis of broken rotor bars in induction machines are based on the monitoring and processing of the stator currents to detect changes in the fundamental and in the space harmonics present in the line current.

THE TEST BENCH

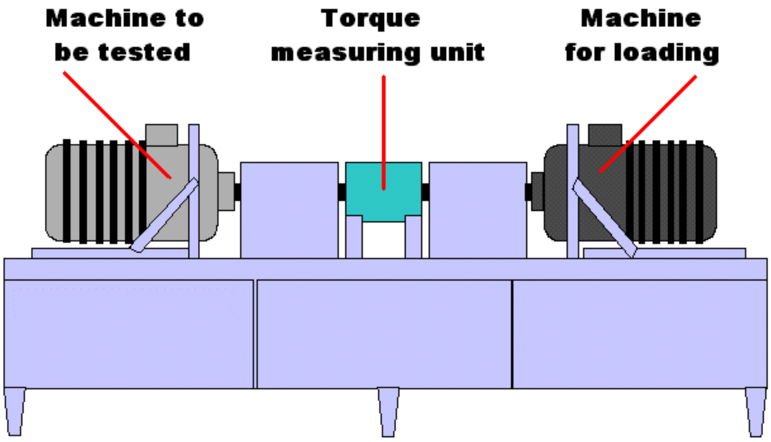


Fig. 1. The test bench

The experimental measurements were made on an intelligent test bench (see Fig. 1). It consists of two coupled electrical machines, the machine to be tested and that used for breaking. Between the two machines is coupled the torque measuring unit (Dr. Steiger Mohilo & Co. GmbH). The machine used for loading purposes is a DC machine fed by a controlled rectifier (SIMOREG DC Master of Siemens).

Several sensors measure parameters such as voltage, current, speed or angular incremental position and torque in order to give signals to the data acquisition unit [3].

The measurement part of the test bench consists of a usual Pentium processor based PC having a National Instruments PCI-MIO-16E-1 type acquisition board. This delivers high performance and reliable data acquisition capabilities, having 1.25 MS/s sampling rate, 16 single-ended analog inputs. It features both analog and digital triggering capability, as well as two 12-bit analog outputs, two 24-bit, 20 MHz counter/timers and eight digital I/O lines.

The electrical signals generated by the transducers must be optimized for the input range of the DAQ board. The SCXI signal conditioning accessory amplifies the low-level signals, and then isolates and filters them for more accurate measurements [4].

Several programs written in LabVIEW 6i were used for the test measurement processes. This is a powerful graphical programming development for data acquisition and control, data analysis and presentation. LabVIEW gives the flexibility of a powerful programming language without the associated difficulty and complexity because its graphical programming methodology is inherently intuitive to the users. The LabVIEW programs are simply made by assembling using drag-and-drop methods software objects called virtual instruments (VIs).

The virtual instrument created for the purpose (see Fig. 2) of processing and analyzing the acquired data from the test bench is easy to use and flexible. Its front panel is an interactive control tool for the entire acquisition software. The assembled block diagram ensures its functionality. The acquired data are stored in simple ASCII-type text files in order to be easy imported in any other program.

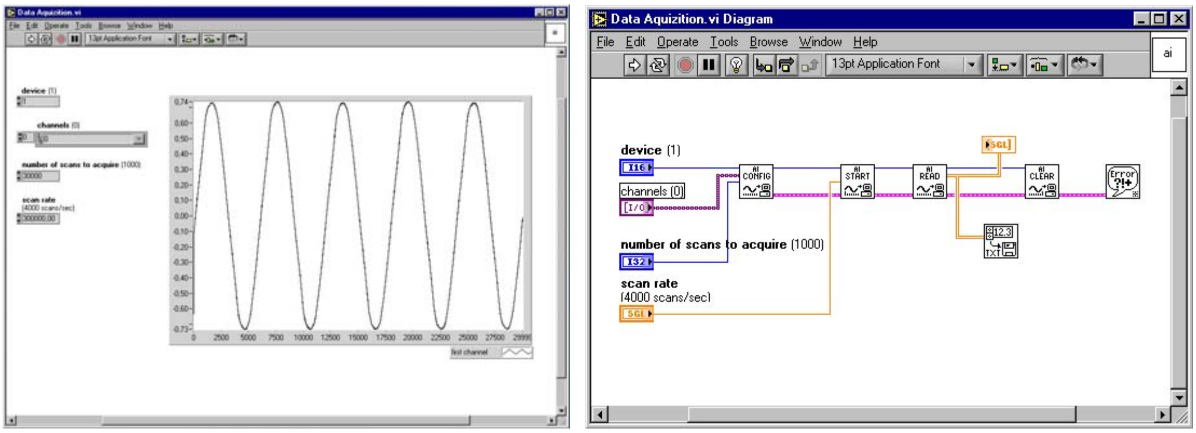


Fig. 2. The front panel and block diagram of the data acquisition VI

The program provides a powerful interface between the operator who co-ordinates the tests and the test bench, because it can be manipulated easy and simply.

TESTS CARRIED OUT

The rated data of the three-phase squirrel cage induction machine (of type B3-90L-1,5×1500) used for testing were: 1.5 kW, 220/380 V (Δ/Y), 6.18/3.56 A (Δ/Y) and 1410 rpm. The rotor cage of the motor had 27 bars.

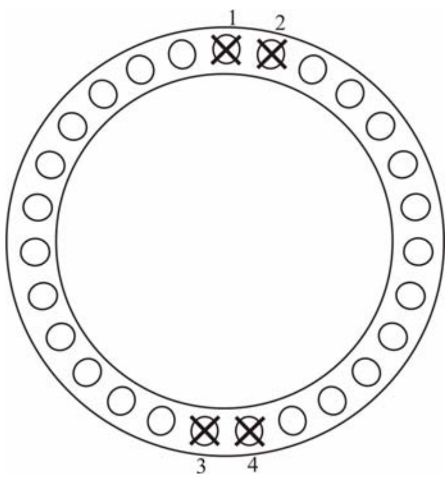


Fig. 3. The damaged rotor bars

First of all the machine was tested under healthy condition. After this broken rotor bar faults were created drilling holes in the end rings. The order and the position of the damaged rotor bars are shown in Fig. 3.

In all cases the same measurements were performed at no-load and at other 7 loads, including also the rated load of the motor. The line voltages and currents, the motor's speed and torque were measured and saved in text files by the above-presented virtual instrument [5].

For detecting the existence of rotor failures the FFT (Fast Fourier Transform) analysis was performed on the measured terminal currents in order to extract their harmonic content [6]. This way the frequency spectrum for the time domain waveform was generated.

In the particular case of the given motor the harmonic components of the line current up to the 56^{th} order ($2\times n\pm 2p$, where n is the number of the rotor bars and p of the pair poles) had to be analysed. Upon Nyquist's theorem the corresponding minimum sampling frequency had to be 5.6 kHz. During the data acquisitions a much higher sampling frequency (300 kHz) had been used.

For the spectrum analysis of the measured line currents a virtual instrument was elaborated in LabView [7]. Its block diagram is given in Fig. 4.

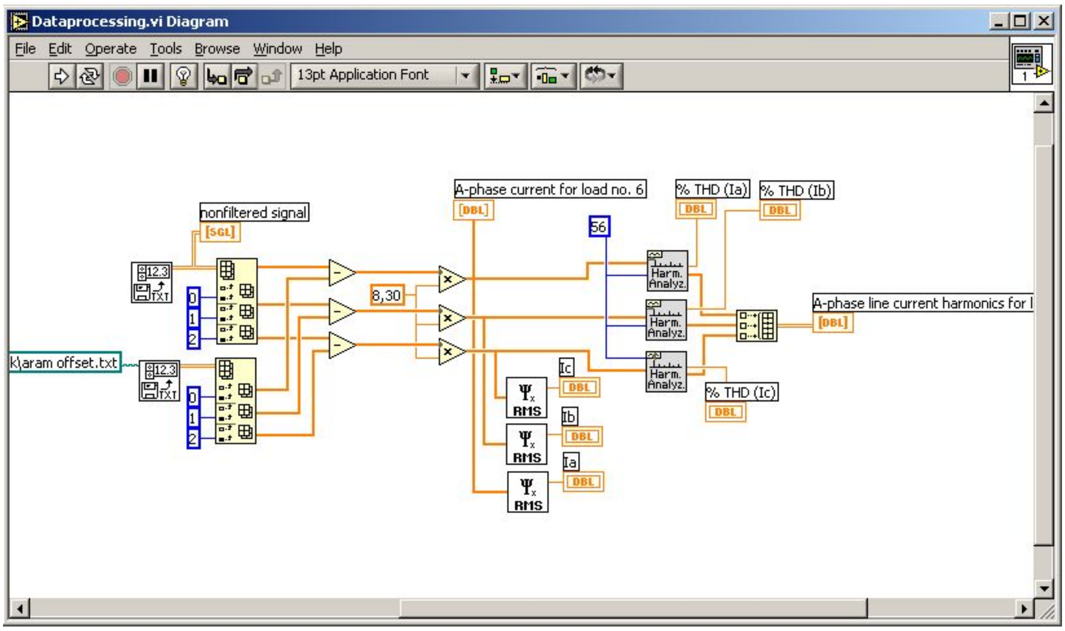


Fig. 4. The block diagram of the FFT analysis VI

RESULTS AND DISCUSSIONS

A lot of measurements have been done. Five different motor conditions were studied (the healthy machine and having up to 4 broken bars), each at 9 different loads. All the obtained results can't be presented here, therefore only the most significant ones will be discussed herein after.

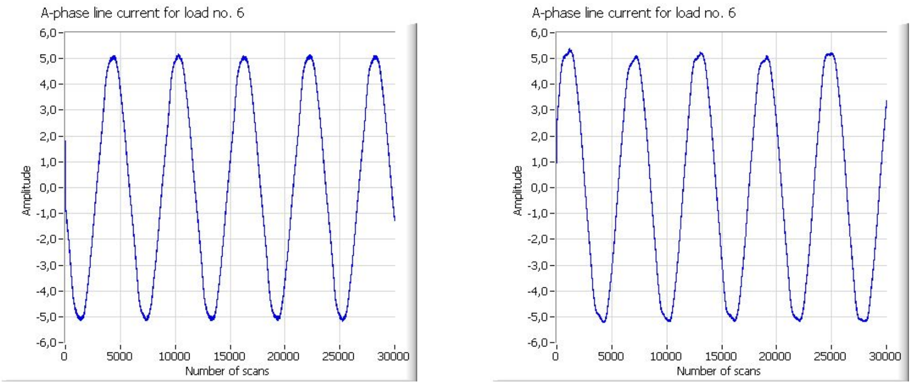
Firstly it can be observed that the harmonics content of measured currents increase for the machine having broken bars. This phenomenon can be explained with the appearance of asymmetries in the motor's structure due the unsymmetrical faults. The best measure of the harmonic content of a signal is its THD (Total Harmonic Distorsion), given by the well-known expression:

$$\mathrm{THD} = 100 \cdot \frac{\sqrt{A(f_1)^2 + A(f_2)^2 + \cdots A(f_n)^2}}{A(f_o)} \quad [\%] \qquad (1)$$

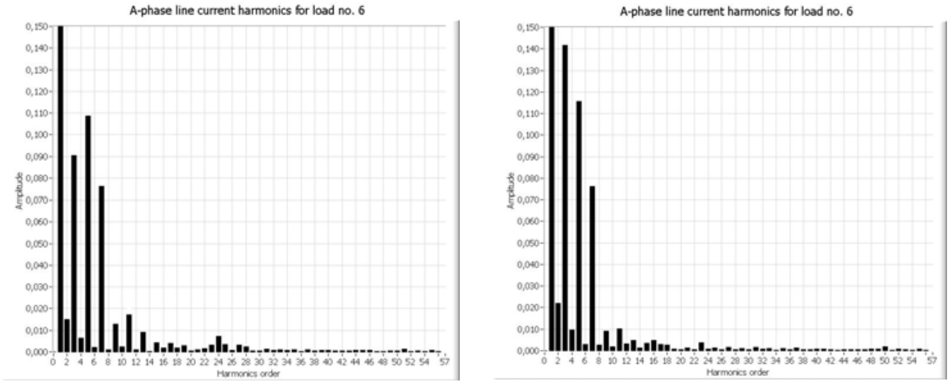
The TDH is the smallest in case of the healthy motor, increases after each of the first 3 bars are broken. The THD of the line current of the motor having 4 broken bars is smaller a little bit that of the motor with 3 broken bars. This is due the partial reinstatement of the symmetry in the rotor structure after cutting the 4^{th} bar (see Fig. 3).

In Fig. 5 the results of the line current's spectral analysis are shown both for the healthy motor and of that having 3 broken bars. Because there are great differences between the amplitudes of the lower and higher order harmonics different domains of the harmonics are given for the same signal.

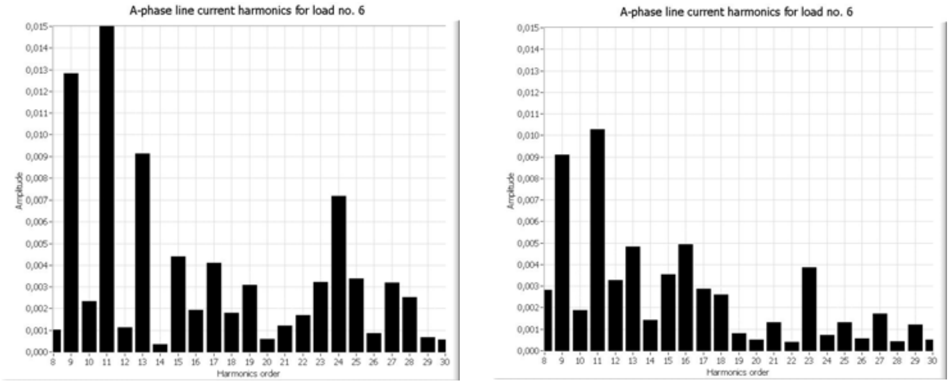
Healthy motor **Motor with 3 broken bars**



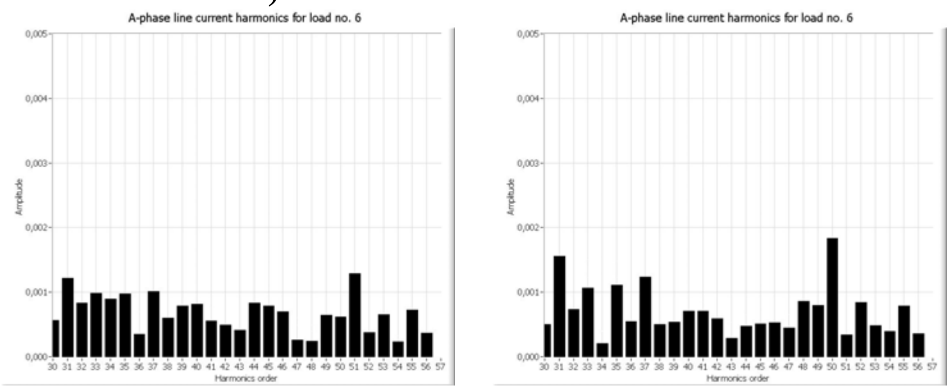
a) The waveform of the measured line current



b) The entire studied spectra of the measured line current



c) The harmonics of order 8÷30



d) The harmonics of order 30÷56

Fig. 5. *Results of the line current's spectral analysis of the healthy motor and of that having 3 broken bars*

The increase of the 2nd harmonic component is a good symptom of the broken bars in the motor. Its amplitude increases function of the number of broken bars and their position. Other higher harmonic components are also increasing when the rotor of the motor is damaged.

These results highlight the usefulness of the applied diagnosis method. Of course the research must be continued in this field in order to be able to distinguish more accurately a healthy electrical machine from one having broken rotor bars. It should be very useful if also the number of the broken bars could be estimated from the line current's spectral analysis.

For more accurate rotor bar faults diagnosis it seems to be necessary to combine two different analysis procedures.

The presented diagnosis method could be applied also for the induction motors with wounded rotors.

ACKNOWLEDGEMENTS

The work was possible due to the support given by the National Council of Scientific Research in Higher Education (Romanian Ministry of Education and Science), respectively the Sapientia Foundation (Cluj, Romania) to the authors.

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