Rotor bars diagnosis in single phase induction motors based on the vibration and current spectrum analysis

Mariana IORGULESCU*, Robert BELOIU* ,Mihai Octavian POPESCU**
*University of Pitesti, Electrical Engineering Departament
Târgul din Vale, No.1, 0300, Pitesti, ROMANIA
iorgulescumariana@mail.com
**University Politehnical of Bucharest, Faculty of Electrical Engeneering
Bucharest, ROMANIA

***Abstract*:** Generally, detection and diagnosis of incipient faults are desirable in order to ensure product quality and improved operational efficiency of induction motors running off the mains power supply. In this paper, the vibration and current spectrum of an induction motor are analyzed in order to achieve information for the detection of rotor bars faults. We observe significant vibration and current spectrum differences between healthy motors and motors with broken rotor bars. The high-frequency spectral analysis of vibration and current provides a method to detect broken rotor bars faults.

The developed system is scalable to power ratings and it has been successfully demonstrated with data from 0.65 kW single phase induction motor.

I. INTRODUCTION

Induction motors are very used for a wide range of activities, industrial application and domestic appliances. For the electric motors used in industrial application it is well-known that the interruption of the fabrication process leads to financial loss. In the utilisation of domestic appliances, the crash of the electric motor induces financial too, because it affects the reputation of the brand. Thus companies which produce domestic appliances should request from the manufacturers of the electric motors o higher quality of their products. In consequence, the electric motor manufacturers should use diagnosis systems that can be detect the motor's fault even after many hours of utilization

The fault diagnosis systems are cheap and the interface with equipment used to process the signal should be simple and easy to handle.

In electric motors, function interruption can be caused by bearing faults, stator faults (inter-turn short circuits), rotor faults (broken rotor bars or rotor end ring), rotor – stator eccentricity (dynamic or/and static eccentricity).

Broken rotor bars rarely cause immediate failure. If there are enough broken rotor bars, the motor may not be able to develop sufficient accelerating torque. The presence of broken rotor bars leads to deterioration of other components of the motor. Various techniques have been developed to detect broken rotor bars in induction motors. We can quote vibration measurement, noise measurement, temperature measurement, Park's Vector current monitoring, and artificial intelligence-based techniques. The most popular techniques are based on the monitoring of the stator current spectrum (MCSA) because of its non-intrusive feature. In this technique, the amplitudes of the lateral bands created by the rotor fault around the supply frequency are monitored. An augmentation of these amplitudes allows appreciating the degree of the failure.

The other method uses the instantaneous power spectrum of one stator phase to calculate a global fault index. Detection of these faults is also possible by frequency domain analysis of the shaft flux or more generally of the axial leakage flux which is monitored by using an external search coil wounded around the shaft of a machine.

Broken bar detection using state and parameter estimation techniques have also been reported.

The current spectrum and the parameter estimation approach have been compared and the former has been found more efficient. For all these methods we should have the knowledge of the healthy motor stator current and it is necessary to take a decision about the rotor state [1], [2], [3].

In this paper we present a broken rotor bar detection method which uses the current FFT spectrum and vibration spectrum. Thanks to these method broken rotor bars could be detected even if the motor operated unloaded.

II. SINGLE MOTOR FAULTS

The major faults of single electrical motors can broadly be classified as following:

- Bearing wear and failure. As a result of bearing wear, air gap eccentricity can increase**,** and this can generate serious stator core damage and even destroy the winding of the stator;
- Stator faults resulting in the opening or shorting of one or more of a stator phase's windings,
- Abnormal connection of the stator windings,
- Static and/or dynamic air-gap irregularities

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- High mechanical unbalance in the rotor which increases centrifugal forces on the rotor;
- Broken rotor bar or cracked rotor end rings
- Critical shaft speed resonance increases forces and vibration on the rotor core [4].
- Looseness or decreased stiffness in the bearing pedestals which can increase the forces on the rotor;

Because the rotor cage failures represent around 5-10% of total induction motor failures, we'll focused our research upon this problem.

The reasons for rotor bars breakage are several. They can be caused by:

- Magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull, electromagnetic noise and vibration;
- Thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, sparking ;
- Mechanical stresses due to loose laminations, fatigued parts, bearing failure ;
- Residual stresses due to manufacturing problems;
- Environmental stresses cause for example by contamination and abrasion of rotor material due to chemicals or moisture;
- Dynamic stresses arising from shaft torques, centrifugal forces and cyclic stresses.

III. CURRENT AND VIBRATION SPECTRUM MONITORING

The techniques used to detect the presence of rotor cage failure are:

a) Rotor bars faults detection by the vibration spectrum analysis. The sideband frequency researched is given by:

$$f_b = kf \,, \qquad (1)$$

where f_b is detectable broken bar frequency, f is mains frequency and k = 1, 2, 3, ...

b) Spectrum analysis of machine stator current (MCSA) to detect broken bar faults. We investigate the sideband components, f_b, around the fundamental one in order to detect broken bars faults.

$$f_b = (1 \pm 2s) f \qquad (2)$$

where f is mains frequency, s is the motor slip

While the lower sideband is specifically due to broken bar, the upper sideband is due to consequent speed oscillation. In fact it shows that broken bars actually give rise to a sequence of such sidebands given by

$$f_b = (1 \pm 2ks) f \,, \qquad (3)$$

where f is mains frequency, s is the motor slip and k = 1,2,3,…..

The motor-load inertia also affects the magnitude of these sidebands. Other spectral components that can be observed in the stator current are given by

$$f_b = [(\frac{k}{p})(1-s) \pm s] f \qquad (4)$$

where, f_b = detectable broken bar frequencies; f is mains frequency, s is the motor slip and k/p = 1,3,5... [5],[6],[7].

IV. ELECTRICAL MOTOR DIAGNOSIS

Experimental methods focus on single induction motor diagnosis. The tested methods are according to standard procedure of product and size measurement. A specialised system was used to measure the noise and vibration with regard to electric motor diagnosis. The measurement was done a noise and vibration studies laboratory. After completing the measurements, we should adapt the method to monitoring of stator current.

Measurement system has the schema presented in figure 1.

The experiment has focused on single induction motor diagnosis, more precisely rotor faults, using vibration and stator current spectrum analysis. This is why the sensors used for measurements were:

- the piezoelectric accelerometer for the vibration measurement ;
- ampere clamp for the stator current measurement.

The motor tested in this paper is a single phase motor, with the following parameters:

- rated voltage 230 V,
- rated power 0.65 kW,
- rated current 1.57 A,
- speed 2800 rpm.

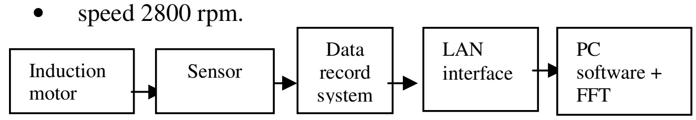

Fig.1 Schematic measurement equipment

Initially the measurements were realised by using electric motor with a "healthy" rotor. Then we did the same measurements for the same motor but with a broken rotor bar, with two broken bars and three broken bars. The bars were interrupted by perforation, according to figure 2.

The main part of the experimental benchmark was multianalyser (Brüel & Kjær) fig.3.

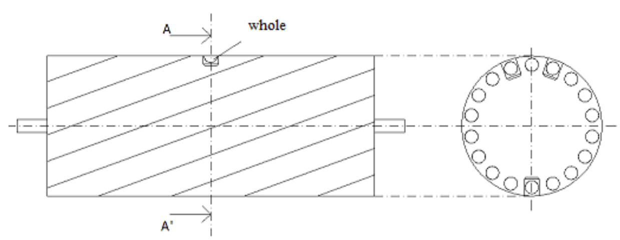

Fig. 2 Rotor cage representation with broken bars

IV.1 VIBRATION SPECTRUM MONITORING

The accelerometer of Brüel & Kjær was mounted on the motor shield and used as a vibration sensor fig 4.

The rotor fault detector was supposed to recognize the rotor bars state and classify it as belonging to one of the following groups: healthy or damaged rotor cage.

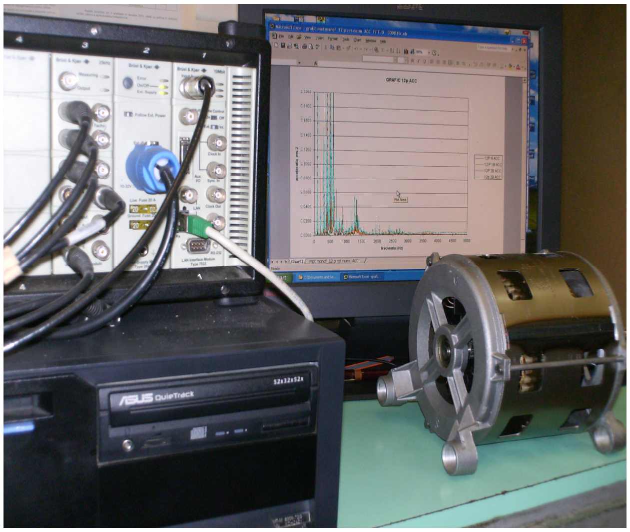

Fig.3 Test bench multianalyser

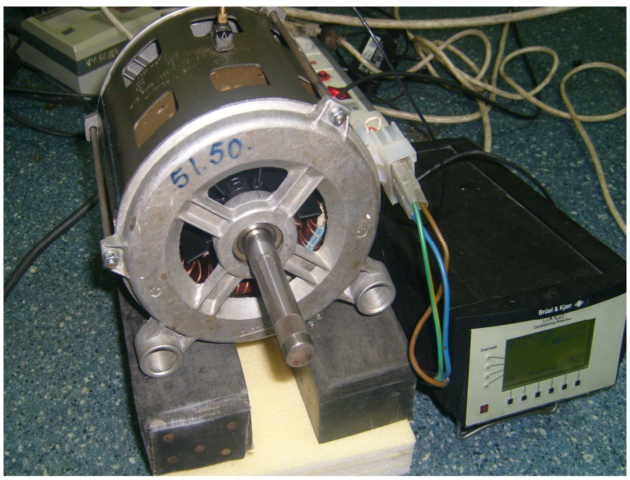

Fig. 4 Vibration motor's measured

The amplitudes of the harmonic components for the induction motor being tested have been calculated according to equation (1). Harmonic spectra are generated from the data collected by the accelerometer using FFT.

The harmonic spectrum from figures 5,6,7,8 is generated based on the data obtained by the piezoelectric accelerometer. The electrical machine frame has a mounted piezoelectric accelerometer like in fig 4. This way vibration signals transmitted to the analyzer are very relevant.

The rotational frequency is f=50Hz. The vibration amplitude for this frequency is important and the amplitudes for other frequencies are small.

The analyzed frequencies are 50 Hz and 100 Hz also.

The vibration amplitude for the analyzed frequencies, for the induction motor with rotor fault (broken bars) are bigger than for the same motor without rotor fault.

It is very important to analyze the amplitude of vibrations because differences greater than 10% will be an indication of rotor problems.

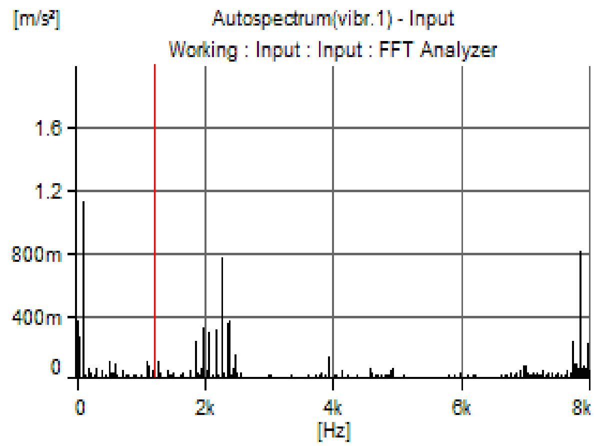

Fig.5 Harmonic vibration spectra for "healthy" single induction motor

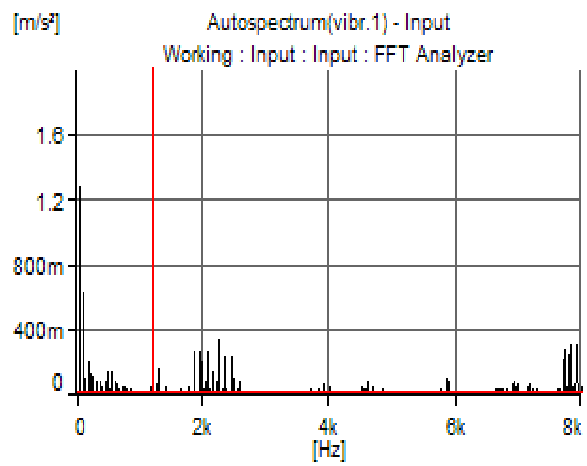

Fig.6 Harmonic vibration spectra for induction motor with one broken bar

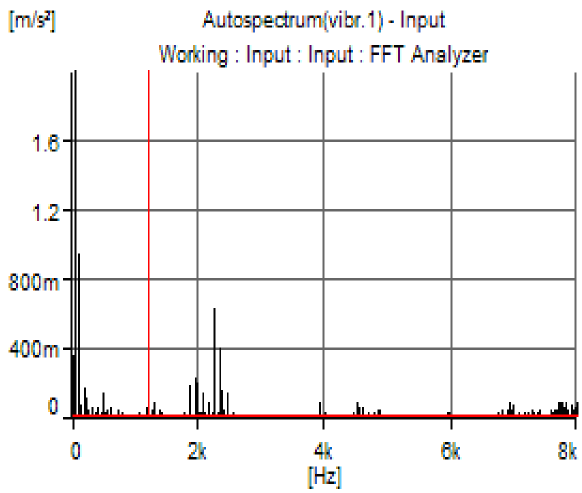

Fig.7 Harmonic vibration spectra for induction motor with two broken bars

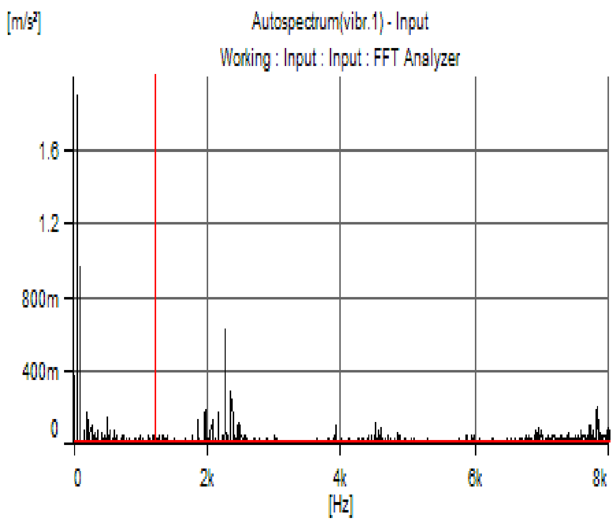

Fig.8 Harmonic vibration spectra for induction motor with three broken bars

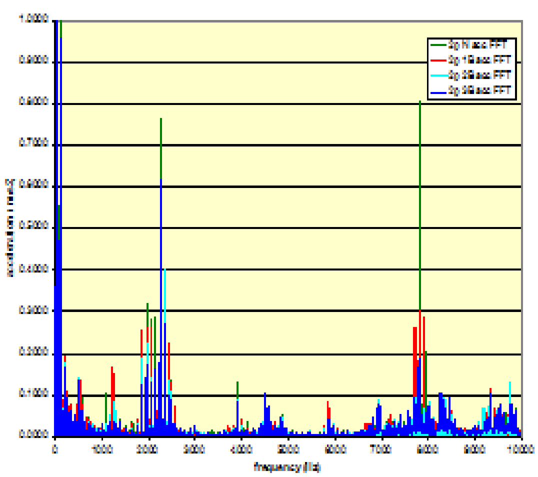
Figure 9 Comparation between harmonic vibration spectrums for healthy and fault rotor bars

We analyzed the amplitudes and observe an increasing of the vibration amplitude in the defective rotor.

For the relevant conclusions we need to zoom in the frequency range 30-90 Hz. So we obtained the spectrum presented in t in figure 10.

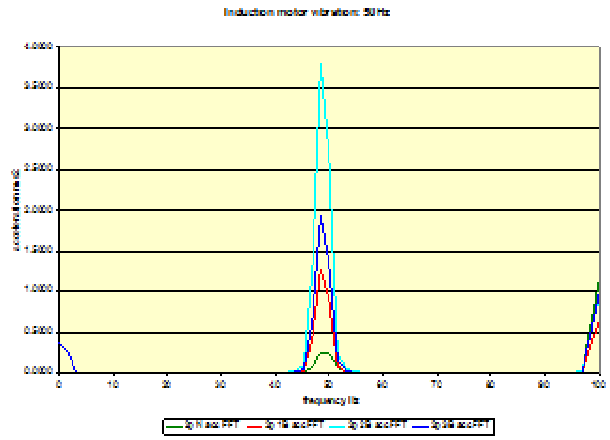
Figure 10 Comparation between vibration spectrum "healthy" and rotor bars fault at 50Hz frequency

For the dynamic unbalanced frequency of the motor, which is 50 Hz, it is important to compare the acceleration evolution of the healthy rotor (balanced) with those of the one broken bar, two broken bars and three broken bars rotors.

From the vibration spectrum at 50 Hz frequency, the acceleration it is:

- a = 0,2557 m/s^2 , for „healthy" rotor,
- a = 1,2700 m/s^2 , for the induction motor with one broken bar,
- a = 3,7900 m/s^2 , for the induction motor with two broken bars,
- a = 1,8900 m/s^2, for the induction motor with three broken bars

We observe that the acceleration corresponding to the motor with two broken bars it is bigger than that for motor with three broken bars. This is this because the third hole was made on the opposite side not near the others. So, the third unbalanced whole balances out the first two unbalanced holes.

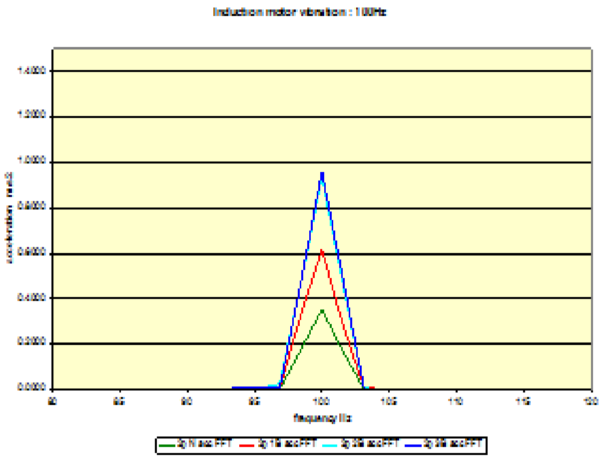

Figure 11 Comparison between vibration spectrum "healthy" and rotor bars fault at 100 Hz frequency

The holes were made in different places in the rotor core, so the unbalances are different.

We made the frequency range 80 – 120 Hz analysis using figure result. Waveform is almost identically for the two broken bars and three broken bars rotor, because the holes were made in different places in rotor core.

For the vibration spectrum at 100 Hz frequency, the acceleration is:

- a = 0, 3530 m/s^2 , for „healthy" rotor,
- a = 0,6160 m/s^2, for induction motor with one broken bar,
- a = 0,9380 m/s^2 ,for induction motor with two broken bars,
- a = 0,9610 m/s^2,for induction motor with three broken bars

We consider the 50 Hz and 100 Hz frequency mains for the dynamic unbalanced and the others harmonic frequencies.

In conclusion, it have proved that $f_b = kf$, (where, f_b is detectable broken bar frequencies, f is mains frequency and k = 1, 2, 3,..) are corresponding to frequency of faults.

IV.2 STATOR CURRENT SPECTRUM MONITORING

The current analysis is very useful for single induction motor manufactures in order to diagnose bearing faults.

In figures 12,13,14,15 we present the harmonic stator current spectrums for the induction motor with "healthy" rotor and fault rotor bars.

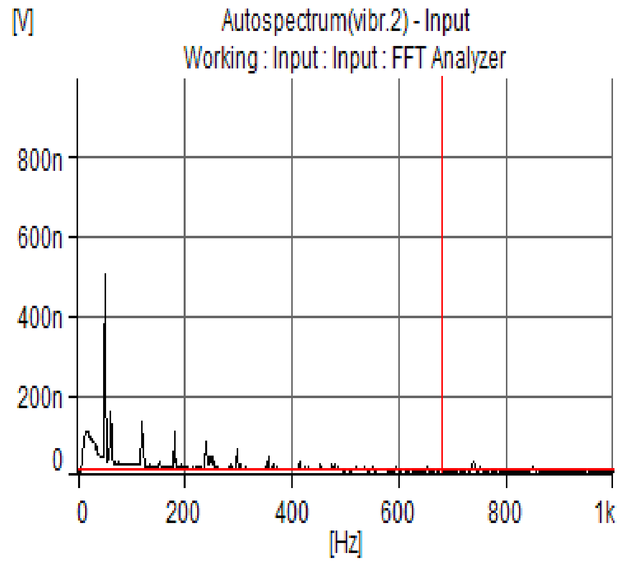

Fig.12 Harmonic stator current spectrum for "healthy" single induction motor

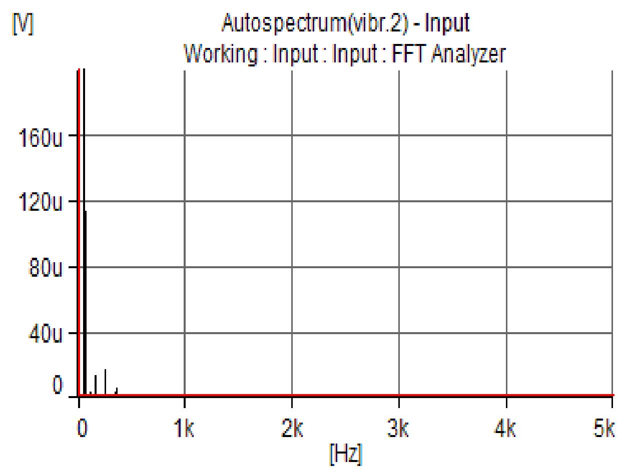

Fig. 13 Harmonic stator current spectrum motor with one broken bar

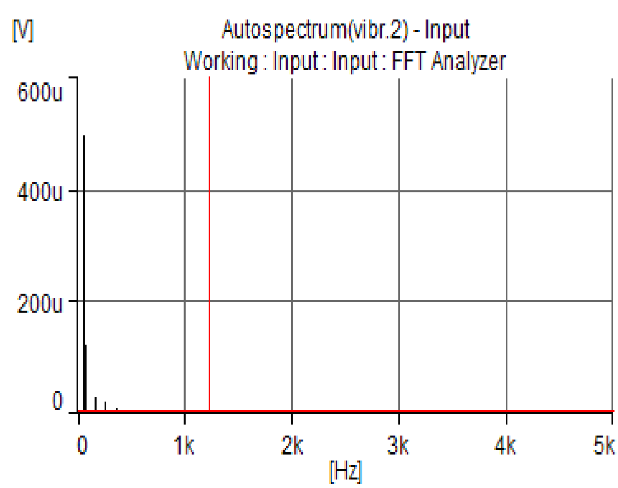

Fig. 14 Harmonic stator current spectrum motor with two broken bars

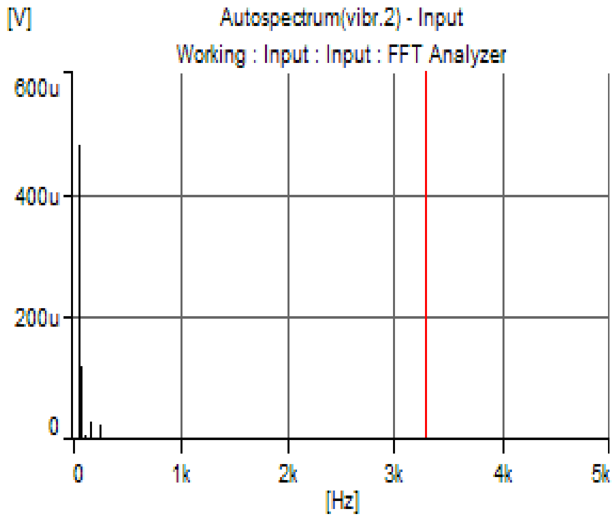

Fig. 15 Harmonic stator current spectrum motor with three broken bars

In figure 16 and we present a comparative analysis of the harmonic stator current spectrums for the induction motor with “healthy” rotor and the ones with broken bars (from one to three broken bars).

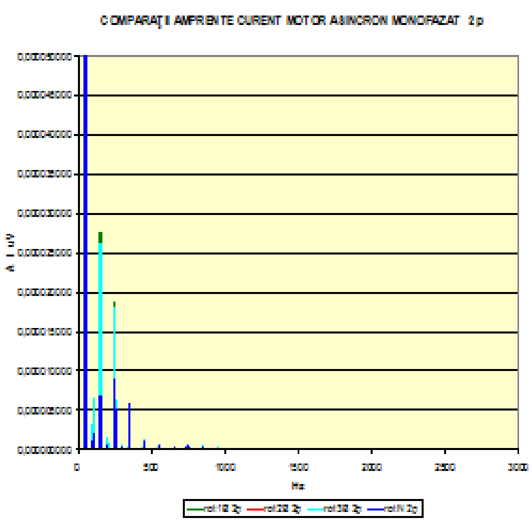

Figure 16 Comparation between harmonic stator current spectrums for “healthy” and fault rotor bars

For the relevant conclusions we need to zoom in the image of 40-60 Hz frequency range. So we get the spectrum in figure 17.

The amplitudes of the stator current harmonic components for the induction motors being tested have been calculated according equations (2) and (3). We observe for a frequency around ±20Hz the mains frequency the amplitude current stator it is bigger with 5% than that for the same motor without rotor fault.

We also analyze the stator current harmonic components at 150, 250 Hz as in figures 18, 19.

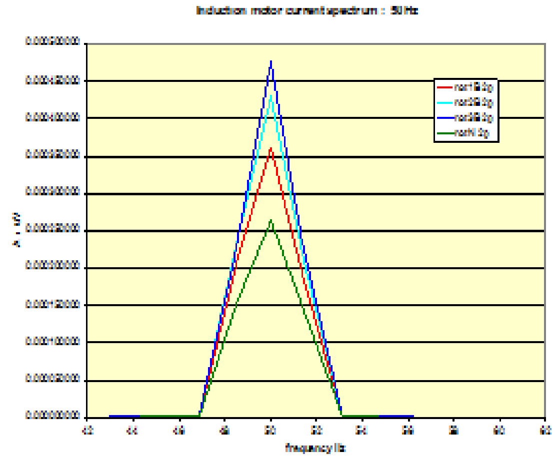

Figure 17 Comparation between stator current spectrum “healthy” and rotor bars fault at 50Hz

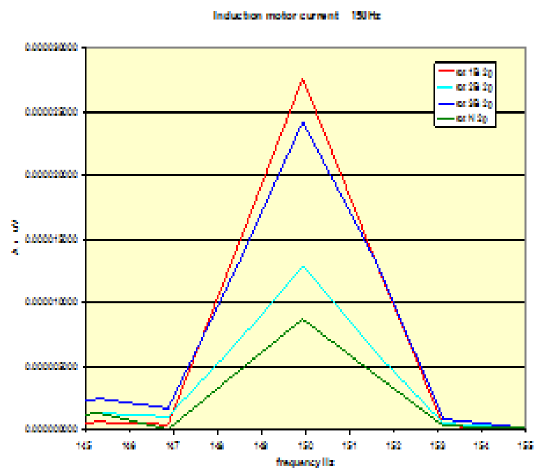

Figure 18 Comparation between stator current spectrum “healthy” and rotor bars fault at 100Hz frequency

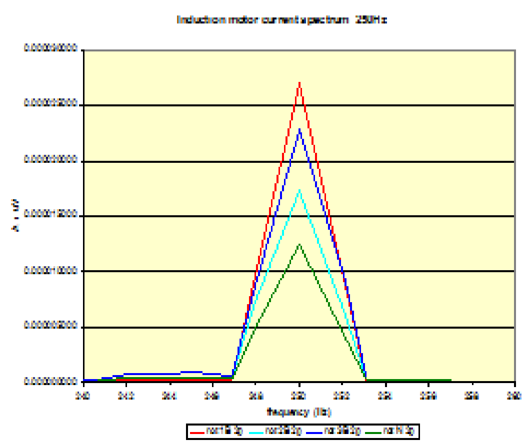

Figure 19 Comparation between stator current spectrum “healthy” and rotor bars fault at 250Hz frequency

A diagnostic procedure using a neural network shall be designed to detect any fault which may come out.

It is demonstrated that the method of stator current signature is very efficient for single induction motor diagnosis, stator faults, rotor faults (in this case rotor broken bars).

CONCLUSIONS

The technique of evaluating the motor condition by performing a FFT of the single induction motor vibration and stator current has been certified by the experimental results. In this case electric motor vibration and stator current monitoring is very useful to detect rotor faults.

By the corresponding zoom we can observe that vibration and stator current it is different at the “healthy” motor related fault motor.

Having made these measurements in the future we want to design a neural network which will help us to build an expert system to help us decide if the motor is healthy or broken.

Thanks to these methods the diagnosis of broken rotor bars could be done even if the motor operated unloaded.

So, the factory maintenance can easily and successfully detect mechanical fault that leads to unexpected downtime.

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