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SOME CONSIDERATIONS REGARDING THE DIAGNOSIS OF THE THREE-PHASE SQUIRREL-CAGE INDUCTION MOTOR COMPONENTS

Ioan Călin ROŞCA *, Melania FILIP**

*Mechanical Engineering Faculty, Transilvania University of Brasov, Romania,
** "Mircea Cristea" College, Brasov, Romania

Abstract: *The main mechanical problem of the electric motors is given by the vibrations developed during the work. Their level and frequencies can leads to faults of different electrical motors parts especially when frequencies value reach the natural frequencies. This is the reason why, natural frequencies determination is very important. This determination can be done by two different ways: based on finite element method (FEM) and experimental modal analysis. In the present paper it is presented a study of the modal analysis of a three-phase squirrel cage induction of 1.5 kW for three parts. There are presented some results obtained from the analytic method of FE comparing with experimental tests.*

Keywords: *modal analysis, finite element method, vibrations*

1. INTRODUCTION

Mechanical vibrations, as behaviour of a mechanical system, are generated by the continuous transformation of kinetic and potential energies of different moving components, or by different external excitation sources.

A reduced level of vibrations means, in the same time, a safety work, reduced level of noise and optimum working regime.

Due these considerations, both vibrations control and decreasing vibration level are essential elements for performance maintaining.

Theoretical dynamic analysis of the mechanical systems is based on mathematical models. The complexity of such models depends on the data and characteristics needed to define the main four parameters: components inertia (mass), systems structure (damping and stiffness), vibration sources, and boundary conditions.

In the case of any electric motor and particular for three-phase squirrel-cage induction motor one of the important problem in their working regime is the detailed knowledge of the natural vibrations (natural frequencies) of different components.

Extracting accurate natural frequency by analytical and experimental methods offer an image of the future possible complex faults that are developed during mode operations.

2. NATURAL FREQUENCIES DETERMINATION

2.1 Bearing frequencies. A long time good operation involves a continuous process of monitoring and diagnosis of electrical motors.

Researches on diagnosis, prediction and identification of the faults were done being high light the main fault sources [3, 6, 7].

One of the main mechanical sources of failure is represented by the bearings. Generally, the main problems connected with the bearings refer to: inner ring rotation, bearing balls rotation yield to the inner or outer rings considered fixed.

In the literature there are presented some relationships used to find the frequencies tied with the bearings [4, 5, 8, 9]:

- for inner ring:

$$f_{in} = \frac{n}{60}\,[Hz] \tag{1}$$

- for ball holder yield to the outer fixed ring

$$f_{ofr} = \frac{n}{120}\left(1 - \frac{D_w \cos\alpha}{d_m}\right) \tag{2}$$

- for ball holder yield to the inner rotating ring

$$f_{ifr} = \frac{n}{120}\left(1 + \frac{D_w \cos\alpha}{d_m}\right) \tag{3}$$

- for ball holder yield to the outer fixed ring

$$f_{bof} = \frac{n\,d_m}{120\,D_w}\left[1 - \left(\frac{D_w \cos\alpha}{d_m}\right)^2\right] \tag{4}$$

- fault frequency on the ball race

$$f_t = \frac{\pi\, d_m\, n}{2b}\left[1 - \left(\frac{D_w \cos\alpha}{d_m}\right)^2\right] \tag{5}$$

where, n is the shaft angular speed given in rot/min, D_w is the ball diamenter [mm], d_m is the medium bearing diameter, α is the contact angle, and b is the fault length on the ball race, in [mm].

Based on these relationships one can identify, in the recorded vibration diagram, the frequencies associated with the main components of the bearings.

2.2 Parts frequencies. The natural frequencies of different parts of the electric motor can be found using both analytical methods, as finite element method (FEM), or by modal experiments [1, 2].

The finite element model is based on the assumption that the electric motor consists in several main parts that are connected by different elements and boundary conditions. The authors considered a three-phase squirrel-cage induction motor of 1.1 kW power and 1500 rpm, manufactured by the company Electroprecizia from Sacele, Romania.

The assembly of the electric motor was considered to be done of seven main solid parts: the frame, the stator, the rotor, the fore and back cases, and the two bearings. For each part was done both analytic and experimental determination of the natural frequencies.

The analytic determination was done using the ABAQUS FEM soft and for experimental tests it was used the Brüel&Kjær PULSE platform.

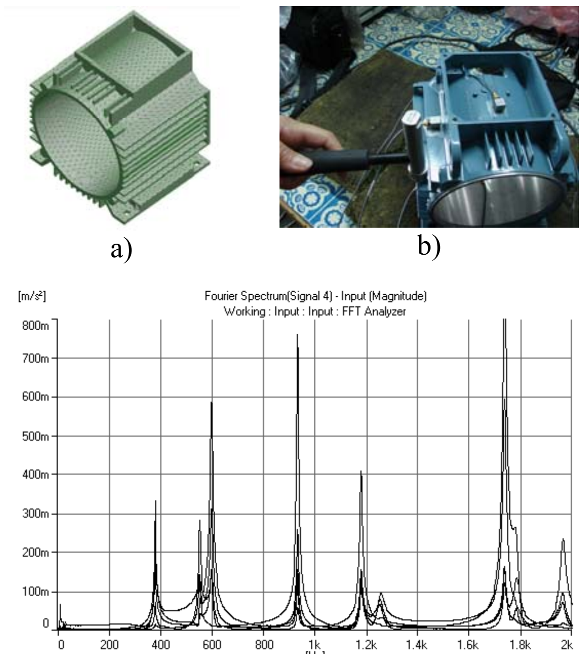

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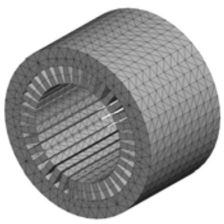
Figure 1 Electric motor frame: a) finite element model; b) modal testing; c) modal response for all five accelerometers.

The equipment used consists of an impact hammer (Brüel&Kjær type 8206-003), five accelerometers (Brüel&Kjær type 4507B), data acquisition platform PULSE 12 (Brüel&Kjær) and dedicated soft for signal processing in time and frequency domains. For the beginning it was analyzed the frame (Figure 1). A particularity of the frame consists in its geometry (holes, cooling ribs, different geometrical shapes, etc.).

The complexity imposed to be chosen for the FEM a free mesh with tetrahedron elements (8327 nodes and 27605 elements).

The modal test was done according with the prescriptions presented in the literature [2].



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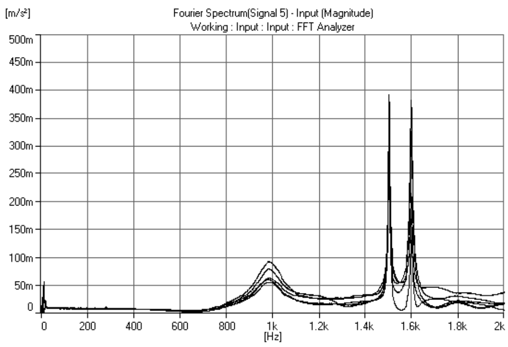

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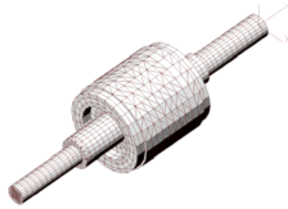
Figure 2 Electric motor stator: a) finite element model; b) modal testing; c) modal response for all five accelerometers.

In case of analytical determination, there were found as main natural freqencies: f_{em1} = 37.661 Hz, f_{em2} = 74.661 Hz, f_{em3} = 134.40 Hz, f_{em4} = 323.64 Hz. Based on experiments there were obtained the following main natural frequencies: f_2 =7.5 Hz, f_{e2} = 378 Hz, f_{e3} = 547.5 Hz, f_{e4} = 596 Hz, f_{e5} = 931.5 Hz, f_{e6} = 1179 Hz, f_{e7} = 1734 Hz.

The next analysed part was the stator (Figure 2). The complexity imposed to be chosen for the FEM a free mesh with tetrahedron elements (4964 nodes and 9794 elements).

Based on finite element method there were found the following natural frequencies of the stator: f_{em1} =121 Hz, f_{em2} =168.26 Hz, f_{em3} = 226.78 Hz, f_{em4} = 278.84 Hz, f_{em5} = 344.18 Hz, f_{em6} = 377.79 Hz, f_{em7} = 401.207 Hz, f_{em8} = 534.82 Hz, and f_{em9} = 542.29 Hz. The experimental modal analysis shows four natural frequencies in the range 0 ÷ 2 kHz: f_2 = 10 Hz, f_{e2} = 986.5 Hz, f_{e3} = 1500 Hz, f_{e4} =1597 Hz.

Another important part analysed was the rotor (Figure 3).



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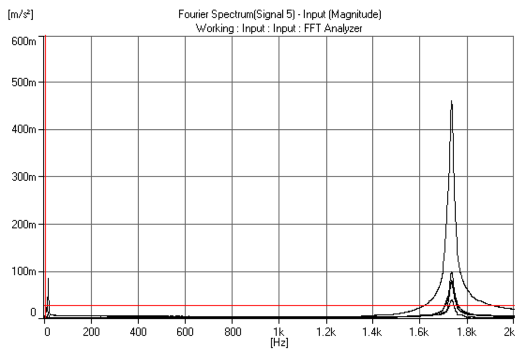

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Figure 3 Electric motor rotor: a) finite element model; b) modal testing; c) modal response for all five accelerometers.

The model of finite elements consists of 6471 nodes and 15792 elements. Using finite method there were found as natural frequencies: f_{em1} = 20.58 Hz, f_{em2} = 99.746 Hz, f_{em3} = 124.53 Hz, f_{em4} = 138.84 Hz, f_{em5} = 195.84 Hz, and f_{em6} = 208.94 Hz. Experimental modal analysis shows as main natural frequencies f_2 = 10 Hz, and f_{e2} = 1732 Hz.

3. CONCLUSIONS

The diagnoses of electrical motor faults involve the knowledge of both natural and the loads frequencies.

In this paper, a modal finite element analysis and a modal test were presented subjected some parts of an electric motor.

The structural complexity of the parts imposes the use of finite element method as general numerical method for natural frequencies determination.

The finite element model is a pure mathematical model subjected to some assumptions as the material characteristics considered the average values that are given by the soft material library. Another assumption is tied with the boundary conditions that some times are not equivalent between finite element model and real modal testing.

The finite element method induces errors but based on it one can find a global behaviour of the modal phenomenon.

The values that were found by both methods are appreciatively the same. The differences are generated by the values that are considered for the material constants: Young's modulus and density). Both values are direct influence in stiffness and in mass. The future work will be concentrated on making an equivalence between the real model and the finite element model.

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