

THREE-PHASE INDUCTION MOTORS WITH SQUIRREL-CAGE ROTOR NOISE-TO-FREQUENCY CHARACTERISTICS

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Abstract: *the paper presents the methodology for obtaining the level of noise in three-phase induction motors with squirrel cage rotor. Investigations include a single-speed motor with 3000 r/min and a two-speed motor with 750 and 1500 r/min. The investigated motors (manufactured by a Romanian company) were placed in a semi-anechoic chamber in order to determine the noise-to-frequency characteristics (spectrograms). The spectrograms were analyzed and the results and conclusions are presented in this paper.*

Key words: *induction motor, magnetic noise, squirrel cage, noise sources.*

1. Introduction

A study of the noise level produced by different three-phase induction motors with squirrel-cage rotor is presented in this paper. A special focus is made on two-speed motors with the rated speed of 750 and 1500 r/min. The admitted noise level in electric motors must be declared in the manufacturer's catalogue and in compliance with IEC 34-9 European standard.

This paper is from a series of other papers [3-11] which deal with the problem of noise in induction motors.

2. Noise Sources in Electrical Machines

The sources of noise [2], [7-9] in a three-phase induction motor with squirrel-cage

rotor are of three types: aerodynamic, mechanical and magnetic which determine a particular type of noise: of aerodynamic, mechanical and magnetic nature.

The aerodynamic sources can be: the fan, the cooling fins on the cage, the air currents when passing through the ventilation air duct. In most of the cases, the main noise source is the fan, excepting the cases when exterior ventilation is used.

The mechanical sources of noise can be of different types: own sources, determined by the natural vibration of the stator core; sources produced by the load, including the noise caused by coupling the motor with the load and mounting the motor on its foundation; auxiliary mechanical noise sources, including the ball bearing noise, the unbalanced rotor noise and the irregular air-gap noise.

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The rotor should be precisely balanced as it can significantly reduce the vibrations. The rotor unbalance causes rotor dynamic vibration and eccentricity which in turn results in noise emission from the stator, rotor and rotor support structure.

The electromagnetic forces cause the so-called electromagnetic noise of the motor. Electromagnetic forces depend on changes of the air-gap width.

The motors were tested in a semi-anechoic chamber at *Electroprecizia SA* in order to determine the noise-to-frequency characteristics. The noise analysis is achieved by separating the noise from the three different sources. The goal is to obtain the noise from each single source. In order to eliminate a source, its level must be reduced by at least 10 dB below the global level of noise, in any frequency band.

We can measure the ball-bearing noise L_{mec} if the motor is driven and the fan is removed. If the fan is not removed, then the measured noise will be composed of the ball-bearing noise and the ventilation noise $L_{mec} + L_V$. From these two measurements, by comparison, the aerodynamic noise may be calculated, considering the rule of addition of the noise levels of different origins:

$$L_{V+mec} = 10x \log(10^{0.1L_V} + 10^{0.1L_{mec}}). \quad (1)$$

If the motor is operated and the fan is removed, the ball-bearing noise and the magnetic noise $L_{mec} + L_{mag}$ could be measured. On the other side, if the motor is operated at no-load, the total machine noise L_{tot} could be obtained on the spectrograms and the result could be compared with the calculated value obtained by:

$$L_V = 10x \log(10^{0.1L_V} + 10^{0.1L_{mec}} + 10^{0.1L_{mag}}). \quad (2)$$

3. Theoretical Background

The limits of noise are established by CEI 34-9 International standard which specifies the maximum allowable levels of the acoustic power for rotating electrical machines, where, for cooling methods, the CEI 34-6 standard is used, and the protection degrees are according to CEI 34-5.

Measuring noise and vibrations serves a double goal: building a finite product, acoustically acceptable for the customer and detecting the design and manufacturing flaws, by measuring a high level of noise or identifying an unusual frequency spectrum [13].

The interactions of the higher order harmonics of the stator and the rotor produce radial forces. When their frequency matches the natural frequency of the stator, resonance appears and thus the noise level is increased. The radial force on unit surface, in every point of the air-gap, is given by [5]:

$$p_r = \frac{B^2(\alpha, t)}{2 \cdot \mu_0}, \quad (3)$$

where $B(\alpha, t)$ is the instantaneous value of the magnetic induction in the air-gap, measured in T (Tesla), on the rotor perimeter, in a point defined by the angle α , at the moment t . μ_0 is the magnetic permeability of air, measured in H/m (Henry/meter).

According to the Maxwell stress tensor, the magnetic pressure waveform at any point of the air-gap, can be given as [1], [12]:

$$p_r(\alpha, t) = \frac{1}{2\mu_0} [b_n^2(\alpha, t) - b_t^2(\alpha, t)], \quad (4)$$

where: $b_n(\alpha, t)$ - the normal component of magnetic flux density in the air-gap at a point determined by the angle α ; $b_t(\alpha, t)$ - the tangential component of magnetic flux density in the air-gap at a point determined by the angle α .

The magneto-motive forces of the stator and rotor of an induction motor have the following forms [1]:

$$F_s(\alpha, t) = \sum_{v=0}^{\infty} F_v \cos(vp\alpha \pm \omega_v t), \quad (5)$$

$$F_r(\alpha, t) = \sum_{\mu=0}^{\infty} F_{\mu} \cos(\mu p\alpha \pm \omega_{\mu} t + \varphi_{\mu}), \quad (6)$$

where: v - the order of the stator magneto-motive force harmonics; μ - the order of the rotor magneto-motive force harmonics; p - number of pole pairs; ω_v - angular speed for the stator magneto-motive force harmonics; ω_{μ} - angular speed for the rotor magneto-motive harmonics; φ_{μ} - the phase difference between the rotor harmonics and the pole axis.

$$p_r(\alpha, t) = \frac{\Lambda_{i0}^2}{2\mu_0} \sum_{v=0}^{\infty} \sum_{\mu=0}^{\infty} \frac{F_v F_{\mu}}{2} \cdot \cos[(v-\mu) \cdot \alpha \pm (\omega_v - \omega_{\mu}) \cdot t + \varphi_{\mu}]. \quad (9)$$

The general expression for the pressure exerted by the radial force on the rotor is:

$$p_r(\alpha, t) = A_r \cdot \cos(r\alpha - \Omega_r t), \quad (10)$$

where: A_r - the amplitude of the magnetic pressure; Ω_r - the angular speed; r - the mode number of the deformation.

The biggest amplitude of the vibrations [11] occurs for mode numbers, $r = 0, 1, 2, 3, 4$.

In the case of interaction of the space harmonics produced by stator and rotor windings, the mode number is given by [1], [10]:

$$r = p_v \pm p_{\mu} = p(6k_1 + 1) \pm (k_2 Z_2 + p), \quad (11)$$

where: p - the number of pole pairs of the motor; p_v - the number of pole pairs of the stator harmonics; p_{μ} - the number of pole pairs of the rotor harmonics; Z_1 - the number of stator slots; Z_2 - the number of rotor

Neglecting the value of iron reluctance, relation (4) becomes:

$$p_r(\alpha, t) = \frac{1}{2\mu_0} [F_s(\alpha, t) + F_r(\alpha, t)]^2 \Lambda_i^2(\alpha), \quad (7)$$

where:

$$\Lambda_i(\alpha) = \Lambda_{i0} \left[1 + \sum_{k=1,2,3}^{\infty} A_k \cos(kZ_1 \alpha) \right], \quad (8)$$

where: Λ_i - the air-gap permeance; Λ_{i0} - the constant component of the relative permeance; A_k - the harmonic air-gap permeance.

It is important to define the most significant part of the magnetic noise which is produced by the term, according to (7):

slots; k_1 - the stator harmonic coefficient: $0, \pm 1, \pm 2$; k_2 - the rotor harmonic coefficient: $0, \pm 1, \pm 2$.

The frequency, at which certain components of the radial forces occur, is given by the well known expression:

$$f_r = \frac{\Omega_r}{2\pi}. \quad (12)$$

The frequencies of the radial forces are [5]:

$$f_r = f \cdot \left[1 \pm k \frac{Z_2 \cdot (1-s)}{p} \right]. \quad (13)$$

The natural vibration frequency of the stator core [1], [10]:

$$f_0 = \frac{1}{\pi D_s} \cdot \sqrt{\frac{E}{\rho \cdot K_y}}, \quad (14)$$

$$K_y = \frac{G_Z + G_w + G_b + G_j}{G_j}, \quad (15)$$

where: D_S - the diameter of the stator core; E - Young's elasticity modulus; ρ - Poisson's ratio; G_Z - the tooth weight; G_w - the winding weight; G_b - the insulation weight; G_j - the stator yoke weight.

For accurate acoustic measurements corre-

sponding measurement instruments have to be used and special room arrangements have to be made. The main equipments used are: a microphone, a frequency analyzer, an oscilloscope and an oscillograph.

The Sound Level Meter is a portable apparatus used for measuring the global level of acoustic pressure, measured in decibels. This apparatus is presented in Figure 1:

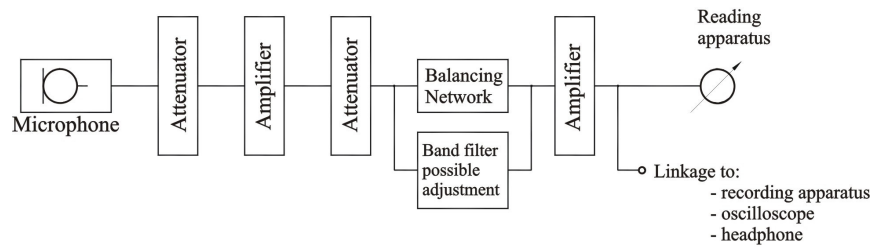


Fig. 1. *Sound Level Meter Scheme*

The Microphone is the most important component of the system as it greatly influences the performance. The Frequency Analyzer shows the noise amplitude spectrum distribution according to frequency.

It is necessary that the instruments used for measurement to take into consideration the sensibility characteristic of the human ear with respect to sound frequency. This was implemented with the help of special adjustment filters and ponderation networks built in compliance with the standard CEI 34-9, which specifies that for electrical machines, the frequency response must match

the A type curve that closely corresponds to the human ear's sensibility characteristic.

4. Noise-to-Frequency Diagrams

The noise-to-frequency diagram from Figure 2 presents the total noise level of a 1.5 kW induction machine, with 3000 r/min. The motor is at no-load operation, and network supplied at 400 V.

Relation (13) is proved to be correct, as peaks between 800 and 1000 Hz appear on the diagram. As an example, for $k = 1, p = 1, f = 50$.

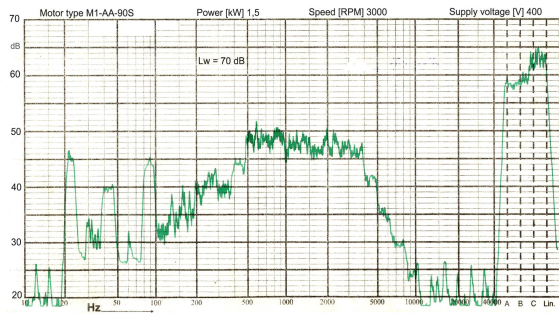


Fig. 2. *No-load operation for a 1.5 kW, 3000 r/min motor, at $U_N = 400$ V and 50 Hz, network supplied*

The next diagrams indicate the noise level for a two-speed motor, 0.05 kW, 750 r/min and 0.2 kW and 1500 r/min, with star or double star connection, respectively. The motor has the fan removed, so there will be no aerodynamic noise. According to relation (13), important peaks appear in the 500-1000 Hz range, for both types of motors.

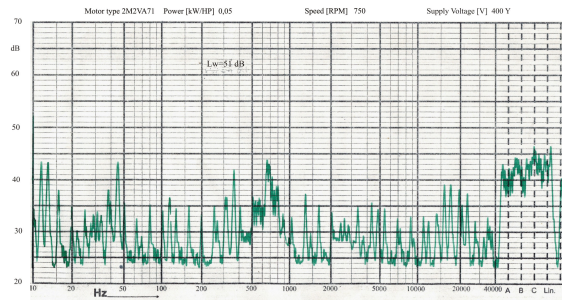


Fig. 3. 2-speed motor, 0.5 kW, 750 r/min at $U_N = 400$ V and 50 Hz, star connected

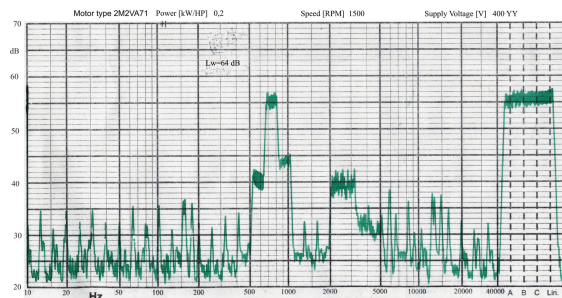


Fig. 4. 2-speed motor, 0.2 kW, 1500 r/min at $U_N = 400$ V and 50 Hz, double star connected

A considerable increase in the noise level may be observed, from 51 dB in the case of 750 r/min speeds to 64 dB in the case of 1500 r/min.

Magnetic and ball-bearing noise is dominant for 1500 r/min. Magnetic noise is dominant for 750 r/min, may be accompanied by ball-bearing noise in certain cases.

5. Conclusions

The paper presents the study of the noise level produced by three-phase induction motors with squirrel-cage rotor. A noise-to-frequency characteristic for one-speed motor and for a two-speed motor is presented. The results prove that the noise levels for

the tested motors are in compliance with the International Standard IEC 34-9, which specifies that the maximum A-weighted sound power level must be 78 dB.

The spectrograms represent an important tool for determining the influences of the different sources of noise to the global noise of the induction motor.

The paper proves that the obtained results from the noise to frequency characteristics correspond to the theoretical background described.

References

- Gieras, J., Wang, C., et al.: *Noise of Polyphase Electric Motors*. Taylor &

- Francis, 2006.
2. Iudin, E.Ia.: *Environment Insulation Against Noises* (in Romanian language). Bucureşti. Publishing House Tehnica, 1968.
 3. Le Besnerais, J.: *The Reduction of Magnetic Noise in PWM-Supplied Induction Machines - Low-Noise Design Rules and Multi-Objective Optimisation*. In: Ph.D. Thesis, Ecole Centrale de Lille, Lille, 2008.
 4. Peter, I.: *The Noise of the Electrical Induction Motors with Squirrel-Cage Rotor*. In: *Electrotehnica* **2** (2003), p. 17-23.
 5. Peter, I.: *The Noise of the Electrical Induction Motors with Squirrel-Cage Rotor*. In: International Conference OPTIM'2004, Braşov.
 6. Peter, I.: *The Noise of the Electrical Induction Motors with Squirrel-Cage Rotor*. In: Ph.D. Thesis, Transilvania University of Braşov, Braşov, 2004.
 7. Peter, I.: *The Noise of the Electrical Induction Motors with Squirrel-Cage Rotor*. In: Homagial Conference ICPE, Bucureşti, 2005, p. 50-64.
 8. Peter, I., Scutaru, Gh., et al.: *The Noise of Two-Speed Three-Phase Induction Motors with Squirrel Cage Rotors*. In: *Revue Roumaine de Science Techniques* **2** (2008), p. 199-212.
 9. Peter, I., Tata, M.: *The Noise of the Electrical Induction Single-phase Motors with Squirrel-Cage Rotor*. In: International Conference OPTIM'2006, Braşov, p. 48-54.
 10. Peter, I., Tata, M.: *The Noise of the Electrical Induction Single-phase Motors with Squirrel-Cage Rotor*. In: EEA 54, *Electrotehnica* **3** (2006), p. 6-12.
 11. Scutaru, Gh., Peter, I.: *The Noise of the Electrical Induction Motors with Squirrel-Cage Rotor*. Braşov. Publishing House Lux Libris, 2004.
 12. Scutaru, Gh., Peter, I., et al.: *The Magnetic Noise of Three-Phase and Single-Phase Induction Motors with Squirrel Cage Rotors*. In: Proceedings of EUROCON'2009 IEEE, Sankt Petersburg, 2009, p. 853-860.
 13. Tolyat, H.A., Kliman, G.B.: *Handbook of Electric Motors*. Taylor & Francis, 2004.