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A NEW SOFTWARE APPROACH TO NOISE LEVEL CALCULATION.

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Abstract: *The paper analyzes the types of noise sources in single speed, three-phase induction motors with squirrel cage rotor. A new, Lab-View based software approach is proposed for calculating the aerodynamic, mechanic and electromagnetic components of noise. For verification, the obtained results are compared with the measurements performed on six types of squirrel cage induction motors, with powers ranging from 0.55 to 1.5 kW and rated speeds of 3000, 1500 and 1000 r/min. The motors were tested in a semi-anechoic chamber. The computed results show good agreement with the measured ones. The software may be used mainly in designing electrical machines.*
Key words: *Induction Motor, Noise Sources, Squirrel Cage Rotors, Software*

1. INTRODUCTION

In this paper, a computerized noise level calculation method for three phase induction motors with squirrel cage rotors is described. The method uses theoretical and experimental data for predicting the magnitude of aerodynamic, mechanic and electromagnetic noise components produced by a motor. An important factor which justifies this type of study is the use of induction motors in different environments requiring silent operation, like air-conditioning systems. Furthermore, the increasing cost of the materials forces the machine manufacturers to limit the use of material which may lead to a weaker structure of the stator core. This causes the motor to become more susceptible to vibrations.

Although the problem of induction motor design has been previously analyzed in many papers like (Arkkio, 1987), most authors present either the electromagnetic or the mechanical aspects of the problem. It is proven that by lowering the width of the air gap or by choosing the wrong relationship between stator and rotor slot numbers, the magnetic sound power level increases especially in the case of variable speed induction motors.

Most noise is generated when the natural frequency of the stator core is close to the frequency of the magnetomotive force. In order to estimate acoustic noise correctly it is necessary to accurately calculate the natural frequency of the stator. There have been many papers like (Besnerais et. al., 2009) that studied the calculation of the mechanical natural frequency of the motor and the stator. Using the Finite Element Method, the effects of stator windings on the resonant frequencies have been studied. Young's modulus, material density of steel sheets and meshing methods were examined by experimental methods and FEM in two dimensional stator models (Zghanjun et. al., 2003). A literature survey has revealed that there are few papers like (Irwin & Graf, 1979) that deal with the calculation of the aerodynamic component of noise, which plays an important role for many large motors.

Because most existing software packages deal only with the traditional design of a motor and overlook the noise level requirements for nowadays motors, in this paper we propose a new and simpler approach to noise level calculation including the aerodynamic component, which can better suit the needs of an experienced motor designer. Six motors are measured in compliance with ISO 1680/1-1986 standard and the measured data is compared with the results obtained from the calculation.

2. THE NOISE SOURCES OF INDUCTION MOTORS

There are three types of noise sources for a cage rotor induction motor:

- Aerodynamic - produced by the circulation of air through the cooling fan and ventilation ducts;
- Mechanical - produced by the bearings, the eccentricity of the rotor or determined by the natural resonance frequency of the stator;
- Magnetic - produced by the magnetic forces (varying in space and time) which act between the stator and rotor.

The aerodynamic component is influenced by factors like: the shape and number of fan blades, the shape and dimensions of the cooling circuit, the speed of the air that passes through the circuit. For calculating the level of the acoustic pressure, corresponding to the aerodynamic component, we used a new formula given by the following expression in dB (Scutaru & Peter, 2004):

$$L_V = 60\log V + 10\log(D_V \cdot b_V) + 80D_V + 10.8 \qquad (1)$$

where:

V - speed of the fan, in r/min;
D_V - external diameter of the fan, in mm;
b_V - width of the blades of the fan, in mm.

The mechanical component of the noise is influenced by: the type and mounting procedure of the bearings, the mechanical tolerances of the parts that come in contact with the bearings, the type of end shields used for the motor. Since there are many types of motors and bearings, the best way to evaluate the level of the mechanical component of the noise is by performing statistical measurements having as parameters, the nominal power and speed of the motor (Scutaru & Peter, 2004), thus giving:

$$L_{wmec} = f(P_N, n). \qquad (2)$$

The magnetic component of the noise is determined by the interaction between stator and rotor magnetic field harmonics. These harmonics can be produced by a series of factors: the distribution of the winding in the stator slots, the presence of the slots on both stator and rotor, the level of eccentricity between the stator and rotor or because of the saturation of the magnetic circuit. As a consequence of these interactions, strong unbalanced magnetic pull forces appear between the stator and rotor, which act upon the parts of the motor bringing them into an oscillation state.

The sound pressure at the surface of a plane radiator, for a force wave with mode number r, is given by (Scutaru & Peter, 2004):

$$P_p = 1820 \cdot f_r \cdot X_r \,, \quad (3)$$

where, f_r is the frequency of the radial force and X_r is the amplitude of deformation.

Because expression (3) is only valid for small motors, we can introduce a more general expression in which the motor is considered to be equivalent to a spherical radiator (Scutaru & Peter, 2004):

$$P_{cil} = P_p \cdot \sqrt{P_r}, \quad (4)$$

where P_r is the radiating acoustic power at the surface of the spherical radiator.

The level of acoustic pressure, for the magnetic component of noise is given by (Scutaru & Peter, 2004):

$$L_{mag} = 20 \cdot \frac{\log p_{cil}}{p_0}, \quad (5)$$

where p_0 is the reference acoustic pressure level.

Therefore, considering the expressions (1), (2) and (5) the expression for calculating the global noise level of the motor, has the following form (Scutaru & Peter, 2004):

$$L_{global} = 10 \cdot \log(10^{0.1L_v} + 10^{0.1L_{mec}} + 10^{0.1L_{mag}}). \quad (6)$$

3. SOFTWARE IMPLEMENTATION

The proposed software is implemented using National Instruments programming environment, Lab-View. Each type of noise source has a separate calculation module that allows the designer to try different configurations for the input parameters, while keeping track of previous results.

For the aerodynamic noise level calculation by using expression (1), the user has to input the external diameter of the fan and the width of the blades. The calculation results are shown in table 1. The mechanical noise level is calculated by linear interpolation of the nominal power of the motor with a dependence of acoustic power levels on standard power values for known motors. The calculation results are shown in table 2. The magnetic noise level is calculated using expression (5). The user has to input motor parameters like: nominal voltage, width of air gap, number of stator and rotor slots. The calculation results are shown in table 3.

4. CONCLUSIONS

The proposed formula for calculating the magnitude of the aerodynamic component of noise is validated through the obtained results, shown in table 1. A good precision is achieved especially in the case of aerodynamic and mechanical components of the noise, as can be seen from tables 1 and 2. The flexible implementation using Lab-View means that new calculation modules may be implemented with ease.

For the measured motors, with powers ranging from 0.55 to 1.5 kW and rated speeds of 3000, 1500 and 1000 r/min, the noise levels calculated for the aerodynamic, mechanical and electromagnetic components are corroborated by the measured results, as shown in the following tables.

In conclusion, this software can constitute a valuable tool in the hands of an experienced motor designer, because of the reliable information it offers about the presumed noise level of an induction motor.

Motor frame size	Speed [r/min]	D_V [mm]	b_V [mm]	Measured L_V [dB]	Calculated L_V [dB]
80	3000	95	24	62	62.4
80	1500	129	24	52.5	56.4
80	1000	129	24	49.3	46
90	3000	100	28	65.1	65
90	1500	145	28	60.2	61.9
90	1000	145	28	58.5	51.3

Tab. 1. Measured and calculated aerodynamic acoustic pressure

Motor frame size	Speed [r/min]	Nominal power [kW]	Measured L_{wmec} [dB]	Calculated L_{wmec} [dB]
80	3000	1.1	72.6	74
80	1500	0.75	57.2	66
80	1000	0.55	66.6	63
90	3000	1.5	74.1	75
90	1500	1.1	70.1	69
90	1000	0.75	64.7	64

Tab. 2. Measured and calculated mechanical acoustic pressure.

Motor frame size	Speed [r/min]	Nominal power [kW]	Measured L_{mag} [dB]	Calculated L_{mag} [dB]
80	3000	1.1	66.2	49
80	1500	0.75	67.2	49.5
80	1000	0.55	66.2	53.3
90	3000	1.5	73.7	49.2
90	1500	1.1	70.1	49.6
90	1000	0.75	64.7	60.4

Tab. 3. .Measured and calculated magnetic acoustic pressure.

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