Magneto-vibro-acoustic Design of PWM-fed Induction Machines

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***Abstract*— The aim of this paper is to study the impact of the PWM supply on the vibro acoustic behavior of the induction machine. Modelling and Measurement results will be shown.**

Keywords—PWM, magnetic forces, NVH, Induction motor.

I. Introduction

Recently we can find IM in automotive application like Tesla or Renault Twizy. Speed control, means that the IM will be supplied with pulse width modulation (PWM). This kind of supply, can degrade motor vibro-acoustic behavior. To tackle these technical challenges and ensure acoustic comfort for users, it is necessary to design a quiet e-motors at the early stage of design. It is the aim of the method proposed in this article. The focus will be made only put on electromagnetic origins of noise and vibrations. One can understand the necessity to couple two physics, electromagnetic and mechanic to analyze generated noise and vibration and how to reduce them. The first aim of this paper is to show a new method (the so-called superimposed damper, already published) [1] to reduce noise and vibration due to PWM supply of IM. The second interest, is to show a new method which is fully finite element (FE) computation [2]. Analytical and semi analytical methods exists in the literature [3], but these methods are available only for a motor considered alone. The proposed method can be useful when the motor is integrated inside more complicated system, like an e-car for instance. Finally, the third interest of this article, is to compare noise and vibration results between the proposed FE method and measurements.

II. Damper Winding Method

A. Principle

The air-gap flux density harmonics in IM are reduced thanks to a second 3-phase winding superimposed to the stator winding, but electrically independent. This one will be named damper winding. It will be connected to 3 capacitors of suitable values. Figure 1 illustrates the principle of the method.

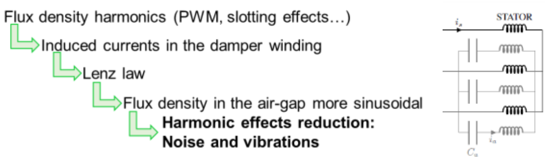

Fig. 1. Principle of the proposed method

B. Studied Induction Motor

The results presented in this paper are relative to a 4kW IM with damper windings. Its characteristics are: 230/400V - 15.3/8:8A - 1435 rpm - p=2 pole pairs.
The damper or auxiliary winding is clearly visible in Fig. 2.

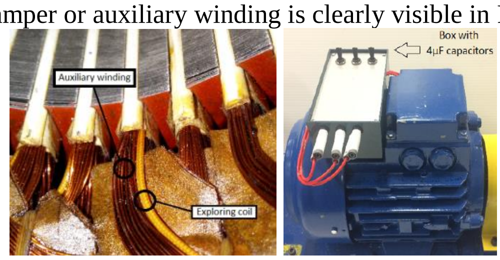

Fig. 2. Auxiliary winding of the studied prototype.

III. Modeling Approachs

A direct coupling between a 2D FE electromagnetic model built with commercial FE software Altair FLUX® and a vibro-acoustic 3D FE model built with commercial software Altair OptiStruct® is presented. The full diagram of the magneto-vibro-acoustic model is given by figure 3. In order to develop the model some hypothesis were formulated. Only the noise of electromagnetic origin is considered, the noise generated by the rotor is not taken into account because of its confinement by the stator one and the constraints are mainly localized on the stator inner radius surface.

A. Electromagnetic Model

The used model is illustrated in figure 4. The motor is supplied by voltage source with fundamental 50Hz and H82 at 4.1kHz. Note that the real spectrum has two group of dominating harmonics the 1st one is at 4kHz and the 2^{nd} one is at 8khz. A no load test is simulated thanks to the transient magnetic application in 2D. The used materials are M800-100A for rotor and stator lamination, Aluminum for squirrel cage, Copper for winding and XC10 for the shaft. The solving scenario contains 7201 steps, one step equal to 0.1°. A 2^{nd} order mesh is used with 13026 elements.

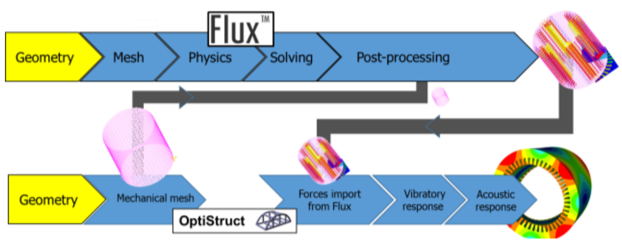

Fig. 3. Electromagnetic and mechanical modeling workflow

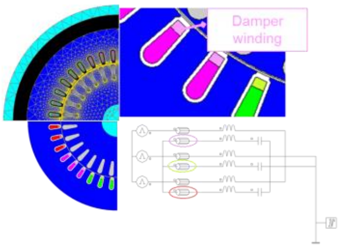

Fig. 4. Electromagnetic Model

B. Mechanical Model

A structural 3D FE model is created to describe the vibration behavior of the machine and an acoustical FE model evaluates its acoustic response. The tooth and stator core is an assembling of laminated iron. This lamination is taken into account using equivalent mechanical properties. The winding are not taken into account. Two models are studied, the stator alone and another one by modelling the stator and the housing. As we can see in figure 5 the modeled housing is close to the real one but not identical, because the CAD file of the real housing is missing. Chosen elastic moduli of the different materials are given in Table 1 where, E, G, ν and ρ are respectively Young modulus, shear modulus, Poisson's ratio and mass density.

TABLE I. MATERIAL CHARACTERISTICS

Parameters	Ex (GPa)	Ey (GPa)	Ez (GPa)	Vxy	Vxz	Vyz
Lamination	0,8	0,8	200	1,2E-03	0,30	0,30
Housing	71	71	71	0,33	0,33	0,33

Parameters	Gxy (GPa)	Gxz (GPa)	Gyz (GPa)	ρ(kg.m-3)
Lamination	0,3	79,3	79,3	7700
Housing	26,7	26,7	26,7	2700

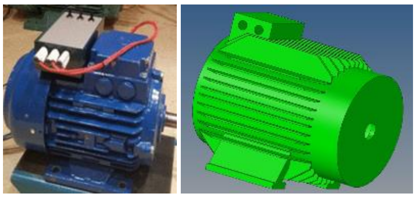

Fig. 5. Real and Modeling housing

IV. RESULTS

A. Experimental results

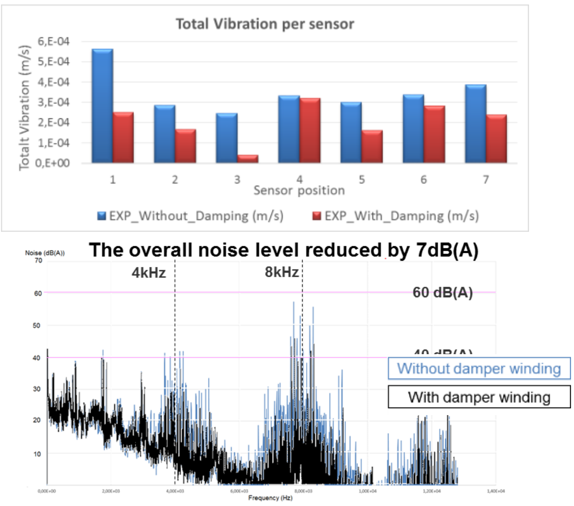

Fig. 6. Measured Noise and Vibration

B. Electromagnetic Modeling results

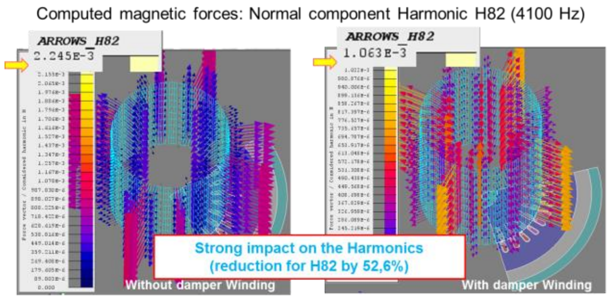

Fig. 7. Computed magnetic forces

C. Mechanical Modeling results

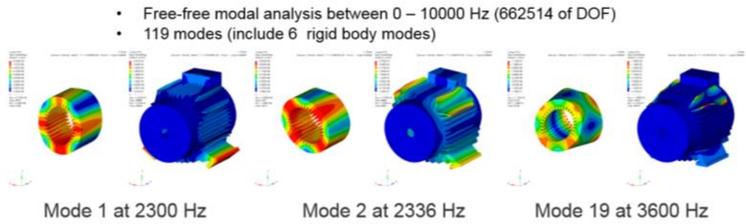

Fig. 8. Modal analysis results

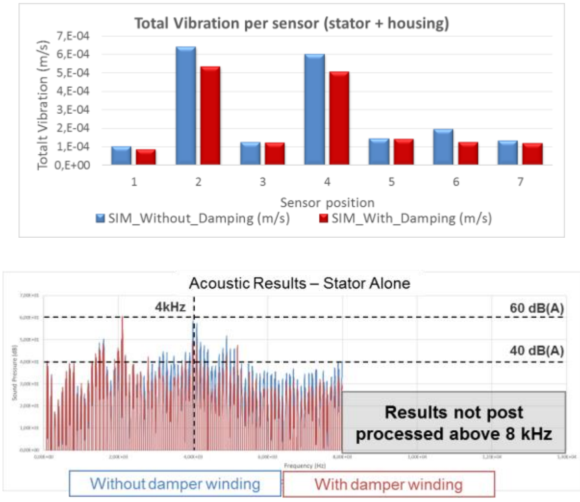

Fig. 9. Noise and Vibration – Modelling results

V. CONCLUSION

Damper winding is an easy and efficient way to reduce the impact of the PWM supply on the Vibro acoustic behavior. There is a good agreement between modelling and measurement results despite the assumption made for the voltage supply and the housing. Modelling method shows that the impact of each harmonic of the PWM supply can be studied separately.

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