Coupled Numerical Simulation Between Electromagnetic and Structural Models. Influence of the supply harmonics on the vibrations for a WRSM.

P.Pellerey, V.Lanfranchi, G.Friedrich
Laboratoire d'Electromécanique, UTC.
Université de Technologie de Compiègne, 60200 Compiègne, France.
Pierre.pellerey@renault.com

Abstract — This paper describes an automatic and fast numerical coupling method between 2D electromagnetic and 3D structural FEM programs software. This approach has been developed for a WRSM but can be applied for any non-skewed machines. The presented coupling method permits to predict the electromagnetic noise in electric machines for different realistic current alimentation. First, an analytical model will be briefly introduced to present the magnetic noise theory, computation algorithms coupling magnetic forces to structural mesh are then developed and finally simulation results will show the influence of supply harmonics on the global vibration level.

I. INTRODUCTION

For automotive applications, the noise of electric machines is an important and complex problem. From a psycho acoustic point of view and compared to internal combustion engines, electric machines generate relatively high frequencies that could be particularly unpleasant for users. Progress in mechanical and aerodynamic noise reduction makes the full understanding of magnetic noise generation crucial [1].

Developing numerical models to foresee and investigate the magnetic noise has been undertaken for MRV [2] and appears to be an efficient way to ensure acoustic services. In order to simulate the vibratory behaviour of the machine we will use a full numerical approach to predict at best phenomena. Combination of 2D electro magnetic and 3D structural dynamic FEM is today the best compromise to forecast magnetic noise with good precision and minimum time computational effort [3]. As numerical cost remains important, the presented coupling introduces a simple way to deal with the adaptation of different meshes. Other studies offer to reduce the time calculation cost when computing the electromagnetic forces [4] or during vibrations calculation [5].

We will show the influence of supply harmonics, due to the interaction between space harmonics of the machine and the automatism, on magnetic noise. Harmonics due to PWM are not considered but can be analytically studied [6].

II. THEORETICAL PRINCIPLE

For any working point of the motor, defined by a load torque T and a rotational speed N, we get the corresponding feeding currents: i_f for the excitation and $\{i_a, i_b, i_c\}$ for the phases currents as well as their associated harmonics $\{i_{fn}, i_{an}, i_{bn}, i_{cn}\}$ by measurements.

We then feed our machine during an electrical period and retrieve radial and tangential Maxwell pressures applied on the stator in order to have the more realistic excitation. We will disregard the rotor force excitations and possible eccentricities consequences [7]. The Maxwell stresses being a combination of spatiotemporal waves they can be defined by a Fourier series, i.e. for the radial ones:

$$\sigma_r(\theta,t)=\sum_{m,n}^{\infty}\sigma_{mn}^{r}\cos(m\theta\pm n\omega t+\varphi_{mn}) \qquad (1)$$

being θ the air gap angular position, ω/p the rotor speed, t the time and φ the phase shift. m and n are respectively the order of the space harmonic and the rank of the time harmonics.

This magnetic excitation is then exported to a structural-dynamic mesh of the motor so that the resulting deformations can be calculated. We solve through a modal frequency response method. The noise is then the consequence of the machine surface vibrations radiated in the air (note that the vibro-acoustic coupling already exists, i.e. ACTRAN® for NASTRAN®).

III. ELECTROMAGNETIC SIMULATIONS

For $T=105$ Nm and $N=1500$ rpm reference signal, the corresponding measured currents are presented fig. 1.

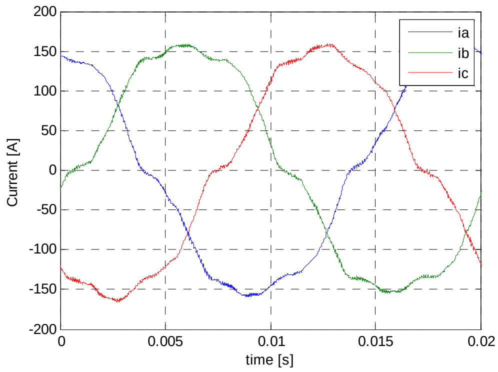

Fig. 1. Measured stator currents (rotor current will be shown too)

To simplify the study we only keep the main harmonics to supply to the FEM MAXWELL 2D® software program. Other measured currents will be presented for the same speed and for different torque (55 - 105 - 220 Nm). Keeping the same rotor speed helps to compare the vibration levels because of the fixed frequencies of mechanical resonances.

In the middle of the air gap, we get the radial and the tangential Maxwell pressures by computing:

$$\sigma_r(\theta,t)=\frac{\mu_0}{2}\left(H_r^{\,2}-H_t^{\,2}\right)=\frac{\left(B_r^{\,2}-B_t^{\,2}\right)}{2\mu_0} \qquad (2)$$

$$\sigma_t(\theta,t)=\mu_0 H_r H_t=\frac{B_r B_t}{\mu_0} \qquad (3)$$

Bi-dimensional spectral analysis of the excitations (*{n,m}* decomposition acc. to eq.1) will be presented to better understand the deformation shapes of the structure.

IV. STRUCTURAL DYNAMIC SIMULATION

We consider that, for a non-skewed machine the stresses are independent of the axial direction (it amounts to neglecting end effects). Therefore, we can impress the same forces value to nodes having the same angular position (the angular position θ_i is defined fig. 2). The creation of a regular mesh helps to simplify the coupling process between 2D and 3D FEM models.

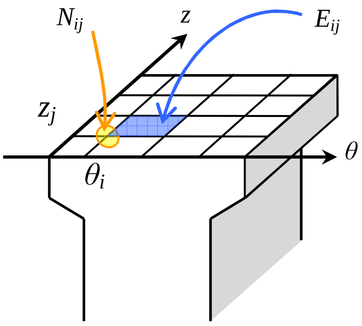

Fig.2. Structural mesh and coordinate system definition for a tooth

Using the conventions of the discrete coordinate system $(\vec{i},\vec{j})$, defined fig. 2, for quadrangle elements (8 nodes) with linear shape function we can calculate the force $F(E_{ij},t)$ applied on each element E_{ij} :

$$F(E_{ij},t)\cong\frac{\tilde{\sigma}(E_{ij},t)S_{tooth}}{(N_l-1)(N_L-1)} \qquad (4)$$

N_l is the number of elements along tooth width, N_L is the number of elements along the tooth length and S_{tooth} is the total tooth's upper surface. $\tilde{\sigma}(E_{ij},t)$ is the average of the pressure (radial or tangential) on the element *ij*. The equation (4) is true if all elements have the same size. Meshing rules to have an efficient coupling will be introduced.

We estimate, by neglecting edge effects on teeth length, that the forces $F(N_i,f)$, for each line *i*, are given by:

$$F(N_i,f)\cong\frac{F(E_{i-1},f)+F(E_i,f)}{2} \qquad (5)$$

The calculated vibratory response on motor housing surface is shown fig. 3 (average level on 12 calculation points). Simulation conditions will be specified.

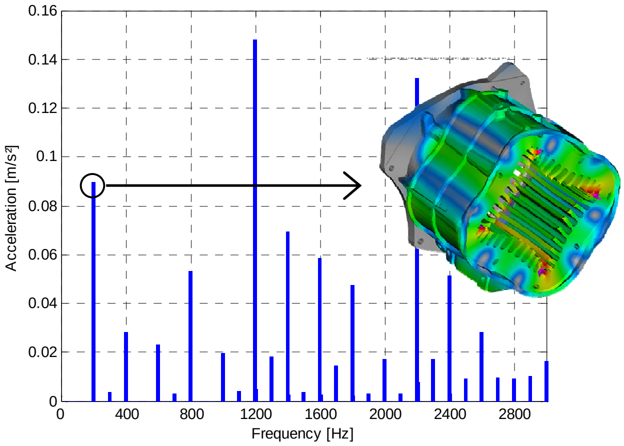

Fig.3. Motor housing average vibratory response

The deformation corresponding to the rank *n=4* (*f=200Hz*) is shown on the right. The deformation is actually a 4th order deformation rotating mode represented for a given phase. The associated deformations for the most important response amplitudes will be shown.

V. CONCLUSION

Different vibratory responses will be presented for the different kind of current supply (sinusoidal or harmonic). The responsibility of the harmonics will be underlined and the physic of the vibrations will be detailed.

VI. REFERENCES

[1] S.J. Yang, Low-noise electrical motors, Clarendon Press, 1981.

[2] B.Schmulling, K. Kasper, K. Hameyer, “Acoustic Optimization of a Switched Reluctance Machine using Numerical Simulation”. ICEM 2006.

[3] M. van der Giet, C. Schlensok, B. Schmülling, K. Hameyer, “Comparison of 2-D and 3-D Coupled Electromagnetic and Structure-Dynamic Simulation of Electrical Machines”, IEEE Transactions on Magn., vol..44, No. 6, June 2008.

[4] S. Biro, O. Weilharter, B. Stermecki, “A Weak Coupling Between Electromagnetic and Structural Models for Electrical Machines”, IEEE Transactions on Magn., vol.46 , Iss.8, pp. 2807-2810, Compumag 2009.

[5] M. Boesing, T.Schoenen, K.A. Kasper, R.W. De Doncker, “Vibration Synthesis for Electrical Machines Based on Force Response Superposition”, IEEE Transactions on Magn., vol.46, iss.8, pp. 2986 - 2989 , Compumag 2009.

[6] J. Le Besnerais, V. Lanfranchi, M. Hecquet, P. Brochet, “Characterization and reduction of audible magnetic noise due to PWM supply in induction machines”, IEEE Trans. on Ind Elec, Vol 57, N°4, pp1288-1295, April 2010

[7] B.A.T. Iamamura, Y.Le Menach, A. Tounzi, N. Sadowski, E. Guillot, “Study of Static and Dynamic Eccentricities of a Synchronous Generator Using 3-D FEM”, IEEE Transactions on Magn., vol.46, iss.8, pp. 3516 – 3519, Compumag 2009.