A Fast Noise-Predictive Multiphysical Simulation Tool of the PWM-Controlled Induction Machine

J. Le Besnerais*, M. Hecquet*, V. Lanfranchi, A. Ait-Hammouda, P. Brochet*, J.E. Masselus*****

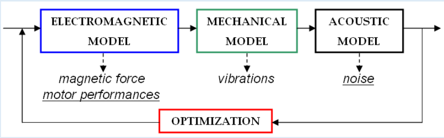
*****L.2.E.P. – Ecole Centrale de Lille, France   **L.E.C. – Université de Technologie de Compiègne   ***Alstom-Transport Belgium

Emails : jean.le_besnerais@centraliens.net, Michel.Hecquet@ec-lille.fr, Pascal.Brochet@ec-lille.fr

Abstract – This poster presents the simulation tool (DIVA) that has been developed to predict the noise and vibration level of electromagnetic origin emitted by an inverter-fed squirrel-cage induction machine. This fast programme is coupled to an optimization tool in order to reach the optimal design of an asynchronous motor and its supply strategy with high performances and low radiated noise.

Key words – magnetic noise, PWM strategies, squirrel-cage motor, skewing effect, multiphysics models, multiobjective optimization.

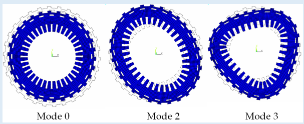
Multiphysical Coupling



The main assumption of the electromagnetic model is the **infinite magnetic permeability** of the iron. The mechanical and acoustic models also suppose that the stator vibrates as a **2D thin ring**.

Mechanical Model

Principle



The static and the dynamic stator deformations Y_s and Y_d are computed from the FFT2 of radial exciting force :

$$F = \sum_{m,\omega} F_{m\omega} \sin(\omega t + m\alpha_s) \rightarrow Y_d(m,\omega) \rightarrow Y_s(m,\omega)$$

$$Y_d = \frac{Y_s}{\sqrt{\left(1-\left(\frac{f}{f_m}\right)^2\right)^2 + (2\xi_m(f)\frac{f}{f_m})^2}}$$

where ξ_m is the damping factor of spatial mode m

Validation

The stator analytical natural frequencies have been validated with FEM software **ANSYS** and experiments :

Mode number	Analytical method natural frequency (Hz)	Experimental method natural frequencies (Hz) and damping coefficients (%)
0	3236	3283 (1.5)
2	674	616 (2.16) – 731 (2.22)
3	1740	1406 (1.47) – 1622 (2.1) – 1769 (1.16)
4	3273	3106 (0.96) – 3383 (0.88)

Acoustic Model

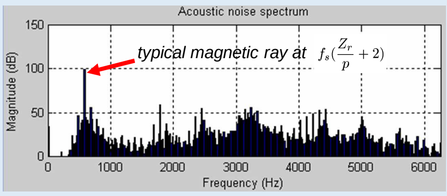
Principle

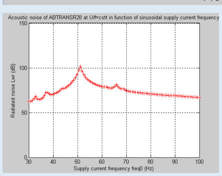
The air pressure level is linked to the stator vibration speed with :

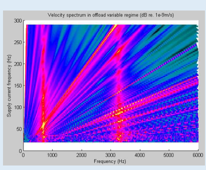
$$P = 2\pi^2 \rho c S \sigma_m f^2 Y_d^2$$

where σ_m is the radiation factor of spatial mode m

Results



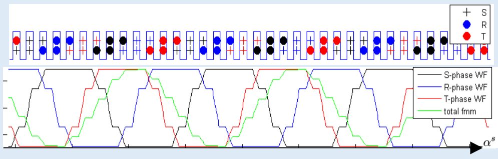




Electromagnetic Model

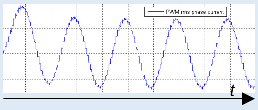
Principle

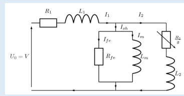
1 - Magnetomotive forces *computation* :



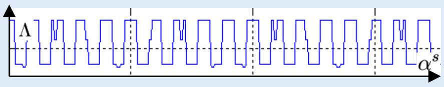
The stator and rotor winding functions are firstly computed.

The PWM phase current levels are then computed on the base of a multilevel single phase equivalent circuit and a **SIMULINK** model.





2 - Permeance *computation* :



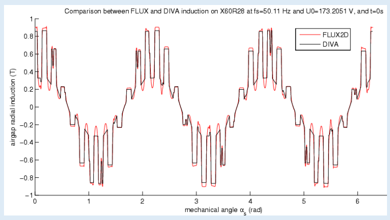
3 - Airgap radial induction *computation* :

The radial induction is :

$$B_n(t,\alpha^s) = \Lambda(t,\alpha^s)\,(f^r_{mm}(t,\alpha^s) + f^s_{mm}(t,\alpha^s))$$

The magnetic force exciting the stator surface is finally approximated by :

$$\frac{d\mathbf{F}}{dS} \approx \frac{B_n^2}{2}\left(\frac{1}{\mu_a} - \frac{1}{\mu_f}\right)\mathbf{n} \approx \frac{B_n^2}{2\mu_0}\mathbf{n}$$

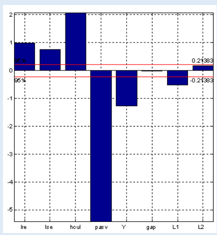


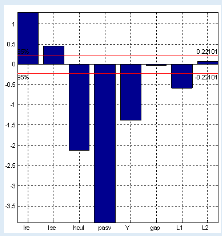
Validation

The airgap radial induction computed by DIVA analytical model compares favorably with FEM **FLUX2D** results on various motors. The motor traction characteristics (efficiency, torque and power) have been also validated by comparison with tests and simulations.

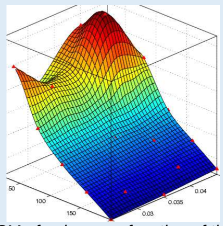
Optimization Results

The **Design of Experiments** method has been coupled to DIVA in order to study the influence of all the design variables on magnetic noise (screenings) and draw some response surfaces.

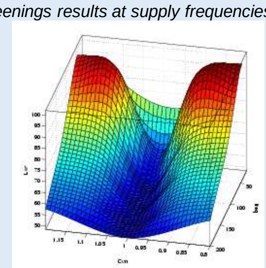




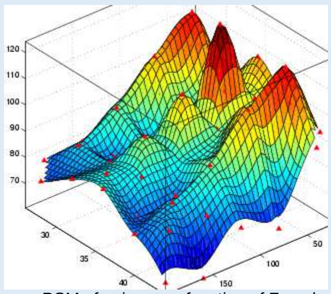
Screenings results at supply frequencies 50 and 70 Hz



RSM of noise as a function of the height of yoke and supply frequency



RSM of noise as a function of skew factor and supply frequency



RSM of noise as a function of Z_r and supply frequency

The **SQP method** confirmed the optimal skew factor found with DoE.

Conclusion and Future Work

This fast simulation tool allows a better understanding of magnetic noise generation. It includes both windings function and Fourier Series approaches in order to do fast simulations suitable for optimization tasks, and harmonic analysis suitable for physical interpretations. The **saturation effects** still need to be investigated, as well as the PWM currents and airgap induction. The multiobjective genetic algorithm **NSGAII** with mixed variables will be used to find the **Pareto-optimality** in terms of magnetic noise and motor efficiency.

An other thesis also aims at computing in DIVA the motor iron losses and temperature, which will allow to include more criteria in the optimization process.