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CAE Based Noise Optimization of Switched Reluctance Electric Motors for Automotive Powertrains

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Abstract

This paper focuses on simulation of noise radiated by Switched Reluctance Motors for automotive powertrains. Since control for maximum efficiency leads to high torque ripple and noise radiation, optimizing the NVH behaviour is essential. The simulation approach, based on electro-magnetic and vibro-acoustic finite element models and applicable to other electric motors, is illustrated with concrete results.

Keywords: switching reluctance motor, optimization, simulation, finite element calculation

1 Introduction

Switched Reluctance Motors are an interesting alternative to Permanent Magnet Synchronous Motors, currently used in most electric powertrains. PMSMs provide high efficiency, but limited availability of rare earth elements could increase their costs.
A reluctance motor produces torque by the tendency of its rotor to move to a position where the inductance is maximized. Figure 1 shows that, by exciting a pair of opposed stator windings, the principle of minimal reluctance causes a torque aligning the rotor and the stator poles.
The industrial use of SRMs has become feasible thanks to the availability of inexpensive, high-power switching devices.
An SRM has no permanent magnets and the rotor consists of laminated iron, resulting in low manufacturing costs. Additionally, SRMs achieve maximum efficiency over a wide speed range, making their average efficiency over a real drive cycle similar to PMSMs.
Next to these advantages, SRMs also pose challenges: complex controls including phase overlap are needed to limit torque ripple caused by phase switching and their operation results in high noise radiation. Optimization of the control strategy to reduce torque ripple has a beneficial effect on noise radiation. Next chapter shows that structural optimization of the motor and its housing can further reduce the noise.

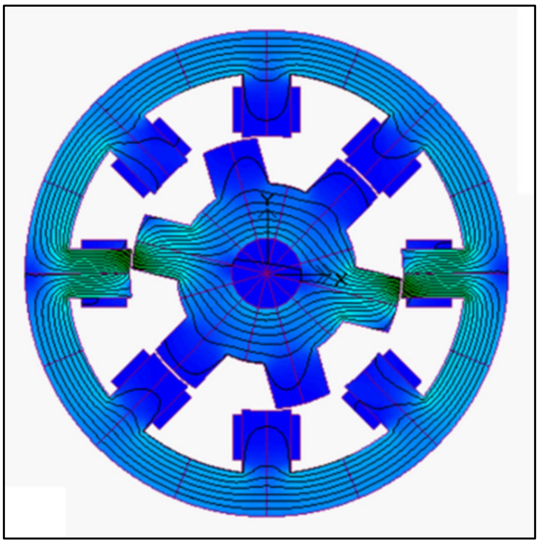

Figure 1: Magnetic Flux in SRM

The work in this paper was carried out on a 4-phase SRM with an 8/6 configuration (8 stator poles, 6 rotor poles), delivering 40 kW peak power and 200 Nm peak torque. This SRM is a.o. designed for used in a CVT based full hybrid powertrain as shown in Figure 2.

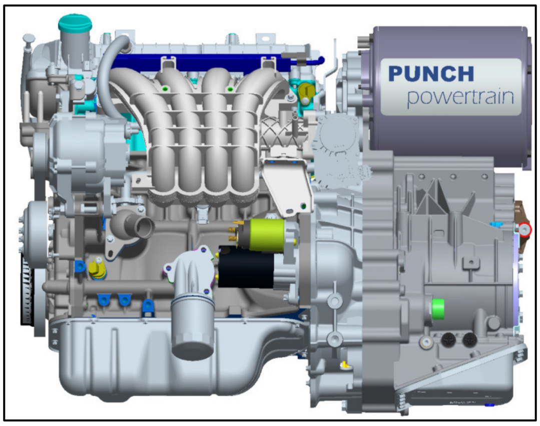

Figure 2: SRM as part of a hybrid powertrain

2 CAE Based Noise Optimization

The CAE process consists of 2 main steps: electro-magnetic simulation and vibro-acoustic simulation. Figure 3 shows a schematic overview.

2.1 Electromagnetic simulation

Current waveforms, describing the phase current as function of rotor angle, revolution speed and torque, were applied to an electro-magnetic FE-model. A 2D-model was used to limit the calculation time. Time domain simulation of a speed sweep (0–8.000rpm) under constant torque was performed.

2.2 Vibro-acoustic Optimization

2.2.1 Correlation of the structural model

The structural model was built-up and correlated step-by-step to accurately represent the dynamics in the required frequency range. This included a.o. the identification of equivalent anisotropic material properties to represent the laminated stator, determination of equivalent representations of the stator windings etc.

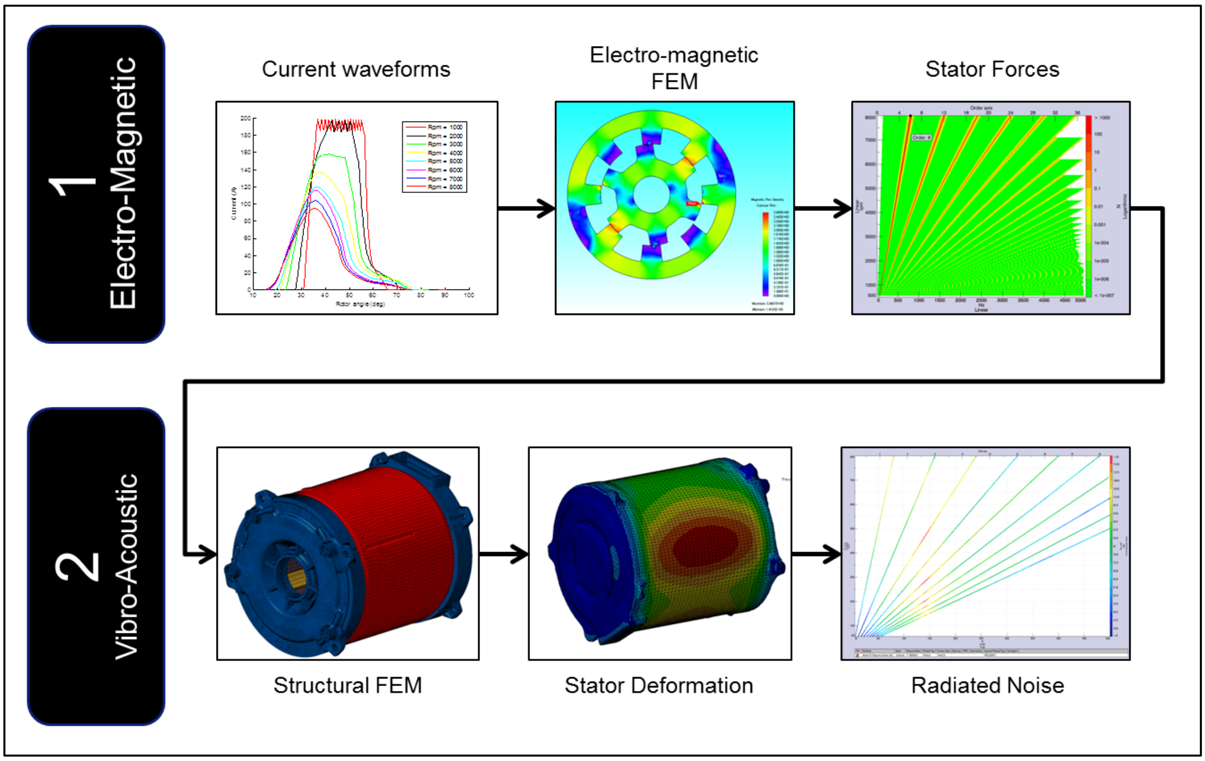

Figure 3: Simulation process for noise radiation of an SRM

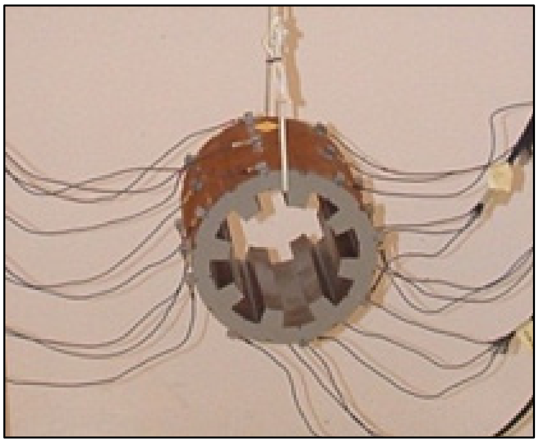

Figure 4: Stator modal tests

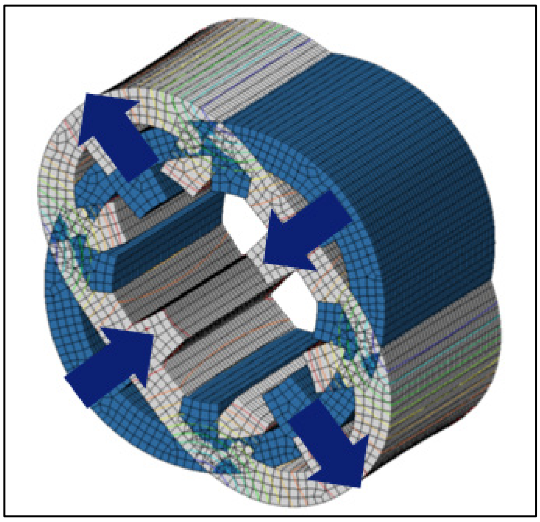

Figure 5: Stator FE results

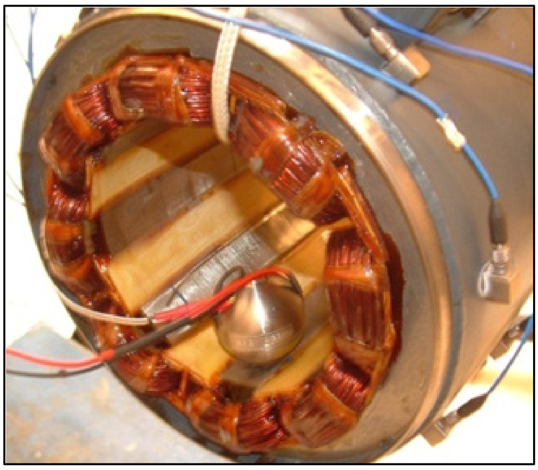

Figure 6: Housing assembly FRF test

The figures illustrate some steps in the correlation: the laminated stator undergoing an FRF-test for modal analysis (Figure 4), the first ovalisation mode obtained from normal modes analysis on the stator FEM (Figure 5), the stator–housing assembly undergoing an FRF-test with a mini-shaker (Figure 6).

Since the stator ovalisation modes significantly contribute to the noise radiation, these modes were given highest priority and their frequency was correlated to within 5% from measurements.

2.2.2 Application of the loads

The vibro-acoustic simulations were performed in the frequency domain, based on order spectra corresponding to the main SRM orders (6th order of motor revolution speed and its harmonics).

Since stator forces were available as time domain nodal forces on the 2D electromagnetic FE-mesh, load application involved: spectral processing of the time domain forces to order spectra, 2D to 3D extrusion, mesh mapping between the electro-magnetic and the structural FE-meshes.

2.2.3 Vibro-acoustic simulation and optimization

Application of the loads to the correlated structural model resulted in housing vibrations for the main SRM orders. The normal vibrations were the input for an acoustic simulation, resulting in sound pressure. A boundary element model with Automatically Matched Layer representing free field termination was used. The noise was monitored at typical field points at 1m distance from the SRM.

Post-processing of the simulation results allowed understanding the reasons behind high noise levels. It was shown that the highest levels occurred when motor orders stroke structural resonances and the stator force pattern matched the mode shape. E.g. when the 18th order stroke the ovalisation mode around 1400 Hz, it showed high vibration levels (Figure 7). This occurs for all odd multiples of the 6th order (Figure 8).

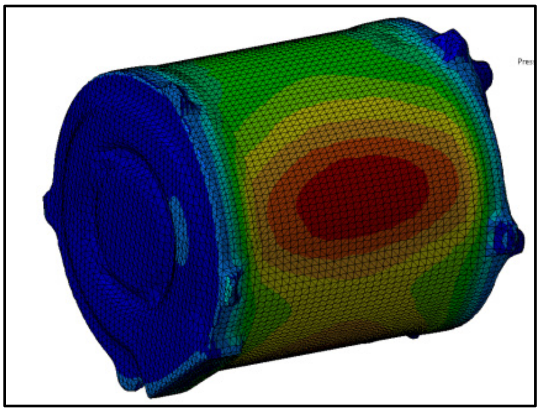

Figure 7: housing normal vibrations for order 18 at 1400 Hz

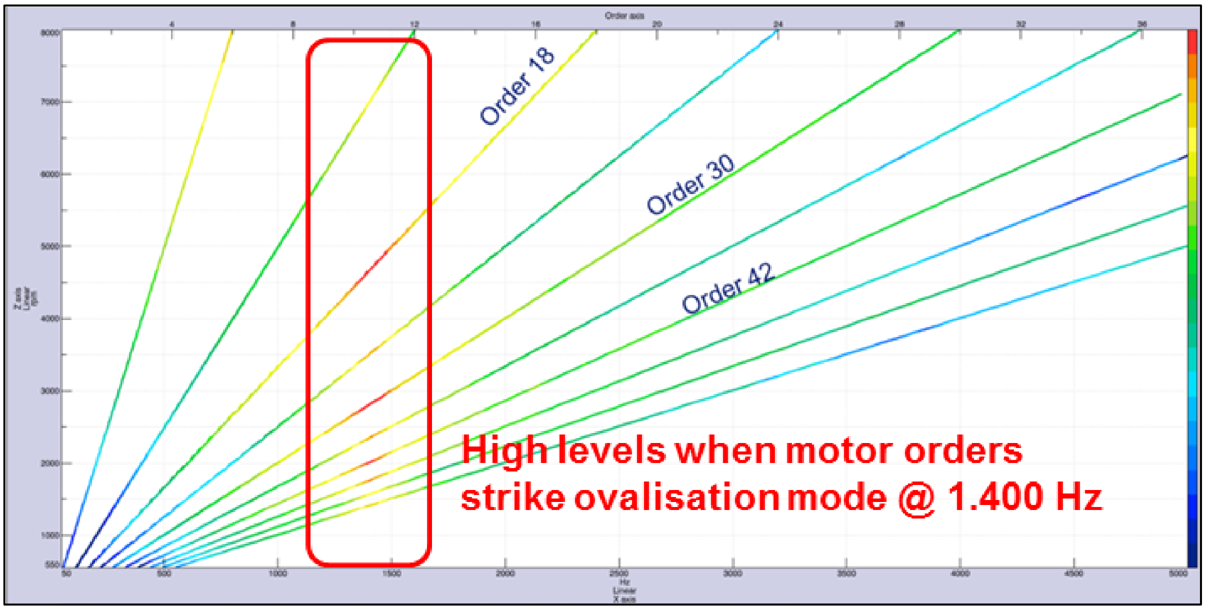

Figure 8: waterfall plot of radiated noise with increased levels around 1400 Hz

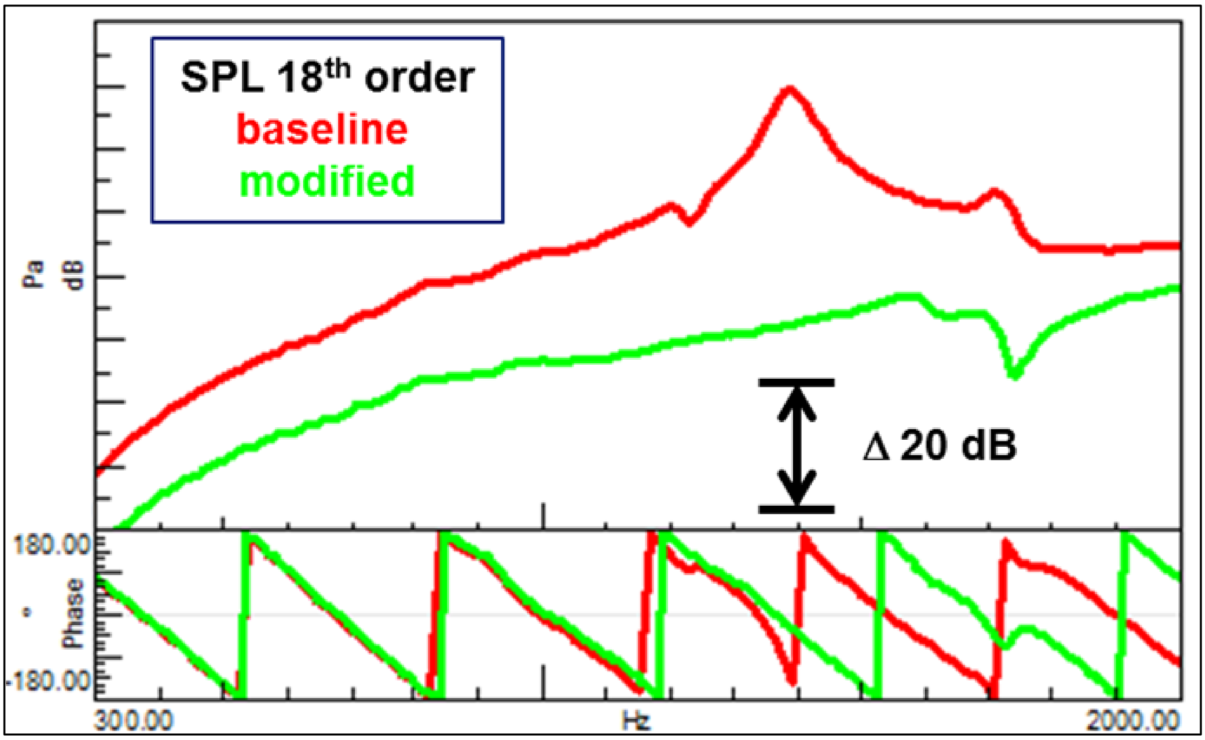

Figure 9: effect of structural modification on the noise levels for order 18

Based on the insight obtained, design changes to the housing and cooling jacket were proposed, aiming at shifting the resonance frequency outside the excitation range of the lowest orders. The resulting effect on order 18 is shown in Figure 9.

3 Conclusions

This paper showed that electro-magnetic and vibro-acoustic finite element models can effectively be used to frontload the design optimization of electric motors for automotive propulsion regarding noise radiation.

Acknowledgments

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References

[1] Knut Kasper, "*Analysis and Control of the Acoustic Behavior of Switched Reluctance Drives*", ISBN: 978-3-8322-9869-2, Aachener Beiträge des ISEA, Vol. 57, Shaker Verlag GmbH, 2011

[2] Saphir Faid et Al., "*Switched Reluctance Motors: Rare-Earth-Free Alternative for Automotive Applications*", technical paper EEVC2012-2400157, European Electric Vehicle Congress, Brussels, Belgium, November 19-22, 2012

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