Electromagnetically excited audible noise – evaluation and optimization of electrical machines by numerical simulation

C. Schlensok, B. Schmülling, M. van der Giet, K. Hameyer
Institute of Electrical Machines, Schinkelstraße 4, D-52056 Aachen, Germany
E-mail: Christoph.Schlensok@iem.rwth-aachen.de

***Abstract*: Disturbing vibrations and noise of electrical machines are gaining impact. Therefore, it is necessary to estimate the electromagnetic, structure-dynamical, and acoustic behavior of the machine during designing and before prototyping. An adequate tool is numerical simulation applying the Finite-Element Method (FEM) and the Boundary-Element Method (BEM) allowing for the structured analysis and evaluation of audible noise also caused by manufacturing tolerances. The methods developed and proved can be applied to any electromagnetic device in general.**

***Keywords*: multi-physics, coupled simulation, acoustics.**

I. INTRODUCTION

The coupled physics of a complete acoustic simulation – starting from the electromagnetic force excitation, computing the mechanical deformation of the electromagnetic device and concluding in the estimation of the radiated audible noise – is a multi-physics problem. The central part of the computational chain is the electromagnetic field simulation of which the surface-force density-waves are derived. These excite the stator of the machine resulting in vibrations. The periodical oscillation of the machines surface is decoupled and radiated as disturbing audible noise.

The structure of an entire acoustic multi-physics simulation-chain is shown in Fig. 1. In a first step a FEM-model of the electromagnetic device is simulated. A systematic, parameter-oriented model allows for a large number of geometry variations. Furthermore, various modes of operation can be considered. Hence, the effects of manufacturing tolerances can be taken into account as well as the designed geometry of the device. The electromagnetic model provides the radial component of the surface-force density used as excitation for the structure-dynamical model. In the mechanical model various materials and geometries can be considered to analyze the vibration. Here, the variants of the electromagnetic model are considered as parameters. In the last step the audible noise of the multitude of variants is estimated and analyzed with an acoustic Boundary-Element (BEM) model.

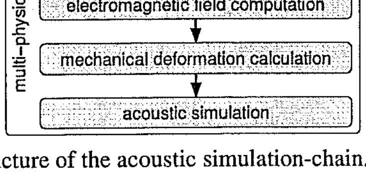

Fig. 1. Structure of the acoustic simulation-chain.

II. ELECTROMAGNETIC FIELD COMPUTATION

In this article an Induction Machine with squirrel-cage rotor (IM) and a Switched Reluctance Machine (SRM) are studied. Both electrical machines are simulated electromagnetically applying appropriate 2-dimensional FEM-models. The process is exemplarily described for the IM. Each of the field problems results in the magnetic vector potential and the flux-density distribution. From the latter torque T, net force F, surface-force density σ, and other quantities are derived.

III. STRUCTURE-DYNAMIC CALCULATION

After the electromagnetic simulation of an electrical machine, a structure-dynamical simulation is performed to determine the deformation or the oscillations. The surface-force density on the stator teeth, which is obtained from the electromagnetic simulation, is used as excitation. As in the electromagnetic case, the calculation of the periodic, mechanical deformation of electrical machines requires a numerical simulation. Due to the large numbers and complexity of its components, it is not possible to find an exact analytical solution. The structure-dynamical simulation is performed by means of FEM. The deformation of the machine is represented by the displacement of the individual nodes of the mechanical FE-model.

IV. ACOUSTIC SIMULATION

The presented calculation method only discusses the noise radiation generated by the electromagnetic deformation. For the acoustic simulation, the mechanical deformation of the machine is converted to a velocity. In principle, calculation of acoustic fields is possible with the FEM. However, for calculation of air-borne noise this method is unfavorable, since the entire region has to be discretised. An alternative is offered by the BEM.

V. CONCLUSIONS

Numerical simulations allow for the consideration of the structure-dynamical and acoustic behavior of an electrical machine a-priori during the phase of design. The proceeding of the numerical simulation is explained based on the considered machines (IM and SRM). On the one hand, the simulated results show good accordance to measurement results, on the other hand the high optimization potential concerning vibrations and noise of the analyzed machines is presented. The presented methods and simulation tools allow the analysis and evaluation of every type of energy converter with respect to its electromagnetic, structure-dynamical and acoustic behavior. By means of measurement devices it is also possible to verify the simulation results. The analysis also provides the detection of manufacturing faults in electrical machines. Therefore, the numerical acoustic simulation is an essential tool for the design, validation and optimization of electrical machines.