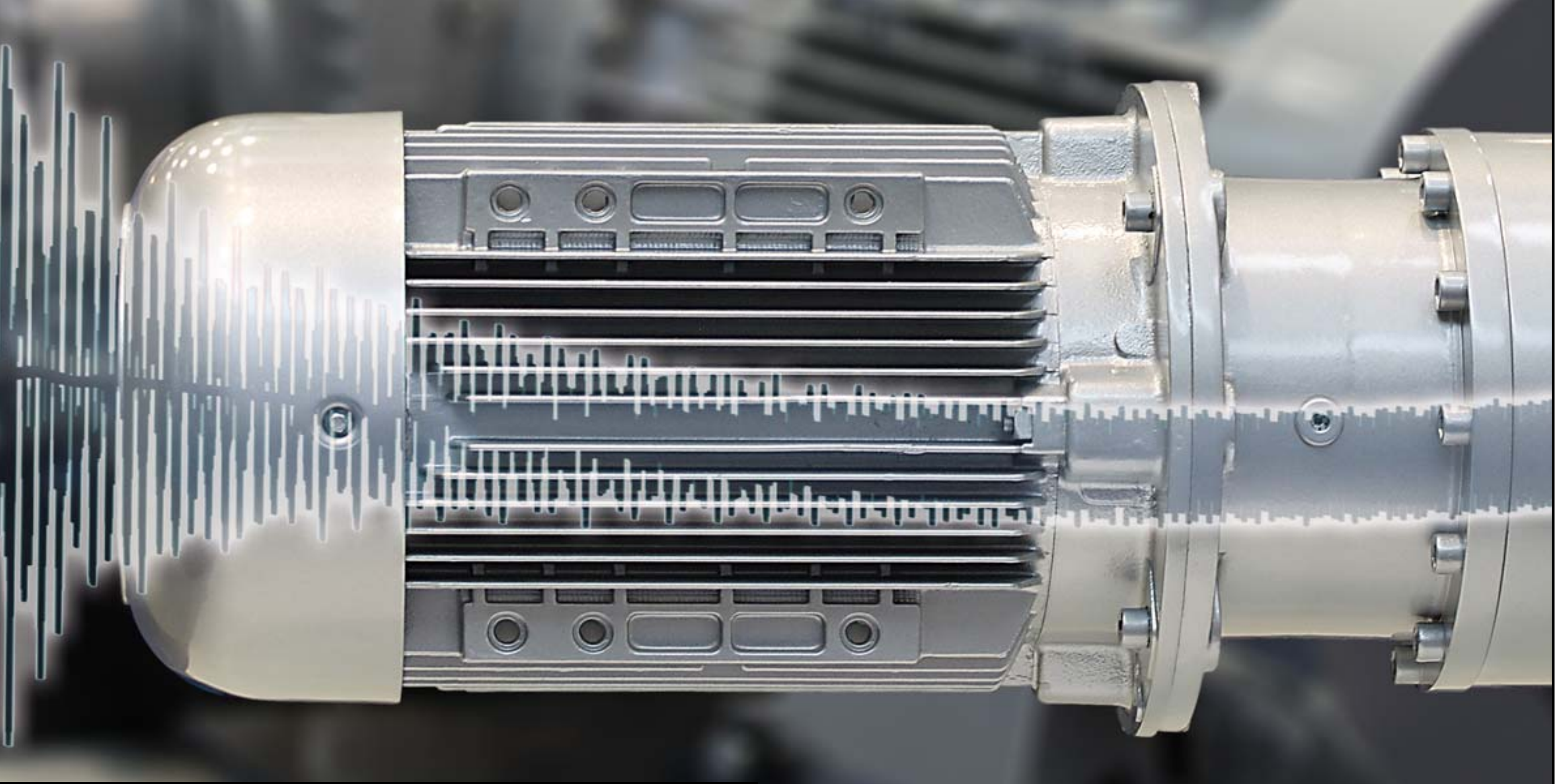

CASE STUDY // ELECTRICAL ENGINEERING

UNDERSTANDING THE ACOUSTIC BEHAVIOR OF ELECTRICAL DRIVES

Operating noise is an important parameter of technical devices operating near humans. Thus, reducing noise emission is often a key goal in order to achieve higher quality standards and new markets.

Engineering the Sound

Operating noise is an important parameter of technical devices operating near humans. Many regulations define maximum values for operating devices. This is especially true for permanent working systems. Furthermore, reducing noise emission is often a key goal in order to achieve higher quality standards and, thus,new markets.

The Sound Propagation Path

Here, the noise sources are categorized into two distinct groups:

1. The first type of noise excitation originates from time varying forces acting on solids. These forces provoke mechanic vibrations (structure bound sound) within the solid parts which propagate up to the outer surface of the bodies. At this outer boundary, the vibrations are partly transferred to the adjacent fluid as a result of a fluid-structure-interaction (FSI).
2. The second type of noise excitation provokes fluid bound vibrations directly. This can be observed in fans, exhaust ventilation and fast moving parts. Here, the vibrations are generated due to the turbulent flow of the fluid.

The process of noise formation and transfer can be described in the frequency domain very conveniently. A particular excitation spectrum F(jω) is multiplied with a frequency dependent transfer function T(jω) which represents the propagation of noise. For the second type of noise T(jω)represents solely the propagation through the fluid, while for the first type, the transfer function represents solid-state-wave-propagation, FSI and finally the fluid bound propagation.

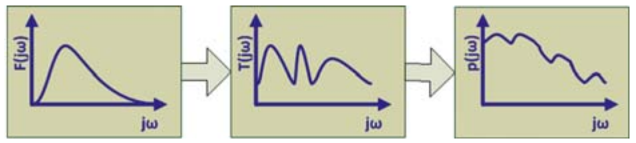

Fig. 1: Block diagram of noise propagation

Electrical Drives as Noise Source

In general, the following sources of noise can be identified in an operating electric motor:

1. Cooling fan (if applicable)
2. Bearings and mechanical connections
3. Vibration of the actuator and housing

From this list, numbers 2 and 3 start as a structure bound sound while 1 generates fluid vibrations directly. 1 and 2 are results of the movement of parts mechanically coupled to the motor while 3 has its origin in the motor's principle of operation itself. Considering this, the Maxwell forces on ferromagnetic parts of the drive are of major interest. These forces are typically maximized to provide the operational torque. The acoustic design for stator's vibration, caused by Maxwell forces, cannot be separated from the design process of the motor itself (which is possible when designing quieter fans and bearings). This article will focus on the third source of operating noise. Furthermore, only structural vibration will be simulated because they correlate with the operating noise in amplitude and frequencies.

Modal Extraction

To predict how the structure will react to the periodic forces, a structural mode superposition analysis can be done. This linear approach is valid because the deformations, caused by the structure bound noise, are small. A mode superposition analysis is much more resource effective than a fully coupled magnetic-structural analysis. By performing a modal analysis, the normal modes and resonant frequencies of the structure can be determined. The results of the modal analysis should be used to determine which normal modes are of interest. The operating noise of an electric drive is mainly determined by the modes which lead to a vibration of the outer housing as a whole. Internal oscillations, for example the stator's teeth, have little contribution to the operating noise.

In Fig. 2 two exemplary normal modes of the outer parts of an electric drive (stator and housing) are shown. The left mode leads to significant deformations at the outer boundary of the motor. The right one depicts mainly a bending of

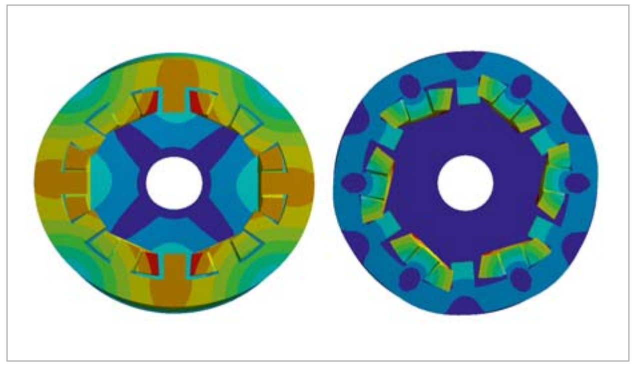

Fig. 2: Normal modes of outer parts of a motor

the stator's teeth. This evaluation of the normal modes and their corresponding frequencies should be used to define the simulation time step in the upcoming analysis to determine the force loads.

Electromagnetic Excitation

When applying a current excitation to the stator's windings, the produced magnetic field interacts with the permanent magnets leading to a tangential force on the rotor and thus a rotational movement. This interaction results in an equal reaction force on the stator. Furthermore, there are also radial forces and torques acting on the stator's teeth. The first step in order to calculate the time dependent forces on the stator's teeth is to simulate the transient magnetic field in the motor. The force is computed by evaluating the Maxwell's stress tensor and integrating it along a path. The stress tensor can be written as:

$$T_M = \begin{pmatrix} B_xH_x - \frac{1}{2}|B||H| & B_xH_y & B_xH_z \\ B_yH_x & B_yH_y - \frac{1}{2}|B||H| & B_yH_z \\ B_zH_x & B_zH_y & B_zH_z - \frac{1}{2}|B||H| \end{pmatrix}$$

The precise mathematical formulation allows its usage only to obtain forces integrating it along closed loops/surfaces. However, in most of the motors, the magnetic co-energy (and, therefore, the terms inside the tensor) is much larger inside the air gap than in the other areas. Fig. 3 shows a contour plot of the magnetic co-energy at the air gap, sta-

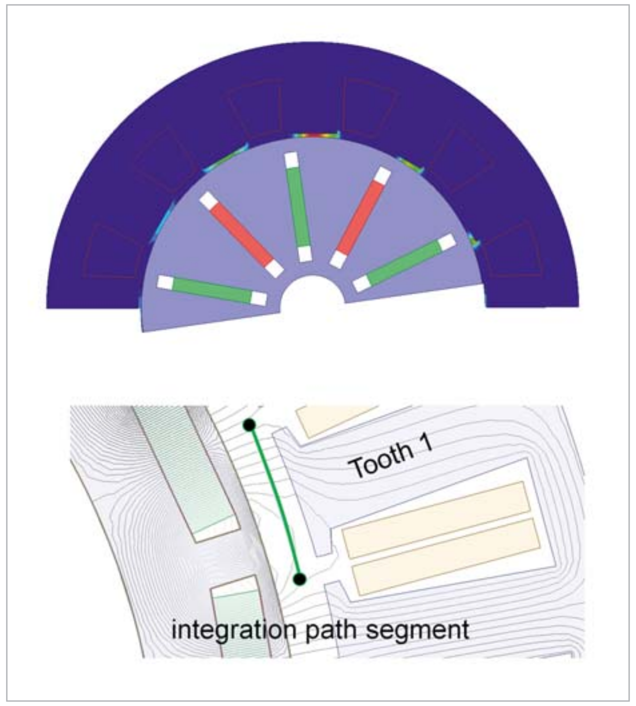

Fig. 3: Co-energy distribution inside the air gap and stator of a synchronous machine with permanent magnets and reduced force integration pathor

tor and windings. The integrated force evaluated along the arc in the air gap is used as a force load on the corresponding tooth. This engineering approach neglects the particular distribution of the force density along the inner side of

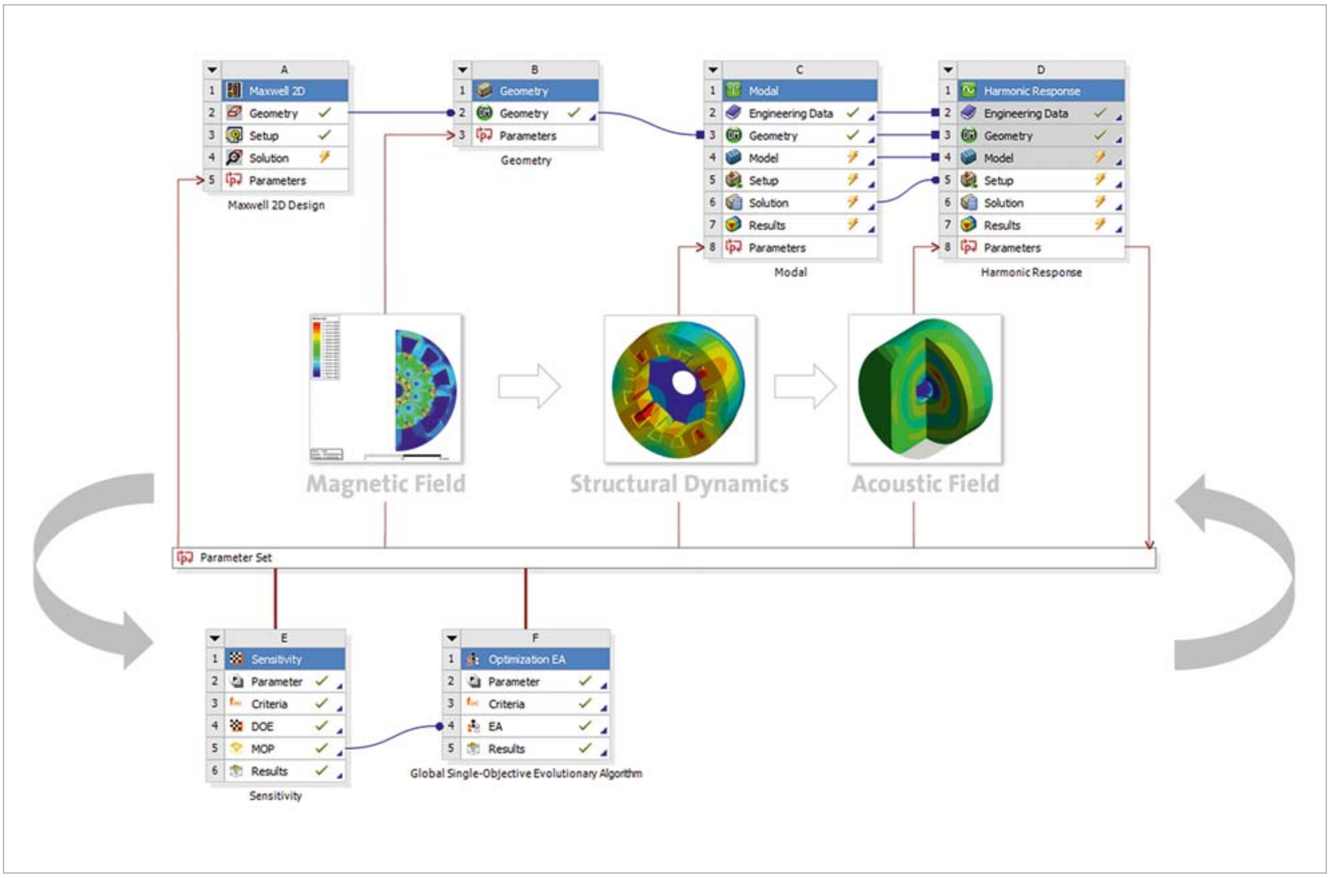

Fig. 4: Full parameterized optimization environment with optiSLang inside ANSYS Workbench

the tooth. The distribution is, however, of minor interest while evaluating the vibrations which will be transmitted to the air at the outer side of the machine.

Harmonic Response Analysis

After determining time dependent forces for each tooth, these quantities are Fourier transformed and used as complex loads in a harmonic response analysis with modal superposition. With this approach, it is possible to determine how the normal modes of the structure will react to the determined magnetic forces.

Sensitivity Analysis and Optimization

Having parameterized the whole workflow, the next step is to couple it to optiSLang inside Workbench for doing a sensitivity study with a subsequent optimization. Several parameters are set in the geometry and also the rotations per second could be varied. The output parameter is the amplitude for the frequency of 600Hz. The sensitivity analysis shows CoPs from 96% – 98% and clearly filters out the important input parameters. This allows doing a quick optimization using the Metamodel of Optimal Prognosis (MOP). As a result, this procedure creates a modified model that vibrates with 30% less amplitude than the original one.

Conclusion

By performing a simulation of the magnetic fields inside a motor, a calculation of the magnetic forces was conducted for evaluating the operating noise according to Maxwell's stress tensor. These forces can be Fourier transformed and applied as excitations to structural mode superposition analysis. This workflow leads to a time and computational resource effective simulation of the vibrations of the motor caused by periodic magnetic forces. This effective workflow can be used as part of the standard motor design process to optimize drives on their operating noise. A seamless workflow can be achieved using ANSYS tools Maxwell and Mechanical combined in the Workbench environment. With optiSLang inside Workbench, a sensitivity study and an optimization can be done in an easy-to-use environment. Thus, an assessment of sound sources and location was performed. For example, magnetic forces that excite stator structure to radiate or distribute sound as well as time varying eddy currents that cause acoustic relevant radial forces were detected.

The workflow also enables the user to develop new designs based on an interdisciplinary optimization workflow in order to meet acoustic regulation and customer comfort criteria.

Authors // Daniel Bachinski Pinhal, Markus Kellermeyer (CADFEM GmbH)
Source // www.dynardo.de/bibliothek