Electric Machine Acoustics Simulation

The Sounds of Silence

Induced noise and vibration of an electric motor is simulated in a joint work of CADFEM with the group EAA (Institut für Elektrische Antriebstechnik) at the Universität der Bundeswehr München. A methodology is presented that includes acoustic effects in the virtual prototype of a permanent magnet motor in an intuitive way, for that three finite element disciplines are coupled: electromagnetics, structural dynamics and acoustics.

Fig. 1: Picture of a simulated machine

Hybrid and electric vehicles requirements for electric machines include high efficiency, high torque density, constant power over a wide speed range, and low noise emissions. Permanent magnet (PM) machines can fulfill those requirements when a good design is reached.

In a PM machine a strong electromagnetic force exists between the rotor magnets and the stator teeth, having components in both the tangential and radial directions. The tangential force results in cogging torque when the stator winding is not energized (excited), and in the electromagnetic torque, including pulsating components when the winding is energized. The radial force which is stronger than the tangential components directly causes mechanical deformation and vibration of the stator. Those forces also load the structure and depending on the resonance frequencies of the complete system, considerable vibrations can be generated, which may result in sound radiation. Noise Predictions with analytical models [1]* might be applied but severe simplifications must be used [2]*, a preferable solution is to use field based (2D/3D) models which is the focus of the present work.

Engineering Workflow

The workflow follows the coupling of three finite element models: electromagnetics, structural dynamics, and acoustics (Fig. 2). The coupling in this case is basically one way, due to the physical phenomena's nature; housing vibration does not change the electromagnetic fields and the noise does not excite the structure [2]*. From the software's point of view this is also a one-way coupling, but all in one platform, the ANSYS Workbench, with sub-systems of Maxwell, ANSYS Mechanical and ANSYS Acoustics Structures, respectively.

Electromagnetics

The machine studied contains a rotor with 4 permanent magnets, a stator with three phase windings, and, externally the housing. The rated power is 0.8 kW at 1000 rpm with an average torque of 2 N.m. The electromagnetic model domain is simplified to one quarter due to symmetry and a transient 2D analysis is performed in Maxwell. The simulation is done at the rated speed without external torque load, which corresponds to the synchronous operation for the 55 Hz current excitation.

Pictures: Universität der Bundeswehr, Institut für elektrische Antriebstechnik (EAA); doglikehorse/shutterstock.com

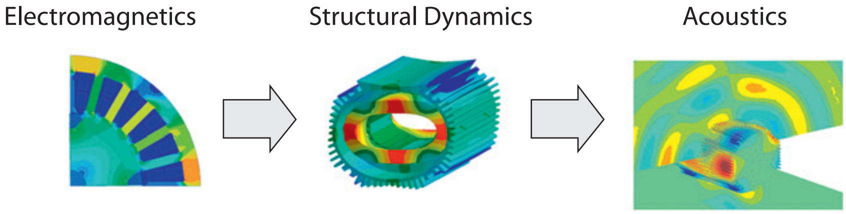

Fig. 2: Engineering Workflow

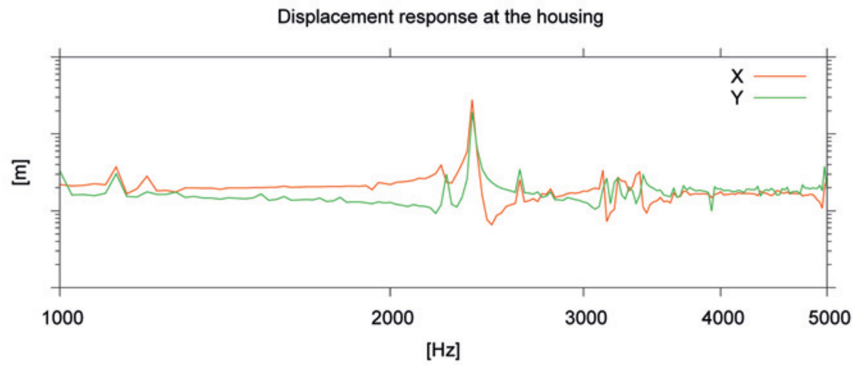

Fig. 3: Results of displacement spectrum of the housing

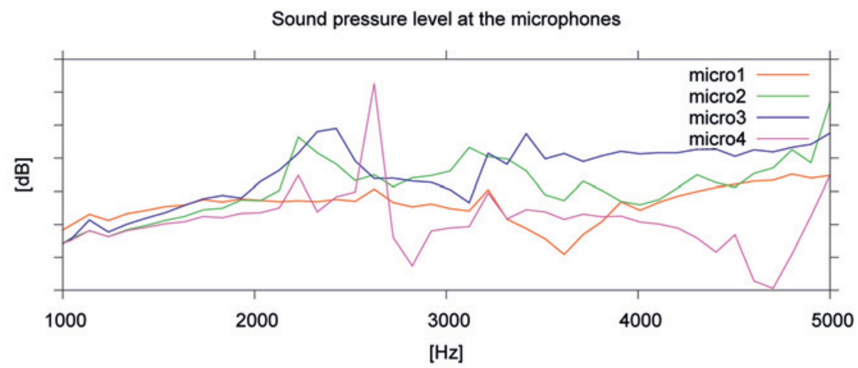

Fig. 4: Frequency response functions at remote microphone positions

Electromagnetic fields are solved and the torque is calculated and checked with reference values from the EAA laboratory. For Vibration analysis is important to calculate all the forces acting in the stator and resulting from the moving magnetic field in the air gap. Forces can be calculated with co-energy or Maxwell stress tensor methods [3][*]. We selected the second option because the entire necessary field is available in one case. Force densities (N.m²) are defined by the equations:

$$f_r = \frac{1}{2} H_r B_r \qquad f_t = H_r B_t$$

Force density fields are integrated over each of the six teeth resulting in a force signal by time. Here radial forces are much higher than the tangential ones, and they are also the main cause of machine vibrations. However the tangential force should not be neglected in the acoustic investigation of the electric machines if qualitative results are desired.

Structural Dynamics

Vibration in an electric machine is related to the excitation forces and the dynamic response of the structure. It is expected small amplitudes in the displacements caused by the excitation forces from the electromagnetic solution (should be a motor not a shaker); this condition allows the use of linear finite element models without accuracy problems. A harmonic response analysis is applied, which has advantages of low computational costs, but the excitation forces are required to be harmonic functions. For this Fast Fourier Transform (FFT) is applied to the force signals at each tooth, transforming time domain data into frequency domain. First, resonance frequencies of the machine are identified with a modal analysis; modes which can be excited by radial forces are the critical ones. The frequencies which generate significant housing displacements are in the range of 2.1 kHz, 2.2 kHz, 2.6 kHz and 5.8 kHz. However, only the harmonic response gives the realistic critical frequencies due to the combined effect of the natural frequencies and the excitation frequencies of the forces. The Results of the displacement spectrum of the housing show higher values for 2.3 kH, where several resonance frequencies are present (Fig. 4). Smaller peaks are also observed around 3 to 3.3 kHz, where excitation forces with higher amplitude play a bigger role.

Acoustics

Acoustics simulation predicts the sound pressure in the air environment based on vibration of structures. The finite element calculation is done in the frequency domain and all inputs need to be frequency domain data. This makes the mechanics-acoustics coupling easy, since the displacement spectrum of the motor housing can be directly used. ANSYS Acoustics Structures, which is based on FFT ACTRAN, is used for this task. It is integrated in ANSYS Workbench. After the air domain and microphone locations were created in the geometry section and meshed, the acoustic setup and coupling with the structural results were done automatically. The ANSYS Acoustics analysis calculated the sound pressure distribution. The hybrid approach of finite and infinite elements allows evaluation of acoustic quantities, e.g., sound pressure level (SPL) in the near surrounding or far field – at no extra cost. The 3D plots give insight in the sound field, while frequency response functions at remote microphone positions (Fig. 5), help analyzing the sound impact on the human ear or checking noise regulation limits.

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InfoSoftware applied

ANSYS Workbench; MAXWELL,
ANSYS Mechanical, ANSYS Acoustics Structures

InfoReferences

* www.cadfem.de/infoplaner