A holistic simulation workflow to design an acoustically optimized electric wheel hub motor

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Abstract

In the paper a holistic simulation workflow is presented which enables the designer to analyze the acoustic behavior of electric wheel hub motors numerically. The applied electric wheel hub motor shows an extraordinary power-to-weight-ratio, as it combines two different types of winding to boost torque sharing the same magnetic circuit [1]. One is an air gap winding and the other one is a slot winding (see Fig. 1, first row, right). In the development process of an engine the acoustics is usually not in the focus of interest. But, it has been proved that the acoustic characteristic of electric engines is a very important topic which should be taken into account in an early stage of the development process. In contrast to combustion engines in electrical engines the first engine orders are related to much higher frequencies (up to 1250 Hz) and the resulting sound is not so noisy. It seems that the radiated sound is caused by a few different frequencies only, as the second and the third engine order are the most important engine orders beside the first order, but even their amplitudes are with about 5% and 2% of the first one comparably small. Hence, the emitted sound of an electric engine is more like a single high frequency tone. Unfortunately, the human auditory perception is very sensitive with respect to such high frequency sounds. Consequently, the noise emission of electric engines is more annoying than the noise emission of combustion engines, even if the amplitudes of the electric sound are lower. For this reason, it is important to consider the acoustic behavior as early as possible in the product development process of an electric engine.

With aid of an overall simulation workflow the acoustics of electric engines can be optimized before the first prototype has been built. The paper at hand presents the simulation workflow of an electric wheel hub motor, which allows the prediction of the acoustic behavior based on the CAD-geometry only. The workflow consists of three steps as shown in Fig. 1. First, the electromagnetic behavior is modeled, where it is common to neglect the differences in the direction of the rotation axis to increase the efficiency. It is sufficient two use a two dimensional model only (see Fig. 1, right upper corner), as the attenuation of the tangential magnetic forces is less than 5% at the boarders. Further, the magnetic forces in radial direction are non-linear and cause stability problems, if they will be linearized. Second, the electromagnetic forces as result of the first step are used to calculate the vibrational behavior of the wheel hub motor. Third, the resulting surface velocity is used to excite the surrounding air and to calculate the air pressure at any point of the surrounding air volume under free field conditions. The vibration and acoustic analyses can be solved in an uncoupled manner, as the feedback of the vibrating air on the much stiffer engine housing can be neglected. For all three solution steps, the electrodynamics, the structural dynamics and the acoustics the finite element method is used. In the vibration and acoustic

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analyses tetrahedral elements with quadratic shape functions are used due to the complex geometry and the required accuracy which is tested by convergence studies. The acoustic simulations can be done with a much coarser mesh due to the larger wave length in the air. But, at the interface between the structure and the air volume it is appropriate to use a co-incident mesh, which is coarsened with increasing distance from the structure to reduce the computational effort of the approach. The developed and numerically tested overall work-flow is finally also validated by measurements.

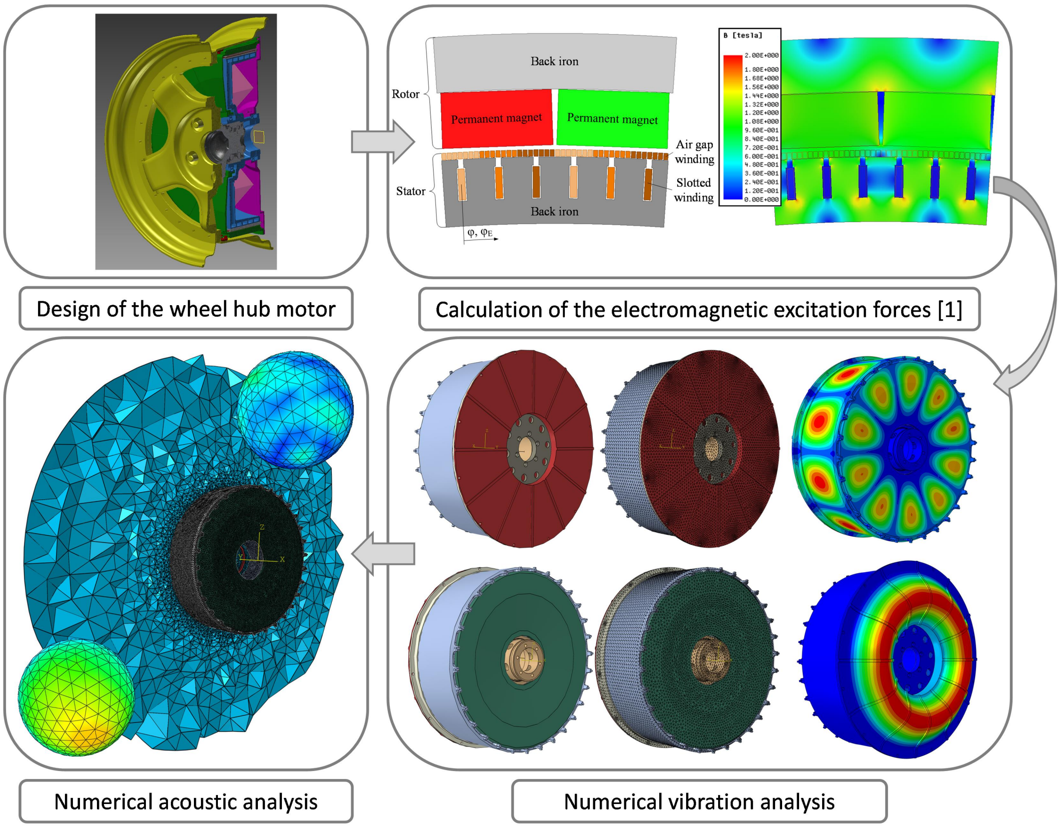

Figure 1: Holistic simulation workflow for calculating the sound radiation of an electric wheel hub motor based on the electromagnetic excitation forces

The presented overall virtual engineering methodology can be used to optimize the design of the wheel hub motor in further steps to fulfill it acoustic requirements. Furthermore, it would be a promising future development to extend the overall workflow by a psychoacoustic post-processing in order to include the special properties of human hearing sufficiently, instead of determining the classical acoustic parameter as sound pressure or power only [2].

References

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