Acoustic Simulation of the Electric Vehicle Motor

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Abstract. People pay more and more attention to NVH (N-noise, V-vibration, and H-harshness) characteristics of electric vehicles and motors. The vibration and noise of the electric vehicle motor is a complex multi physical field problem, related to electromagnetic, mechanical, structural and sound fields. In this paper, firstly, the Maxwell electromagnetic field analysis software is used to build the electromagnetic simulation model of PMSM (Permanent magnet synchronous motor) motor, and then the electromagnetic excitation is calculated. Then, the magnetic solid coupling analysis is carried out by using the Maxwell module and harmonic response module of ANSYS Workbench, and the harmonic response of the motor structure under the action of electromagnetic excitation is simulated. After the simulation of magnetic-structure coupling is completed, the BEM (Boundary element method) simulation of the permanent magnet synchronous motor is carried out with the acoustic simulation software LMS Virtual Lab. The acoustic simulation of the permanent magnet synchronous motor shows that the sound pressure level at three measurement points have obvious peak value at 3700Hz, 4500Hz, 5400Hz and 6400Hz respectively. The acoustic simulation results lay the foundation for the vibration and noise reduction of the motor.

Keywords: Electric vehicle motor; Acoustic simulation; FEM; BEM.

1. Introduction

At present, electric vehicles are more and more popular. At the same time, people pay more and more attention to NVH characteristics of electric vehicles and motors. The vibration and noise of motor is a complex multi physical field problem, related to electromagnetic, mechanical, structural and sound fields. As for the source of motor vibration noise, it is generally accepted that the main factors of electromagnetic vibration are electromagnetic force, torque ripple and cogging torque. The main methods of research on electromagnetic vibration and noise of permanent magnet motor are analytical method, finite element method and experimental method [1-8]. In this paper, firstly, the Maxwell electromagnetic field analysis software will be used to build the electromagnetic simulation model of PMSM motor, and then the electromagnetic excitation will be calculated. Then, the magnetic solid coupling analysis will be carried out by using the Maxwell module and harmonic response module of ANSYS Workbench, and the harmonic response of the motor structure under the action of electromagnetic excitation will be simulated. After the simulation of magnetic-structure coupling is completed, the BEM’s simulation of the permanent magnet synchronous
motor will be carried out with the acoustic simulation software LMS Virtual Lab. Lastly, the acoustic characteristics of the motor will be analyzed and its simulation results will lay the foundation for the vibration and noise reduction of the motor.

2. Electromagnetic Simulation

In this paper, Maxwell electromagnetic software is used to build the electromagnetic field simulation model of the permanent magnet synchronous motor with the known basic structural parameters. The motor is an internal rotor type three-phase permanent magnet synchronous motor, with 4 pole pairs and 72 slots. The rotor is equipped with inserted "V+1" type magnetic poles, and the cooling mode of circulating water cooling is adopted. The basic parameters of the motor are shown in Table1. Fig.1 is the electromagnetic simulation model of the permanent magnet synchronous motor. Specific meshing results of electromagnetic finite element are demonstrated in Fig. 2. After the mesh is divided and the finite element simulation calculation is carried out for the working condition of 3000rpm rotor speed and 20Nm load of the motor. The transient simulation duration is 0.02s and the step length is 0.00005s. The radial electromagnetic force density at each spatial angle at the reference position at 0.01s was extracted, and the spatial distribution characteristic curve of this physical quantity was obtained, as demonstrated in Fig. 3.

Table 1. Basic parameters of the permanent magnet synchronous motor.

| Parameters       | Data     | Parameters       | Data     |
|------------------|----------|------------------|----------|
| Phase number     | 3        | Rated power /kW  | 40       |
| Pole number      | 4        | Peak power /kW   | 85       |
| Number of slots  | 72       | Rated speed /rpm | 3000     |
| Rated voltage/VDC| 350      | Maximum speed /rpm | 10000   |

Furthermore, the calculation results of at each time sampling point in the whole simulation period are scanned, and the radial component, tangential component and radial electromagnetic force of the air gap flux density are extracted in the light of time and space, and the space-time distribution map of the air gap radial flux density is drawn with the space angle as the x-axis and the time length as the y-axis respectively is shown in Fig.4. The space-time distribution of the air gap tangential flux density is shown in Fig.5 and the space-time distribution of the radial electromagnetic force is shown in Fig.6. The above simulation results show that the radial and tangential components of the air gap radial flux change periodically with time and space; In the same space-time coordinate system, the change form of radial

Figure 1. Electromagnetic simulation model of permanent magnet synchronous motor.

Figure 2. Electromagnetic finite element grid.
The electromagnetic force is the same as that of the air gap radial flux density, the change frequency is the same as that of the air gap tangential flux density, and the numerical value is the same as the theoretical calculation result, which verifies the theoretical calculation conclusion.

**Figure 3.** Spatial distribution of the radial electromagnetic force.

**Figure 4.** Space time distribution of the air gap radial flux density.

**Figure 5.** Space time distribution of the air gap tangential flux density.
3. Harmonic Response Simulation of Motor Structure
After the electromagnetic simulation calculation is carried out, the ANSYS Workbench is used, and the Maxwell module and harmonic response module are selected to analyze the magnetic structure coupling, and the harmonic response of the motor structure under the electromagnetic excitation force is simulated. Under the working condition of 3000rpm and 20Nm load, the harmonic response of the magnetic-structure coupling model is simulated. The frequency range is 0-10000Hz, and the frequency interval is 50Hz. The vibration acceleration response results of the motor are calculated, and the deformation and vibration acceleration response nephogram are drawn. At the same time, the focus on the vibration acceleration response of observation points A and B (as shown in Fig. 7.), respectively extract the axial vibration acceleration and vertical vibration acceleration of the observation point at the center of the end face, and the axial vibration acceleration and radial vibration acceleration of the observation point at the center of the top of the circumferential surface, and the amplitude spectrum of vibration acceleration are drawn. The spectrum of vibration acceleration amplitude in specified direction of specific observation point is shown in Fig. 8.

Figure 6. Space time distribution of radial electromagnetic force.

Figure 7. Observation points of vibration response.
4. Acoustic Simulation and Analysis

After the magnetic solid coupling simulation is finished, the acoustic simulation software LMS virtual Lab is used to analyze the acoustic field boundary element (BEM) of the permanent magnet synchronous motor. The BEM method needs to import the vibration response analysis results into the motor structure grid as the pre simulation link data, to draw the boundary element grid of the shell, and to transfer the vibration response analysis results to the boundary element grid. Finally, the radiation noise value and its distribution on the set field point grid are obtained through sound field calculation and analysis. The acoustic boundary element model and the observation points are demonstrated in Fig. 9.

The acoustic simulation results at three observation points are extracted. In order to observe the sensitive frequency band of the human ear and get close to the human auditory perception, the A-weighted sound pressure level spectrum at each observation point is calculated respectively, and then the third octave is processed. The sound pressure level spectrum curves of three observation points are demonstrated in Fig. 10. The sound pressure level spectrum of three observation points shows that the sound pressure level of each measurement point has obvious peak value at 3700Hz, 4500Hz, 5400Hz and 6400Hz respectively, so it is necessary to cut down the vibration and noise of the motor.

![Figure 8. Amplitude spectrum of vibration acceleration in main direction of at two observation point.](image)

![Figure 9. Acoustic boundary element model of the permanent magnet synchronous motor.](image)
5. Conclusions
In this paper, the acoustic simulation of the permanent magnet synchronous motor is carried out. The major results can be drawn as follows:
(1) Maxwell software, workbench harmonic response module and LMS virtual Lab software are used to build the three-dimensional model, electromagnetic model and acoustic model of the permanent magnet synchronous motor. The magnetic-structure acoustic coupling method is employed to simulate the electromagnetic, harmonic response and acoustic of the motor.
(2) The acoustic simulation of the permanent magnet synchronous motor shows that the sound pressure level of at three measurement points have obvious peak value at 3700Hz, 4500Hz, 5400Hz and 6400Hz respectively, so it is necessary to cut down the vibration and noise of the motor further.

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