Model Validation for Stator and Rotor of an Electric Vehicle Motor

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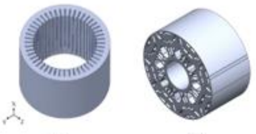
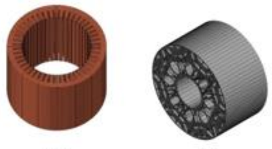
Introduction

In recent years, with the rapid development of electric vehicles, more and more attention has been paid to the NVH issues of electric vehicles. Therefore, the vibration and noise of the motor have attracted much attention. To solve the problems related to vibration and noise of the motor, a finite element model (FEM) equivalent to the actual structure is needed to facilitate subsequent analysis and research. Although research on motor vibration has been ongoing for many years, because the motor stator is made of multiple silicon steel sheets laminated, it is more complex than other integrally formed structures, which can easily lead to considerable errors between simulation results and experimental data. [1]. Chai et al. [2] approximated the stator of the permanent magnet synchronous motor as a continuous solid with composite material, and evaluated the equivalent elastic coefficient of the stator material according to the Voigt-Reuss equation, and then used FEA and EMA to verify the consistency between the two. If the stator material is assumed to be orthotropic materials during finite element analysis, there will be a high consistency between the material parameters of the finite element model and the material parameters of the actual structure [3, 4].

Modeling and modal analysis

To obtain a FEM that is equivalent to the actual structure, this study uses modal verification to test the validity of the FEM. First, the geometric model and FEM of the stator and rotor of a motor are established, as shown in Fig. 1 and 2, respectively. The commercial software ANSYS Workbench is used to conduct FEA of the model, and the modal parameters are obtained. Material properties of rotor and stator cores includes that the Young's modulus is 180GPa, Poisson ratio is 0.3, and mass density is 7600 kg/m$^{3.}$ Next, we conducted an experimental modal analysis (EMA) of the rotor and stator. The rotor and stator was suspended to simulate the free boundary, as shown in Fig. 3. We then used a moving impact hammer and a fixed accelerometer to conduct experiments to obtain the modal parameters of the rotor and stator. Finally, the results obtained by FEA are compared with the ones through EMA, and the modal assurance criterion (MAC) is used to verify the consistency between the two modal vibration shapes obtained from EMA and FEA to ensure whether the FEM is equivalent to the actual structure.


(a) (b)
Fig 1. Model of motor (a)Stator (b)Rotor


(a) (b)
Fig 2. Finite element model (a)Stator (b)Rotor


(a) (b)
Fig 3. A setup for Modal testing of motor (a)Stator (b)Rotor

Comparison of results

From the results of modal identification, there is a large error between the natural frequencies obtained from FEA and ones through EMA in the 3rd, 4th, 7th, 11th, and 13th modes corresponding to stator, with the maximum error as high as 39.81%, while the 17th, 18th, 21st, and 22nd modes corresponding to rotor, with the maximum error as high as 88.70%. The reason for this phenomenon may be that the rotor and stator is assumed to be an isotropic material in FEA. However, the actual structure is made of multiple laminated silicon steel sheets and is not an integrally formed structure. Therefore, assuming that the rotor and stator is made of isotropic material cannot be equivalent to the actual structure. In terms of vibration shapes, although the MAC value of the low-order mode is high, the MAC of the high-order mode is very low. The reason may be that the measurement degree of freedom we selected in the experiment is insufficient and cannot fully describe the relatively complex behavior corresponding to high-frequency mode, so the MAC value lower, as shown in Table 1.

Table 1. Comparison of results between FEA and EMA

No. of Mode	Frequency (Hz)		Frequency Error (%)	MAC	Type
	EMA	FEA			
1	623.88	633.48	1.53	0.95	Stator
2	634.88	633.52	-0.21	0.69	
3	733.28	1025.21	39.81	0.75	
4	744.47	1025.22	37.71	0.74	
5	1695.76	1710.35	0.85	0.84	
6	1703.36	1710.38	0.41	0.88	
7	1870.18	2310.87	23.57	0.76	
8	2164.09	2310.90	6.78	0.12	
9	3085.57	3107.43	0.70	0.65	
10	3092.9	3107.55	0.47	0.75	
11	3256.22	3759.56	-15.45	0.26	
12	-	3759.59	-	-	
13	3850.04	4702.12	22.13	0.02	
14	4665.56	4702.31	0.79	0.55	
15	4674.74	4937.13	5.61	0.00	
16	4822.64	4937.14	2.38	0.03	
17	5740.58	3785.40	51.65	-	Rotor
18	5741.77	4791.26	19.84	-	
19	6070.59	5057.98	20.02	-	
20	6071.37	5553.77	9.32	-	
21	11196.84	5933.69	88.70	-	
22	11568.90	6574.03	75.98	-	

Conclusion

To obtain a finite element model of the rotor and stator that is equivalent to the actual structure, this study conducted FEA and EMA respectively. According to the results, the following two points can be summarized:

1. Since the rotor and stator is made of laminated silicon steel sheets, setting the rotor and stator as isotropic material in the FEA cannot obtain a model equivalent to the actual structure; in the future, the isotropic material will be corrected to be positive based on the literature. Using anisotropic materials makes the natural frequencies between FEA and EMA more consistent.
2. Due to insufficient measurement freedom, the measurement freedom cannot describe high-order modal shapes (corresponding to stator) and results in a low MAC value. In the future, the measurement freedom can be adjusted or increased to obtain a more complete mode shapes.

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