

The Role of Support Structures in Enhancing FE Modeling and Electromagnetic Vibration Prediction of PMSM Stator Systems

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Accurate prediction of electromagnetic vibration and noise is essential for understanding and mitigating the NVH (Noise, Vibration, and Harshness) characteristics of electric motors. This study presents a detailed numerical modeling approach for an electric motor system, comprising a permanent magnet synchronous motor (PMSM) and its support structure, to enhance the accuracy of electromagnetic vibration and noise prediction. First, the magnetic force acting on the stator's inner surface was investigated through a two-dimensional (2D) transient electromagnetic analysis, and its characteristics were analyzed. Second, a three-dimensional (3-D) finite element modal analysis of the stator system was conducted, taking into account the anisotropy of the stator core and armature winding. Then, the natural frequencies of the end cover and the entire motor were analyzed. Furthermore, a finite element model and modal analysis of the PMSM's support structure system were also developed. The accuracy of simulation results were validated by comparing its natural frequency results to impact hammer test data, showing relative errors of less than 5%. Based on the accurate structural model of the integrated structure comprising the PMSM and its support structure, the electromagnetic vibration characteristics of the system were investigated by applying electromagnetic force excitations on the stator's inner face under two conditions: 1) the standalone PMSM, and 2) the integrated PMSM with its support structure. The influence of the support structure on electromagnetic vibration behavior of the PMSM was then evaluated. Finally, a vibration experiment of the PMSM prototype was carried out to validate the simulations results. The findings revealed that the support structure significantly increases specific vibration levels. Therefore, to improve the accuracy of motor vibration predictions, the support structure should be taken into consideration.

Index Terms—Permanent magnet synchronous motors, finite element modeling, electromagnetic force, vibration.

I. INTRODUCTION

PERMANENT magnet synchronous motors (PMSMs) are widely used in industry for their high efficiency and power density. As motor technology advances, the demand for low-noise, high-performance machines has led to extensive research on vibration and noise over the past decades [1].

Electromagnetic vibration, caused by the excitation force waves generated by the air-gap magnetic field acting on the stator core, is one of the primary sources of vibration in electric motors [2]. Radial force harmonics with low mode numbers can induce low-frequency vibrations, especially when their frequencies align with the stator's natural modes [3]. Thus, accurately identifying these natural frequencies is critical for mitigating electromagnetic vibration. The finite element method (FEM) is a widely used and reliable approach for modeling electromagnetic vibration in electric motors. While conventional models typically include the stator, windings, and housing, incorporating additional sub-components can significantly enhance accuracy. For instance, a detailed 3D FE model in [4] captured electromagnetic vibration characteristics more precisely by including components often omitted in simplified models. However, the role of certain parts, particularly the end cover, remains unclear. While some studies indicate that the end cover has a negligible effect [5], others demonstrate a considerable influence on the motor's dynamic characteristics [6]. This inconsistency reveals a research gap regarding the end cover's contribution to accurate electromagnetic and vibration modeling of PMSMs. Beyond accurate modeling of the PMSM itself, external structural components also play a significant role in determining electromagnetic vibration responses [7]. As

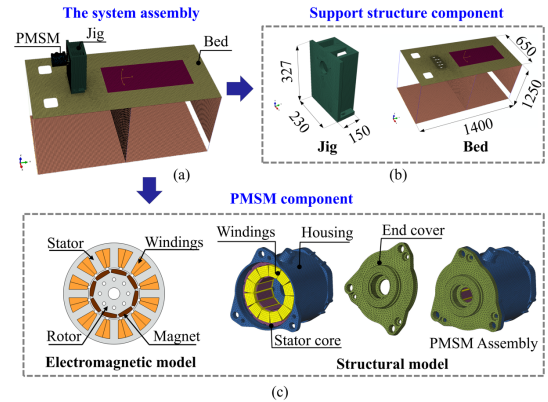


Fig. 1: High-fidelity multiphysics model (a) The system assembly (b) Support structure component (c) PMSM component

noted in [8], discrepancies between simulated and experimental results may stem from the omission of support structures. However, their impact on the accuracy of electromagnetic vibration prediction in motors has yet to be systematically investigated.

To address these challenges, this paper proposes a methodology for analyzing the electromagnetic vibration characteristics of a PMSM, incorporating the effects of the end cover and support structure to improve the accuracy of vibration predictions.

II. METHODOLOGY

A. Specification of Structure

As shown in Fig. 1(a), the high-fidelity multiphysics model includes the integrated structure of the PMSM and its support

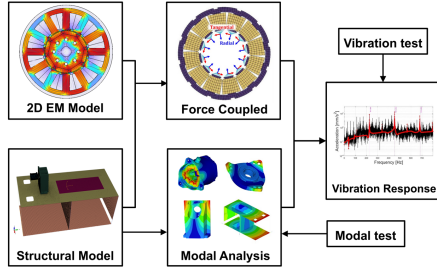


Fig. 2: Electromagnetic vibration calculation procedure of the motor

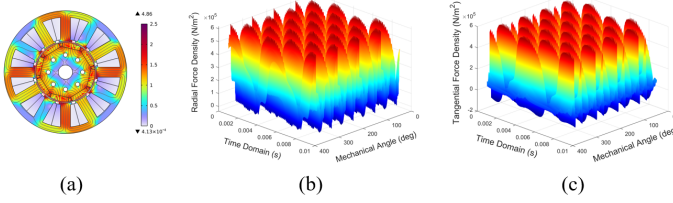


Fig. 3: Electromagnetic model: (a) Magnetic field distribution at the initial time, (b) 3D waveform of radial magnetic force density, (c) 3D waveform of tangential magnetic force density

components. The support structure, comprising the jig and bed, is depicted in Fig. 1(b), while Fig. 1(c) shows the PMSM configuration with rotor, stator core, windings, end cover, and housing. This integrated model enables the analysis of how support structures affect the accuracy of electromagnetic vibration prediction.

B. Analysis Procedure

The overall analysis procedure for the electromagnetic vibration of the electric motor system is represented in Fig. 2. This multiphysics simulation model combines electromagnetic field and mechanical analysis to provide a comprehensive understanding of the system's vibration behavior. First, a 2-D electromagnetic FE model is built with the software COMSOL Multiphysics 6.0. The radial and tangential components of the airgap magnetic flux density and magnetic force density are computed along a mid-airgap path. Then, the concentrated electromagnetic forces on each stator is calculated by the magnetic force density integration. Then, the 3-D structural model is built with the software ABAQUS, and modal test is employed to validate the model. Then, the electromagnetic forces are loaded from the EM model to the structural model by the weakly coupled analysis. The vibration response is compared between a with and without the support structure. Finally, the accuracy of calculated vibration is validated by conducting an experimental study.

III. RESULTS AND DISCUSSION

Using the proposed modeling approach, electromagnetic and structural analyses are performed. Figure 3 illustrates the electromagnetic characteristics, while Figure 4 presents the 3D finite element modal analyses of the stator, end cover, full motor, and support structure. The accuracy of the simulation was validated against data from impact hammer tests, showing

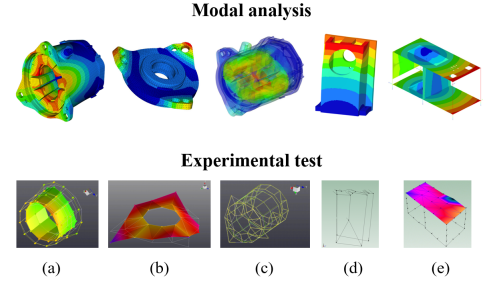


Fig. 4: Modal analysis and experimental modal test of: (a) Stator with coil and housing, (b) End cover, (c) Assembled PMSM, (d) Jig, and (e) Bed

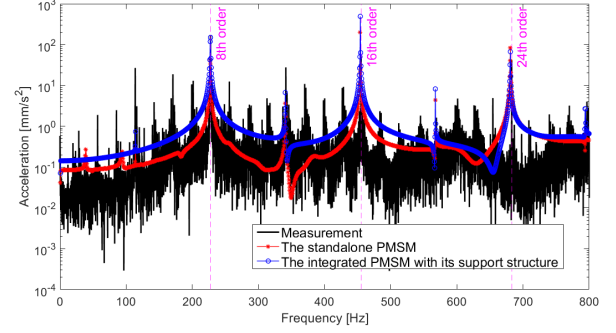


Fig. 5: Acceleration responses obtained from the simulation of the standalone PMSM, the integrated structure, and the experiment

that the errors in natural frequency were below 5%. Figure 5 compares vibration responses, indicating that the integrated structure model aligns more closely with experimental results than the standalone motor model.

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