Interface-Based Damping Enhancement in Electric Vehicle BLDC Motors Using Rubber Materials

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ABSTRACT

With the growing emphasis on ride comfort in electric vehicles, minimizing vibrations in electric motor assemblies has become increasingly important. Structural vibrations can negatively impact motor performance and long-term durability. This study focuses on reducing mechanically induced vibrations in BLDC motors by introducing a synthetic vibration damping material at critical interface locations. The material is strategically placed between the front plate and motor casing, as well as between the back plate and motor casing, to isolate vibrations and reduce structural transmission. The effectiveness of this approach is evaluated through Finite Element (FE) modal analysis. The results show a significant reduction in structural vibrations after implementing the damping material. This study presents a vibration control strategy using synthetic damping material to improve the NVH performance of electric motors and contribute to enhanced reliability in electric vehicle applications.

Keywords: *Vibration damping, Electric vehicle, FE analysis, BLDC motor, Damping materials.*

1 INTRODUCTION

The increasing adoption of electric vehicles (EVs) has brought a renewed focus on the refinement of drivetrain components, especially the electric motor. One such motor widely used in EVs is the Brushless DC (BLDC) motor, valued for its high torque-to-weight ratio, compact size, and operational efficiency. However, unlike internal combustion engines, which produce continuous vibration due to combustion events, BLDC motors exhibit a complex vibration profile arising from mechanical unbalance, electromagnetic interactions, structural coupling, and assembly-related imperfections. These vibrations are a key source of NVH (Noise, Vibration, and Harshness) challenges in electric vehicles [1].

Among the different structural elements of the BLDC motor, the front and back plates—which are bolted to the motor casing—serve not only as mounting structures but also as vibration transmission paths. When the motor operates at or near its structural resonant frequencies, these interfaces can amplify vibrations and transfer them directly to the chassis, resulting in reduced ride comfort, component fatigue, and long-term structural degradation. Traditional approaches to mitigating these vibrations often focus on stator cavity treatments or external motor mounts [2], but interface-level damping at mechanical junctions remains relatively underutilized in this context.

To address this gap, this study proposes a novel passive damping approach, which involves inserting a synthetic viscoelastic damping layer at the interface between the front plate and casing as well as the back plate and casing of a BLDC motor. These interfaces are chosen for their structural significance, as they are the primary points of force transfer during operation. By disrupting the mechanical continuity using damping materials with energy absorption characteristics, the objective is to suppress resonance amplification and minimize vibration propagation through the motor housing [3].

The dynamics of BLDC motors are highly sensitive to boundary conditions, especially during structural vibration analysis. Modal characterization of such motors is therefore essential to understand the natural frequencies and mode shapes that contribute to NVH behavior. Previous studies have shown the effectiveness of free-free boundary modal analysis to evaluate the dynamic response of motor components independent of mounting influences [4]. This technique eliminates external constraints and focuses purely on the structure's inherent resonant behavior, making it ideal for evaluating the effect of internal damping modifications.

Finite Element (FE) modal analysis is used in this study to assess the performance of the proposed damping strategy. A 3D structural model of the BLDC motor is developed with and without the synthetic damping material at the defined interfaces. The mode shapes and natural frequencies are extracted to quantify the changes in vibrational response. This approach follows methodologies previously applied to analyze structural resonance in powertrain housings [5], engine mount behaviour [3], and electric motor casings [6], where viscoelastic materials showed significant damping capacity at targeted frequencies.

A key aspect of this work is the material selection and placement strategy. The synthetic damping material used in this study is optimized for its frequency-dependent loss modulus, allowing for maximum energy absorption within the operational frequency range of the motor. While damping rings have been mounted directly inside stators in earlier studies [2], this study shifts focus to interface layers that do not interfere with the motor's magnetic circuit. This design choice ensures that electromagnetic performance remains unaffected, preserving torque output and operational efficiency.

Past research on NVH optimization in motor assemblies and casings supports the idea that even minor modifications at structural junctions can lead to significant performance enhancements [7], [8]. However, practical implementation of such solutions must account for manufacturability, cost, and robustness under real-world loading. Therefore, the proposed SilentCore system is designed to be compact, non-invasive, and compatible with existing motor architectures. Such modular damping interventions are especially beneficial in electric two-wheelers and three-wheelers, where external NVH treatment options are limited due to packaging constraints.

The broader implications of this research lie in developing scalable and material-efficient NVH reduction solutions for compact electric propulsion systems. By strategically damping vibration at its source—i.e., the motor structure itself—this method addresses a crucial pain point in EV design without compromising motor integrity or thermal management. The findings from this study could also support future developments in smart NVH systems, where embedded damping layers dynamically adjust to operating conditions.

In summary, this paper presents a targeted vibration damping strategy for BLDC motors by embedding synthetic damping material at structurally sensitive interfaces. The effectiveness of this approach is evaluated through FE modal analysis under free-free conditions, focusing on changes in mode shapes and natural frequencies. The results demonstrate the potential for enhancing NVH performance in electric vehicle motors using passive internal damping, contributing to quieter operation, extended motor life, and improved user comfort.

2 METHODOLOGY

CAD Modelling and Interface Preparation

The present study focuses on enhancing vibration damping in a 1 kW, 3000 RPM Brushless DC (BLDC) motor by introducing synthetic damping materials at the casing-plate interfaces. Unlike traditional internal damping techniques, this approach targets the motor's structural boundaries—specifically the front plate-to-casing and back plate-to-casing joints—where high stress concentrations and structural transmission paths are observed during dynamic operation.

A high-fidelity 3D model of the BLDC motor assembly was created in Creo Parametric 11.0, representing the rotor, stator, casing, end plates, shaft, and fasteners. To accommodate the synthetic interface layers, a 1 mm clearance was introduced between the casing and the mounting plates. This spacing enabled the insertion of a continuous synthetic damping material without altering the core mechanical dimensions of the motor.

The final assembly, including damping interfaces, was exported to ANSYS Workbench for downstream simulation. The goal was to replicate real-world assembly conditions while embedding damping properties directly at mechanical joints where transmission of structural vibration typically occurs.

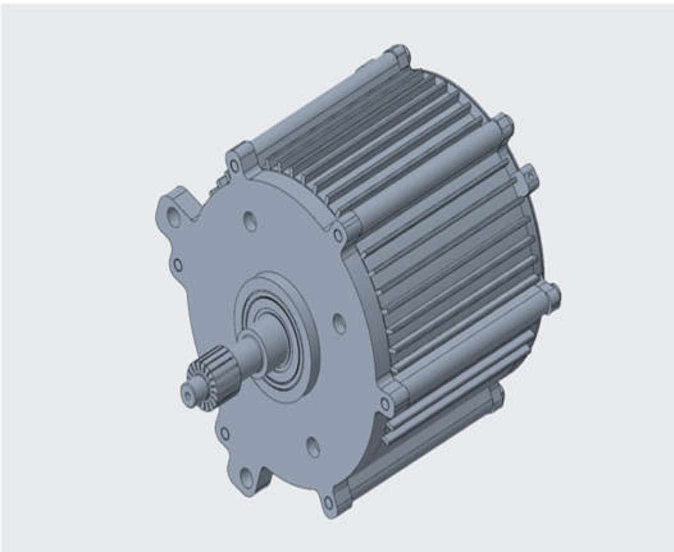


Fig 1. BLDC Motor Assembly

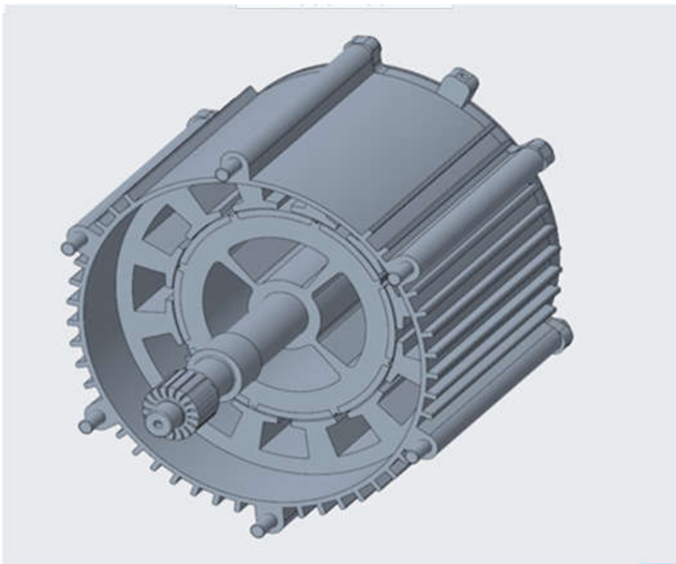


Fig 2. Rotor assembly

Finite Element Modal Analysis with Interface Damping

The finite element mesh was generated in ANSYS Mechanical, using second-order tetrahedral elements with a refined mesh at the interface zones to ensure accurate capture of strain gradients and mode shapes. The modal analysis was conducted under free-free boundary conditions to observe the structure's inherent dynamic behaviour without external constraint influences.

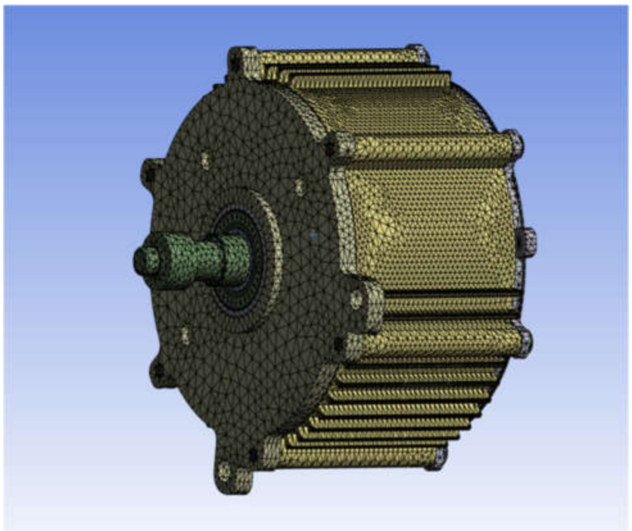


Fig 3. Mesh Model of BLDC Motor

Material properties for each motor component were sourced from manufacturers' datasheets and published literature, as shown in Table 1. The synthetic interface layer (a viscoelastic composite polymer) was modelled with isotropic linear elastic behaviour augmented by structural damping characteristics.

Table 1 – Material Properties for FE Simulation

Component	Material	Density (kg/m³)	Young's Modulus (GPa)	Poisson's Ratio
Casing	Aluminum	2700	70	0.35
Rotor Shaft	Mild Steel	7800	200	0.30
Stator Core	Silicon Steel	7305	205	0.27
End Plates	Stainless Steel	7600	190	0.27
Magnet	NdFeB	7500	160	0.24
Fasteners	Brass	8400	100	0.34
Interface Layer	Synthetic Rubber	910	0.15	0.48
	Natural Rubber	930	0.05	0.49

Damping Modelling Technique

A frequency-independent structural damping model was employed using the DMPRAT command in ANSYS APDL, with damping ratios derived from the loss factor (η) of the synthetic material. Experimental characterization of the interface polymer yielded a loss factor of 0.18[6], resulting in a damping ratio (ζ) of 0.09, which was applied uniformly across all vibration modes.

This modelling approach emphasizes localized damping at mechanical boundaries rather than internal absorption, offering a scalable method for structural vibration reduction without significantly altering the motor's electromagnetic design.

To simulate the dynamic behaviour of the BLDC motor assembly during modal analysis, simplified and physically representative boundary conditions were implemented. Since the copper windings of the rotor coil were not geometrically modelled, a point mass equivalent to the actual mass of the windings was applied at the rotor shaft location **Error! Reference source not found.**. This approach preserved the inertial effects of the windings without adding meshing complexity. These assumptions enabled an efficient and sufficiently accurate modal representation of the motor structure for finite element analysis.

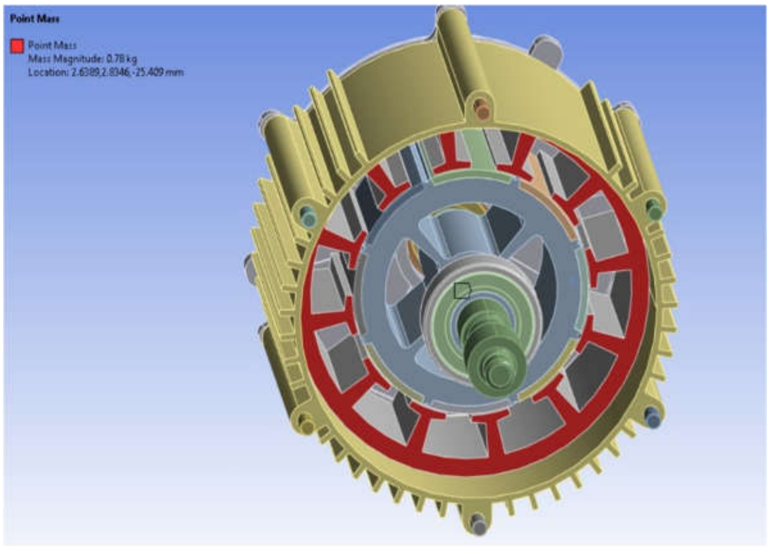
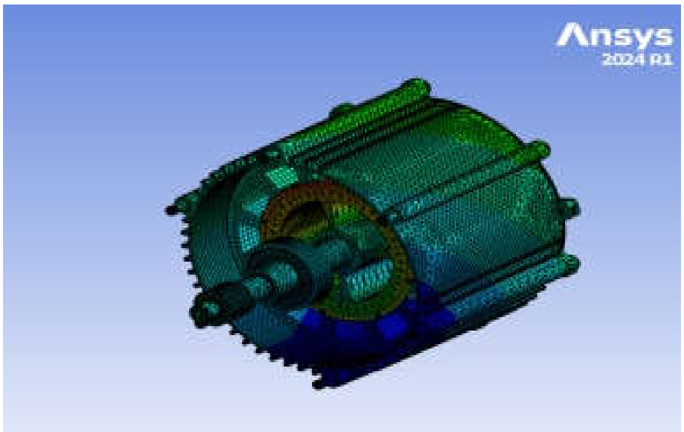
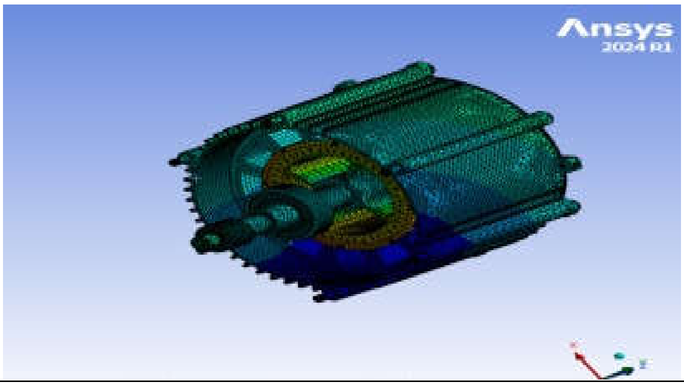


Fig 4. Point mass addition in modal analysis

3. Results

Table2: Simulation result Undamped natural frequency mode

Modes	Natural Frequency (Hz)	Mode Shape Deformation
1	684	
2	769	

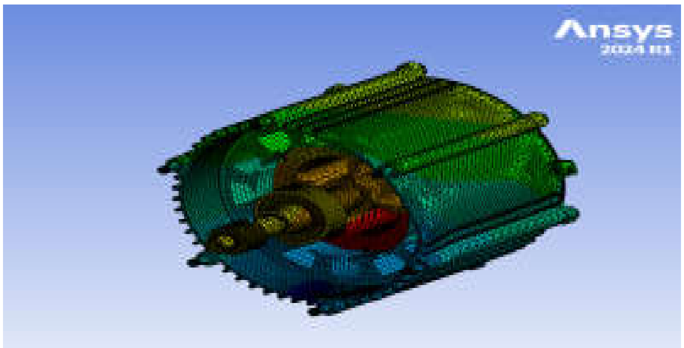
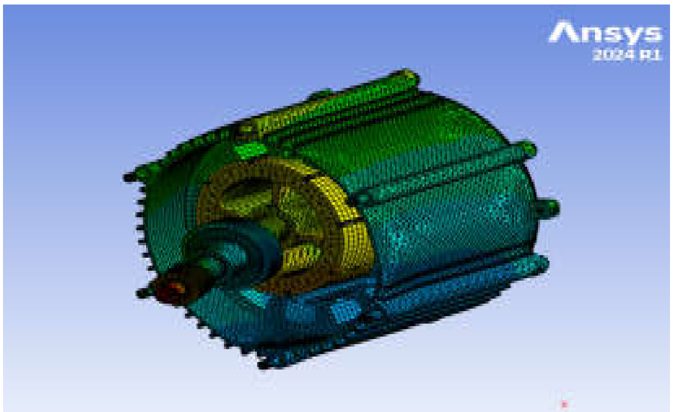
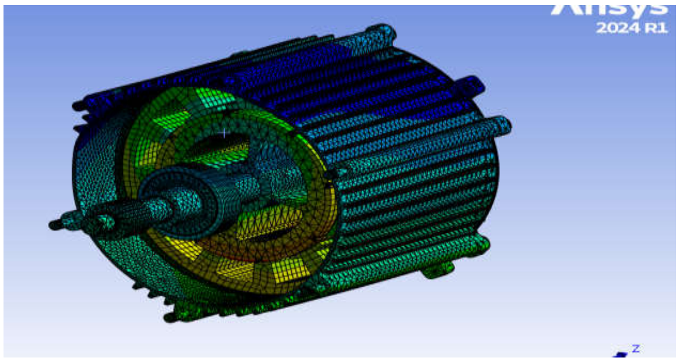
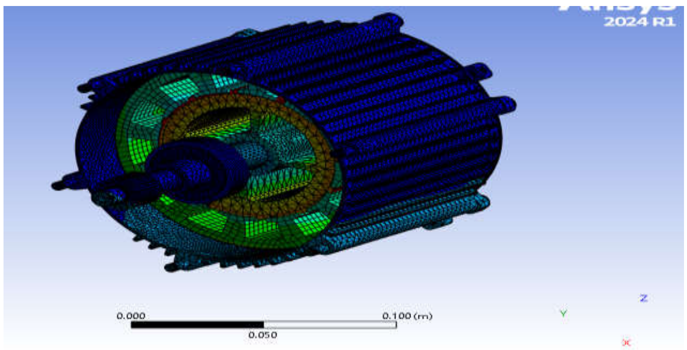
3	1040	
4	1125	

Table3: Simulation result damped natural frequency modes using Synthetic Rubber

Modes	Natural Frequency (Hz)	Mode Shape of structure
1	722	
2	780	

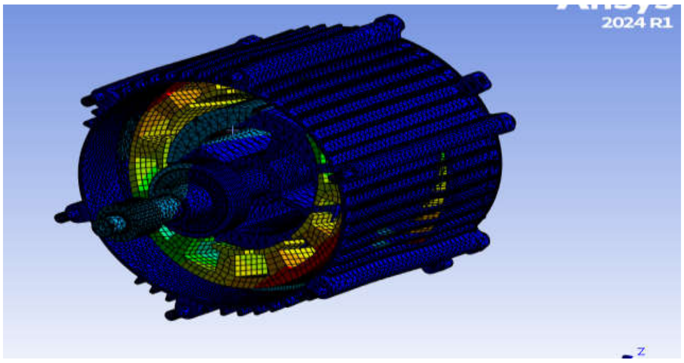
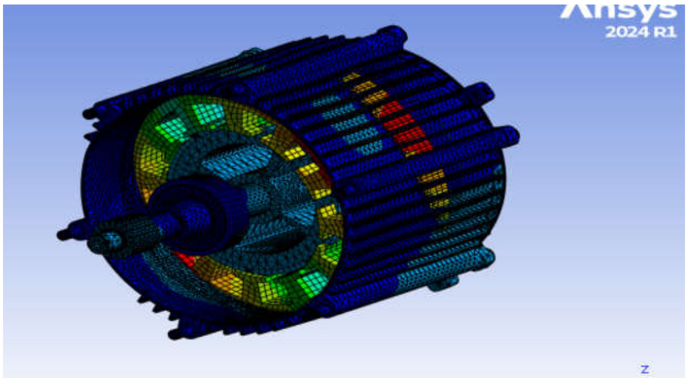
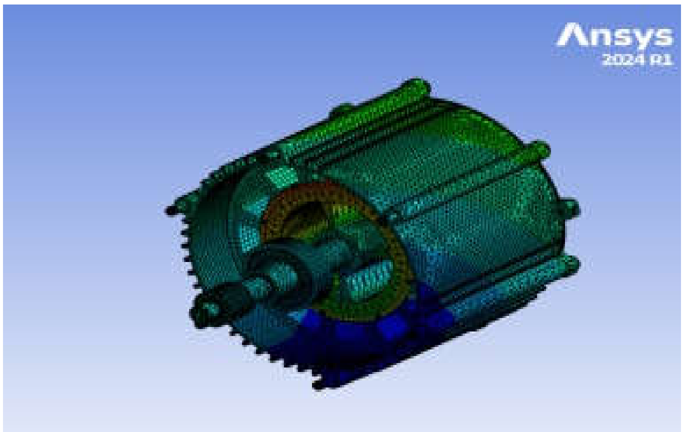
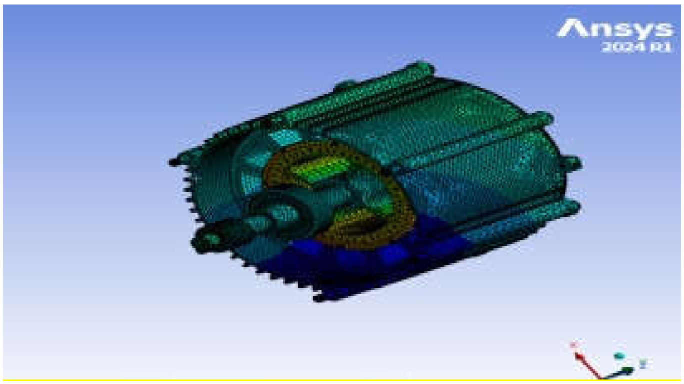
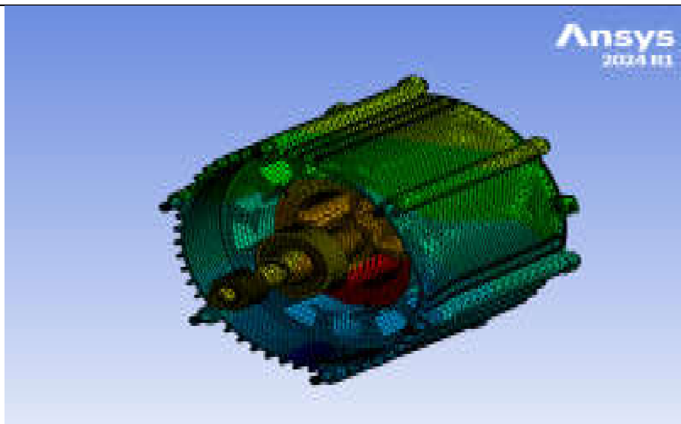
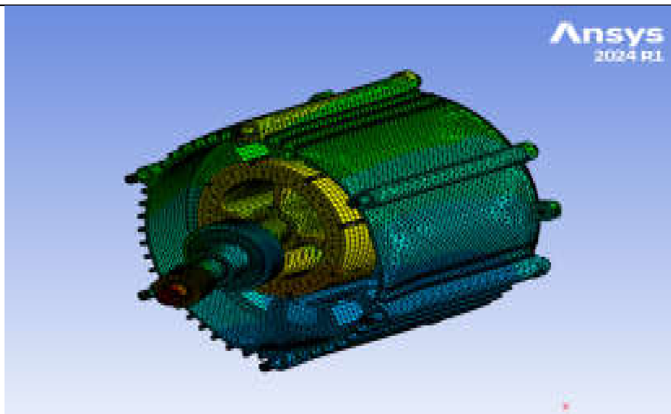
3	1106	
4	1120	

Table 4. Simulated and Experimental Natural frequency modes using Natural Rubber

Modes	Simulated Natural Frequency (Hz)	Mode Shape Deformation
1	724	

2	890	
3	1029	
4	1207	

Results and Discussion

Table 5: Comparison of natural frequency of Undamped Motor vibration and damped motor using vibration damping materials.

	Undamped Frequency (Hz)	Damped Frequency (Hz) Using vibration Damping materials	
Mode	Before Optimization Baseline	Synthetic rubber	Natural rubber
1st	684	722.87	724
2nd	769	780.46	890

3rd	1040	1106	1029
4th	1125	1120	1207

The modal analysis of the BLDC motor after introducing damping layers between the stator and yoke shows that both synthetic and natural rubber significantly influence the structural dynamic behavior, but in different ways across the vibration modes. The first mode frequency increases from 684 Hz to approximately 723 Hz with both materials, indicating a uniform rise in stiffness and improved resistance to low-frequency bending. In the second mode, natural rubber exhibits a far more pronounced stiffening effect, elevating the frequency from 769 Hz to 890 Hz, whereas synthetic rubber produces only a marginal increase to 780.46 Hz. For the third mode, synthetic rubber raises the frequency from 1040 Hz to 1106 Hz, demonstrating better performance in higher-frequency stiffness enhancement, while natural rubber slightly lowers it to 1029 Hz due to its higher damping characteristics that reduce effective stiffness. In the fourth mode, natural rubber again shows dominant stiffening behavior by increasing the frequency from 1125 Hz to 1207 Hz, whereas synthetic rubber results in a slight reduction to 1120 Hz. Overall, natural rubber consistently delivers greater stiffening across most modes, whereas synthetic rubber provides a more balanced stiffness–damping response. These shifts in natural frequencies effectively move the resonance points away from potential excitation sources, improving the overall NVH performance of the motor.

Conclusion-

This study presented a targeted vibration damping strategy for BLDC motors by introducing synthetic and natural rubber layers at structurally sensitive interfaces. The proposed method focused on the front plate–to–casing and back plate–to–casing joints, which act as primary vibration transmission paths in electric vehicle motor assemblies. Finite Element modal analysis, supported by Experimental Modal Analysis, demonstrated that integrating damping materials at these mechanical boundaries effectively alters the dynamic characteristics of the motor without affecting its electromagnetic performance or design envelope.

The results showed that both synthetic and natural rubber improve the vibrational behaviour of the BLDC motor, but with distinct performance tendencies. Natural rubber provided the highest stiffness enhancement, significantly increasing the natural frequencies in the 1st, 2nd, and 4th modes, thereby shifting resonances away from typical operational and excitation ranges. Synthetic rubber offered a more balanced damping–stiffness response, especially in the 3rd mode, where it achieved the largest frequency rise. These modifications reduce the likelihood of structural resonance, lower the vibration propagation through the casing, and enhance the overall NVH performance of the motor.

The interface-layer damping approach proposed in this research is compact, non-intrusive, and compatible with existing BLDC motor architectures, making it suitable for electric two-wheelers, three-wheelers, and compact EV platforms. By controlling vibration at its source, this method contributes to quieter operation, improved structural durability, and enhanced user comfort. Future work may explore advanced viscoelastic materials, temperature-dependent damping properties, and integration of smart adaptive damping layers to further optimize vibration control in next-generation electric propulsion systems.

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