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DESIGN AND ANALYSIS OF VIBRATION FIXTURE FOR EV BATTERY

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Abstract

The growing adoption of electric vehicles (EVs) has intensified the need for safe, durable, and reliable battery systems. Since EV batteries are subjected to dynamic loading and vibration during real-world operation, a dedicated vibration fixture is essential for experimental validation and durability testing. This project focuses on the design and analysis of a vibration fixture specifically developed for EV battery modules. A systematic approach is adopted, beginning with the identification of battery dimensions, mounting requirements, and loading conditions. The fixture is designed to simulate road-induced vibrations while ensuring rigid support, ease of assembly, and compliance with international testing standards. Finite Element Analysis (FEA) is employed to evaluate stress distribution, deformation, and natural frequencies, ensuring that the fixture does not resonate within the test frequency range. The optimized design achieves a balance between strength, weight, and manufacturability, enhancing reliability and repeatability in testing. The outcomes of this work provide a robust platform for battery vibration testing, contributing to the improvement of EV battery safety, performance, and lifecycle validation.

Keywords: Vibration Fixture for EV, Finite Element Analysis.

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I. Introduction

Electric vehicle (EV) technology has progressed rapidly, with battery systems becoming the most critical factors influencing vehicle performance, safety, and operational reliability. During real-world driving, EV batteries are subjected to continuous vibration inputs generated by road irregularities, chassis dynamics, and drivetrain forces. These vibrations can lead to structural stresses, accelerated material fatigue, and reduced overall battery health, ultimately impacting long-term performance and safety. Therefore, a reliable and vibration-resistant mounting system is essential to ensure proper battery integration and durability within the vehicle.

The effectiveness of battery mounting depends heavily on the design of the fixture that secures the battery to the EV chassis. The stiffness, geometry, and dynamic response of the mounting fixture determine how road-induced loads are transmitted and distributed across the battery housing.

Poor or generic mounting solutions may introduce local stress concentrations, inadequate support, or unfavorable vibrational behavior, which increase the risk of mechanical damage and reducing battery lifespan. Existing mounts adapted from non-EV applications often fail to meet the specific structural and dynamic requirements of modern battery modules.

To address these limitations, this research focuses on the design and analysis of a dedicated vibration-resistant mounting fixture engineered specifically for EV battery integration. The proposed fixture is developed to provide rigid support under real driving vibrations while remaining lightweight, manufacturable, and compatible with battery and chassis geometries. Finite Element Analysis (FEA) is conducted to evaluate structural stiffness, stress distribution, deformation, and natural frequencies, ensuring the fixture avoids resonance and maintains reliability under multi-axis loading conditions. The final design delivers an optimized battery mounting solution that enhances safety, structural stability, and long-term durability in electric vehicles.

II. Literature Review

1. Li, J. (2024) – LFP Battery Failure Under Vibration

Li (2024) experimentally investigates how square LFP cells behave under sinusoidal, random, and shock vibration conditions. Industrial CT imaging reveals small structural shifts—such as side-gap changes and tab-area deformation—without major collapse. Random vibration produces the most complex internal movements because it excites multiple modes simultaneously. Electrical performance shows minimal short-term degradation, though long-term exposure may accumulate damage. The study highlights edge regions and tab interfaces as critical failure initiation zones. It also emphasizes that fixture stiffness and mounting clearances strongly influence observed damage patterns.

2. Liu, Y. (2024) – Structural Optimization of Automotive Battery (FEA & Modal)

Liu (2024) performs detailed FEA and modal analysis on an EV battery pack to study stress, deformation, and vibrational behaviour. The paper identifies natural frequencies and mode shapes that could be excited by road-induced inputs. It proposes stiffness reinforcements and lightweighting strategies that shift frequencies away from damaging ranges. Optimization studies help reduce mass while keeping stresses within safe limits. The work also shows how pack-level design changes affect local cell clamp loads. These insights directly aid fixture designers in avoiding resonant excitation during testing.

3. Sabeel, K. (2025) – Vibration Effects on Thermal & Mechanical Behaviour Sabeel et al. (2025) review how vibration influences mechanical integrity, thermal pathways, and electrochemical behaviour in lithium-ion cells. They show that vibrations can cause micro-separation of electrode layers and increased internal resistance. Vibration also alters thermal conduction paths, contributing to localized heating. The review notes major inconsistencies in how fixtures and boundary conditions are reported across studies. It advocates for standardized protocols and combined vibration–thermal testing. The paper provides clear future research directions for reliable battery vibration modelling.

4. Kociu, A. (2025) – Finite Element Analysis of Li-Ion Cells

Kociu et al. (2025) compare homogenized and detailed layered FE models to evaluate lithium-ion cell mechanical response. The results show that simplified models can still predict global deformation and modal behaviour accurately with lower computational cost. Stress concentrations under compression, bending, and dynamic loading are mapped to potential failure points. The study identifies how small changes in casing thickness or tab stiffness can alter resonant response. It also gives practical guidance for avoiding over-constrained boundary conditions in fixtures. The models provide a useful foundation for pack-level vibration simulations.

5. Hooper, J.M. (2023) – Defining Vibration Test Profiles for EV Batteries

Hooper et al. (2023) develop representative vibration PSDs based on real vehicle measurements, enabling realistic durability testing. The study condenses long-duration road data into lab-compatible profiles covering approximately 5–200 Hz. It demonstrates accelerated testing methods that equate hours of lab testing to thousands of miles of usage. Detailed documentation of measurement setup improves repeatability for other laboratories. The report also stresses that fixture stiffness and mounting method strongly influence transmissibility. These findings provide practical guidelines for test profile generation.

6. Ślaski, G. (2024) – Mounting Techniques for EV Battery Vibration Testing

Ślaski et al. (2024) compare conventional screw mounting with alternative clamping mechanisms for shaker-based battery tests. While alternative methods can reduce setup time, they often compromise uniform clamping forces. Tests show that mounting method changes boundary conditions and thus affects modal response and accelerance levels. Safety concerns are noted for unsecured or uneven mounting during long-duration vibration. The study recommends verifying transmissibility whenever non-standard mounts are used. Overall, it highlights trade-offs between flexibility, safety, and test accuracy.

7. Research Preprint (2025) – Impact of Vibrations on Li-Ion Cells & BTMS

This preprint summarizes recent findings on how vibration affects both cell ageing and battery thermal management systems. It reports that vibration alters mechanical compression and contact resistances, which in turn affect heat generation and local temperatures. Combined vibration–thermal stresses accelerate ageing more than single-stressor tests. The paper highlights diagnostic tools such as impedance mapping and thermography for detecting vibration-induced hotspots. It emphasizes the need for standardized combined-environment test protocols. The overview identifies multi-physics modelling as a key research priority.

8. Plaumann, B. (2023) – Damaging Frequency Ranges in Battery Packs
Plaumann (2023) examines which frequency bands most contribute to structural fatigue in EV battery packs. Low-to-mid frequencies are shown to cause major structural damage, while higher frequencies affect connectors and small fittings. The paper demonstrates how pack geometry and boundary conditions shift damaging frequency ranges. It also discusses how damping assumptions influence fatigue predictions. Recommendations include ensuring fixture rigidity and selecting shaker bandwidths that cover relevant damaging frequencies. The work helps refine test spectra for realistic durability evaluation.

9. Li, R. (2025) – Capacity & Impedance Under Vibration and Temperature
Li et al. (2025) study combined vibration and temperature effects on lithium-ion cell degradation. Results show that vibration accelerates impedance growth, especially at elevated temperatures. Capacity fade is greater under combined stress than under vibration- or temperature-only conditions. Some vibration frequencies cause transient impedance spikes linked to internal micro-movements. The study uses EIS and cycling data to correlate mechanical strain with electrical changes. Findings support the need for combined-environment testing in future standards.

10. Awan, U.S. (2025) – Cell Geometry & Vibration Performance
Awan et al. (2025) analyze how cell geometry (cylindrical, prismatic, pouch) affects vibration response in battery assemblies. All geometries show different natural frequencies, damping behaviour, and stress distributions under excitation. Cylindrical cells behave differently from planar prismatic cells due to varying contact patterns and stiffness. Pouch cells show the highest compliance and are sensitive to over-clamping. The study provides specific recommendations for clamp design, contact area selection, and allowable torque. These insights help create geometry-optimized vibration fixtures.

Novelty of work: The novelty of this work lies in developing a dedicated vibration-resistant mounting fixture specifically designed for securing EV batteries within the vehicle structure, rather than relying on traditional mounts adapted from ICE vehicles or generic support brackets. Unlike existing studies that mainly focus on battery pack durability or thermal management, this research addresses the mounting system itself as a critical structural component, capable of isolating road-induced vibrations while ensuring safe load transfer to the chassis. The design incorporates battery-specific geometry, weight distribution, and real driving vibration spectra, enabling a mount that is both structurally optimized, and application-specific. The integration of modal, static, and dynamic FEA ensures that the fixture avoids resonance and maintains stiffness under multi-axis loads, an aspect not extensively explored in current EV mounting research. This combined approach results in a lighter, stronger, and more reliable battery mounting solution, offering enhanced safety, reduced vibration exposure, and improved long-term battery health within electric vehicles.

III. Problem Statement

- Electric vehicle (EV) batteries are subjected to continuous vibration loads during real-world driving, which can lead to structural fatigue, performance degradation, and reduced service life if not properly supported.
- Existing battery mounting solutions often rely on generic brackets or adapted components that do not adequately consider the battery’s weight, geometry, or dynamic behavior within the vehicle chassis.
- This can result in insufficient stiffness, uneven load distribution, and the possibility of resonance under operational vibration frequencies.

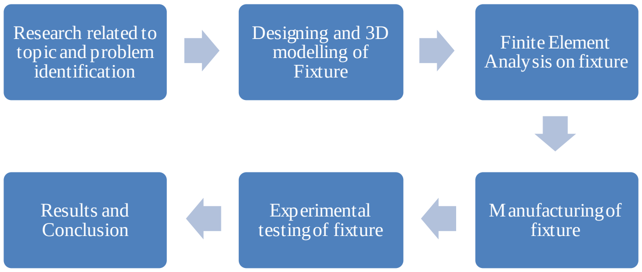
- Therefore, there is a need for a dedicated, structurally optimized vibration-resistant mounting fixture that can securely integrate the battery into the EV while minimizing vibration transmission and ensuring long-term safety and durability.

IV. Objectives

The aim of this project is to design and analyze a specialized vibration fixture for EV batteries that ensures secure mounting, replicates real-world vibration conditions, and provides accurate and reliable results during durability testing. The primary objectives are:

- To design the vibration fixture for electric vehicle battery using cad tool.
- To perform static analysis of vibration fixture for battery to find out the stress and deformation occurred vibration fixture.
- To perform modal analysis using ANSYS to find out vibration modes of battery fixture.
- To perform the harmonic analysis using ANSYS.

Research Methodology



V. Finite Element Analysis

The finite element method (FEM), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements.

FEM is best understood from its practical application, known as finite element analysis (FEA). FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm. In applying FEA, the complex problem is usually a physical system with the underlying physics such as the Euler-Bernoulli beam equation, the heat equation, or the Navier-Stokes equations expressed in either PDE or integral equations, while the divided small elements of the complex problem represent different areas in the physical system.

In present research for analysis ANSYS (Analysis System) software is used. Basically, its present FEM method to solve any problem. Following are steps in detail

1. Geometry

2. Discretization (Meshing)
3. Boundary condition
4. Solve (Solution)
5. Interpretation of results.

Workbench contain analysis of different types namely static, modal, harmonic, explicit dynamics, CFD, ACP tool post, CFX, topology optimization etc. as per problem defined.

Step 1: Details of material namely copper, steel, grey cast iron, composite material, fluid domain material is defined in engineering data. i.e. ANSYS default material is structural steel.

Step 2: Import of geometry created in any CAD software namely CATIA, PRO E, SOLIDWORK, INVENTOR etc. in geometry section. If any correction is to be made it can be created in geometry section in Design modeler or space claim.

Step 3: In model section after import of component

- Material is assigned to component as per existing material
- Connection is checked in contact region i.e. bonded, frictionless, frictional, no separation etc. for multi body components.
- Meshing or discretization is performed i.e. to break components in small pieces (elements) as per size i.e. preferably tetra mesh and hexahedral mesh for 3D geometry and for 2 D quad or tria are generally preferred.

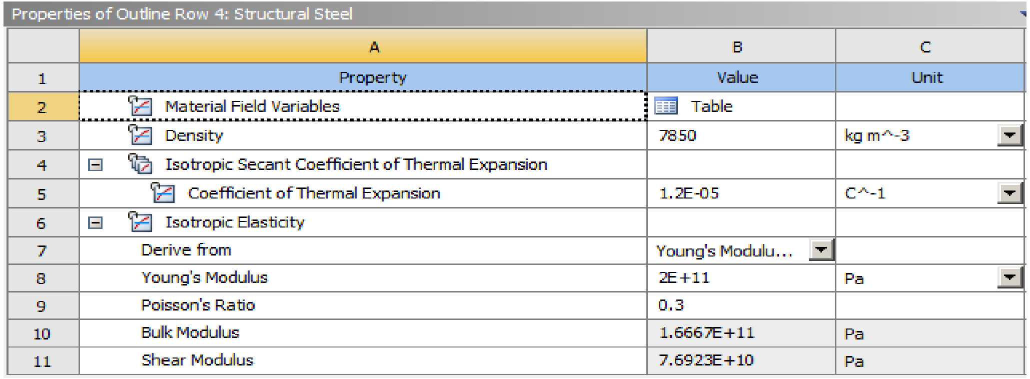
Step 4: Boundary condition are applied as per analysis namely in fixed support, pressure, force, displacement, velocity as per condition.

Step 5: Now problem is well defined and solve option is selected to obtain the solution in the form of equivalent stress, strain, energy, reaction force etc.

Vibration analysis of battery fixture design 1 (MS)

Material properties

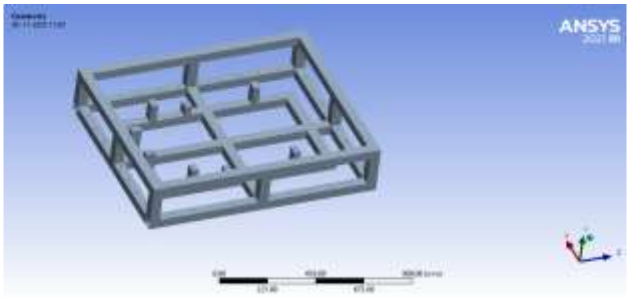
Table. Material properties of Structural steel.

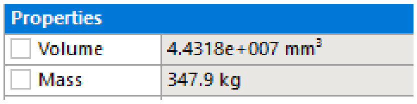


Properties of Outline Row 4: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Geometry

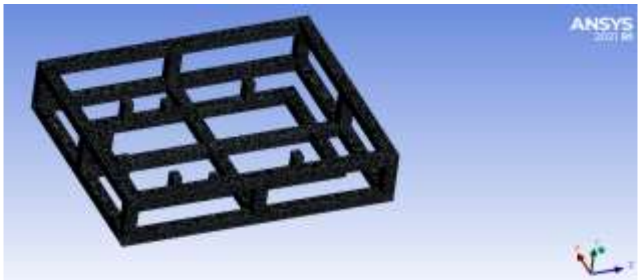


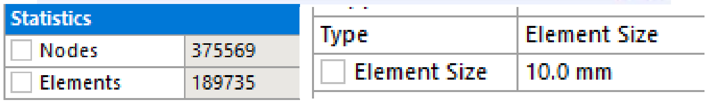


Properties	
☐ Volume	4.4318e+007 mm^3
☐ Mass	347.9 kg

Fig. Geometry of MS battery fixture.

Meshing





Statistics	
☐ Nodes	375569
☐ Elements	189735

Type	Element Size
☐ Element Size	10.0 mm

Fig. Meshing details of MS battery fixture.

Boundary conditions

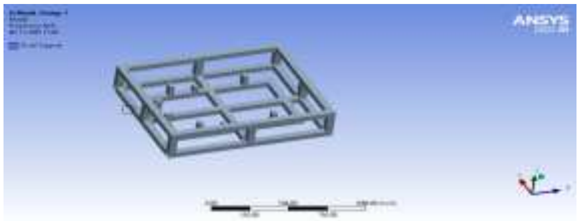


Fig. Boundary conditions for Modal analysis of MS battery fixture.

Mode shape 01

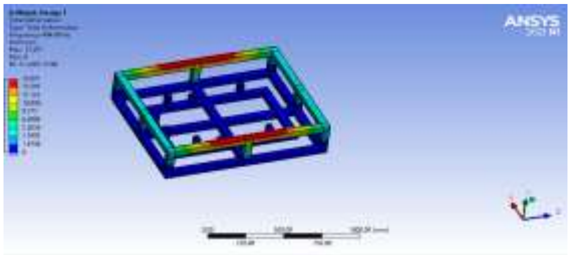


Fig. Natural frequencies for mode shape 1 of Modal analysis of MS battery fixture.

Mode shape 02

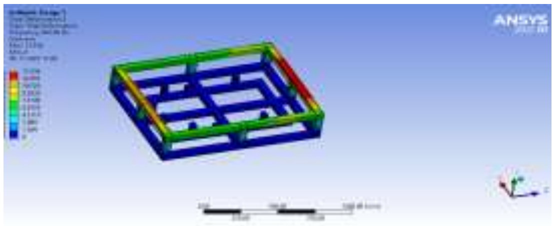


Fig. Natural frequencies for mode shape 2 of Modal analysis of MS battery fixture.

Mode shape 03

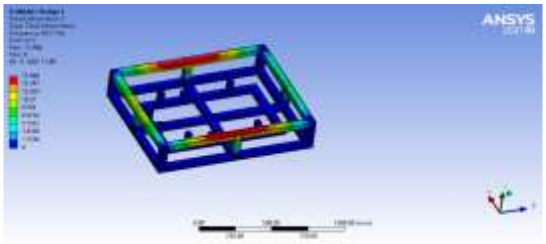


Fig. Natural frequencies for mode shape 3 of Modal analysis of MS battery fixture.

Mode shape 04

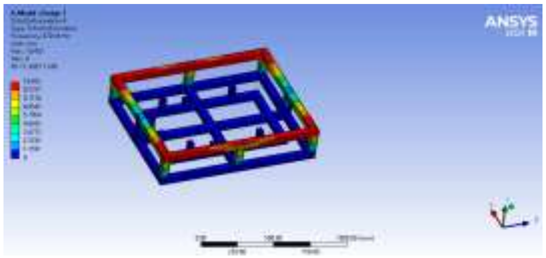


Fig. Natural frequencies for mode shape 4 of Modal analysis of MS battery fixture.

Mode shape 05

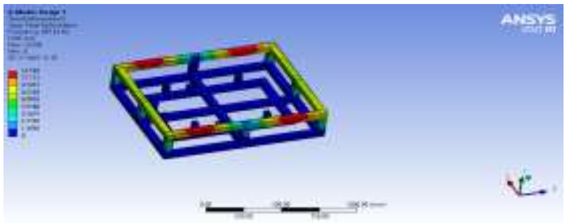


Fig. Natural frequencies for mode shape 5 of MS battery fixture.

Mode shape 06

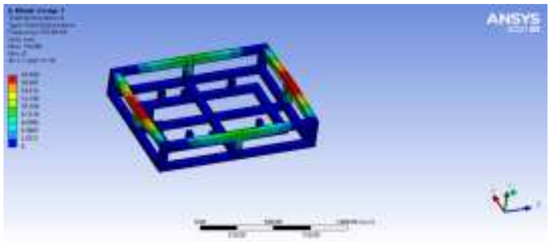
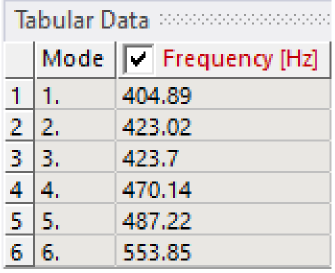


Fig. Natural frequencies for mode shape 6 of Modal analysis of MS battery fixture.

Table. Mode no. and their frequencies for Modal analysis of MS battery fixture.



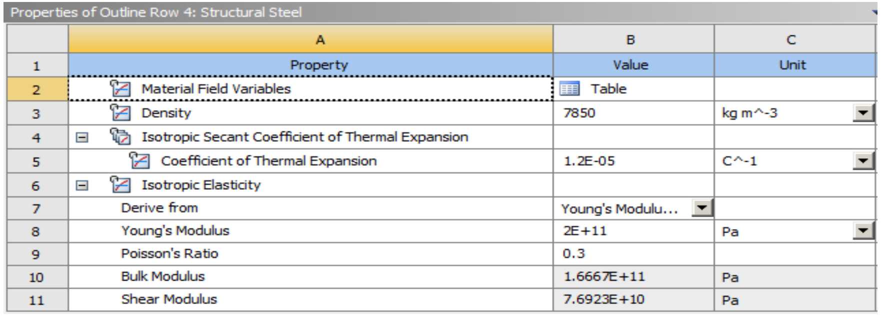
Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	404.89
2	2.	423.02
3	3.	423.7
4	4.	470.14
5	5.	487.22
6	6.	553.85

Static analysis of battery fixture design 1 (MS)

Material properties

Table. Material properties of Structural steel.



Properties of Outline Row 4: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	⊟ Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	⊟ Isotropic Elasticity		
7	Derive from	Young's Modulu...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Geometry

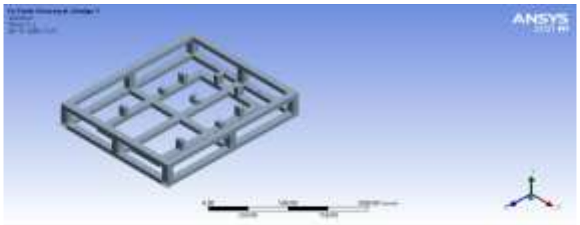
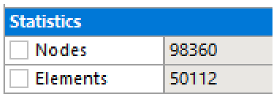


Fig. Geometry of MS battery fixture.

Meshing



Statistics

☐ Nodes	98360
☐ Elements	50112

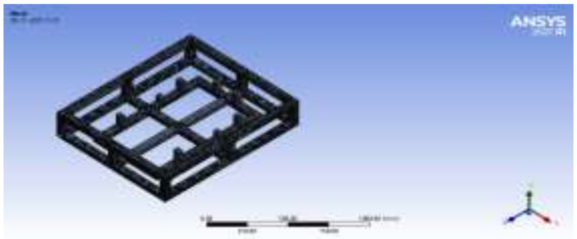


Fig. Meshing details of MS battery fixture.

Boundary conditions

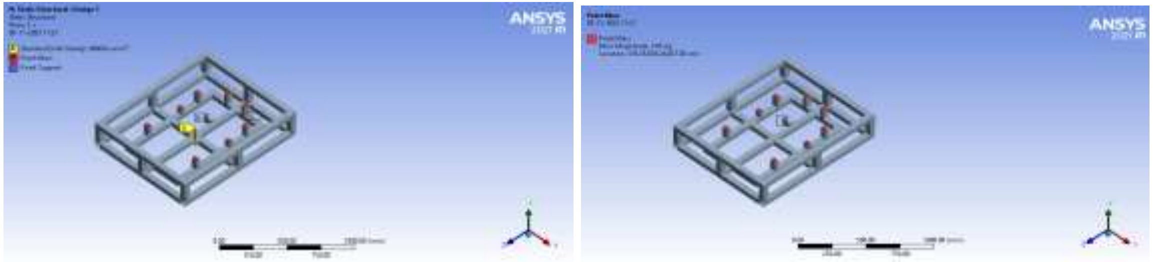
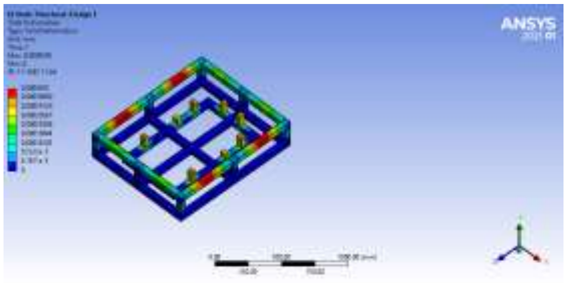


Fig. Boundary conditions for Static Structural Analysis of MS battery fixture.

Results

Total deformation



Total deformation of MS battery fixture.

Equivalent stress

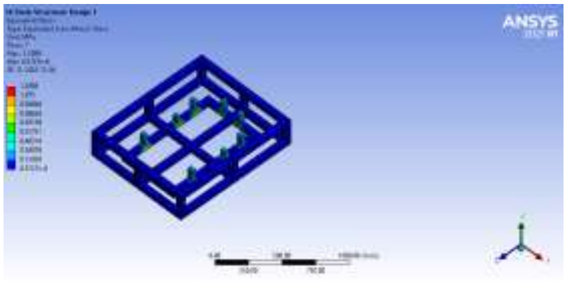
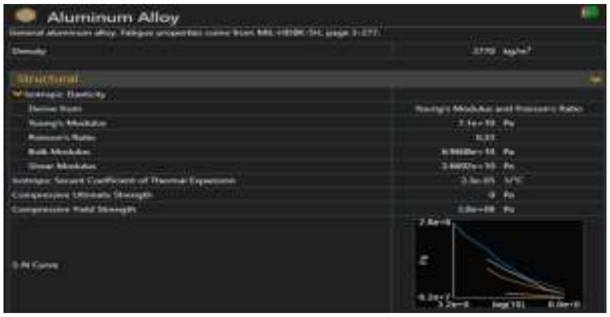


Fig. Equivalent Stress of MS battery fixture.

Vibration Analysis of battery fixture design 1 (Aluminium Alloy)

Material properties



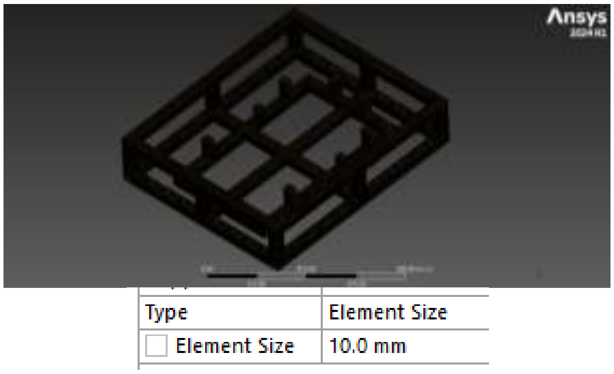
Aluminum Alloy

General aluminum alloy. Fatigue properties come from MIL-HDBK-5H, page 3-277.

Density	2770 kg/m³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	7.1e+10 Pa
Poisson's Ratio	0.33
Bulk Modulus	6.9608e+10 Pa
Shear Modulus	2.6692e+10 Pa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05 1/°C
Compressive Ultimate Strength	0 Pa
Compressive Yield Strength	2.8e+08 Pa
S-N Curve	

Fig. Material properties of Aluminium Alloy.

Meshing



Type	Element Size
☐ Element Size	10.0 mm

Fig. Meshing details details of Al battery fixture.

Results:

Mode shape 01

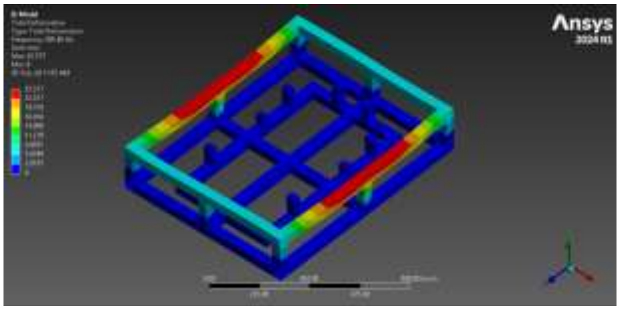


Fig. Natural frequencies for mode shape 1 of Modal analysis of Al battery fixture.

Mode shape 02

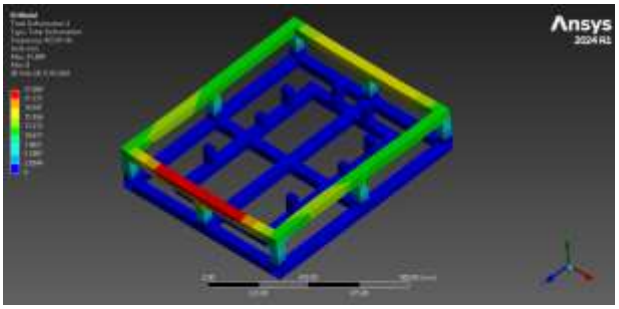


Fig. Natural frequencies for mode shape 2 of Modal analysis of Al battery fixture.

Mode shape 03

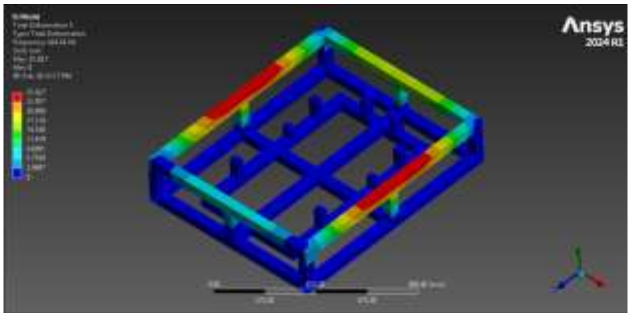


Fig. Natural frequencies for mode shape 3 of Modal analysis of Al battery fixture.

Mode shape 04

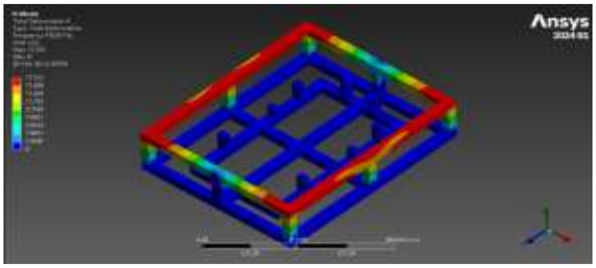


Fig. Natural frequencies for mode shape 4 of Modal analysis of Al battery fixture.

Mode shape 05

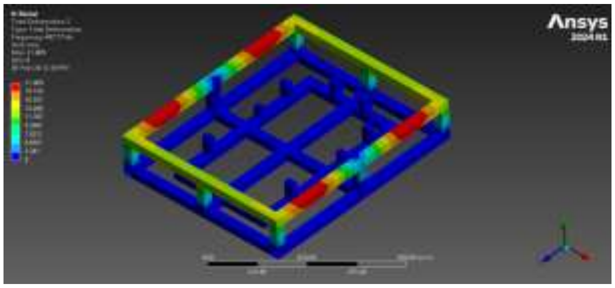


Fig. Natural frequencies for mode shape 5 of Modal analysis of Al battery fixture.

Mode shape 06

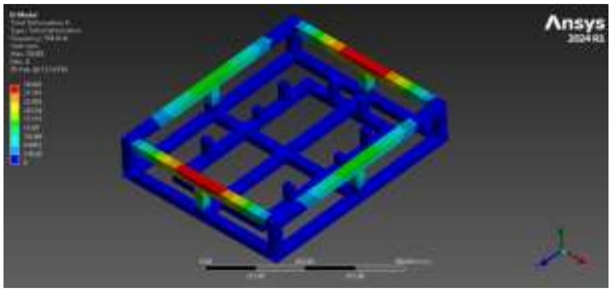
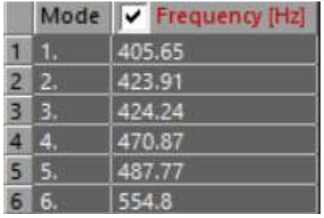


Fig. Natural frequencies for mode shape 6 of Modal analysis of Al battery fixture.

Table. Mode no. and their frequencies for Modal analysis of Al battery fixture.



	Mode	☑ Frequency [Hz]
1	1.	405.65
2	2.	423.91
3	3.	424.24
4	4.	470.87
5	5.	487.77
6	6.	554.8

Static analysis of battery fixture design 1 (Aluminium Alloy)

Boundary conditions

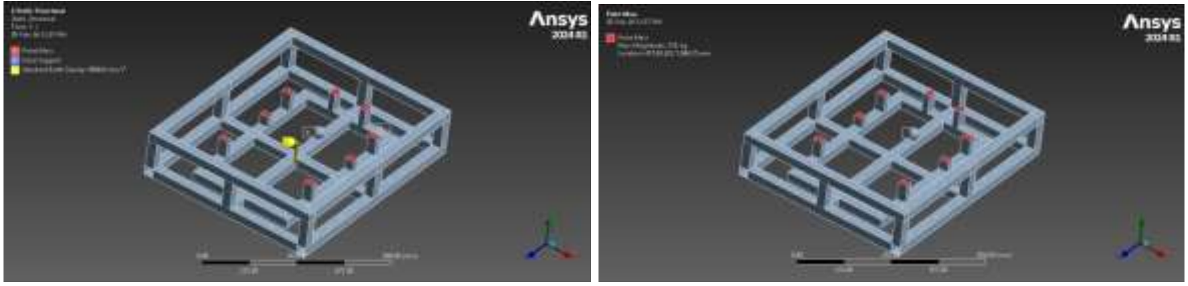
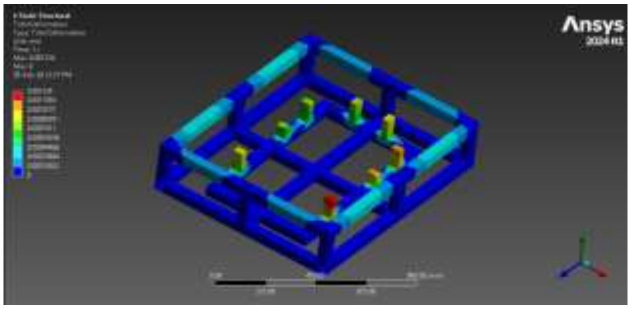


Fig. Boundary conditions for Static Structural Analysis of Al battery fixture.

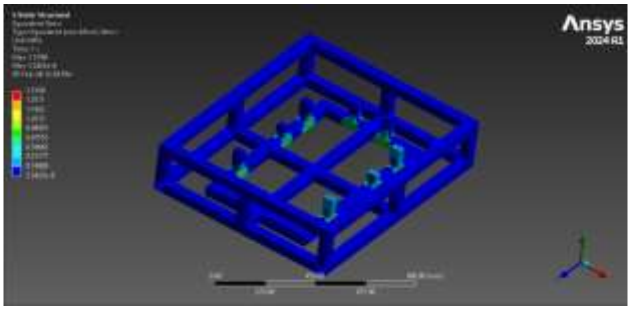
Results

Total deformation



Total deformation of Al battery fixture.

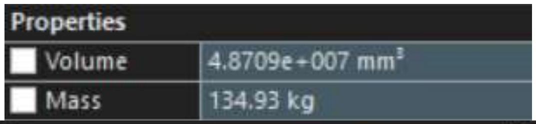
Equivalent stress



Equivalent Stress of Al battery fixture.

Vibration analysis of battery fixture design 2 (Aluminium Alloy)

Geometry



Properties	
☐ Volume	4.8709e+007 mm^3
☐ Mass	134.93 kg

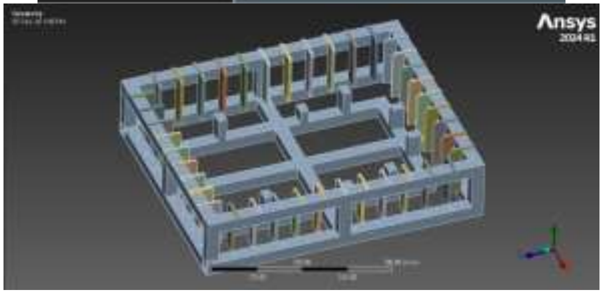
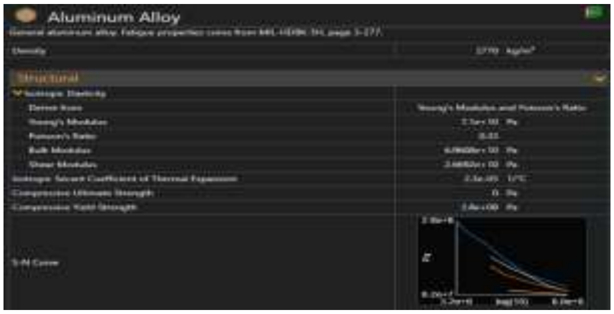


Fig. Geometry of Al battery fixture design 2.

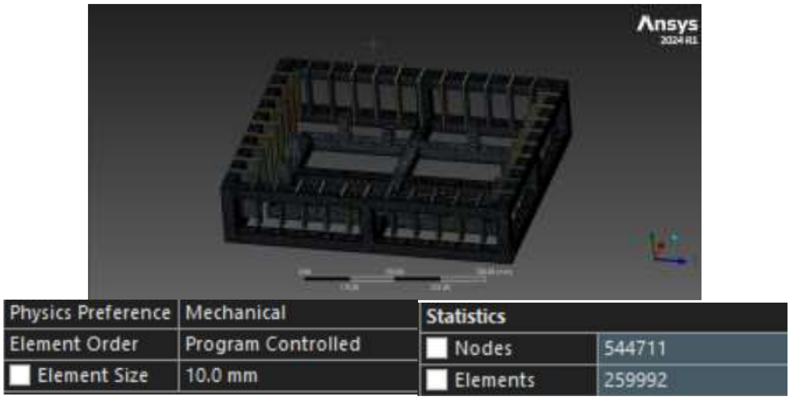
Material properties



Aluminum Alloy

Fig. Material properties of Aluminium Alloy.

Meshing



Physics Preference	Mechanical
Element Order	Program Controlled
☐ Element Size	10.0 mm

Statistics	
☐ Nodes	544711
☐ Elements	259992

Fig. Meshing details of Al battery fixture design 2.

Boundary Conditions:

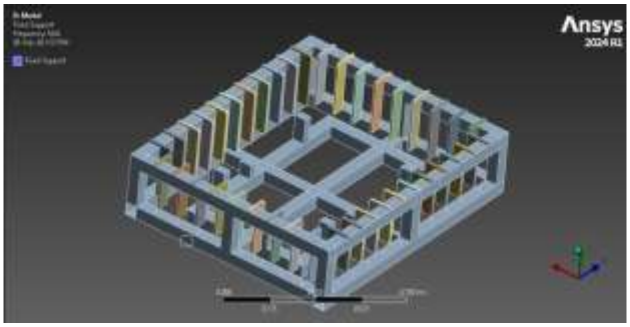


Fig. Boundary conditions for Modal analysis of MS battery fixture.

Results:

Mode shape 01

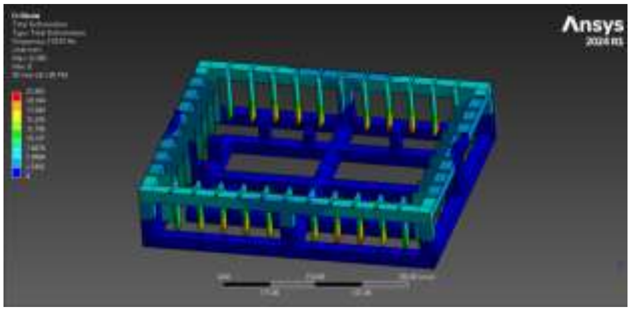


Fig. Natural frequencies for mode shape 1 of Modal analysis of Al battery fixture 2.

Mode shape 02

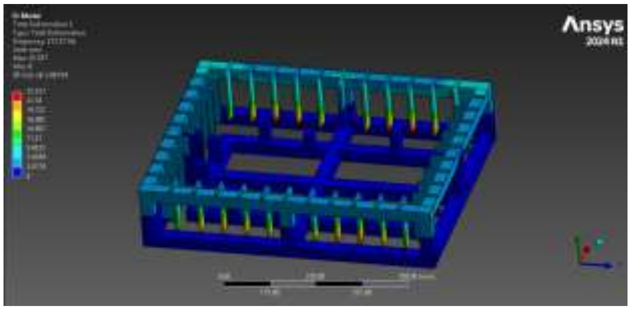


Fig. Natural frequencies for mode shape 2 of Modal analysis of Al battery fixture 2.

Mode shape 03

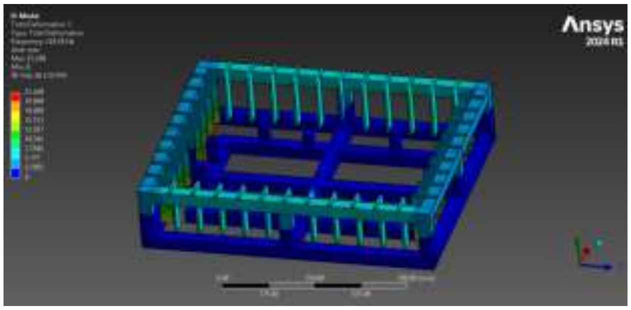


Fig. Natural frequencies for mode shape 3 of Modal analysis of Al battery fixture 2.

Mode shape 04

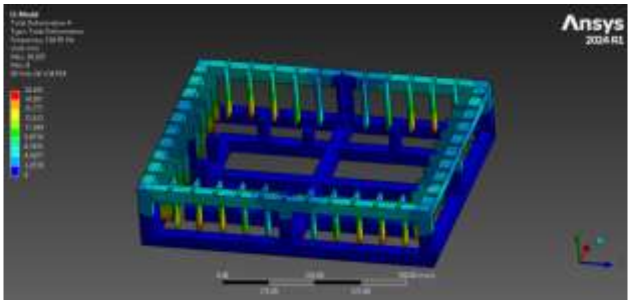


Fig. Natural frequencies for mode shape 4 of Modal analysis of Al battery fixture 2.

Mode shape 05

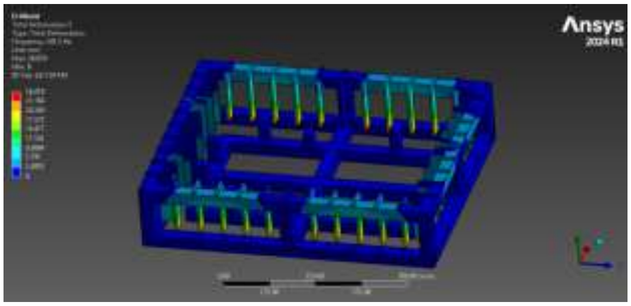


Fig. Natural frequencies for mode shape 5 of Modal analysis of Al battery fixture 2.

Mode shape 06

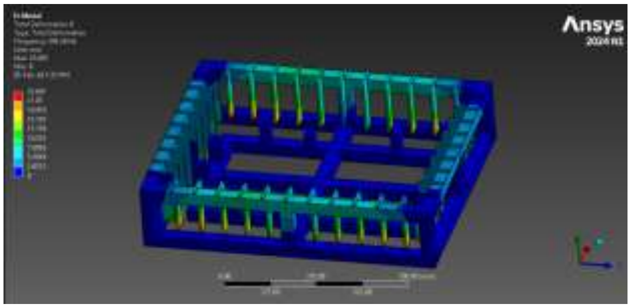
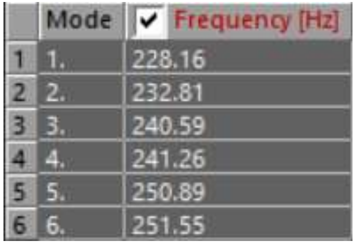


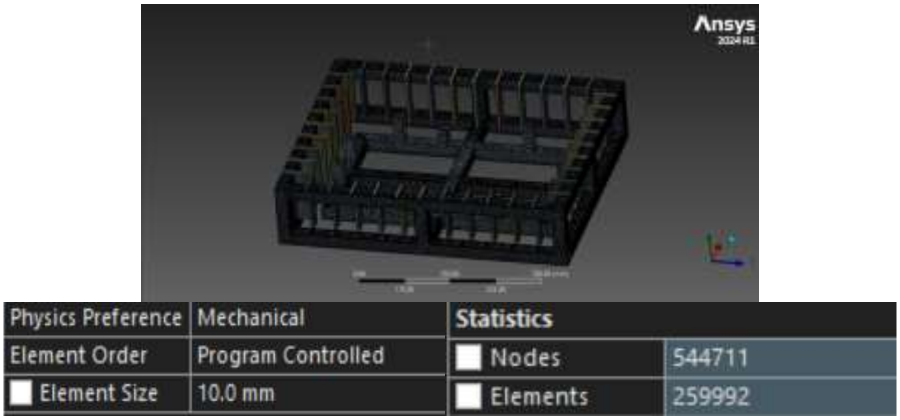
Fig. Natural frequencies for mode shape 6 of Modal analysis of Al battery fixture 2.

Table. Mode no. and their frequencies for Modal analysis of Al battery fixture 2.



	Mode	☑ Frequency [Hz]
1	1.	228.16
2	2.	232.81
3	3.	240.59
4	4.	241.26
5	5.	250.89
6	6.	251.55

Static analysis of battery fixture design 2 (Aluminium Alloy)
Meshing



Physics Preference	Mechanical
Element Order	Program Controlled
☐ Element Size	10.0 mm

Statistics	
☐ Nodes	544711
☐ Elements	259992

Fig. Meshing Details of Al battery fixture 2.

Boundary conditions

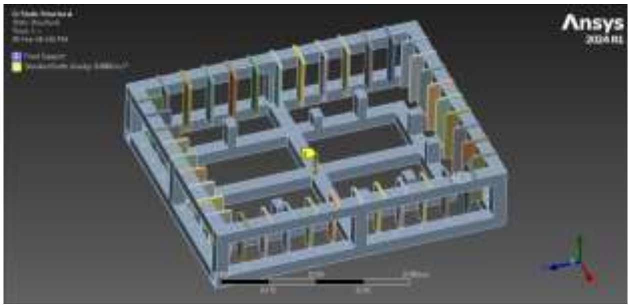


Fig. Boundary conditions for static structural analysis of Al battery fixture 2.

Results
Total deformation

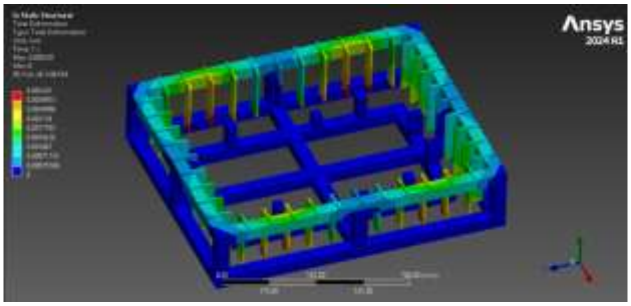


Fig. Total Deformation of Al battery fixture design 2.

Equivalent stress

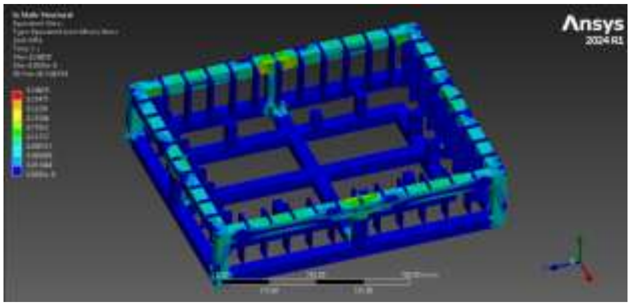


Fig. Equivalent Stress of Al battery fixture design 2.

FEA Results

Modal analysis results for Design 1 fabricated from mild steel (MS) showed high natural frequencies at 404.89 Hz, 423.02 Hz, 423.70 Hz, 470.14 Hz, 487.22 Hz, and 553.85 Hz, indicating a highly rigid structure. While such high frequencies ensure separation from typical road-induced excitation, they also suggest excessive stiffness, which can increase vibration transmissibility to the battery system.

A similar trend was observed for Design 1 using aluminium alloy, with natural frequencies in the range of 405.65–554.80 Hz, confirming that the geometry of Design 1 inherently results in over-stiff behavior regardless of material selection.

In comparison, Design 2 manufactured from aluminium alloy exhibited lower but well-distributed natural frequencies between 228.16 Hz and 251.55 Hz. These frequencies remain sufficiently above dominant vehicle excitation ranges, while providing a more compliant structural response. This balance reduces the likelihood of resonance and limits direct transmission of high-frequency vibration to the battery assembly.

Static structural analysis of Design 1 (MS) resulted in a maximum total deformation of 0.0004285 mm and an equivalent von Mises stress of 1.2094 MPa, indicating extremely high stiffness and negligible stress levels. However, this performance was achieved at the cost of a very high mass of 347.9 kg, making it unsuitable for lightweight EV integration.

For Design 1 (Aluminium alloy), the maximum deformation increased slightly to 0.001334 mm with an equivalent stress of 1.5199 MPa, while the mass was significantly reduced to 122.76 kg. Despite the weight reduction, the structural response remained excessively stiff for vibration accommodation.

Design 2 (Aluminium alloy) demonstrated a maximum deformation of 0.003201 mm and a low equivalent stress of 0.28659 MPa, confirming adequate strength and favorable stress distribution. The associated mass of 134.93 kg represents an acceptable compromise between stiffness and weight, aligning well with EV design requirements.

Conclusion

This study investigated the structural and dynamic performance of EV battery mounting fixture designs with the objective of achieving an optimal balance between vibration resistance, structural safety, and mass efficiency. The results demonstrate that increasing stiffness beyond a certain threshold does not yield functional benefits and may instead contribute to unnecessary weight and increased vibration transmission.

Although Design 1, in both mild steel and aluminum alloy configurations, exhibited very high stiffness and minimal deformation, it was found to be over-engineered for EV battery mounting applications. In contrast, Design 2 fabricated from aluminum alloy provided a more balanced structural response, with natural frequencies safely separated from operational excitation ranges, sufficient stiffness to maintain battery stability, and improved vibration compliance.

Therefore, Design 2 (Aluminum alloy) is identified as the most suitable configuration for EV battery mounting, offering effective vibration mitigation, structural reliability, and weight efficiency. The findings highlight the importance of geometry-driven optimization and appropriate material selection in EV battery integration. Future work will focus on fatigue life prediction, experimental validation, and vehicle-level vibration response assessment under combined loading conditions.

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