Integrated Design and Analysis of a Battery Mounting Bracket Tray in Four-Wheelers

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Abstract: ***The rapid expansion of electric vehicles (EVs) necessitates continuous advancements in their components to improve performance, safety, and efficiency. This paper presents a comprehensive study on the optimization design and analysis of battery brackets specifically tailored for electric vehicles. Battery brackets are critical components that secure the battery pack, impacting both vehicle safety and battery performance. This research focuses on optimizing the design of a battery bracket to achieve maximum structural integrity while minimizing weight. A comprehensive design process were employed, incorporating finite element analysis (FEA) and topology optimization techniques using ANSYS. Initially design will be created using Solid works 2022 and then FEA analysis will be perform to evaluate the bracket's stress distribution, deformation, and safety factors under loading conditions. Topology optimization were used to identify optimal material distribution within the bracket, maximizing stiffness and strength while minimizing mass. The optimized battery bracket design will validate through experimental testing using universal testing machine and compared to the initial design. The results demonstrated significant improvements in terms of weight reduction, stress distribution, and safety factors. The methodology and findings can be applied to the development of safer, more efficient, and cost-effective electric vehicles.***

Keywords: Composite material, Vibration analysis, Finite Element Analysis, Natural frequency, Mode shape

Nomenclature

Hz	Frequency in Hertz
F	External force matrix N
k	Global stiffness matrix
u	Displacement matrix (mm)

1. Introduction

The rapid advancement of electric vehicle (EV) technology has intensified the demand for high-performance, lightweight, and cost-effective components. Among these, the battery bracket plays a critical role in ensuring the safety, stability, and longevity of the battery pack the core energy source of an EV. The primary function of the battery bracket is to support and protect the battery pack from mechanical stresses, vibrations, and other dynamic loads encountered during vehicle operation.

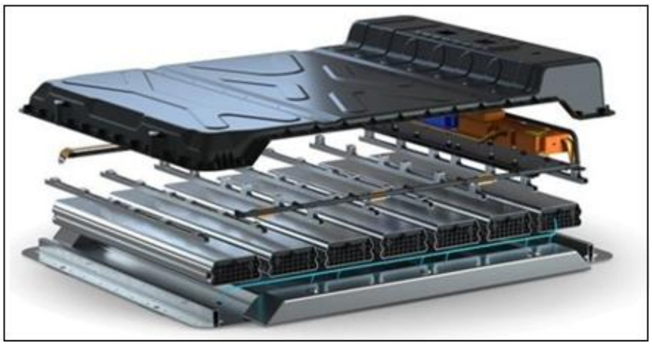

Figure 1: Design layout of car battery bracket

As battery packs grow in size and complexity to meet increased energy and range requirements, the structural and functional performance of the bracket becomes even more vital This study aims to explore and implement optimization strategies for battery bracket design in electric vehicles. By leveraging state-of-the-art simulation tools and optimization algorithms, the research focuses on improving structural integrity, reducing weight, and enhancing cost efficiency.

Various design parameters, material choices, and loading scenarios are systematically investigated to develop an optimized bracket that aligns with stringent performance, safety, and manufacturability criteria. Through this approach, the study seeks to contribute to the development of more robust and efficient EV battery support systems, ultimately advancing the overall performance and sustainability of electric vehicles.

The objective of this study is to explore and implement optimization strategies for battery bracket design in electric vehicles. By utilizing advanced computational tools and techniques, including Finite Element Analysis (FEA) and optimization this research aims to enhance the structural integrity, reduce the weight, and improve the cost-effectiveness of battery brackets.

The advanced strategies to optimize electric vehicle (EV) battery pack design, focusing on lightweight construction, structural performance, and manufacturing feasibility. By replacing traditional metal materials with carbon fiber composites, a 56% reduction in battery pack weight is achieved through structural optimization and resin curing simulations. Using ANSYS, the battery pack is further refined under conditions such as sharp turns and bumpy roads to enhance safety, collision resistance, and compliance with technical standards. The vibration characteristics of the battery bracket are analyzed using frequency response and modal analysis, leading to design modifications that improve stiffness and stress tolerance while minimizing NVH (noise, vibration, and harshness).

To further support lightweight design, topology optimization and 3D printing are applied, resulting in a 49.2% weight reduction of the bracket with uniform stress distribution and precise assembly. In addition, static and dynamic analyses of the battery box identify structural weaknesses, which are addressed through design improvements that meet performance requirements. Machining of battery trays is enhanced through dynamic modeling that emphasizes fixture stiffness, improving the accuracy of surface geometry predictions. Finally, laser welding of 6xxx-series aluminum extrusions commonly used in battery trays is optimized using filler wires and beam shaping techniques to reduce cracking and improve weld integrity.

The selection and mechanical isolation for electric two-wheeler (ETW) battery enclosures using FMMEA and FEM analyses. Materials like AL6061, Steel and Teflon are evaluated under static, dynamic, and thermal loads.

1.1 Different kinds of battery brackets are available in the market

1.1.1. Universal Car Battery Bracket:

Universal Car Battery Holder allows you to use different sizes of batteries depending on how much power they provide. It's made from durable plastic and can handle temperatures ranging from 0°F to 140°F. Its design makes installation easy as well as removal simple. Simply loosen the four screws located around the perimeter of the unit, lift the cover plate, insert the desired battery into the slots provided, and reattach the cover plate.

1.1.2. Single Size Car Battery Brackets:

A single-size battery holder will fit most vehicles that require a single type of battery. Since these units come pre-assembled, you don't even have to worry about drilling or cutting anything. All you have to do is remove the old battery by loosening the retaining nut, slide the new battery into position, and re-tighten the nut. Some models may be equipped with an additional set of locking tabs that help prevent the battery from slipping during transport.

1.1.3. Dual Sized Car Battery Brackets:

If you need a versatile solution with dual sizing functionality, the Dual-Sized Car Battery Bracket is an ideal choice. Designed with two sets of mounting slots, it allows for quick and easy switching between standard and high-voltage batteries eliminating the need to purchase multiple brackets. Simply align the appropriate slot with your battery type before installation. The bracket comes with all the necessary mounting hardware, ensuring a hassle-free setup. Once installed, there's no need to worry about loose components each bolt can be securely tightened using the included wrench, providing a stable and reliable fit every time.

2. Methods and Material

To achieve this, a 3D CAD model of the existing battery bracket will be created based on standard specifications. Various design ideas and parts from past studies will be compiled to develop a comprehensive understanding of design approaches and materials used. The collected data will then be analyzed and categorized to identify critical design attributes. Using ANSYS software, modal analysis of the current bracket will be performed to evaluate its dynamic behavior under operating conditions. Results from the finite element analysis (FEA) will be compared with previous studies to validate the model. Based on this evaluation, suitable baseline materials and advanced composite alternatives will be selected to guide future improvements in battery bracket design.

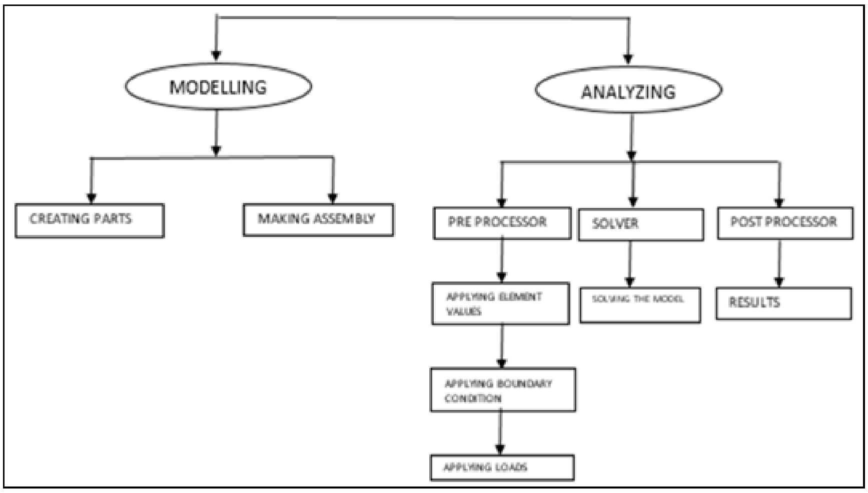

Figure 2: Flow chart of methodology for the bracket

Battery trays for four-wheelers are typically made from various materials, including:

1) Aluminum: Commonly used due to its durability and resistance.

In the automotive industry, aluminium is highly valued for its ability to enhance NVH (Noise, Vibration, and Harshness) performance. The material's low density helps reduce vehicle weight, improving fuel efficiency while also contributing to a quieter ride. Aluminium's good damping characteristics allow it to absorb vibrations, reducing noise transmission through body panels and chassis components. The material's strength-to-weight ratio enables the design of rigid yet lightweight parts, which helps control road noise and vibrations. Aluminium's excellent corrosion resistance also ensures that its NVH properties remain consistent over time, preventing material degradation that could lead to increased noise and vibration.

2) Structural Steel:- Offers high strength-to-weight ratio and corrosion resistance.

A In the automotive industry, structural steel plays a crucial role in managing NVH (Noise, Vibration, and Harshness) due to its high strength and durability. Steel's stiffness and rigidity help reduce the transmission of vibrations through the vehicle's frame, contributing to a more stable and quieter ride. Although heavier than aluminium, steel's dense structure can help lower the frequency of vibrations, particularly in components like the chassis, suspension systems, and body-in-white. Steel can be tailored with different alloying elements to enhance its performance in NVH applications, offering a balance of strength, toughness, and resistance to fatigue.

3) ABS (Acrylonitrile Butadiene Styrene): Known for its strength and impact resistance.

ABS has strong structural stiffness and dimensional stability in addition to impact resistance, which is important for parts that need to hold their shape and functionality over time. Because of these characteristics, ABS brackets can sustain the weight of the battery even in the face of constant stress or temperature cycling that is frequently encountered in automotive settings without buckling or losing their structural integrity. ABS's lightweight design is another advantage, supporting the automobile industry's continuous attempts to reduce vehicle bulk for improved fuel economy and, in the case of electric vehicles, longer battery life. ABS delivers significant weight savings over conventional metal brackets without sacrificing battery support system functionality.

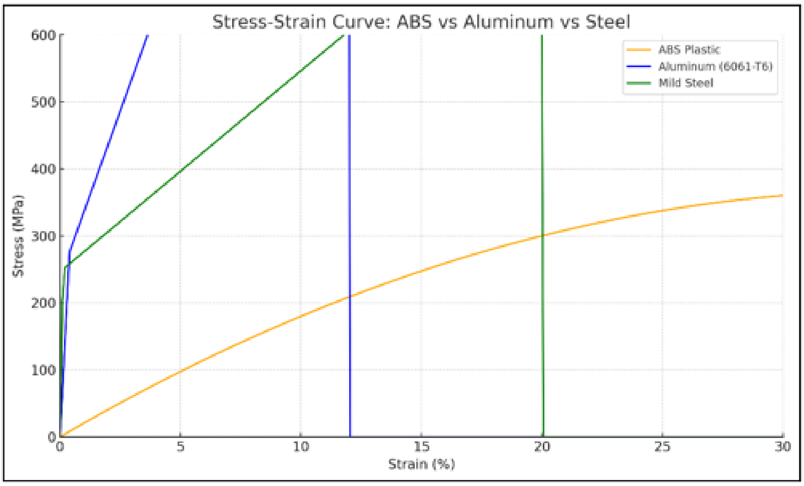

Figure 3: Stress Strain Curve

3. Results and Discussion

Modal analysis is a technique used in engineering to study and understand the dynamic behavior of a structure when subjected to vibrational forces. It identifies the natural frequencies at which a structure resonates, the mode shapes that describe how the structure deforms at each frequency, and the damping characteristics that determine how quickly vibrations subside. This analysis is essential because every physical object has a set of natural frequencies, and if external vibrations match these frequencies, it can lead to resonance, causing excessive movement or even structural failure.

In practical applications, modal analysis is performed using computational tools like ANSYS through Finite Element Analysis (FEA). It is especially important in industries such as automotive, aerospace, and civil engineering, where components are exposed to dynamic loads. For instance, in vehicle design, components like battery brackets must be tested for their response to road-induced or engine-induced vibrations.

$$\{F\} = [K]\{u\} \qquad (1)$$

Where
$\{F\}$ = External force matrix,
$[K]$ = Global stiffness matrix
$\{u\}$ = Displacement matrix.

Modal analysis of an ABS battery bracket for a four-wheeler is a crucial step in assessing its dynamic behavior under operational conditions. It involves determining the natural frequencies and mode shapes of the bracket to identify how it responds to vibrational loads. Since ABS plastic is lightweight and commonly used for such components, understanding its vibration characteristics helps prevent resonance. Resonance can lead to amplified vibrations, which may cause premature failure or damage to the bracket and surrounding parts. The analysis is typically performed using Finite Element Analysis (FEA) tools like ANSYS or Abaqus. Accurate boundary conditions and material properties are essential for reliable results. The outcome helps in optimizing the design to ensure structural integrity and noise reduction. It also contributes to enhancing ride comfort and system reliability in vehicles. By identifying critical frequencies, engineers can modify geometry or add damping. Overall, modal analysis ensures the bracket's performance meets safety and durability standards.

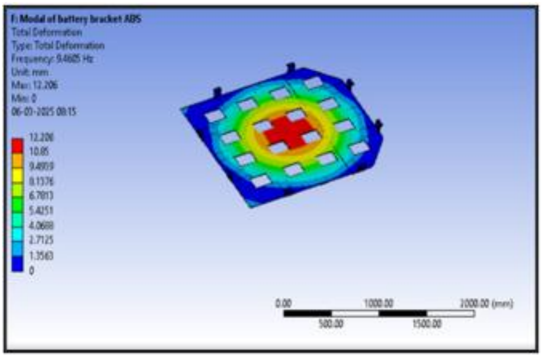

Figure 4 Mode Shape 1

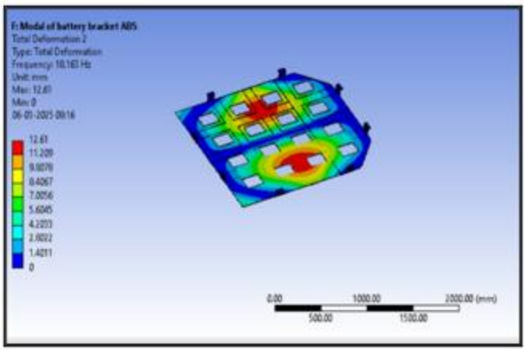

Figure 5 Mode Shape 2

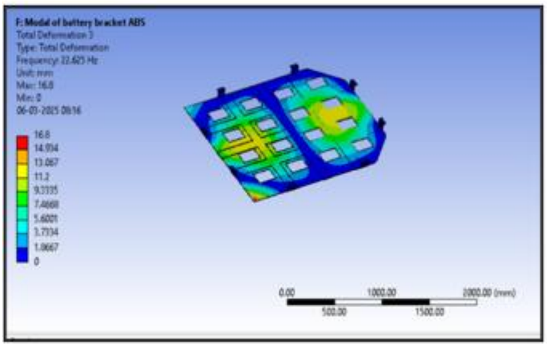

Figure 6 Mode Shape 3

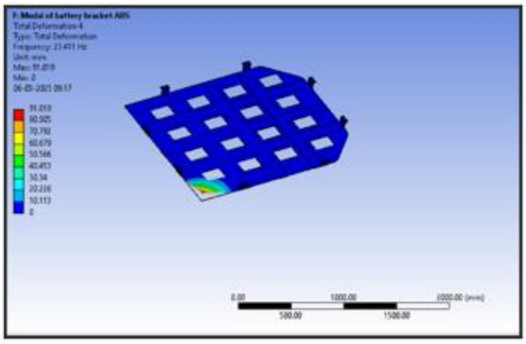

Figure 7 Mode Shape 4

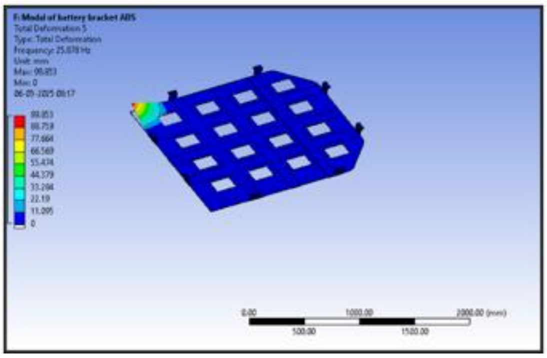

Figure 8 Mode Shape 5

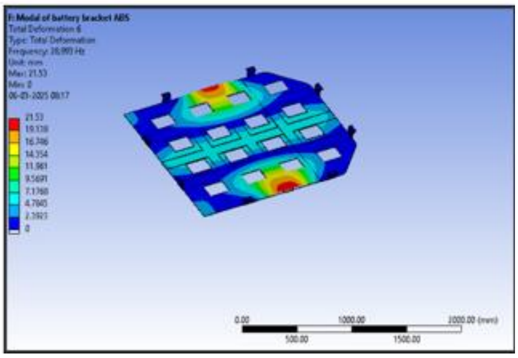

Figure 9 Mode Shape 6

1) **Figure 4:** Mode 1 (9.46 Hz):
   This is the first and most flexible mode, typically showing large global bending of the bracket. It indicates low overall stiffness and should be evaluated for resonance risk with engine or road vibrations.
2) **Figure 5:** Mode 2 (18.16 Hz):
   This mode likely shows torsional deformation or rocking about the mounting points. It suggests areas that may benefit from improved lateral or diagonal stiffness.
3) **Figure 6:** Mode 3 (22.62 Hz):
   Involves combined bending and twisting, often affecting side arms or extensions of the bracket. This may highlight stress concentrations at joint or weld locations.
4) **Figure 7:** Mode 4 (23.41Hz):
   This mode may be localized near specific features like bolt holes or cutouts. A slight increase in frequency suggests minimal added stiffness over Mode 3.
5) **Figure 8:** Mode 5 (25.87 Hz):
   The bracket starts to display more complex vibrational behavior, likely involving cross-bracing or diagonal elements. Reinforcement in load-carrying paths can raise this mode further.
6) **Figure 9:** Mode 6 (28.99 Hz):
   This high-frequency mode reflects the bracket's stiffest regions. It may involve minor vibrations in localized components or interactions with the vehicle frame.

4. Conclusions

This study of the vibration characteristics of the battery bracket in electric vehicles. Initially, a 3D model is constructed, and then ANSYS is used to perform static and modal analyses on the model.

The modal analysis of the battery bracket reveals its natural frequencies and vibration modes, which are crucial for ensuring structural integrity and performance.

The static analysis complements this by assessing the bracket's load-bearing capacity under various operational stresses, ensuring it can withstand the applied forces. Together, these analyses provide essential insights for optimizing the design, enhancing durability, and ensuring the overall reliability of the battery bracket in its intended application.

The fact that a thermoplastic like ABS, when optimized, shows reasonably low deformation under the applied load (as indicated by FEA) suggests its potential suitability for battery bracket applications, especially where weight reduction is a key design driver. However, further analysis of stress levels and long-term durability would be necessary.

Conflict of Interest

The authors declare no conflicts of interest and authors have no relevant financial or non-financial interests to disclose.

Authors Contribution

Authors are encouraged to provide an author statement file describing their specific contributions to the article using the appropriate author contribution roles to increase transparency. The corresponding author is responsible for ensuring that all authors agree on the accuracy of the descriptions. Authors equally contributed to this work.

Ethics

There are no ethical issues with the publication of this manuscript.

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