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From Concept to Road: A Review of Chassis Design for Electric Vehicles

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Abstract

The automotive industry is undergoing a rapid transformation propelled by the electric vehicle (EV) revolution, with the chassis serving as a pivotal element. In this study, chassis designs the unique characteristics of electric vehicles. The traditional internal combustion engine (ICE) chassis is being redefined to optimize performance, safety, and efficiency for electric propulsion systems. The absence of a traditional engine and the integration of electric motors pose new challenges and opportunities for chassis engineers. Weight distribution, structural integrity, and aerodynamics become paramount considerations to ensure optimal handling, efficiency, and safety in electric vehicles. The evolution of electric vehicle chassis design focuses on maximizing the benefits of electric vehicles. Lightweight materials, strategic placement of battery components, and aerodynamic enhancements are integral aspects of modern electric vehicle chassis. The chassis plays a crucial role in supporting the overall efficiency and performance of electric vehicles, contributing to extended driving range, enhanced acceleration, and improved energy utilization.

Keywords: Internal combustion engine, electric vehicle, rechargeable batteries, energy transformation, battery integration, fossil fuels, 3D printing

INTRODUCTION

Electric vehicles (EVs), which provide a greener and more sustainable option to conventional gasoline-powered cars, are drastically altering the transportation environment. EVs are cars that run on one or more electric motors rather than a petrol engine. Rechargeable batteries, which they use to power the motors and supply the necessary energy for driving, store energy. EVs are a major factor in lowering air pollution and greenhouse gas emissions because they emit no tailpipe emissions, in contrast to gasoline-powered cars. The chassis of an electric vehicle serves as the backbone for the remarkable efficiency and environmental friendliness of electric propulsion systems, representing the heart of the vehicle's clean energy transformation. In stark contrast to traditional combustion engines relying on fossil fuels, electric vehicle chassis, powered by electric motors, contribute to environmental health by eliminating the need for fuel combustion.

Beyond their environmental benefits, electric motors embedded in the chassis redefine the driving experience, offering immediate torque for exhilarating acceleration without the need for traditional engine revving. The efficiency of electric motors, converting nearly 90% of energy into power, far surpasses the 30–40% conversion rates of combustion engines. This heightened efficiency extends beyond performance, resulting in increased driving range and reduced energy consumption. The characteristic quietness of electric motors replaces the familiar roar of combustion engines, contributing to a more serene driving experience. Additionally, electric motors enhance comfort by

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recovering energy during braking and redirecting it back to the battery, further optimizing the vehicle's range. The lightweight and compact nature of electric motors provides designers with unprecedented creative freedom for the chassis. This versatility translates into improved handling, well-balanced weight distribution, and spacious, aesthetically pleasing car interiors. Furthermore, electric vehicle owners benefit from reduced maintenance costs and time, thanks to the simplified and less intricate nature of electric motor components.

LITERATURE REVIEW

Research in Electric Vehicle (EV) chassis design encompasses lightweight materials, crashworthiness improvements, battery integration, and advanced manufacturing techniques. Researchers explore structural optimization, employing composites and high-strength materials for weight reduction. Safety remains a priority, with studies focusing on meeting crashworthiness standards [1–8]. Battery integration into chassis structures and the concept of structural batteries are subjects of active investigation. Advanced manufacturing, including 3D printing, is explored for complex geometries and optimized structures through the references [9–14]. Smart and adaptive chassis systems, regenerative braking, and lifecycle analyses contribute to overall efficiency. Connectivity features are increasingly integrated for real-time monitoring and predictive maintenance in the evolving landscape of EV chassis research [15]. Moreover, a growing emphasis on energy recovery and regeneration explores capturing and utilizing energy during dynamic events like braking. Researchers address sustainability concerns with lifecycle analyses, assessing environmental impacts from material extraction to recycling [16, 17]. Connectivity innovations integrate sensors and data analytics for real-time monitoring, predictive maintenance, and performance optimization in EV chassis.

Ladder frame

A ladder frame chassis for electric vehicles (EVs) serves as the structural foundation of the vehicle, providing support, stability, and accommodating key components such as the electric motor, battery packs, and other essential systems. The design of the ladder frame chassis is characterized by longitudinal rails resembling a ladder, creating a robust and durable framework as shown in Figure 1. Table 1 shows the specifications of ladder chassis.

Structural Integrity

Provide a robust and durable structure to support the weight of EV components, particularly battery packs.

Weight Distribution

Ensure effective distribution of weight along the length for stability and optimized handling.

Flexibility in Design

Enable diverse body styles and configurations for a range of EV models.

Figure 1. Ladder frame chassis of electric vehicle.

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Integration of Electronic Components

Seamlessly integrate electric motor and battery packs to optimize drivetrain efficiency.

Enhanced Safety

Leverage inherent strength to absorb and distribute impact forces, enhancing occupant safety.

Weight and Efficiency

Ladder frames are typically heavier than alternatives like unibody structures. In EVs, minimizing weight is crucial for optimizing energy efficiency and extending the driving range. The added weight can counteract the benefits of electric propulsion systems.

Space Utilization

Ladder frames may limit space utilization, especially when accommodating batteries in EVs. Effective battery integration becomes challenging, potentially reducing the overall capacity and performance of the electric powertrain.

Handling and Dynamics

The inherent design of ladder frames, with separate chassis and body components, can result in compromised handling and dynamics, affecting the overall driving experience. This can be particularly noticeable in comparison to more modern and integrated chassis designs.

Adaptability to EV Architecture

Ladder frames may not be inherently well-suited for accommodating the unique requirements of EV architecture, including the distribution and cooling of batteries, motor placement, and the need for aerodynamics to enhance efficiency.

Manufacturing Complexity

The manufacturing process for ladder frames can be simpler compared to certain other chassis types. However, adapting this traditional approach to meet the specific demands of EVs might require additional engineering and design considerations, potentially increasing manufacturing complexity.

Cost Considerations

Implementing ladder frames in EVs may involve additional costs related to optimizing the chassis for electric propulsion, battery integration, and ensuring safety standards are met. This could affect the overall cost-effectiveness of the vehicle.

FEA is applied to this basic design in order to check to see if it satisfies the requirements for acceptance. After that, the design is further altered by adding lightweight cross members. Chassis built of different materials is modified to make it lighter until the design satisfies the requirements for approval. The ultimate chassis chosen is optimized through thickness optimization to minimize weight. The design is feasible if the thickness optimization for the selected chassis is successful. As a result, the improved chassis' approval criteria are verified again. Should the thickness optimization not work, the design is deemed unworkable as a chassis. Therefore, the chassis is rebuilt. The entire procedure starts with post-processing, continues with thickness optimization, and ends with verifying acceptance criteria to ensure the chassis design is workable.

Comparison of Ladder frame with other types of Chassis

The characteristics of the ladder chassis for different parameters are mentioned in Table 1. Comparison of Ladder frame could be easily understood by the table presented in Table 2.

DIFFERENTIAL AXLE

In Electric Vehicles (EVs), the differential axle is pivotal for distributing torque from the electric motor to the wheels, facilitating varying wheel speeds during turns. Traditional open differentials, common in EVs, evenly distribute power but may face traction challenges. Some EVs incorporate Limited-Slip Differentials or electronic differentials for enhanced performance and stability. Torque vectoring systems, prevalent in electric drivetrains, optimize handling by adjusting torque to specific wheels. Advanced setups, such as direct-drive axles, can eliminate traditional differentials. Overall, differential design in EVs evolves for efficiency, improved handling, and compatibility with diverse driving conditions. Vehicle axles come in various types, each serving distinct functions. One example is shown in Figure 2. Dead axles provide support without propulsion, live axles receive power, tandem axles distribute weight, portal axles enhance ground clearance, and independent suspension axles improve ride comfort.

Table 1. Specification of Ladder Chassis.

S. No.	Parameter	Value	Unit
1	Front Overhang	400	mm
2	Rear Overhang	250	mm
3	Wheelbase	1500	mm
4	Width of Chassis Rails	50	mm
5	Length of Chassis	2500	mm
6	Body Weight	1.5	N

Table 2. Comparison of Ladder frame with other types of Chassis.

S. No.	Features	Ladder Frame chassis	Monocoque chassis	Space Frame Chassis	Unibody Chassis
1	Structural Design	Longitudinal rail interconnected by cross members	Single-unit structure providing both body and chassis	Tubular space frame with interconnected members	Integrated body and chassis structure
2	Weight	Heavy	Light	Light	Moderate
3	Rigidity	Less rigid	Highly rigid	Moderate	Moderate
4	Manufacturing Complexity	Simple	More complex	Moderate complexity	Moderate complexity
5	Handling and Stability	Less stable in dynamic condition	Improved stability and handling	Good handling	Balanced handling
6	Common Application	Trucks, SUVs	Passenger car, some SUVs	Performance and racing cars	Passenger cars, some SUVs
7	Repair and maintenance	Easy	Difficult	More difficult	Moderate difficulty
8	Cost	Cost effective	More costly	High cost	Moderate cost

Figure 2. Differential axle.

Steering System

The steering system in Electric Vehicles (EVs) is a critical component responsible for controlling the direction of the vehicle. Most EVs use electric power steering (EPS) systems. EPS replaces traditional hydraulic systems with an electric motor, enhancing energy efficiency and allowing for dynamic adjustments based on driving conditions. This technology contributes to overall EV efficiency, reduces energy consumption, and facilitates the integration of advanced driver assistance features. Additionally, some EVs incorporate steer-by-wire systems, eliminating physical connections between the steering wheel and wheels for more flexibility in design and automated driving capabilities. Steering systems in Electric Vehicles (Figure 3) primarily utilize electric power steering (EPS), enhancing energy efficiency and enabling dynamic adjustments. Regenerative steering recovers energy during steering maneuvers. Variable-assist-steering tailors assistance levels, while drive-by-wire systems eliminate mechanical links for flexible control.

BLDC MOTOR

Brushless DC (BLDC) motors play a pivotal role in Electric Vehicles (EVs), providing numerous advantages for efficient and reliable propulsion. One BLDC motor is shown in Figure 4. Renowned for their high efficiency, BLDC motors enhance the overall performance of EVs, contributing to improved acceleration and power-to-weight ratios. Their regenerative braking capability further boosts energy efficiency by converting kinetic energy back into electrical energy. The reliability and durability of BLDC motors, attributed to their minimal wear and tear, results in reduced maintenance requirements, extending the operational life of EVs. Operating silently, these motors enhance the driving experience, emphasizing comfort and quiet operation. Sinusoidal control of BLDC motor is shown in Figure 5.

Ladder Frame of EVs

The establishment of stringent quality standards in India ensures the production of ladder frame chassis with consistent and high-quality manufacturing practices. The ladder frame chassis presents distinct advantages over alternative chassis designs. Its structural characteristics contribute to superior load-bearing capabilities, optimal weight distribution, enhanced durability, and effective absorption of external forces. Economically, electric vehicles are suitable as the cost for designing could be estimated as per the parts price involved in Table 3.

Figure 3. Steering system.

Figure 4. BLDC Motor.

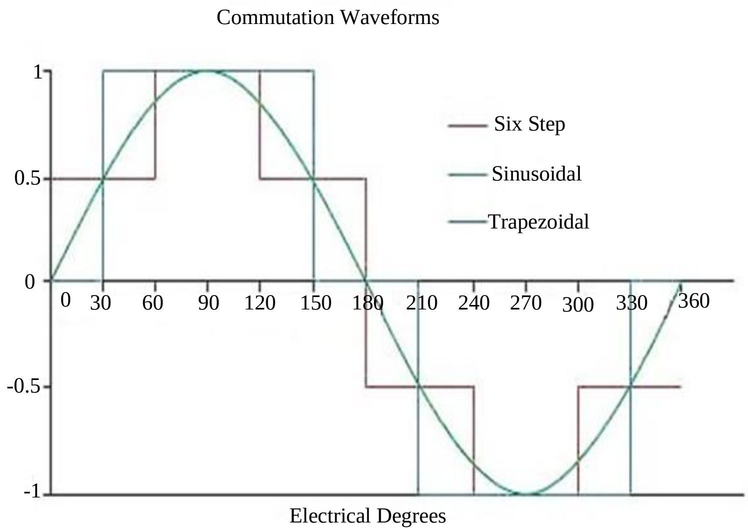

Figure 5. Sinusoidal Control BLDC Motor.

Table 3. Cost analysis of Electric Vehicle.

S. No.	Component	Quantity	Amount (Rs)
1.	1500 W Motor	1	17950
2.	1500 W Motor Controller	1	10600
3.	42” Differential	1	13000
4.	Paddle Throttle	1	1424
5.	Handbrake	1	325
6.	Wiper Motor Set	1	1624
7.	Suspension	4	13000
8.	Steering set	1	12000
9.	DC to DC Power Converter	1	2800
10.	12 mm wiring Harness		2500
11.	Axle Set (front)	1	12000

The ladder frame chassis design excels in applications where robust construction is paramount, providing a stable platform for various industries such as automotive, aerospace, consumer goods, medical equipment, instrumentation, and automation. This commitment to quality not only safeguards reliability but also enhances the overall performance of products utilizing the ladder frame chassis. The design and development of ladder frames for Electric Vehicles (EVs) could focus on several key areas to enhance their performance, efficiency, and overall sustainability. Here are potential directions for future research and improvements in ladder frames for EVs:

Material Innovations

- Explore advanced lightweight materials with high strength and durability to reduce the overall weight of the ladder frame. This can contribute to increased energy efficiency and extended driving range for EVs.
- Investigate the use of composite materials and alloys to strike a balance between strength and weight, addressing both safety and efficiency concerns.

Structural Optimization

- Utilize advanced simulation and optimization techniques to refine the design and structural layout of the ladder frame. This can lead to improved load distribution, enhanced rigidity, and better crashworthiness.

- Implement topology optimization to identify areas where material can be strategically added or removed for optimal strength and weight characteristics.

Integration of Battery Technology

- Research ways to integrate the ladder frame with the EV's battery system for improved space utilization and weight distribution.
- Explore innovative methods for incorporating structural batteries or integrating battery cells directly into the ladder frame structure.

Smart and Adaptive Chassis Systems

- Develop adaptive chassis systems that can dynamically adjust the frame's characteristics based on driving conditions, load, and performance requirements.
- Implement advanced sensor technologies and machine learning algorithms to optimize the chassis in real-time for improved handling, comfort, and energy efficiency.

CONCLUSION

In conclusion, the ladder frame chassis presents distinct advantages over alternative chassis designs. Its structural characteristics contribute to superior load-bearing capabilities, optimal weight distribution, enhanced durability, and effective absorption of external forces. The ladder frame chassis design excels in applications where robust construction is paramount, providing a stable platform for various industries such as automotive, aerospace, consumer goods, medical equipment, instrumentation, and automation.

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