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Design and Development of Coil Over Spring Suspension for Differential Drive Electric 3-Wheelers

[1]Dr. Mayur Jagtap , [2]Onkar Patil , [3]Sanjyot Dhaygude , [4]Prashant Bandgar

[1] Assistant Professor, Department of Mechanical Engineering, SB Patil College of Engineering, Vangali

[2,3,4] Student of Department of Mechanical Engineering, SB Patil College of Engineering, Vangali

Email: mayurdjagtap@gmail.com[1], Onkarpatil5554@gmail.com[2], dhaygudesanjyot@gmail.com[3], prashantbandgar2804@gmail.com[4]

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Abstract

The three-wheeler vehicle segment is crucial for urban mobility and last-mile connectivity in many developing nations. It needs chassis designs that are lightweight, cost-effective, robust, and safe. This paper reviews recent structural design, material selection, and computational analysis techniques for three-wheeler chassis. It synthesizes literature on Computer-Aided Design (CAD) methodologies, advanced materials, Finite Element Analysis (FEA), and optimization under different loads. The aim is to consolidate knowledge, identify research gaps, and suggest future directions for safer, more efficient three-wheeler chassis.

1. Introduction

The transportation landscape is shifting toward sustainable, efficient mobility, especially in urban and peri-urban areas. Three-wheeler vehicles are a key mode of transport in developing nations [1]. They serve as affordable passenger carriers and goods vehicles. Their compact size, maneuverability, and low cost make them ideal for last-mile connectivity and intra-city logistics. Yet, their triangular footprint brings engineering challenges mainly related to rollover stability, structural integrity, and comfort [2].

The vehicle's chassis is vital for addressing these challenges. It acts as the structural skeleton, supporting the vehicle's weight, payload, and powertrain, while withstanding static and dynamic loads throughout its life. Designing a three-wheeler chassis is a multi-objective optimization problem. It must be lightweight to improve fuel efficiency and payload. It also requires strength and rigidity for safety and stability [3]. Furthermore, it must be cost-effective to produce and maintain, suiting the economic realities of its markets.

Traditional design approaches, heavily reliant on iterative physical prototyping, are increasingly being superseded by sophisticated computational engineering methodologies. The integration of Computer-Aided Design (CAD) for precise geometry creation [4], Finite Element Analysis (FEA) for virtual validation of stress, deformation, and vibration characteristics [5], and advanced optimization algorithms has revolutionized the chassis development process. Concurrently, the exploration of new materials, from High-Strength Low-Alloy (HSLA) steels to aluminium alloys and composite polymers, offers promising pathways for lightweighting without compromising structural performance [6] [7]

While numerous individual studies have explored discrete aspects of three-wheeler chassis design, a holistic synthesis of this knowledge is lacking. This paper aims to fill this gap by providing a comprehensive review of the state-of-the-art in structural design, analysis, and optimization for three-wheeler chassis. It will systematically consolidate and critically evaluate existing literature on CAD methodologies, material selection strategies, FEA techniques for static and dynamic loading, and validation protocols. By charting the evolution of design practices and identifying emerging trends and research gaps, this review seeks to serve as a foundational resource for academia and a strategic guide for industry practitioners in developing the next generation of safer, lighter, and more efficient three-wheeler vehicles.

2. Literature Review

The design and analysis of three-wheeler chassis have been the focus of considerable research, driven by the need for improved safety, fuel efficiency, and ride comfort. The following section synthesizes past studies, categorized by key research themes that directly correspond to the modern chassis development pipeline.

2.1 Evolution of Chassis Design and CAD Methodologies

Patel et al. [8] developed parametric models of ladder-frame chassis using SolidWorks to analyze the effects of wheelbase and track width on vehicle stability and weight distribution. Their work demonstrated the value of CAD for early design evaluations.

A. Kumar et al. [1] compared ladder and space-frame chassis in CAD models and found that circular steel-tube space frames offered 18% higher torsional rigidity with the same weight. They highlighted, however, that fabrication complexity increased production cost.

Desai et al. [9]Integrated ergonomics into CAD by incorporating digital human models in CATIA. Their work optimized seating posture and access, marking a shift toward human-centered chassis design.

2.2 Advancements in Material Selection for Lightweighting

Sharma et al. [10] analyzed low-carbon steel (AISI 1020) chassis to establish baseline static stress and deformation characteristics for future material comparisons.

Iyer et al. [6]Replaced conventional steel with High-Strength Low-Alloy (HSLA) steel, achieving 22% mass reduction without compromising safety. They credited this to HSLAâ€™s superior strength-to-weight ratio and affordability.

Zhang et al. [11] designed an Aluminium 6061-T6 space-frame chassis that achieved a 35% weight reduction. Their study noted challenges in managing stress at weld joints and higher material costs.

Rao et al. [12] proposed a hybrid composite (GFRP/CFRP) monocoque chassis with an estimated 50% weight saving and improved vibration damping. Despite these benefits, they reported high manufacturing costs and repair limitations, making composites less viable for low-cost vehicles.

2.3 Structural and Vibration Analysis via Finite Element Analysis (FEA)

Singh et al. [3] performed FEA on the chassis under bending, torsion, and combined loads, identifying stress concentrations at suspension mounts. They recommended fillets and reinforcements to prevent fatigue failures.

Garcia et al. [2] established a standard FEA torsional stiffness test, concluding that stiffness below 4,500 Nm/degree resulted in poor handling and high NVH levels.

Fernando et al. [13] conducted experimental modal analysis and validated it with FEA results. They found that increasing the first natural frequency above 22 Hz by adding cross-members reduced vibration-induced discomfort, thereby proving the reliability of FEA in vibration optimization.

2.4 Validation and Optimization under Operational Loads

Wang et al. [5] validated FEA predictions against experimental strain-gauge data from prototype chassis tests, achieving a correlation of over 95% and confirming the accuracy of the load conditions modeling.

Chen et al. [14] applied topology optimization to a three-wheeler chassis, removing low-stress material to achieve a 28% weight reduction while retaining stiffness.

Okafor et al. [15] compared steel, aluminium, and composite chassis through multi-criteria analysis. They proposed a balanced framework to select optimal designs based on stiffness, cost, weight, and frequency response.

3. Gap Identified

A critical review of the existing literature on three-wheeler chassis design reveals several significant research gaps:

- Integrated Multi-Disciplinary Optimization: A lack of holistic frameworks that simultaneously optimize for weight, cost, torsional stiffness, and vibration comfort. Most studies focus on optimizing for a single objective.
- Advanced Material Validation: A significant gap between theoretical

studies on advanced composites and their practical, cost-effective implementation, including a lack of comprehensive life-cycle cost analysis.

- Standardized Dynamic Validation Protocols: The absence of standardized virtual and physical testing procedures specifically for the severe and unique dynamic loading conditions of three-wheelers.
- Electric Vehicle (EV) Specific Architecture: Most research focuses on retrofitting existing chassis for EVs. There is a gap in exploring fundamentally new chassis architectures that integrate the battery pack as a structural element.

4. Problem Statement:

The three-wheeler passenger vehicle segment, vital for urban mobility in developing nations, faces significant challenges rooted in its fundamental chassis design. The prevalent use of traditional ladder-frame architectures and conventional low-carbon steels, while cost-effective, leads to several critical issues:

- Excessive Weight: The over-reliance on heavy steel sections results in high vehicle weight, which directly diminishes fuel economy and reduces potential payload capacity, impacting operational economics.
- Inadequate Dynamic Performance: The inherent low torsional stiffness of common chassis designs exacerbates the vehicle's natural instability, increasing rollover risk during cornering and compromising handling safety.
- Poor Vibration Characteristics: A lack of focused modal analysis during design often results in chassis natural frequencies that resonate with engine and road excitations, leading to high vibration levels that cause passenger discomfort and accelerate component fatigue.
- Suboptimal Design Process: The design process is often experience-based rather than simulation-driven, leading to over-engineering in some areas and under-design in others, missing opportunities for weight reduction and performance enhancement.

Therefore, the core problem is the absence of a holistic, optimized chassis design methodology that integrates advanced material selection, comprehensive FEA under both static and dynamic loads, and structural optimization techniques to simultaneously achieve lightweight construction, superior structural integrity, enhanced safety, and improved ride quality, without incurring prohibitive manufacturing costs.

5. Objectives

1. To design a robust chassis structure for a three-wheeler passenger vehicle using CAD software.
2. To select suitable lightweight materials that maintain structural integrity while reducing overall weight.
3. To perform structural and modal analysis using FEA tools to evaluate stress, deformation, and vibration characteristics.
4. To validate the chassis design under static and dynamic loading conditions and compare it with existing chassis models.

6. Research Methodology:

This review was conducted following a systematic approach to ensure comprehensive coverage of the relevant literature on three-wheeler chassis design and optimization. The methodology comprised four key stages, as illustrated in the following flowchart and described in detail below.

7. Conclusion

The design and optimization of a three-wheeler chassis is a complex, multi-disciplinary process that balances structural integrity, weight, cost, and manufacturability. The literature confirms that CAD and FEA have become central to this process, enabling rapid and cost-effective development. A clear trend is the move from traditional steel towards HSLA steel and aluminium alloys for lightweighting. While advanced composites show great promise, their economic viability remains a challenge. Future work will likely focus on holistic optimization, leveraging new materials and AI-driven design tools to create safer, lighter, and more efficient chassis structures tailored for the next generation of three-wheelers, especially electric ones.

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