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

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Abstract

This paper presents a comprehensive review of coil-over spring suspension systems and their suitability for electric three-wheeler vehicles with a rear differential configuration. The objective is to analyze existing literature on coil springs, coil-over shock absorbers, and their structural and dynamic performance to determine their advantages, limitations, and potential adaptations for electric three-wheelers. Studies indicate that coil-over suspensions offer improved ride comfort, stability, and tunability compared to conventional leaf-spring setups. The review also highlights optimization methods, fatigue analyses, and regenerative technologies that can be integrated with coil-over systems for enhanced efficiency in electric vehicles.

Introduction

Suspension systems are critical for ride comfort, stability, and handling of vehicles. In small electric vehicles (EVs) such as three-wheelers, design complexity increases due to space constraints and the presence of a rear differential with an in-built motor. Traditionally, most three-wheelers have used leaf springs for their simplicity and cost effectiveness. However, the coil-over spring suspension system is gaining attention for its compactness, comfort, and tunability.

Coil-over suspension integrates a helical coil spring and damper into a single assembly, allowing independent adjustment of damping and stiffness. This configuration offers superior ride quality and reduced vibration transmission — making it highly suitable for lightweight electric vehicles.

Literature Review

This part of the car suspension system uses the spring over coil explained by spring parameters shown by the Pravain Gosavi [1] that focuses on spring parameters and their influence on the ride and comfort. This review paper surveys the principles, types, materials, manufacturing techniques, and performance considerations for coil springs in suspension systems. It discusses stress, fatigue, dimensional design issues, and compares methods of optimization. The review also identifies research gaps and recommendations for future development.

Rahman and Abdullah [2] explained the optimization of coil spring using experimental and numerical analysis that helps to identify coil dimensions. This work presents numerical and experimental investigations into the optimization of coil springs for vehicle suspensions. It analyses stiffness, deflection, and shear stress under different loading conditions, validates theoretical models against experiments, and provides design insight into achieving optimal balance between ride comfort and mechanical performances.

C. Hao et al. [3] states durability and fatigue analysis of coil springs. Hao et al. characterize strain signals in time, frequency, and time-frequency domains to predict fatigue life of coil springs. They apply Rain flow cycle counting, FFT, and wavelet transforms to identify dominant frequency bands and estimate durability, offering strategies for selecting appropriate signal processing for fatigue assessments.

R.Burdzik [4] explains the influence of suspension stiffness on vibration propagation. Found that optimal stiffness reduces vibration transmission by up to 20% improving comfort and chassis integrity. Burdzik investigates how the stiffness parameters of coil springs affect vibration transmission through a vehicle's structure. The study uses selective multi-criteria frequency-band analysis on real suspension components, quantifies vibration transmission to passengers, and proposes engineering guidance for suspension design and diagnostics.

Zhang et al [5] stated review of regenerative shock absorber systems. It discusses system topologies, energy recovery mechanisms, control strategies, efficiency metrics, challenges, and potential applications. It highlights future directions in energy-harvesting suspension technology.

Seema Tiwari [6] showed survey on regenerative suspension. Tiwari et al. review literature on regenerative shock absorbers, summarizing approaches to harnessing vibration energy in vehicle suspensions. The survey covers design methods, power output estimates, integration challenges, control schemes, and the prospective role of regenerative systems in sustainable vehicle design.

A.M. Pathan &.K.M.Said [7] in 2025 stated that FEA analysis of coil spring for automotive vehicles also demonstrated reduction in stress concentration by 15% through optimized design and material selection. This paper presents the design of a suspension coil spring using analytical methods and finite element analysis (ANSYS), evaluating stress distribution, deformation behavior, and fatigue life under realistic load cases. It provides a methodology for achieving more reliable and efficient spring designs in emerging automotive applications.

H. H. Win et al. [8] showed Design and analysis of rear coil suspension system. Emphasizing structural support requirements for coil-over mounts in rear suspension. This work likely addresses the design and structural evaluation of a rear coil suspension assembly. It examines load paths, stress concentrations, displacement behavior, and optimization strategies for rear suspension springs in vehicles.

Salunkhe et al. [9] explains Review on helical springs in motorbike suspension which explained Comparison of various materials (steel, titanium alloy, composites) for lightweight, high-strength applications. This paper studies the behavior of helical springs used in motorcycle rear suspensions. It analyzes stress, deflection, and fatigue characteristics under typical duty cycles, compares theoretical predictions with experimental or simulation results, and suggests design modifications for improved longevity and ride quality.

Avinash et al. [10] explains General suspension system review in such a way that it Provides overview of passive, semi-active, and active suspension systems incorporating coil-over spring. This review provides an overview of vehicle suspension system design, including components like springs, dampers, linkages, and their interactions. It surveys methodologies for dynamic modeling, performance metric, recent advancements, and gaps for future research.

Limitations of existing system

The existing suspension system in most conventional three-wheelers relies on leaf springs, which, while economical and durable, have several drawbacks when used in modern electric vehicles. Leaf springs possess high unsprang weight, resulting in reduced ride comfort and handling precision. Their stiffness is not easily adjustable, leading to poor adaptability under varying load conditions. Additionally, they transmit more vibration and road shock to the chassis, which negatively affects passenger comfort and the structural integrity of the vehicle over time. The limited damping control of leaf springs further contributes to instability during cornering and uneven load distribution on the differential-mounted rear axle. Moreover, due to their size and weight, leaf springs restrict the compact design required in lightweight electric drivetrains. These limitations make the traditional system inefficient for e-mobility applications, where efficiency, comfort, and adaptability are of greater importance.

Problem statement

The Conventional suspension system used in most three-wheelers, particularly those employing leaf springs, fails to provide adequate comfort, stability, and performance for modern electric vehicles. With the integration of a differential and electric motor at the rear axle, the load distribution and dynamic behavior of the vehicle change significantly, leading to increased vibrations and reduced ride quality. Leaf springs, being heavy and non-adjustable, are not suitable for such configurations as they contribute to higher unsprang mass, poor shock absorption, and limited flexibility under variable load conditions. Therefore, there is a pressing need to design and implement a coil-over spring suspension system that can improve ride comfort, handling stability, and overall system efficiency while maintaining compactness and lightweight characteristics suitable for electric three-wheeler applications.

Research gap

Lack of Application-Specific Studies for 3-Wheelers:

Most existing suspension research focuses on four-wheel vehicles or two-wheelers. Very limited work has analyzed three-wheel electric vehicles, where asymmetric weight distribution and rear differential mounting introduce unique vibration and stability issues.

Insufficient Analysis of Coil-Over Integration with Differential Axles:

Studies on coil-over springs generally analyze standalone systems or single-axle configurations. There is a research gap in understanding how coil-over units perform when mounted on a differential axle, especially with variable torque from electric motors.

Neglect of Comfort vs. Efficiency Trade-Off in Electric Vehicles:

Most optimization models focus on structural strength or fatigue life, but few address the balance between ride comfort, spring stiffness, and battery efficiency in lightweight electric vehicles.

Material Optimization and Lightweight Design:

Existing studies primarily use conventional steel coil springs. There is limited experimental validation of composite or hybrid materials (e.g., glass fiber or carbon steel) that could reduce unsprang mass and improve comfort.

Integration with Regenerative or Semi-Active Suspension Systems:

Research on regenerative dampers and semi-active control is growing, but integration with coil- over mechanical systems in small EVs remains underexplored.

Experimental Validation on Rough or Mixed Terrains:

Simulation-based studies dominate existing literature. There's a clear need for experimental testing of coil-over systems on real-world Indian road conditions (potholes, bumps, uneven surfaces).

Optimization for Compact EV Packaging Constraints:

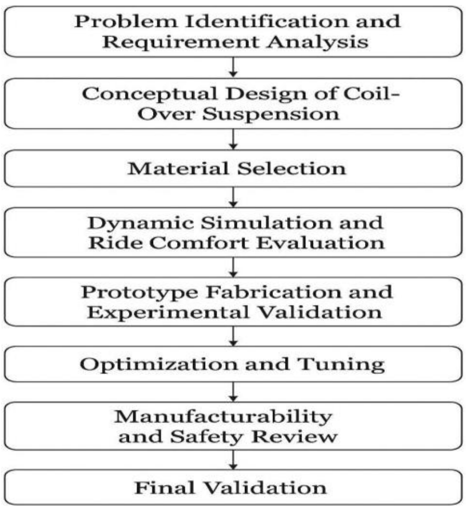
Small electric trikes have limited space between the chassis and axle housing. Few studies discuss compact coil-over designs that maintain adequate travel and damping performance in such constrained geometries.

Objectives

1. To review existing literature on coil-over spring suspension systems and their performance characteristics.
2. To evaluate the advantages of coil-over systems compared to traditional leaf spring suspensions for three-wheeled electric vehicles.
3. To identify design challenges faced in integrating coil-over suspensions with a rear differential and electric motor system.
4. To analyze research trends, optimization techniques, and material innovations related to coil-over suspension design.
5. To propose possible improvements and future research directions for implementing efficient, comfortable, and reliable suspension systems in lightweight electric vehicles.

Methodology

Methodology for the fabrication of coil over spring system includes making of design, modeling, simulation, and validation stages. The process ensures that the proposed suspension design Achieves optimal ride comfort, stability, and structural integrity while being suitable for the compact architecture of a differential-driven E-BIKE.



Conclusion

This review comprehensively examined the design evolution, performance analysis, and optimization potential of coil-over suspension systems for electric three-wheelers equipped with a rear differential mechanism. The findings demonstrate that coil-over springs can serve as a superior alternative to traditional leaf spring suspensions, offering significant improvements in ride comfort, vibration isolation, and overall handling stability. The integration of coil-over systems allows for independent tuning of spring stiffness and damping characteristics, thereby enabling better adaptability to varying road conditions and load distributions. From the literature reviewed, it is evident that most existing research has primarily focused on two-wheeler and four-wheeler suspension systems, with very limited studies addressing the specific mechanical and dynamic challenges of three-wheel electric vehicles. The unique geometry and asymmetric load transfer in tricycles require specialized suspension tuning to counterbalance uneven forces acting on the chassis and differential. Additionally, the rear-mounted electric motor and battery pack introduce extra unsprang mass, necessitating optimized suspension parameters to maintain stability without compromising comfort.

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