Innovative Suspension Design with Nested Helical Coil Springs for Improved Ride Comfort and Stability

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***Abstract*—This paper presents the design and analysis of a four-link suspension system incorporating nested helical coil springs for the rear axle of a military truck. Traditional leaf springs were replaced with a coil spring-based suspension to enhance wheel travel and improve off-road mobility. Detailed design calculations were carried out based on SAE spring design manuals and IS standards. A rigid axle of 7-ton capacity was adapted to a four-link suspension with two coil springs per side. The spring dimensions, stiffness, stress values, and fatigue life cycles were determined. Load distribution across suspension components was calculated, and a multi-body dynamic simulation was performed using MSC ADAMS/Car to analyze wheel travel and camber variations. Results demonstrated improved ride comfort, higher roll stiffness, and enhanced mobility in cross-country terrains.**

***Index Terms*—Four-link suspension, coil spring design, vehicle dynamics, MSC ADAMS, nested spring, heavy vehicle.**

I. INTRODUCTION

The development of suspension systems has played a vital role in advancing vehicle dynamics and passenger comfort. The first automobile powered by a steam engine was built in France by Nicolas-Joseph Cugnot in 1789. Later, in 1885, Daimler Benz introduced the first practical automobile using a four-stroke petrol engine in Germany. Over time, the need for enhanced mobility, ride comfort, and durability led to advancements in suspension systems. Suspensions are essential not only for ride comfort but also for protecting chassis and critical working parts from road shocks.A dependent suspension system generally employs a live axle, where both wheels remain parallel and perpendicular to the axle. In contrast, an independent suspension allows each wheel to move vertically without affecting the other, offering significant benefits in terms of comfort, control, and safety. Nearly all passenger vehicles and light trucks employ independent suspension due to improved ride quality and space optimization for engines. However, for heavy-duty and military vehicles, there is a growing need for suspension systems that balance strength with flexibility in off-road terrains. This study proposes the design of a four-link suspension system supported by nested helical coil springs to replace conventional leaf springs in a military truck. The objective is to improve wheel travel, off-road mobility, and load-bearing capacity while ensuring durability under fatigue loading.

II. LITERATURE REVIEW

Various studies have been conducted on vehicle suspension systems, focusing on the design, optimization, and dynamic performance of coil and multi-link suspensions. Timoney et al. (1988) presented work on heavy vehicle independent suspension, emphasizing improved mobility. Prior (1992) highlighted the role of multi-body system analysis in suspension design. Kami et al. (1984) and Murakami et al. (1989) investigated multi-link suspensions for passenger cars, while Shim and Velusamy (2007) explored lightweight vehicle suspension design. These studies establish the importance of suspension optimization in both comfort and durability. However, limited work has been done on the application of nested helical coil springs in four-link suspensions for heavy-duty vehicles, which this study addresses.

III. METHODOLOGY

The methodology involves spring design, material selection, calculation of stiffness and stress, life cycle estimation, four-link design, load distribution analysis, and multi-body dynamic simulation using MSC ADAMS/Car.

i Spring Design

Detailed design calculations were performed as per SAE spring design manual and IS standards. The material selected was IS GRADE 51CrMoV4 as per IS 3195:1992. Input data included total load, modulus of rigidity, tensile strength, spring index, and clearance factor. Dimensions such as wire diameter, mean diameter, pitch, and free length were determined for both inner and outer springs.

ii Fatigue Life Estimation

Fatigue life cycle was calculated based on endurance factors and stress analysis. The spring design achieved an estimated life of approximately 11 million cycles, indicating durability under repeated load conditions.

iii. Four-Link Design and Load Calculations

The four-link suspension system was designed to provide longitudinal and lateral support. Section modulus, moment of inertia, and stress distribution were calculated. Load distribution across ball joints, control arms, and steering arm was analyzed through free body diagrams.

IV.SPECIFICATIONS

Table 1: Specification of springs

Sr.No	Parameter	Values (Inner/Outer)
1	Wire dia. of spring (mm)	32 / 21
2	Mean dia. of spring (mm)	188 / 122
3	Inner dia. of spring (mm)	156 / 101
4	Outer dia. of spring (mm)	220 / 143
5	No. of active coils	7.16 / 10.1
6	Total no. of coils	8.65 / 11.6
7	No. of dead coils	1.5 / 1.5
8	Free length of spring (mm)	505 / 505
9	Solid length of spring (mm)	229.12 / 212.1
10	Pitch of the coil (mm)	62 / 46
11	Stiffness (N/mm)	213.05 / 107.27
12	Wind direction	Right hand / Left hand

Table 2: Load Calculations for Four-Link Suspension System

Sr.No	Descriptions	Values
1	Front axle Braking force per wheel (FSB)	51.59
2	Vertical Force (FV)	103.38
3	Lateral Force (FL)	68.92
4	Force on upper ball joint (FUS)	41.13
5	Force on lower ball joint (FLS)	92.82
6	Force on steering arm (FSB)	33.12
7	Force on lower control arm (FLC)	-74.23
8	Force on lower control arm vertical (FLCV)	-11.58
9	Force on lower control arm horizontal (FLCH)	73.34
10	Force on upper control arm horizontal (FUCH)	-108.88
11	Force on upper control arm vertical (FUCV)	111.63
12	Front axle Braking force per wheel (FSB)	51.59

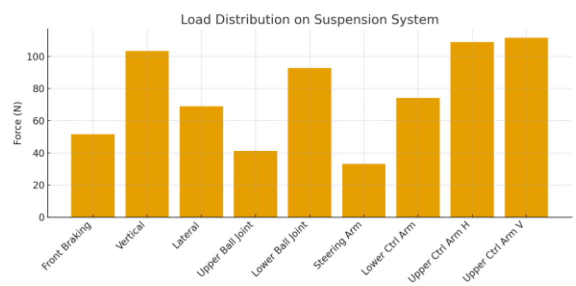

Fig.1: Load Distribution on Suspension System

V. SIMULATION AND RESULTS

A multi-body dynamic simulation was carried out using MSC ADAMS/Car software. The virtual prototype of the suspension system was tested under different wheel travel conditions, including single-wheel, parallel, and opposite displacements. Graphical results included wheel travel versus time and camber angle versus wheel travel, validating the improved performance of the designed suspension system.

VI. CONCLUSION

The proposed four-link suspension system with nested helical coil springs demonstrated significant improvement in off-road mobility, wheel travel, and ride comfort compared to conventional leaf springs. Stress analysis and fatigue calculations confirmed the safety and durability of the design. Simulation results supported the theoretical findings, proving that the system can effectively replace leaf springs in military trucks. Future work will involve prototype development and experimental validation under real-world operating conditions.

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