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Title of the Project: Optimization of Quarter-Car Semi-Active Suspension Performance Through Variable Spring Configurations Using Simulink.

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Abstract

The main goal of this research to use Simulink to optimize quarter-car semi-active suspension systems using variable spring configurations. Semi-active suspensions real time adjust damping characteristics to balance ride comfort and handling performance. The study will develop a precise model of the system, including vehicle mass, primary suspension spring, semi-active damper, and extra spring. The semi-active damper will be controlled by a PID controller. The research will enhance understanding of variable spring configurations for optimizing semi-active suspension systems, potentially benefiting the automotive industry.

Keywords: Semi-Active, Simulink, PID, Spring Configuration.

1. Introduction

The suspension system is a combination of components that successfully work together to preserve the automobiles from road disturbances. The vehicle's suspension system, composed of springs and dampers, provides insulation between the body and wheel and axle, reducing shocks and vibrations from uneven road surfaces, preventing excessive rebounding.

There are three types of suspension system that are active suspension system, passive suspension system and semi active suspension system. Semi-active suspension systems combine active and passive suspension systems, providing a cost-effective and adaptable driving experience. They adjust shock absorber damping force based on road surface feedback. A Proportional-Integral-Derivative (PID) controller is a common feedback control technique used in engineering and automation systems, adjusting control variables based on proportional, integral, and derivative terms. This study explores the use of variable spring configurations in a semi-active suspension system to further improve performance. By dynamically altering the spring stiffness, the system can better adapt to road conditions, optimizing ride comfort, road holding, and suspension travel. Using Simulink for simulation, the research aims to model, analyze, and optimize the suspension system, utilizing a spring in series and a spring in parallel with the semi active suspension system.

2. Literature Review

This literature review provides a comprehensive analysis of recent advancements and information on suspension systems, including active, passive, and semi-active components. Suspension technology dates back 61,000 years, with Hooke's Law, developed in 1678 by 17th-century physicist Robert Hooke, significantly influencing suspension systems [1]. Sun and Yang's 2008 research demonstrates an active suspension system that enhances automobile performance and efficiency by combining passive and active components, using a linear vehicle model [2] . Kumar et al.'s 2021 study examines suspension system behavior using a detailed vehicle model and PID feedback controller, comparing passive and active responses to various road inputs and factors [3]. Haonan He et al.'s 2021 study reveals that an inerter improves the performance of an active-passive vehicle suspension system, enhancing ride comfort and stability on high speeds or uneven road conditions [4] .Haonan He et al. proposed a 2023 passive-active-combined suspension design method to enhance ride comfort and active force demands, indicating future research on semi-active suspension configurations [5].

3. Methodology

In this research, we seek to enhance the efficacy of a quarter-car semi-active suspension system through the

examination of different spring configurations utilizing Simulink for analysis. The methodology implies the creation of a dynamic model for a quarter-car suspension system utilizing Simulink, which includes configurable spring and damper elements. The results will provide information on how to use customised spring combinations to achieve the maximum efficiency in semi-active suspension systems.
Here's a flowchart that illustrates the outline of this research.

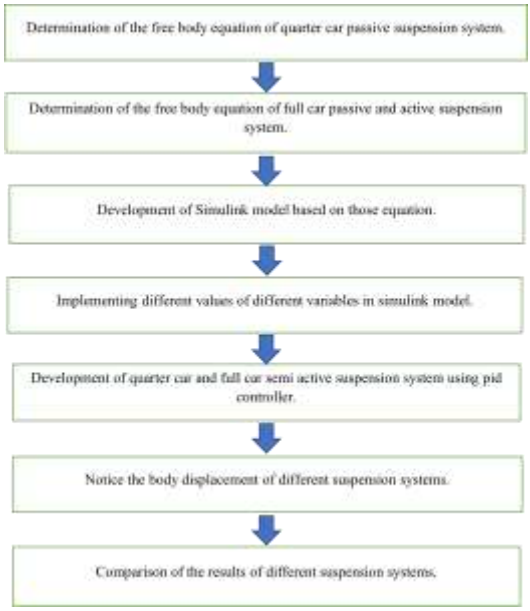


Fig 1. Flowchart of the methodology

4. Mathematical Modeling

The 2DOF suspension system's dynamic behavior can be described using second-order ordinary differential equations (ODEs), assuming linear motion and ignoring friction and non-linearities, resulting in semi-active suspension system governing equations:

$$M1\ddot{X}1 + b1\left(\dot{X}1 - \dot{X}2\right) + k1(X1 - X2) = 0 \quad (1)$$

$$M2\ddot{X}2 + b1\left(\dot{X}2 - \dot{X}1\right) + k1(X2 - X1) + b2\dot{X}2 + k2X2 = b2\dot{W} + k2Xr \quad (2)$$

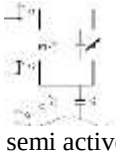


Fig 2. Quarter car semi active suspension model

The Quarter Car Model for Passenger Car has a Semi Active suspension system, with parameters like M1=241.5 kg, M2=41.5kg, K1=6000 N/m, K2=14000 N/m, b1=1200 N-s/m, b2=1500 N-s/m and an extra spring with coefficient of spring K3=2000 N/m which is used alternately in parallel and series and a PID controller: K_p= 1.2, K_i= 5, K_d= 0.2.

5. Simulation and Data Analysis

The simulation uses equations from section 1 to 2, with the step function as the input, revealing the motion of the car's body and wheels.

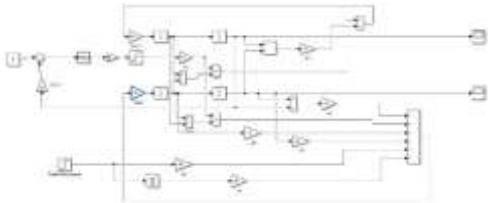


Fig 3. Quarter car semi active suspension system

A sprung mass representing the vehicle body, an unsprung mass representing the wheel and axle, a variable spring-damper mechanism characterising the semi-active suspension, and a step input block intended to simulate a road profile are the main components of the Simulink model of a quarter-car semi-active suspension system in fig 3.

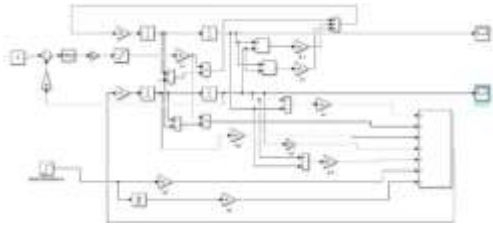


Fig 4. Quarter car semi active suspension system with an extra spring in parallel

A parallel spring with a stiffness of 2000 N/m is part of the quarter-car semi-active suspension Simulink model shown in Figure 4. By simulating the suspension's reaction to road irregularities, this setup enables semi-active control that aims to improve ride comfort and stability. The suspension's reaction to change in the spring layout is evaluated by the model.

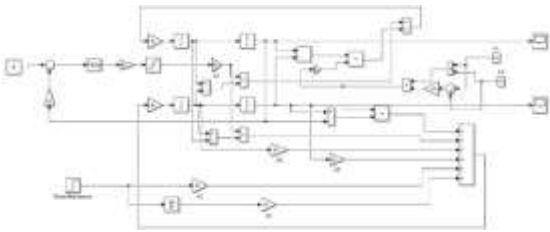


Fig 5. Quarter car semi active suspension system with an extra spring in series

A quarter-car semi-active suspension system with an extra spring connected in series with a spring constant of 2000 N/m is illustrated in Figure 5 employing the Simulink model.

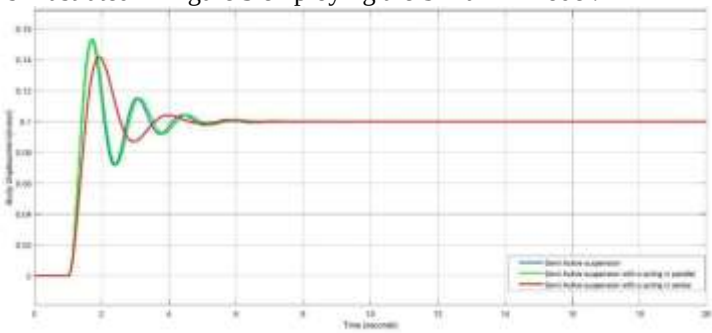


Fig 6. Body displacement (m) vs time (sec)

In Figure 6, the body displacement of the car is measured, revealing an overshoot of 0.057m and a settling time of 8 seconds for Semi active suspension system. For the simulation of Semi-active active suspension with an extra spring in parallel, getting an overshoot of 0.05m and a settling time less than 8 seconds. The graph also presents an overshoot of 0.03m and a settling time is about 6 seconds of the Semi-active suspension with a spring in series.

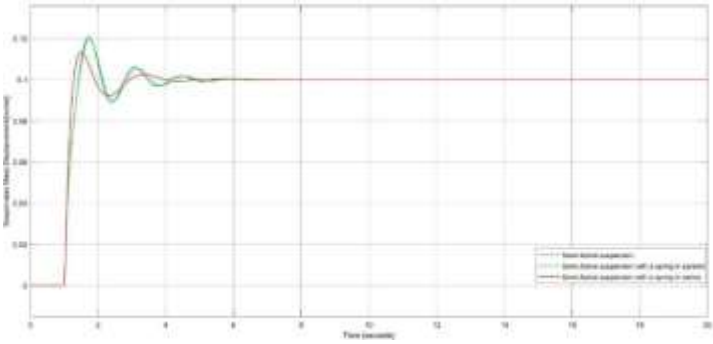


Fig 7. Suspension displacement (m) vs time (sec)

In Figure 7, the suspension mass displacement of the car is measured, revealing an overshoot of 0.02m and a settling period

of 8 seconds in conventional Semi-active suspension. For Semi-active suspension with a spring in parallel has an overshoot less than 0.02m and a settling period of about 7 seconds. On the other hand, the suspension mass displacement of the Semi-active suspension with an extra spring in series is measured, revealing an overshoot nearly about 0.015m and a settling period of about 5 seconds from this figure.

6. Result and Conclusion

The performance analysis of a quarter-car semi-active suspension system with variable spring configurations using Simulink demonstrates that the system with an extra spring in series outperforms the parallel configuration in terms of ride comfort and dynamic response. The series spring configuration effectively handles road disturbances with reduced overshoot and a quicker settling time. As there is less body displacement in semi active suspension with an extra spring in series, minimal level of disturbance may be felt by the passengers. The series setup's lower stiffness facilitates smoother energy absorption and faster system stabilization. The parallel spring configuration offers more stability but sacrifices comfort due to higher stiffness, resulting in more overshoot and longer settling time and a higher level of body displacement is shown in the graph. The study suggests that series structures are more suitable for applications requiring comfort and control, while parallel configurations are better suited for stability-sensitive situations.

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