

Robust Vehicle Suspension System by Converting Active & Passive Control of a Vehicle to Semi-Active Control System Analytically

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Abstract – In this research work a simplified translational model of an automotive suspension system is constructed by only considering the translation motion of one wheel of a car. Passive Vehicle Suspension System is converted into Semi Active Vehicle System. Major advantage achieved by this system is that it adjusts the damping of the suspension system without the application of any actuator by using MATLAB® simulations. The semi-active control is found to control the vibration of suspension system very well.

Keywords – Vehicle Suspension System; Active Control System; Passive Control System; MATLAB

I. INTRODUCTION

Suspension system separates the wheel of the vehicle from the vehicle body in order to avoid any jerks due to rough roads. They ensure the comfort of the passengers by absorbing shocks and dissipating them. A conventional vehicle Suspension System constitutes of a damper (energy dissipating element) and a helical or leaf spring (energy storing element) [1]. Since no energy can be added by these two elements, such suspension system is called passive vehicle suspension system.

There are limitations of passive vehicle suspension system due to a compromise between spring rate and damping characteristics in order to achieve required output [2]. A single degree of freedom spring mass damper with high damping value can perform well in the vicinity of high frequency [3, 4]. Due to this compromise between spring rate and damping, active and semi-active systems are gaining reputations in the suspension systems. Passive and active suspension systems are shown in Fig. 1.

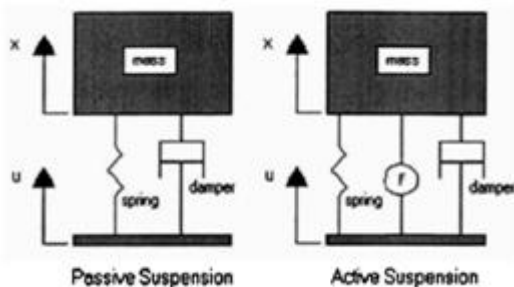


Fig. 1 Schematic diagram for passive and Active system

Semi Active System utilizes external source of power for the sake of adjusting damping levels, for operating embedded controller and sensors attached. Controller detects the level of damping required by sending signal and automatically adjusting the damping level in a real time. In an automotive suspension this is achieved by the use of an active damper that is attached in parallel to the conventional spring.

In this research quarter vehicle suspension model with semi active control system is established in MATLAB and finally their performance are compared on the basis of the result for the MATLAB.

Physical model of passive vehicle suspension system

A quarter vehicle suspension system [5] is shown in Fig. 2. This model is used to check the performance of the other semi active systems. Linear spring is used to model the stiffness of the tire, axle, tire and other moving parts are represented by mass m_1 , suspension system by a spring, viscous damper and supported vehicle components by mass m_2 [6].

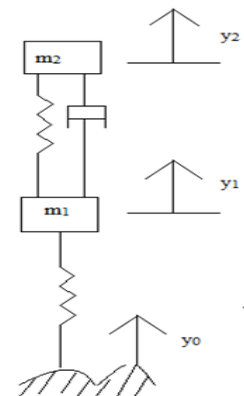


Fig. 2 Free body diagram for quarter suspension system

In the model;

K_1 = spring constant showing stiffness of the tire

m_1 = mass of the car

K_2 = spring constant of the suspension spring

m_2 = mass of the wheel of car

Transfer function for open loop system $T(s)$ can be determined as:

$$T(s) = \frac{4s^2 + 3.333s + 3.333}{s^4 + 5.833s^3 + 9.833s^2 + 3.333s + 3.333} \quad (1)$$

This system shows a steady state error. So the transfer function for closed loop system is:

$$T(s) = \frac{4s^2 + 3.333s + 3.333}{s^4 + 5.833s^3 + 13.83s^2 + 6.667s + 6.667} \quad (2)$$

All the closed loop poles lie in left half of root locus diagram as shown in Fig. 3 so the system is stable. But response time is very high (less than a second is the requirement) as depicted in figure with blue curve.

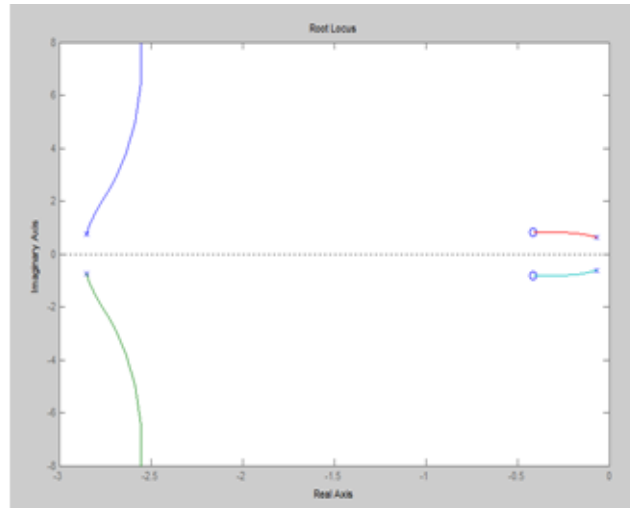


Fig.3 Loop poles and root loci

II. Controller design

It is evident from the above discussion that assuming system depicted in Fig. 3 is stable and can be controlled by using either semi active or active system. Most common semi active control policy is Skyhook control. For this controller, introduce extra pole in a system so that the location of all closed loop poles can be controlled [7, 8]. This control system should be designed to have a maximum overshoot of 10% (but we designed it for 9.5% to avoid any non-linearity) and a settling time of .8 sec (design for .74sec) [9].

After solving by state space variable method the transfer function is;

$$T(s) = \frac{1.421e-014s^3 + 4s^2 + 3.333s + 3.333}{s^4 + 11.64s^3 + 91.11s^2 + 76.72s + 67.71} \quad (3)$$

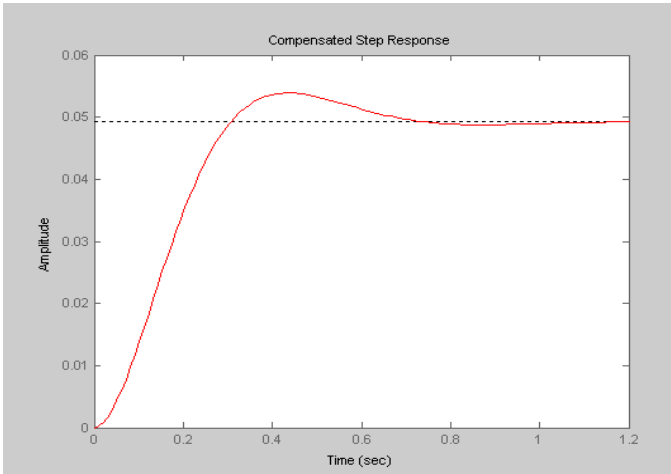


Fig. 4 Time response diagram for a controller

$$G(s) = \frac{-2.842e-014 s^3 + 4 s^2 + 3.333 s + 3.333}{s^4 + 108.9 s^3 + 8217 s^2 + 6861 s + 6771} \quad (4)$$

By solving the above transfer function for the observer design we have time response diagram for the observer. It is clear from the Fig. 5 that time response for the observer is nearly ten times higher than the previous one but steady state error is too higher which shows that system is highly unstable.

Nyquist Criterion

The contribution due to Nyquist is of very mathematical nature and deals also with the system which is unstable in open loop. System whose open-loop frequency response loci do not encircle the -1 point will be stable in closed loop, i.e. their open loop gain is less than unity at the phase-crossover frequency [12]. Loci of the system which encircle the -1 point are unstable in closed loop. Loci of the system which pass through the -1 point are marginally stable and will oscillate continuously at the phase-cross frequency [13]. The time response diagram of the control system is shown in Fig. 6 using MATLAB.

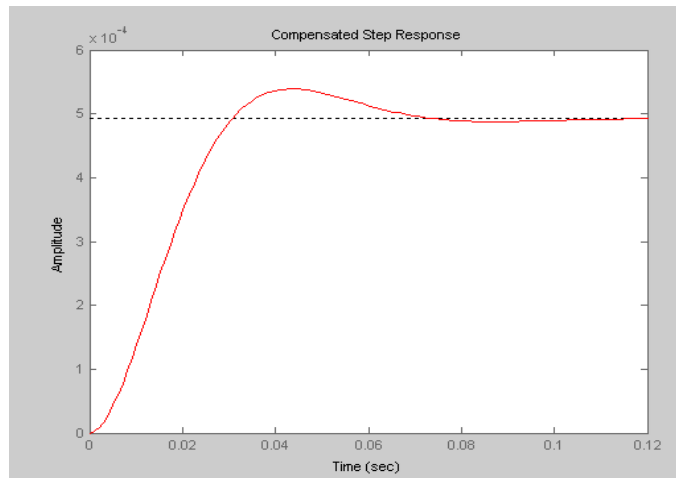


Fig. 5 Time response for observer design

Solving the above transfer function with MATLAB the time response diagram of the control system is shown in Fig. 4. It reveals a large steady state error but required time response. So system is controllable. Steady state error can be reduced via integral control but we switch to other systems to avoid complexity.

Observer Design

To avoid cost and equipment observer design is preferred over controller design. Moreover it may be faster as 10 times than that of the controller [10, 11], so we find the results by designing an observer for the suspension system.

Solving the above with required inputs, transfer function is obtained as below;

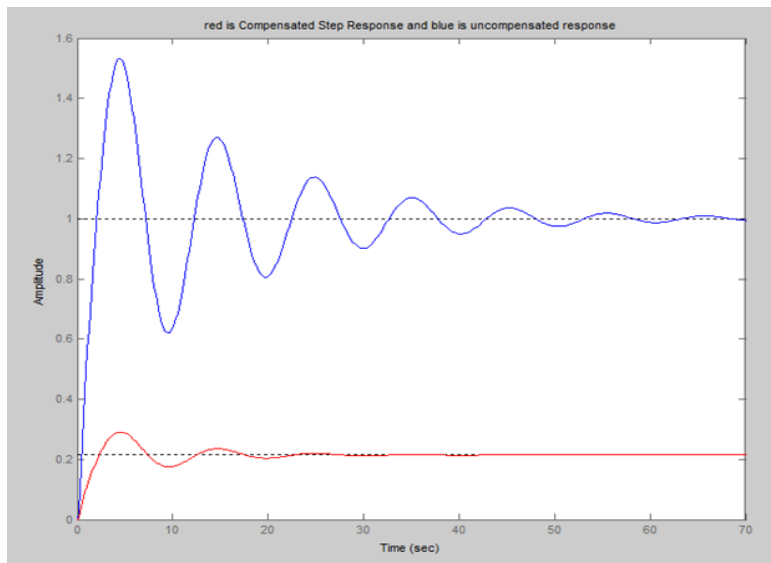


Fig. 6 Stability via Nyquist

It reveals a large over shoot, settling time and oscillations. So system is unstable. In the compensated response the system has large steady state error and settling time. The Nyquist diagram is shown in Fig. 7.

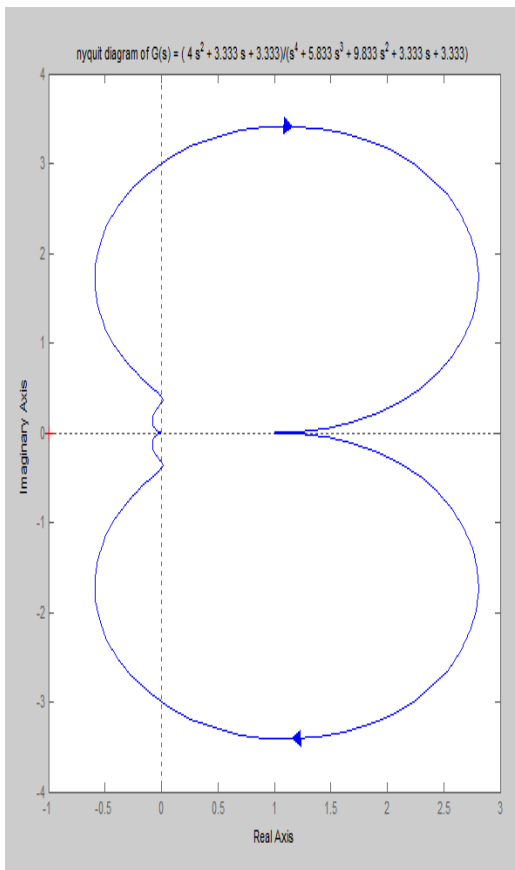


Fig. 7 Nyquist Diagram

Bode plot

In bode plot the logarithm of the magnitude of transfer function is plotted against the logarithmic frequency function ω . The phase ϕ of the transfer function is plotted separately against the logarithmic frequency [14].

The transfer function is given by following equation:

$$G = \frac{4 s^2 + 3.333 s + 3.333}{s^4 + 5.833 s^3 + 9.833 s^2 + 3.333 s + 3.33} \times K \quad (5)$$

The logarithmic gain in dB vs. ω is drawn on one set of axis while the phase ϕ vs. ω is drawn on another set of axis. The Bode plot is shown in the Fig. 8 .

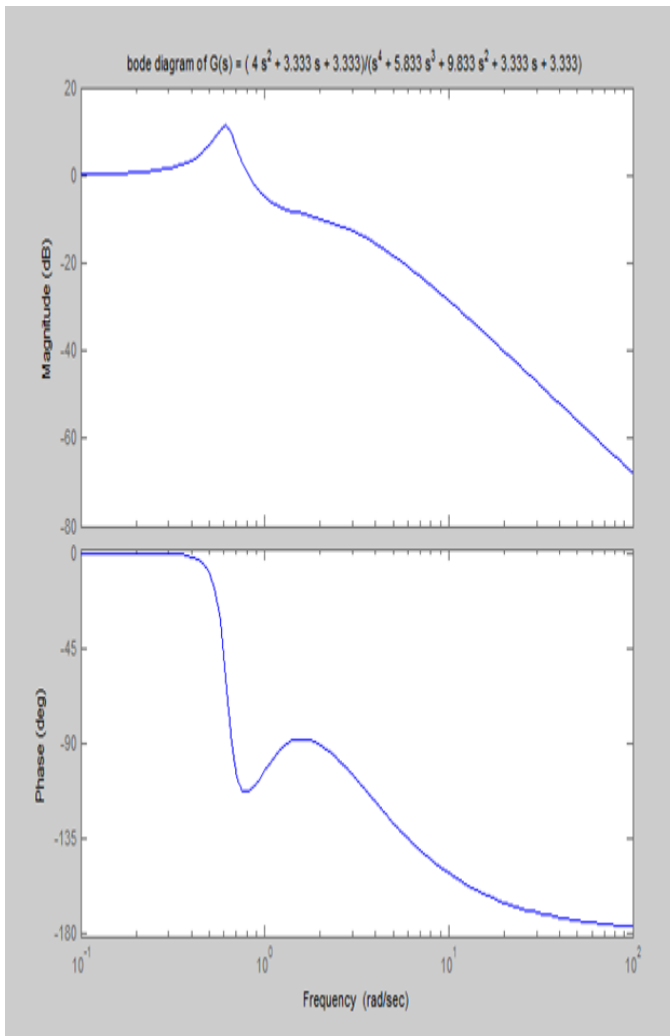


Fig. 8 Stability via Bode Plot

Lead Compensator

The purpose of a lead compensator is to increase the bandwidth with the increase in gain crossover frequency. While the phase diagram is raised to higher frequencies that results in large phase margin and higher phase margin frequencies [17]. Lower percentage of overshoots with small peak times are obtained in the time domain. Fig. 10 shows the time response of a lead compensated system using MATLAB. It shows that the system has very less overshoot (up to 5%) and settling time less than 0.5 second. So system is highly stable.

Lag Compensator

The purpose of a lag compensator is to improve the static error constant by increasing only the low frequency gain without any resulting instability and increase the phase margin of the system to yield the desired transient response [15]. Fig. 9 shows the time response of the lag compensated system using MATLAB. It reveals that the system has overshoot greater than 10% and settling time up to 10 second. So system is reasonably stable [16].

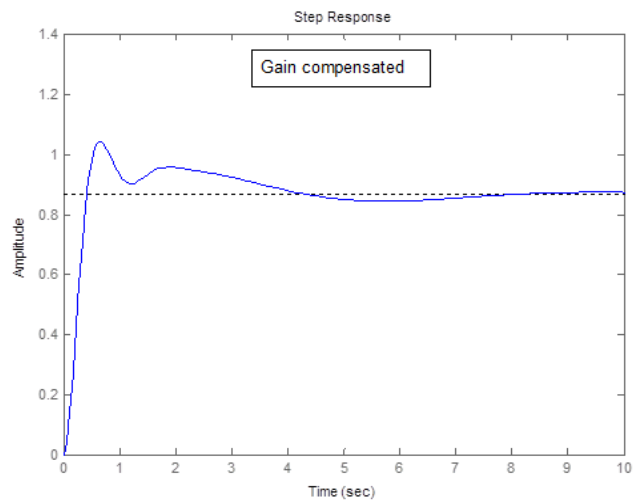


Fig. 9 Lag Compensator

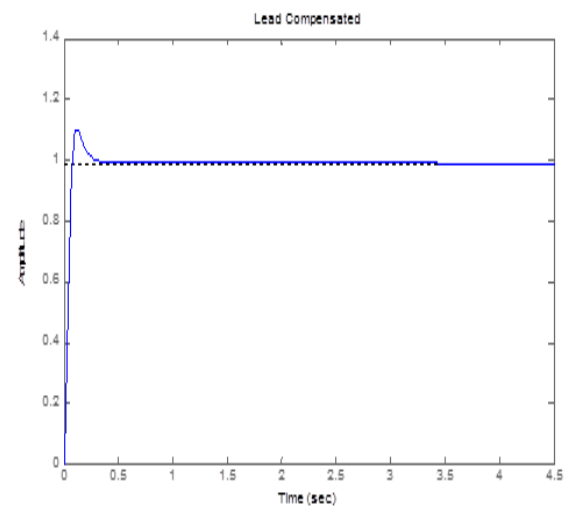


Fig. 10 Lead Compensator

Lag-Lead Compensator

The designing technique of Lead and Lag compensation forms the basis for the designing of a lag-lead compensator using frequency response technique [18].

The frequency response curve is altered by the phase lead portion of the lag-lead compensator by the addition of phase lead angle and an increase in phase margin at the given crossover frequency. Attenuation is provided by the phase lag portion near and above the gain crossover frequency. The time response diagram of the lead compensated system is shown in figure 10 using MATLAB. It shows that the system has very less overshoot (up to 5%) and settling time less than 0.5 second. So system is highly stable.

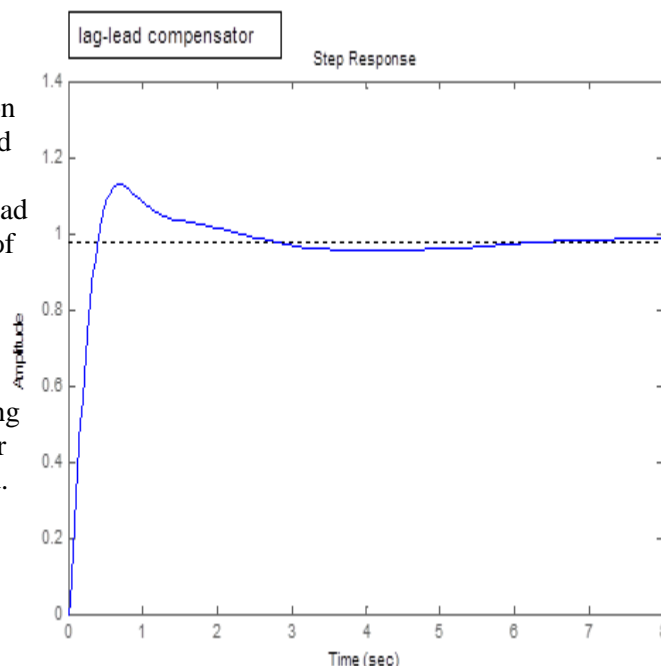


Fig. 11 Lag-Lead Compensator

III. CONCLUSIONS

Following conclusions can be drawn from the current research work:

1. The system is stable under lag, lead and lag-lead compensator.
2. The best suited compensated design is lead compensation under which the system is exceptionally stable.
3. It showed that the system has very less overshoot (up to 5%) and settling time less than 0.5 second.

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