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Research Article

Performance Analysis of Skyhook, Groundhook and Hybrid Control Strategies on Semiactive Suspension System

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Abstract

The purpose of this paper is to analyze effect of skyhook, groundhook and hybrid control strategies on semiactive suspension system through computer simulation of quarter-car model in MATLAB/SIMULINK. The ride comfort and handling characteristics of suspension system were observed for step input. The performance of passive suspension system model was compared with skyhook, groundhook and hybrid controlled semiactive suspension system performance. The result shows that skyhook control will offer better ride and handling as compared to other controllers.

Keywords: *Groundhook, Skyhook , Hybrid Controller, Quarter Car, Semiactive Suspension System.*

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1. Introduction

The aim of a vehicle suspension is to provide an isolation of a vehicle body from road irregularities and to ensure good road holding. The first goal lies within the area of ride analysis and concern a problem of how to reduce a discomfort experienced by vehicle occupants. The second one lies within the area of handling analysis. Here, the handling means an ability of a vehicle to safely accelerate, brake and corner with the “ease-of-use” (Masi 2001) (Rajmani 2006). The design goal is to minimize both the acceleration of the body and the dynamic tire load, while operating within the constraints of suspension rattle space for a given suspension parameter set.

The common passive suspension systems inherently lead to a compromise between ride and handling. A highly damped suspension results in good vehicle handling, but at the same time has the disadvantage of causing passenger perceived harsh ride. A harsh ride may not only be unacceptable, but also it may damage cargo. On the other hand, a low damped suspension may significantly improve the perception of rid, but it can reduce the stability of the vehicle.

The need to reduce the effects of this compromise has led to the development of active and semiactive suspensions. Active suspensions use force actuators. Unlike a passive damper, which can only dissipate energy, a force actuator can generate a force in any direction regardless of the relative velocity across it. Using a good control policy, it can reduce the compromise between comfort and stability (Kruczek 2004). However, the complexity and large power requirements of active suspensions make them too expensive for wide spread commercial use. (Miller et al. 1989) Semiactive dampers are capable of changing their damping characteristics by using a small amount of external power. Semiactive suspensions are less complex, more reliable, and cheaper than active suspensions. They are becoming more and more popular for commercial vehicles.

Semi-active suspensions were first proposed by Karnopp. Many studies have been carried out since then, including various control techniques applied to quarter, half and full vehicle models. The performance of semi-active suspension systems relies heavily on real-time control strategies. Research on semi-active control strategies focused primarily on linear techniques, such as optimal control (Aleksander et al. 1991) and skyhook control (Karnopp et al. 1979), (Hada et al. 2007) further nonlinear techniques also been applied by different authors. Recently researchers also applied the Fuzzy logic (G Slaski et al. 2011), (Rajeshwari et al. 2009) Genetic Algorithm, neural networks, Artificial Intelligent Techniques etc, to semi-active suspension control and elaborated their performances.

Of the previous studies mentioned in literature, the majority have been analytical studies. Model simulations and analytical studies have dominated the studies in semiactive suspension system. This paper aims to complement the analytical studies in the past and to contribute to the investigation of semi-active suspension systems with different controllers.

2. Quarter-Car Semi-Active Suspension System Models

A semiactive damper suspension system, Figure 1, varies the damping force in real time depending on the dynamics

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of the controlled masses. The semiactive system utilizes a feedback loop to control the damping force at any time. The feedback is usually taken as the velocities of the bodies that the suspension controls. A processor can then use the feedback data to calculate the desired damper control force, which must be converted into a control signal that will adjust the damper. The signal that is sent to the actuator changes the damper's resistance to velocity and therefore changes the damper force. Finally, the feedback loop is completed as the changing damper force alters the acceleration of the controlled bodies and the feedback variables in ways that would not have occurred had a passive system been used.

Table 1 Parameters for Simulation

Parameter	Symbol	Value	Unit
Sprung mass	m_s	535	Kg
Unsprung mass	m_u	40	Kg
Damping coefficient	c_s	3002.3	Ns/m
Tire damping	c_u	300	Ns/m
Spring stiffness	k_s	96000	N/m
Tire stiffness	k_t	350000	N/m
Controller gain	G	-	-
Critical damping coefficient	Zeta	-	-
Maximum damper force bounded	C_{on}	15000	Ns/m
Minimum damper force bounded	C_{off}	300	Ns/m
Hybrid controller gain	Alpha (α)	0-1	-

Researchers used linear lower order models for initial development and analysis of semi active suspension system (Goncalves 2001), (Williams et al. 2005). After successful application using simple models, then more complex models, with nonlinearities and more DOF should be used. In this research a 2 DOF model is used to test the performance of different controller's viz. skyhook, groundhook, hybrid on the semiactive suspension system.

A typical vehicle primary suspension can be modeled as "quarter-car" model. This 2 dof model represents one of the four corners of the vehicle; hence, often referred to as the "quarter-car" model. It represents the dynamics of the sprung-mass, unsprung mass, and suspension along the vertical axis of the vehicle through equations of motion.

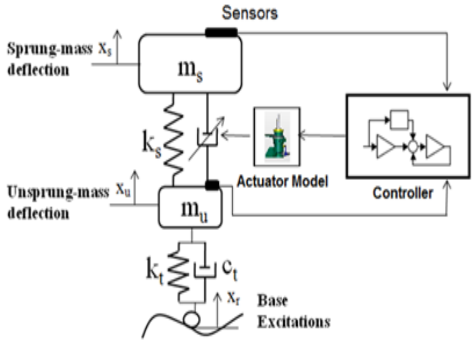

Fig.1 Quarter car model for semi active suspension system

For Sprung Mass:-

$$m_s \ddot{x}_s + F_{sa} + k_s (x_s - x_u) = 0 \quad (1)$$

For Unsprung Mass:-

$$m_u \ddot{x}_u + F_{sa} + k_s (x_u - x_s) + c_t(\dot{x}_u - \dot{x}_r) + k_t (x_u - x_r) = 0 \quad (2)$$

Using above equations a numerical model is developed in MATLAB/SIMULINK which represents the dynamics of quarter car suspension system and it is then used for simulation purpose to predict performance of different controllers of semiactive suspension.

3. Control methods

The better ride and handling can be achieved by better controller design. In this paper, we used the traditional skyhook, groundhook and hybrid controllers to adjust damping force in order to improve suspension dynamics.

3.1 Skyhook Control

The Skyhook law was patented in 1974 by Karnopp. The damper connected to the sky (a fixed y-axis coordinate). An intuitive sense of how Skyhook control works, if the suspension damper is expanding and the sprung body is moving towards, then Skyhook control turns the damper on and the damper pulls down on the sprung body.

The switching law turns the damper off when the direction of the damper velocity is not consistent with the direction of the desired damper force. In other words, if it is desired to have the MR suspension damper pull down on the sprung body but that damper is being compressed, then only an upwards force is available from that damper. The control law will turn the damper off in an effort to minimize the upwards push from the suspension damper. This limitation of semi active control is recognized in a paper by Karnopp. One drawback examined here to using the switch is that it introduces a large jerk, or a rapid change in acceleration, to the bodies.

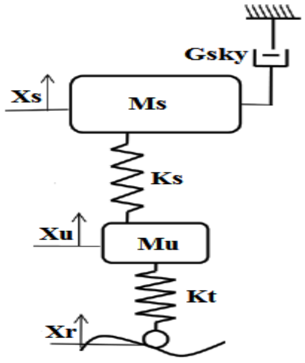

Fig.2 Ideal Skyhook configuration

The difference between Skyhook and passive is that the Skyhook controller varies the damper force such that the damper force is equal to,

$$\begin{aligned} F_{sa} &= G_{sky}\,\dot{x}_s && ;\text{ if } && \dot{x}_s V_{su} > 0 \\ F_{sa} &= 0 && ;\text{ if } && \dot{x}_s V_{su} < 0 \end{aligned} \qquad (3)$$

Where,

Fsa = Desired damping force, N

$\dot{x}$s = Sprung-mass velocity, m/s

Vsu = $\dot{x}$s - $\dot{x}$u ; Relative velocity between sprung & unsprung-mass, m/s

Gsky = Skyhook gain, N/m/s

3.2 Groundhook Control

The groundhook model differs from the skyhook model in that the damper is now connected to the unsprung-mass rather than the sprung-mass. Under the groundhook configuration, the focus shifts from the sprung-mass to the unsprung-mass.

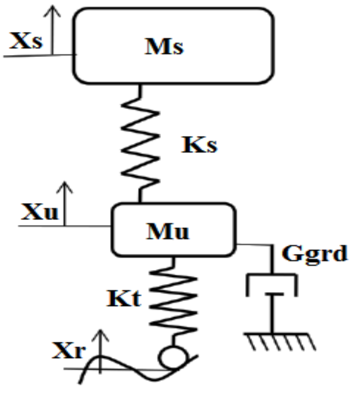

Fig.3 Groundhook configuration

The logic of the groundhook control policy is similar to the skyhook control policy, except that it is intended to control the unsprung-mass.

$$\begin{aligned} F_{sa} &= G_{rnd}\,\dot{x_u} && ;\text{ if } && -\dot{x_u} V_{su} > 0 \\ F_{sa} &= 0 && ;\text{ if } && -\dot{x_u} V_{su} < 0 \end{aligned} \qquad (4)$$

Where,

$\dot{x}$u = Unsprung-mass velocity, m/s

Ggnd = Groundhook control gain, N/m/s

3.3 Hybrid Control

An alternative semi-active control policy, known as hybrid control, combines the concept of skyhook and groundhook control to take advantage of the benefits of both. With hybrid control, the system can be set up to function as a skyhook or groundhook controlled system, or a combination of both.

$$\begin{aligned} \sigma_{sky} &= \dot{x_s} && ;\text{ if } && \dot{x_s} V_{su} > 0 \\ \sigma_{sky} &= 0 && ;\text{ if } && \dot{x_s} V_{su} < 0 \end{aligned}$$

$$\begin{aligned} \sigma_{rnd} &= \dot{x_u} && ;\text{ if } && -\dot{x_u} V_{su} > 0 \\ \sigma_{rnd} &= 0 && ;\text{ if } && -\dot{x_u} V_{su} < 0 \end{aligned}$$

$$F_{sa} = G\,[\,\alpha\,\sigma_{sky} + (1-\alpha)\sigma_{rnd}] \qquad (5)$$

α is control ratio;

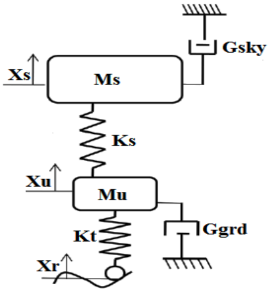

Fig.4 Hybrid configuration

The variables σsky and σgnd are the skyhook and groundhook components of the damping force, α is the relative ratio between the skyhook and groundhook control also called as weighting factor, and G is a constant gain. When α = 1, hybrid control reduces to pure skyhook control, and when α = 0, it becomes groundhook control. As value of weighting factor tend from zero to one hybrid system changes from skyhook system to groundhook suspension system.

4. Simulations & Interpretation of Result

Two important characteristics of a vehicle suspension are its ride comfort and handling ability. The ride comfort can be inferred by analyzing the sprung body dynamics. Several factors can adversely affect the ride comfort. The first factor is large vertical sprung-mass acceleration (Masi 2001), (Ivers et al. 1989) which is generally considered unwanted. The second factor is a large vertical sprung-mass displacement, is also undesirable.

The second vehicle response characteristic is the vehicle handling, which is inferred by analyzing the unsprung body dynamics. We will also assume that an inconsistent tire/road contact, created by large unsprung body displacements, will result in poor vehicle handling. (Ivers and Miller 1989) discuss improved vehicle handling as a result of increased tire contact forces.

The purpose of this paper is to discuss the effect of skyhook, groundhook and hybrid controller on suspension dynamics. For different values of gain, G, viz. 1000, 2000, 4000, 8000, MATLAB/SIMULINK simulation were performed using quarter car model. Input road profile taken as step input of 0.01 m value and accelerations, displacements at respective masses observed for analysis of suspension performances. Transmissibility plots are obtained for each of control and ride comfort and handling is measured. Transmissibility of sprung mass is defined as ratio of sprung mass displacement to the input displacement xs/xr and transmissibility of unsprung mass is ratio of unsprung displacement to the input displacement xu/xr respectively.

4.1 Skyhook Control

Fig. 5a shows sprung mass acceleration for skyhook controlled suspension that is plot against time trace by varying values of gain, increasing values of gain reduces amplitude the peak of acceleration and also settling time is reduced.

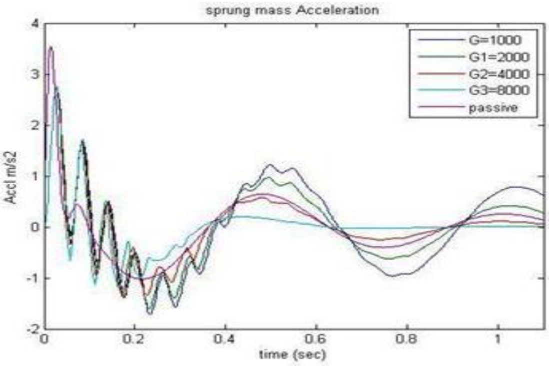

Fig.5a Skyhook sprung mass acceleration

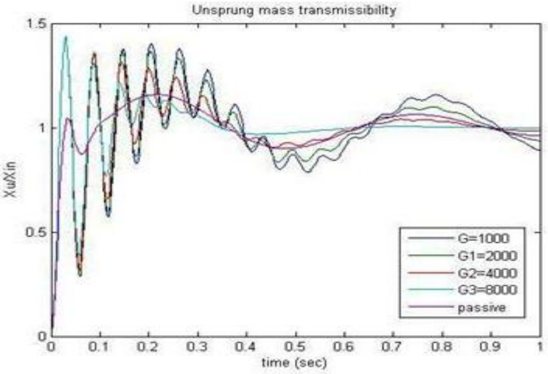

Fig. 5b: Skyhook unsprung mass transmissibility

This gives better ride comfort to the vehicle suspension system. Unsprung mass transmissibility Fig. 5b shows passive transmissibility curve peak values are less than skyhook transmissibility values, so with increasing gain reduces handling of vehicle performance at unsprung mass. Skyhook control gives better ride comfort performance while handling performance is little compromised.

4.2 Groundhook Control

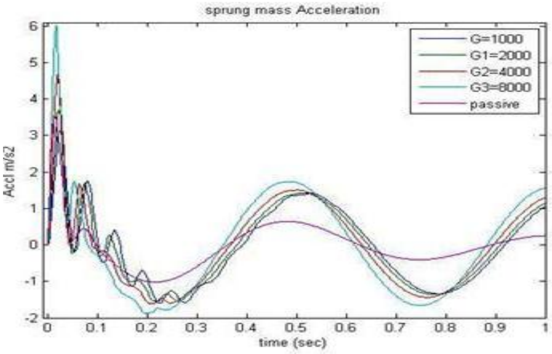

Fig. 6a Groundhook sprung mass acceleration

Fig. 6a shows the plot with passive sprung mass acceleration and groundhook sprung mass acceleration with different values of gain values, graph shows the peak values amplitude of groundhook acceleration is increased as the gain increase. This reduces the ride comfort performance quarter car model. In Fig. 6b unsprung mass transmissibility is reduced as the damping force gain value is increased, this improves the handling performance of vehicles suspension system.

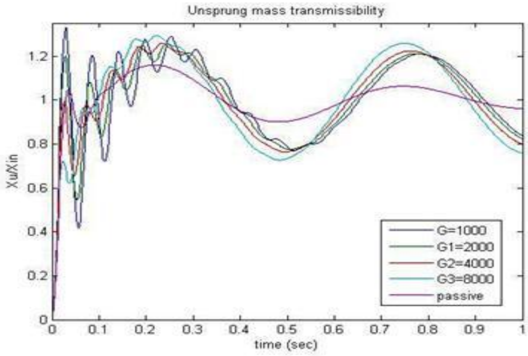

Fig. 6b: Groundhook unsprung mass transmissibility

Unlike skyhook in groundhook unsprung mass transmissibility is less and sprung mass transmissibility is more. There is a demand for both better ride comfort and handling performance to the suspension which cannot be gained by any single of skyhook and groundhook. This can come for some demand in hybrid control suspension system.

4.3 Hybrid Control

Hybrid control is combination of skyhook and groundhook control, alpha α weighting factor determines the skyhook or groundhook control effect it is relative between skyhook and groundhook. With alpha value equal to one control is completely skyhook i.e. better ride comfort performance is obtained. When alpha value is zero control is completely groundhook i.e. better handling performance is obtained.

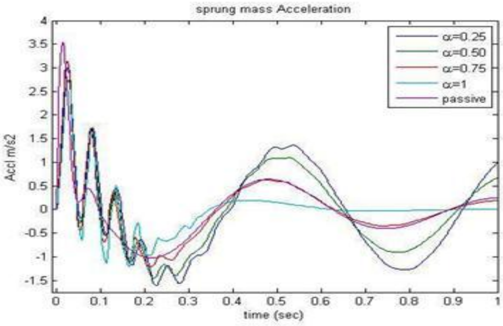

Fig. 7a: Hybrid sprung mass acceleration

Fig. 7a shows the sprung acceleration amplitude, as weighting factor is increased the peak value is reduce and also the settling time is reduced giving better ride performance. In Fig. 7b with smaller value of weighting factor transmissibility is less to give better handling performance. From above controls it can be seen that skyhook give better performance at sprung masses as the basic requirement for passenger.

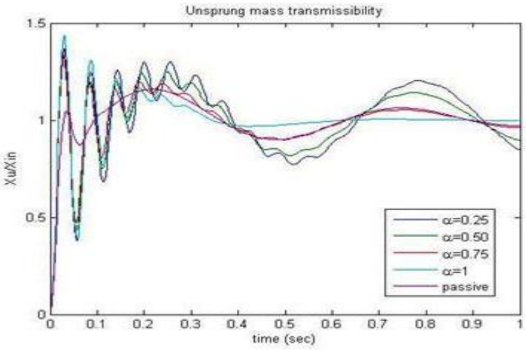

Fig.7b Hybrid unsprung mass transmissibility

Conclusions

In this paper extensive computer simulations were performed to examine the effects that various control techniques, such as, skyhook, groundhook and hybrid, have on the performance of semiactive dampers in controlling the dynamical response of a quarter-car semi-active suspension system and compared with passive suspension system.

Table 2 Comparison table of peak reduction percentage

Parameters (Performance)	Semi-active suspensions		
	Skyhook	**Groundhook**	**Hybrid**
Ride(As)	High(65-90)	Low(11)	Medium(5-17)
Handling(x_u)	Low	High(5-30)	Medium
Settling time (Stability)	High(30-70)	Low	High(30-70)

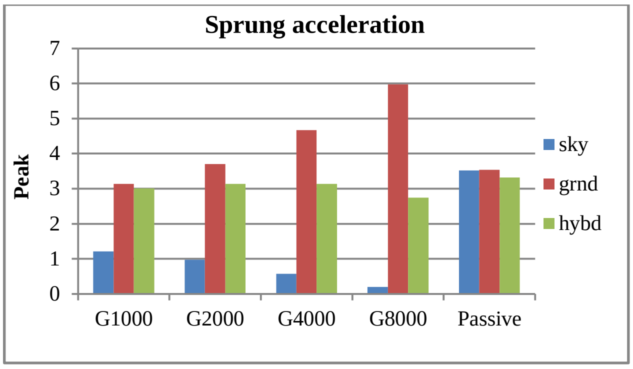

Fig.8 Sprung accl peak graph

The simulation result shows that for given road input of 0.01m to suspension system, skyhook control offers better ride comfort and handling than passive, groundhook and hybrid controls. Future scope for research could be finding optimal of gain of each controller which could give the best suspension performance.

- Increasing skyhook gain gives better ride but handling is little compromised.
- Increasing Groundhook gain better handling obtained since low unsprung mass transmissibility of displacement.
- As weight factor of hybrid varies from 0-1 control shifts from Groundhook to skyhook.
- Skyhook gives better performance at sprung masses as basic requirement for passenger.

In addition, one can explore effect of these controllers on frequency domain also.

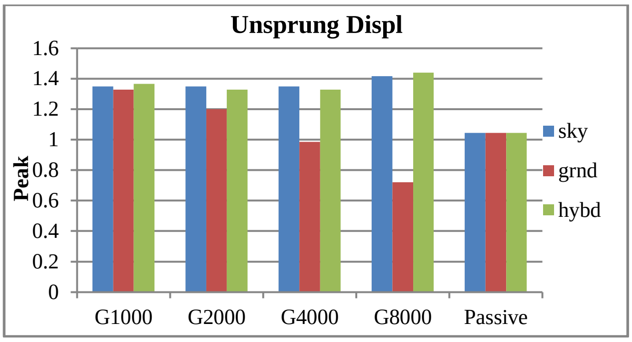

Fig.9 Unsprung Displacement peak graph

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