

Control of semi-active suspension system using PID controller

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Abstract. This paper aims to scrutinize the performance of semi-active suspension system using a PID controller by applying Bouc-Wen model for magneto-rheological fluid. The mathematical model is being simulated in the MATLAB Simulink environment. Two crucial road excitation were given to the suspension system namely sine and random input. The results of the both have been presented and their hysteric behaviour has been studied. Results show that by applying a controller the desired effect can be reached.

1. Introduction

The classification of a vehicle suspension is done in three types i.e. passive suspension system, active suspension system and semi-active suspension system, which is based on operational mode to increase the safety of the vehicle, ride comfort and overall performance of the vehicle.

Earlier the passive suspension systems were used in the automobile which lacks feedback mechanism in the damper with no controlled springs. On the contrary, active suspension system has a wide range of operation as adjust the damping force with the help of actuator and thus adapting variations of roads. Active systems were studied in 1960 and many further models were proposed. The modification in active suspension is necessary due to the fact that it required a high supply of current. Then came semi-active suspension system in the 1970s and gained popularity because of output damping force is highly adaptive with very lesser power consumption than active suspension system. Therefore, semi-active suspension system usually falls in between the active suspension system and semi-active suspension system. The fluid used in the semi-active systems is electro-rheological (ER) fluid and magneto-rheological (MR), these types of fluids have micron size particles of iron suspended in the oil. These vary the stiffness of the fluid when the voltage is applied to the fluid as the iron particles align themselves in the externally applied magnetic field. The semi-active control is studied by Lai et al. [1] and Yao et al. [2] In this paper Bouc-Wen model of the MR fluid is implemented which was used by Spencer et al. [3].



Daniel Fischer et al [5] created a mathematical model using variable damper system for active suspension systems as well as designed active parts for fault detection. Eski et al. [6] designed a robust control, based on neural networking, for the full suspension system and compared it with standard PID. G. Priyandoko et al. [7] implemented a hybrid control technique for the control of active suspension system using adaptive neuro active force and skyhook technique. M. S. Kumar [8] made an active suspension system for quarter car model using PID control strategy. P. E. Uys et al. [9] investigated spring and damper settings for optimal ride comfort studied at different road profiles. Daniel A. Mantaras et al. [10] studied the kinetic behaviour of McPherson type steering suspension and determined caster steer and camber angle.

In this paper, a Proportional-Integral-Derivative (PID) controller is used which controls the error between the damping force and the force from the road. The simulation model of the quarter suspension system of an automobile is done in MATLAB Simulink environment with the application of Bouc-Wen fluid model with a controller.

This paper tries to study the performance of semi-active active suspension control in a two degree of freedom model of quarter car.

2. System Modelling

The mathematical model of semi-active suspension is based on following observations

- The suspension system is assumed to be linear or approximately linear for quarter car considering two degrees of freedom.
- The minor forces are neglected such as flex in the vehicle joint and gear system etc. thereby reducing the complexity of the vehicle.
- The damping and stiffness property is also possessed by the tyre material which is to consider.

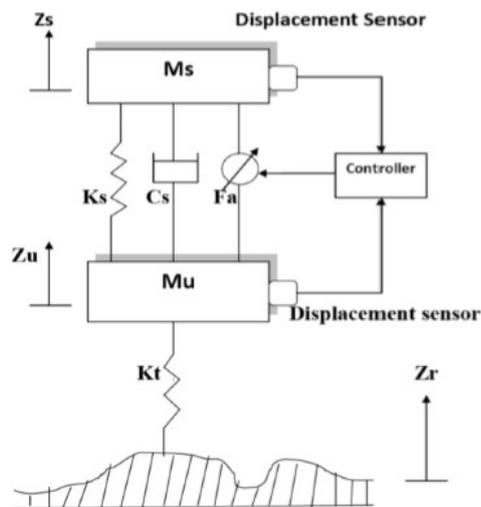


Fig 1. Quarter Semi-active suspension system [4]

From fig 1. following equation has concluded

$$m_s \ddot{z}_s + k_s(z_s - z_u) + c_s(\dot{z}_s - \dot{z}_u) + U(t) = 0 \quad (1)$$

$$m_u \ddot{z}_u + k_s(z_u - z_s) + c_s(\dot{z}_u - \dot{z}_s) + k_t(z_u - z_r) = U(t) \quad (2)$$

Bouc-Wen equation is as follows:

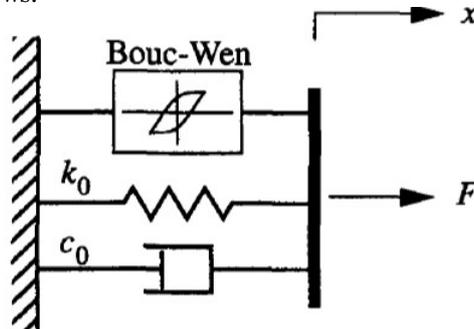


Fig 2. Bouc-Wen model for MR dampers [3]

From the fig 2. the following equations have been derived

$$F = c_0 \dot{x} + k_0(x - x_c) + \alpha z \quad (3)$$

$$\dot{z} = -\gamma |\dot{x}| z |z|^{n-1} - \beta \dot{x} |z|^n + A \dot{x} \quad (4)$$

where,

F=Damping force

x=Initial displacement of the piston

k₀=stiffness of fluid

c₀=damping coefficient of the fluid

By adjusting parameters γ , β , and A of the above equations (3) and (4) one can control the smoothness of pre-yield and post-yield region of the MR fluid.

z is an evolutionary variable that encompasses the history of the dependence of response. The parameters depend upon the voltage with is given by equation as:

$$\alpha = \alpha_a + \alpha_b u \quad (5)$$

$$c_0 = c_{0a} + c_{0b} u \quad (6)$$

where u is the output obtained from the first-order filter and given relation in terms of voltage as:

$$u = -\eta(u-v) \quad (7)$$

For this purpose, the following values are taken

Sr. No.	Parameters	Values
1	γ	1 cm ⁻²
2	β	-1 cm ⁻²
3	A	1.5
4	n	2
5	K ₀	300 N/cm
6	c _{0a}	4400 N-s/cm
7	c _{0b}	442 N-s/cm
8	η	190
9	α_a	10872 N/cm
10	α_b	49616 N/cm

Table 1. Parameters used for Simulink model of Bouc-Wen

Parameter values for equation (5), (6) and (7) are taken as from Table 1. The control implementation of the Bouc-Wen in suspension is done with the help of error measurement. The error is continuously taken as the difference between the force experienced on the sprung mass due to road excitation and

the damping force generated by the simulated Bouc-Wen model. This error is further reduced by the PID controller.

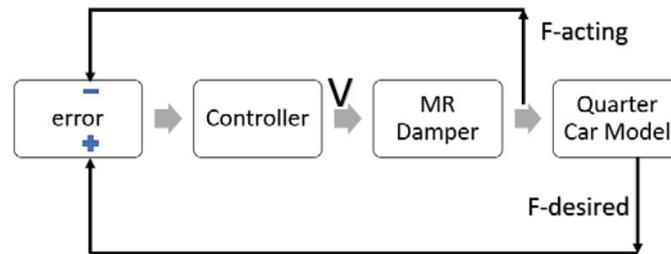


Fig 3. Flowchart of the control system

3. Simulation under MATLAB SIMULINK

The mathematical model of the quarter semi-active suspension system is made in the simulation block by using the equations. The modelling in Simulink is based on the equations (1) and (2). The model is made based on Fig 3.

Sr. No.	Parameter	Symbol	Quantities
1	Mass of vehicle body	M_s	2500 kg
2	Mass of the tyre and suspension	M_u	320 kg
3	The coefficient of suspension spring	K_s	80000 N/cm
4	The coefficient of tyre material	K_t	50000 N/cm
5	Damping coefficient of the dampers	C_s	15020 N-s/m

Table 2. Parameters used in the system simulation. Adapted from [4].

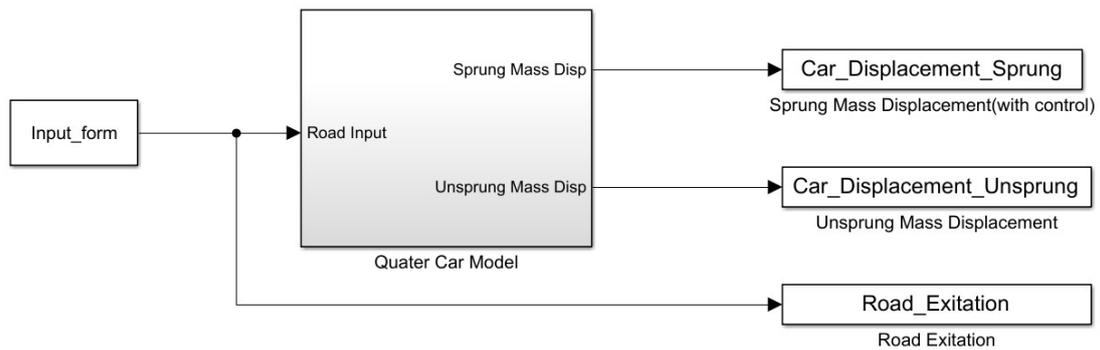


Fig 4. Simulation Model of Quarter Semi-Active Suspension System

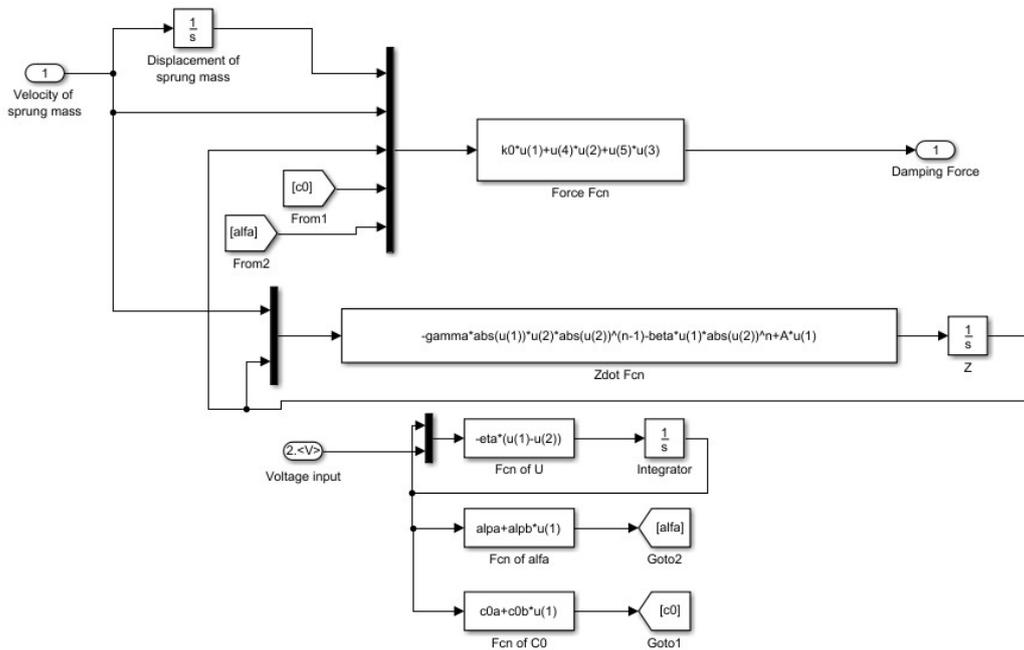


Fig 5. Simulink Model of Bouc-Wen

In Fig 4. Simulation model of sprung mass and un-sprung mass have been made under quarter car model mask. The input forms are sine excitation and random excitation. The sprung mass is experiencing the force excitation generated from the road and that force is generating a specific damping force via a voltage command. The error of force transmitted to sprung mass and damping force produced is reduced by the controller. Thus, gives the desired suspension affect.

In Fig 5. the simulation model of Bouc-Wen fluid model is applied to the suspension. The Bouc-Wen model covers the non-linear hysteric behaviour of the MR fluid and velocity of piston – damping force graph is shown below.

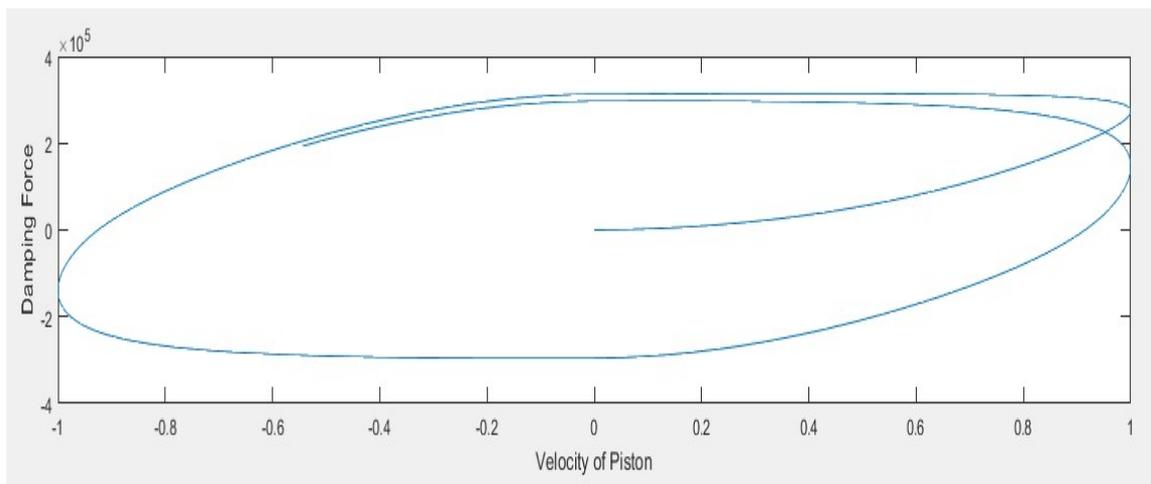


Fig 6. The hysteric behaviour of MR fluid

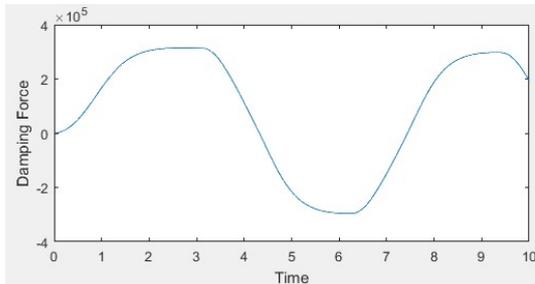


Fig 7. Damping Force v/s time graph
Displacement of piston

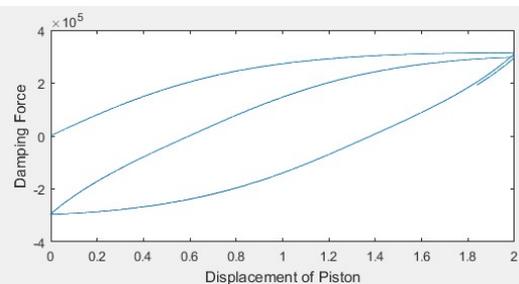


Fig 8. Damping Force v/s Displacement of Piston

The Fig. 6 gives the hysteric behaviour which is observed in the MR fluid and how the damping force varies with the rate of change of piston velocity. Similarly, in Fig 7 and Fig 8 the damping force with respect to time and displacement of the piston is studied.

4. Simulation Results

The error between the external force from the road and the available damping force is measured by the PID controller. The damping force is produced by the Bouc-Wen model in accordance with the applied force. For tuning the controller, the following values are taken [4]

$$K_p=800$$

$$K_d=5000$$

$$K_i=3500$$

These values are taken by adjusting manually in the Simulink considering settling time and peak overshoot.

The road profile in the suspension system is to be taken as first the sine input and then the random input on the output is observed through the simulation.

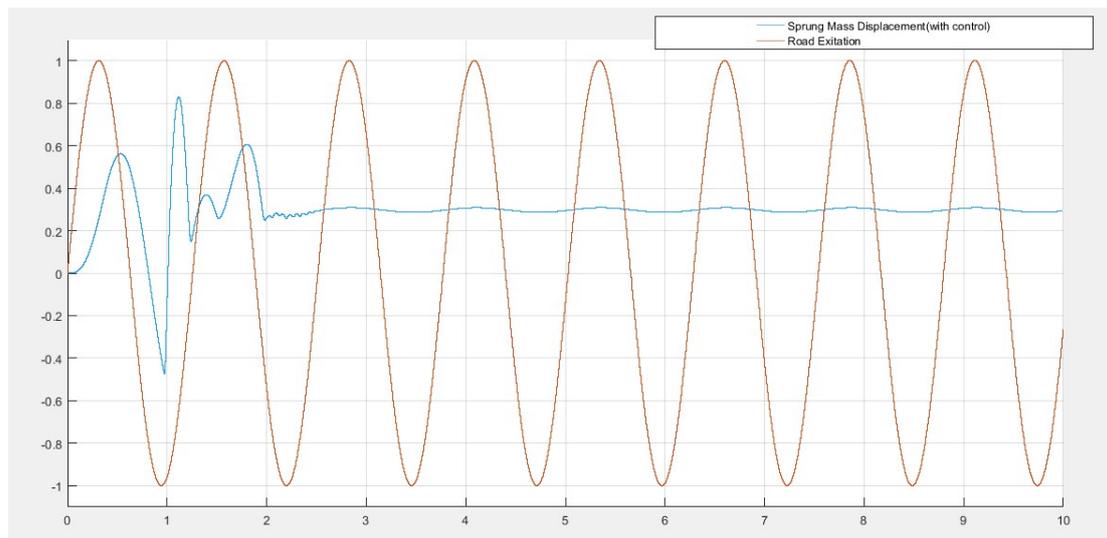


Fig 9. Sprung mass displacement when road profile is a sine input

Fig 9 gives us the displacement of sprung mass when the road input profile is in form of sine wave. With initial overshooting and undershooting, the sprung mass becomes stable. With initial

overshooting and undershooting, the sprung mass becomes stable. The sprung mass becomes stable in almost 2.5 sec with the sprung displacement of 0.8mm.

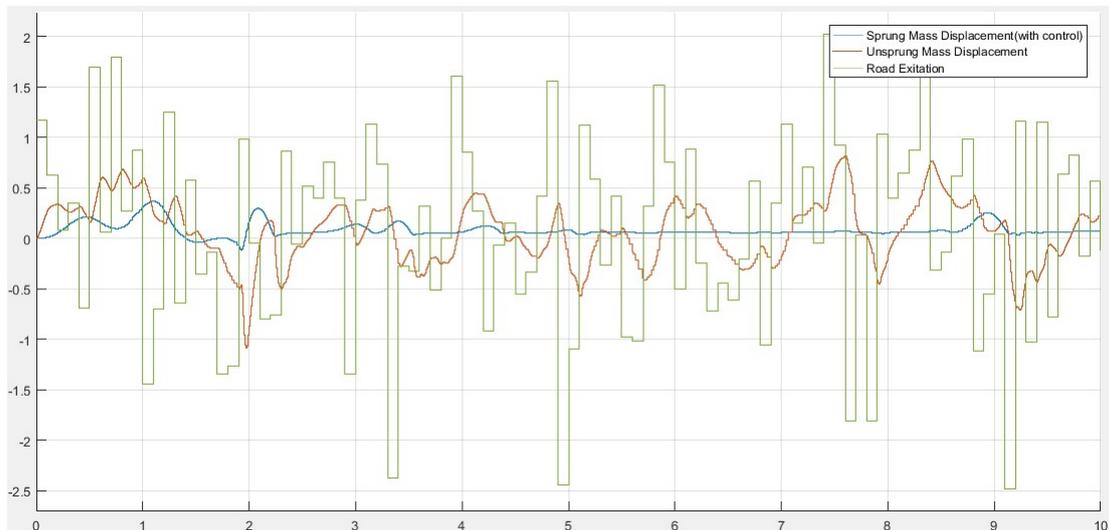


Fig 10. Sprung and un-sprung mass displacement when road profile is random input

Fig 10 gives us the displacement of sprung mass when the road profile is in form of random input. Here the case is due to random motion the sprung mass comes in good stability after some time. At the start, the oscillations are significantly high but after 3.5 seconds the sprung mass becomes stable at random road excitation with a displacement of 0.1mm from the initial position.

On the other hand, the un-sprung mass displacement is comparatively high but it is not our concerned. Thus, we can observe PID is doing controlling the damping force in accordance with road profile. The linearizing in case of sine road profile is comparatively easier than random input profile as the mean of sine is zero, therefore, it is linear in less time. Other values of proportional, derivative and integral gain can also yield desired results. MATLAB coding interface help in obtaining the hysteresis curve and displacement-time and displacement-velocity graphs. By changing values of α , β , γ , η a smoother hysteric can be obtained.

5. Conclusion

In this present study, every aspect of quarter car model is considered including the tyre stiffness and its damping also controller system along with the complex MR fluid model has been presented. The hysteresis curve is obtained between the damping force and velocity of the suspension piston as this model studies the non-linear hysteric behaviour of the MR fluid. Thus, considering all the fluid parameters the control is efficient thereby, increasing the stability of the vehicle. It also demonstrated the random excitation and also with periodic excitation and after few seconds the sprung mass is becoming stable which account for better stability for the semi-active system.

Future work may include a better control technique for linearizing the sprung mass displacement in less time such as a LQG (Linear Quadratic Gaussian) control technique can be best applied and used in high-speed cars and trains also a robust method in order to make cost-effective semi-active suspension system. The Bouc-Wen MR model gives a vast variety of applications such as from cars to trains. This is a technology in which extensive researches are being carried out worldwide.

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