Sharma et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(3), 169-173
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.10.3.03

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Simulation of Quarter-Car Model with Magnetorheological Dampers for Ride Quality Improvement

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ABSTRACT:

A semi-active suspension system using Magnetorheological (MR) damper overcomes all the inherent limits of passive and active suspension systems and combines the advantages of both. This paper gives a concise introduction to the suspension system of a passenger vehicle which is presented along with the analysis of semi-active suspension system using MR fluid dampers based on Bingham model. MR dampers are filled with MR fluids whose properties can be controlled by applying voltage signal. To further prove the statement, a quarter car model with two degrees of freedom has been used for modeling the suspension system the sprung mass acceleration of passive suspension system has been compared with the semi-active suspension system using the Bingham model for MRF damper. Simulink/MATLAB is used to carry out the simulation. The results drawn show that the semi-active suspension system performed better than the passive suspension system in terms of vehicle stability.

KEYWORDS:

Magnetorheological damper; Active suspension; Ride quality; Bingham model; Simulink model

CITATION:

S.K. Sharma and R.C. Sharma. 2018. Simulation of Quarter-Car Model with Magnetorheological Dampers for Ride Quality Improvement, *Int. J. Vehicle Structures & Systems*, 10(3), 169-173. doi:10.4273/ijvss.10.3.03.

1. Introduction

The vehicle suspension system (SS) placed between the tyre and chassis to provide relative motion between them SS consists of dampers, shock absorbers, springs and bump stops which attach the car body to its wheels. The SS consists of springs and dampers are mounted in parallel linking the vehicle body to its wheels. The spring stores the mechanical energy and thus allows the wheel to move relative to the car body when the wheel undergoes various road profiles [1-5]. The spring stores the potential energy which is changed into kinetic energy of the car body which is dissipated by the damper [6-7]. The vehicle SS aims at the vehicle stability [8-9] and ride comfort [8, 10-14]. The basic functions of automotive suspension on a vehicle are as follows:

a) To isolate the vehicle from road turbulence.
b) To make a better road holding.
c) To sustain the static weight of the vehicle.

SS is categorized as passive, semi-active, active. A passive SS uses conventional oil dampers and is reliable, simple and cheap. The tuning of the conventional passive dampers requires the physical change of their valves. The passive SS is not able to function satisfactorily in a broad range of road states because the setting is kept fixed during their lifetime.

Active and semi-active suspensions contain manage a system that forces the system to achieve optimized conditions [15-18]. Active suspensions make use of electro-hydraulic actuators which gives a required control force, calculated by the system controller. When active SS is compared with passive, it gives a high control performance for a wide range of frequency, thus, it is better than passive. However, it requires a high power supply, sensors, and servo-valves. Therefore, it is expensive and is not used for commercial applications [15-22]. A semi-active suspension makes use of magneto-rheological dampers whose force is indirectly commanded through a controlled amendment in damper properties. This transformation gets settled once the damper controller receives associate info from the system controller. Semi-active SS has benefits of each i.e. passive and active SS. It is highly economical than active suspension and provides better ride comfort and vehicle stability. If there is a failure of control system than it can also work as passive SS. Magnetorheological fluid (MRF) damper is a semi-active damper, filled with MR fluid which changes the physical characteristics when subjected to the magnetic field. Two nested controllers are necessary for semi-active SS incorporating with MRF damper.

MRF is a functional fluid that changes its physical characteristics when a magnetic field is applied. MRF consists of suspended ferrous particles like carbonyl iron particles that are micron-sized, and are dispersed in a carrier medium [23-28]. When a magnetic field is applied, these suspended particles in MRF get magnetized and align themselves with structures like chains which resist the shear deformation of fluid. This change in material results in a rapid increase in viscosity or in the formation of a semisolid state. The first is system controller, it computes the desired damping force needed by the MRF damper to achieve the given system conditions. The second is damper controller, which commands the damper to generate the desired force. This controller effectiveness depends on its skills to deal with the nonlinear hysteretic nature of the vehicle. In this paper, a quarter car model with two degrees of freedom has been used for modeling the SS, the sprung mass acceleration of passive SS has been compared with the semi-active SS using Bingham model for MRF damper.

2. Mathematical modeling

2.1. Passive suspension system

A quarter-car model is used in this work to study the ride quality of road vehicle. As mentioned earlier, SS are classified as passive, semi-active and active systems. Typical features are the required energy and the characteristic frequency of the actuator. Passive systems are the most common. So far, several models have been developed, such as quarter car, half car and full car suspension. For analysis purpose, the quarter car model shown in Fig. 1 can be effectively used to study vehicle vibrations generated by road irregularities. The equations for this model are as follows:

$$M_s A_s = -\left[K_s\left(X_s - X_u\right) + C_s\left(V_s - V_u\right)\right] \quad (1)$$

$$M_u A_u = \left[K_s\left(X_s - X_u\right) + C_s\left(V_s - V_u\right)\right] - \left[K_t\left(X_u - q\right) + C_t\left(V_u - V_q\right)\right] \quad (2)$$

Where, M_s and M_u = sprung and unsprung mass vehicle respectively, K_s, C_s and K_t, C_t are the SS and tires parameters respectively.

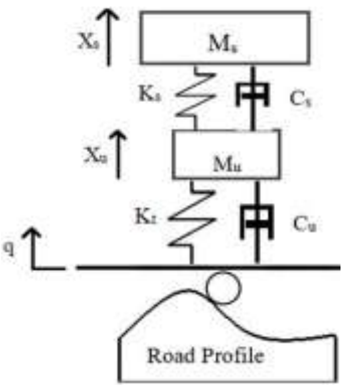

Fig. 1: Quarter car model for passive SS

2.2. Semi-active suspension system

The modeling of the quarter car using semi-active suspension system is described in this section. To simulate and identify a parameter of the MRF liquids, Bingham plastic model was proposed in 1985. Bingham model which is based on the rheological structure is shown in Fig. 2. There is a Coulomb friction element f_c which is parallel to the dashpot C_o. According to Bingham's MRF damper model, the damping force F for non-zero piston velocities V is expressed as,

$$F = f_c sgn\dot{x} + c_o\dot{x} + f_o \quad (3)$$

Where f_c is the frictional force, c_o is the viscous damping parameter and f_o is a force due to the existence of the accumulator. The characteristics of Bingham model is shown in Fig. 3 and it can be assumed that the shape of Bingham model force will be equal to Coulomb force plus friction force. The damping coefficient will be equal to the linear relationship between the force and the velocity differences.

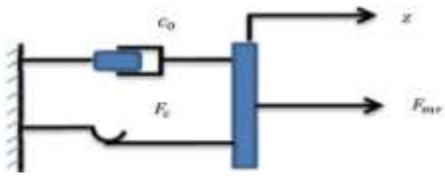

Fig. 2: Rheological structure of an MRF damper - Bingham model

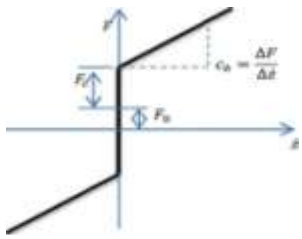

Fig. 3: Response to Bingham model

Fig. 4 demonstrates the quarter car model for semi-active SS with MRF damper and controller. Here, M_s and M_u are the one-quarter of sprung mass and unsprung mass (wheels, spring, and dampers) respectively. X_s and X_u are the displacements of masses and q represent the disturbances caused due to change in road profile, k_t is the tire stiffness; k_s is the spring constant for spring between wheel and chassis. For the system, V_s and V_u are the absolute velocity of sprung mass and unsprung mass respectively. The force f_a of semi-active SS is the function of the system controller. The controller generates the required voltage V in the MRF damper. The equations obtained from the above model for SS and vehicle body are,

$$M_s A_s = -\left[k_s\left(X_s - X_u\right) + f_a\right] \quad (4)$$

$$M_u A_u = \left[k_s\left(X_s - X_u\right) + f_a\right] - \left[k_t\left(X_u - q\right) + C_t\left(V_u - d/dt(q)\right)\right] \quad (5)$$

The design parameters for Bingham Model are taken from [13]. Table 1 shows the values of different parameters for current values.

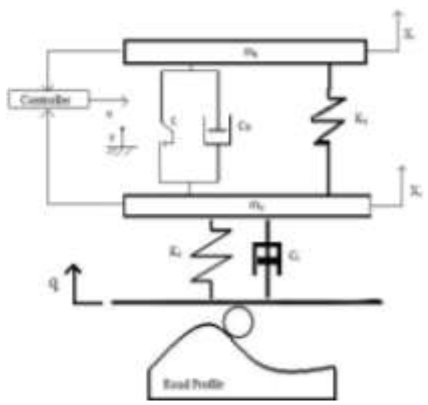

Fig. 4: Vehicle quarter car model with semi-active SS

Table 1: Parameters of Bingham model

Current	Value of parameter		
I [A]	f_c	C_0 [Ns/m]	f_0[N]
0.0	49.95	735.9	195.5
0.4	262.13	3948.7	186.28

3. System dynamics models

Modeling of quarter car model for passive SS is done using the Simulink software. Fig. 5 shows Simulink model of passive SS. Similarly, semi-active SS is modelled using Simulink and Bingham model parameters are used for MRF damper modeling. Fig. 6 shows the Simulink model of a semi-active SS. Table 2 shows values of various SS parameters. In order to model both the SSs, these parameters are taken into consideration. A random road input to compare the acceleration of sprung mass for passive and semi-active SS. Fig. 7 shows the random road profile input to the system models. A quantitative comparison between the passive SS to semi-active SS in terms of RMS amplitude (acceleration and displacement) of the vehicle body can be calculated using percentage reduction index (PRI),

$$PRI = \frac{Passive - semiactive}{passive} \times 100 \tag{6}$$

By using the above, one can identify the improvement in the ride indices.

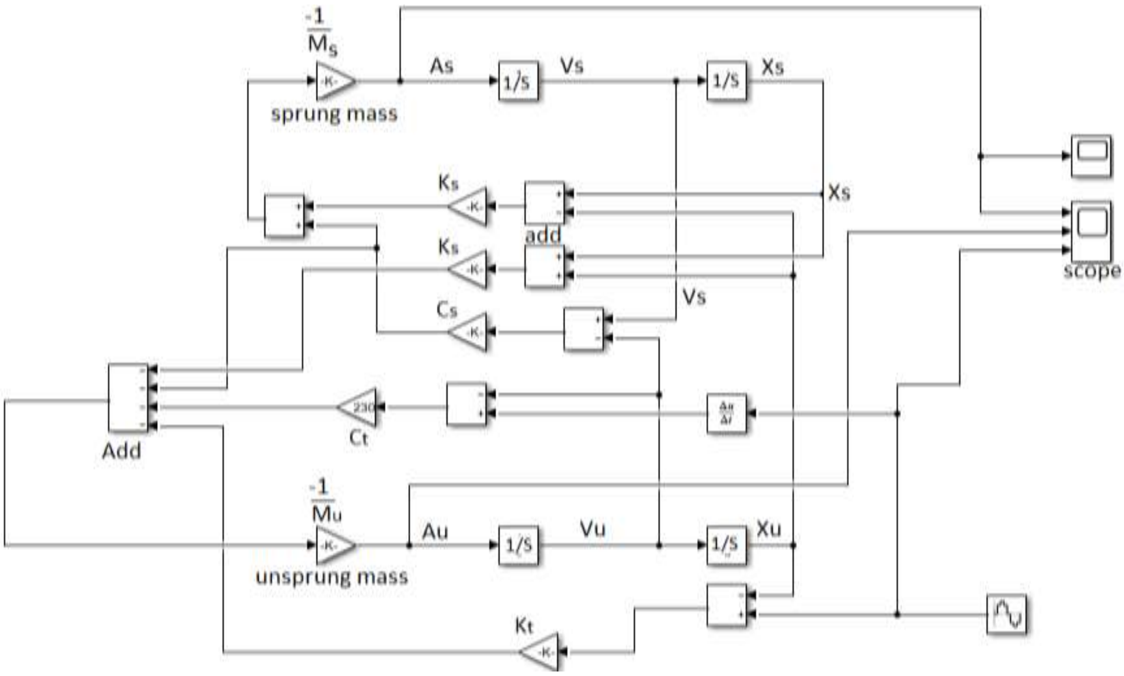

Fig. 5: Simulink modeling of passive SS

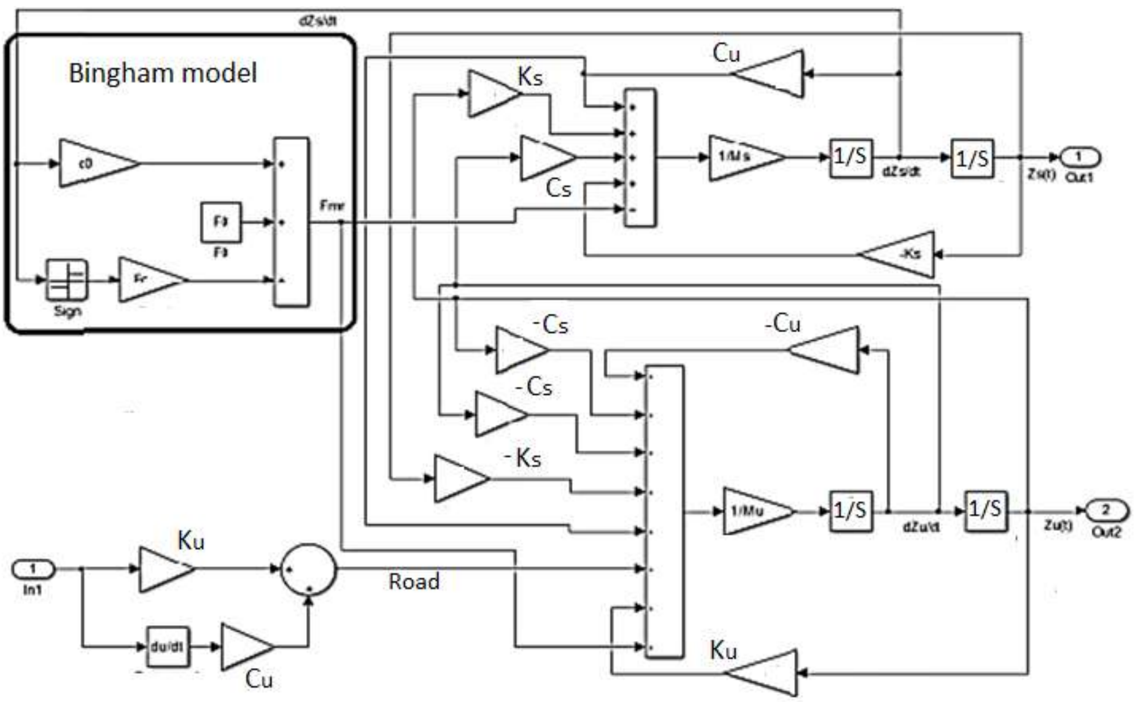

Fig. 6: Simulink modeling of semi-active SS using Bingham model

Table 2: Suspension parameters of quarter car model

System parameter	Value
Sprung mass	450 kg
Unsprung mass	45 kg
Suspension stiffness	22000 N/m
Passive damper coefficient	2300 N-s/m
Tire stiffness	176000 N/m
Tire damping coefficient	230 N-s/m

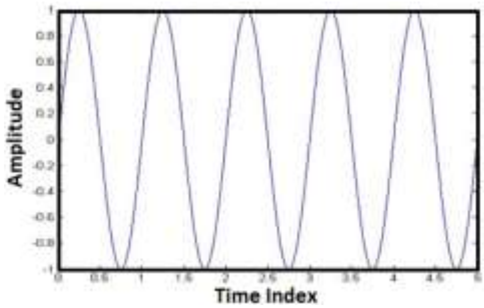

Fig. 7: Random road input

4. Results and discussions

Modeling of passive SS shows the results in Fig. 8, a graph of sprung mass acceleration of passive SS as well as semi-active SS. Fig. 9 shows the displacement response of the passive and semi-active SS for sprung mass acceleration. Table 3 shows the maximum sprung mass acceleration for passive and semi-active suspension and the difference between both.

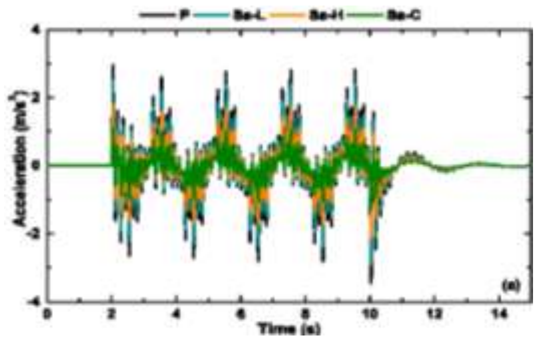

Fig. 8: Sprung mass acceleration (passive suspension) vs. time

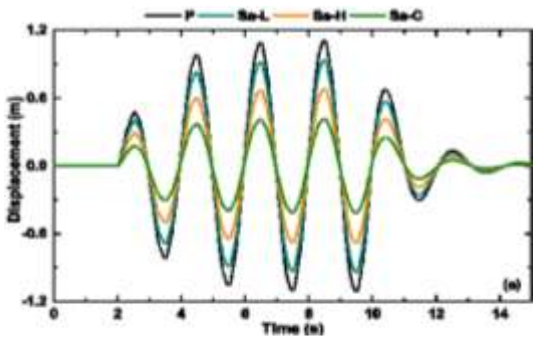

Fig. 9: Displacement response of sprung mass acceleration

Table 3: RMS value of sprung mass acceleration for passive and semi active system

SS	Sprung mass acceleration
Passive	1.55
Semi-active	1.26
PRI	23.02%

5. Conclusions

The passive suspension system and semi active suspension system with MR damper (Bingham Model) for quarter car model is analysed in this research work. The simulation results indicate that semi-active suspension system gives the lower value of maximum sprung mass acceleration for given road irregularity. It was also found that the improvement in the ride quality by percentage reduction index is 25.15 % for the semi-active suspension system. Therefore, based on an evaluation of the information obtained from the vehicle response, it was concluded that semi-actively controlled vehicles represent the better ride quality over the car models with the passive suspension system.

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