Simulation and comparison of quarter-car passive suspension system with Bingham and Bouc-Wen MR semi-active suspension models

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Simulation and Comparison of Quarter-Car Passive Suspension System with Bingham and Bouc-Wen MR Semi-Active Suspension Models

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Abstract. In this paper we want to transposion the suspension system in MATLAB, Simulink®, based on equation of motion. Consider only vertical movement of the car, neglecting roll and pitch. All movements of the car axes are modeled as having equal amplitude. The characteristic equations that describe the behavior of dynamical systems based on FBD (Free Body Diagram) of automotive suspension. It will make two models, one passive and one Bingham semi-active. Their responses will be compared between them, and with another Bouc-Wen semi-active model, more complex.

Semi-active suspension systems have received significant attention in recent years because they offer the adaptability of active control devices without requiring large power sources.

Given that both passive and semi-active dampers are in mass production will follow the normal parameters and their economic efficiency.

These models are used for initial design of suspension system.

Keywords: automotive suspension, quarter-car, passive, semi-active.

INTRODUCTION

The function of automotive suspension system is not only to isolate the effect of road surface irregularities on the passengers to improve the ride comfort but also it has to control the dynamic tyre load with acceptable suspension working space to enhance the vehicle stability and safety.[5]

The passive suspension's drawbacks can be overcome by resorting to one of three techniques, adaptive, semi active or fully active suspension. A semi-active suspension utilizes a passive spring and an adjustable damper with fast response (less than 10 ms) and the damping force is controlled in real time to improve the control of ride and handling.

Various semi-active dampers are being employed in different vibration isolation systems. Two such dampers are the newly conceived Electro-Rheological (ER) and Magnetorheological (MR) dampers. MR Fluid is composed of oil, usually mineral or silicon based, and varying percentages of ferrous particles that have been coated with an anti-coagulant material. Engineering notes by Lord Corporation (Ahmadian, M., 1999) have reported that when unactivated, MR Fluid displays Newtonian-like behavior when exposed to a magnetic field, the ferrous particles that are dispersed through out the fluid form magnetic dipoles. These magnetic dipoles align themselves along lines of magnetic flux.[1]

SUSPENION MODELS

Figure 1 (a) shows a simplified passive suspension system with two-degrees-of-freedom (2-DOF) quarter-vehicle model.

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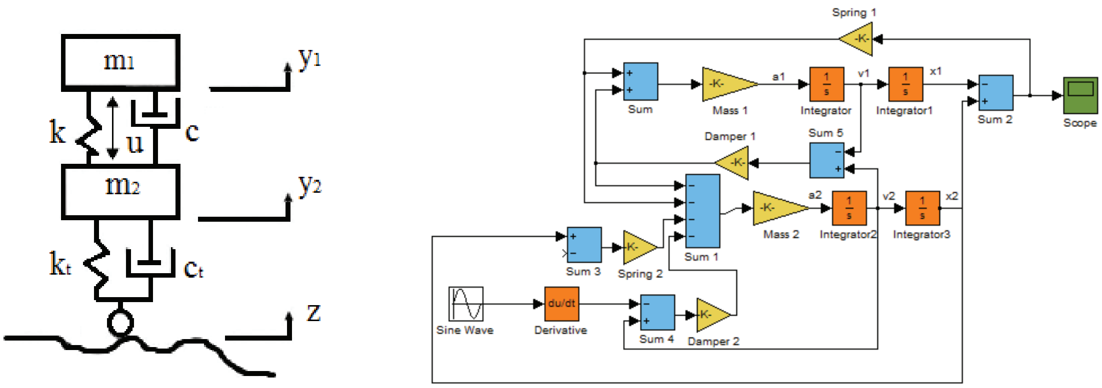


FIGURE 1. (a) Quarter-car suspension model (Chi et al., 2008); (b) Passive suspension system in Simulink

The governing equations of motion of the 2 DOF quarter-vehicle model are:

$$\begin{cases} m_1 \ddot{y}_1 + c\left(\dot{y}_1 - \dot{y}_2\right) + k\left(y_1 - y_2\right) = 0 \\ m_2 \ddot{y}_2 + c_t\left(\dot{y}_2 - \dot{z}\right) + k_t\left(y_2 - z\right) - c\left(\dot{y}_1 - \dot{y}_2\right) - k\left(y_1 - y_2\right) = 0 \end{cases} \tag{1}$$

Final model of the passive suspension system in Simulink is shown in Figure 1 (b).

There are three main types of MR dampers. These are the mono tube, the twin tube, and the double-ended MR damper. Of the three types, the mono tube is the most common since it can be installed in any orientation and is compact in size.[1]

A magnetorheological damper (MRD), shown in Figure 2, is not very different from a conventional viscous damper. The key difference is the magnetorheological (MR) oil and the presence of a solenoid embedded inside the damper which produces a magnetic field.

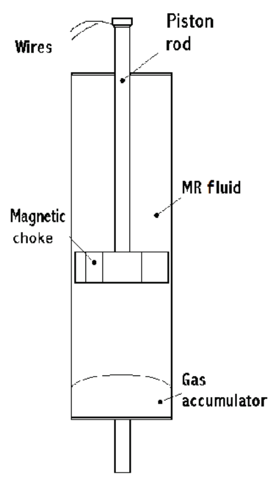


FIGURE 2. Principle of a magnetorheological damper[2]

The behaviour of MR fluids is often described as a Bingham plastic model having a variable yield strength, which depends upon the magnetic field H. At fluid shear stresses above the field-dependent yield stress $\tau_y(H)$ the fluid flow is governed by the Bingham plastic equation. At fluid stresses below the yield stress the fluid acts as a viscoelastic material. This behaviour is described by equation (2):

$$\tau = \begin{cases} \tau_y(H) + \eta\dot{\gamma} & \tau > \tau_y \\ G\gamma & \tau < \tau_y \end{cases} \tag{2}$$

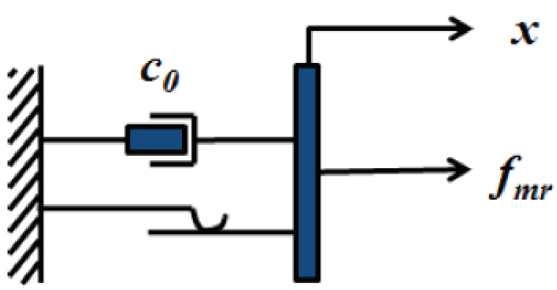
where H is the magnetic field, $\dot{\gamma}$ is the fluid shear rate and η is the plastic viscosity (*i.e.*, viscosity at $H = 0$), G is the complex material modulus (which is also field dependent).

Based on this model of the rheological behaviour of smart fluids, an idealised model, known also as Bingham model, was proposed in 1985. This model consists of a Coulomb friction element placed in parallel with a viscous dashpot. In order to obtain a better approximation of the experimentally measured data, an elastic element was added in parallel with these two elements (Figure 3.a.). In the model, the damping force is generated by:

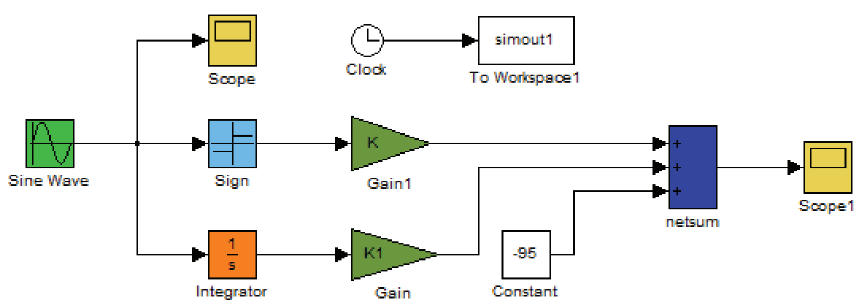
$$F_{mr} = F_c \operatorname{sgn} \dot{x} + c_0 \dot{x} + F_0 \tag{3}$$

where c_0 is the damping coefficient, f_c is the frictional force directly related to the yield stress, f_0 is the offset force, x is the imposed relative displacement and $\dot{x}$ its time derivative.[3]

The Simulink model of the Bingham system is shown in Figure 3. (b).



(a)



(b)

FIGURE 3. Bingham mechanical model[8] and Bingham Simulink model

A model that can capture a large variety of hysteretic behaviour is the Bouc–Wen model. A schematic representation of a Bouc-Wen based model of an MR damper is shown in Figure 4. (a)[3]. The Bingham model is clearly linear and since the MR damper is highly nonlinear, this model will not be an area of focus and detailed study.[8]

The model equation is given by:

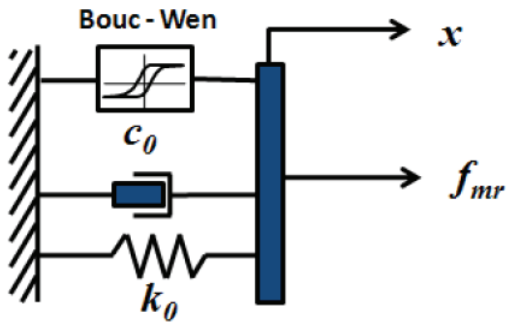
$$\dot{z} = -\gamma|\dot{x}|z|z|^{n-1} - \nu\dot{x}|z|^n + A\dot{x} \tag{4}$$

By changing the parameters γ , ν and A, the shape of the evolutionary variable z can vary from a sinusoidal to a quasi-rectangular function of the time. When the model is completed with viscous dashpots or springs the system response can predict a wide range of hysteretic behaviour. The damping force is given by:

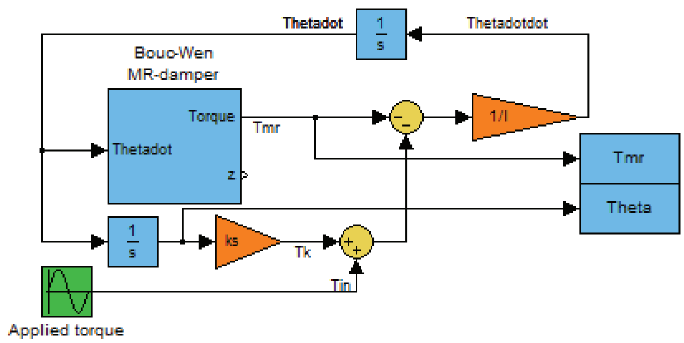
$$F_{mr} = c_0 \dot{x} + k_0 (x - x_0) + \alpha z \tag{5}$$

where the parameter α determines the influence of the model on the final force value.[3],[6]

Bouc-Wen model reproduced in Simulink is presented in Figure 4. (b).



(a)



(b)

FIGURE 4. Bouc-Wen mechanical model[3] and The physical system with the MR damper[8]

The Bouc-Wen model is the most commonly used model to capture the behavior of non-linear hysteric systems such as the MR damper. This model can produce a variety of hysteric patterns.

RESULTS AND DISCUSSIONS

Typical features of the different types of suspension are the required energy and the characteristic frequency of the actuator as visualized in Figure 5.

The response of passive system in Simulink shown in Figure 6. The response in Simulink of second system, with Bingham characteristic is shown in Figure 7.

The Bouc-Wen model were compared with the models above, achievement in Simulink, is shown in Figura 8.

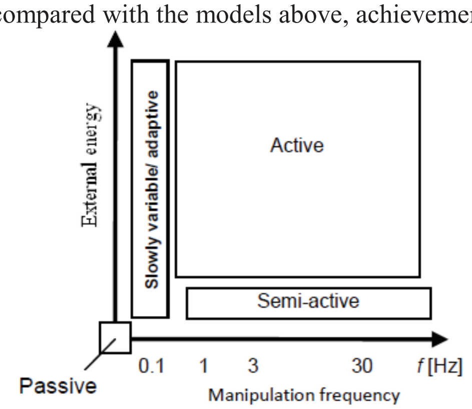


FIGURE 5. Comparison between passive, adaptive, semi-active and active systems[7]

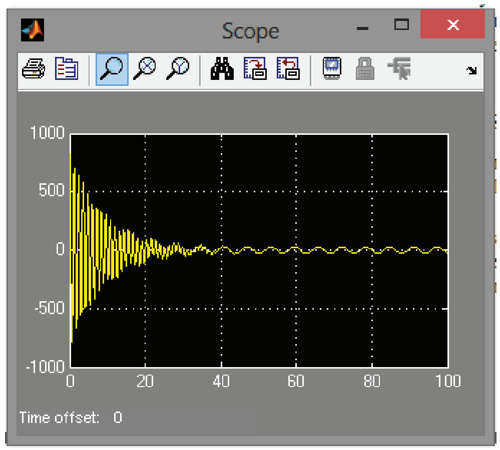


FIGURE 6. Passive resonse in Simulink

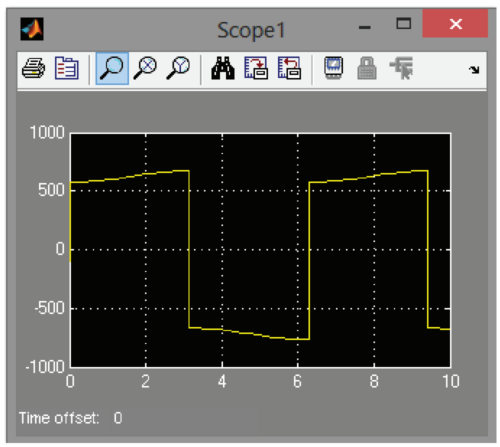


FIGURE 7. Bhingam characteristic in Simulink

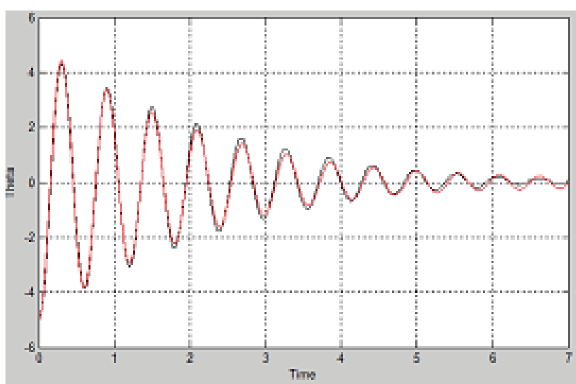


FIGURE 8. Bouc-Wen model[8]

CONCLUSIONS

The study of rheology as such, the theory behind rheological fluids, their properties and their application to vibration control. The design and fabrication of MR damper suited to vehicle suspensions were carried out.[1]

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