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EXPERIMENTAL STUDY OF MAGNETORHEOLOGICAL SUSPENSION DAMPER FOR VIBRATION CONTROL

NITIN AMBHORE[1], SHYAMSUNDAR HIVARALE[2], AVINASH SOMATKAR[1], DR. D. R. PANGAVHANE[3]

1. Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune, India.
2. Crash and Safety Simulation, Tata Consultancy Services Limited, Pune, India.
3. Director, Prestige Institute of Engineering and Science, Indore, India.

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Corresponding Author

Mr. Nitin Ambhore

Abstract

Magneto rheological (MR) dampers are being developed for a wide variety of applications where controllable damping is desired. MR damper is an intelligent damper, which is used as automobile suspension for vibration control. Vibration control of vehicle suspension systems has been a very active subject of research, since it can provide a very good performance for drivers and passengers. MR fluids dampers are very effective to control vibration, which use MR fluids to produce controllable damping force and provide both the reliability of passive systems and the facility of active control systems with small power supply. In this paper, the response of MR dampers is presented with Bouc-Wen model.

1. INTRODUCTION

Isolation or suspension systems can be used to control the vibration of moving systems. To reduce the system vibration, effective vibration control of the isolation or suspension systems is necessary [1]. The properties of automobile suspension mostly influence the vehicle ride quality and safety. At present, the widely used hydraulic mount is incapable of real-time performance adjustment based on road situation and vehicle operation estate. Therefore, it is necessary to develop an intelligent automobile suspension which is capable of real-time performance adjustment. MR damper is an intelligent damper, which is used as automobile suspension for vibration semi-active control [2].

Vibration control techniques have classically been categorized into two areas, namely, passive and active controls [1]. In passive systems, the vehicle chassis is supported by only springs and dampers. The designer pre-sets the fix damping properties to achieve optimum performance for the intended application. While in active systems, the springs and dampers are replaced, in parted or fully by actuators. The advantage of an active approach is that it can adapt for system variations, and can be much more effective than passive systems [5]. Compared with active and passive suspension systems, the semi-active suspension system combines the advantages of both active and passive suspensions; i.e. it provides good performance compared with passive suspensions and is economical, safe and does not require either higher-power actuators or a large power supply [3]. In particular, it has been found that MR fluids can be quite promising for vibration reduction. MR damper is becoming the most promising vibration controller in the intelligent suspension and motivated many automotive industries, due to their mechanical simplicity, high dynamic range, low power requirements, large force capacity, and robustness, offer an attractive means of vibration protection [4,6].

In early semi-active suspension, the regulating of the damping force can be achieved by adjusting the orifice area in the oil-filled damper, thus changing the resistance to fluid flow, but the changing of speed is much slow for using of mechanical motion. More recently, the possible applications of electrorheological (ER) and MR fluids in the controllable dampers have been discussed by many researchers [1,3,6].

In order to study the performance of the MR damper, several models were proposed by many investigators [1,3,4-9]. These models can accurately capture both the force–displacement and the force–velocity hysteresis loops [8]. The success of MR dampers in semi-active vehicle suspension applications is determined by two aspects: one is the accurate modeling of the MR dampers and the other is the selection of an appropriate control strategy [9]. In addition, theoretical and experimental researches have demonstrated that the performance of a semi-active control system is also highly dependent on the choice of control strategy. Therefore, some semi-active control schemes have been presented and compared and many other approaches, such as neuro fuzzy control and observer-based control are also incorporated into the semi-active control [10,11].

2. MR DAMPER

Nowadays dampers based on MR fluids are receiving significant attention especially for control of structural vibration and automotive suspension systems. In this section, MR damper has been studied in detail.

2.1. Physical study

The MR damper has a physical structure much like a typical passive damper: an outer casing, piston, piston rod and damping fluid confined within the outer casing. The main difference lies in the use of MR fluid and an electromagnet. The electromagnet in the MR damper can be made with coils wound around the piston. The wire connecting this electromagnet is then lead out through the piston shaft.

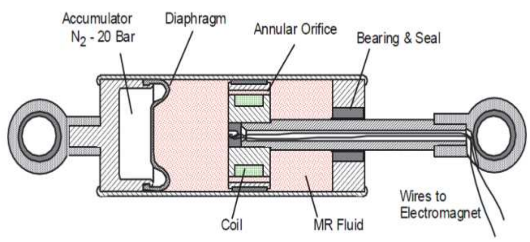

Figure 1 The mono MR damper

2.2. MR fluid

MR fluids fall into a class of smart fluids whose rheological properties change in the presence of a magnetic field. MR fluids consist of a carrier fluid, typically a synthetic or silicone based oil, and ferromagnetic particles (20–50 µm in diameter). In addition to these particles it might also contain additives to keep the iron particles suspended. In the presence of a magnetic field, however, the particles align and form linear chains parallel to the field. The chains act to restrict fluid movement and solidify the suspension thus increasing its viscosity [7].

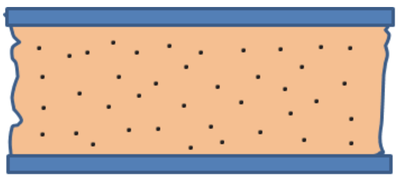

Figure 2 Magnetic particles in the MR fluid

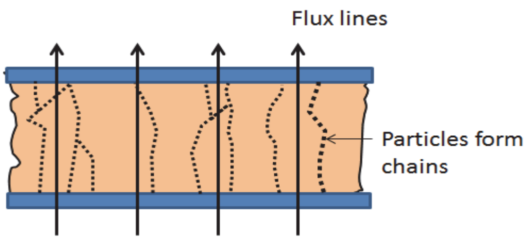

Figure 3 Particles aligning along the flux lines

With a properly designed magnetic circuit, the apparent yield stress of the MR fluid will change within milliseconds [1]. When electromagnets are used to generate the magnetic fields, the apparent yield stress is controlled by the supply current. A significant amount of work on developing electromagnetic circuits for controlling MR fluids has lead to designs that require relatively low voltages and exhibit fast response times [2,3]. Due to their unique properties, MR fluids have been used in semi-active vibration control devices.

Controlling the yield stress of a MR fluid is important because once the peek of the yield stress is reached the fluid cannot be further magnetized and it can result in shearing. It is also known that the MR fluids can operate at temperatures ranging from -40 to 150° C with only slight changes in the yield stress. Hence it is possible to control the fluids ability to transmit force with an electromagnet and make use of it in control-based applications. MR Fluids can be used in three different modes Flow mode, Squeeze-flow mode, and shear mode [8].

2.2.1 Flow mode

MR device is said to operate in flow mode when the MR fluid is used to impede the flow of MR fluid from one reservoir to another. Fluid is flowing as a result of pressure gradient between two stationary plates. This mode is used in dampers by using the movement to be controlled to force the fluid through channels, across which a magnetic field is applied.

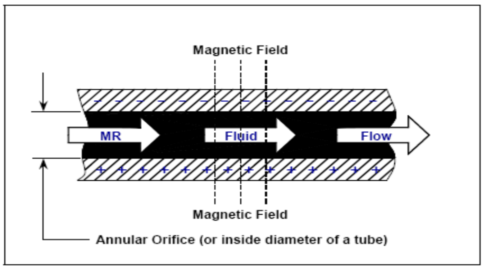

Figure 4 MR fluid valve mode [14]

2.2.2 Shear mode

In this mode the fluid is in between two plates moving relative to one another. A thin layer (≈ 0.005 to 0.015 inch) of MR fluid is developed between two paramagnetic moving surfaces. The shear mode is useful primarily for dampers that are not required to produce large forces. It is used in clutches, brakes, locking and chucking devices.

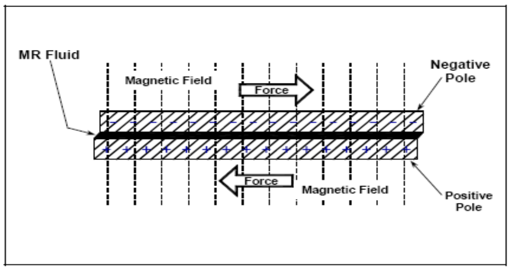

Figure 5 MR fluid in shear mode [14]

2.2.3. Squeeze flow mode

In this mode the fluid is in between two plates moving in the direction perpendicular to their planes. It is most useful for controlling small movements with large forces. A thin film of MR fluid that is developed between paramagnetic pole surfaces as shown in figure 6.

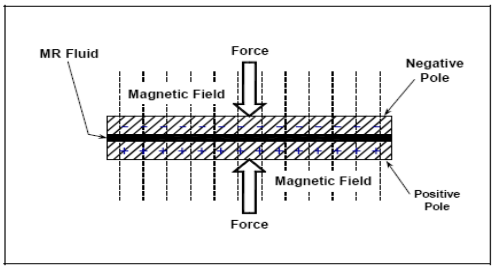

Figure 6 MR fluid in squeeze mode [14]

Based on flow dynamic theory, the governing equations of different modes are given below.

A. The flow mode which applied in most damper and shock absorber prototypes

$$F_n = \frac{12\eta LQ}{wh^3} A \qquad (1)$$

$$F_\tau = \frac{cL_a \tau_0}{h} \operatorname{sgn}(v_0) A_p \qquad (2)$$

Equation (1) a gives the viscosity contributions to the yield force and equation (2) sheds details for its rheological counterpart.

Where the parameter η is post fluid viscosity, L is the effective length of an MR device, Q is the volumetric flow rate which is the product of piston area A_p and motion velocity v_0, ω is the average radius of the MR fluid laminar slice, h is the width of fluid flow, c is a function of the flow velocity profile with a value ranging between 2 and 3, L_a is the pole length of the MR device, and τ_0 is the yield stress of the MR fluid under different external excitations.

B. The direct shear mode mostly seen clutch and brake devices

$$F_{sn.\eta} = \frac{\eta \omega L}{h} v_0 \qquad (3)$$

$$F_{sn.\eta} = \omega L_a \tau_0 \operatorname{sgn}(v_0) \qquad (4)$$

All the parameters involved in the direct shear mode are the same as those in the flow mode mentioned before.

C. Squeeze mode

$$F_{sq.\eta} = \frac{3\pi\mu r_p^{\ 4}}{2(x_0 + x)^3} v_0 \qquad (5)$$

$$F_{sq.\eta} = \frac{4\pi\tau_0 r_a^{\ 4}}{3(x_0 + x)^3} \operatorname{sgn}(v_0) \qquad (6)$$

r_p is the radius of the piston, r_a is the active radius that activates the MR fluid in squeeze mode, and x_0 is the initial gap between the bottom of the bobbin and the bottom of the outer cylinder.

3. MR DAMPER MODEL

The MR damper, however, is an intrinsically nonlinear device, which makes the modeling and design of suitable control algorithms an interesting and challenging task. To evaluate the potential of MR dampers in control applications and to take full advantages of its unique features, a mathematical model that accurately reproduces the dynamic behavior has to be developed through a suite of tests conducted using MR damper. To practically implement the device for real time vibration control one has to develop. While the previous studies on MR dampers have shown promising results.

Based on mechanisms, both nonparametric and parametric models have been reported in literature to describe the observed behaviors of electro-rheological (ER) and MR devices. Modeling the behavior of the MR damper has been studied by many researchers who have each formulated their own models which mainly include: Bouc-Wen model, modified Bouc-Wen model, neuro-fuzzy model, neural networks model, nonlinear Bingham plastic model [1,5,10,11].

3.1. Bouc-Wen model

The Bouc-Wen hysteresis model possesses an appealing mathematic simplicity and is able to represent a large class of hysteresis behavior. The Bouc-Wen model has been extensively used to simulate hysteresis loops because it can accurately portray force displacement and force velocity behavior. To evaluate the performance of MR dampers in vibration control applications Bouc–Wen model is adopted for the study. A mechanical model was developed by Spencer [12]. The schematic model is shown in figure 7.

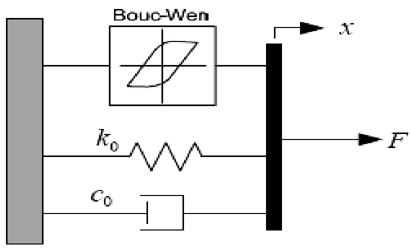

Figure 7 Bouc–Wen model

This model describes MR damper force as

$$F = c_0\dot{x} + k_0(x - x_0) + \alpha z \quad (7)$$

$$\dot{z} = -\gamma|\dot{x}||z|^{n-1} - \beta\dot{x}|z|^n + A\dot{x} \quad (8)$$

where *x* is the displacement at the damper location; *z* is the evolutionary variable; and γ, β, *n*, and *A* are parameters controlling the linearity in the unloading and the smoothness of the transition from the preyield to the postyield region.

The characteristic diagram for a typical automotive MR damper is shown in figure 8.

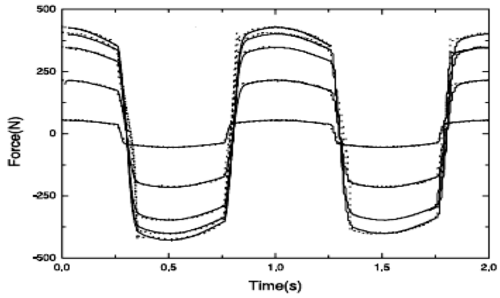

Figure 8(a). Force-Time characteristics of MR damper [14]

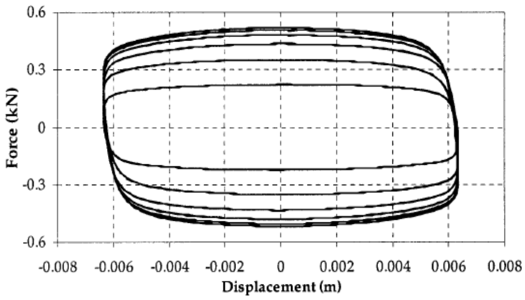

Figure 8(b). Force-Displacement characteristics of MR damper [14]

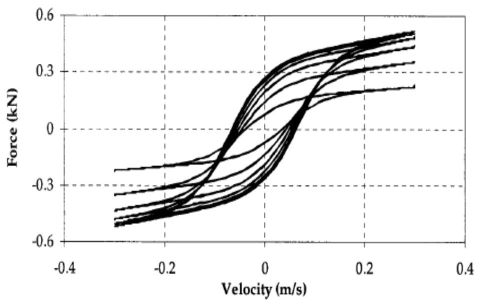

Figure 8(c) Force-Velocity characteristics of MR damper [14]

4. EXPERIMENTAL SET UP AND RESULTS

The schematic test set up is shown in figure 9 is used for the purpose of obtaining MR damper response data for parameter identification. The dynamic response of the damper can be measured for prescribed waveforms and frequencies. The vibration is used to produce excitation for the damper. It consists of a shaker and a matching power. The amplifier receives an electrical signal, amplifies it and sends it to the shaker. The load cell can sense the damping force under different conditions. A laser vibrometer is used to measure the related displacement and velocity.

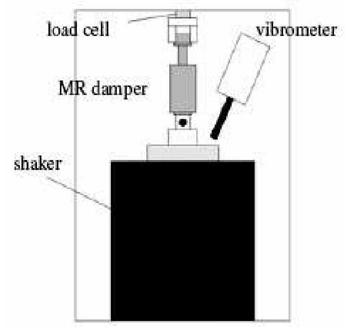

Figure 9 Schematic test setup for the MR damper

A series of tests is conducted to measure the response of the damper under various combinations of frequencies, amplitude of damper stroke and current supply. The shaker is driven with a sinusoidal signal of excitations is used. The excitation frequencies are 1, 1.5 and 2.0 Hz and the amplitudes of excitation was 38mm. The applied electric current is from 0A to 1A. Experimental data is collected at intervals of 0.1A. The response of MR damper is shown in figure 10.

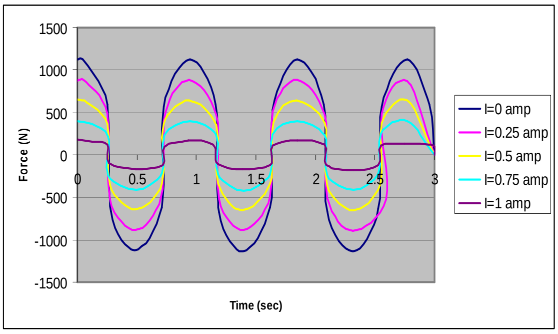

Figure 10(a) Damping force and time curve

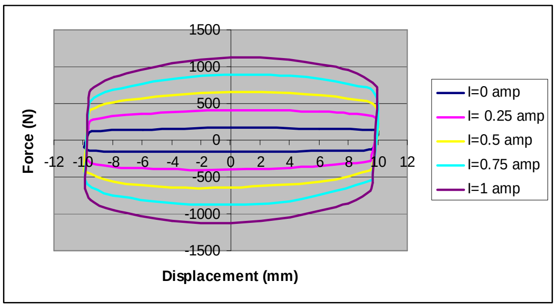

Figure 10(b) .Damping force and displacement curve

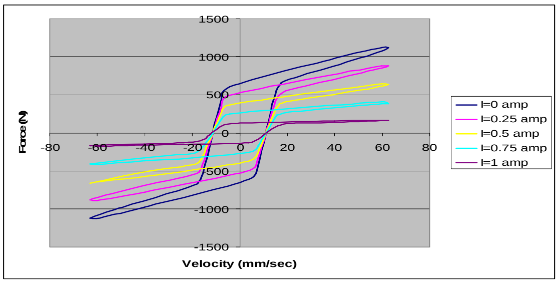

Figure 10(c) Damping force and velocity curve

5. CONCLUSION

Nowadays dampers based on MR fluids are receiving significant attention especially for control of structural vibration and automotive suspension systems. Because of their simplicity, low power consumption, scalability and ability to achieve short time responses, such MR fluid dampers are quite promising for applications in machine tools and gun recoil on naval gun turrets. This paper has presented a Bouc–Wen model for a MR damper. The response of MR damper has been studied for different electric current to represent the hysteretic relationship between the damping force and velocity. From the experiment investigation for the MR damper, it has been shown that the MR damper has a very broad changeable damping force range under magnetic field and the damping coefficient increases with the electric current, but decreases with excitation amplitude.

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