DYNAMIC CHARACTERIZATION OF A VEHICLE MAGNETORHEOLOGICAL SHOCK ABSORBER

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Abstract

Magnetorheological (MR) shock absorbers have received remarkable attention in the last decade due to being a potential technology to conduct semi-active control in structures and mechanical systems in order to effectively suppress vibration. It is therefore vitally important to understand dynamic behavior of such devices whose non-linear hysteresis is a complicated phenomenon. In the present paper, a MR shock absorbers has been designed, fabricated, tested and a fully-parametric modeling has been done using classical Bouc-Wen hysteretic model. Finally, the model has been verified against experimental data and excellent agreement has been observed between experimental and simulated data.

Keyword: Magnetorhelogical shock absorbers, MR shock absorbers, MR devices, MR Fluid, Bouc-Wen model

1. Introduction

Magnetorheological (MR) fluid are suspensions of magnetically polarizable particles with a few microns in size dispersed in a carrying liquid such as mineral or silicon oil. When a magnetic field is applied to the fluid, particles in the fluid form chains, and the suspension becomes like a semi-solid material due to increase in the apparent viscosity. Under the magnetic field, an MR fluid behaves as a non-Newtonian fluid with controllable viscosity. However, if the magnetic field is removed, the suspension turns to a Newtonian fluid in a few milliseconds, and the transition between these two phases is highly reversible, which provides unique feature of magnetic-field controllability of the flow of MR fluids. Owing to these advantages, magnetorheological (MR) shock absorbers have received much interest from different field of applications including, but not limited to, automotive suspensions, seismic vibration mitigation, large bridges vibration control, knee prosthesis [1].

Effective control of a MR shock absorber mainly depends on understanding of its non-linear hysteretic behavior under an applied magnetic field. Therefore, one needs to develop control algorithms that take maximum advantage of unique features of the MR shock absorbers, and the models must be adequately characterize intrinsic nonlinear behavior of the shock absorber [2].

Most commonly used model for describing nonlinear behavior of MR shock absorber is Bouc-Wen model. The Bouc-Wen model has been used to describe hysteretic behaviors .The general Bouc-Wen model predicts the force-displacement behavior of the shock absorber well, and it possesses force-velocity behavior that more closely resembles the experimental data.

The present study deals with the experimental and modeling approaches of dynamic performance of a linear MR shock absorber. Hence, a linear MR shock absorber has been designed, fabricated, and tested. Finally, the dynamic behavior of the present shock absorber was modeled by using analytical solution of simple Bouc-Wen model. The unknown coefficients in the model have been estimated by the parameter-optimization-technique.

2. Current-dependent analytical solution of the Bouc-Wen model

The Bouc-Wen model, whose schematic is shown is Fig. 1, is a numerically tractable dynamic model resembling both force-displacement and force-velocity behavior of MR dampers. The model essentially consists of a first-order nonlinear differential equation that relates the input displacement to the output restoring force in a hysteretic way. It is possible to accommodate the response of the model to the real hysteresis loops by choosing a set of parameters appropriately.

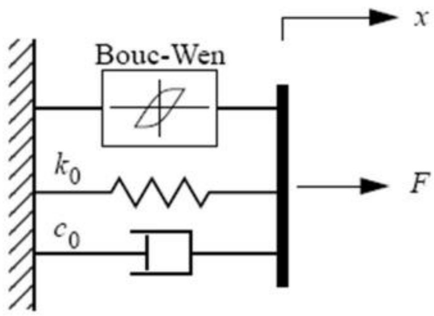

Fig. 1: Simple Bouc-Wen model.

The total damping force in the Bouc-Wen can be expressed by Spencer et al. [2] as follows

[illegible] (1)

where *z* is evolutionary variable and described by a first order differential equation,

[illegible] (2)

After some mathematical manipulations and assumptions, eq.(1) becomes following

□
□ □□ □□□ cos□□ □□□ □ □□ □□sin□□ □□□
□ □ □□ □/(□ □ □) tanh □ □ □□□ □ □□□□□ cos□□ □□ (3)
□ 1/(□ □□□ □ □□) atanh □ (□ □□□ □ □□ □ □□)/(□√□) □□□ □

where *a* is the half stroke of the MR damper and □ is angular velocity of the piston head. As a result, the total damping force of the MR damper has been expressed in a compact explicit form. The seven parameters □, □, □, □, □□, □□, and □□□ will be estimated via an optimization technique by matching the experimental data and model results.

3. Experimental study

The prototyped damper, SAUMRD002 was tested on a mechanical scotch-yoke type shock machine of Roehrig Engineering Co. to obtain its characteristic curves as force vs. time, force vs. velocity, and force vs. displacement.

4. Results and discussions

In the present study, the characteristic parameters □, □, □, □, □□, □□, and □□□ of an analytical expression derived based on the Bouc-Wen model were estimated for the prototyped MR damper, SAUMRD002 employing a parameter optimization technique. Calculations were performed using the experimentally determined force-time curves of SAUMRD002 and the analytical expression given by Eq. (3).

Variation of the estimated parameters with the applied current, 0A, 0.2A, 0.4A, 0.6A, 0.8A, 1.0A, 1.5A and 2.0A, excitation frequency of 0.63 Hz and half stroke of 12.5 mm is sketched in Fig. 2.

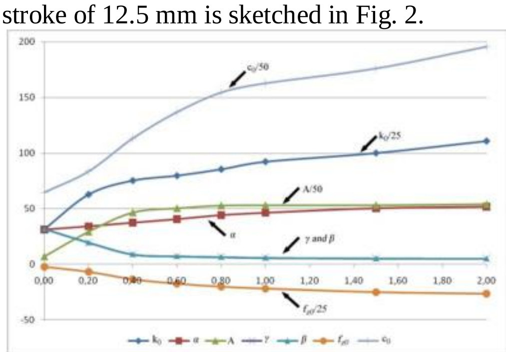

Fig. 2: Parameters c_0, k_0,Ŭ, *A*, ɔ, ɓ, f_{z0} versus current excitations

Comparisons between the model results and experimental data for each excitation current are given in Fig. 3.

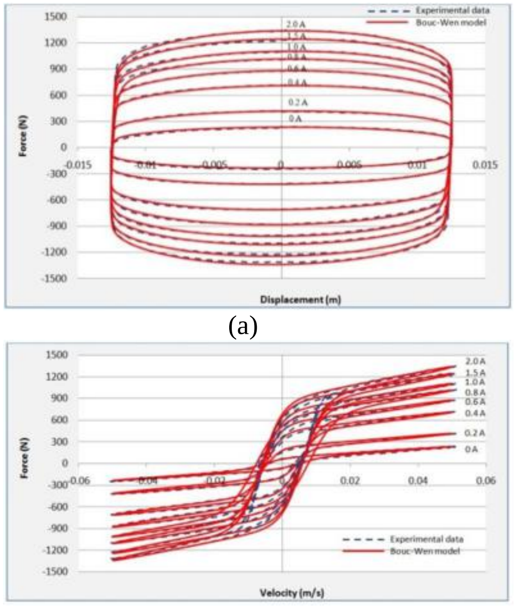

Fig. 3: Comparisons between the model results and experimental data for excitation currents of 0 A , 0.2 A, 0.4 A, 0.6 A, 0.8 A, 1.0 A, 1.5 A, and 2.0A: (*a*) force-displacement and (*b*) force-velocity.

It is observed that there is a good agreement between the results obtained from the Bouc-Wen model and experimental data. It can be deduced from Fig. 3.*b*, the model can perfectly characterize the hysteresis behavior of the MR damper. In addition to the graphical evidence, a quantitative error analysis will be carried out.

5. Error analysis

The error analysis between the predicted force obtained from the model and experimentally measured force has been done as a function of time, displacement and velocity, which was given by Spencer et al. [3]

Table 1

Results of error analysis of MR damper model

Current	□□	□□	□□□
0	0.071198	0.009732	0.027629
0.2	0.023816	0.002763	0.009592
0.4	0.022833	0.002653	0.009306
0.6	0.024801	0.002763	0.010393
0.8	0.047609	0.005099	0.020425
1.0	0.027848	0.003028	0.011604
1.5	0.029597	0.003294	0.01215
2.0	0.029427	0.003208	0.012244

6. Conclusions

The comparisons showed that there was good agreement between the model results and experimental data. Through the optimization process, all parameters, except only one (that is *n*), have been assumed to be variable as opposed to what most of authors did in the literature so far. Finally, the model has been verified against experimental data and excellent agreement has been observed between experimental and simulated data.

Acknowledgement

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