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Modelling and identifying the parameters of a magneto-rheological damper with a force-lag phenomenon ☆

G.R. Peng [a], W.H. Li [a,*], H. Du [b], H.X. Deng [c], G. Alici [a]

[a] School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
[b] School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
[c] School of Instrument Science and Opto-Electronics Engineering, Hefei University of Technology, Hefei, Anhui 230009, China

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ABSTRACT

In this study a model based on the Bouc–Wen–Baber–Noori (BWBN) method was proposed to describe the distorted hysteretic behaviour of a self-constructed magneto-rheological (MR) damper whose mechanical performance was measured with an Instron test machine. The experimental results indicated that the MR damper exhibited a force-lag phenomenon. The parameters of the modified BWBN model were identified with the MATLAB SIMULINK Design and Optimisation toolbox. A comparison between the experimental results and modelling predictions revealed that the proposed model could well present the force-lag phenomenon.

1. Introduction

Magneto-rheological fluids are suspensions of micro-sized magnetic ironic particles dispersed in non-magnetic carrying fluids that can form micro structures that look like chains, in the presence of an external magnetic field, and by doing so they exhibit increased viscosity and sound yield stress. Apart from that the fluids' rheological properties can alternate continuously and reversibly in matter of milli-seconds, characteristics which have inspired the design of a large variety of MR devices [1,2].

Among the numerous applications of MR apparatus, studies associated with an MR damper controlling semi-active suspension systems and vibration attenuation applications of civil structures are very attractive [3,4]. MR dampers have the advantage of being safe from faults, they consume low power, the force is controllable, they respond rapidly, and so on [5,6], but their non-linear force/displacement and hysteretic force/velocity characteristics are very complex. This hinders their widespread use because the design of a proper control strategy for MR dampers is based on a tractable model of their behaviour. This means that having a reliable model of an MR damper is a prerequisite before any applicable controller can be designed [7,8].

Many models, usually in the form of differential equations with several parameters to control their damping performance have been proposed because the damping force depends not only on the current that activates the magnetic field, it also depends on working conditions such as the stroke and frequency at which the MR damper moves. In light of this description,

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* Corresponding author. Tel.: +61 2 4221 3490.
E-mail address: weihuali@uow.edu.au (W.H. Li).

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the hysteretic characteristics of an MR damper can be expressed as follows, as a function of current, displacement, velocity, and acceleration:

$$F(t) = f(I, x, \dot{x}, \ddot{x}), \tag{1}$$

where $F(t)$ is the damping force, I is the applied current, x is displacement of the piston, and $\dot{x}$ and $\ddot{x}$ are the velocity and acceleration of the piston. Stanway et al. [9] developed a Bingham plastic model, which is a simple parametric model, to summarise the damping hysteresis phenomenon that contains a coulomb friction element as a signum function to vibration velocity in parallel with a viscous dashpot element. Li et al. proposed a visco-elastic plastic model by separating the varied working conditions of MRF in the damper system because the MR fluid is often considered to behave like a visco-elastic body in pre-yield mode and then viscous behaviour in the post-yield region where the effects of inertia begin to take effect. [10]. Bouc and Wen proposed a Bouc–Wen hysteresis model which possesses an appealing mathematical simplicity and has the ability to represent a large class of hysteretic behaviour [11,12]. The Bouc–Wen model has been used extensively to simulate hysteresis loops because it can describe the hysteretic behaviour of the force displacement and force velocity accurately. In this model, the force in a non-linear hysteretic system is divided into two parts: a non-hysteresis component that possesses a functional relationship with instantaneous displacement and velocity; and an evolutionary component that represents the hysteretic nature with respect to the time history of imaginary displacement. Dyke et al. [13] further modified the typical class of the Bouc–Wen model by introducing another internal displacement and proposing that some parameters of the dampers' model can be described as a function of external field excitation which would track the behaviour of the MR damper better at varied levels of magnetic field strength. Moreover, other models that use polynomial curve-fitting [14,15], black box [16] and non-parametric approaches also exist [17], but these types of MR damper model are more flexible even though the physical definition of some parameters in the model cannot be expressed explicitly.

There are three major methods used to identify the parameters in the model, the separately constrained non-linear optimisation method, the analytical method, and stochastic search method. The constrained non-linear optimisation method [4,12] is used the most. Due to there being more complex forms of Bouc–Wen type models, the analytical method that uses the relationship between the model parameters and hysteresis loops of MR damper models to identify parameters has been adopted [18,19]. The stochastic search method, like the genetic algorithm (GA), is widely used because of its flexibility in solving complicated dynamic problems [20,21].

Established MR damper models have been successfully applied to countless research projects and commercial applications of the MR damper [22,23], but they fail to take the distorted hysteresis loops, which exist widely in many MR dampers [24], into consideration. For instance, the force-lag phenomenon, which is mainly caused by fluid compressibility and vacuum for flow block at an active gap of MR dampers, is shown in Fig. 1. In this figure, the hysteretic loop of MR dampers has some distortions, phenomena that are commonly observed in many applications [25]. Most current studies focused on the measurement as well as the solution for these distortions, whereas modelling the force-lag phenomenon is rarely reported. Thus it is very necessary to study the method for modelling the deformed hysteretic loops of MR dampers.

In this study, a model that can describe the deformed hysteretic loops of MR dampers is proposed. To begin, the experimental setup of the dynamical test of the self-manufactured MR damper is introduced and the results of the hysteresis loops of the experiments are given, after which the conventional Bouc–Wen model was used for the analysis, and then the shortage of this model is discussed. A modified model is then presented and successfully validated by the experimental results.

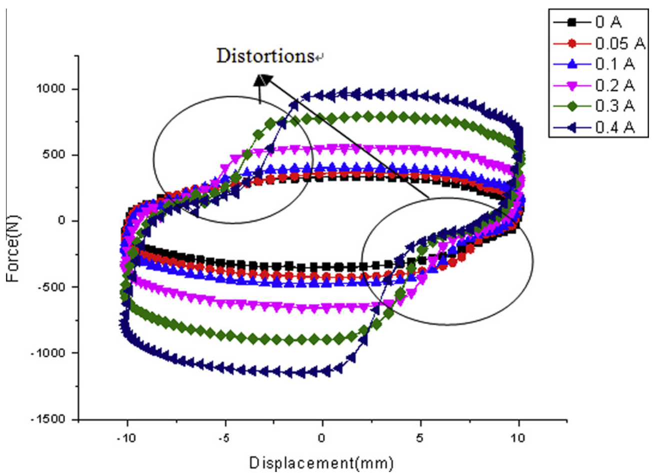

Fig. 1. Distorted force–displacement relationship observed from the damper test.

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