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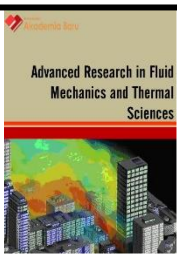

Application of Magneto Rheological Damper Semi Active System in Warren Truss Bridge Structure

Fatemeh Behbahani[1,*], Uswah Khairuddin[2], Rubiyah Yusof[1]

[1] Department of Artificial Intelligence and Robotics (CAIRO), Malaysia-Japan International Institute of Technology (MJIIT), UTM, Kuala Lumpur, Malaysia
[2] Department of Mechanical Precision Engineering, Malaysia-Japan International Institute of Technology (MJIIT), UTM, Kuala Lumpur, Malaysia

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ABSTRACT

This paper considers the application of magnetorheological (MR) damper, RD-8040-1, for attenuation vibration in flexible truss bridge deck structures. The modelling and identification of the damper property by using SAP2000 analysis software from an experimental data set generated by dynamic tests of the MR damper mounted in a testing machine where velocity and current are used as input, and the force as output. Theoretical investigations and in-site experiments are carried out in Chamran's laboratory, Ahvaz, Iran. Truss bridges are an innovative structure that shall be studied in their systems and connections to earn stability and damping in related to certain lateral loads such as seismic load's post-earthquake load. The issue of damping is the cooperation between elements in the truss bridge of deck systems. Significantly, MR damper among components based on their reaction can be defined in the form of a percentage of control of loads in the structure of deck in a bridge system. This article proposes the application of damper at interconnecting of bridge deck through minimizing vibration force by using the Bouc-wen model. In summary, this paper is understood the effect of damping application on overall formation nonlinear analysis Models at this major element.

Keywords:
Magnetorheological damper (nonlinear); Warren truss bridge; Seismic analysis; dynamic forces; modified Bouc-Wen model

1. Introduction

One of the challenging viewpoints for using and improving smart devices by reason of their inherent nonlinear feature, to attain great efficiency and performance is the improvement of models that can accurately explain their unique characteristics. For semi-active control of bridge system, MR dampers are generally used which can be seen in review papers by several authors [1-4]. In this article, the characteristics of MR dampers are made a summary of the experimental responses under

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[*] *Corresponding author.*
E-mail address: pegah65behbahani@gmail.com

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various conditions. According to this, the parametric dynamic modeling for MR devices and identification technique for MR damper is explained. In the past two decades, the researchers have been concentrated the models for MR dampers on how to develop modeling precision. Even if the force-displacement behavior is perfectly denoted for MR dampers by a most maximum of the suggested dynamic models, the simple parametric models with great precision cannot detected and the measured force – velocity response in the area of zero velocity is still working on that by most of the researcher for describing more accurate in hysteresis behavior of MR damper, when the efficacy of hysteresis arises to take effect. Also, the parametric dynamic and inverse parametric models for MR dampers are rarely explored with on-line updating capability. Additionally, MR dampers can be described with a dynamic model for the force-velocity and force-displacement behavior which is not only defined by the dynamic model itself but also defined by the identification technique.

1.1 Magnetorheological Fluids

MR fluids display a fast, eversible and adjustable transmission from a free-flowing to a semi-solid state on the usage of an exterior magnetic field. MR fluids can give a simple, manageable and fast response; therefore, they have attracted noteworthy notice nowadays it was conducted by Kordonsky [5]. In the late 1940s, Rabinow [6] demonstrated the first diagnosis and improvement of MR devices ascribed to Rabinow at the US National Bureau of Standards and later, Simon *et al.,* [7] described the effective magnetic properties of magnetorheological fluids. When the magnetic field is exerted, the particles are rowed with the exterior field that makes them to form linear chains parallel to the field. This happening can confine the fluid movement. Accordingly, the yield stress is technologically advanced and the variation and fluctuation can happen in only a few milliseconds depend to magnitude of the applied magnetic field. The main benefit of MR fluids stems from their large and controllable dynamic yield stress induced by the high magnetic energy density which be dissolved in the fluids conducted by several researchers [8-13] and also some researcher attempt to design new damper, for example, Unuh *et al.,* [17] introduced the new OEM damper which can yield necessary magnetic flux and shear stress and this magnetic flux density to react with superior properties of MR fluid.

2. Experimental Setup

From a theoretical viewpoint, MR devices can be used of the low voltage sources. Additionally, these devices are most promising for natural disasters and cost-sensitive uses because of without awe of dielectric breakdown.

In this paper, we will focus on the parametric dynamic model for MR damper which is used RD-8040-1 to describe the MR damper model as displayed in Figure 1 and also, Table 1 is characterized of this type of damper. The MR damper is subjected to various loading conditions by a damping force testing machine which makes force and displacement caused to the damper. This information is accomplished to compute the model parameters. As a final point, the predicted model is compared with the experimental results presenting the efficiency of the parametric model to predict the MR behavior.

Fig. 1. MR damper model RD-8040-1 (short stroke) with current driver

Table 1
Specification data for the fluid damper RD8040-1

Lord MR damper RD-8040-1	
Parameter	Value
Extended length (mm)	208
stroke length (mm)	55
Body Diameter (mm)	42.1 max
Shaft Diameter (mm)	10
Weight (g)	800
Operating temperature (°C)	Damper should be stored -40 to +100 (-40 to +212 °F)
Electrical characteristics:	
Maximum input current (A)	2 max
Input voltage (VDC)	12 DC
Resistance (Ω)	5 Ω at ambient temperature 7 Ω at 71°C
Mechanical characteristics:	
Maximum extension force (N)	2500
maximum tensile strength	8896
Maximum operating temperature (deg)	71°C max
MR fluid (MRF132-DG) data	
Response time (ms) (amplifier & power supply dependent)	<15 (time to reach 90% of max level during a 0 to 1-amp step input)

In the experimental system, it is employed as a controller and a hydraulic actuator to run the damper. So that collect the experimental force, velocity, and displacement responses of the MR damper, RD-8040-1, which is jointed to a hydraulic actuator with the aim of apply harmonic input at one end of MR damper at various frequencies that was taken to laboratory university of Chamran, Ahvaz, Iran, for measured analysis in the damping force analysis machine, as illustrated in Figure 2. The actuator has a 3.5 cm diameter cylinder and a ±20 mm stroke fitted with low friction Teflon seals to decrease non-linear effects. Also, the servo valve with a frequency range of 0-50 Hz, made by Moog Inc., is used such as the final control target to adjust the movement. The data acquisition system including up to eight control axes, up to four analog input channel users, and four analog output channel users. Sinusoidal displacement input is given to the test damper. The experimental results are repeated to test again for different current (0–2A in steps of 0.5 A) applied to the damper. The experimental responses are collected in two categories: force-displacement and force-velocity for variation of frequency of 1 to 6 Hz in 1 (Hz) intervals. The force- displacement for each frequency and the maximum force versus frequency illustrates that the higher values of currents cause to investigate values of forces for damper. With the fixed stroke at 30 mm (amplitude of ±15 mm), the frequency of input fluctuation is risen steadily to gain various speeds. During every test run, by the Wonder Box of Lord Corporation model RD-3002-03 (control driver) is applied a fixed current to the coil and the current are measured using a multimeter. The current given is measured by DC clamp current meter. In other words, Braz-César *et al*., [15] indicated a converter with fixed input voltage and output current which is monitored on the MR damper response as for the current although the input voltage can be measured to denote the damper response. The displacement of the piston-rod of damper (stroke) is obtained in the hydraulic actuator by a position sensor. Moreover, a computer connected with the control software is utilized to make system vibrations, as the computer with a current amplifier circuit sent the current signal to tune the damper feature. Test runs are taken at different levels of current applied to the damper. As a result, the response signals measured by the position sensor (LVDT) and the load cell is returned to the computer to implement all information gaining with input and output signals. The experimental damping forces are illustrated against the time, displacement and velocity in Figure 3(a), (b) and (c), respectively. The experimental peak force with the current is shown in Figure 3(d). The damping forces against the displacement with a frequency of 1.00 Hz and storks of (3 to 15mm) for the current of 0.5 A are shown Figure 4(a) and (b), respectively. And also, with different frequencies of 1 to 6Hz, amplitude of 15mm with 0.5 A against the displacement and velocity are illustrated in Figure 5(a) and (b), respectively, and the force-frequency is illustrated in Figure 5(c).

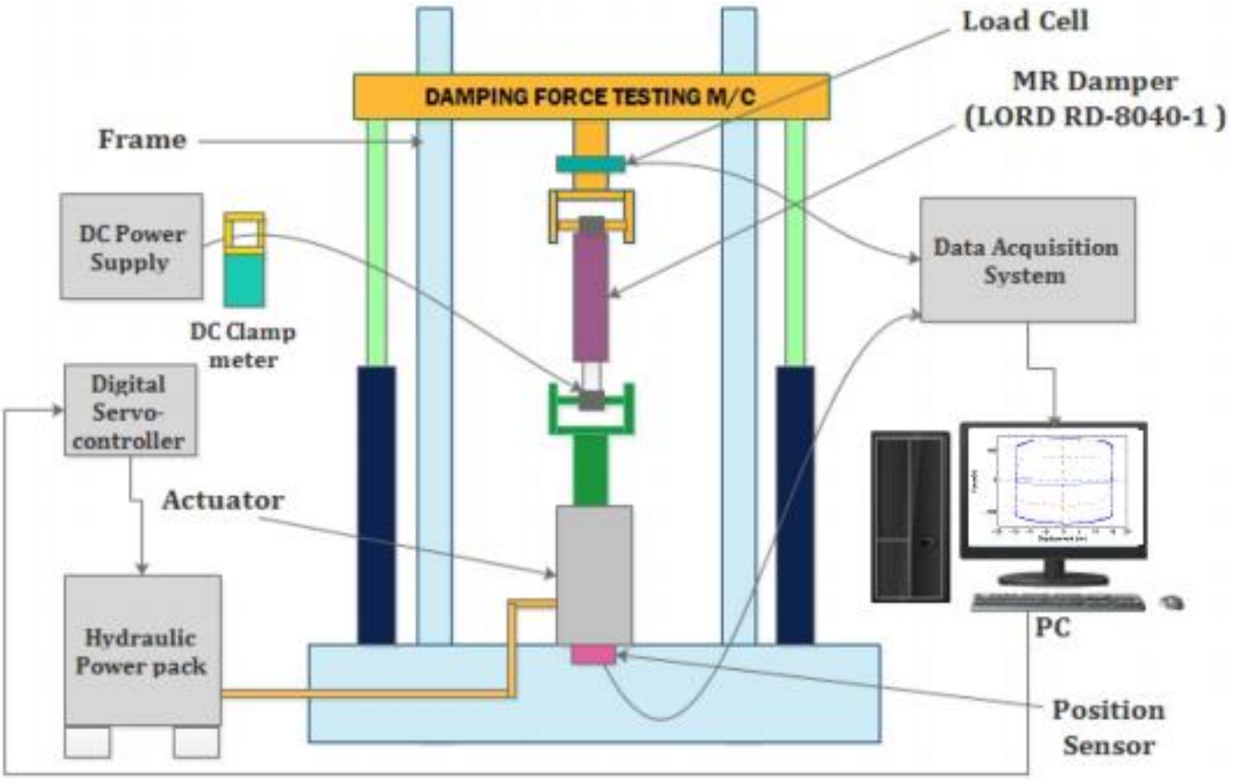
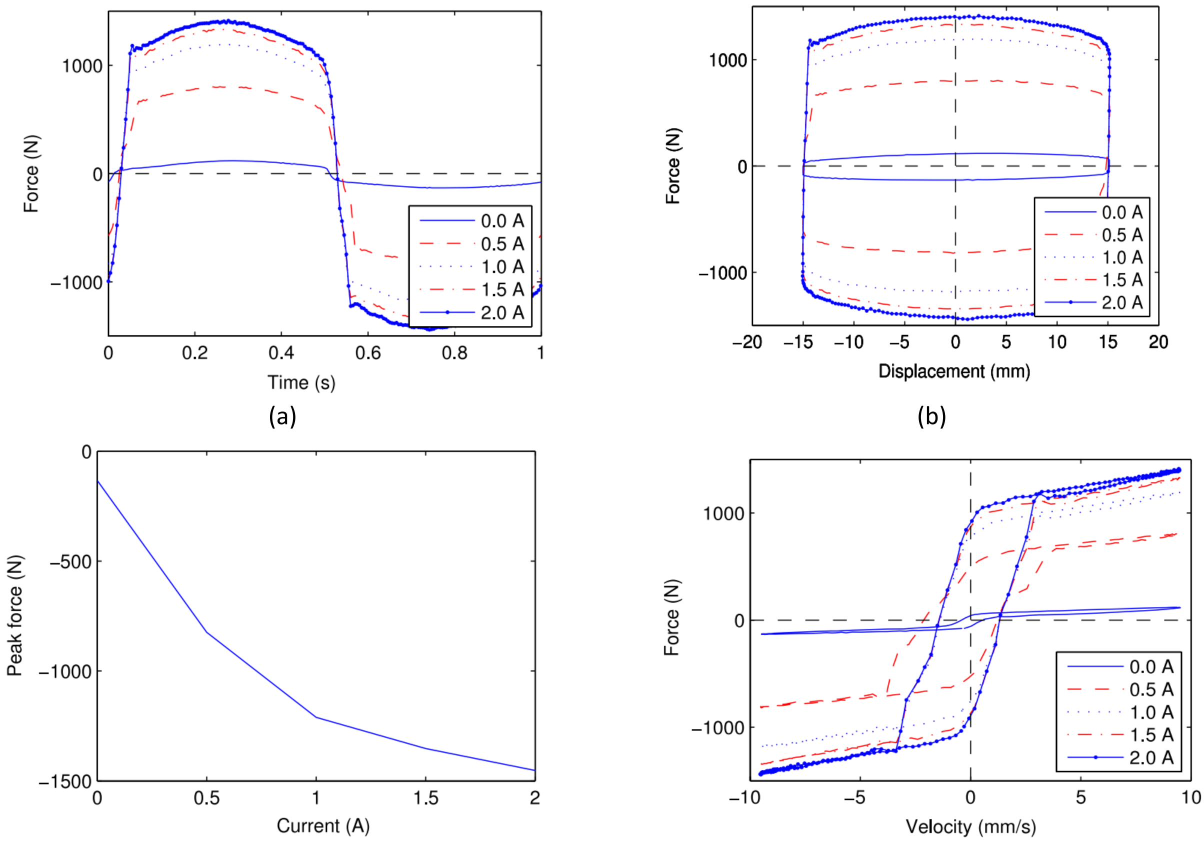


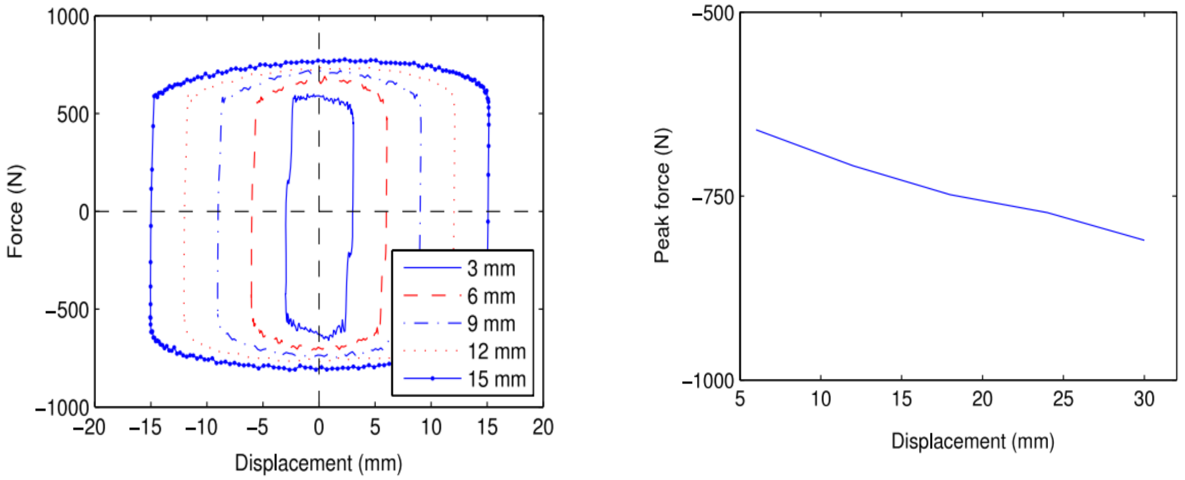
Fig. 2. Schematic of experimental setup [16]



(a) (b)

(c) (d)

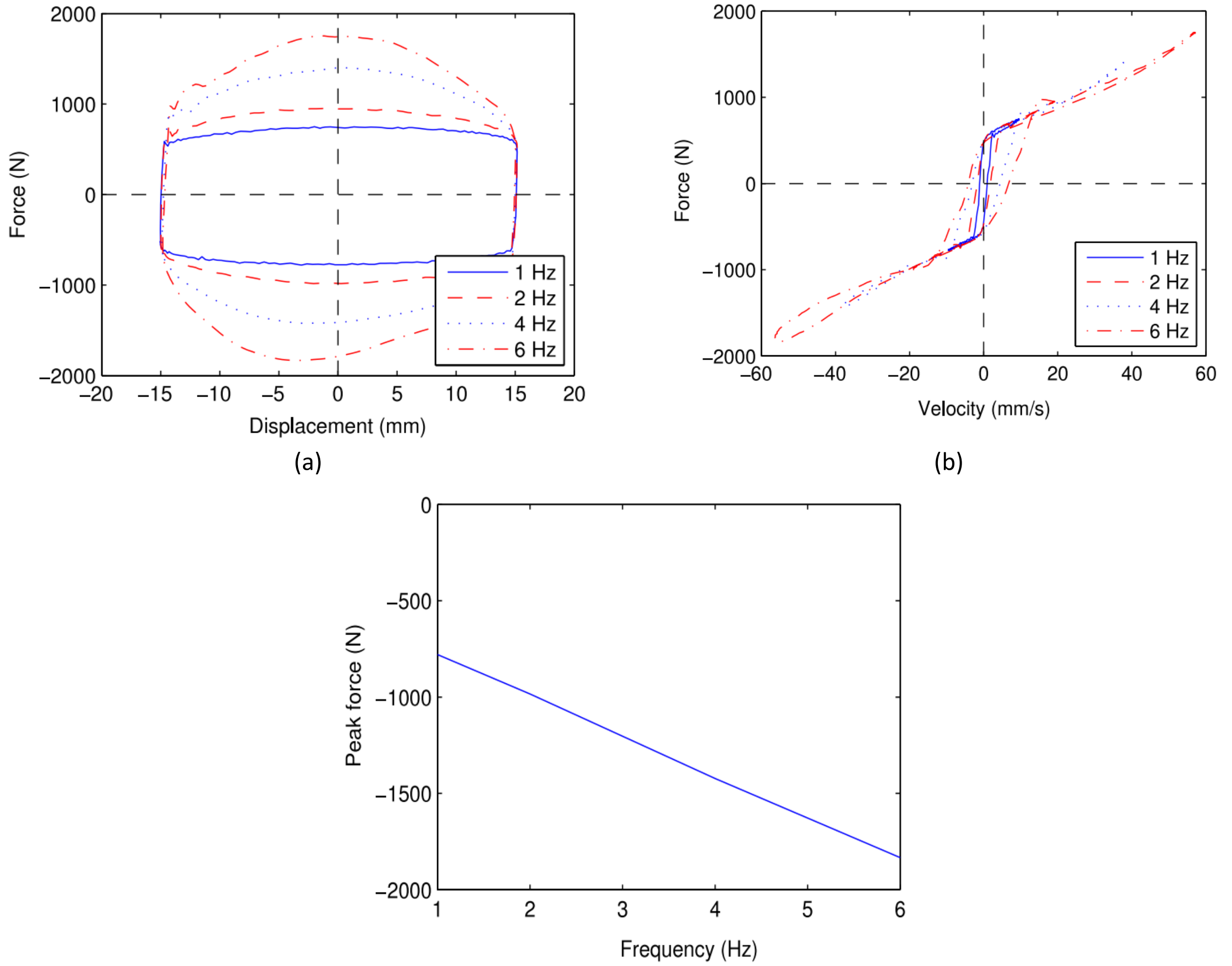
Fig. 3. Damping forces with a stork of 15 mm and 1 Hz for different current: (a) force-time (b) force-displacement (c) force-velocity and (d) force-current



(a) (b)

Fig. 4. Damping forces with a different stork and 1 Hz for current 0.5A: (a) force-displacement (b) peak force- displacement

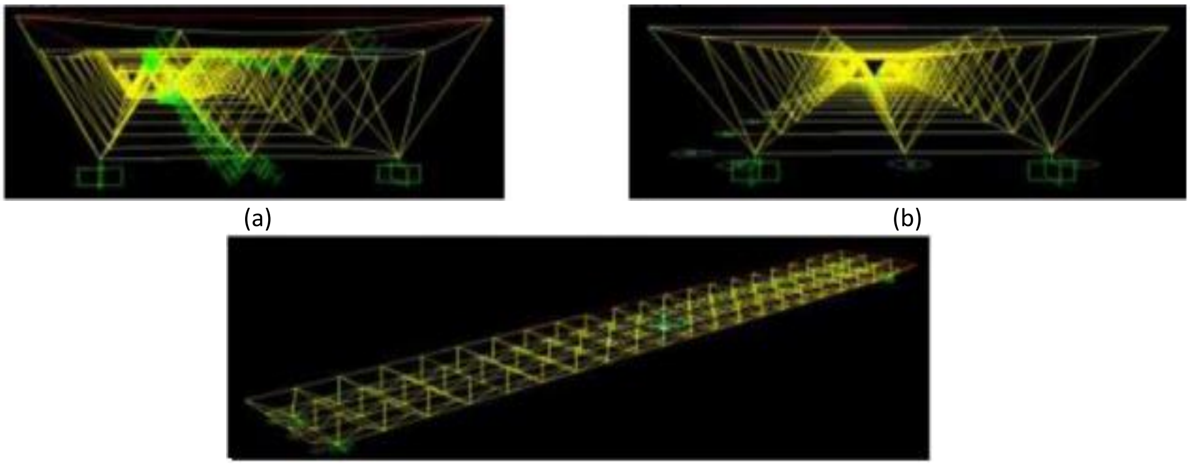
The proposed structure is truss bridge which has 100 m length and 10 m width. The type of a truss is warren in two directions with divisions of 5m. The Magnetic damper parameter has been defined in central perpendicular members longitudinally. The regular dynamic force has been loaded on it to check the function of a damper in controlling of vibration cause of dynamic force which is verified by experimentation (See Figure 6).



(a) (b)

(c)

Fig. 5. Damping forces with a stork of 15 mm and 1 Hz for different frequencies with current of 0.5A: (a) force-displacement (b) force-velocity and (c) force-frequency



(a) (b)

(c)

Fig. 6. Truss bridge structure (a) by using damper (b) without damper (c) full structure of the bridge

3. Methodology

The MR damper is a set of linear and/or nonlinear springs, dampers, and physical elements which is characterized by the parametric modeling method. Different parametric models for MR dampers consist of the Bingham, biviscous models, Dahl hysteresis models, viscoelastic–plastic models, Bouc–Wen hysteresis models, LuGre hysteresis models and etc. have been discovered. These parameterized models can make a consternation range for MR dampers by identifying the parameters. While a model is nominated, the parameters are defined in that way the error is reduced between the measured data and the prediction responses. Here, the proposed model is modified Bouc-Wen which approved by Spencer *et al.,* [9].

3.1 Mechanical Model

The mechanical model of the device illustrated in Figure 7 has been indicated to properly estimate the MR damper behavior with a wide variety of inputs. The model is administrated by the following equations

$$c_1\dot{y} = \alpha z + c_0(\dot{x}_d - \dot{y}) + k_0(x_d - y) \tag{1}$$

The force measured is known by

$$f = \alpha z + c_0(\dot{x}_d - \dot{y}) + k_0(x_d - y) + k_1(x_d - x_0) \tag{2}$$

From Eq. (1), the total force can also be written as

$$f = c_1\dot{y} + k_1(x_d - x_0) \tag{3}$$

While the evolutionary variable z is governed by

$$\dot{z} = -\gamma|\dot{x}_d - \dot{y}|z|z|^{n-1} - \beta(\dot{x}_d - \dot{y})|z|^n + A\,(\dot{x} - \dot{y}) \tag{4}$$

And the internal displacement (y) of the damper given by Solving Eq. (1) for $\dot{y}$ results in

$$\dot{y} = \frac{1}{c_0 - c_1}\{\alpha z + c_0\dot{x}_d + k_0(x_d - y)\} \tag{5}$$

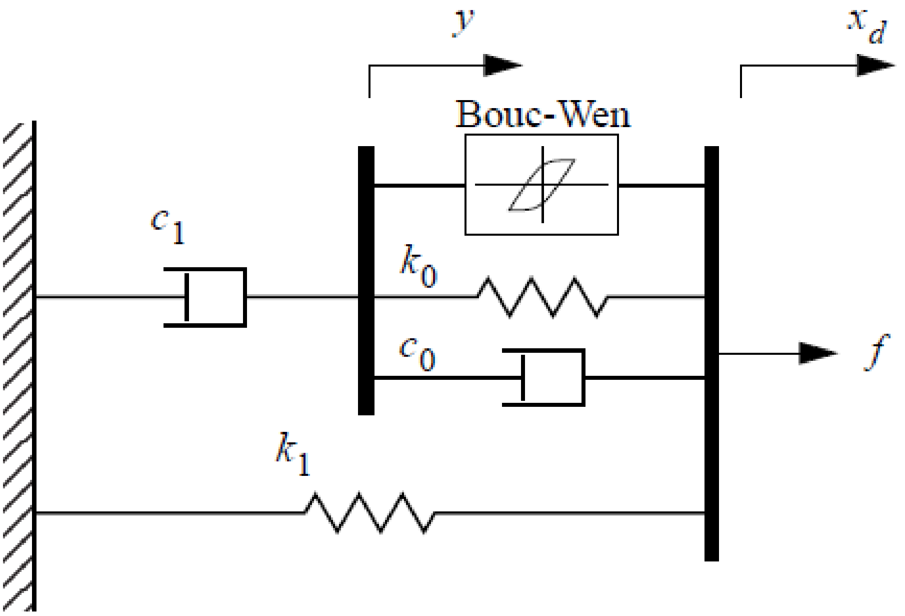


Fig. 7. Spencer model for MR dampers [9]

Here, k_1 is the accumulator stiffness and c_0 and c_1 are the viscous damping at larger and smaller velocities, respectively. k_0 is displayed to control the stiffness at large velocities, and x_0 is the initial displacement of spring k_1 related to the nominal damper force induced the accumulator. x_d and f are the displacement and the force created by the MR damper respectively; the internal displacement of the MR damper is y . Where, A, β, γ, and n are dimensionless quantities internal displacement (piston movement). For small amounts of the positive exponential parameter n the transition from elastic to post-elastic branch is smooth, whereas for large values the transition becomes abrupt, approaching that of a bilinear model. Parameters β and γ control the size and shape of the hysteretic loop. Ma *et al.,* [10] explained that the parameter A in the original formulation of the model, but it became evident that it is redundant. The non-linear shape of the hysteretic curve can be tuned by varying the values of the parameters A, β, γ, and n in Bouc-Wen block. Generally, these parameters are fixed but the parameters α, c_0, c_1 are supposed to be functions of the applied current.

Behavior of MR damper is accurately described by the modified Bouc–Wen model, all parameters which pertain the feature of hysteresis's shape with current excitation should be detected. All parameters are known

$$\theta = (c_0, c_1, k_0, k_1, x_0, \alpha, \gamma, \beta, n, \eta \text{ and } A \qquad (6)$$

The parameters are predicted on the applied current (I), that is specified by the voltage (v) applied to the current driver. It approved a linear relationship between the parameters and the applied voltage that is covered by Spencer *et al.,* [9]

$$\alpha = \alpha(u) = \alpha_a + \alpha_b u \qquad (7)$$

$$c_1 = c_1(u) = c_{1a} + c_{1b} u \qquad (8)$$

$$c_0 = c_0(u) = c_{0a} + c_{0b} u \qquad (9)$$

Here, the damping coefficient and Coulomb force of the damper are known as c_{0a} , c_{1a} , and α_a are at 0 V, respectively, and u is an inherent variable to define functional dependence of the applied voltage v. The relationship between u and v is shown by the first-order filter given by

$$\dot{u} = -\eta(u - v) \tag{10}$$

The time response of the MR is reverberated by η. The larger η states more rapidly response time, and v is the operating voltage is transferred to the current driver. A 14 constant parameters should be determined

$$\theta = (c_{0a}, c_{0b}, k_0, c_{1a}, c_{1b}, k_1, x_0, \alpha_a, \alpha_b, \gamma, \beta, n, \eta \ and \ A) \tag{11}$$

3.2 Identification and Validation

The parameters of the models are detected by measured data to create the hysteresis loop approve. A total of 14 parameters which are specified in Table 2, is gained to portray the damper by experimental data and a constrained nonlinear optimization algorithm. The proposed model is the most common model for evaluating the dynamic behavior of MR dampers in theory. The mentioned model is created in MATLAB/ Simulink so that to calculate the output damping force. The Eq. (3) and Eq. (5) can be stated by the integrators and summation, and the unknown parameters are replaced by the constant values in Simulink. The equations are collected in embedded MATLAB functions. The velocity of the piston is computed from displacement by differentiators. The proposed model illustrates in Simulink is shown in Figure 8 and also comparison of predicted and experimental results is shown in Figure 9 as well.

Table 2
Parameters for the Model of MR Damper

Variable	Value	Variable	Value
C_{0a}	784 N.s.m^{-1}	α_a	12441 N m^{-1}
C_{0b}	1803 N.s.V^{-1}.m^{-1}	α_b	38430
C_{1a}	14649 N.s.m^{-1}	γ	136320 m^{-2}
C_{1b}	34622 N.s.V^{-1}.m^{-1}	n	2
K_0	3610 Nm^{-1}	β	2059020 m^{-2}
K_1	840 Nm^{-1}	η	190 s^{-1}
x_0	0.0245m	A	58

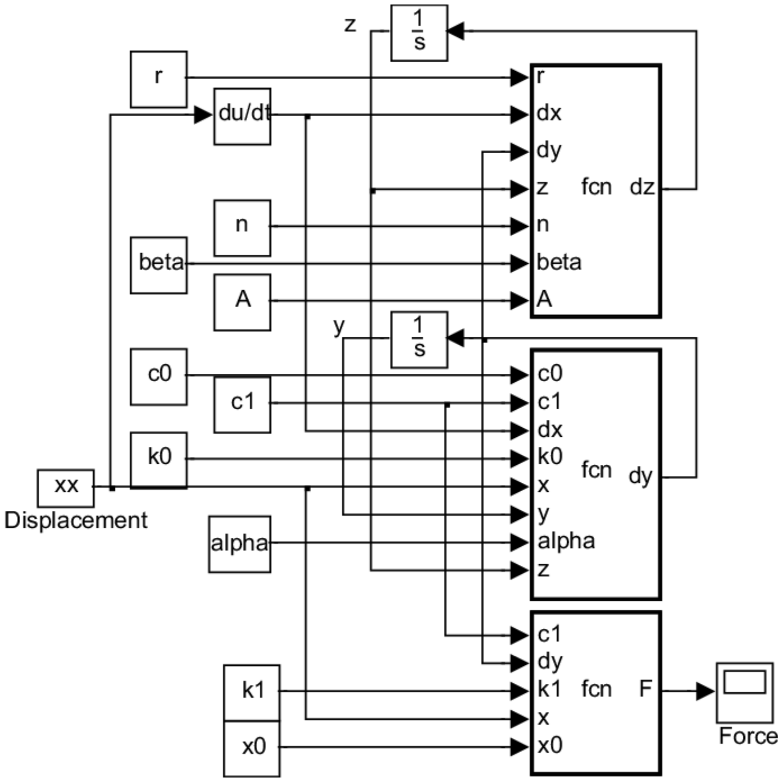


Fig. 8. The Bouc-Wen modified model described in Simulink [11]

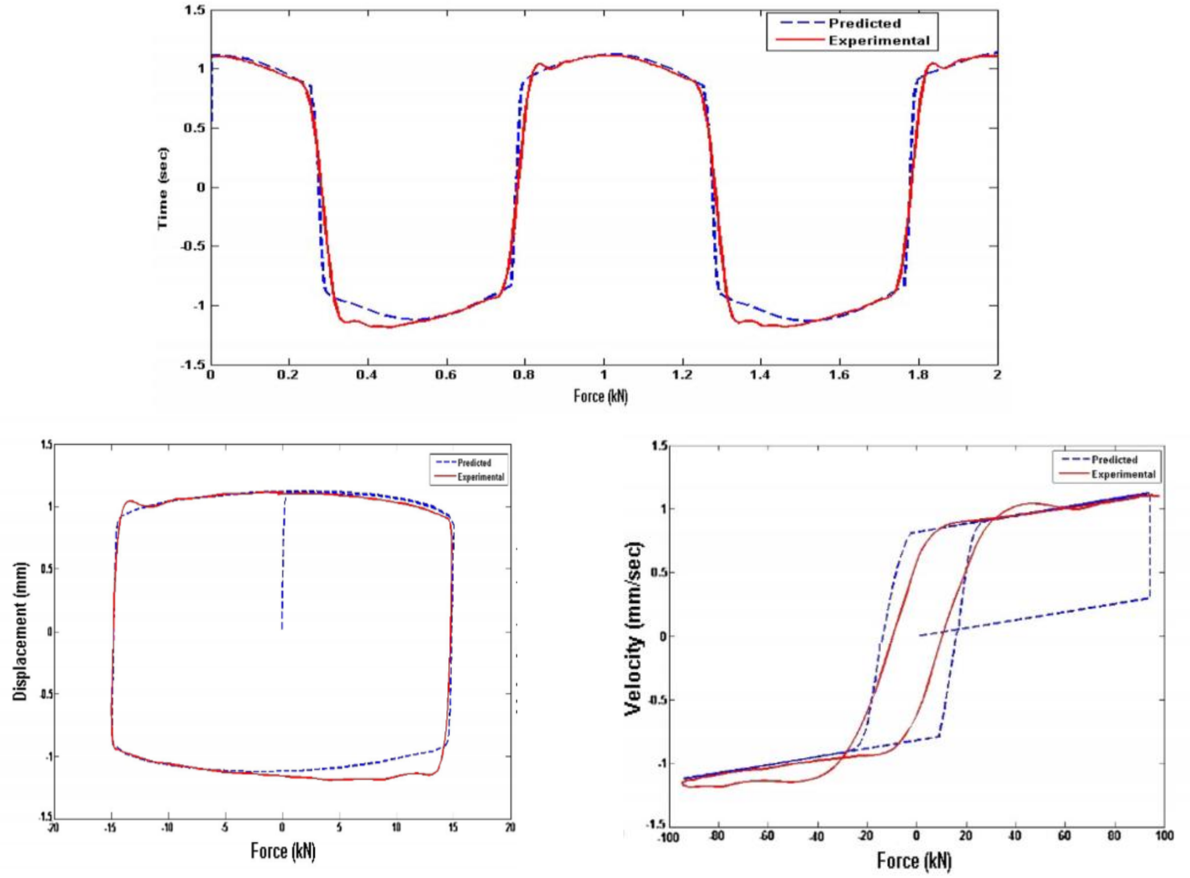


Fig. 9. Comparison of predicted and experimental results of RD 8040-1 short stroke MR damper with sinusoidal excitation of 15 mm amplitude, 1 Hz frequency, 1 A input current

In Spencer *et al.,* [12] the model errors have been evaluated by means of an experimental setup with actuators, displacement and force transducers. In others Word, the error between the predicted force and the experimental force are calculated as a function of time, velocity and displacement. The following explanations have been utilized for numerical evaluation of normalized errors which provided by Dominguez *et al.,* [14].

$$E_t = \sqrt{\frac{\int_0^T (f_{exp} - f_{model})^2 dt}{\int_0^T (f_{exp} - \bar{f}_{exp})^2 dt}} \tag{12}$$

$$E_x = \sqrt{\frac{\int_0^T (f_{exp} - f_{model})^2 \left|\frac{dx}{dt}\right| dt}{\int_0^T (f_{exp} - \bar{f}_{exp})^2 \left|\frac{dx}{dt}\right| dt}} \tag{13}$$

$$E_v = \sqrt{\frac{\int_0^T (f_{exp} - f_{model})^2 \left|\frac{d\dot{x}}{dt}\right| dt}{\int_0^T (f_{exp} - \bar{f}_{exp})^2 \left|\frac{d\dot{x}}{dt}\right| dt}} \tag{14}$$

f_{model} is the predicted force, f_{exp} denotes the experimental force, and $\bar{f}_{exp}$ is the experimental force's average value along the T period. E_t , E_x and E_v are normalized errors between model and experimental force in time, displacement and velocity, respectively. Errors up to 15% for time, 4% for displacements and 13% for velocities have been informed for various current levels.

4. Result and Conclusions

As the given results explicate, it is feasible to forecast the non-linear hysteretic behaviour of a damper by a proposed model. The output damping forces are attained with modified Bouc-Wen and compare the estimated force and experimental force. At the beginning, the dynamic responses were measured by testing experiments on a machine test with different sinusoidal displacement excitations and different frequencies, applied currents and 15mm amplitude. Accordingly, the parametric modelling of MR damper was given and the identification and justification technique was demonstrated. In general, the models for MR dampers have been concentrated in the past two decades on how to develop the modelling precision. Their summing-up be described as follows

i. The behavior of force-displacement for MR dampers is perfectly displayed by the Modified Bouc-Wen model and force-velocity is still should be evaluated with better response and high accuracy.
ii. A parametric model with high accuracy for MR damper can be found but no simple model.
iii. "Whether one dynamic model for damper can portray the force-displacement, and force-velocity behavior is not only determined by the dynamic model itself but also determined by the identification method".

The results of the aforementioned model are demonstrated in Figure 9 in a comparison with the real damping behaviour for a 1Hz and 1A of the applied current to a predicted force of the truss bridge structure of MR damper. The outcomes illustration that the nonlinear feature of the damper can be guesstimated with remarkable precision for the force-displacement, force-velocity, and force-time relation notwithstanding the changing of applied current for the damper. The proposed model indicates a great predicting at the end, especially on the low current. As the value of velocity is high, the model defines well the hysteresis behaviour. As a result, the Modified Bouc-Wen model can estimate the damping force with higher precision.

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