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MODELLING OF MAGNETORHEOLOGICAL DAMPER DYNAMIC BEHAVIOUR BY GENETIC ALGORITHMS BASED INVERSE METHOD

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The modelling of magnetorheological (MR) dampers by an inverse method is proposed. A modified Bouc-Wen modified dynamical model is considered and its parameters are obtained by using genetic algorithms (GA). The experimental data consist in time histories of current, displacement, velocity and force measured both for constant and variable current. The model parameters are determined using a set of experimental measurements corresponding to different current constant values. Next, the resulting model is validated on the data measured for variable current.

Key words: Magnetorheological damper, genetic algorithm, inverse method.

1. INTRODUCTION

In recent years have been reported many applications of MR-dampers, in various areas such as vehicle suspensions, seismic protection of buildings during earthquakes, semi-active control of sagged cables, engine mounts or fluid power systems.

The MR-dampers allow for variable control of energy dissipation in a simple design. Rapid response time and efficient power requirements make the systems one of the most effective means possible for interfacing mechanical components with electrical controls. These properties are due to the MR fluids ability to change from a free-flowing liquid to a semisolid in milliseconds when exposed to a magnetic field, and instantly back to a liquid when the field is removed. The MR fluids used in dampers are suspensions of micron-sized magnetically soft particles in synthetic oil. When the current applied to the damper is zero the fluid is not magnetized and the particles exhibit a random pattern. In the magnetized state, the applied magnetic field aligns the metal particles into fibrous structures, changing the fluid rheology to a near plastic state. By tuning, the current supplied to the electromagnetic circuit of the damper, a variation of the magnetic field is obtained that allows for any level between the low forces in the “off” state to the high forces in the “on” state. In addition, the damping performance is nearly independent of velocity providing high or low damping at any velocity, according to the employed semi-active control strategies. This is difficult to produce with other hydraulic systems.

Both parametric and non-parametric models have been developed to portray the observed behaviour of MR-dampers. Spencer et al. [1] developed a phenomenological parametric model that accurately portrays the response of a MR-damper to cyclic and random excitations for both constant and variable magnetic field. The proposed solution is a modified Bouc-Wen (BW) model that has a set of parameter, depending on the current variation. Other works, for example [2] and [3], study the efficiency of the model identification based on some computational intelligence paradigms (fuzzy logic, neural networks). In addition, in [3], one can find a comparative analysis of different models with respect to the approximation accuracy, which could guide the user in choosing the suitable model for his application. For instance, Butz and Stryke [4] have shown that the difference of using the modified BW and Bingham plastic models in a vehicle suspension system is very small.

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In this paper is proposed a method of finding the BW modified model parameters by using the genetic algorithms optimization procedure. In first step, there are found the values of parameters for a set of constant values of applied current and an imposed cyclic motion, such that the predicted response optimally fit the experimental data. The second step consists in obtaining the variation law for each parameter versus current, considering the corresponding values from step one. The resulting model is validated by comparison of predicted and experimentally obtained responses for some cases with variable control current.

2. EXPERIMENTAL DATA

The experimental data were obtained by testing a LORD magnetorheological damper, [7], under various loading conditions for both constant and variable control current within the range 0.02-1.75 amps. The internal resistance of the device, measured at 30°C, is 5.2 Ω. This value was considered in order to obtain the current corresponding to the variable control voltage supplied to the current driver.

The experimentally measured response of the MR-damper due to a 1.5 Hz imposed cyclic motion with an amplitude of 1.6 cm is shown in fig.1 and fig.2, for four constant current levels, 0.1 A, 0.2 A, 0.6 A and 1.75 A.

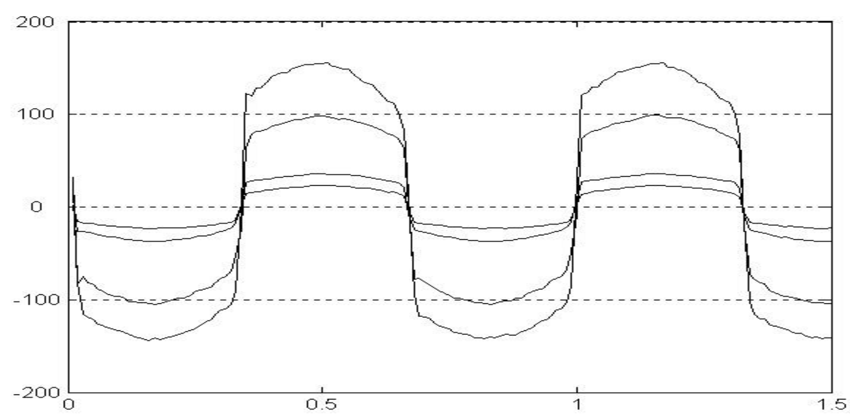

Fig. 1. Force [daN] vs. time [s]

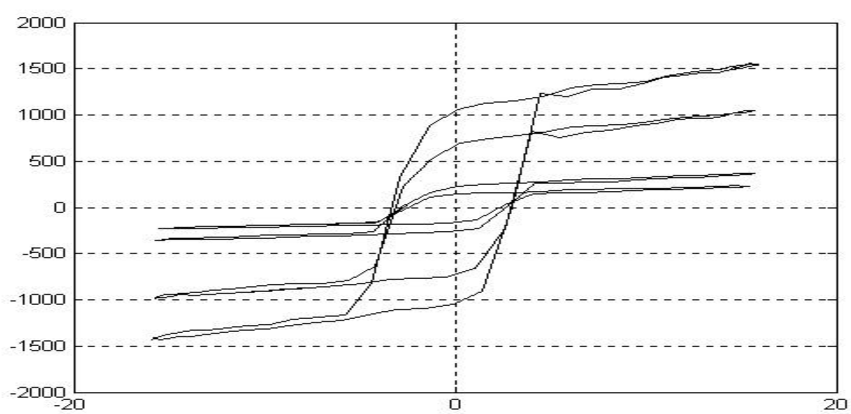

Fig. 2. Force [N] vs. velocity [cm/s]

As one can see from figure 2, in the range of small velocities the force variation displays an important hysteretic behaviour, while for larger velocities the force varies almost linearly with the velocity. These two distinct rheological regions over which dampers operate are known as the pre-yield and the post-yield regions. The laminar flow of the damper fluid in the post-yield state provides a quiet operation because no noise is generated by oil rushing through valves and there is no turbulence as in the case of conventional hydraulic dampers.

3. MECHANICAL MODEL FORMULATION

There are several mechanical models for describing the dynamical behaviour of MR-damper. The best results in portraying the hysteretic behaviour are obtained, using Bouc-Wen modified model [1], depicted in figure 3.

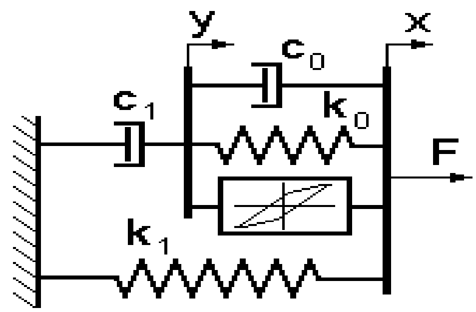

Fig. 3. Bouc-Wen modified mechanical model

In this model the damping force generated by the device is given by

$$F = c_1\dot{y} + k_1(x - x_0) \tag{1}$$

where x is the total relative displacement, x_0 the initial deflection of the accumulator gas spring with stiffness k_1. The partial relative displacement y and the evolutionary variable z are governed by the coupled differential equations

$$\dot{y} = \frac{1}{c_0 + c_1}(c_0\dot{x} + k_0(x - y) + kz) \tag{2}$$

$$\dot{z} = -d|\dot{x} - \dot{y}|z|z|^{n-1} - g(\dot{x} - \dot{y})|z|^n + \alpha(\dot{x} - \dot{y}) \tag{3}$$

The parameters n, d, g, α, k_1 are considered fixed and the parameters c_0, c_1, k and k_0 are assumed to be functions of the applied current u: $c_0 = c_0(u)$, $c_1 = c_1(u)$, $k = k(u)$, $k_0 = k_0(u)$. If $v(t)$ is the applied current, then the dynamics involved in the MR fluid reaching rheological equilibrium is modelled by the first order filter:

$$\dot{u} = -\frac{1}{T}(u - v) \tag{4}$$

4. MODEL PARAMETERS IDENTIFICATION BY GA

The modified Bouc-Wen model includes the previous mentioned parameters (c_0, c_1, k, k_0) that depend on the applied current. In order to determine the corresponding functional dependencies, a GA based inverse method is applied. For different constant current values {u = 0.02A, 0.06A, 0.1A, 0.2A, 0.4A, 0.6A, 0.8A, 1.05A, 1.45A, 1.75A) and cyclic imposed motion (frequency 1.5 Hz, amplitude 1.6 cm), the values of parameters c_0, c_1, k, k_0 are determined by using GA, such that the predicted force F_p to fit the measured force F_{exp}. Then, by analyzing the dependence between current and the obtained values of parameters one determines the functions $c_0 = c_0(u)$, $c_1 = c_1(u)$, $k = k(u)$, $k_0 = k_0(u)$.

In the proposed method, the parameter finding is tackled as a black box optimization problem. It is well known that genetic algorithms are robust probabilistic search techniques with very good results in black box optimization. They are based on the mechanism of natural genetics and natural selection, start with an initial population of (encoded) problem solutions and evolve towards better solutions, [9].

For the considered optimization procedure it is employed a real coded GA, [10], with four real genes corresponding to the four coefficients c_0, c_1, k, k_0. By using appropriate scaling factors, it can be assumed that the parameters take on values within the interval [0, 1]. In addition, other characteristics of applied GA were:

- averaged crossover with probability 0.8;
- uniform mutation and Monte Carlo selection;
- objective function - rms error between the predicted and experimental response.

For the numerical simulations were chosen the following values of the fixed coefficients: n=2, d =5 N/cm, g =61.3 cm^{-2}, α =30.56, k_1 =5.4 N/cm. Applying the proposed GA, after about 500 generations, was yielded the values given in table 1.

Table 1 The parameters values obtained by GA

$u[A]$	$c_0\left[\frac{Ns}{cm}\right]$	$c_1\left[\frac{Ns}{cm}\right]$	$k\left[\frac{N}{cm}\right]$	$k_0\left[\frac{N}{cm}\right]$
0.02	1.21	103	29.5	5.27
0.06	3.40	83.5	153	3.06
0.10	4.65	139	239	0.223
0.20	9.66	336	340	4.68
0.40	16.9	839	585	9.88
0.06	28.8	933	898	19.9
0.80	32.2	1018	1049	12.4
1.05	35.0	1078	1145	13.3
1.45	47.3	1116	1144	16.3
1.75	40.5	1225	1339	20.1

The accuracy of GA optimization can be seen from the figures 4a, 4b and 5a, 5b showing the predicted and experimentally obtained response for 0.06 and 1.75 amps.

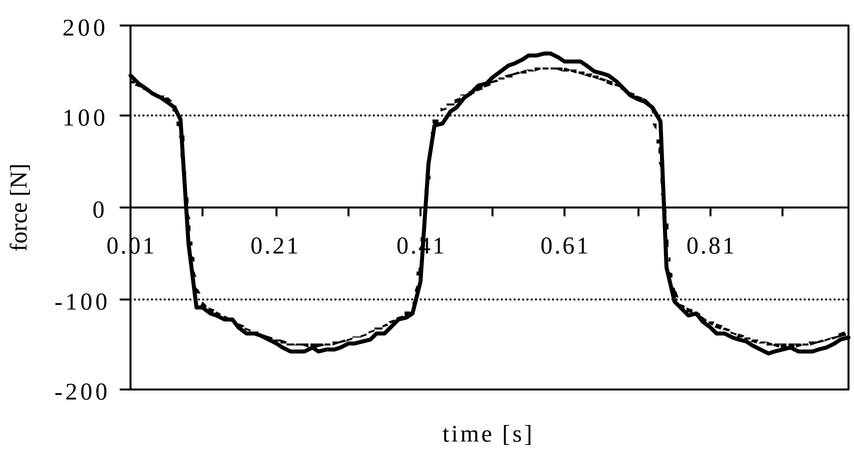

Fig. 4a. Force vs. time for 0.06 A _____ experimental; …... predicted

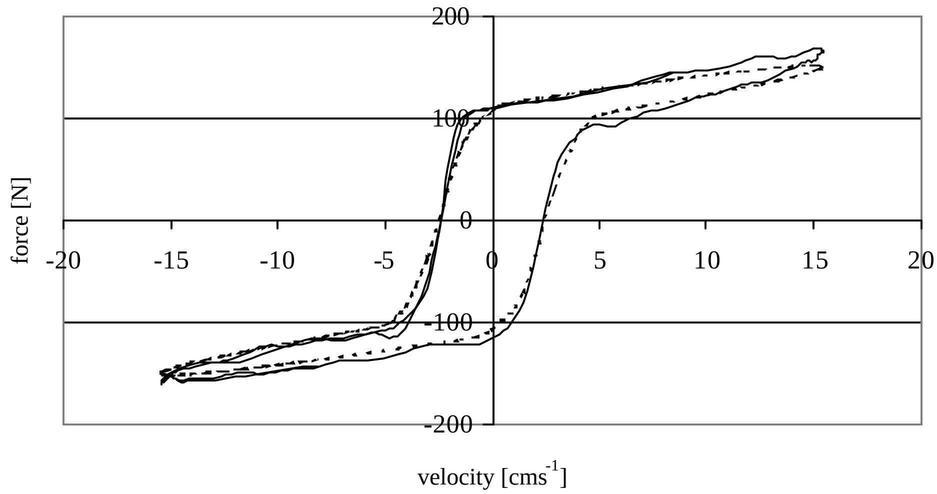

Fig. 4b. Force vs. velocity for 0.06 A _____ experimental; …… predicted

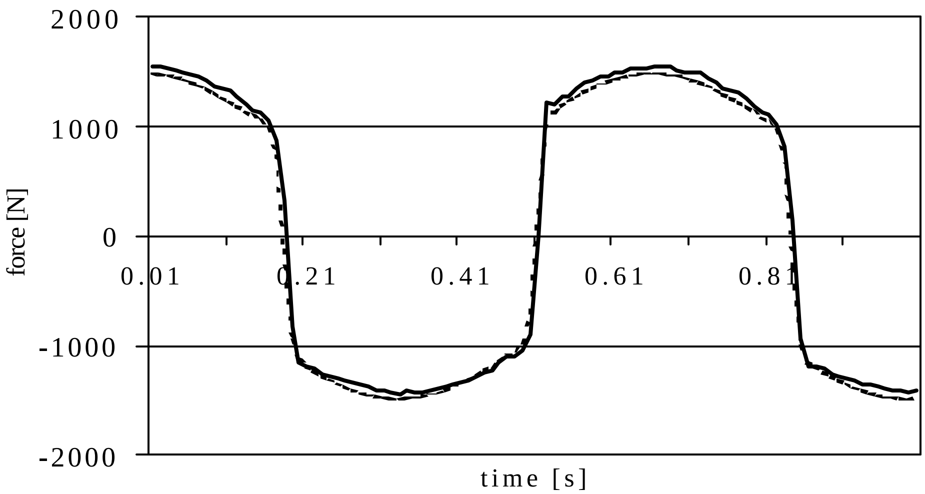

Fig. 5a. Force vs. time for 1.75 A _____ experimental; ……. predicted

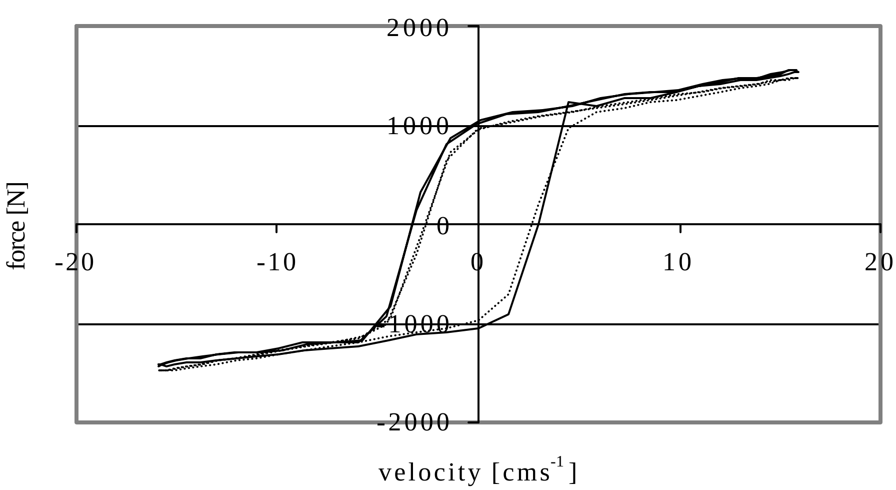

Fig. 5b. Force vs. velocity for 1.75 A _____ experimental; …… predicted

Because the variation of k_0 with respect to the current values is not relevant and taking into account its mechanical significance, this parameter, can be given the mean value k_0=10.5 N/cm. The functional approximations for the remaining parameters c_0, c_1, k, obtained by using the values from table 1 are:

$$c_0(u) = 26.134 \cdot u + 5.164 \tag{5}$$

$$c_1(u) = 1150 \cdot tanh(1.95 \cdot u) \tag{6}$$

$$k(u) = 1297.2 \cdot tanh(1.3 \cdot u) \tag{7}$$

The graphical representations of the parameters functional approximations are given in figures 6, 7 and 8 respectively. Therefore, the BW modified model is completely defined and it must be tested for different loading conditions and variation patterns of the applied current.

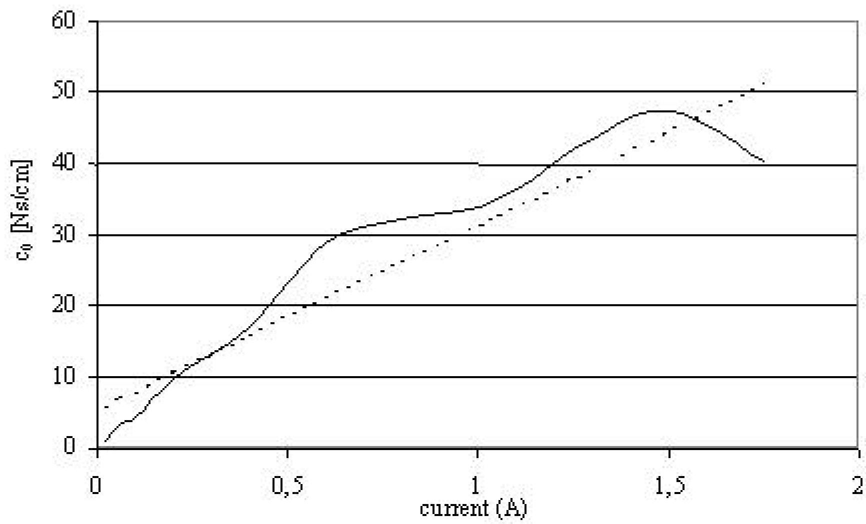

Fig. 6. The parameter c_0 vs. current u, experimental (___) and predicted (….)

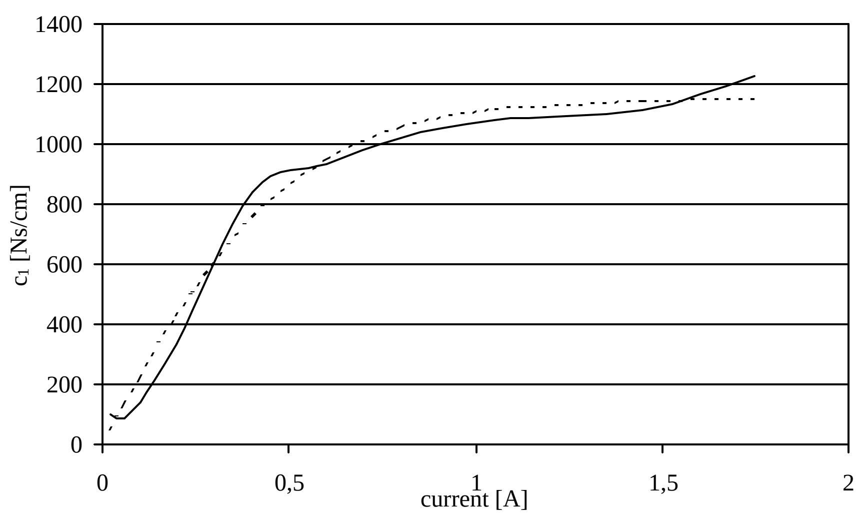

Fig. 7. The parameter c_1 vs. current u, experimental (___) and predicted (….)

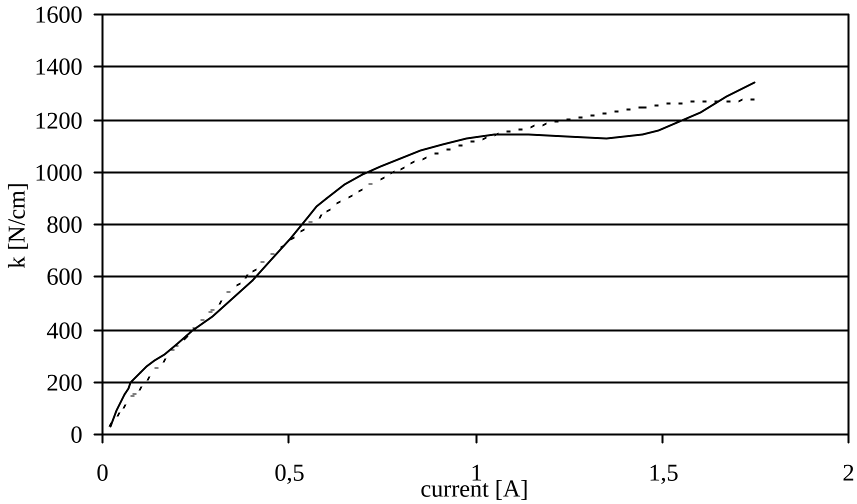

Fig. 8. The parameter k vs. current u, experimental (___) and predicted (….)

5. MODEL VALIDATION

In this section, it is made a comparison between the measured force and predicted force computed for the obtained model. Simulations were performed using the experimentally determined displacement x and calculated velocity $\dot{x}$ of the piston rod in determining the force generated in the damper model. The model efficiency in describing the dynamic behaviour of the MR damper has been investigated in a variety of deterministic tests. When compared with experimental data, the model was shown to predict accurately, at least from the practical point of view, the response of the MR damper over a wide range of operating conditions. To illustrate this assertion, the results obtained in three test cases are presented bellow.

The time histories of the displacement, velocity and of the voltage applied to the current driver for each test case are plotted in fig. 9-11.

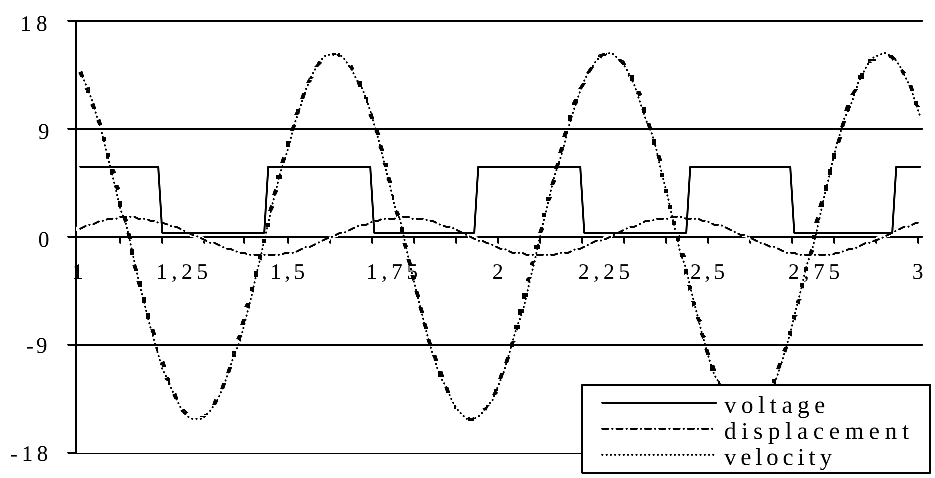

Fig. 9a. Time histories of the voltage [volts], displacement [cm] and velocity [cm/s] in the first test case

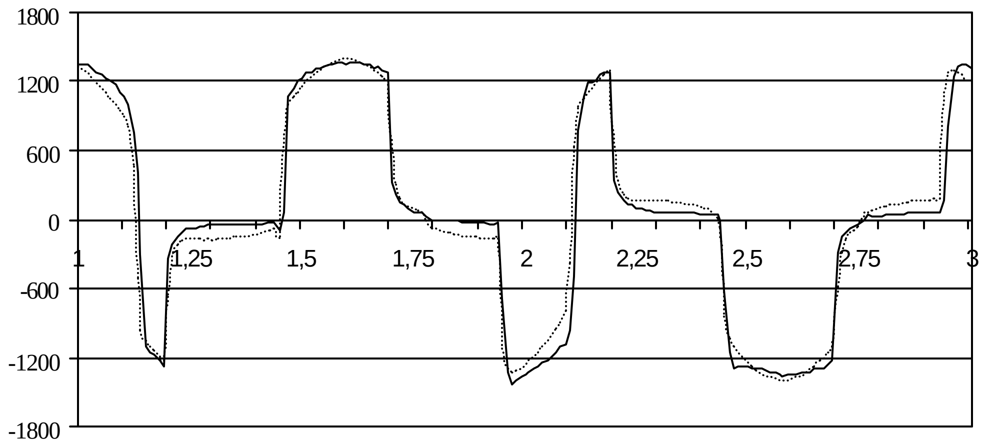

Fig. 9b. Force [N] versus time [s] in the first test case _____ experimental; …… predicted

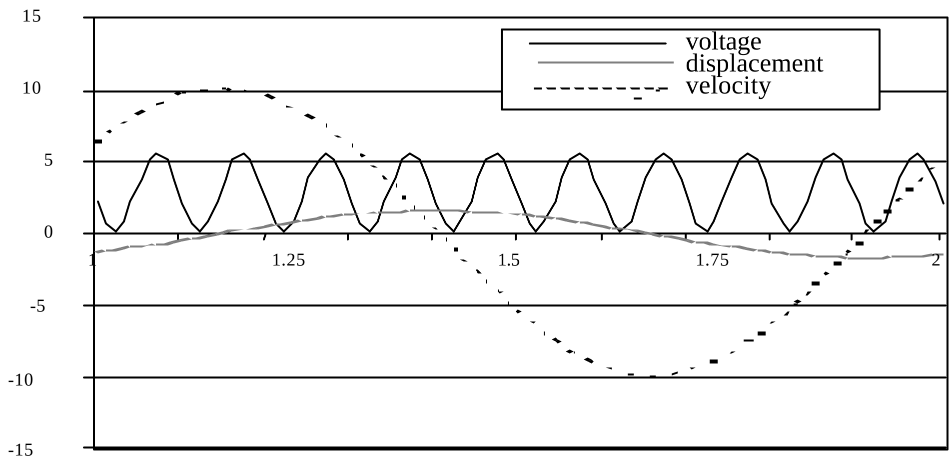

Fig. 10a Time histories of the voltage [volts], displacement [cm] and velocity [cm/s] in the second test case

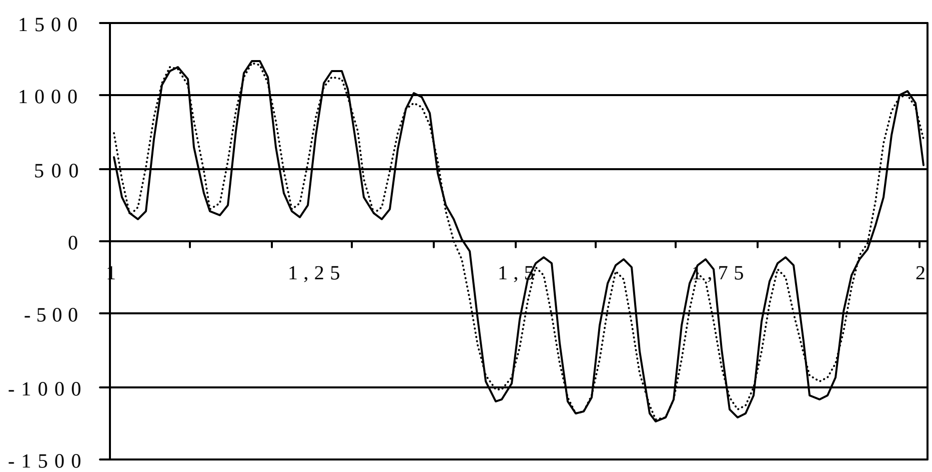

Fig. 10b. Force [N] versus time [s] in the second test case _____ experimental; …… predicted

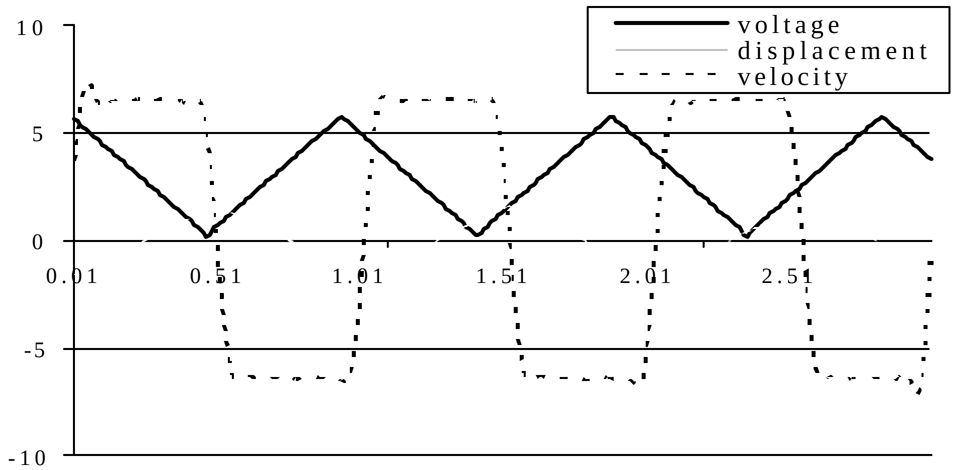

Fig. 11a. The voltage [volts], displacement [cm] and velocity [cm/s] for the third test case

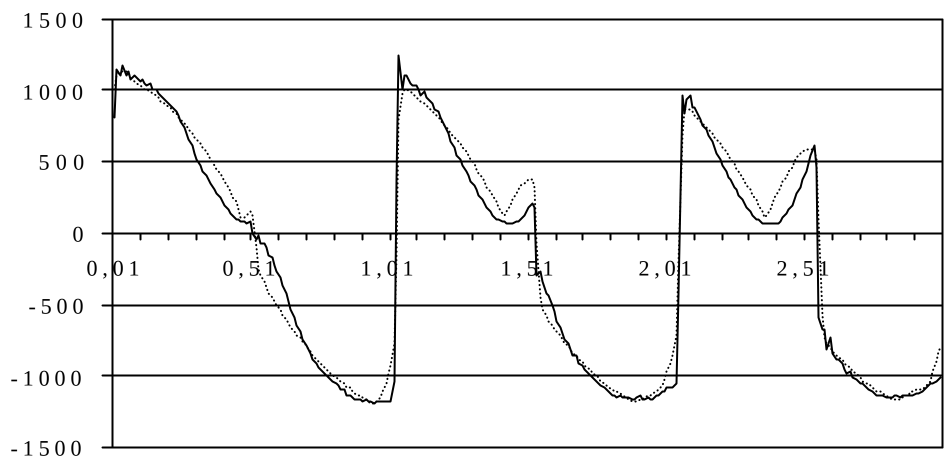

Fig. 11b. Force [N] versus time [s] in the third test case_____ experimental; …… predicted

6. CONCLUSIONS

The GA assisted inverse method, developed in this paper, proved very efficient for determining a mechanical model to predict the dynamic behaviour of a typical MR damper.

A variety of representative tests showed that the model determined from experimental data obtained for constant levels of the applied magnetic field and harmonic imposed motion is accurate over a wide range of operating conditions and is adequate for control design and analysis.

One can conclude that the modified Bouc-Wen model, with proper values of the involved parameters, can accurately portray the behaviour of MR dampers.

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