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Study on Magnetorheological Dampers for Semi-active Control of Buildings by Using the Fuzzy Logic Control System

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Abstract—*This research examines the performance of magnetorheological dampers in the semi-active control of buildings by using the fuzzy logic control system. The current paper performance of fuzzy logic algorithm assuming Gaussian membership functions in the response control of a building is investigated. For this purpose a structural model of a building is developed and then responses of the structure is calculated by using Newmarks method. In simulation procedure a fuzzy logic algorithm using Gaussian membership function has been developed to determine the input voltage to MR damper. Fuzzy logic is a suitable way for fast decisions and acceptable accuracy. Choosing the appropriate membership function in fuzzy algorithms plays a vital role to achieve the appropriate results and in this investigation the performance of Gaussian membership function is demonstrated. Modified bouc-wen model is used and the modeling has been done in MATLAB. By using El-centro data, the performance of MR damper has been evaluated. Control system and MR damper were modeled in Simulink environment. .The entire computation has been done using the Fuzzy Logic and SIMULINK toolboxes in MATLAB.*

1. INTRODUCTION

MR damper is identified as a potential device for semi active control for building frames because of its mechanical simplicity, low power requirement, high dynamic range, large force capacity and robustness. Since it is an energy dissipation device that cannot add mechanical energy to the structural system, an MR damper is very stable phenomenological model of a typical MR damper, based on Bouc–Wen hysteresis model (Spencer et. al., 1997) is proposed in connection with the control of responses of structures like building frames and bridges. A comprehensive study of the adequacy of various types of dynamic models of MR damper has been done by Jung etc. al. (2003).

Iwata etc all have described the applicability of the MR damper to base-isolated building structures. They proposed a simple semi-active control algorithm, which aims at controlling the hysteresis shape. In order to verify the effectiveness of the proposed method, shaking table tests were carried out using a newly-developed MR fluid damper. It was shown that the MR damper significantly improves the performance of base-isolated structures

.Jung et al. proposed a semi-active control strategy using MR dampers by investigating the ASCE first generation benchmark control problem for seismic responses of cable-stayed bridges. The modified Bouc-Wen model was considered as a dynamic model of the MR damper. The numerical results demonstrated that the performance of the proposed control design is nearly the same as that of the active control system. In addition, semi-active control strategy has many attractive features, such as the bounded-input, bounded output stability and small energy requirements. The results of this preliminary investigation, therefore, indicated that MR dampers can be effectively used to control seismically excited cable-stayed bridges.

In the current paper performance of fuzzy logic algorithm with assuming Gaussian membership functions in the response control of a four storey building is investigated. For this purpose first, a structural model of a building is developed. In simulation procedure a fuzzy logic algorithm using Gaussian membership function has been developed to determine the input voltage to MR damper. Fuzzy logic is a suitable way for fast decisions and acceptable accuracy. In addition choosing the appropriate membership function in fuzzy algorithms plays a vital role to achieve the appropriate results and in this investigation the performance of Gaussian membership function is demonstrated.

In this mass of each floor has been calculated by using STAAD pro and by using newmarks method responses are calculated. Here Modified bouc-wen model is used and the modeling has been done in MATLAB. By using El Centro data, the performance of MR damper has been evaluated in this paper. The entire computation has been done using the Fuzzy Logic and SIMULINK toolboxes in MATLAB

2. STRUCTURAL MODEL

The building considered for study is a four-story RC building. Mode of the building is shown in Fig. 1.The superstructure damping ratio is assumed to be 5% for all modes .After analyzing the model in Staad Pro, mass of each floor has been calculated and is tabulated in Table 1

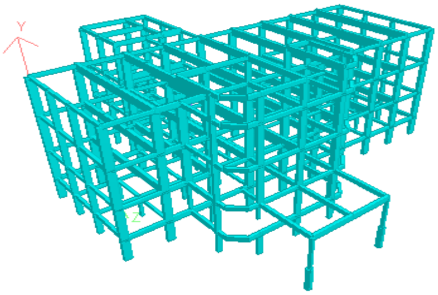

Fig. 1: Building Model

Table 1: Mass of each floor

Storey	Weight(kg)
Top	699337
First	457410
Second	843292
Ground	869877
Plinth	367930

Considering the building as a single degree of freedom system,

(a)Total mass = 3.24×10^6 kg

(b)Stiffness calculation

Lateral stiffness = $\sum_{\text{columns}} 12EI/h^3$

k = 11.38×10^6 kg/m

(c)Damping coefficient

Damping coefficient

= $(5/100) \times 2 \times (km)^{1/2}$

c = 118.2×10^3 kg-sec/m

3. MR DAMPER MODEL

Damping system with smart fluid is considered a kind of semi-active control system. This group of instruments includes dampers in which fluid viscosity is changeable. This change in viscosity changes stiffness of dampers and consequently increases or decreases their desire to absorb energy.

a) Dynamic analysis by semi-active control-Modified Bouc-wen model

This model consists of a viscous damper tied with original Bouc-wen model in series and a spring which works in parallel with the whole system is shown in Fig. 2

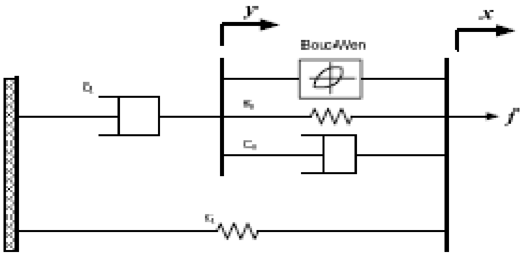

Fig. 2: Simple Model of MR damper

Force produced by damper in modified Bouc-wen model is described as follows:

$$F=\alpha z + C_0(\dot{x} - \dot{y}) + K_0(x-y) + K_1(x-x_0) = C_1 \dot{y} + K_0(x-x_0) \quad (1)$$

Where z is an evolutionary variable that accounts for the history dependence of the response. The evolutionary variables z and y are governed by:

$$z' = -\gamma | x' - y' | z | z |^{n-1} - \beta(\dot{x} - y) | z |^{n} + A(x' - y') \quad (2)$$

$$y' = (1/(C_0 + C_1)(\alpha z + C_0 x' + k_0(x-y) \quad (3)$$

In which K_1=accumulator stiffness, C_0=viscous damping at large velocities, C_1=viscous damping for force roll off at low velocities, K_0=stiffness at large velocities, x =relative displacement of one end of the MR damper; x_0=the piston velocity, y=internal displacement of the MR damper, and x_0=initial displacement of spring K1.

To determine a model which is valid under fluctuating input voltage, the functional dependence of the parameters on the input voltage must be determined. Since the fluid yield stress is dependent on input voltage, α can be assumed as a function of the input voltage v. Moreover, as determined from the experiment results, C_0, and C_1 are also functions of the input voltage.

γ, β , and A are the parameters that control the shape of the hysteresis loops in Bouc-Wen yielding element. Finally, α and n are other parameters that refer to the internal state z and determine its coupling with the force f and its evolution.

To specify a model dependent on volatile magnetic field, relation of damper parameters with exerted voltage should be determined. Since MR fluid yielding resistance changes directly with intensity of magnetic field, parameter α in Eqs. (4) to (7) is regarded as a function of an exerted voltage. The relationship between MR dampers input current and input voltage using these coefficients is defined as follows:

$$\alpha = \alpha(u) = \alpha a + \alpha bu \quad (4)$$

$$C1 = C1(u) = C1a + C1bu \quad (5)$$

$$C0 = C0(u) = C0a + C0b \quad (6)$$

In these equations, value of u is calculated from the following differential equation, where V is input voltage to MR damper:

$$u' = -\eta(u - V) \qquad (7)$$

The above equation is necessary to model the dynamics involved in reaching rheological equilibrium and in driving the electromagnet in the MR damper.

Table 2 provides the optimized parameters for the dynamic model that were determined to best fit the data based on the experimental results of a 20-ton MR damper [5]. In order to obtain the parameters for the 100-ton (i.e., 1000kN) damper considered in this study, the experimental data of the 20-ton damper have been linearly scaled up 5 times in the damper force.

Table 2: Parameters of 200KN MR damper

Parameter	Value	Parameter	Value
Coa	110 KN.sec/m	αα	46.2 KN/m
Cob	114.3 N.sec/m/v	αb	41.2 KN/m/v
Ka	0.01 KN/m	γ	164 m-2
C1a	8359 KN-sec/m	β	164 m-2
C1b	7482.9 KN-sec/m/V	A	1107.2
K1	0.485 KN/m	n	2
X0	0 m	η	100 sec-1

b) *Fuzzy Control*

Fuzzy logic is a way to decide the best between some choices which do not need so much precision but speed to react in time. Making decision of fuzzy control is based on “if-then” rules. The procedure of controlling by fuzzy algorithms has three steps: (1) Fuzzification, where the inputs are converted to fuzzy linguistic values using membership functions. (2)Decision making, in this part by useing “if-then” rules the algorithm make decision about the value of the output. (3) Defuzzification, where the fuzzy output is converted to a crisp value.. The input set of the controller includes velocity and displacement of the structure. These variables are normalized to 1 and -1, and also distributed by three Gaussian membership functions. The velocity and displacement were normalized by the absolute maximum velocity and displacement respectively.

The letters N, Z and P which are used in the membership functions and fuzzy rules with the meaning of negative, zero, and positive, respectively (Fig. 3).The output of the controller will be either 0 or 0.5, or 1 which is shown by Z or M or L, respectively. These numbers will be the input voltage of MR damper before defuzzification, indeed we need to scale them to a real voltage and according to MR damper voltage capacity, and it will be between 0 to 10V. It is noted that in this investigation Sugeno fuzzy system was used for the membership function of outputs and this system is similar to Mamdani fuzzy system in the fuzzification step where the inputs are converted to fuzzy linguistic values using membership functions, but the membership function of outputs is not identical. In the Sugeno fuzzy system, the membership function of outputs is linear or constant (Zhao and Collins, 2003). In the current paper, we assumed that the membership function of outputs are defined in the interval [0, 1] with three constant values 0, 0.5 and 1, corresponding to Z, M, L respectively. The rules which are used in this study have been shown in Table 3. The performance surface of fuzzy controller has been shown in Fig. 4. It is noted that First the structure first the structure is excited by earthquake excitation and then the response of structure can be obtained. These responses include displacement, velocity and acceleration of the stories. Among these values, the velocity and displacement of the base are recorded in each step of time and are sent to the fuzzy controller and the MR damper. K_d and K_v are the fuzzification factors for the input data. The controller processes the data and by using the fuzzy rules chooses the suitable voltage to send it to MR damper. K_u is the defuzzification factor. MR damper creates a force by using these voltages,

Table 3: Fuzzy rules

		Displacement		
		N	Z	P
Velocity	N	L	M	Z
	Z	M	Z	M
	P	Z	M	L

It is noted that to normalize input variables, scaling factors were employed for displacement and velocity respectively. Since the output universe of discourse was also normalized, a scaling factor K_u is required because scaling factors are responsible for mapping inputs and outputs to universes of discourse, they have a large effect of controller’s performance. K_u or defuzzifier factor was supposed 5 since the maximum voltage would be limited to 5 v. On the other hand since the output’s universe of discourse was normalized, defuzzifier factor was required and chosen as K_u=5

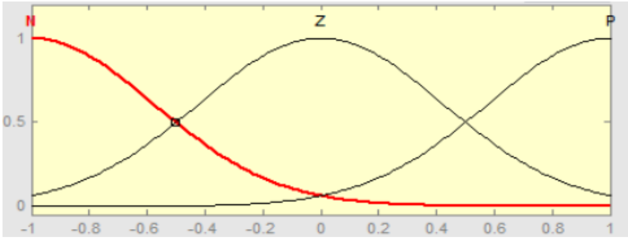

Fig. 3: Gaussian membership function

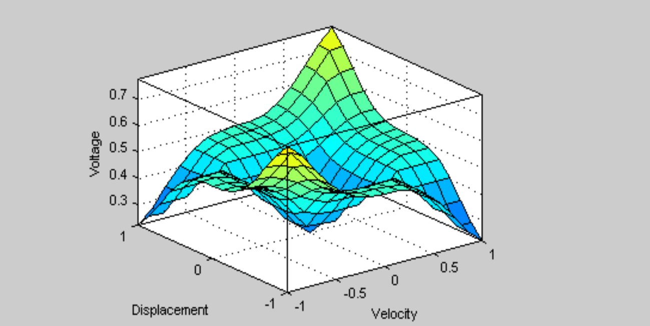

Fig. 4: Performance surface of fuzzy logic controller obtained from matlab

4. NUMERICAL MODEL AND INTRODUCING SEISMIC SIMULATION

For studying the MR damper force system, Newmark method is chosen as the time stepping method and the steps included in that is given below

a) Response calculation by Newmark's method

1. Average acceleration method ($\alpha = \frac{1}{2}$, $\beta = \frac{1}{4}$)

1.0 Initial calculations

- 1.1 $\ddot{u}_0 = (p_0 - c\acute{u}_0 - (f_s)_0)/m$
- 1.2 select Δt
- 1.3 $a = (4m/(\Delta t)) + 2c$; and $b = 2m$

2.0 Calculations for each time step, i

- 2.1 $\Delta\acute{p}_i = \Delta p_i + a\,\mathring{u}_i + b\,\ddot{u}_i$
- 2.2 determine the tangent stiffness, $k_i = k$
- 2.3 $\acute{k} = k_i + (2c/\Delta t) + (4m/(\Delta t)^2)$
- 2.4 $\Delta u_i = \Delta\acute{p}_i / \acute{k}$
- 2.5 $\Delta\mathring{u}_i = (2\Delta u_i/\Delta t) - 2u_i$
- 2.6 $u_{i+1} = u_i + \Delta u_i$; and $\mathring{u}_{i+1} = \mathring{u}_i + \Delta\mathring{u}_i$
- 2.7 $(fs)_{i+1} = (fs)_i + k_i\Delta u_i$
- 2.8 $\ddot{u}_{i+1} = (p_{i+1} - c\,\mathring{u}_{i+1} - (fs)_{i+1})/m$

3.0 Repetition for next time step. Replace i by i+1 and repeat steps 2.1 to 2.8

Mass and stiffness values of the SDOF system is used to find the responses. El Centro data is used as the input of newmarks algorithm, this algorithm is developed in Matlab and the output responses are shown in Fig. 5.This responses are used as the input of the fuzzy logic controller.

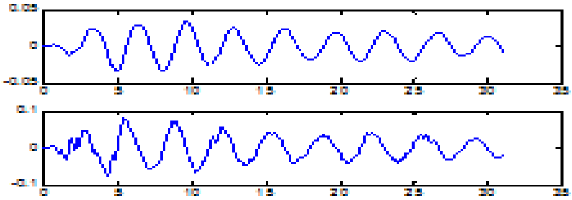

Fig. 5: Displacement, velocity, acceleration

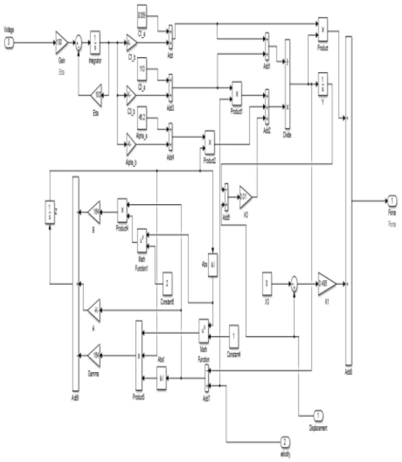

Fig. 6: Schematic view of code written in Simulink for MR damper

For modeling MR damper, Modified Bouc-WEN dynamic model was used. Equations (1) to (7) were modeled in Simulink as shown in figure 6, where the inputs are voltage (output of fuzzy control system), displacement and velocity, and the output is force of MR damper. The entire system has also been modeled in Simulink as shown in Fig. 7

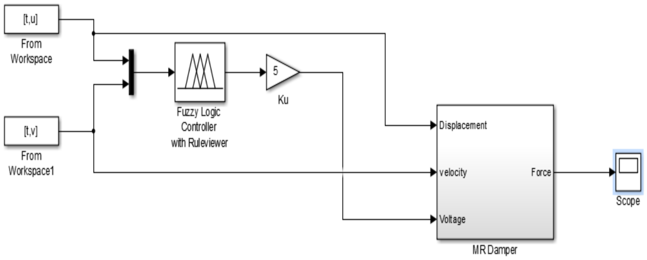

Fig. 7: Control model

5. NUMERICAL RESULTS

The output of the Newmarks time stepping is given as the input of fuzzy logic controller and for that El Centro earthquake data is being used. By using the workspace tool of Simulink the data is imported .At each time interval the variation of voltage from the fuzzy controller system is shown in Fig. 8.Fig. 9 shows the variation of damping force of MR damper.

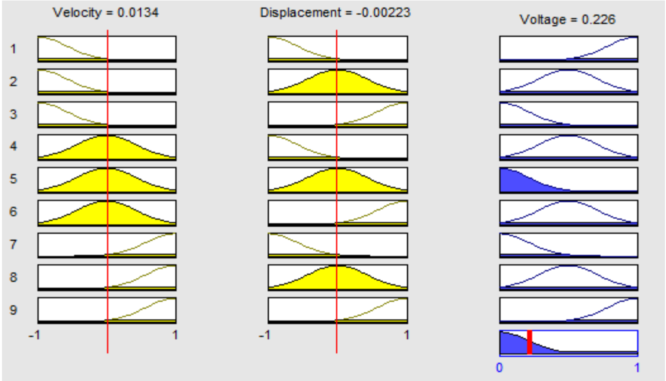

Fig. 8: Simulation result of fuzzy logic controller

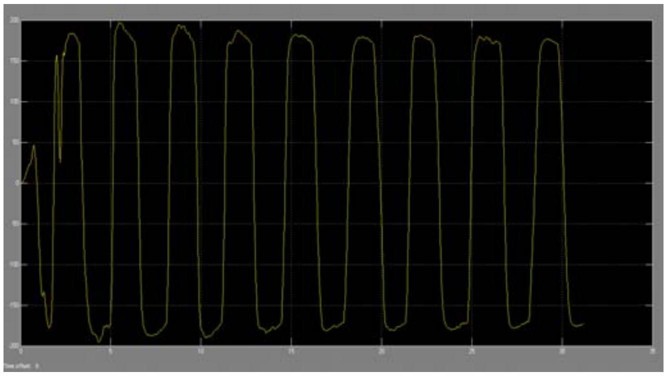

Fig. 9: Variation of damping force

The MR damper force varies in at each interval of time and the maximum force exerted by the MR damper when El Centro earthquake data is applied for the 200KN damper is 190 KN.

6. CONCLUSIONS

This paper focuses on application of a fuzzy logic algorithm in the response control of a building with MR damper under earthquake excitations. A fuzzy logic algorithm with Gaussian input membership function is developed. The performance of the MR damper under the earthquake data has also been evaluated. From this it is conclude that the damper performs well under the fuzzy logic controller. The maximum damping force under the El Centro earthquake for a 200 KN damper is limited with in the capacity of damper. The efficiency of MR damper under the fuzzy logic system for a SDOF system is verified. Fuzzy control is simple to simulate and performs well under seismic excitation.

7. ACKNOWLEDGEMENT

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