Journal of Manufacturing Engineering, June, 2013, Vol. 8, Issue. 2, pp 85-91

MAGENTOREHOLOGICAL (MR) FLUID DAMPERS AND ITS ANALYSIS

*Pradeep V Malaji[1] and Sakri M I[2]

[1, 2] B.L.D.E.A's CET, Bijapur, Karnataka-586101, India

ABSTRACT

Magneto-rheological (MR) fluids are now well established as one of the leading materials for use in controllable structures and systems. Commercial application of MR fluids in various fields, particularly in the vibration control, has grown rapidly over the past few years. In this paper, properties of magneto-rheological (MR) fluids, behavior of MR damper under sinusoidal, harmonic, impulsive and impact loading have been discussed. The scope of future research on MR fluids dampers is presented

Keywords: *MR fluid and Damper.*

1. Introduction

Magnetorheological (MR) fluids are classified as controllable fluids because their rheological properties (elasticity, plasticity, and viscosity) respond to an applied magnetic field. MR fluids consist of a carrier fluid, typically a synthetic or silicone based oil, and ferromagnetic particles (20-50 microns in diameter). In the absence of a magnetic field, MR fluids flow in a linear viscous state. However, in the presence of a magnetic field the particles align and form linear chains parallel to the field, Figure 1. The chains act to restrict fluid movement and solidify the suspension. With a properly designed magnetic circuit, the apparent yield stress of the MR fluid will change within milliseconds [2]. The greatest change is typically observed when the magnetic field is normal to the flow of MR fluid. In common MR damper designs, the difference in damping forces may increase by a factor of 10 or more between the passive and fully active states [3]. Properties of MR fluid are listed in Table1.

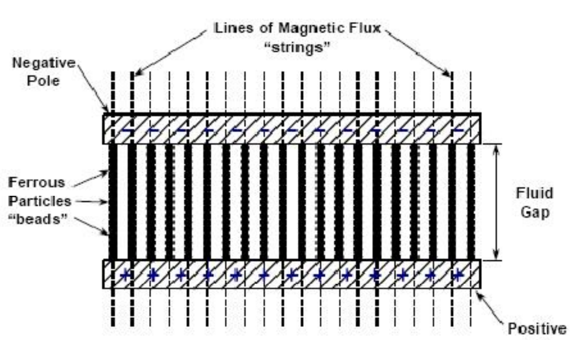


Fig. 1 Schematic of MR Fluid Particles Aligning with Magnetic Field [4]

Corresponding Author - E- mail: pvmalaji@yahoo.co.in

Table 1: Summary of the Properties of MR Fluids [1]

Property	Typical Value
Initial Viscosity	0.2-0.3 Pa-s at 25^0 c
Density	3-4 g/cm^3
Magnetic field strength	150-250 kA/m
Yield point	50-100kPa
Response Time	Few milliseconds
Power supply	2-25 V, 1-2 A
Working temperature range	-50 to 100^0 C

Three common configurations of MR dampers exist: mono-tube, twin-tube and double ended.

The mono-tube MR damper, Figure 2 (a), has only one volume of MR fluid and an accumulator to accommodate the change in volume due to the additional volume displaced as the piston shaft enters the housing. Mono-tube dampers are the most common configuration. The twin-tube MR damper, Figure 2 (b), has two concentric tubes connected with a valve. The valve allows for MR fluid to flow from the inner to the outer tube to adjust for piston displacement. The third common configuration is the double-ended design, Figure 2 (c). Because the piston shaft is the same diameter throughout the body, double-ended dampers do not need to account for changes in volume.

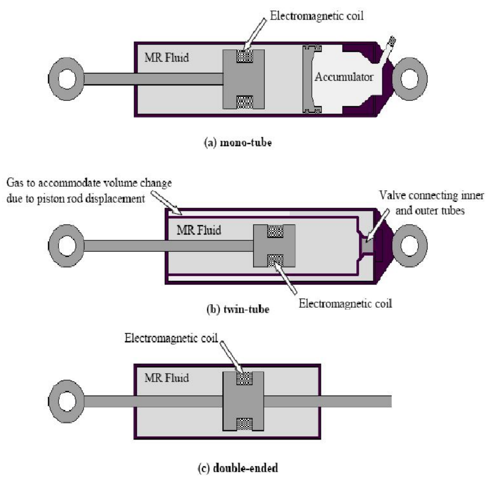


Fig. 2 Common Configurations of MR Dampers

Three common modes of operation exist in MR damper designs: squeeze, shear, and valve mode, diagramed in Figure 3. Squeeze mode MR dampers offer the greatest difference in damping force for a given change in magnetic flux. However, the amount of displacement achievable for a squeeze mode MR damper is significantly less than the other modes. The shear mode is used to control damping in rotary applications. An example of a shear mode rotary damper is the MR brake developed by Lord Corporation . The valve flow mode is the most common mode used for MR dampers. The two dampers studied in this work operate in the valve flow mode.

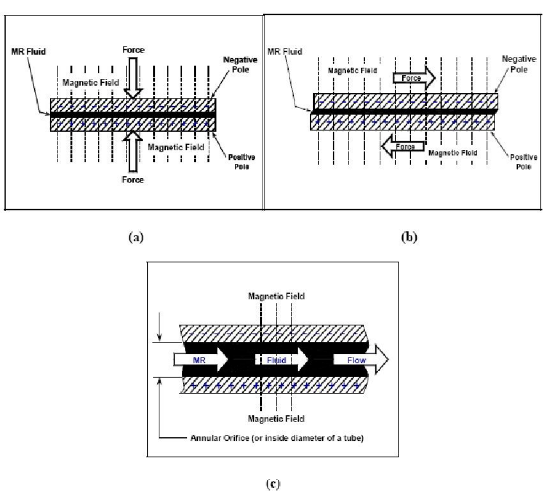


Fig. 3 Three Common Modes of Operation for MR Fluid Dampers; (a) Squeeze Mode; (b) Shear Mode; and (c) Flow Mode [4]

2. Analysis of MR Damper

2.1 Dampers subjected to sinusoidal loads

A linear magneto-rheological (MR) damper, supplied by Lord Corporation, was tested and modeled by W H Li et all [5] under dynamic conditions, the effects of displacement amplitude, frequency, and magnetic fields on the mechanical properties of MR damper, such as damping force, equivalent-damping capability, were experimentally studied. A viscoelastic–plastic model is proposed to model the MR behavior. It is shown that the damper response can be satisfactorily predicted with this model.

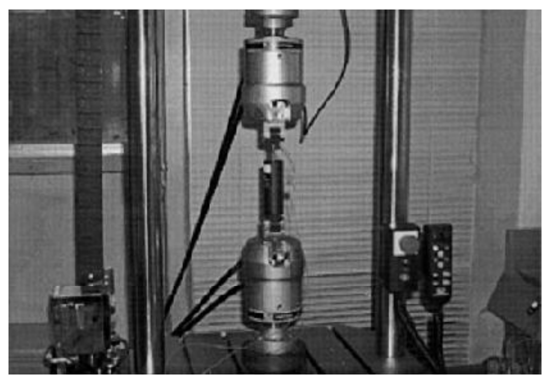


Fig. 4 Picture of the INSTRON Test Machine

Damper used: MR damper (RD-1005), supplied by Lord Corporation

3. Experimental Set-up

The MR damper was tested using a computer-controlled INSTRON (model 8874) test machine, as shown in figure 4. Mechanical properties of a linear MR damper under sinusoidal excitation were experimentally studied. The effects of magnetic field, displacement amplitude and driving frequency on the response forces are experimentally studied. The damping force increases gradually with the magnetic field except for the field saturation. Also, the damping force increases significantly with the increase of displacement amplitude. The experimental results show that the damping effect does not depend on oscillation frequency so much in the very low range of the frequency (below 2.0 Hz), and there is almost no inertial effect on the damping force. However, when the oscillatory frequency is above 4.0 Hz, there exists distinct obvious nonlinearity due to fluid inertial effect. Magnetic field, amplitude and frequency dependence of equivalent damping factors is also discussed. The experimental results show that the equivalent damping factors are one or two orders higher than that of ER fluids. The MR damper performs preyield region and postyield region under cycling excitation. Based on preyield and postyield mechanisms, a viscoelastic–plastic model is proposed to describe the overall behavior of MR damper. The reconstructed force versus displacement and force versus velocity cycles indicate that the model can predict the MR damper behavior very well. A mathematical model, which can accurately reflect the higher frequency on the effect of damping force, still needs further study.

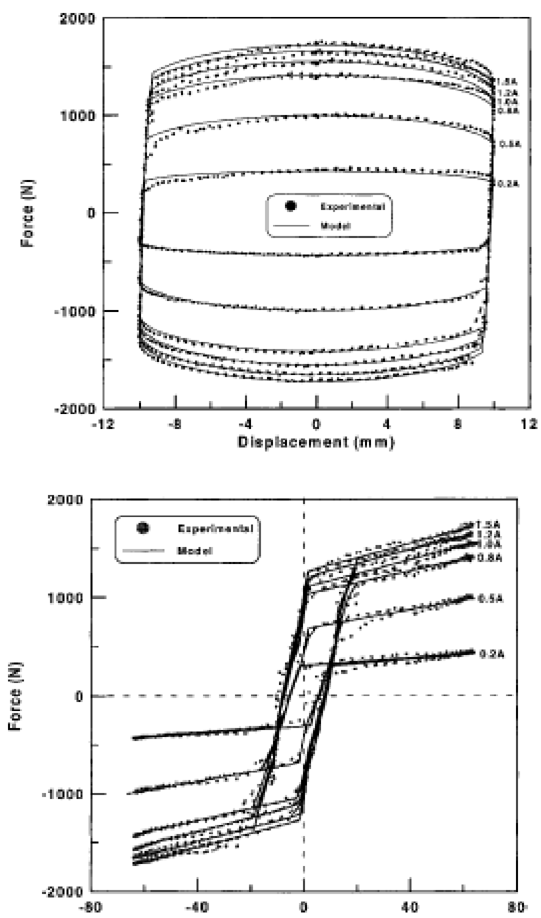


Fig. 5 Comparison of Experimental Data with Model-Predicted results for various magnetic fields (a) Force versus displacement, (b) force versus velocity. X0 = 10 mm, f = 1.0 Hz

2.2 Dampers subjected to impulsive loads

The performance of electro-rheological (ER) and magneto-rheological (MR) fluids under impulsively-applied loads was investigated by Ali K El wahed et al [6]. The ER fluid device, which is operating in the squeeze flow mode, was tested with four different ER fluids, while the MR fluid device is a commercially available shock absorber in which the flow resistance of the fluid is controlled by a small electromagnetic element. Both devices were tested in an experimental rig, capable of providing fast loading that represents the typical loading of an explosive shock in air or the typical loading of a hydrocarbon type explosion. These devices were seen to exhibit sufficient field-induced damping forces when subjected to various mechanical and electrical inputs and hence, they are capable of providing adaptable fixing characteristics for blast resistant and structural members such as blast walls on offshore platforms. In addition, the performance of the ER fluid device under fast loading could be predicted by a theoretical model based on the assumption of a bi-viscous fluid characteristic, and was found to compare very well with that acquired experimentally.

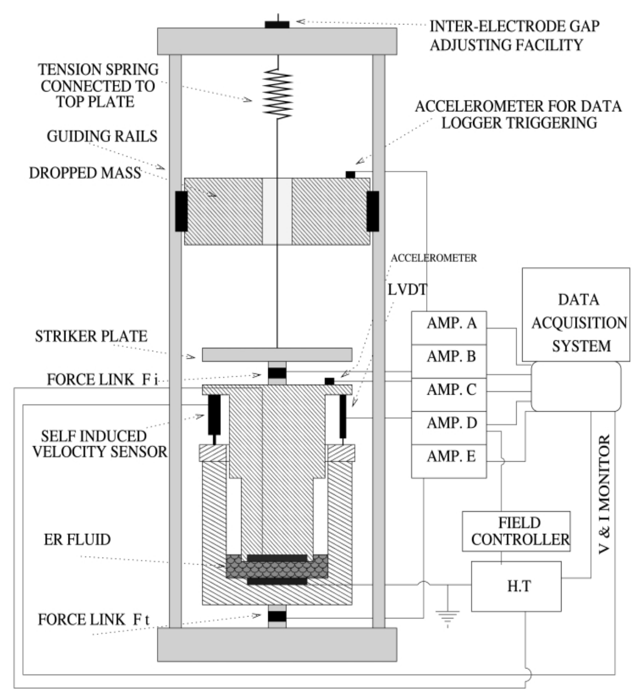


Fig. 6 Experimental Arrangement

In this work the performances of ER and MR fluid devices subjected to various impulsive loading conditions have been investigated through a series of instrumented drop hammer tests of particular interest are the performance characteristics of these devices under shock loading typical of blast conditions The MR fluid shock absorber was also subjected to the above loading conditions and it was seen that highdamping characteristics could be achieved.

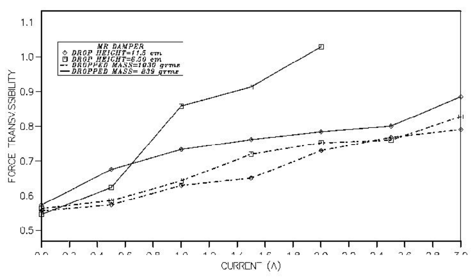


Fig. 7 Force Transmissibility Vs Current for Two Drop Heights and Two Masses

3. Harmonic Analysis

A single-degree-of-freedom (SDOF) isolation system with an MR fluid damper under harmonic excitations were studied by W H Liao et al[7]. A mathematical model of the MR fluid damper with experimental verification was adopted. The motion characteristics of the SDOF system with the MR damper are studied and compared with those of the system with a conventional viscous damper. The energy dissipated and equivalent damping coefficient of the MR damper in terms of input voltage, displacement amplitude and frequency were investigated. The relative displacement with respect to the base excitation was also quantified and compared with that of the conventional viscous damper through updating the equivalent damping coefficient with changing driving frequency. In addition, the transmissibility of the MR damper system with semi-active control was also discussed. The results of this study are valuable for understanding the characteristics of the MR damper to provide effective damping for the purpose of vibration isolation or suppression.

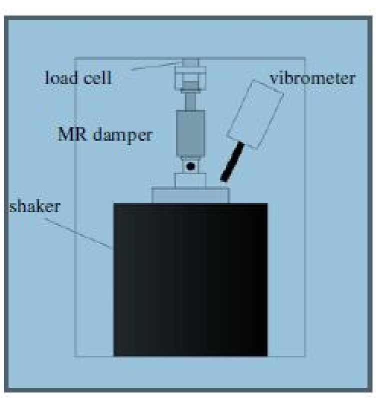


Fig. 8 Schematic Test setup for the MR Damper

The MR damper used in this study was RD-1005-1, which was manufactured by Lord Corporation

In this experiment, the shaker is driven with a sinusoidal signal with a fixed frequency, and the voltage applied to the damper is held at a constant level. Three sets of experimental data are obtained according to three voltage levels (0, 1, and 2 V). Each set of data consists of displacement, velocity and damping force. it can be seen that the damping coefficient decreases as the excitation amplitude is raised under the same input voltage. For the same amount of increment in displacement amplitude, the damping coefficient for the higher voltage input decreases more. And showed that the damping coefficient of the MR damper working at higher frequencies is smaller

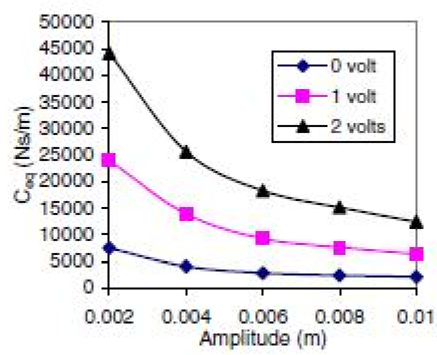


Fig. 9 Equivalent Damping Coefficient versus Displacement Amplitude

2.4 Dampers subjected to impact load

James A. Norris et al [8] have done experimental analysis of magneto-rheological dampers when they are subjected to impact and shock loading. A drop-tower is developed to apply impulse loads to the dampers.

The drop-tower design uses a guided drop-mass, which is released from variable heights to achieve different impact energies. The nominal drop-mass is 55 lb and additional weight may be added to reach a maximum of 500 lb. The nominal drop-mass of 55 lb is used throughout the study. Five drop-heights were investigated: 12, 24, 48, 72 and 96 in., corresponding to impact velocities of 86, 127, 182, 224 and 260 in./s, respectively. Two MR damper configurations were tested, a damper with a single-stage, double-ended piston and a mono-tube damper with a two-stage piston. The results indicate that the two damper configurations exhibit different force–displacement characteristics during impulse loading. For the single stage, double-ended damper, the peak force occurs close to the beginning of the impact. Conversely, the two-stage, mono-tube damper does not reach the peak force until after the nitrogen accumulator bottoms out. To verify this behavior, a theoretical model of the accumulator was derived and compared to the experimental data. Additionally, the results show that at large impact velocities, the peak force does not depend on the current supplied to the damper, as is commonly the case at low velocities. This phenomenon is hypothesized to be the result of the fluid inertia preventing the fluid from accelerating fast enough to accommodate the rapid piston displacement. Thus, the peak force is primarily attributed to fluid compression, rather than the flow resistance (‘‘valving’’) associated with the fluid passing through the MR valve. Dampers were designed by James Poyonor[9]

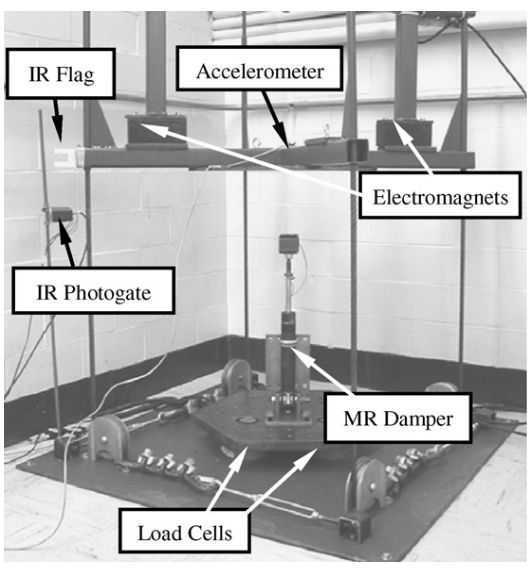
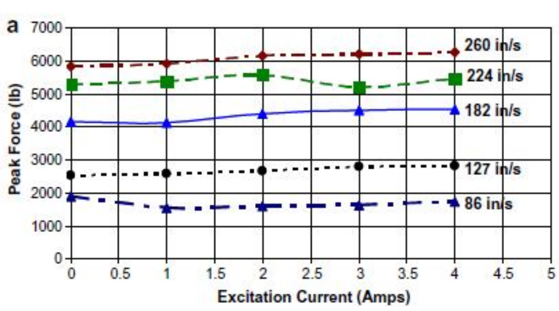


Fig. 10 Experimental Arrangement



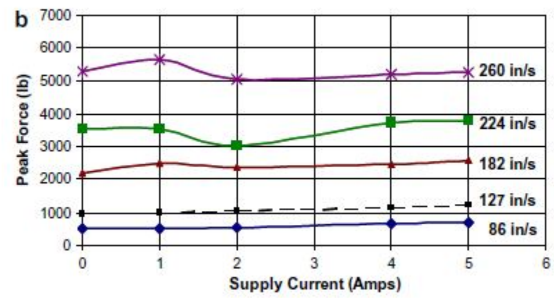


Fig. 11 Peak Force Transmitted at Different Damper Currents for Various Impact Velocities; (a) Double-Ended Damper; (b) Mono-Tube Damper

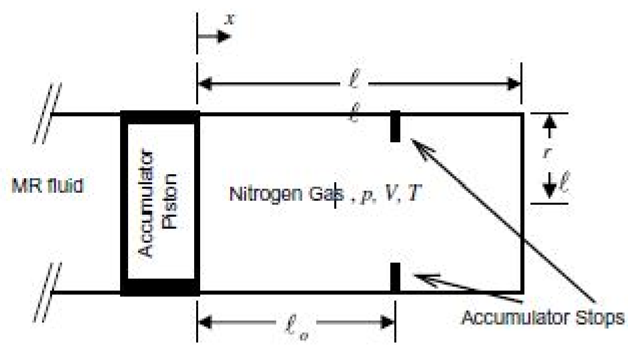


Fig.12 Nitrogen Accumulator Schematic for Modeling

Force produced by the accumulator, F(x), is

$$F(x) = \frac{\pi r^2 p_0}{1 - x/l} \text{ where } 0 < x \le l_0 \qquad (1)$$

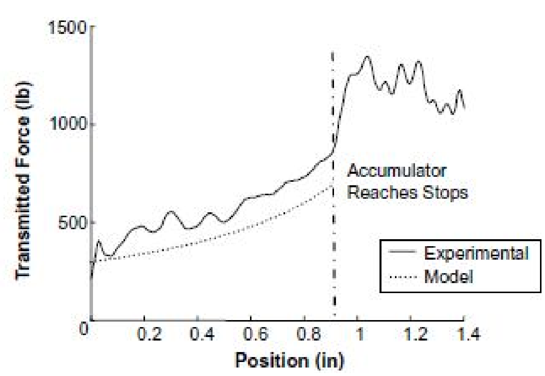


Fig. 13 Comparison of the Accumulator Model with Experimental Data

A test case of 127 in./s impact velocity and 4 A supplied to the MR damper, is shown in Fig. 13. The difference between the theoretical accumulator force and the experimental force is hypothesized to be due to forces associated with shearing the MR fluid.

XIANG Hengbo et al [10] studied a commercial MRD (type RD-1005-3) manufactured by Lord Corporation experimentally in order to investigate its isolation performance under the impact loads. A new mechanical model of MRD was proposed according to the data obtained by impact test. A good agreement between the numerical results and test data was observed, which showed that the model was good to simulate the dynamic properties of MRD under impact loads. It is also demonstrated that MRD can improve the acceleration and displacement response of the structure obviously under impact loads

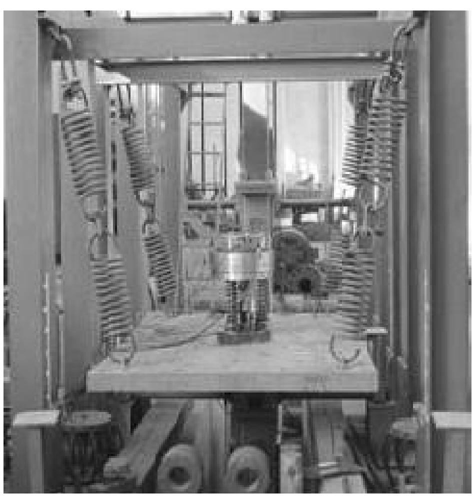


Fig. 14 Setup of the Shaking Table for Shock

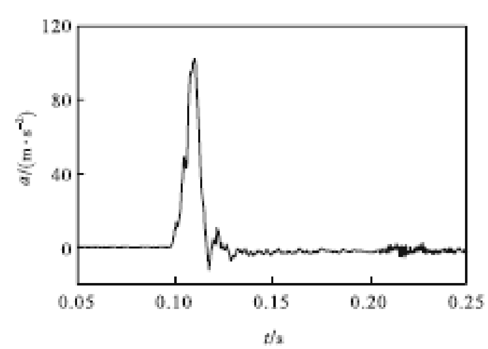


Fig. 15 Impact Loads on Basement

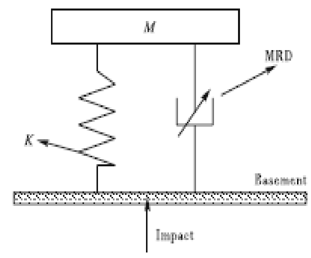


Fig. 16 SDOF Simplified Model for the Test Structure

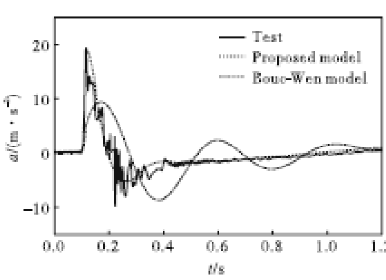
Proposed Bouc-Wen model

Based on the modified Bouc-Wen model[11] and test data, a new model is proposed as follows:

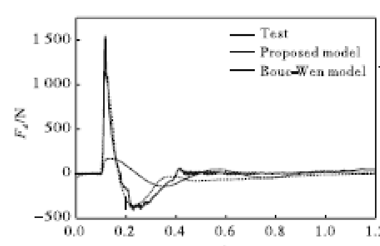
$$F_d = C_0(I)x + K_0(I)\dot{x} + \alpha(I)z + f_z \quad (2)$$

$$z = \frac{1}{\sqrt{\gamma(I)}}\tan\left\{\sqrt{\gamma(I)}\left[x + \dot{x}_h(I)\right]\right\} \quad (3)$$

Where parameters α and γ control the shape of hysteresis force *vs* velocity curve, and $\dot{x}_h$ controls the width. f_z is the offset force due to the accumulator of the MRD, which has no effect on dynamic response of the structure isolated by MRD.

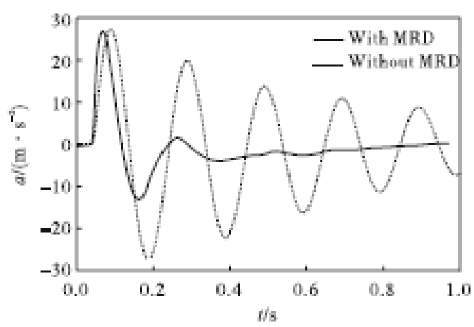


(a) Structure acceleration

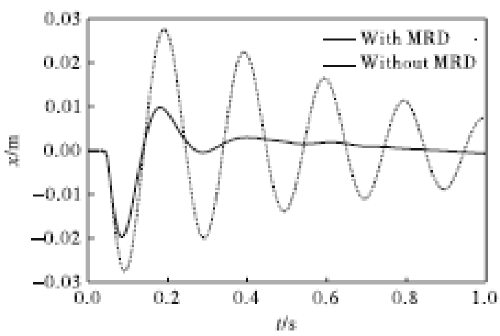


(b) Damping force

Fig. 17 Comparison between Numerical Results, and Test Data



(a) Acceleration



(b) Relative displacement

Fig. 18 Comparison between Responses of Structure, with and without MRD

The properties of MRD have much difference between impact loads and harmonic loads. Under impactloads, the elastic and damping coefficients of MRD enlarge greatly. It is demonstrated that the MRD has good shock isolation performance under impact loads. The acceleration and relative displacement of the structure attenuate quickly by the isolation of MRD, especially in the negative peak values of both structure acceleration and relative displacement

4. Conclusion

Behavior of MR damper under sinusoidal, harmonic, impulsive and impact loading have been discussed.

Investigations on the design of controllable magneto-rheological (MR) fluid devices have focused heavily on low velocity and frequency applications. The extensive work in this area has led to a good understanding of MR fluid properties at low velocities and frequencies. However, the issues concerning MR fluid behavior in impact and shock applications are relatively unknown. While the previous studies on MR dampers have shown promising results, it should be noted that the MR dampers either in passive-on or semi-active controlled modes could be further explored as compared with systems with conventional viscous dampers and not much of work was done on investigation of characteristics' of MR damper.

References

1. *Spencer B F, Dyke S J, Sain M K and Carlson J D (1996), "Phenomenological Model of a Magneto-Rheological Damper", Journal of Engineering Mechanics, Vol. 123, 230-238.*

2. *Phule P (2001), "Magnetorheological (MR) Fluids: Principles and Applications", Smart Materials Bulletin, Vol. 2001, 7-10.*

3. *Gavin H, Hoagg J and Dobossy M (2001), "Optimal Design of MR Dampers", Proceedings of U.S. Japan Workshop on Smart Structures for Improved Seismic Performance in Urban Regions, K. Kawashima, et al., eds., Seattle WA, pp. 225-236.*

4. *Yang G, Carlson J D, Sain M K and Spencer B F (2002), "Large-scale MR Fluid Dampers: Modeling and Dynamic Performance Considerations", Engineering Structures, Vol. 24, 309-323.*

5. *Li W H, Yao G Z, Chen G, Yeo S H and Yap F F (2000), "Testing and Steady State Modeling of a Linear MR Damper under Sinusoidal Loading", Smart Materials and Structures, Vol. 9, 95-102.*

6. *Ali K El, Waheda, John L Sproston and Graham K Schleyer (2002), "Electrorheological and Magnetorheological Fluids in Blast Resistant Design Applications", Materials and Design, Vol. 23, 391-404.*

7. *Liao W H and Lai C Y (2002), "Harmonic Analysis of a Magnetorheological Damper for Vibration Control", Smart Materials and Structures, Vol. 11, 288-296.*

8. *James A Norris and Mehdi Ahmadian (2008), "Experimental Analysis of Magnetorheological Dampers when Subjected to Impact and Shock Loading", Nonlinear Science and Numerical Simulation, Vol. 13, 1978-1985.*

9. *Poynor J C (2001), "Innovative Designs for Magneto-Rheological Dampers", Virginia Polytechnic Institute and State University, Blacksburg.*

10. *XIANG Hengbo, FANG Qin, GONG Ziming and Hao W U (2008), "Experimental Investigation into Magnetorheological Damper Subjected to Impact Loads", Transactions of Tianjin University, Vol. 14, 540-544.*

11. *Domingnez A, Sedaghati R and Stiharu I (2006), "A New Dynamichysteresis Model for Magnetorheological Dampers", Smart Materials and Structures, Vol. 15, 1179-1189.*