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Experimental investigation of Magneto-rheological damper

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Abstract

In recent years, intensive research works are concentrated on the development of semi-active control devices. A semi-active control system can also be explained as a system that mainly requires a small external power source for functioning and applies the motion of the structure to generate the control forces. A semi-active control system typically begins from a passive control system, which is followed by a change to permit the flexibility of mechanical properties. The mechanical properties of the semi-active control devices may be modified depending upon the response from the excitation and/or from the calculated reaction. Magneto-rheological (MR) dampers are a type of a semi-active control device that, in the presence of Magneto-rheological (MR) fluid, responds to the applied vibrations. This type of damper has copper winding in it, forming an electronic circuit internally with a combination of MR fluids. The effectiveness of MR damper greatly depends on the command voltage to the copper winding. In the present study, the response of MR Damper to the command voltage, and the excitation frequency is experimentally evaluated. MR damper is supported by a wall mounting rigid fixture and connected to a shake table by a fixing unit. The voltage is varied from 0 V - 10 V with an interval of 2 V. Command voltages is applied to the MR damper with the help of voltage regulator and digital multi meter. The effect of excitation frequency is also studied (1 Hz – 8 Hz). While conducting the experimental work, acceleration values are obtained through the Data acquisition system. These acceleration values are integrated to get the velocity and displacement response. The relation between the displacement, velocity, acceleration of the MR damper, and the frequency of shake table and command voltage is studied. From the experimental work, it is observed that the displacement response of the damper is effectively controlled by increasing the command voltage.

Keywords: Magneto-rheological (MR) damper, semi-active control device, command voltage, excitation frequency.

1. Introduction

For structural stability of civil structures from seismic response there are several techniques which provide safety to the structures. Some techniques involved in seismic response stability are base isolation, active stability process, passive control process, and semi-active process. So far there have been many works carried out in the above mentioned topics. MR damper comes under the category of semi-active control device. MR dampers are basically used in building structures, cable stayed bridges and vehicles which act as a shock absorbing device.

Carlson (1994); Carlson and Weiss (1994); Carlson, *et al.* (1995) have explained from their study that, MR fluids are the magnetic analogs of electro-rheological fluids and mostly consists of micron sized , magnetically polarizable particles scattered in a carrier medium such as mineral or silicone oil [Carlson, *et al*. (1996)]. When a magnetic field is applied to the fluids, particle chains form, and the fluid becomes a semi-solid and exhibits visco-plastic behavior similar to that of ER fluids. Transition to rheological equilibrium can be achieved in a few milliseconds, allowing the construction of devices with high bandwidth. From their research work it is explained that recently developed MR fluids show very well compatibilty for use in controllable fluid dampers. Additionally, Carlson and Weiss (1994) indicated that the achievable yield stress of an MR fluid is an order of magnitude greater than its ER counterpart and that MR fluids can operate at temperatures from –40°C to 150°C with only slight variations in the yield stress.

Moreover, MR fluids are not sensitive to impurities which are commonly encountered during manufacturing and usage, and little particle/carrier fluid separation takes place in MR fluids under common flow conditions.

Further a wider choice of additives (surfactants, dispersants, friction modifiers, anti-wear agents, *etc.*) can generally be used with MR fluids to enhance stability, seal life, bearing life, *etc.*, since electro-chemistry does not affect the magneto-polarization mechanism.

Kori and Jangid, (2009) have explained that MR dampers had proven that using a small amount of external power can reduce the structural response due to an earthquake. The performance of MR damper depends upon the control law applied. The damper force is directly

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dependent upon input command voltage.

G. Yang *et al.* (2002) have said that MR dampers are one of the prominent recent devices developed to reduce structural vibration. The device has the quality of mechanical simplicity, high demand range, low power requirements, large force capacity, and robustness.

A. R. Tsouroukdissian *et al.* (2008) have stated that precise modeling of these devices involve using various laws of physics, which is a difficult task, semi-physical models are more in use to describe its behavior being a substitute to it.

The Semi-active control system had presented considerable attention for taking care of structures against natural hazards such as strong earthquakes and high winds, as they offer the reliability of passive control systems as well as maintain the versatility and flexibility of full active control systems. (Jung and Lee, 2002)

B. F. Spencer *et al.* (1996) have investigated that, the semi-active control devices had been gaining importance in the last previous years because of their unique characteristic such as flexibility of active control devices without needing the associated large power sources. It is very well known that Magneto-rheological (MR) dampers are semi-active control devices that use MR fluids to generate controllable dampers.

Sun Quing *et al*, (2003) have investigated that several tests that had been conducted at different earthquake excitations and various excitations provide the ability of the MR damper to exceed the performance of a comparable passive system in a variety of conditions.

S. J. Dyke *et al.* (1996) have explained that protection of Civil Engineering structures for earthquake hazard reduction describes a comparatively new area of research that is growing vastly. For this, the control systems for the structures have distinctive requirements and constraints. As an illustration, during a serious seismic event, the external power to a structure may be serious, providing control schemes relying on large external power provision ineffective.

Seung Yong Ok *et al.* (2006) have analyzed that a semi-active fuzzy control technique to strengthen the seismic performance of cable-stayed bridges using magneto-rheological dampers was used. Standard semi-active control techniques need a primary controller as a benchmark to obtain the desired control force and regulate the input voltage of the MR damper by differentiating the demanding control force and the actual damper force in a secondary controller.

In the present study, it has been acknowledged that MR dampers come under the class of semi-active devices which are based on controllable fluids (Stanway *et al.*, 1987; Gamota and Filisko, 1991; Spencer *et al.*, 1997; Jolly *et al.*, 1999; Choi *et al.*, 2001).

In last years, the application of semi – active control for retrofitting a building structure has received importance for different types of retrofitting procedures. One of the technique conveys that by connecting a delicate building to an adjoining building by semi – active devices would notably enhance the ability of delicate building for seismic forces. From this paper it is known that, a ten storey delicate building is linked to an adjoining tough building by applying magneto – rheological (MR) dampers, for mainly improving the overall execution of the delicate building with regard to displacement, drift and base shear. A fuzzy logic controller is particularly developed by fuzzyfying the responses of the coupled system for this. The overall execution of the control strategy is differentiated with the passive – on and passive off controls. Pounding mitigation within the two buildings is also analysed using all three control procedures. Yet coupling strategy always improves the possibility of pounding mitigation. The effects show that there exists a basic frequency ration within the two buildings for which the highest control of the delicate building response takes place with no retribution on the tough building. There also remains an underlying frequency ratio where managing of the shaky building response is obtained at the charge of amplification in the tough building. [M. Abdeddaim *et al.*, 2017; and M. Abdeddaim *et al.,* 2019;]

The primary feature of controllable fluids is their capability to reversibly change from a free-flowing, linear viscous fluid to semi-solid material. The yield strength can be varied in milliseconds when exposed to a magnetic field. MR fluids consist of micron-sized, magnetically polarizable particles dispersed in mineral or silicone oil. When a magnetic field is applied to the fluids, chain formation of particles are seen, and the fluid becomes a semi-solid and display visco-plastic behavior. Another appealing feature of MR fluids is that they can operate at temperatures from 40 to 150°C with only slight variations in the yield stress. Additionally, MR fluids are almost completely insensitive to impurities. The MR fluid can be controlled with a low voltage (0 – 10 V) and current operated power supply resulting only 0 – 1.44 Amps. All these features make MR dampers attractive as actuators controlled by the voltage to be used in different engineering fields.

2. Objective of the study

The objectives of the paper are to study the effect of voltage and excitation frequency on the response of MR damper.

3. Theory of MR Damper

3.1 Fluid Action in MR Damper

MR fluids consist of magnetic (typically iron) particles in a carrier fluid. In the presence of a magnetic field, the micron-sized particles link and change the fluid to a semi-solid in milliseconds. When the magnetic field is removed the fluid just as quickly reverts to its natural free following state. Furthermore, the degree to which the fluid changes to a semi-solid is proportional to the strength of the magnetic field, giving the fluid infinite controllability & precision.

Figure 1 explains MR fluid for two conditions (a) without application of charge and (b) with application of charge.

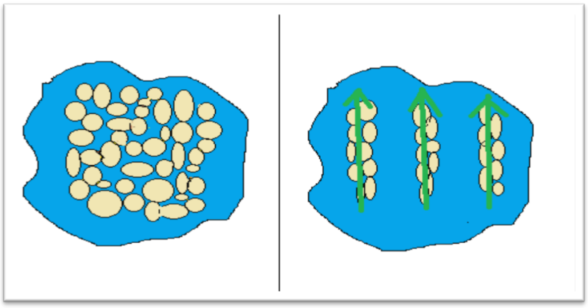

Figure 1: Fluid action in MR Damper (a) without application of charge (b) with the application of charge.

The MR Fluid of 'Arus MR Tech' organization, whose product code AMT – DAMPRO ® is used for experimental work. MR fluid is a special type of fluid usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity, to the point of becoming a viscoelastic solid. Importantly, the yield stress of the fluid when in its active ("on") state can be controlled very precisely by varying the magnetic field intensity. The conclusion is that the fluid's ability to transmit force can be controlled with an electromagnet, which gives rise to its many possible control-based applications. Table 1 presents the technical specification of MR fluid, which was used for experimental work.

3.2 Working principle of Magneto-rheological Damper

The MR damper includes a fluid that moves into different chambers via small orifices in the piston, changing "shock" energy into heat. Though, in an MR damper, an electrical circuit is introduced in the piston assembly. As electrical current is provided to the damper, a coil inside the piston generates a magnetic field and immidiately changes the properties of the MR fluid in the piston. As a result, the resistance of the damper can be continuously changed in real-time by modulating electric voltage to the damper.

Table 1: - Technical specification of MR fluid.

Technical Specifications		
AMT Dampro		
Sr.no	Description	Value
1.	Appearance	Dark gray liquid
2.	Density g/cm^3	2.45 – 2.55
3.	Operating temperature range	-20 to +150 (-4 to +302)
4.	Max yield stress @ 140 KA/m	60 Kpa
5.	Viscosity at 0ºC Pa.s	0.650
6.	Response Time	<Milliseconds
7.	Flash point ºC (ºF)	>180(>356)
8.	Power Requirements	2 – 24V at 0.5 – 2A

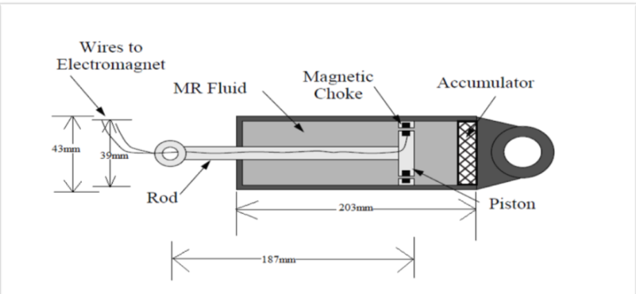

Figure 2: Schematic Diagram of MR Damper.

Table 2: Major dimensions of the MR damper

Sr.no	*Description*	*Value*
1.	Height of piston assembly	187mm
2.	Height of MR Damper assembly	203mm
3.	External radius of damper container	43mm
4.	Internal radius of damper container	39mm

As shown in Figure 2, a clear concept of MR damper along with its principal dimensions shown in Table 2 and its parts are explained accordingly. A manufactured model of MR damper is used, the details of the same are mentioned in 'Design, Fabricate and Experimentally Evaluate the Performance of Magnetorheological Fluid Damper' (S.Shrimandil (2017) *et al*)

Figure 3 explains the image of the internal assembly of MR Damper, which has a washer at its bottom and copper windings above it. Also a threaded cap is provided to keep the internal assembly secured into the damper container.

4. Experimental Investigation

An experimental investigation of the response of MR damper is carried out to study the effect of command voltage and excitation frequency. The parameters applied to it includes excitation frequency of 1 – 8 Hertz. The command voltage supplied to the damper is varied from 0V to 10V with an interval of 2V, with current values of 0A, 0.28A, 0.57A, 0.86A, 1.15A, and 1.44A. The resistance value of the copper windings is 6.91 Ohm. Testing activity is carried out on a horizontal cam shake table, which has an amplitude of 2.5 mm. The MR damper is tested, and its acceleration, velocity and displacement responses are obtained.

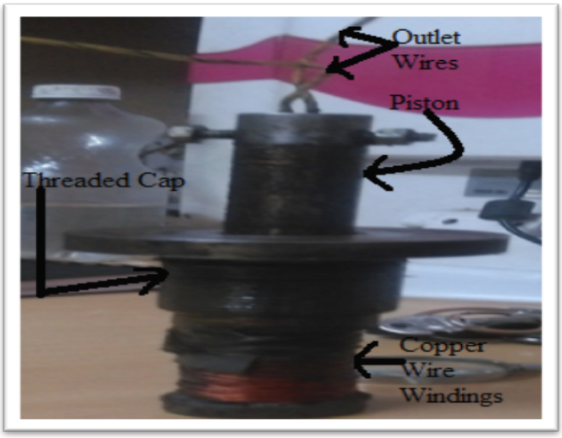

Figure 3: Internal assembly of MR Damper.

Table 3: Voltage and Corresponding current values.

Sr. no.	*Voltage value*	*Corresponding current value*
1.	0V	0A
2.	2V	0.28A
3.	4V	0.57A
4.	6V	0.86A
5.	8V	1.15A
6.	10V	1.44A

The values of voltage and the corresponding current values are presented in Table 3. The experimental investigation is carried out in Structural dynamics lab, AISSMS College of Engineering, Pune.

4.1 Supporting Fixtures for the Damper

The MR Damper is supported with a wall mounting cantilever fixture attached to the wall acting as a rigid end for the damper. A shake table fixture is bolted upon the shake table which connects damper's piston to the shake table. Figure 4 shows the fixture assembly for the MR damper.

4.2 Electronic Setup

The MR damper is a semi-active vibration control device which is electronically supported for its operational purpose. A digital multi-meter and a voltage regulator having 0 – 10 voltage range are used for regulating the voltage. These electronic devices are used for applying a command voltage to the MR Damper as shown in Figure 5.

4.3 Data Acquisition setup.

Data Acquisition is a method of examining the signals that measure practical physical state and modify the obtained readings from the result into digital numeric quantity that can be controlled by a computer. QuickDAQ software system is used for the data acquisition process. An accelerometer is connected to the piston which recorded the acceleration response of MR damper.

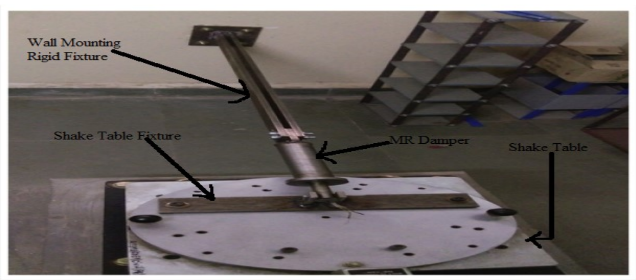

Figure 4: Fixture assembly for MR Damper.

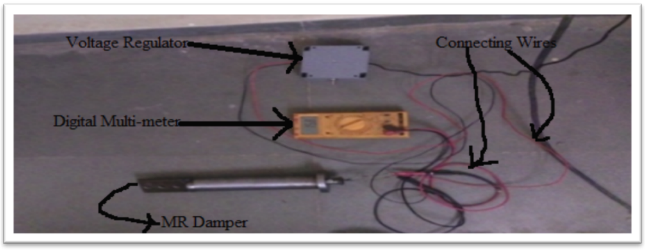

Figure 5: Electronic setup for MR damper.

4.4 Experimental Work

Figure 6 represents the experimental setup of MR Damper testing process which includes MR damper, damper fixtures, electronic setup and data acquisition system. Data has been acquired from the data acquisition system in the form of acceleration for excitation frequency 1 Hz – 8 Hz and voltage range 0V – 10V. Readings are obtained from the process carried out.

5. Results

5.1 *Effect of frequency response of MR Damper.*

According to the experimental work carried out, the MR Damper is in a position of continuous movement. The results obtained in this process are of Time History response. Results with respect to the accelerations are obtained which are later integrated to obtain the values of velocity and displacement. The peak value of acceleration, velocity and displacement are obtained by different combinations of the frequency and velocity, set for the required combination. Data acquisition system is used to obtain readings for the necessary combination of frequency and voltage provided. The MR Damper gets in to motion, due to the vibration force provided by the shake table. The shake table provides a vibratory force which as a result makes the MR Damper move to the frequency on which it is set. Table 4 shows the acceleration, velocity, and displacement response for the different combinations of excitation frequency and voltage.

Figure 6: Experimental Setup of MR damper testing process.

Table 4: Maximum values of response quantities for excitation frequency and the applied voltage**.**

Frequency	*Parameters*						
	Voltage	0V	2V	4V	6V	8V	10V
1Hz	Acceleration (mm/s^2)	0.186	0.311	0.302	0.187	0.181	0.269
	Velocity (mm/s)	1.610	0.513	0.441	0.650	0.588	0.343
	Displacement (mm)	17.135	13.628	13.392	12.497	6.761	6.334
2Hz	Acceleration (mm/s^2)	0.449	0.833	0.474	0.385	0.474	0.402
	Velocity (mm/s)	1.529	2.933	1.477	2.170	1.978	2.343
	Displacement (mm)	17.671	15.817	14.612	12.659	12.096	11.796
3Hz	Acceleration (mm/s^2)	0.825	1.055	1.028	0.931	2.727	2.727
	Velocity (mm/s)	3.699	5.571	2.935	3.883	2.453	5.296
	Displacement (mm)	18.176	17.814	16.822	15.515	13.697	13.601
4Hz	Acceleration (mm/s^2)	0.977	2.033	2.368	1.585	1.729	1.154
	Velocity (mm/s)	3.620	4.009	4.964	2.532	3.365	1.750
	Displacement (mm)	18.991	18.564	17.459	15.653	14.675	13.936
5Hz	Acceleration (mm/s^2)	1.134	2.537	1.858	1.626	1.881	1.977
	Velocity (mm/s)	8.538	3.961	4.144	12.529	1.522	4.145
	Displacement (mm)	19.730	18.400	15.302	15.430	16.659	15.229
6Hz	Acceleration (mm/s^2)	1.430	1.576	1.961	1.642	2.457	2.103
	Velocity (mm/s)	10.985	2.036	2.587	2.281	2.984	5.025
	Displacement (mm)	20.586	18.823	18.354	18.261	16.993	16.670
7Hz	Acceleration (mm/s^2)	1.503	2.177	1.868	2.154	1.849	1.948
	Velocity (mm/s)	5.665	5.494	3.456	4.015	2.846	3.040
	Displacement (mm)	19.089	18.955	18.402	18.226	17.466	16.062
8Hz	Acceleration (mm/s^2)	1.687	1.434	2.166	2.174	1.960	1.917
	Velocity (mm/s)	4.928	5.456	11.703	6.659	3.241	3.885
	Displacement (mm)	20.640	19.417	17.999	18.474	18.042	17.843

Here, in Table 4 the highest values of the acceleration, velocity, and displacement for command voltage and excitation frequency of 1Hz – 8Hz are presented. It could be seen from the table that with an increase in voltage the displacement has decreased. Also, it is understood that as the value of excitation frequency has increased the displacement has also increased. This is due to the higher frequencies applied to the MR damper, which excites the MR damper to show high displacement response. It is very interesting to note that higher acceleration response at lower values of frequencies is observed at lower voltage (2V), and as the frequency is increased, a higher response is observed at the higher voltage (8V).

Response of MR damper for 8Hz frequency is shown in Figure 7, Figure 8, and Figure 9. These responses are for time v/s acceleration, time v/s velocity, and time v/s displacement, respectively.

Figure 7, demonstrates the time history of the acceleration response. In Figure 8, the velocity response is plotted against the time, it is observed that as voltage increases the velocity decreases and it is maximum for 4V, after this the velocity response decreases with increase in the the voltage. Figure 9 shows that lower displacement response is observed at 4V and it is lowest at 10V.

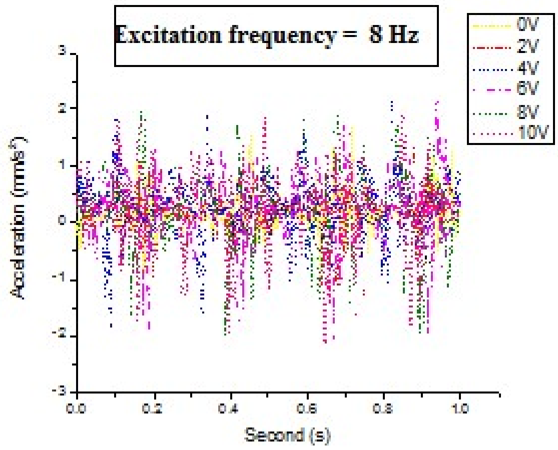

Figure 7: Time v/s acceleration response for 8Hz.

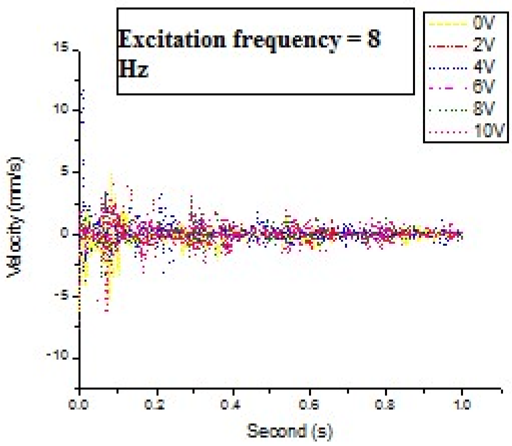

Figure 8: Time v/s velocity response for 8Hz.

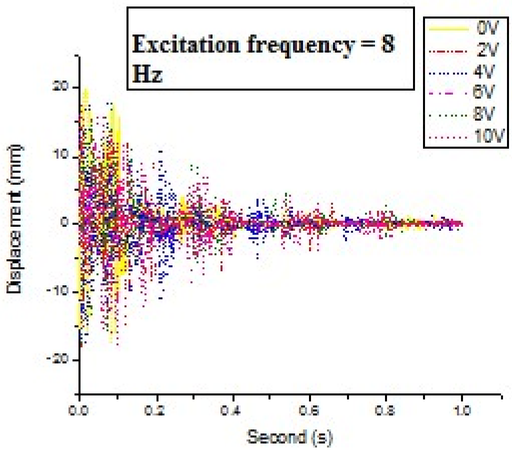

Figure 9: Time v/s displacement response for 8Hz

It is noted that the MR damper is operating in the frequency range of 1Hz – 8Hz, therefore when the frequency of the shake table is increased the displacement also increases which can be seen in Table 4, whereas, reduction in the displacement is achieved by increasing voltage from 0V – 10V. The increase in voltage results in change in state of MR fluid from liquid to a semi-solid state.

5.2 Results showing the effect of voltage on the damper displacement subjected to continuous applied frequency: -

Voltage range of 0V – 10 V is provided to the MR Damper. The displacements obtained for the voltage ranges differ as the voltage value is increased. The highest amount of displacement is observed as 20.640 mm for 0V – 8Hz combination. The lowest value of displacement is observed as 6.334 mm for 10V – 1Hz combination.

Figure 10 explains the effect of voltage on displacement response of the MR damper for excitation frequency of 1Hz – 8Hz. It can be seen that by increase in the voltage, the displacement of the damper has reduced. This is due to the applied voltage changes the state of the MR fluid from liquid to semi-solid, offering resistance to displacement.
For 1 Hz frequency the highest value of displacement is 17.135 mm (0V) and lowest value of displacement is 6.334 mm (10V). Similarly, for 8 Hz frequency, the highest amount of displacement is 20.640 mm (0V) and the lowest value of 17.843 mm (10 V) is observed. A similar response is observed for all other considered frequencies.

5.3 Results showing the effect of voltage on the damper velocity subjected to continuous applied frequency: -

Figure 11 explains the effect of voltage on Velocity response of the MR damper for excitation frequency of 1Hz – 8Hz. It is understood from the figure that the response generated is irregular in behaviour.

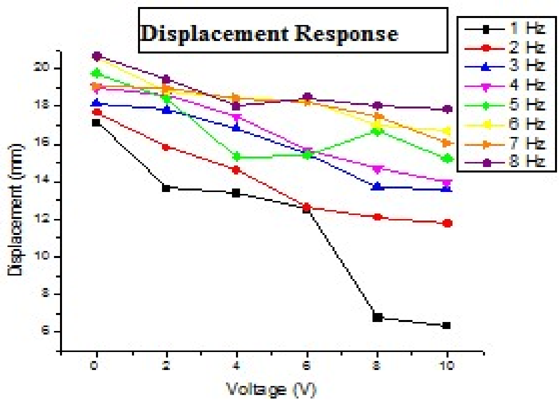

Figure 10: Effect of voltage on displacement response of the MR damper.

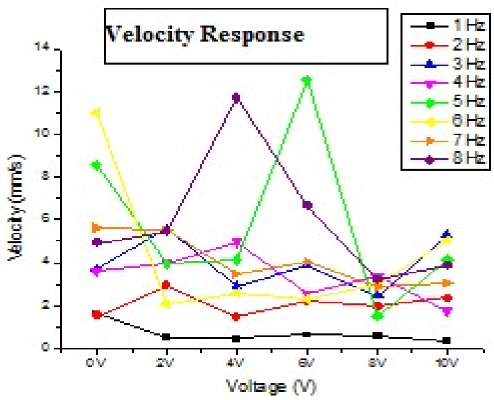

Figure 11: Effect of voltage on velocity response of the MR damper.

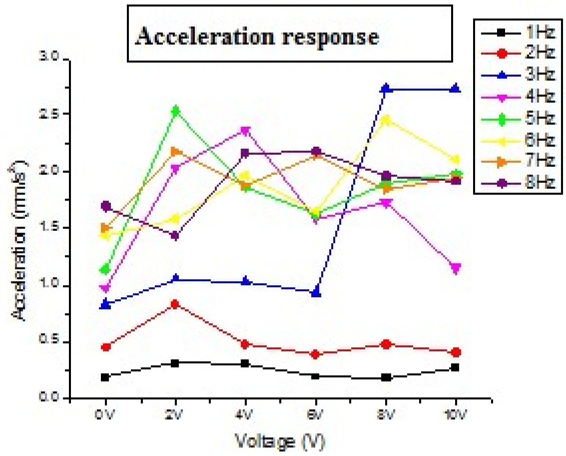

Figure 12: Effect of voltage on the acceleration response MR Damper.

In Figure 11, the response of voltage with respect to velocity for 1 – 8 Hz frequency is plotted. It is observed that the highest velocity response is observed at 0V and the lowest velocity response is observed at 8V. For 5 Hz and 8 Hz frequency the velocity behavior observes extreme irregularity with the maximum velocity at 4V and 6V, respectively.

5.4 Results showing the effect of voltage on the damper acceleration subjected to continuous applied frequency: -

In Figure 12, the acceleration response for voltage and excitation frequency is plotted. Figure 12 explains the effect of voltage on the acceleration response, for excitation frequencies of 1Hz – 8Hz. From the figure, it is seen that the response of acceleration with respect to voltage is constantly changing. The acceleration response at 1 Hz and 2Hz are of similar nature with minimum acceleration resonse at 6V. However, drastic change is observed for 3 Hz frequency such that there is increase in acceleration response from 0.931 mm/s^2 to 2.727 mm/s^2 at 6V to 8V and it is constant for 10V.

For 4 Hz to 8 Hz the value of acceleration response is observed to be similar nature, with minimum for 0V, increasing for 2V and then again gradually reducing for the subsequent increase in the voltage.

The acceleration response when integrated with respect to time gives the velocity. Similarly, the velocity response, when integrated with respect to time gives the displacement. Here it is seen that the displacement response is considered as the refined response, giving a general trend of the beahviour MR damper subjected to different voltages and excitation frequencies, where the results so obtained are nearly uniform, as mentioned in the sub-topic *5.2* of this study.

6. Conclusion

From the above study, it can be concluded that the command voltage and excitation frequency of the MR damper plays an important role in determining the displacement, velocity and acceleration responses. The conclusions from the above results can be made as stated below

1. The effect of voltage on displacement response explains that as voltage increases, the displacement reduces

due to the change in the state of fluid from liquid to semi-solid state.

2. It is observed that the highest velocity response is observed at 0V and the lowest velocity response is observed at 8V.

3. It is very interesting to note that higher acceleration response at lower frequencies is observed at lower voltage (2V) and as the frequency is increased, the higher response is observed at higher voltage (8V).

4. As the value of excitation frequency has increased the displacement has also increased. This is due to the higher frequencies applied to the damper excites the MR damper to show high displacement response.

Disclosures

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References

1. A. R. Tsouroukdissian, F. Ikhouane, J. Rodellar and N. Lao, (2008) Modeling and identification of a small-scale Magneto-rheological Damper. IFAC Proceedings Volume, Elsevier, Science Direct, volume 43, issue 10, pg no 1-12.

2. B.F. Spencer Jr, S.J. Dyke, M.K. Sain and J.D. Carlson, (1996) Phenomenological Model of a Magneto-rheological Damper. ASCE Journal of Engineering Mechanics, volume 123, issue 3, pg no 1-23.

3. B. F. Spencer, Jr., S. J. Dyke, and M.K. Sain, (1996). Magneto-rheological dampers: a new approach to seismic protection of structures. Proc. Conf. on Decision and Control, 676–681.

4. D.R. Gamota, and F.E. Filisko, (1991). Dynamic Mechanical Studies of Electrorheological Materials: Moderate Frequencies. Journal of Rheology, Vol. 35, pp. 399–425.

5. G.Yang, B.F. Spencer Jr, J.D. Carlson and M.K. Sain, (2002) Large scale MR fluid dampers: modeling and dynamic performance considerations. Engineering Structures, Elsevier, Science Direct, volume 24. Issue 3, pg no 1-29.

6. G.Z. Yao, F.F. Yap, G. Cheng, W.H. Li and S.H. Yeo, (2002) MR damper and its application for semi-active control of vehicle suspension system. Mechatronics, Elsevier, Science Direct, volume 12, issue 7.

7. H. J. Jung, I. W. Lee and B.F. Spencer Jr, (2002) State of the art of MR damper based control systems in Civil Engineering Application. Structural Engineering and Mechanics, proceedings of US-Korea Workshop on Smart Infrastructural Systems.

8. J. D. Carlson, (1994). The Promise of Controllable Fluids. Proc. of Actuator 94 (H. Borgmann and K. Lenz, Eds.), AXON Technologie Consult GmbH, pp. 266–270.

9. J. D. Carlson, and K.D. Weiss (1994). A Growing Attraction to Magnetic Fluids, Machine Design, August, pp. 61–64.

10. J. D. Carlson, D.M. Catanzarite, and K.A. St. Clair, (1995). Commercial Magneto-Rheological Fluid Devices, Proceedings of the 5th International Conference on ER Fluids, MR Fluids and Associated Technology, U. Sheffield, UK.

11. J. G. Kori and R.S. Jangid, (2009) Semi active MR dampers for seismic control of structures. Bulletin of the New Zealand Society of Earthquake engineering, Volume 42, number 3, pg no 157-166.

12. M. Abdeddaim, A. Ounis, T. K. Dutta and M. K. Shrimali (2017) Retrofitting of a weaker building by coupling it to an adjacent stronger building using MR dampers, Structural Engineering and Mechanics, Volume 62 Issue 2, Pages; 197-208.

13. M. Abdeddaim, A. Ounis, S. D. Bharti, M. K. Shrimali (2019) Seismic Retrofitting Using the Concept of Coupling Two Adjacent Buildings, Recent advances in Structural Engineering, Volume 2, Springer Singapore.

14. M. R. Jolly, J. W. Bender and C. Thomas, J. David (2000). ‘‘Properties and Application of Commercial Magneto rheological Fluids,’’ Lord Research Center Lord Corporation.

15. R. Stanway, J.L. Sproston, and A.K. El-Wahed (1996). Application of Electrorheological Fluids in Vibration Control: A Survey, Smart Materials and Structures, 5(3):351–358.

16. S. B. Choi, S. K. Lee, and Y. P. Park, (2001) A Hysteresis Model for Field-Dependent Damping Force of a Magneto rheological Damper, Journal of Sound and Vibration, 245(2):375–383.

17. S.J. Dyke and B.F. Spencer, (1997) A Comparison of semi-active control strategies for the MR damper. Proceedings of the IASTED, International Journal Conference, Intelligent Information System.

18. S. Shrimandil, S. Zambare, V. S. Rawat and A. Pawar, (2017) Design, Fabricate and Experimentally Evaluate the Performance of Magnetorheological Fluid Damper. International Journal of Innovative Research in Technology, volume 4, issue 1.

19. S. Y. Ok, D. S. Kim, K. S. Park and H. M. Koh, (2006) Semi-active fuzzy control of cable-stayed bridges using magneto-rheological dampers. Engineering Structures, Elsevier, Science Direct, volume 29, issue 5.

20. S. Quing, Z. Ling, Z. Jinxiong and S. Q. Xuan, (2003) Experimental study of the semi-active control of building structures using the shake table. The Journal of the International Association of Earthquake engineering, Earthquake engineering and structural dynamics, John Wiley and sons.

21. Z. Jiang and R.E. Christenson, (2012) A fully dynamic magneto-rheological fluid damper model. IOP Publishing Ltd, Smart Materials and Structures, volume 21, number 6.