"Design and Development of Semi-Active Beams Based on Embedded Magneto-Rheological Fluid Dampers"

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ABSTRACT:

There are two types of vibration controlling strategies which are passive strategies and active strategies. But one modified strategy was developed known as semi-active vibration control strategy. MR phenomenon was studied. Need of these semi-active devices was explained. Economical, durable and robust MR damper was developed. MR fluid filled beam and MR fluid was prepared. Two types of composite beams are developed and experimented by varying the dimensions of beams, iron particle percentage in magnetorheological fluid, magnetic field at different excitation current. For this composite beam with increase in magnetic field, damping was increased and the frequency shift was observed. Also change in amplitude of vibration was observed.

Keywords: *Amplitude, Damping, Magnetic field, MR phenomenon*

I. INTRODUCTION

Modern industry has a great need of advanced damping system which could dissipate energy from the random vibration to improve structural safety and system performance. Most of the existing systems are equipped with the passive damping system because of its simplicity in reflecting or absorbing part of input energy without any power requirement. Another important vibration reduction approach is the semi-active system which takes advantages of both the passive and active damping systems. Magneto Rheological (MR) dampers and Electro Rheological (ER) dampers are the two main examples of this approach. However due to various advantages of MR dampers over ER dampers, MR dampers are getting more attention. MR dampers are the same as classical dampers except the fluid used in the damper. This fluid is called as MR fluid. MR damper fluids are relatively new semi-active devices that utilize MR fluids to provide controllable damping forces. MR dampers are one of the most promising control devices for engineering applications because they have many advantages such as small power requirement, reliability and low price to manufacture. MR fluids are always better than ER fluids. MR fluids had more yield strength than ER fluids. Operating temperature range is also high for MR fluids as compared to ER fluids. Power supply needed for MR fluids is very less than ER fluids. As per above comparison between MR fluids & ER fluids we can say that MR fluids are always better than ER fluids.

Semi-active devices are capable of charging the properties as per requirement with minimum power requirement and less complicated design as compared to the active devices. This helps in reducing the manufacturing and operating cost as compared with active devices. Most of the semi-active devices are based on the fluids with rheological properties such as Electro Rheological (ER) and Magneto Rheological (MR) fluids. Due to various advantages, semi-active vibration reduction devices are becoming popular in various applications in automobile, mechanical, civil and aerospace engineering. These fluids can provide significant and rapid changes in the damping properties with application of an magnetic field.

With the extensive research on MR fluids and MR dampers, researchers have shifted focus on development of MR fluid based applications. However lot of work is needed in the development of semi-active beams which will have enormous applications. Main focus of MR based beam was based on MR elastomer based beams which helped in achieving variable stiffness along with variable damping. Recently, few researchers have started developing sandwich beams based on the MR fluids.

To overcome these shortcomings, this work focuses on developing beams based on the Principles equivalent to MR fluid dampers. In this study, various configurations of MR dampers will be embedded in the beams and their damping and stiffness performance will be studied.

In the present study, two types of cantilever sandwich MR beams are fabricated and these vibration responses under varying magnetic fields are studied. In the first type free and forced vibration response of aluminium sandwich beam is presented. The comparison of partially treated aluminium beam against the fully filled beam is evaluated. In the second type composite cylindrical MR sandwich beam subjected to forced vibrations is studied. It consists of an external stainless steel pipe with end mass, an inner interchangeable rod (of different diameter and material) and sandwich layer of MR fluid. Results showed that under increased magnetic field vibration controllability of cantilever beams is improved in turns of variations of vibration amplitudes and shift of peaks in resonant natural frequencies.

II. LITRATURE REVIEW

Carlson et al. [1] discovered that Controllable magnetorheological (MR) fluid devices had reached the stage where they were in commercial production. Such devices had found application in a variety of real world situations ranging from active vibration control to aerobic exercise equipment. Examples of several, commercial MR fluid devices were described and the comparative ability of MR and ER fluids to meet the needs of particles devices was discussed.

According to Karakocet et al. [2], design considerations for building an automotive magneto-rheological(MR) brake were discussed. The proposed brake consists of multiple rotating disks immersed in a MR fluid and an enclosed electromagnet. When current was applied to the electromagnet, the MR fluid solidifies as its yield stress varies as a function of the magnetic field applied. This controllable yield stress produced shear friction on the rotating disks, generating the braking torque. In this work, practical design criteria such as material selection, sealing, working surface area, viscous torque generation, applied current density, and MR fluid selection were considered to select a basic automotive MR brake configuration. Then, a finite element analysis was performed to analyze the resulting magnetic circuit and heat distribution within the MR brake configuration. This was followed by a multidisciplinary design optimization (MDO) procedure to obtain optimal design parameters that can generate the maximum braking torque in the brake. A prototype MR brake was then built and tested and the experimental results showed a good correlation with the finite element simulation predictions. However, the braking torque generated was still far less than that of a conventional hydraulic brake, which indicated that a radical change in the basic brake configuration was required to build a feasible automotive MR brake.

Pan et al. [3] developed analytical model of a magnetorheological damper and its application to the vibration control. Magnetorheological (MR) fluid and its damper had received a great deal of attention in the recent years. It was very useful for this MR controllable damper in the vibration control system, especially as a semi-active control device. To develop the control algorithms that take maximum advantage of the unique features of the MR damper, a model was needed to be developed that can adequately characterize the damper intrinsic behavior. Following a review of three mechanical models for MR damper the effect of these models on the vibration control was analyzed in a one-degree-of-freedom system. Numerical simulations were performed when the MR damper was used as the passive type damper on-off type damper and quasi-skyhook type damper. The results show that the models were less affecting the vibration control performance, and the MR damper appears the best control performance in the quasi-skyhook type.

Vibration analysis of a multi-layer beam containing magnetorheological fluid by Rajmohan et al. [4] exhibited rapid variations in their rheological properties when subjected to varying magnetic field and thus offered superior potential for applications in smart structures requiring high bandwidth. MR sandwich structures could apply distributed control force to yield variations in stiffness and damping properties of the structure in response to the intensity of the applied magnetic field and could thus provided vibration suppression over a broad range of external excitation frequencies. This study investigated the properties of a multi-layered beam with MR fluid as a sandwich layer between the two layers of the continuous elastic structure. The governing equations of a multi-layer MR beam were formulated in the finite element form and using the Ritz method. A free oscillation experiment was performed to estimate the relationship between the magnetic field and the complex shear modulus of the MR materials in the pre-yield regime. The validity of the finite element and Ritz formulations developed was examined by comparing the results from the two models with those from the experimental investigation. Various parametric studies had been performed in terms of variations of the natural frequencies and loss factor as functions of the applied magnetic field and thickness of the MR fluid layer for various boundary conditions. The forced vibration responses of the MR sandwich beam were also evaluated under harmonic force excitation. The results illustrated that the natural frequencies could be increased by increasing the magnetic field while the magnitudes of the peak deflections could be considerably decreased, which demonstrated the vibration suppression capability of the MR sandwich beam.

Vibration analysis of a partially treated multi-layer beam with magnetorheological fluid by Rajmohan et al. [5] suggested that semi-active vibration control based on magnetorheological (MR) materials offered excellent potential for high bandwidth control through rapid variations in the rheological properties of the fluid under varying magnetic field. Such fluids may be conveniently applied to partial or more critical components of a large structure to realize more efficient and compact vibration control mechanism with variable damping. This study investigated the properties and vibration responses of a partially treated multi-layer MR fluid beam. The governing equations of a partially treated multi-layered MR beam were formulated using finite element method and Ritz formulation. The results showed that the natural frequencies and transverse displacement response of the partially treated MR beams were strongly influenced not only by the intensity of the applied magnetic field, but also by the location and the length of the fluid pocket. The application of partial treatment could also alter the deflection pattern of the beam, particularly the location of the peak deflection.

III. ANALYSIS

MR sandwich cantilever beams of various configurations were tested on the experimental setup. It consists of an exciter, oscillator, FFT analyzer, fixture for holding the beams and software for getting results. The experiments are organized in three different sections.

3.1 Aluminium plate beam

Middle filled aluminium plate cantilever beam containing magnetorheological fluid with 50% iron particles was experimented. Without any external magnetic field this beam was studied and also studied the effect of external magnetic field on the beam.

Without any magnetic field the response showed higher amplitudes of vibration 2.17mm and it was observed that resonance frequency of the beam was 30Hz. With further increase in magnetic field 500 gauss there was slight decrease in amplitude of vibration up to 1.55mm and resonance frequency remained same to 28Hz.

Figure 1 Aluminium plate beam middle filled

Table 1 Displacement Response for Different Excitation Current without any Magnetic Field

Frequency in Hz	Current in Amp	Displacement in mm
24		0.749
26		1.82

Frequency in Hz	Current in Amp	Displacement in mm
24		0.564
26	0.6	0.761
28		1.04
30	0.9	2.13
32		5.24
34		1.58
36		0.896

28		2.08
30		2.17
32		1.04
34		0.769
36		0.478

Table 2 Displacement Response for Different Excitation Current with Magnetic Field 550 gauss

Frequency in Hz	Current in Amp	Displacement in mm
24		0.560
26		1.02
28		1.55
30	0.6	1.08
32		0.715
34		0.474
36		0.323

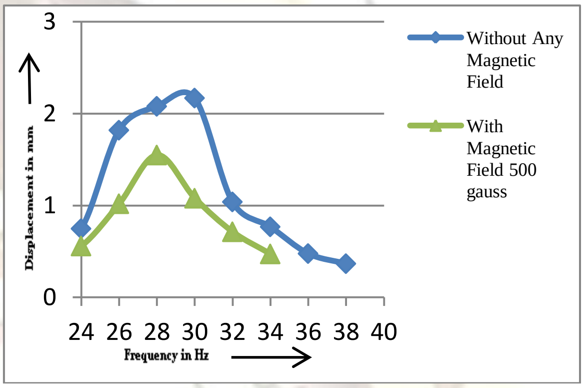

Figure 2 Displacement Response Curve for Aluminium Plate Beam Middle Filled and 50% Iron Particles at Different Magnetic fields

3.2 Cantilever Beam with 0.5mm gap (inner diameter of steel cylinder was 17mm and outer diameter wooden of rod was 16mm) and Magnetorheological fluid with 30% iron particle

MR sandwich beam was assembled to maintain 0.5mm gap and fitted on the fixture for testing. Tests were conducted at different frequencies and different currents and the displacements were obtained for various magnetic fields.

Figure 3 Experimental setup for MR sandwich beam with applied magnetic field

Table 3 Displacement Response for Different Excitation Current without any Magnetic Field

Table 4 Displacement Response for Different Excitation Current with Magnetic Field 600 gauss

Frequency in Hz	Current in Amp	Displacement in mm
24	0.9	0.624
26		0.818
28		1.08
30		2.52
32		3.65
34		1.29
36		0.938

Without any magnetic field the response showed higher amplitudes of vibration 5.24mm and it was observed that response frequency of the beam was 32Hz. With further increase in magnetic field 600 gauss there was slight decrease in amplitude of vibration up to 3.65mm and resonance frequency remained same to 32Hz.

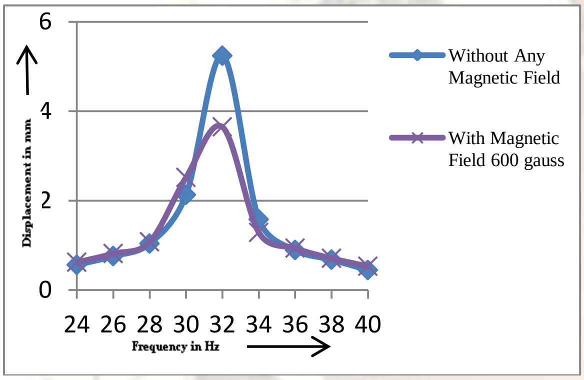

Figure 4 Displacement Response Curve for Beam with Wooden Rod having Field Gap 0.5mm and 30% Iron Particles at Different Magnetic fields

3.3 Cantilever Beam with Metal Rod, Gap 0.5mm (inner diameter of steel cylinder was 17mm and outer diameter steel of rod was 16mm) and Magnetorheological Fluid at Various Magnetic Fields

MR sandwich beam was assembled to maintain 0.5mm gap and fitted on the fixture for testing. Tests were conducted at different frequencies and different currents and the displacements were obtained for various magnetic fields.

Table 5 Displacement Response for Different Excitation Current without any Magnetic Field

Frequency in Hz	Current in Amp	Displacement in mm
16	0.9	0.400
18		0.487
20		0.675
22		1.08
24		3.23
26		1.14
28		0.480

Without any magnetic field the response showed higher amplitudes of vibration 3.23mm and it was observed that resonance frequency of the beam was 24Hz. With further increase in magnetic field 550 gauss there was considerable decrease in amplitude of vibration up to 2.46mm and resonance frequency remained same to 24Hz.

Table 6 Displacement Response for Different Excitation Current with Magnetic Field 550 gauss

Frequency in Hz	Current in Amp	Displacement in mm
16	0.9	0.424
18		0.559
20		0.841
22		1.46
24		2.46
26		1.08
28		0.576

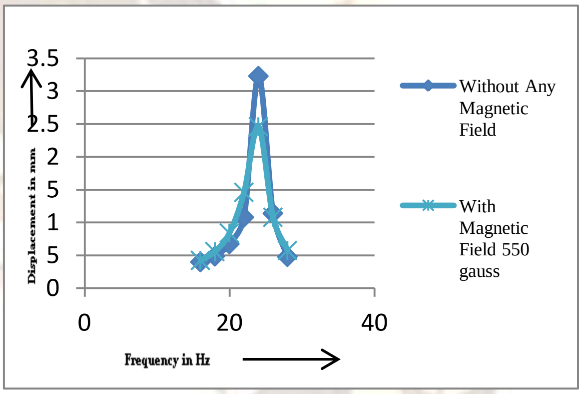

Figure 5 Displacement Response Curve for Beam with Metal Rod having Field Gap 0.5mm and 30% Iron Particles at Different Magnetic fields

IV. CONCLUSION

According to the readings and related plotted graphs for aluminium plate beam middle filled by varying intensities of applied magnetic field both change in frequency and damping was observed. Also with increase in magnetic fields the amplitude of vibrations reduced. It was observed that for steel cylinder and wooden rod composite beam with increase in magnetic field, damping was increased. For steel cylinder and steel rod composite beam also damping was increased with increasing magnetic field. The structural vibrations can be reduced by using MR fluid filled beams with very simple and economical arrangement. Also variable damping can be obtained by varying the compositions and the applied magnetic field.

REFERENCES

[1] Carlson J.D., Catenaries D.M., and St. Clair K.A. (1995) "Commercial Magnetorheological Fluid Devices," *Proceedings of 5th International Conference*

on ER Fluids, MR Fluids and Associated Technologies, Sheffield.

[2] Karakoc K., Park E.J. and Suleman A. (2008) "Design Considerations for an Automotive Magnetorheological Break." *Journal of Mechatronics, volume 18, pages 434-447.*

[3] Pan G., Matsuhisa H. and Houda Y. (2000), "Analytical Model of a Magnetorheological Damper and Its Application to The Vibration Control." *Paper from Industrial Electronics Society 2000, IECON2000, 26th Annual Conference of the IEEE, volume 3, pages 1850-1855.*

[4] Rajamohan V., Sedaghati R. and Rakheja S. (2010) "Vibration Analysis of Multilayer Beam Containing Magnetorheological Fluid." *Journal of Smart Materials and Structures, volume 19, issue 1, number 1,015013*.

[5] Rajamohan V., Sedaghati R. and Rakheja S. (2010) "Vibration Analysis of a Partially Treated Multilayer Beam with Magnetorheological Fluid."*Journal of Sound and Vibration, volume 329, pages 3451-3469.*