Manufacturing and Testing of Cantilever Beam using Magnetorheological Approach

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Abstract- The concept of vibration study in various structures using maganetorheological fluids has been the area of interest in last few year. The major research work has been performed on the various structures to control vibration with electrorheological fluids, but there has been less work with the magnetorheological fluids. This study is about an active vibration control technique for cantilever beams with magnetorheological approach under externally applied magnetic fields using permanent magnets. This study presents an active vibration control technique applied to smart beam the smart beam consist of an aluminium beam modelled in cantilevered configuration. MR fluid has ability to change rapidly its rheological properties upon exposure to an applied magnetic field and the precise controllability make MRF technology use for many applications. The cantilever structure was manufactured by adding a layer of MR fluid between the adjacent elastic layers and the properties of such sandwich beams were studied. The testing was all about reduction in amplitude of vibration by increasing magnetic field applied to MR cantilever beam. Form graphs we say that magnification factor decreases when there is a decrease in amplitude of vibration. As there is a increase in damping coefficient increases due to increased damping and decreased transmissibility. Hence vibrations reduction be done by using maganetorheological approach.

Keywords: Magnetorhological Fluid; MR Cantilever Beam; Permanent Magnet; Natural Frequency; Vibration Amplitude.

I. Introduction

In the cantilever structured systems subjected to the mechanical vibration, amplitudes can be varying from some nanometers to meters depending upon the nature of application. Vibration occurred in the system causes failure of system, discomfort and inefficiencies in operations. Such structural vibrations can be reduced by different ways. The most common ways are stiffening, damping and isolation of structure. Primary objective of the study is to offer vibration control device in the form of a cantilever beam whose stiffness and damping properties can be tuned by using magnetorhelogical approach. Magnetorheological fluids are non-colloidal suspensions of magnetizable particles that are on the order often of microns (20-50 microns) in diameter. The fluid was developed by Jacob Rabinowat the US national Bureau of Standards in the late 1940's. Magnetorheological devices are capable of much higher yield strengths when activated. The major difference between Ferro fluid and Magnetorheological fluid is the size of the polarizable particles. In Ferro fluids, these particles' Magnitudes are smaller than those of Magnetorheological fluids; i.e. they are 1–2 microns, in contrast to 20 –50 microns for Magnetorheological fluids. For the first few years, there was a flurry of interest in Magnetorheological fluids but this interest quickly waned. In the early 1990's there was resurgence in Magnetorheological fluid research that was primarily due to Lord Corporation's research and development. Magnetorheological fluid is composed of oil, usually mineral or silicone based, and varying percentages of ferrous particles that have been coated with an anti-coagulant material. When inactivated, Magnetorheological fluids display Newtonian-like behavior. When exposed to a magnetic field, the ferrous particles that are dispersed throughout the fluid form magnetic dipoles. These magnetic dipoles align themselves along lines of magnetic flux, as shown in Figure 1[1, 2]. Many researchers had performed the theoretical as well as experimental work with Electrorheological approach. For vibration minimization, use of smart fluids was the main area of research in the last some decades. However, focus was more on the use ER fluids as compared with MR fluids[4-8]. MR fluids is useful for higher bandwidth control, due to its rapid changes in the rheological properties under varying magnetic fields.[9]. The dynamic responses of a MR fluid adaptive structure using the energy approach was analyzed by Yalcintas and Dai [10, 11]. Sun et al. [15] investigated the dynamic responses of a MR sandwich beam using an energy approach analytically. He had given comparison between measured data and analytical results. The results of such investigations recommended use of MR fluid for higher degree of controllability. The objective of this work is to provide vibration control to cantilever beam which is manufactured by simple and readily available cheaper material by using magnetorheological approach.

II. DESIGN AND MANUFACTURING OF MR SANDWICH BEAM

In this case a cantilever beam was fabricated as simple mechanical model in the farm of sandwich structures. The details of fabrication of this beam are as given below.

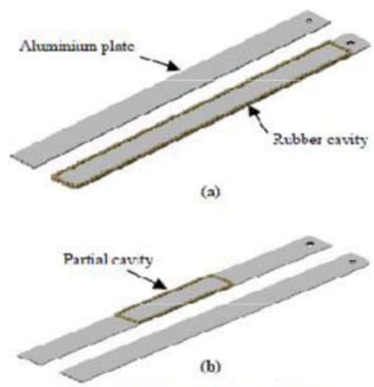

Fig. 1. Arrangement of aluminium beams

A simple sandwiched cantilever beam is manufactured to implement the magnetorheological approach. Some simple model can be effectively represented as a cantilever beam structure like an aircraft wing, a helicopter blade, a solar panel of a solar vehicle etc. For simplicity, assumption is made that there will be planner movement and isotropic beam of constant cross section. In the case of a long slender beam experiencing small strains and moderate deformation is considered. Furthermore, it is assumed that:

i) No extension of the beam's neutral axis occurs;
ii) No slipping occurs between the aluminium layers and the MR layer;
iii) All three layers have the same tranverse displacement
iv) No shear strains exist inside the aluminium layers. [3]

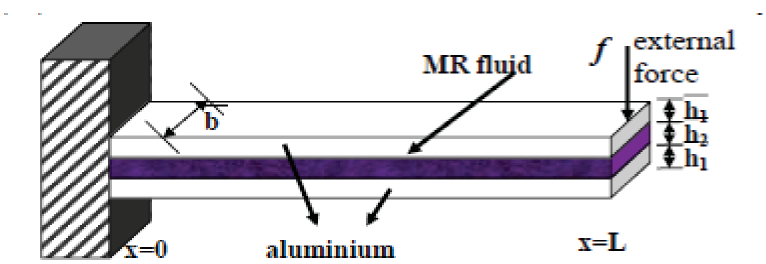

Fig 2 Configuration of MR sandwich beam

When the beam is subject to external movement, the displacements, rotation, and shear strain of the beam are shown in Figure 3

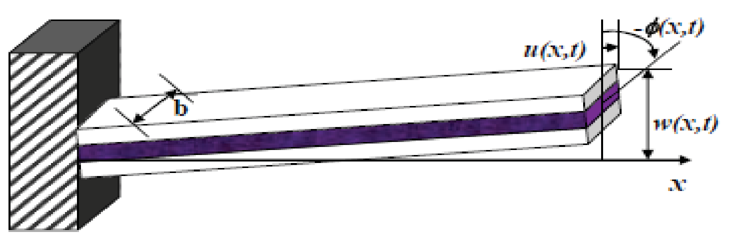

Fig 3 Variables of the MR sandwich beam.

The longitudinal extension of the mid surface of the top plates , transverse displacement, cross section rotation, and shear strain of the MR layer are represented by *u(x,t), w(x,t), (x,t)* And *(x,t)* respectively. [3]
The dimensions of such smart canteliver beam are as given in table no 1.

Table No 1 MR sandwich beam parameters

Beam dimensions	
L= 440 mm	b= 100mm
h1= 3 mm	h2= 3mm, h3=3 mm
Aluminum layer = 271kg/m3	Ep= 70 GPa
MR layer (Lord MRX-336AG)	

Manufacturing of aluminium sandwich beam (MR SANDWICH BEAM)

In this type, fully filled beams were prepared. A fully filled aluminium beam with two elastic aluminium strips (440 mm x 100 mm x 11 mm) with zero magnetic permeability. To maintain a uniform gap of 3 mm and contain the fluid in between the top and bottom layers, high strength rubber of 3 mm thickness and 100 mm width was applied around the edges using an adhesive. The arrangement of strips prior to gluing is as shown in Fig. 1. The strips were glued and sealed to avoid any leakage. For filling the MR fluid in the cavity, a small hole of 1 mm diameter was drilled in each side of the beam. From one end, MR fluid was injected by using a hypodermic syringe. This allowed air bubbles to escape from the hole on the other side. Finally, the two holes were sealed and allowed to dry. Commercially available 'Rapid Fevitite' was used for gluing and sealing. In this study, MR fluid was prepared with 28% iron particles volume fraction. Iron particles of average size 300 micron were used to improve the magnetic affinity. The preparation cost of the fluid was almost 1/10th as compared to the commercially available fluids. These MR fluids were tested to find their magnetic induction and flux density values.

III. EXPERIMENT AND RESULT

Many devices used to conduct the experiments included – a rigid frame set up for mounting cantilever beam, permanent magnets, an amplifier, oscillator, exciter, accelerometer, data acquisition system and dynamic signal analyzer. Permanent magnets of circular shape with high power were used to generate magnetic field. To measure magnetic field intensity, a Gauss meter which was made by PISCO company (model DGM-102) was used. Two rows of magnets were formed at the top and bottom side of the beam, by fastening the magnets to adjustable aluminium square hollow rods which were attached to a rigid frame. Magnetic field intensities were varied by changing the distance between the magnet rows and by adding or removing magnets from the rows. A schematic of the experimental setup is presented in Fig. 4.For application of forced vibrations, exciter (model ID-230) with a capacity to produce 200 N peak sine force and maximum displacement of 12 mm peak to peak along with function generator produced by the company Instrol devices was used. The exciter was driven by power amplifier and oscillator which generated sinusoidal signals in the frequency range from 1Hz to 10 kHz. The accelerometer was installed on the free end of the beams. A dynamic signal analyzer was used to acquire and process input/output signals with the NVgate software. The vibration response was obtained in terms of natural frequencies and vibration amplitudes as output results.

TABLE II: MATERIAL PROPERTIES

Material	***Density(r) (kg/m^3)***	***Young's modulus (E) GPa***
Aluminium	2710	70
Stainless Steel	7480	193
Wood	420	11
MR fluid	3000	--

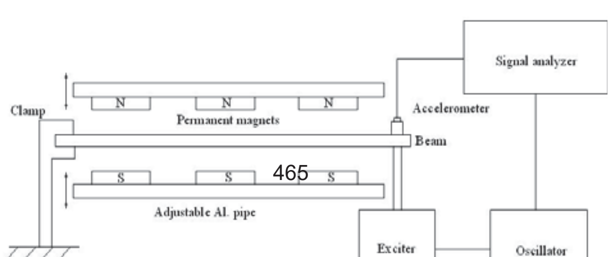

Fig. 4 (a) Block diagram of experimental setup

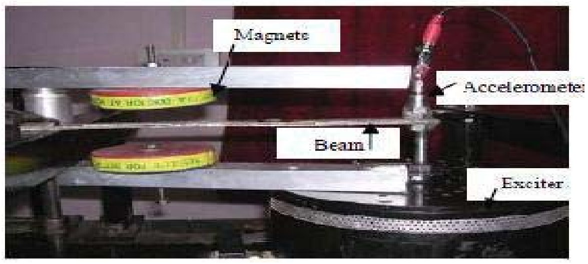

Fig. 4 (b) Photograph of experimental setup

Results were taken on the plot of acceleration Vs frequency. Results were taken with various frequencies like 18 Hz, 20 Hz, 22 Hz, 24 Hz, 26 Hz, 28 Hz, 30 Hz. Out of which results are discussed here for the 18, 22, 26.and 30 Hz respectively. The plots for the same are given below. In this plot acceleration is taken on the Y-axis and frequency is taken on the X-axis.

RESULT OF 18 HZ FREQUENCY:

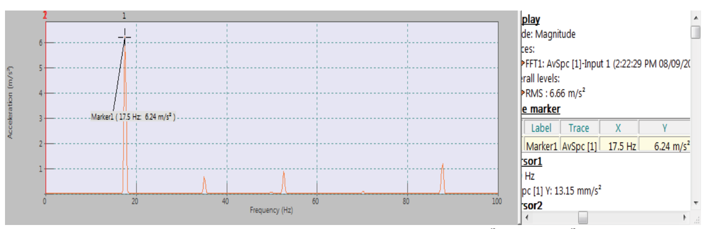

Fig. 4.1 18 Hz without Magnetic Field (Accl^n Vs Freq^n)

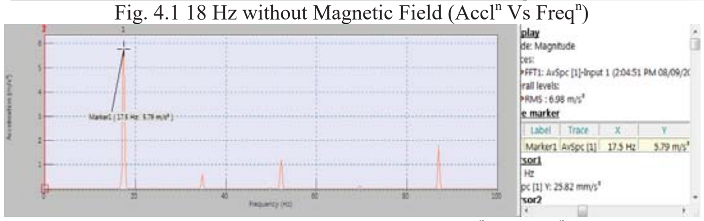

Fig. 4.2 18 Hz with Magnetic Field(Accl^n Vs Freq^n)

In the above graph, acceleration at 18 Hz with magnetic field (5.79 m/s^2) is decreased as compared with 18 Hz (6.24 m/s^2) during without magnetic field.

*RESULT OF 22 HZ FREQUENCY***:**

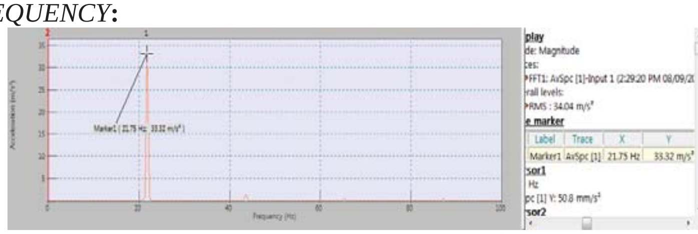

Fig. 4.3 22 Hz without Magnetic Field (Accl^n Vs Freq^n)

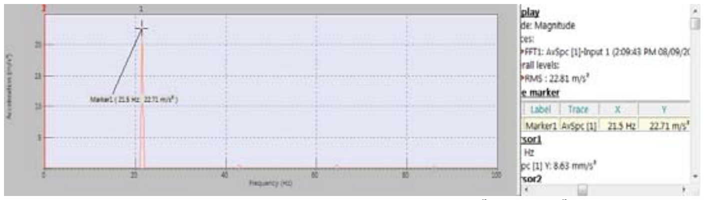

Fig. 4.4 22 Hz with Magnetic Field ($Accl^n$ Vs $Freq^n$)

From the above graph we conclude that acceleration at 22 Hz with magnetic field (22.71 m/s^2) is decreased as compared with 22 Hz (33.32 m/s^2) during without magnetic field.

RESULT OF 26 HZ FREQUENCY:

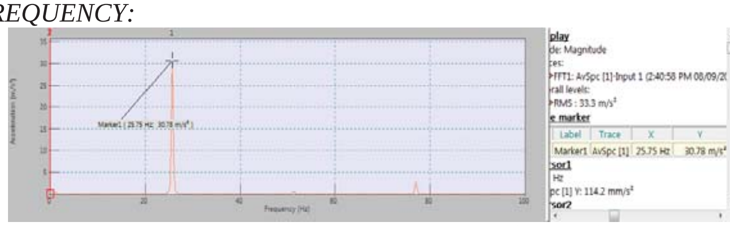

Fig. 4.5 26 Hz without Magnetic Field ($Accl^n$ Vs $Freq^n$)

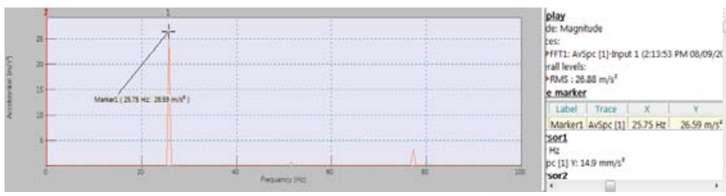

Fig. 4.6 26 Hz with Magnetic Field ($Accl^n$ Vs $Freq^n$)

From the above graph we can analyze that acceleration at 26 Hz with magnetic field (26.59 m/s^2) is decreased as compared with 26 Hz (30.78 m/s^2) during without magnetic

RESULT OF 30 HZ FREQUENCY:

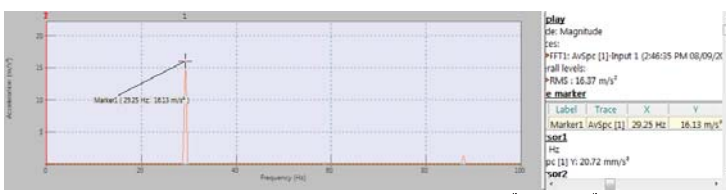

Fig. 4.7 30 Hz without Magnetic Field ($Accl^n$ Vs $Freq^n$)

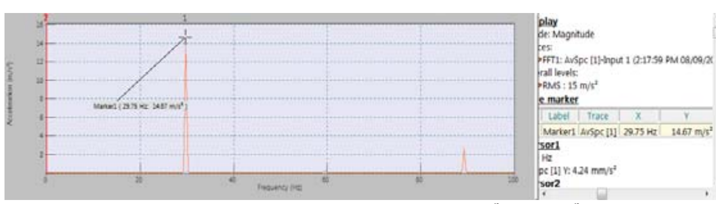

Fig. 4.8 30 Hz with Magnetic Field ($Accl^n$ Vs $Freq^n$)

From the above graph we can analyze that acceleration at 30 Hz with magnetic field (14.67 m/s^2) is decreased as compared with 30 Hz (16.13m/s^2) during without magnetic field.

In addition to this, Plot of frequency Vs acceleration is drawn. In this plot we have taken frequency on X-axis and Acceleration on the Y-axis. In this plot we have compared acceleration with magnetic field and acceleration without magnetic field at root of the cantilever beam.

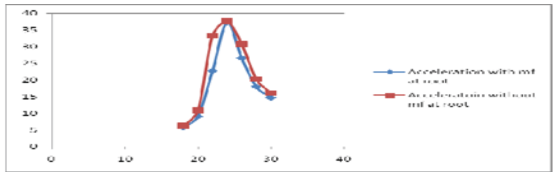

Fig. 4.9 Plot of Frequency Vs Acceleration

Plot of frequency Vs acceleration for tip and root is drawn. In this plot we have taken frequency on X-axis and Acceleration on the Y-axis. In this plot we have compared acceleration with magnetic field at root and acceleration with magnetic field at tip of the cantilever beam.

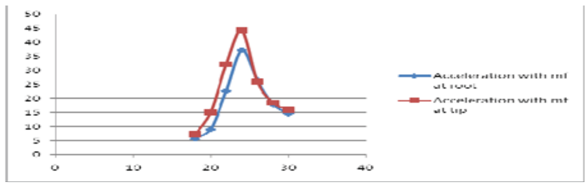

Fig 4.10 Plot of Frequency Vs Acceleration
(For tip and root)

Plot of frequency Vs RMS acceleration is drawn. In this plot we have taken frequency on X-axis and RMS acceleration on the Y-axis. In this plot we have compared RMS acceleration with magnetic field and RMS acceleration without magnetic field at root of the cantilever beam.

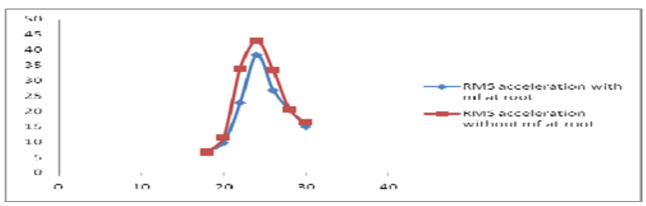

Fig. 4.11 Plot of frequency Vs RMS acceleration

IV. CONCLUSION

The effectiveness of MR fluid is depends on the type of the application in which it is used, the conditions to which the fluid is exposed and the duration of exposure. MR fluids that are considered good in one application may fail miserably in another type of application. MR fluid development is of course a matching act that is highly related with MR device design. To evaluate the quality of an MR fluid, it is important to check the actual conditions in which it will be used and not just the rheological properties measured under normal laboratory conditions. The testing was all about reduction in amplitude of vibration by applying magnetic field to MR cantilever beam.

This concept of vibration control can be applied to any other application by detecting the vibration produced in that system. Depending on the dimension of MRF pocket and intensity of vibration coming from the device we can use the quantity of MR fluid.

The conclusion from the graphs is that as amplitude of vibration decrease magnification factor decreases. As damping increases, damping coefficient increases and hence transmissibility decreases. Hence vibrations are reduced.

REFERENCES

[1] J. D. Carlson, M. R. Jolly, Mechatronics 10 (2000) pp. 555–569.

[2] W.H. Li, G.Z. Yao, G. Chen, S.H. Yeo, F.F. Yap, Smart Materials & Structures 9 (1) (2000) pp. 95–102.

[3] Gong X.L., Zhang X.Z., and Zhang P.Q., Fabrication and Characterization of Isotropic Magnetorheological Elastomers, Polymer Testing, Vol.24 (2005) pp. 669-676.

[4] Ghandi M.V., Thompson B.S. and Choi S.B., A new generation of innovative ultra-advanced intelligent composite materials featuring electro-rheological fluids: an experimental investigation Compos. Mater. 23 (1989) pp. 1232–55.

[5] Choi Y., Sprecher A.F. and Conrad H., Vibration characteristics of a composite beam containing an electrorheological fluid J. Intell. Mater. Syst. Struct.1 (1990) pp. 91–104.

[6] Berg C.D., Composite structure analysis of a hollowcantilever beam filled with electro-rheological fluid J. Intell. Mater. Syst. Struct. 7 (1996) pp. 494–502.
[7] Lee C.Y., Finite element formulation of a sandwich beam with embedded electro-rheological fluids J. Intell. Mater. Syst. Struct. 6 (1995) pp. 718–28.
[8] Phani A.S. and Venkatraman K.,Vibration control of sandwich beams using electro-rheological fluids Mech. Syst. Signal Process. 17 (2003) pp. 1083–95.
[9] Oyadiji S.O., Applications of electro-rheological fluids for constrained layer damping treatment of structures J. Intell. Mater. Syst. Struct. 7 (1996) pp. 541–9
[10] Yalcintas M. and Coulter J.P., Electrorheological material based non-homogeneous adaptive beams Smart Mater. Struct. 7 (1998) pp.128–43.
[11] J. Wang, G. Meng, Magnetorheological fluid devices: principles, characteristics and applications in mechanical engineering, Proceedings of Institution of Mechanical Engineers Part I: Journal of Materials 215 (2001) pp.165–174.
[12] J. D. Carlson, K. D. Weiss, A growing attraction to magnetic fluids, Machine Design 66 (1994) pp.61–64.
[13] M. Yalcintas, H. Dai, Magnetorheological and electrorheological materials in adaptive structures and their performance comparison, Smart Materials and Structures 8 (1999) pp. 560–573.
[14] M. Yalcintas, H. Dai, Vibration suppression capabilities of magneto-rheological materials based adaptive structures, Smart Materials and Structures 13 (2004) pp. 1–11.
[15] Q. Sun, J. X. Zhou, L. Zhang, An adaptive beam model and dynamic characteristics of magnetorheological materials, Journal of Sound and Vibration 261 (2003) pp. 465–481.