EXPERIMENTAL INVESTIGATION OF VIBRATION CHARACTERISTICS OF MAGNETORHEOLOGICAL FLUID WITH SINGLE ROTOR SYSTEM

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Abstract – Magnetorheological fluids are materials that respond to an applied magnetic field with a dramatic change in their rheological behavior. The essential characteristic of these fluids is their ability to reversibly change from a free-flowing, linear, viscous liquid to a semi-solid with controllable yield strength in milliseconds when exposed to a magnetic field. Magnetorheological fluids find a variety of applications in almost all the vibration control systems especially in automobile suspensions, seat suspensions, clutches, robotics, design of buildings and bridges, home appliances like washing machines etc.This paper focuses on obtaining the Torsional Vibration Characteristics of a shaft attached to a disc immersed in Magnetorheological fluids which is manufactured in-house. For this an experimental setup consisting of a single rotor is fabricated to test the fluid. Testing of the Magnetorheological fluid is done under active and inactive states and the superiority of damping under active state for two electromagnets at set of distances apart is proved by finding out the damping factor in each condition.

Index terms - Magnetorheological fluids, Torsional Vibration, Damping factor

I. INTRODUCTION

Magnetorheological Fluid is in fact a carrier fluid, usually oil, which is filled with micrometer-sized magnetic particles. When subjected to a magnetic field, the magnetic particles inside increase the fluid's viscosity, rendering it viscoelastic solid [1].A Magnetorheological fluid usually consists of 20-40 percent iron particles, suspended in mineral oil, synthetic oil, water or glycol. The fluid also contains a substance which prevents the iron particles from settling.

When the coil of the damper system, which contains the Magnetorheological fluid, is not energized i.e. when it is in the OFF/normal position – the Magnetorheological fluid is not magnetized and the particles inside, distributed randomly, allow the fluid to move freely, acting like a regular damper fluid.However, when the system is turned "ON", and a charge which creates a magnetic field is applied, the particles become energized and align into fibrous structures, usually perpendicular on the direction of the magnetic flux. This restricts the movement of the fluid, proportional to the power and intensity of the magnetic field. Thus far, most reported MR dampers are based on the flow mode because of its simple configuration and large damper force due to hydraulic amplification. In contrast, shear mode Magnetorheological dampers are not as thoroughly studied. Therefore, in this study, we focus on shear mode MR dampers [2].

Generally, shear mode dampers have been used on rotating machinery to inhibit the occurrences of unwanted oscillations. These oscillations adversely affect machine performance and can result in permanent damage to the machine itself. Thus, the function of rotary dampers is to dampen undesired rotation of an object by supplying a resisting torque to a shaft. Generally, conventional passive shear mode dampers work on the principle of viscous fluid shearing, i.e., energy is dissipated by the shear motion of a viscous fluid between two different wall surfaces. In the absence of a magnetic field, shear mode MR dampers are similar to conventional passive shear mode dampers. However, shear mode MR dampers can produce additional damper force or torque resulting from the yield stress of MR fluids in response to the magnetic field.

In literature Prasad Ranbhare, Kuldip Rade et al. [1] have done the experimental and numerical investigations of the torsional vibrations of a two rotor shaft system. for torsional vibrations in free, forced, damped and undamped condition. Harish Hirani [2] has given an overview of the basic structure of Magnetorheological fluids, explaining the different configurations of Magnetorheological fluid using different magnetic particles. Prof. Vaibhav Sawalkar et al. [3] have prescribed the constituents for the preparation of Magnetorheological fluid and a method for testing it. The constituents used are silicon oil as carrier fluid, iron alloy powder for magnetic material and grease [AP3] as additive each according to their quantities. A. Ashfak et al. [4] have aimed at vehicular suspension systems which shows that the damping force varies linearly with electric current.

II. BASICS OF LOGARITHMIC DECREMENT

The logarithmic decrement represents the rate at which the amplitude of a free damped vibration decreases. It is defined as the natural logarithm of the ratio of any two successive amplitudes. It is found from the time response of under-damped vibration

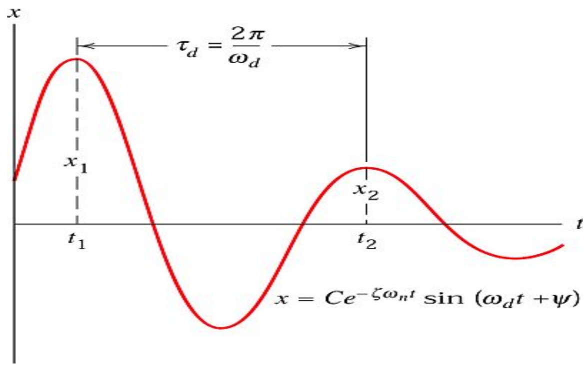

Figure 1: Logarithmic decrement [3]

The logarithmic decrement is calculated using the formula

$$\delta = \frac{1}{n} \log_e \frac{X_0}{X_n}$$

where, X_0 = amplitude at starting position.
X_n= amplitude after 'n' cycles.
From logarithmic decrement, we can calculate the damping factor (ξ) by using the formula

$$\delta = \frac{2\pi\xi}{\sqrt{1-\xi^2}}$$

III. EXPERIMENTAL SETUP

The block diagram of an experimental setup is shown in Figure: 2

To achieve the desired vibration characteristics, an experimental setup of a vertical single rotor system is created. The rotor is mounted on a shaft, which is fixed at both the ends by means of bolts. A cylindrical object is mounted on the rotor. The rotor and this cylindrical object are fixed together by means of bolts. The twist/torsional moment is applied to the system by means of this cylindrical object When the cylindrical object is twisted the shaft also twists along with it, but due to the stiffness of the shaft it will try to regain its original position as soon as the force is removed. When the force is removed the shaft will now try to come to its original form thereby exhibiting torsional vibrations.

The setup components designed and selected for fabrication with the part of following dimensions.

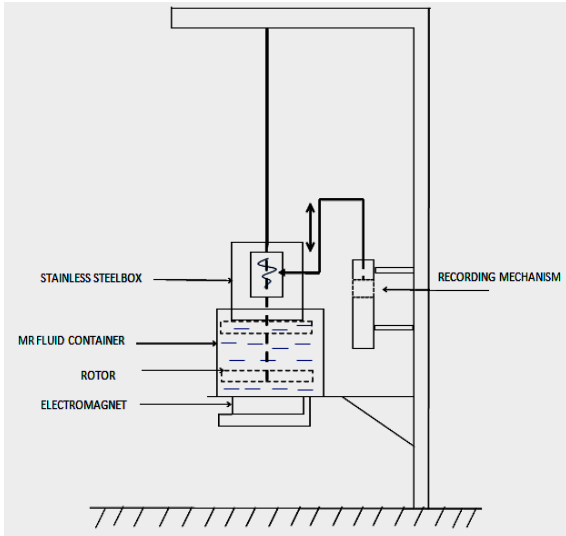

Figure: 2 Block diagram of Experimental setup

Table.1 Components dimensions

COMPONENT	Material	DIMENSION (mm)
C Channel	Mild Steel	800 x 75 400 x 75 200 x 75
Magnetorheological fluid container	Plastic	Φ270 x 60
Rotor	Nylon	Φ220 x 20
Bucket	Aluminium	Φ170 x 200
Shaft	Mild Steel	Φ3 x 800
Damper	Steel	Φ40 x 260

Figure: 3 Experimental Setup (Fabricated)

IV. COMPONENTS OF THE SETUP

A. Support Structure

The support structure is an assembly of C-Channels that supports the Magnetorheological fluid container, recording mechanism and damper. C-Channels are held together by means of bolted plates on either side of the channels.

B. Magnetorheological fluid

As discussed earlier, the fluid is a mixture of fine iron powder (50 micron) in silicone oil along with grease as an additive to prevent settling of the powder. Composition of above components to make 2L of the fluid is as follows:

Iron powder = 2Kg
Silicone oil = 1.8L
Grease = 200g

This mixture is then stirred with the help of mixing blade attached to a motor, which runs at 60 rpm, in order to obtain a uniform solution of Magnetorheological fluid.

C. Electromagnet

The core of the electromagnet is made of mild steel and it is wound with enameled copper wire of diameter 0.1 mm. number of turns of the electromagnet is 610. Two such electromagnets are used. The electromagnet is powered by a 12V battery and a maximum magnetic field of 2000 gauss.

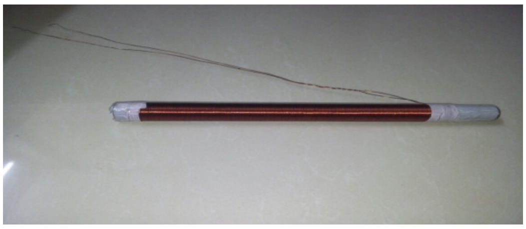

Figure: 4 Electromagnet

D. Recording Mechanism

The recording mechanism consists of a steel shaft of 3 mm diameter at the end of which a Nylon rotor and a stainless steel container is mounted and welded. A paper is attached to this setup on which the graph will be plotted with the help of a piston cylinder damper setup on which a pen is mounted. The piston in the damper moves at a rate of 1.14 cm/s.

Figure: 5 Recording mechanism

V. TESTING OF MAGNETORHEOLOGICAL FLUID:

To validate the working of Magnetorheological fluid it is necessary that it's viscosity increases under the influence of magnetic field. The viscosity increases as the magnetic field increases. To calculate viscosity sinking ball method is used.The ball used is a marble of spherical shape. The Magnetorheological fluid (300 ml) is taken in a plastic beaker of 500 ml. The densities of Magnetorheological fluid and marble are calculated. The marble is dropped from the 100 ml mark and time is measured for the marble to reach the bottom of the beaker. The distance form 300 ml mark to the bottom is measured and velocity is calculated as a ratio of distance to time. The viscosity of the fluid can be given as

$$\eta = \frac{2(\rho_s - \rho_l)gr^2}{9v}$$

where, ρ_s is the density of the sphere in g/ml
ρ_l is the density of the Magnetorheological fluid in g/ml
g is the acceleration due to gravity in m/s^2
r is the radius of the marble sphere in m
v is the velocity in m/s
η is the viscosity of the Magnetorheological fluid in Pa-s

For marble,
Diameter d = 1.5 cm = 0.75 cm
Weight m = 4.53 g
Volume v = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi x\ 0.75^3 = 1.761$ in cm^3
Density = $\frac{m}{v} = \frac{4.53}{1.761} = 2.57$ g/ml
For Magnetorheological fluid,
Weight m = 65 g
Volume V = 300 ml
Density = $\frac{m}{V} = \frac{65}{300} = 0.217$ g/ml

Distance between 300 ml mark and bottom of beaker
d = 8 cm = 0.08 m
Time required for marble to reach bottom from 100 ml mark t = 4.7 s
Velocity = $\frac{d}{t} = \frac{0.8}{4.7} = 0.017$ m/s

Viscosity is given by,
$$\eta = \frac{2(\rho_s - \rho_l)gr^2}{9v}$$
$$\eta = \frac{2(2.57-0.65) x\ 9.91\ x 0.075^2}{9\ x\ 0.0176}$$
η = 0.013 Pa-s

This is the viscosity for non-energized Magnetorheological fluid i.e. not under the influence of magnetic field. Then current is passed through the electromagnet by varying the resistance using rheostat. The steps in rheostat are of 2.5Ω in a 10Ω rheostat. The following results were obtained:

Table 2 Viscosity of Magnetorheological fluid for different values of current supplied

Current (A)	Time for the marble to reach bottom of beaker (s)	Viscosity(Pa-s)
1.2	1.36	0.022
1.65	3.6	0.035
2.47	5.5	0.05
4.83	8	0.07
8.5	10.2	0.16

The above table proves that viscosity of the Magnetorheological fluid increases with the current supplied and its plot on graph is as follows.

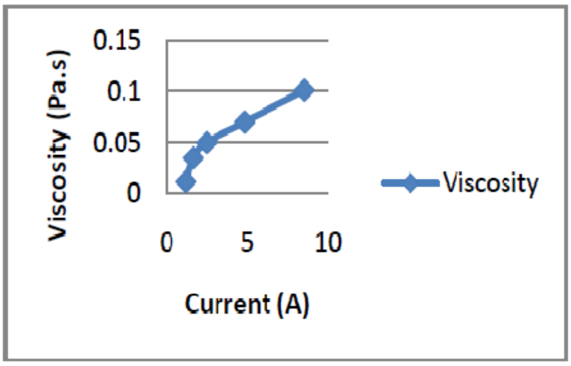

Figure: 6 Graph of viscosity vs. current

VI. TESTING WITH EXPERIMENTAL SETUP

Magnetorheological fluid is used to damp the vibrations. Use of damping fluid reduces the time taken by the shaft to stop vibrating. Initially the fluid will not be energized and it will be used to damp the torsional vibrations and its corresponding characteristics will be noted. Now the fluid will be energized, thereby increasing the damping (due to increased viscosity), and again it will be used to damp the vibrations.

TESTING USING GYROSCOPE SENSOR

To obtain a graph showing the response of the Magnetorheological fluid with respect to damping when subjected to torsional vibrations, a Gyroscopic sensor along with an Arduino module was used. The Arduino, with the necessary connections was connected to a Gyroscopic sensor mounted on a breadboard. A Gyroscopic sensor or simply Gyro sensor measures the angular velocity. The Arduino and breadboard is attached to the container which is subjected to torsional vibration. When the bucket is subjected to torsional vibrations the Gyroscopic sensor plots the graph of Angular velocity vs. sampling rate on the computer. The maximum and minimum limits are adjusted so as to bring the plotted graph in view.The entire setup along with the gyroscope and Arduino connections is shown in Figure: 7

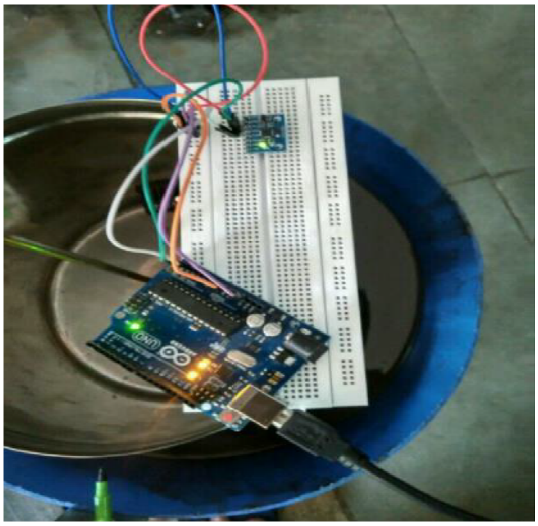

Figure: 7 Arduino and circuit using breadboard

Figure: 8 show the response of the fluid in its non-energized state, when subjected to torsional vibrations. When the container is twisted and released, it can be seen that a maximum angular velocity of 2500 degree/second was attained which then slowly decreases to zero because of the damping action provided by the fluid.

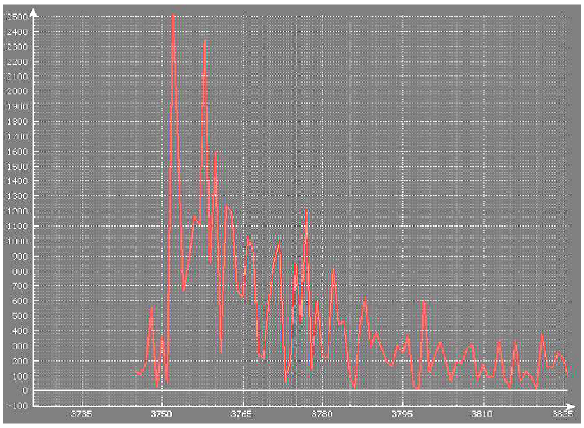

Figure: 8 Damping response of Magnetorheological fluid in normal state

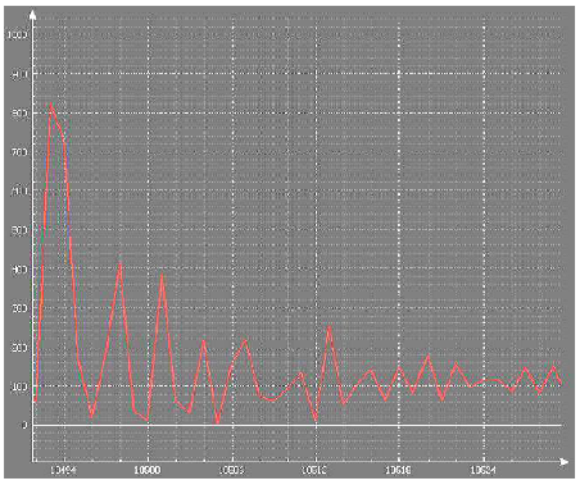

Figure: 9 Damping response of Magnetorheological fluid in energized state

Figure: 9 shows the damping response of the fluid when it is energized. Here, it is seen that the maximum angular velocity that was obtained was approximately 800 degrees/second and it slowly decreases to zero. Here we can also see that the vibrations are much less as compared to the vibrations when the fluid was not energized and it takes less time to damp the rotor.

It can be concluded from the two graphs that the damping obtained when the fluid is energized is better than the damping obtained when the fluid is not energized.

TESTING USING DAMPER MARKER ARRANGEMENT

In order to obtain the Logarithmic decrement a damper-marker arrangement is used. It consists of damper and a marker connected together. The marker is attached to the rod that connects to the piston in the damper. So when the rod is pulled up, the piston and marker also move up. On releasing the rod, the piston and marker will move downwards at a steady rate. The downward movement is guided by a slot through which the marker moves. To obtain the readings, the marker is kept touching a sheet of paper on the stainless steel box. After that the rotor is given a fixed angular displacement and released. While releasing the rotor, the rod connecting the marker and piston is also released from its topmost point. These actions occur simultaneously. So the angular motion of stainless steel box combined with the linear downward motion of marker will give us the Logarithmic decrement. The marker will plot the same on the paper attached to the stainless steel box.

A. Free vibrations curve when the fluid in its normal state

The graph obtained using pen and damper arrangement shows logarithmic decrement of torsional vibration of the rotor due to the damping action provided by the Magnetorheological fluid in its normal state is as shown in Figure: 10

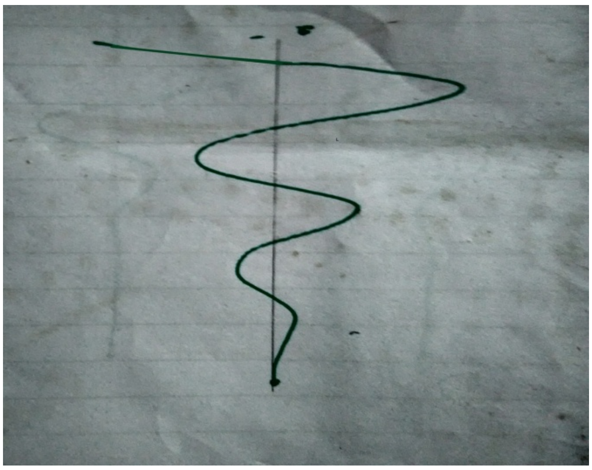

Figure: 10 Free-vibrations plot when Magnetorheological fluid in non-energized state

The properties calculated from this graph are:
- Maximum amplitude = 3.2 cm
- Amplitude after 2 oscilations = 1.5 cm
- Logarithmic decrement = 0.378
- Damping ratio = 0.06

B. Free vibrations curve when the fluid in energized state

Two electromagnets are sealed using plastic foil and placed in a parallel manner in the fluid. The optimal position of the electromagnets is to be checked and hence damping is checked at the possible extreme positions. Initially the electromagnets are placed with their opposite poles near to each other. When the electromagnets are placed within a distance of 60mm between their axes, the opposite poles are attracted and the poles stick together. The plot obtained when the two electromagnets are joined is shown in figure: 11

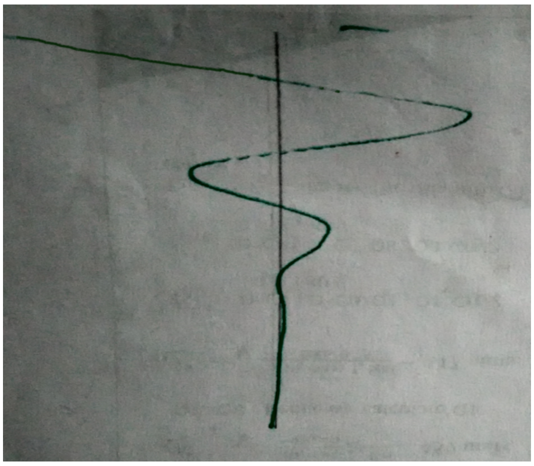

Figure: 11 Free-vibrations plot when Magnetorheological fluid in energized state and electromagnets joined together

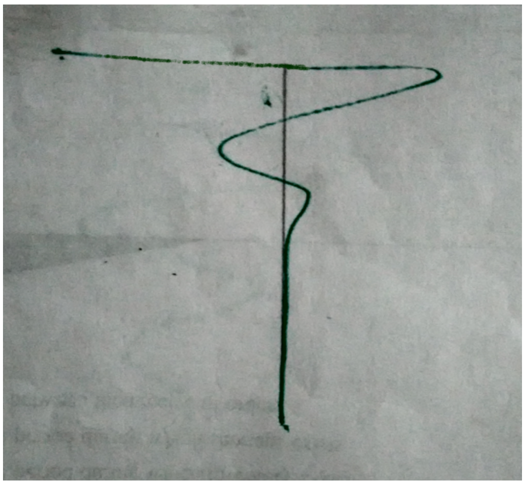

Figure: 12 Free-vibrations plot when Magnetorheological fluid in energized state and electromagnets 90mm apart

The properties calculated from this graph are:
Maximum amplitude = 2.9 cm
Amplitude after 2 oscilations = 0.7 cm
- Logarithmic decrement = 0.71

- Damping ratio = 0.112

Next the damping is checked when the electromagnets are placed at a maximum distance between their axes in the container of diameter 270mm. The distance between their axes is found out to be 90mm. The plot for this arrangement is shown in Figure: 12

The properties calculated from this graph are:

- Logarithmic decrement = 0.916
- Damping ratio = 0.144

Similarly, free vibrations plots, when electromagnets are kept 80 mm and 70 mm apart are found out to observe a trend of damping factor with distance between the electromagnets. These are shown in Figure:13 and Figure:14 respectively

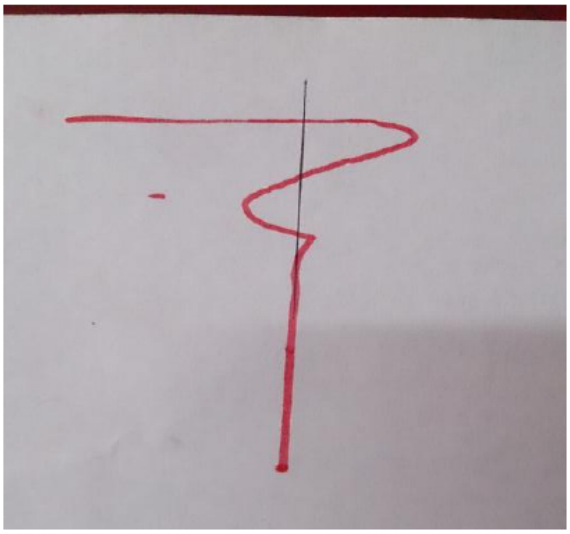

Figure: 13 Free-vibrations plot when Magnetorheological fluid in energized state and electromagnets 80mm apart

Here, logarithmic decrement δ = 0.883 and damping ratio ξ = 0.136

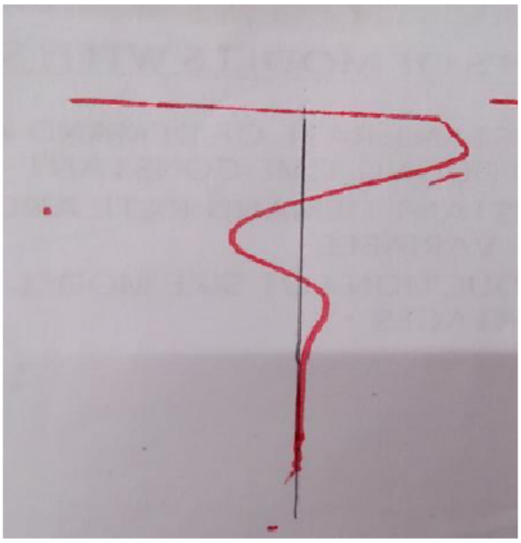

Figure: 14 Free-vibrations plot when Magnetorheological fluid in energized state and electromagnets 70mm apart

Here, logarithmic decrement δ = 0.779 and damping ratio ξ = 0.123

The plot of trend of the damping factor with different spacing between the electromagnets is shown is Figure: 15

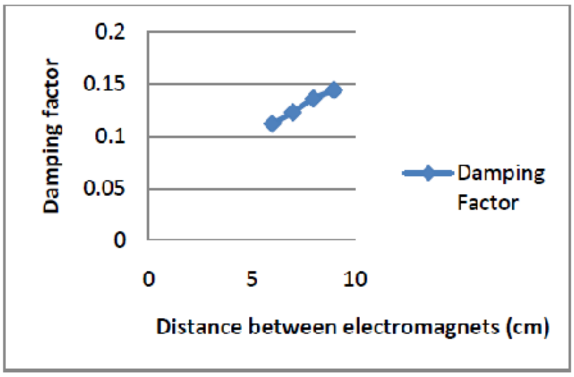

Figure: 15 Graph of damping factor vs distance between electromagnets

CONCLUSION

Logarithmic decrement and damping ratio of the Magnetorheological fluid in its normal and energized state are calculated using the pen and damper arrangement. It is concluded that the energized fluid gives better damping.The damping factor follows an increasing trend as the distance between electromagnets is increased with best damping observed when the electromagnets are kept at a maximum distance from each other within the available dimensions of fluid container.

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