SEMESTER REPORT

on

"System Identification of MR Damper"

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for

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We would also like to thank the Workshop Instructors and Superintendent Mr Vijay Suryawanshi for their assistance and cooperation. They played a key role in the fabrication of our damper and setup.

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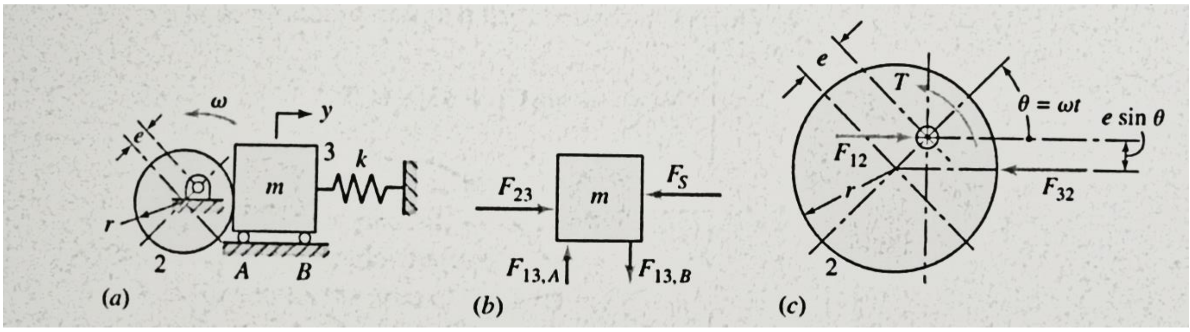
Design of a cam to generate a sinusoidal input for a seat vibration setup

In order to take our studies on human body vibration analysis and ergonomics, we proposed to design a CAM which would generate a sinusoidal input to a seat attached to a follower.

Model-



The CAM follower physical model

An eccentric CAM was used as elaborate analytical solutions for its dynamics were available in literature. Also, it would generate the desired sinusoidal oscillatory motion at the output. The CAM would be accompanied by a flat-face follower as this design would be mechanically stronger and less complicated to design and fabricate given the various mechanical elements that are present in a roller follower.

CAM kinematics:

$$y = e - e\cos\omega t \quad ; \quad \dot{y} = e\omega\sin\omega t \quad ; \quad \ddot{y} = e\omega^2\cos\omega t$$

For the dynamic model, we assume that there is no friction and there is a preload P=kδ where δ is the preload compression given to the follower spring during installation.

Summing forces on the follower mass in the y-direction gives:

$$\sum F^y = F_{23} - k(y+\delta) = m\,\ddot{y}$$

The force F_{23} is the contact force between the cam and the follower and hence can have only a positive value. Hence, substitution of the expression for y in the above equation of motion gives

$$F_{23} = (m\omega^2 - k)e\cos\omega t + (ke + P)$$

As the maximum probability of contact force becoming zero is at the top of the follower motion (ωt=180°), that value is substituted and F_{23} is made zero in order to find the value for k (minimum required value is obtained as this is the limiting case).

$$k = \frac{m\omega^2}{2e+\delta}$$

where

$$m = 100\ kg\ (say)$$
$$\omega = 2\pi \times 5 = 31.4\frac{rad}{s}$$

$$e = 0.01\ cm$$
$$\delta = 0.01\ cm$$

Thesis values are arbitrary but conservative. Hence, substitution of these values gives:

$$k = 3287 \frac{kN}{m}$$

which is a very unrealistic value for a spring.

Let us assume that this spring is available and can be installed. However, we shall see in further calculations that the system parameters are far too unrealistic to be fabricated on the required scale.

Maximum value of F_{23} occurs at ωt=0, giving

$$F_{23(max)} \cong 132\ kN$$

Maximum Torque required

$$T_{max} \cong 480\ N.m$$

Maximum Power required

$$P \cong 15\ kW$$

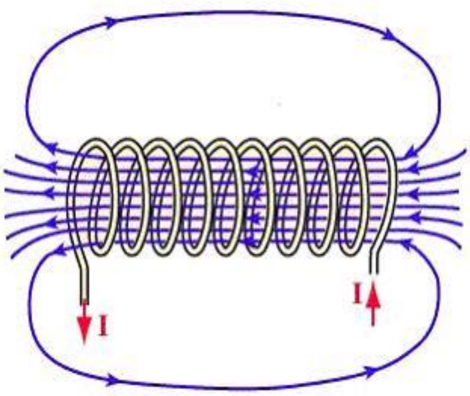
These values are far too unrealistic to be implemented as anticipated and cannot be implemented with current constraints. As this is the most ideal model, we can safely assume that any other model would produce similar or worse results. The idea of using a cam for a human seat vibration setup is therefore terminated.

Conversion of Passive Damper to MR Damper (Attempt 1)

<u>Setup</u>

To convert passive damper into active damper we required two modifications in our passive damper.

- To produce uniform magnetic field inside the cylinder of damper. This was achieved by using the basic principle of solenoid, electric current through the coil creates uniform magnetic field inside the coil. For this, we wound the outside of cylinder of damper with wire.



(Solenoid Magnetic Field)

Strength of magnetic field inside a solenoid is given by:

$$B = \frac{\mu N I}{L}$$

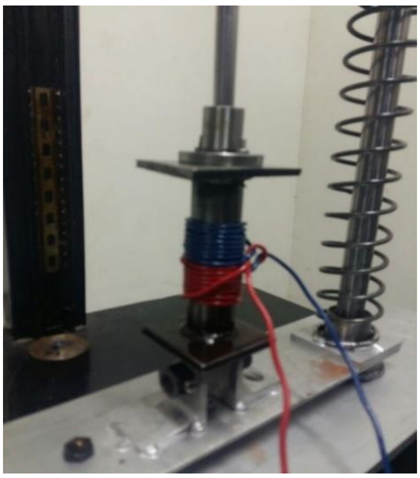
B: Magnetic field.

μ: Permeability.

N: Number of coil turns (16 number of coil turns for our damper).

I: Current flowing through coil.

L: Length of coil (6cm for our damper).



(Passive Damper converted to MR Damper)

Use of Magnaflux Spray

Secondly, the oil used inside the cylinder should be magnetized so that when it experiences magnetic field, there is change in viscosity of oil. For this purpose, Magnaflux spray used in Magnetic particle inspection for cracks and creeps was mixed with SAE-40 oil which is used in our passive damper and different concentrations of magnetized oil were prepared.

(Magnaflux Spray)

This kind of MR damper can be reverted back to passive damper anytime whenever required.

Experimentation

MR dampers, like all magnetic materials, must possess a hysteresis curve. This curve can be represented between the current provided to the MR fluid, and its viscosity. Since the damping coefficient of a damper is directly proportional to the viscosity of the fluid inside it:

$$c = \mu\left[\frac{3\pi D^3 l}{4d^3}\left(1+\frac{2d}{D}\right)\right]$$

C is the damping coefficient, μ is the viscosity
D, d and l are damper dimensions

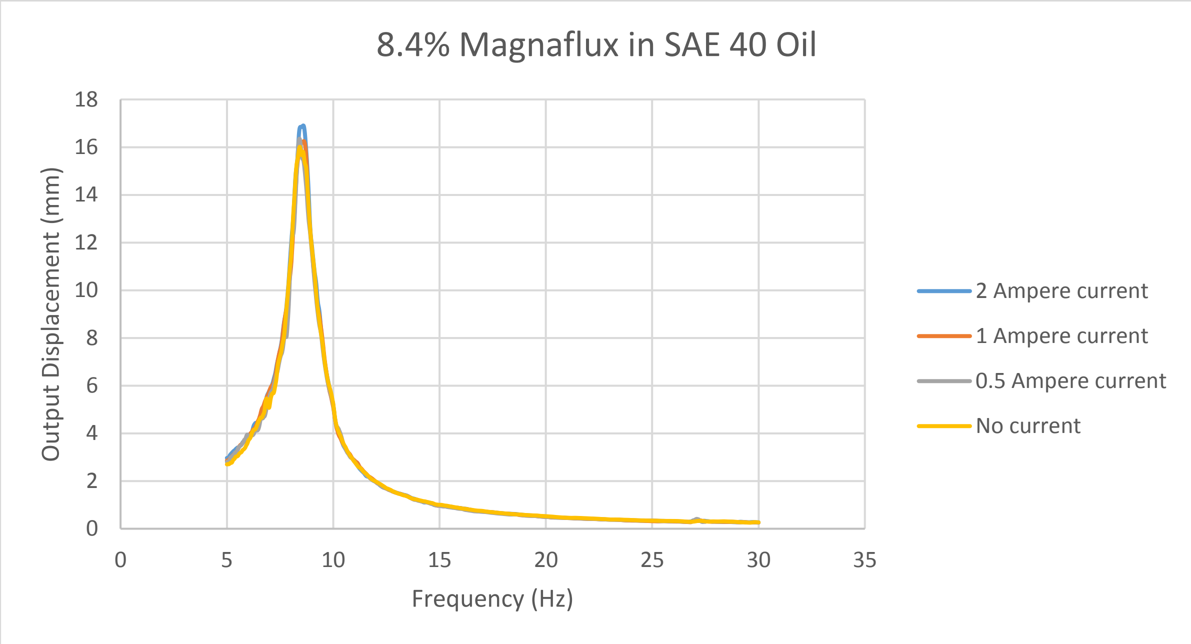
A change in the current must produce corresponding changes in the damping provided by the damper. This is taken as a sufficient condition for the success of the experiment.

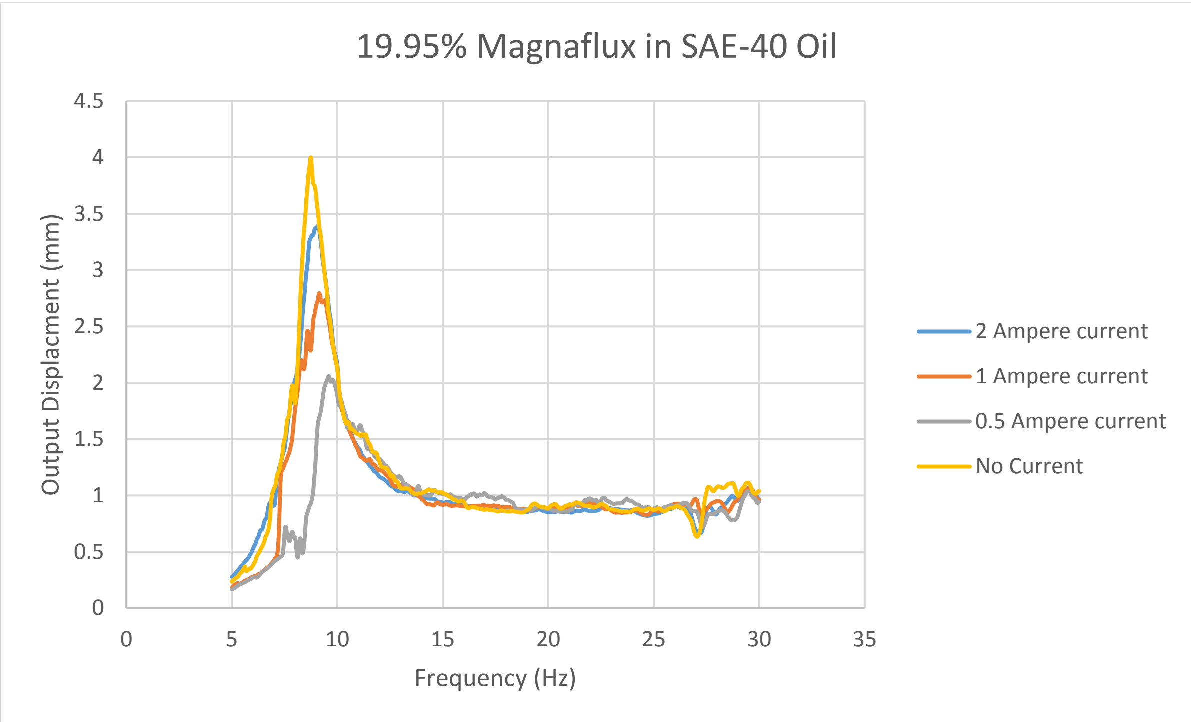
PROCEDURE

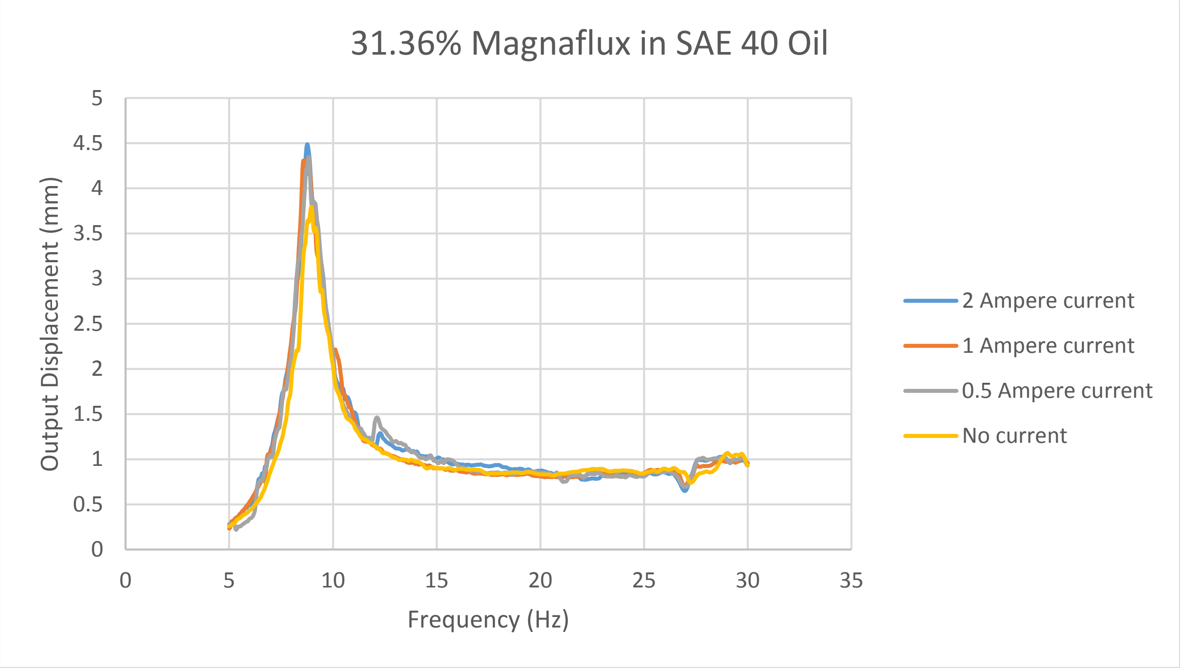
- Magnaflux-14 AM was added to SAE 40 Oil. All concentrations are measured as Wt./Wt. %
  The standard weight of oil taken = 118.27 g.

- Three concentrations were prepared. The shaker test was carried out for each of these currents while passing different amounts of current through a coil wrapped around the damper cylinder.
- A *sine sweep test* was carried out from 5Hz to 30Hz using constant displacement input from the shaker = 2 mm.

RESULTS OBTAINED FROM EXPERIMENTS







INFERENCES

- No substantial change can be seen in the resonating frequencies of the system upon changing the current.
- Similarly, no change is observed in the resonating frequency upon change in concentration.
- There should have been a change in the resonating frequency if the damping of the system was changing due to varying currents. Therefore we can conclude that the damper, upon addition of Magnetic Inspection fluid, and with current passing around the cylinder, DOES NOT behave as an active MR Damper.
  There could have been two major reasons for this failure:

    - *Magnetic Shielding* occurs. Since the coil is wrapped outside the cylinder, the fluid (and therefore the magnetic particles) might be shielded by the effects of the solenoid by the cylinder material (Mild Steel).

    - The concentration of magnetic particles might be very low to have any significant effect on the damping. The Magnaflux-14 AM only has a 5% proportion of particles to petroleum suspension. Therefore, when we add a portion of Magnaflux-14 AM to the SAE 40 oil, the proportion of magnetic particles introduced into the oil is very low. Thus, the question arises if there is a particular 'threshold' concentration beyond which magnetic particles have a significant effect on the viscosity of the MR fluid.

Conversion of Passive Damper to MR Damper (Attempt 2)

Magnetic Nano-Particles

Magneto Rheological fluid

Electro-rheological (ER) fluid changes viscosity when an electric current is applied directly to the fluid itself. ER fluid was first invented and patented in the 1940s, and to varying degrees, development has continued ever since. It has been tested in a wide range of applications, from torque converters, clutches and dampers to synthetic muscles and dampers in powered prosthetic arms and legs. It works, but its shear strength (its resistance to shearing movement) is limited. Despite huge investments in research and development, ER fluid is still far from ready for any practical applications.

Magneto-rheological (MR) fluid on other side has shear strength about 10 times stronger than ER fluid. Invented at the same time as ER fluid, the two have many similarities. Both can use oil, silicone, water or glycol as the base fluid, and both contain polarizable particles suspended in the fluid. Polarizable means the particles can be forced to align in a specific way. These suspended polarizable particles are the basic difference between ER and MR fluids. ER fluid uses particles that polarize when directly exposed to an electric current. MR fluid uses somewhat larger particles of iron that polarize when surrounded by a magnetic field.

Our Approach

Fe^{3+} ions were created using the chemical reaction of $Fe(OH)_3$ and HCL. Two types of Iron particles were used purified iron particles and unpurified iron particles. Three different concentrations were made. One with pure particles having concentration 7.5% by weight of pure iron particles in SAE 40 oil, other with impure iron particles having concentration 8.75% by weight of impure iron particles in SAE 40 oil. These two concentrations were used while conducting test with old model of MR Damper having coil wound around cylinder.

Below are the tables describing the observations made while making the above mixture of magnetized fluid:

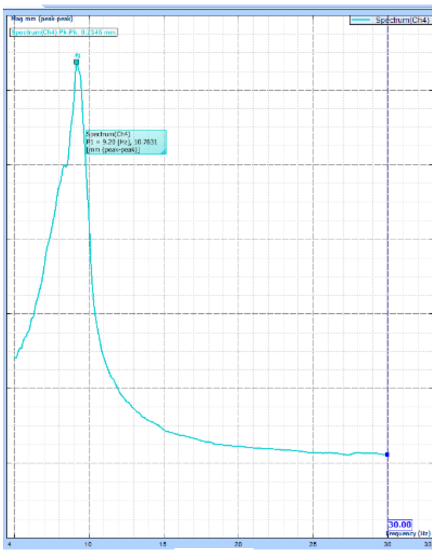
Old MR Damper (impure Particles)	
weight of empty bottle (g)	19.87
Bottle + Particles (g)	22.89
Weight of Particles (g)	3.02
Weight of Bottle + Oil + Particle (g)	63.11
Weight of Oil (g)	40.22
Wt/Wt % of oil	7.508702

Old MR Damper (Pure iron particles)	
Empty Bottle Weight (g)	21.07
Bottle + Particles (g)	22.17
Particle Wt. (g)	1.1
Bottle + Particles + Oil (g)	34.74
Oil (g)	12.57
Wt./Wt. %	8.750994

Experimentation

Test 1: 7.5% wt/wt rough nanoparticles

Sweep Sine Responses for the above concentration are given below.



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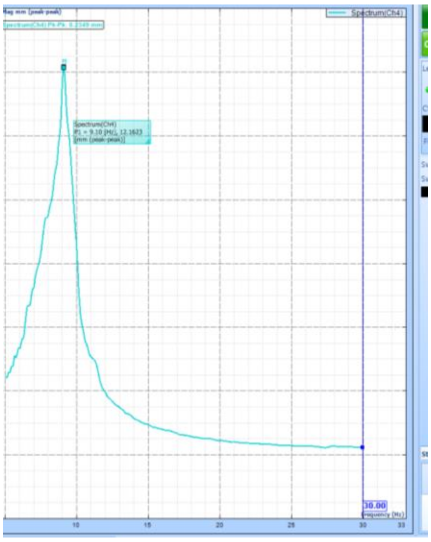
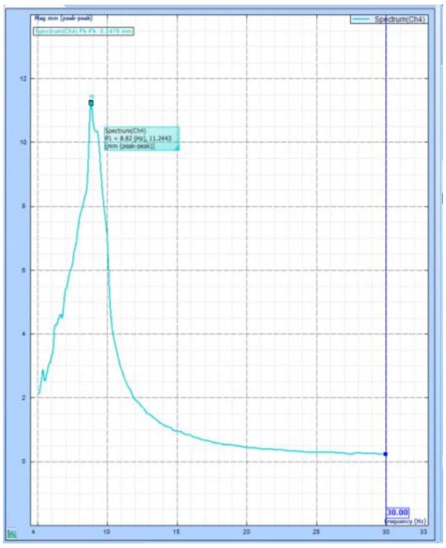
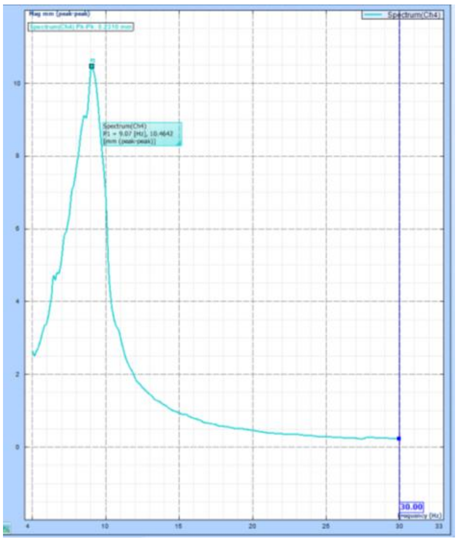


0.5A



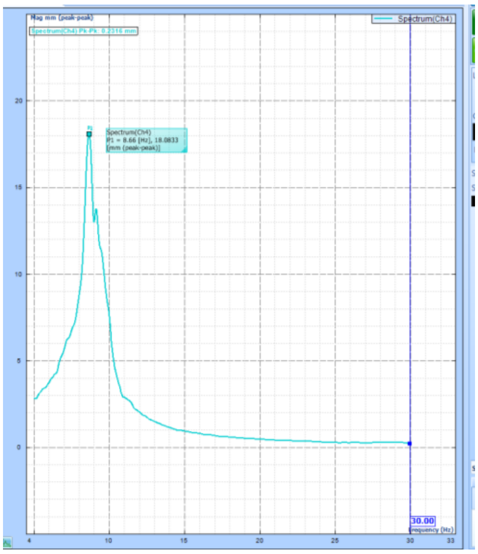
1A



2A

Test 2: 8.75% wt/wt rough nanoparticles

Sweep Sine Responses for the above concentration are given below.



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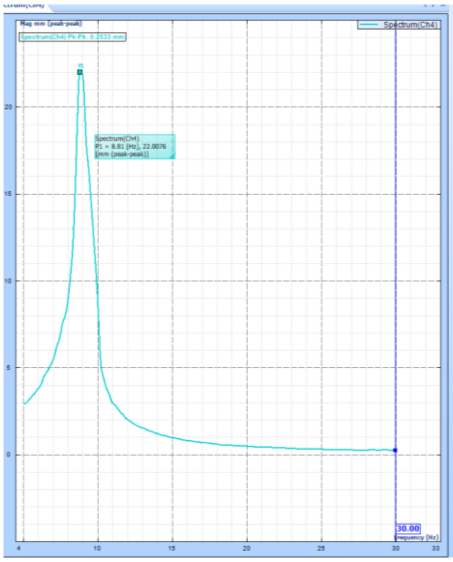
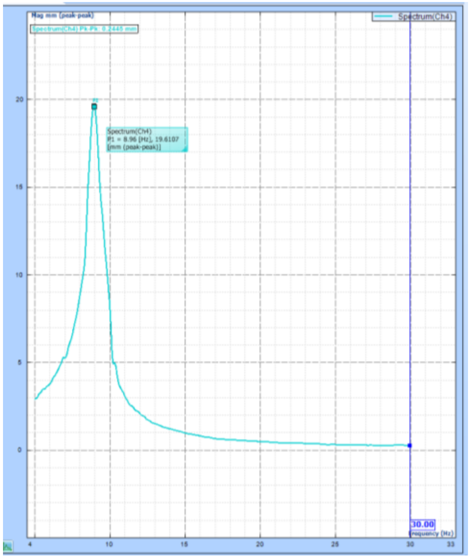


0.5A



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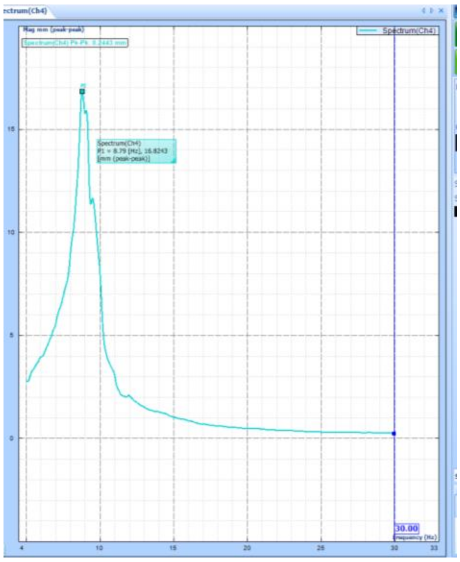


2A

Summary of Results

For the old MR damper setup and nano particles, following were the results.:

Current	**Unrefined Particles**	**Refined Particles**
0 Ampere	9.2 Hz	8.66 Hz
0.5 Ampere	9.1 Hz	8.81 Hz
1 Ampere	8.8 Hz	8.96 Hz
2 Ampere	9.07 Hz	8.79 Hz

Conversion of Passive Damper to MR Damper (Attempt 3)

Design of a piston around which current-carrying coil can be wrapped

By our current experimentation with the new mixture of oil and magnetic particles, there has been no change in the damping constant of the system for current varying between 0-2A. Therefore, there is a possibility that the magnetic field experienced by the fluid is not strong enough due to the shielding effect of the steel cylinder.
Thus, a new design of the piston in which the current-carrying coil would be wrapped around the piston was to be created.

Points to be taken care of for this design-

1. The groove made in the piston should be of appropriate dimensions so that the piston surface is kept as flat as possible. The safe wire diameter required for this specified order of current is about 0.8 to 1.2mm. Hence the groove depth was decided to be fixed at 1mm.
2. Since there will be wiring coming out of the inside of the cylinder, there should be appropriate arrangements in the sealing made for the same.
3. Overall sealing should be made tight as magnetic nanoparticles are expensive and leakage cannot be afforded. The need for sealing was eliminated in this iteration of design by extending the piston further into the cylinder hence keeping a healthy clearance (about 2cm more than the passive damper) between the upper surface of the fluid and the cylinder opening.

The piston outer diameter was fixed at 17mm and shaft diameter at 10mm (following the passive damper dimensions).

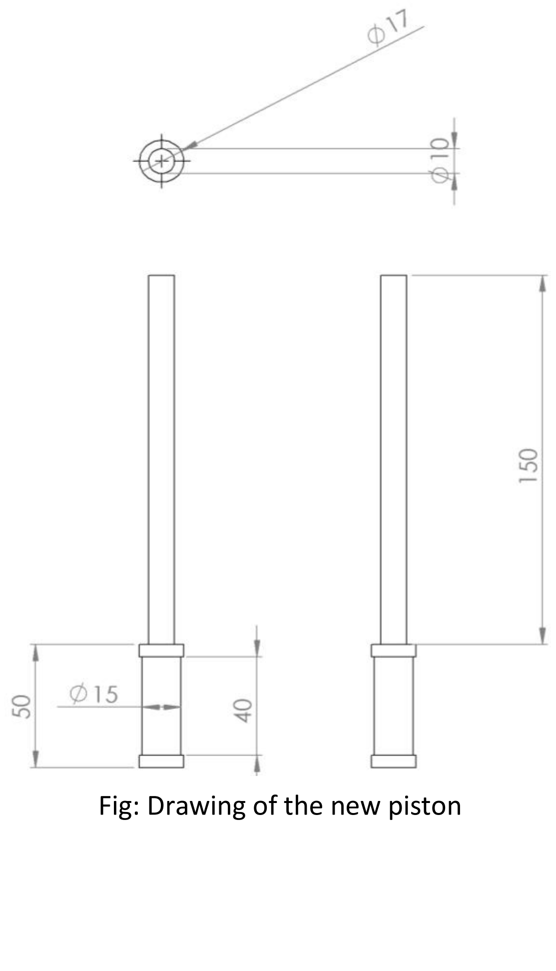


Fig: Drawing of the new piston

Fabrication of the New Piston

New Piston for the MR Damper was manufactured on Lathe machine carried out in our workshop.

Equipment Used: 25mm MS solid cylinder rod of 30cm length (issued from workshop), Lathe Machine, Vernier Caliper, Flat fine file, Emery paper, 8mm winding wire, feviquick.

Required dimensions of piston: 170mm length of shaft, 50mm length of piston, 10mm diameter of shaft, 17 mm diameter of piston at the ends with 4mm length at each end, middle part of piston is made to be of 15.8mm diameter with its length to be 42mm.

10mm diameter of shaft passes through the linear bearing to keep it centric with the cylinder and tight fits into the upper connector which has hole for the same of 10mm depth 10mm diameter. Linear bearing is screwed on the upper plate of cylinder containing magnetized fluid.

Procedure followed for manufacturing:

- 30mm MS solid cylinder rod of 300mm length is taken a 5mm hole is drilled at one of the faces of MS rod so as to reduce the wobbling by holding the rod in chuck and tailstock of Lathe machine.
- Carrying out the turning operation to reduce diameter from 25 mm to 17mm for 240mm of length of work piece from one end.
- Further carrying out turning operation to reduce 17mm diameter to 10mmdiameter for 180mm of length from the same end.
- To get the middle part of piston from 17mm to 15.8mm, it is machined from 184mm to 234mm from the same end.
- Parting tool is used on both the ends to get the final length of piston and shaft to 220mm as required.
- Winding wire was wound around the middle part of piston with 64 turns.
- Feviquick was used to make sure winding wire is glued to piston and doesn’t loosen up.
- Two ends of the winding wires come out from one of the screw holes of linear bearing out of the cylinder.

Dimension	DESIGN (mm)	ACTUAL (mm)
Piston Diameter (inner)	15	15.4
Piston Diameter (outer)	17	17.1

Table: Piston Dimensions

Setup

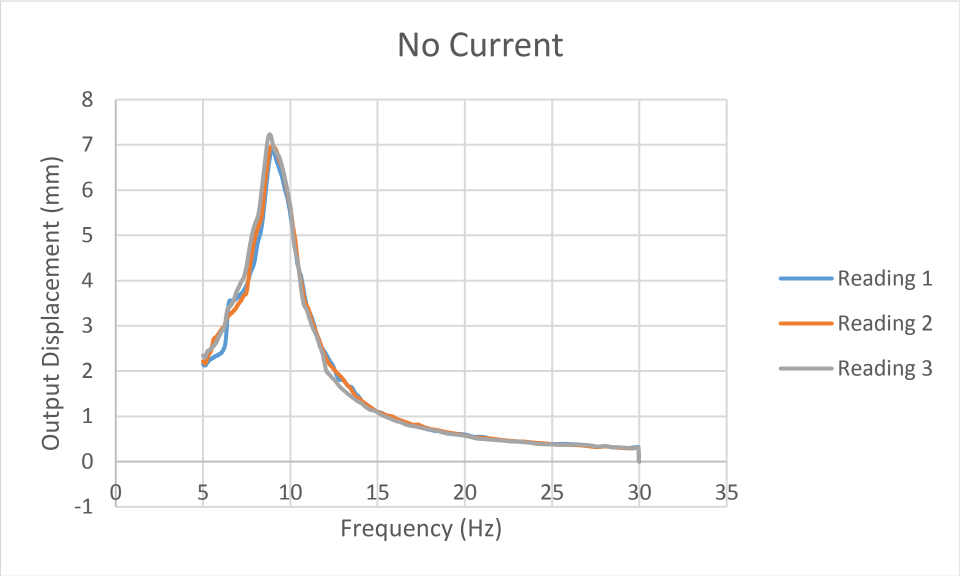
For new MR Damper 6.04% by weight of pure iron particles in SAE 40 oil was used. Multiple readings were taken for different value of the current 0, 0.5, 1, 1.5, 2 Amperes.

New MR Damper (Pure iron particles)	
Weight of empty bottle(g)	19.18
Weight of bottle + oil(g)	75.28
Weight of bottle + oil + particles(g)	78.67
Weight of Oil(g)	56.1
Weight of Particles(g)	3.39
Concentration Wt/Wt(%)	6.042781

Fig: The new piston wrapped with 20AWG (0.8mm) enamelled wire

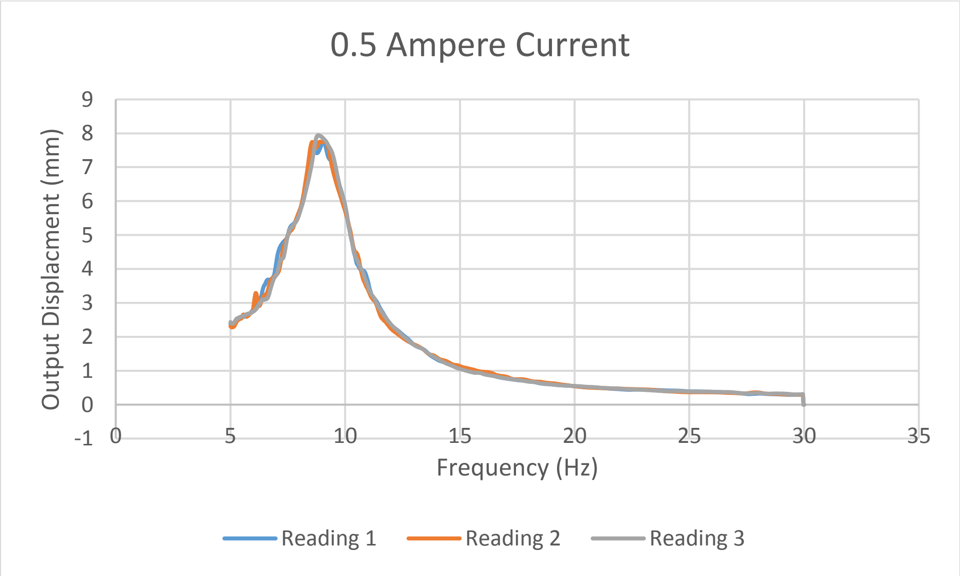
Experimentation

The same experiment was conducted with the new model of the damper that has been fabricated. The results can be seen as follows:



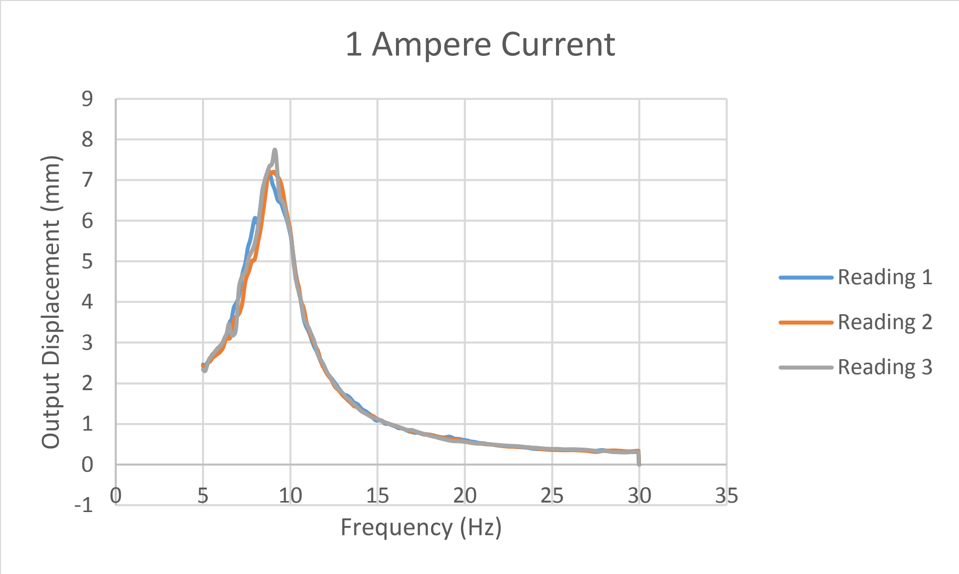
Average Peak Frequency: 8.91 Hz

Average Peak Displacement: 7.051 mm



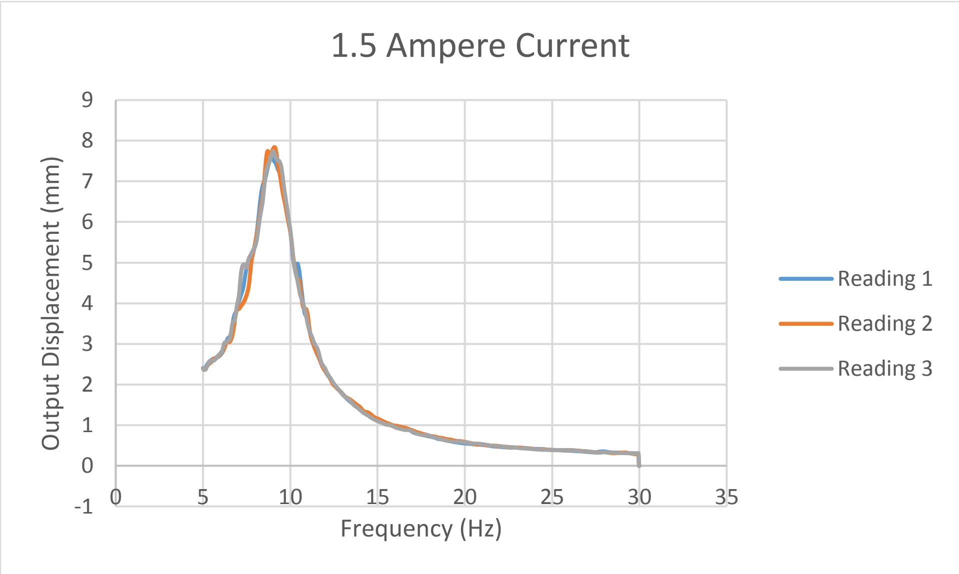
Average Peak Frequency: 8.99 Hz

Average Peak Displacement: 7.816 mm



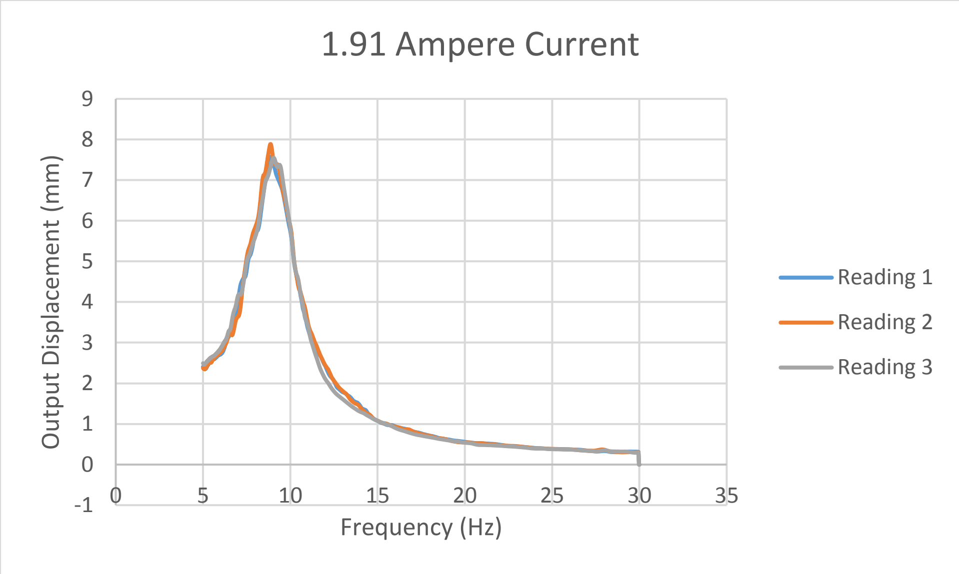
Average Peak Frequency: 8.90 Hz

Average Peak Displacement: 7.372 mm



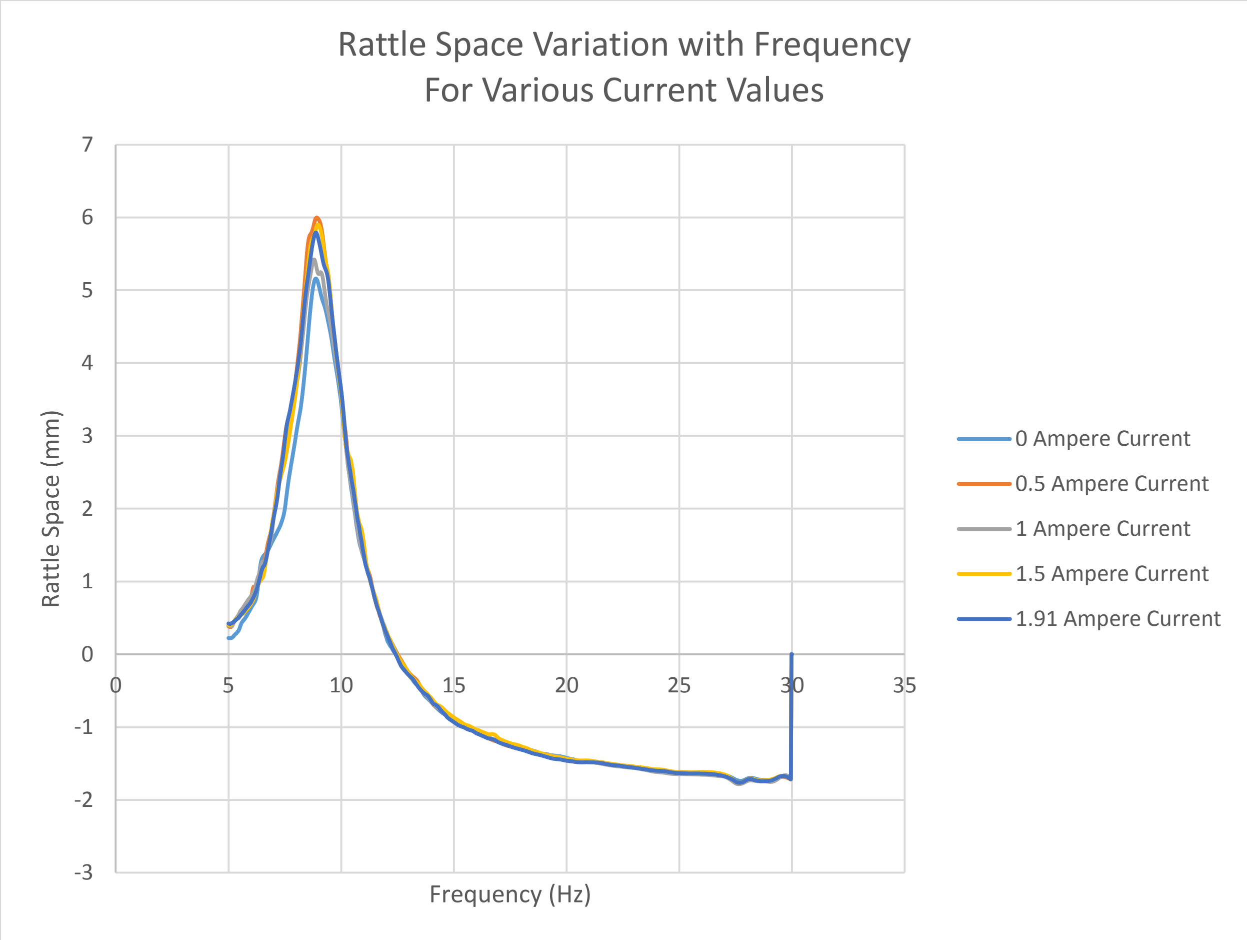
Average Peak Frequency: 9.01 Hz

Average Peak Displacement: 7.731 mm



Average Peak Frequency: 8.91 Hz

Average Peak Displacement: 7.668 mm



Although there is slight variation of the resonant frequency, it is not uniform, nor can any predictable pattern be observed. The variation can simply be attributed to arise from experimental errors, which would not be present in an ideal scenario. Thus the attempt to construct an inexpensive MR Damper has failed.

Possible Reasons for failure:

1. The ferromagnetic particles are heavy. They do not float in the oil but rather settle down to the bottom of the cylinder and therefore no effect can be observed on the fluid's viscosity.
2. The number of turns on the piston may not be enough to generate a field strong enough to magnetise the fluid and affect its viscosity.

Further:

A surfactant such as oleic acid, or more commonly a detergent, can be added to the oil. This will increase the surface tension of the fluid and prohibit the particles from settling down.

Better methods for obtaining/purifying of particles can be used so that the particles are finer and lighter.

Conclusion

After successfully designing, fabricating and testing the passive damper, the objective of this semester's work was to design and fabricate a low-cost active damper. After gathering the required materials and exhaustive experimentation, a total of three attempts were possible in the stipulated time. Unfortunately, the results indicate that the attempts were unsuccessful.

However, there still exists a good possibility of ensuring active response from the setup by following the suggestions mentioned above as well as further research on MR damper technology.