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Design, Synthesis and fabrication of Magneto Rheological Fluid Damper for low Frequency Application

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ABSTRACT: *Magneto-rheological (MR) fluids are a class of controllable fluid that responds to an applied magnetic field with a change in rheological behavior. Interest in MR fluids derives from their ability to provide simple, quiet, rapid-response interfaces between mechanical systems and electronic controls. These fluids have important applications in the field of damping systems. In order to control an MR damper, it is necessary to have a clear understanding of the behavior of the MR fluid which can be achieved by conducting experiments and prepare a database which can help in predicting the response of MR fluid under any given conditions. This paper introduces a method to conduct such experiments. By these experiments all the parameters which do not appear in the idealized model can be studied and a comprehensive model can be developed.*

Keywords: *Magneto rheological fluids, Vibration control, suspension system, single degree freedom system*

I. INTRODUCTION

Magneto-rheological (MR) Fluids are a class of controllable fluids whose viscosity can be varied by the application of external magnetic field. MR fluid was discovered by Jacob Rabinow in 1949. When subjected to a magnetic field, MR fluids change from a liquid to a semi-solid state. Alternatively, in the absence of a magnetic field, MR fluids have viscous properties comparable to household paint. Interest in controllable MR fluids derives from their ability to provide a rapid response interface between an electronic control system and a mechanical system. Use of MR fluids for engineering applications is gaining importance during recent years because of certain advantages. The advantages of using MR devices include, ease of control, simple in construction, durability, low power consumption, smooth-acting, step less torque control, fast reaction, ease of installation (control signal is led by two wire cables) and almost linear characteristics.

The magneto-rheological response of MR fluids results from the polarization induced in the suspended particles by application of an external field. The interaction between the resulting induced dipoles causes the particles to form columnar structures, parallel to the applied field. These chain-like structures restrict the motion of the fluid, thereby increasing the viscous characteristics of the suspension. The mechanical energy needed to yield these chain-like structures increases as the applied field increases resulting in a field dependent yield stress. In the absence of an applied field, MR fluids exhibit Newtonian-like behavior.

Preparation of the MR fluid

Properties of the MR fluid which are used in designing a damper system is given in Table 1.

Table 1. Properties of MR Fluid used in designed damper

Carrier Fluid --- Silicone Oil
Solid Particles --- Carbonyl Iron Particles
Volume Fraction of Solid Phase --- Varied from 20% to 35%
Mass Density of Iron Powder --- 7.8 gm/cc
Mass density of silicone oil --- 1.25 gm/cc
Colour --- Dark Gray

The carbonyl iron powder and Silicone oil which is an organic liquid were used to prepare the MR fluid. The volume fractions of components of the mixture were varied as per the requirements. As per the calculation for the particular volume fraction, required volume of Silicone oil and iron powder were taken in a container, then the mixture was stirred continuously for 24 hours with the mechanical stirrer in order to get uniform distribution of iron particles in the silicone oil.

2.1 Calculation for 100cc of 35 % volume fraction MR Fluid

Total volume of MR fluid = 100 cc

35 % volume fraction of iron powder = 0.35 X 100 = 35 cc

Mass density of iron powder = 7.8 gm/cc
Mass of iron powder = 7.8 X 35 = 273 gm.
65 % volume fraction of silicone oil = 0.65 X 100 = 65 cc.
For other volume fractions the mass of iron powder and volume of silicone oil are tabulated as follows.

Table 2. MR Fluid constituents for different volume

Total volume of MR Fluid = 50cc, Density of iron powder = 7.8gm/cc		
Vol. Fraction (in %)	Mass of iron powder (in gm.)	Volume of silicone oil (in cc)
20	78	40
25	97.5	37.5
30	117	35
35	136.5	32.5

2.2 Filling the fluid gap of the MR damper

Since the MR Fluid is a colloidal mixture of silicone oil and iron powder, filling the MR Fluid into narrow space of the assembled damper was difficult. Gravity filling of the fluid leads to non-uniform distribution of the fluid and unfilled volume. So the fluid is injected in to the brake. Two threaded ports were created that are sealed during operation bygrub screws. To inject the fluid, both ports must be opened. One port is an intake port, while the other port allows displaced air to exit. A syringe with a modified tip, to fit into the intake port is used to inject the fluid in to the damper. The total fluid volume in the MR damper was only 100 cc, so the filling process was fast. The fluid is filled till some amount of fluid comes out through the exit port. This ensures the complete filling of the fluid gap. Once the fluid is in, both ports can be closed with the grub screws completing the assembly of the brake.

Design of spring mass damper system

In order to control an MR damper, it is necessary to have a clear understanding of the behavior of the MR fluid. It is therefore necessary to conduct experiments and prepare a database which can help in predicting the response of MR fluid under any given conditions. In this method, MR damper was designed and fabricated as shown in Fig 1[4] and in the experimental design the one end of damper is held fixed while the other end is excited using an electro-magnetic shaker. It was therefore proposed to study the damper characteristics using a single degree of freedom base excited spring-mass damper set up is as shown in Fig 2.

Fig 1 Designed MR damper

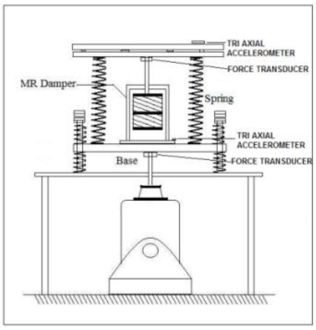


Fig 2 Schematic of Spring mass damper system

Using LabVIEW 2009 the time domain plots of displacement for the free vibration of a spring mass system with MRF damper are drawn and verified in the subsequent sections. The plots show how fast the system returns to equilibrium position as the current and volume fraction of iron powder increases. With this knowledge, one can turn to an MR fluid specification sheet and choose appropriate fluid parameters. MR fluids are suspensions of micron-sized, magnetizable particles in a carrier fluid. They mainly consist of the following three components: magnetizable particles, a carrier fluid, and some additives. The magnetizable particles in MR fluids induce polarization upon the application of an external magnetic field, which results in the MR effect of the MR fluids. The magnetic field is a function of Ampere-turns (NI), where N is the number of turns and I is the current. So the flux density can be increased by either keeping N constant or varying I or by keeping I constant and varying N. Hence the current is varied in the above experiments [3]. Damping coefficient of a MR damper always depends on the viscosity of the MR fluid which in turn is a function of the magnetic effect produced by the electromagnetic coil assembly.

Experimental analysis using data acquisition and signal processing software labview. The experiment was initiated to produce the input harmonic waveform to the spring mass damper setup. To ensure homogeneity of the MR fluid, a trial run was first performed for approximately 10 cycles of oscillations. This will ensure the fluid to be well dispersed before the actual data acquisition commences. 9 sets of data were collected subsequently for combinations of different current and frequency inputs to the MR damper. The current values used were 0A, 0.5A and 1.0A while the frequency input values were 0.5Hz, 1.0Hz and 1.5Hz. The amplitude of oscillation was kept constant at 10mm. The damper stroke was positioned at its centre before the test was carried out to avoid the extreme positions of the damper stroke [5]. The computer then recorded the data values of time, displacement and force. The sine wave generated by the Agilent signal generator is fed to the shaker through a power amplifier. The process of dynamic analysis of the spring mass damper system is as shown in Fig 3.

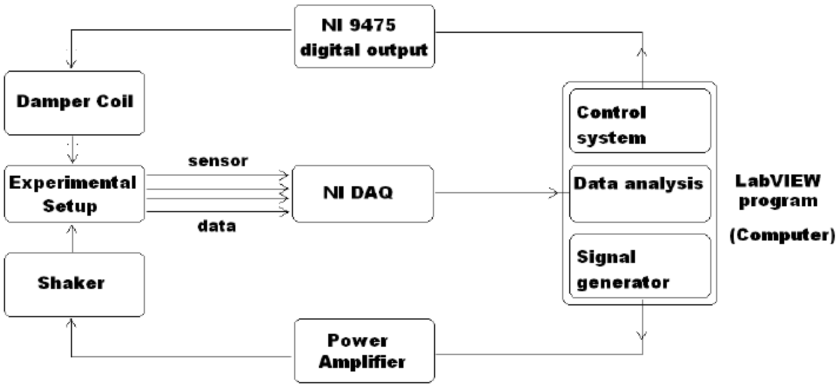


Fig 3 Structure of DAQ experiment

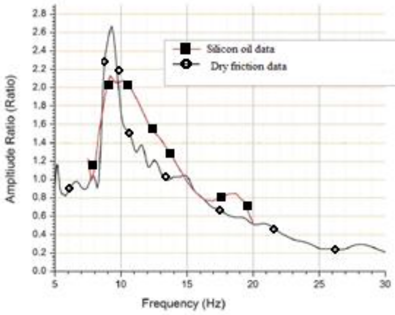
The function generator generates most standard waveform with NI-FGEN which implements frequency sweeping and hopping, waveform linking and looping, and frequency shift keying modulation for complex measurement solutions. The NI-FGEN VI is placed in Case Structure of the block diagram initializing the loop. A graphical programme which includes two accelerometers for getting top and bottom plate accelerations and two force transducers are used to acquire the force transmitted through the DAQ as shown in fig 4. Forced vibration tests with base excitation were also carried out to study the dynamic behavior of damper at different frequencies using spectral measurement tool kit for each sensor for different frequencies. [5] Experiments are conducted at various frequencies to have a different damping force. In order to find the working frequency range, the setup was subjected to forced excitations using the sine sweep in the range of 5 Hz to 30 Hz with 30 frequency sub steps as shown in fig 5. The damper was used in the dry friction state. The figure 5 illustrates the variation of amplitude ratio vs. Frequency of excitation for a sweep sine test carried out on designed experimental set up in order to find out the range of natural frequencies of the system under base excitation system. Clearly the figure 6 shows the major peak to be at 9.75 Hz. The seep sine test gives us the resonant mode of the system for wide range of frequencies. Thus a frequency of 8Hz to 12Hz was selected as the operating frequency range for further experiments. The following cases were considered for experimentation of Sweep sine test, Dry Friction, Silicon oil, MR Fluid without magnetic field, MR Fluid with magnetic field.

II. RESULTS AND DISCUSSION

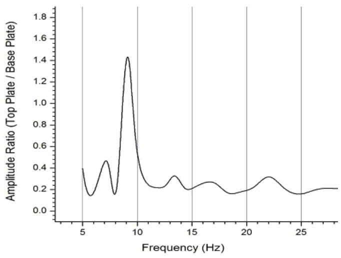
The performance test comprises of frequency sweep held at constant displacement input. The magnetic field was varied by current, which is adjusted to be 0A, 0.2A, 0.4A, 0.6A, 0.8A, 0.9A. The damper's shaft was excited at constant displacement amplitude of ±15 mm during which the frequency was adjusted to be 0.5 Hz, 1 Hz, 2 Hz, and 4 Hz, respectively. Initially damper was used without any effects of shearing. No fluid was present in the inner cylinder of the damper. This method gives the frictional damping factor of the damper. Amplitude ratio is the ratio of the RMS amplitude of vibration of the top plate to that of the base plate expressed in equation (1) [5]. Dynamic characteristics for Viscous-Silicon for 1 Volts to 7.5 Volts of applied magnetic field for sweep sine test was carried out for20-30 steps as shown in Fig 6. In order to get the dry frictional characteristics of MRF damper sweep sine test is carried out to get an average of Max Peak of Magnification Factor 2.08, Natural Frequency 9.24 Hz, with a Damping Factor ς 0.2814 as shown in Fig 4.

$$\zeta = \frac{1}{\sqrt{2}} \times \frac{\sqrt{((a^2-1)(a^2-\sqrt{a^4-a^2}))}}{(a^2-1)}$$

Equation (1)
ς = damping factor, a=amplitude ratio at peak



The experiment was repeated for MRF damper with viscous oil such as silicon oil to get the change in dynamic property for different applied electric field as shown in Fig 6. The viscous-damping force is directly proportional to the relative velocity between the two ends of the damping device. In this case Silicon oil was filled in the inner cylinder of the damper. A total of 35ml of silicon oil was used. This gives an additional viscous damping due to shearing of the fluid on top of the existing frictional damping. Since the coil of the damper is not supplied with voltage, there is no electromagnetic field and hence no rheological effect of the MRF. Thus, the damping in this scenario is due shearing of the MRF and due to frictional damping as shown in Fig 5[5] The MRF damper with voltage corresponding to 5V (1.25A) is given to the magnetic circuit in the damper.. The minimum damping factor of the damper is 0.2139, in the dry friction damping case. When shearing effect is introduced in the damper, the damping increases as expected. The average damping is found to be 0.277. The net increase in damping due to shearing effect is 0.06. In case 2, silicone oil is used as the fluid for the shearing effect. Silicone oil is chosen because it is also the base fluid of MRF. Further magnetorheological fluid is filled in the damper. This shows the effect of the suspension iron particles on the behaviour of the silicon oil. The average damping factor in the case of MRF without external excitation is 0.4054. The net increase of 0.1277 can be attributed to the effect of iron particles. Next, the rheology effect of MR fluid was taken into consideration.



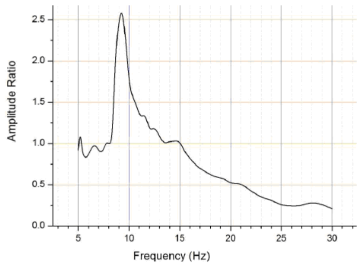


Fig 4 Sweep sine test Fig 5 Dry friction dampingFig 6 Viscous Damping using silicon oil

III. CONCLUSION

A semi active control system has been proposed for the experimental setup. The experimental setup has been constructed with an electromagnetic shaker for excitation in a base excited system with suitable springs and an existing damper. The setup has been constrained to operate with a single degree of freedom by suitable means [4]. The excitations were generated on a NI PXI-5412 on a PXI-1031 chassis. They have been treated both qualitatively and quantitatively. To start with, the damper has been run with dry friction alone. It has then been filled with silicone oil for the purpose of studying the effect of shearing on the damping factor. A suspension of micron sized iron particles in silicone oil has been prepared. The damper has been filled with this liquid and tests have been carried out to find out the suspension’s viscous properties. It has then been proceeded to apply a current through the coils of the damper.

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