Design and evaluation of a linear damper working with MR shear thickening fluids

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Abstract
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Design and Evaluation of a Linear Damper Working with MR Shear Thickening Fluids

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ABSTRACT
Magnetorheological (MR) materials and shear thickening fluids are both smart materials and their combination could offer both MR and ST effects. This study looks at the properties and behaviour of magnetorheological shear thickening fluid (MRSTF) in particular whilst applied as a semi-active energy absorber. A device with two forms of varying vibration control has been created and measured. The result shows that this MRSTF filled damper showed both MR and properties.

1. Introduction
Vibration control, a field devoted purely to the absorption of impact energy, has seen vast advancements over time with the implementation of fluid filled shock absorptive dampers [1]. More recently, semi-active devices operating with media possessing varying fluidity properties have been greatly studied [2-5] as their working modes can be adjusted. Magnetorheological (MR) materials are examples of these variable flow rate or force characteristic mediums [5]. Applying an external magnetic field to these intelligent materials alters the rheological properties of the body. This alteration is completely reversible and a transition from a liquid to a near solid state occurs very quickly (milliseconds) [3].

Shear thickening fluid (STF) is a similar type of ‘quasi-Newtonian’ substance; it possesses a low viscosity until the transition of the critical shear rate where it increases dramatically [2]. STF’s are defined by Zhang et al [6] as ‘concentrated colloidal suspensions composed of non-aggregating solid particles suspended in fluids.’ The same as MR substances the change in flow properties is completely reversible; however, unlike MRFs, STFs do not require the application of an external field.

In this paper, the result of combining the advantages of MR and ST fluids in vibration control is illustrated. The prepared MRSTF, ‘smart fluids,’ rheological properties are tested and illustrated with the experimental performance of the fluid in a prototype damper.

2. Method
A kind of shear thickening fluid (STF) was fabricated with the purpose of serving as the base for the tested fluid medium. The STF consists of ethylene glycol solvent in which fumed silica particles (14 nm primary particles) were suspended at a weight fraction of 25% in the entire fluid body. Micron sized carbonyl iron particles, at a 20% weight fraction, were immersed amongst the STF and thoroughly mixed under a high shear condition to introduce the ability to produce the Magnetorheological effect. A vacuum chamber removed air bubbles excited in the mixture and the desired MRSTF is ready to be tested [7,8] and its rheological properties are shown in Fig. 1.

![Rheological properties of MR STF with various magnetic flux](image)

Fig. 1 Rheological properties of MR STF with various magnetic flux

The MRSTF filled damper was designed as shown in Fig. 2. Inside the piston head there is a coil which can generate electromagnetic field and affect the MRSTF’s mechanical properties. This damper mainly consisted of piston head, tube, caps, and spring and its magnetic flux field was analysed by finite element analysis software package Flux. This result is shown in Fig. 3.

![Damper design](image)

Fig. 2 Damper design. 1, Bearing; 2, Piston head; 3, Screwable cap; 4, Spring seat; 5, Piston rod; 6, Tube; 7, Tube cap.

3. Results and Discussion
The prototype damper was clamped within an MTS Landmark test system, between two coaxially mounted Linear-variable Displacement Transducer (LVDT) load cells. The MTS Landmark operates by servo hydraulic system capable of exerting large axial loads on the test
specimen. The damper test system provides harmonic excitation to the damper and records signals taken through the load cells. The signals were saved to a computer via a data acquisition (DAQ) board measuring various feedback data series, these being time, axial displacement and axial force.

Fig. 3 Flux density of Electromagnetic component

The damper performance was tested under different testing conditions; the simple harmonic motion (sine function) used had its frequency varied, whilst altering applied magnetic field to test its MR effect. In this experimental study, excitation frequencies of 0.5, 1 and 2 Hz were used. Fluctuating the current output from an external power supply (from 0 to 1 A with 0.1 A step and 1 to 3 A with 1 A step) for each test means the internal electromagnets field will increase. Fig. 4 and 5 display the performance of the MRSTF filled damper.

Fig. 4 Force versus time with various frequencies

Fig. 4 presents applied axial force versus time for three different frequency sets. Comparing each plot it is clear that shear thickening is occurring at the fluid piston interface due to the size of force spike for each displacement with the greatest force required to achieve the initial compression location. Each of the three fluids are in neutral state, that is to say, no current is applied to the electromagnet. The representation is reliant completely on speed activation.

Fig. 5 shows the first cycle of compression and extension for 6 runs at a constant frequency of 1 Hz stepping the current in 0.5 A intervals. It is noted that the curves are not perfect ellipses and this damper showed an opposite properties of usually MRF dampers. What is meant by this is that as increasing the applied current to the damper coil, the measured damping force decreases and this also proves that the damper has shear thickening and magnetorheological properties at the same time.

Fig. 5 Axial force versus velocity with various currents

4. Concluding remarks

In this study, an MRSTF consisting of nano sized silica particles suspended in an ethylene glycol, solvent, mixed with carbonyl iron particles was fabricated. The dynamic property of the fluid was tested by a rheometer. Initial findings from the rheometrical testing were extracted and similar trends prevailed when the fluid was applied to MTS damper testing.

A prototype internal electromagnet semi-active damper was designed and fabricated based on research made into similarly performing devices. A secondary element in vibration control is provided as the system exhibits the ability to not only analyse a stiffness coefficient but also a variable damping coefficient. The axially compressing MTS test procedure produced a series of outputs measuring the response of the damper under various loading conditions. Analysing this data series displays the MRSTF to behave as a quasi-Newtonian fluid over a large range of dynamic shear rates with varying magnetic flux densities.

References