Experimental Study on Modified MR Damper

Yashpal M. Khedkar\textsuperscript{1*}, Sunil Bhat\textsuperscript{2} and H. Adarsha\textsuperscript{3}

1 Department of Mechanical Engineering, SVERI’s College of Engineering, Pandharpur, Maharashtra, India
Email: ymkhedkar@coe.sveri.ac.in
2,3 Faculty of Engineering and Technology, Jain University, Bangalore, Karnataka, India
Email: b.sunil@jainuniversity.ac.in, h.adarsha@jainuniversity.ac.in.

Abstract: Many systems in Industrial sector face the problems of vibrations. Vibration control equipment like MR damper is employed to minimize these vibrations. In this context, magnetorheological fluid (MR Fluid) is introduced as a damper fluid to improve the damper’s vibration reduction capacity significantly. This damper is known as Magnetorheological damper (MR damper) in which electromagnetic piston produces attractive impact to enact MR liquid. However, some problems are observed in MR damper due to internal electromagnetic piston configuration. Therefore, modification is proposed in the damper. The proposed design consists of a conventional MR damper filled with MR fluid and an external assembly of permanent magnet fitted around the damper. The modified MR damper has been tested under different parametric conditions with MR fluid AMT-Dampro. The results convincingly indicate that the modified damper delivers excellent performance by generating effective damping capacity that can be utilized for necessary applications.

Keywords: Damping force; Magnetorheological Damper (MR damper); Magnetorheological Fluid (MR fluid/MRF); Vibration control

1. Introduction
Vibration control technology has remained a challenging area of study for many engineers and researchers. Excessive vibrations are the main problem faced by the civil structures; vehicle systems, industrial equipment etc. Different kinds of vibration control devices have been developed to moderate the vibrations in the last few years. The Magnetorheological dampers (famous as MR dampers) are introduced to reduce the excessive vibrations at various fronts. It is an improved version of a classical hydraulic damper. Simple damper oil is replaced by a smart fluid named Magnetorheological fluid (MR fluid). This MR fluid has a good combination of the carrier liquid and freely suspended iron particles. MR fluid works as ordinary damper oil in case of zero magnetic fields (OFF state condition). As soon as a magnetic field is applied to it (ON state condition), freely suspended iron particles form a chain-like arrangement. This structure resists the external excitations that lead to a substantial drop in vibrations. The electromagnetic field is generated with the help of electromagnet on the piston of the damper. Electromagnet contains multiple numbers of copper coil windings. Electric current is passed through the windings to produce an electromagnetic field. But from the application point of view, there may be possibilities of unavailability of electric current or battery provision at an actual site. Moreover, some common defects like hard cake formation, clumping, oxidation and settlement of MR fluid particles are found in MR damper [1]. Also, the copper coil comes in contact with the carrier oil which sometimes results in short circuit. In addition, a lot of heat is generated during the damping process. As MR fluid is a good conductor of heat, the heat generated affects fluid’s viscosity adversely.
So, permanent/hybrid magnets have been tried out in some of the recent designs to find the solutions for the existing damper problems. Although the use of an internal permanent/hybrid magnet at piston of MR damper has certainly addressed the heat and short circuit problems, it promotes continuous ON state condition. Such issues open up the scope for modification of MR damper by using an external permanent magnet assembly.

1.1. Magnetorheological fluid

As discussed earlier in section I, the principle of magnetorheology is based on the change in rheological characteristics of the fluid under the influence of the magnetic field. Magnetorheological fluid is one of the types of smart fluid. It’s viscosity changes suddenly (in few milliseconds) upon the application of the magnetic field. Magnetorheological fluid is prepared with the proper combination of the carrier liquid, ferromagnetic particles and additives. Ferromagnetic particles are freely suspended in carrier fluid in no magnetic field condition. The volume fraction of ferromagnetic particles added is about 20% to 40% of the total volume (25 to 80 % by its weight). There is no magnetic field known as OFF state condition while the state when the magnetic field is applied is known as ON state condition. In ON state condition, the ferromagnetic particles form the chain-like structure due to magnetic field strength. The damping capacity has been tremendously improved due to MR fluid particles [4]. This behaviour of MR fluid particles is illustrated in figure1.

![Figure 1. MR Fluid in the presence of magnetic field](image)

2. Literature review on MR dampers

Raju Ahmad et al. [5] discussed the potential application of MR fluids in their research. The concept of magnetorheology has been used to prepare magnetorheological fluid (MRF), magnetorheological elastomer (MRE), magnetorheological grease (MRG), magnetorheological polymer gels (MRPG), and magnetorheological plastomers (MRPs). MRF is very easy to prepare, very sensitive to change in the magnetic field and unresponsive to contamination. Due to these properties, MRF is very famous as a smart material used for vibration control.

Xiao et. al. [6] have put a new aspect of MR damper design. One of the modified MR damper designs consists of a permanent magnet. This design has been developed to resolve the fail-safe problem of MR dampers. A permanent magnet and magnetic valve have been utilized in it. This model has been based on electromagnetism theory and the Bingham model. Permanent magnet and self-sensing compact devices have also been developed further by Hu. et al. [7]. Kim et al. [8] have taken this work further. A tunable MR damper has been another device operated by permanent magnets. There was no use of an electromagnetic piston to produce magnetic fields in it. 2 DoF quarter car model with hybrid magnet MR damper has been developed by Dakshnamoorthy et al. [9]. This experiment was quite successful for improvement in tire deflection, ride comfort and suspension control. Magnetic shields (and sandwiched shields) are also used in some cases for twin-tube MR dampers with a single-coil in it by Ganesha et al. [10]. Deviation in the flux lines has been observed in it due to the effect of such shields.

Literature review reveals that most of the work reported on MR dampers is with electromagnets or permanent magnets located on the pistons inside the dampers. Khedkar et al. [11] suggested that there is scope for damper modification by using an external permanent magnet assembly. The present paper is an effort in this direction.
3. Methodology
MR damper is modified as a semi-active MR damper using external permanent magnet assembly around the damper filled with magnetorheological fluid AMT-Dampro. The modified MR damper has been tested on a test rig by changing excitation frequency of exciter, excitation current and magnetic field. The effect of magnetorheology on velocity and damping force has been recorded. The best suitable configuration of modified MR damper with excitation current, excitation frequency and magnetic field is suggested from the results obtained from the experimental analysis.

3.1. Details of MR Damper Set up
A twin-tube MR damper is fabricated. It consists of two cylinders and piston arrangement. Outer cylinder and piston rod have an eye arrangement. Lower and upper eye have been fixed to the piston rod and closed end of outer cylinder respectively. These eyes are helpful to fix the damper to the test rig or any equipment where the damper is to be used on the ground. In this experiment, lower end has been fixed with a hub of the exciter. The intensity of the magnetic field is varied by changing the distance between the magnets. The MR fluid which is readily available in the market i.e. AMT-Dampro used for testing purpose. The properties of MR fluids are consolidated in Table 1, which helps to understand MR fluid's workability.

| Properties of MR Fluid     | AMT-Dampro |
|----------------------------|------------|
| Density (gm/cm³)           | 2.45       |
| Viscosity (Pa.s) @ 40⁰c    | 0.29       |
| Response time              | < milliseconds |
| Flash Point(⁰c)             | > 180      |
| Operating Temperature Range(⁰c) | -20 to +150 |
| Solid Content by weight %  | 73         |
| Yield stress (kPa)         | 42         |

From the table, it can be seen that a wide range of yield stress is achieved in MR fluids at less intensity of the magnetic field. Excellent quality stabilizing agents have been added to the fluids. These fluids have good settling resistant property. One can vary the operating temperature of all fluids from -20⁰ to +150⁰C. The fluids have improved properties like optimum viscosity, enhanced lubricity and wear resistance.

3.2. Experimental setup and testing
The damper parameters affect their force-velocity characteristics. Force-velocity characteristics have been recorded for a different combination of magnetic force intensity, excitation frequency and excitation current. Experimental setup to obtain force-velocity characteristics is as shown in figure 2. The exciter from Instrol devices, Bangalore, India, has been utilized to provide the MR damper excitations. A function generator attached to the exciter consists of a power amplifier and oscillator. This set up generates sinusoidal signals. Load cell and dial gauge indicators have also been used to measure the parameters like force, displacement, and velocity. The setup also consists of a load cell and dial gauge for measurement of force and displacement. The specifications of the devices which are part of this setup are provided in Table 2.
Figure 2. Experimental setup for modified MR damper testing

Table 2. Specifications of instruments used in the experimental setup

|                                |                                |
|--------------------------------|--------------------------------|
| **Power Amplifier**           |                                |
| Maximum power output          | 250 VA into 1.5 Ohm            |
| Frequency Response            | 1 Hz-10 kHz within +1Db        |
| Harmonic Distortion           | Less than 1 %                  |
| Gain at 1 kHz                 | 20 dB + 1Db                    |
| **Vibration Exciter Model ID-230** |                        |
| Peak sine force               | 200 N                          |
| Maximum displacement          | 12 mm peak to peak             |
| Maximum allowable payload     | 3 kg                           |
| **Oscillator**                |                                |
| Waveform      | Sinusoidal                      |
|--------------|--------------------------------|
| Frequency Range | 1 Hz-10 kHz                   |
| Frequency Response | Within + 1 dB with ref. at 1 kHz |
| Total Harmonic distortion | Less than 1 %                 |
| Indication accuracy | +0.2 % of the range or better |

**Load Cell**

| Type                  | Strain gauge type               |
|-----------------------|--------------------------------|
| Rated Capacity        | 20 Kg                          |
| Resolution            | 0.01 Kg                        |
| Accuracy              | 0.05 % of the rated capacity   |

**Dial Gauge**

| Rated Capacity | 4 mm  |
|----------------|-------|
| Resolution     | 0.01 mm |

The damper is fixed at its lower end on the horizontal middle beam of an experimental test rig. This horizontal beam is movable in the vertical direction to adjust the position of MR damper to attach it with the exciter. A proper slot is provided on the middle horizontal beam. This provision is made to fix the external permanent magnet assembly around the damper. One can change such a permanent magnet assembly position to bring about the magnetic field change due to the slot provided on the horizontal middle beam. When the permanent magnet's assembly is kept 30 cm away from the damper, it gives very less magnetic intensity, which is almost null for the fixed damper. This condition is the OFF state condition. Multiple magnetic field generation at the MR damper starts when permanent magnet assembly is kept 15 cm away from it. The intensity of the magnetic field is increased when the distance between permanent magnet assemblies is reduced. This condition is ON state condition. Magnetic field intensity can be varied by adding or removing of permanent magnets too. The upper end of the damper is connected to the exciter hub. The range of excitation current has been varied from 1.5 A to 6 A with an equal interval of 1.5 A. The excitation frequency of exciter has been set as 2 Hz, 4 Hz, 6 Hz and 8 Hz. The magnetic flux generated with external permanent magnet assembly has been set as 0 G (OFF state condition), 2000 G, 4000 G and 7000 G.

**4. Results and discussion**

Figure 3 to 6 show the Force-velocity characteristics of modified MR damper. The AMT-Dampro has been used as MR fluid. In the testing, it is observed that there is an increment in force as velocity increases in modified MR dampers. However, these graphs are non-linear. As excitation frequency increases from 2 Hz to 8 Hz, there is a reduction in the force for the same value displacement value. This effect has been recorded for all values of excitation current viz. 1.5 A, 3 A, 4.5 A, and 6 A at all excitation frequencies, especially at ON state condition. The difference between ON state force and OFF state force is very less at an excitation frequency of 2 Hz and 4 Hz. There are considerable variations in force-velocity characteristics at an excitation frequency of 6 Hz and 8 Hz. The Force and
Velocity vary from 0.4 N-5.2 N and 0.2 mm/s to 27.8 mm/s for modified MR damper. The best performance of damper with MR fluid AMT-Dampro is recorded at higher excitation frequency, i.e. 6 Hz and 8 Hz.

**Figure 3.** Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for the different magnetic field at 2 Hz

**Figure 4.** Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for the different magnetic field at 4 Hz

**Figure 5.** Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for the different magnetic field at 6 Hz
Figure 6. Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for the different magnetic field at 8 Hz

Figure 7. Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for different excitation current at 2 Hz

Figure 7 to 10 shows Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for different excitation currents at different excitation frequencies viz. 2 Hz, 4 Hz, 6 Hz, and 8 Hz. The observations indicate that the velocity at 1.5 A at 2 Hz and 4 Hz are almost very close at all applied magnetic fields. A considerable difference has been observed in force-velocity characteristics in all graphs. AMT-Dampro MR fluid gives better results at high excitation current (4.5 A and 6 A) and high excitation frequency (6Hz and 8Hz).

Figure 8. Force-velocity characteristics of modified MR damper with AMT-Dampro fluid for different excitation current at 4 Hz
5. Conclusions
Experiments have been carried out on modified MR damper to study its force-velocity characteristics. The conclusions are as follows:
Force-velocity characteristics of modified MR damper improve with the application of MR fluid-AMT-Dampro. Considerable changes are observed in force-velocity characteristics of modified MR damper at higher excitation frequency.
The graphs plotted (Fig. 3 to 6) help to decide force-velocity characteristics range of modified MR damper at different excitation currents. The excellent range of force-velocity characteristics has been observed at 6 A excitation current and 8 Hz excitation frequency with MR fluid AMT-dampro. The velocity varies from 2 mm/sec to 27.7 mm/sec, and force varies from 1.3 N to 4.2 N at this combination (refer fig. 10).
The results reported in the paper signify the excellent performance of modified MR damper for vibration control.

1) Conflict of Interest
The authors have no relevant financial or non-financial interests to disclose.

2) Author Contributions
All authors contributed to the study conception and actual experimentation. Mr Yashpal M. Khedkar performed material preparation, data collection, and analysis. He wrote the first draft of the manuscript. Dr. Sunil Bhat and Dr. H. Adarsha reviewed and edited the manuscript. All authors commented on the previous version of the manuscript.
References

[1] Wahid S A, Ismail I, Aid S, and Rahim M S A (2016) *IOP Conf Seri: Mat Sci and Engg.*, 114:1-11.

[2] Singh H, Singh Gill and Sehgal S (2016) *Ind J Sci Tech* 9: 1-5.

[3] Mahmudur R, Zhi C O, Sabariah J, Md Meftahul F and Raju A (2017) *J of Zhe Univ SCIENCE A* 18:991-1010.

[4] Poynor J C (2001) Innovative Designs for Magneto-Rheological Dampers. Ph.D. Thesis, Virg Poly Insti State Univer Blacksburg, VA, USA.

[5] Ahamed R, Choi S B, and Ferdaus M M (2018) *J Int Mat Sys and Struct* 29:2051-2095.

[6] Xiao P, Gao H and Niu L (2017) *J Mech Sci Tech* 31:3109-3119.

[7] Hu G, Lu Y, Shuaishuai S and Weihua L (2017) *Senc and Act A: Phy*, 255: 71-78.

[8] Kim W H, Park J H, Kaluvan S, Yang S L, and Choi S B (2017) *Sen and Act A: Phy*, 255: 104-117.

[9] Dakshnamoorthy E, Arjunan S and Radhakrishnan A (2018) *J Brazil Soc Mech Sci and Engg* 40:1-10/367.

[10] Ganesha A, Patil S, Kumar P N and Murthy A (2020) *J Mech Engg Sci* 14: 6679 – 6689

[11] Khedkar Y M, Bhat S, Adarsha H (2019) *IEEE/ASME Tra on Mech*, 13: 256-264, 2019