

# Investigation on Magnetorheological Damper for Its Various Applications

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**Abstract:** - Magneto Rheological damper is a special type of damper that is filled with Magnetorheological fluids which can be controlled by magnetic field using an electromagnet. These types of smart fluids change their physical properties when subjected to magnetic field and turn into visco-elastic solids in few milliseconds. This property allows the MR damper to be used as a shock absorber by controlling its damping characteristics by changing the intensity of electromagnet. This paper focuses on the various applications of MR dampers in latest technologies.

**Keywords-** Magneto rheological damper, Electro rheological damper, Vehicle, Suspension

## I. INTRODUCTION

The magnetorheological damper was patented by J. David Carlson and Michael J. Chrzan on 11 Jan 1994. The discovery of MR fluids is ascribed to Jacob Rabinow in 1940's. MR dampers are semi-active devices that are filled with magnetorheological fluids. When magnetic field is applied, the MRF varies from liquid to semi-solid state in just few milliseconds, so the outcome is an infinitely variable, controllable damper are capable of large damping forces[1]. The MR fluid is controlled by magnetic field using an electromagnet. As the electromagnet intensity increases the fluid viscosity also increases within the damper. MR dampers offer a striking solution to energy absorption in mechanical systems could be considered as "fail-safe" device. Many everyday items are already incorporating smart materials (bikes, cars, glasses, washing machines) and the number of applications for them is growing steadily.

Magnetorheological (MR) fluid is a functional fluid that changes its physical characteristics when magnetic field is applied. Magnetorheological fluids (MRFs) consist of suspended ferrous particles like carbonyl iron particles that are micron sized, and are dispersed in a carrier medium. When magnetic field is applied these suspended particles in MRF gets magnetised and align themselves in structures like chains which resists the shear deformation of fluid. This change in material results in a rapid increase in viscosity or in the formation of a semisolid state[2]-[5].

## II. MR FLUIDS AND ITS BEHAVIOUR

Magnetorheological fluids consists of micron sized, ferrous particles (mainly iron) that are suspended in an appropriate carrier medium such as mineral oil, synthetic oil, water or ethylene glycol. The MR effect is immediately reversible if the magnetic field is reduced or removed. Response times of 6.5 ms have been recorded. If the magnetic field is reduced or removed, the MR effect is straight away reversible. The recorded response time is 6.5 milliseconds. MR materials that have been already developed are usually stable in temperature ranges from  $-50^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ . Magneto rheological materials are more advantageous than electro rheological materials. In compare to electro rheological materials, MR fluids are more constructive because of the large change in their physical properties[6]. On comparison to ER materials, MR materials respond less to moisture and contaminants, and as a result they could be used in dirty or contaminated environments. The power (50 W) and voltage (12–24V) requirements for MR materials activation are comparatively small as compared with ER materials. Moreover, the MR Fluid and different carriers is given in Table 1.

TABLE 1: MR FLUIDS AND DIFFERENT CARRIERS

MR fluid	MRF-132LD	MRF-240BS	MRF-336AG
Fluid base	Synthetic oil	Water	Silicone oil
Operable temp. range $^{\circ}\text{C}$	-40-150	0-70	-40-150
Density (g/cc)	3.055	3.818	3.446
Weight percent solids	80.74%	83.54%	82.02%
Coefficient of thermal expansion	$0.55-0.67 \times 10^{-3}$	$0.223 \times 10^{-3}$	$0.58 \times 10^{-3}$
Specific heat @ $25^{\circ}\text{C}$ (J/g $^{\circ}\text{C}$ )	0.80	0.98	0.68
Thermal conductivity (w/w $^{\circ}\text{C}$ )	0.25-1.06	0.83-3.68	0.20-1.88
Flash point ( $^{\circ}\text{C}$ )	> 150	>93	> 200
Viscosity @ $10\text{s}^{-1}/50\text{s}^{-1}$ (Pa-sec)	0.94/0.33	13.6/5.0	8.5

## III. CONSTRUCTION AND WORKING OF MR DAMPER

MR dampers consist of a piston, magnetic coil, accumulator, bearing, seal, and damper reservoir which are filled with

MRF. The fig.1 shows the schematic diagram of MR damper. In this damper as soon as the piston rod enters the housing, MRF in the piston head flows from high pressure chamber to low pressure chamber through orifices. The accumulator consists of a compressed gas and its piston provides a moveable barrier between MRF and the gas. When a current travels through the solenoid a magnetic field is developed which causes the fluid to change its state from the fluid to semi-solid. When there is no external magnetic field applied, the iron particles are randomly suspended and the fluid shows behaviour of an incompressible fluid and this act like a passive system. The properties of semi-active system can be regulated in response to a command signal using a small external power source[2].

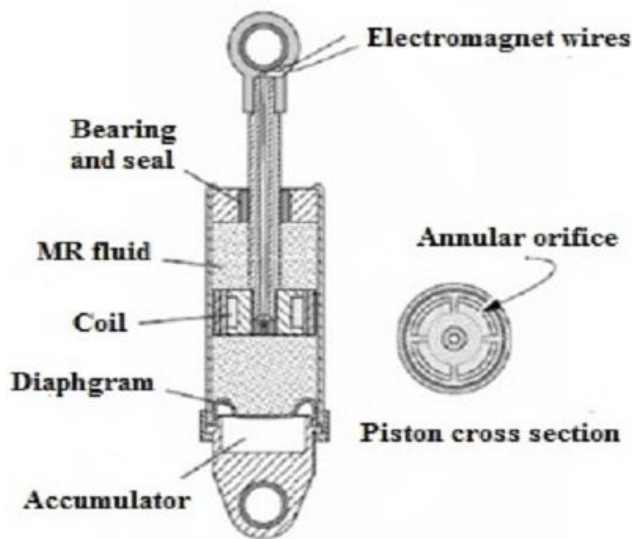


Fig.1- MR Fluid Damper constructional model

#### IV. APPLICATIONS

MR dampers are used as a shock absorbing or damping and vibration controlling device. It has a vast range of application in field of automobile, defence and various medical purposes. This Magneto Rheological Shock Absorber is used in mentioned automobiles i.e., Buick Lucerne, Cadillac ATS, CTS-V, DTS, XLR, SRX, STS, Chevrolet Corvette, Camaro ZL1, Ferrari 458 Italia, 599GTB, F12 Berlinetta, Shelby GT350, Holden HSV E-Series and Lamborghini Huracán[7]–[10]. However, The applications of MR damper system is not only restricted up to shock absorbers in automobiles but also it is being used in man researches in field of defence, medical applications like prosthetic limbs and in designing massive structures with can be full proofed from natural disasters[1], [11]–[14].

##### 4.1. MR Damper in Automobile Sector

Semi active suspension systems are becoming more popular in automobiles as they can overcome all the inherent limitations of passive and active suspension systems and also combine the advantages of both. This is due to their design simplicity, infinite possible dynamics, low voltage requirements, better damping capacity. Ride comfort and vehicle stability are two main concerns while designing an effective suspension system. The selection of damper is typically a tradeoff between these requirements.

The selection of MR fluid is done on the basis of purpose the vehicle is serving i.e., sports cars, luxury cars or heavy vehicles. Semi active suspension system using MR dampers necessitates two nested controllers as shown in fig 2 and fig 3. A system controller which reads the road profile and computes damping force required. Since MR dampers function on the applied voltage, a damper controller commands the damper to give the desired force. There are various control algorithms to perform the above mentioned function[6].

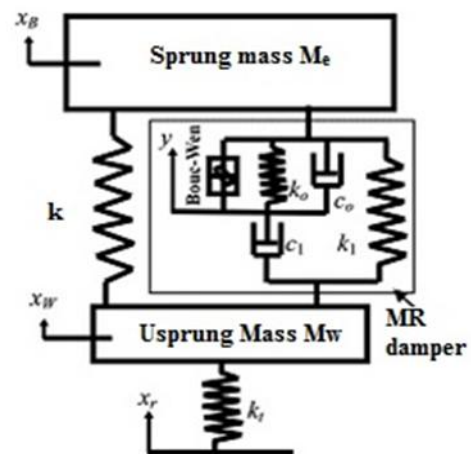


Fig.2. Quarter Model of a vehicle suspension system

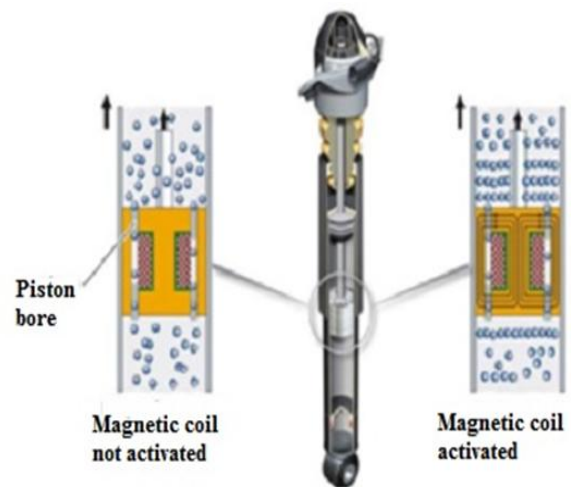


Fig.3. MR damper ON and OFF state

Other than the application of MR dampers in vehicle suspension system, it can also be used in car seat suspension. This easy to implement, improved design for car seat will improve the ride comfort for driver and the passengers. The problem of poor feel of seat suspensions can be removed by employing MR damper using skyhook algorithm. MR dampers have a lot of potential to be used in motorcycle suspensions system also. Currently, it is used in only high end sports bikes. Motorcycle suspension designers have historically sought a good compromise between a comfortable ride and performance handling. The new Ducati Multistrada 1200 S shown in the fig.4 has an innovative Ducati skyhook suspension with reduced vibrations and better vehicle stability[6].



Fig 4- Ducati Multistrada 1200 S with DSS Semi active suspension system.

Unfortunately, this comprises generally leads to a suspension design that is good for a mix of performance and comfort, yet does not excel at either of the two. Usually the tuning of motorcycle suspension system is done by changing the fluid viscosity of the front fork. In case of using a MR damper, changing the fluid viscosity is consummated by varying the magnetic field intensity using electromagnets. The use of MR dampers can be seen in quite a few four wheeler vehicles but still its use in two wheelers is very less due to its cost. There are many studies and researches carried out in application of MR dampers for motorcycle suspension system. They all prove that it is perfect solution for improving the stability of motorcycles and are far better than the conventional OEM suspension systems[6].

#### 4.2. MR Damper in Structural Applications

MR dampers are one of the most prospective semi active control devices for civil engineering applications to earthquake hazard mitigation, because they have many advantages such as small power requirement, reliability, and low price to manufacture. A smart passive system based on an MR damper system without including a power supply, controller, and sensors consists of an MR damper and an electromagnetic induction (i.e., EMI) system that uses a permanent magnet and a coil. The electromotive force induced by movement of a structure can control MR damper effectively without any external power supply and control. The

Dongting Lake Bridge is a cable-stayed bridge crossing the Dongting River[6].



Fig 5. Dongting Lake Bridge, China

When the bridge was made, the designer realised it was sensitive to vibrations due to wind and heavy raining as shown in fig 5. So a study was carried out, which deduced that with the help of MR dampers this problem can be resolved. Other than this MR dampers are used in railway bridges and buildings in earthquake prone areas.

#### 4.3. MR Fluid in Defense

Researches are being carried out to develop smart Kevlar vest with layers of MR fluids. These vests can be hardened before a blink of the eye by applying magnetic field across it. In the absence of magnetic field, the vest is light and flexible but with a flip of a switch it can stiffen as shown in fig 6. Defence research agencies are designed armour suits using MR fluids that can sustain impact of grenades by preventing the shrapnel from piercing the suit. The United States of America's army, California is working on using MR dampers in army heavy vehicles like Army's HMMWV Hummer. Still it is going to take more work in this field before MR fluid vest can stop bullets in battles[6].

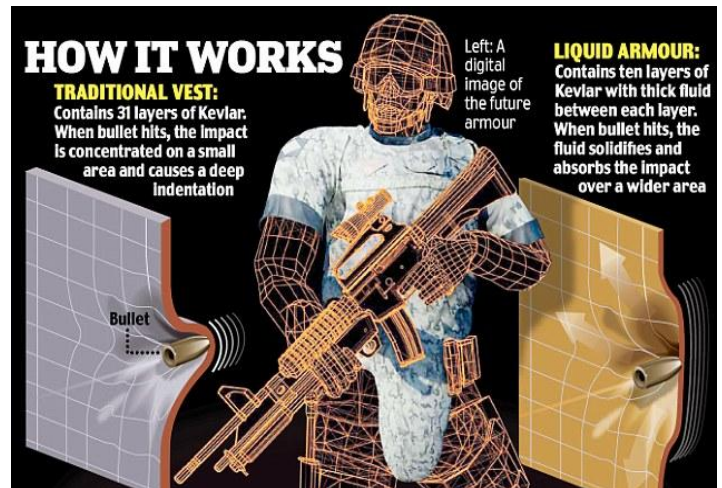


Fig6. MR fluid used in Kevlar vest

#### 4.4. MR Damper in Prosthetic limbs

It is one of the major innovations in prosthetic limbs for amputees. Biedermann Motech, (a Germany based

manufacturer of spinal implants and prosthetic legs) has also recently commercialized an MR damper for a prosthetic knee; this includes in-house damper, controller and battery as shown in fig 7. The use of MR damper in prosthetic legs have made it many times more responsive than the conventional stepper motor power devices. MR technology provides infinitely variable, real-time damping control. Slopes and stairs have been giving real hard time to amputees but with this system they can experience nearest neural human response time possible. Conventional stepper motor-powered prosthetic devices lack the same degree of stability that BiedermannMotech's battery-operated and electronically controlled MR damper knee mechanisms can provide and they are more flexible and have less complicated controlling capabilities. This MR damper is incorporated with different sensors to adjust any changes in the walking speed, up or down hill motion. The system analyzes the patients gait to adapt knee motion accordingly and respond to it in few milliseconds[6].

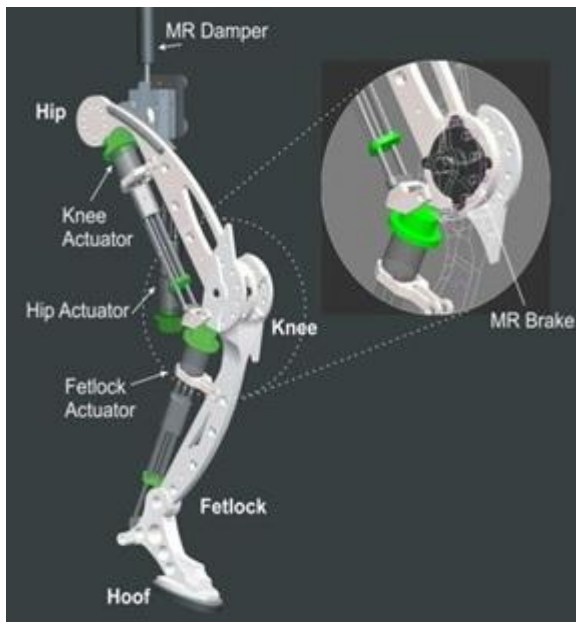


Fig 7. Application in Prosthetic Leg

The receptiveness of this MR Fluid is below 10 milliseconds, and the resistance against force can be varied over an infinite range. This property makes MR fluid perfect for improving this technology.

#### 4.5. MR Dampers in Rail Vehicles

So as to solve increasing traffic problems and air pollution, the importance of rail vehicles has risen as one of the mass transportation systems[15]–[22]. One of the most important factor to provide comfort, safety and stability in rail vehicles is suspension system which absorbs the energy caused by disruptive effects and aims to reduce transmitting of vibrations to the car body to cover the rail irregularity which

creates shock and vibrations on passengers[23]–[25]. There are two such systems i.e., active and semi-active suspension system as shown in fig 8. Since the required forces to keep the system stable are excessive in rail vehicles, active suspension system can become unstable. So, the more appropriate solution to this is using a semi active suspension system using MR dampers. It can precisely control its damping characteristics according to the rail track profile[2]–[5], [7]–[10], [15]–[26]. It is proven through various researches and studies that rail vehicle vibrations have been abridged through the damping force generated by MR damper.

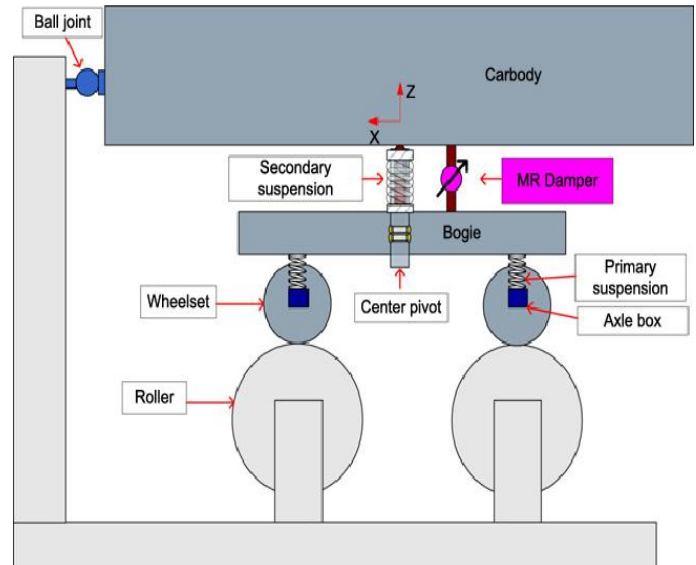


Fig. 8 Semi active suspension model using MR dampers.

## V. EXPERIMENTAL SETUP OF MR DAMPERS

### 5.1. Construction and Testing

The experimental set up consists of vibration exciter, laptop and two accelerometers (one placed near or on the vibration exciter and other on top on mass pan).

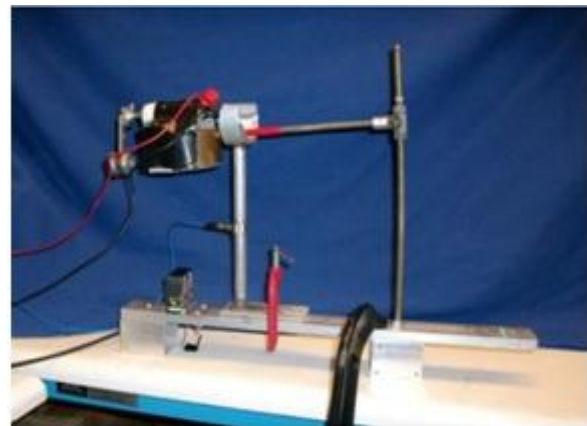


Fig 9 (a) Experimental setup

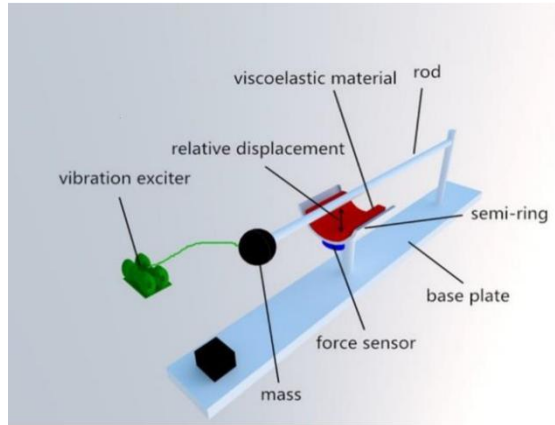


Fig 9(b) Sketch of the experiment

The MR damper was used in this study has 36.5cm length with 1333gm weight. Also it requires bottom fixture length 5cm with M8 internal thread with 12V and 9amp.D.C.power supply as shown in Fig 9 .

5.2. Response of Frequency, Amplitude response at different loading condition.

When the MR damper experiment was held out without magnetic field under zero load, 200gm load, 400gm load respectively the frequency was found to be decreased with an increase in the ratio of input to output( $X/X_{st}$ ) and as when the MR damper experiment was tested with magnetic field under same loads respectively the frequency decreased with decrease in the ratio of input to output( $X/X_{st}$ ) as shown in Table 2.

**Table 2: Frequency, Amplitude response at different loading condition without Magnetic field.**

Loading condition	Accelerometer Position	frequency	Amplitude(m/s <sup>2</sup> )	Ratio( $X/X_{st}$ )
Zero load	Upper	22.325	X=4.396	1.38
	Lower		$X_{st}$ =3.183	
250g	Upper	21.00	X=5.212	1.41
	Lower		$X_{st}$ =3.690	
500g	Upper	19.350	X=12.230	1.50
	Lower		$X_{st}$ =8.110	

**Table 3:Frequency, Amplitude response at different loading condition without Magnetic field.**

Loading condition	Accelerometer Position	frequency	Amplitude(m/s <sup>2</sup> )	Ratio( $X/X_{st}$ )
Zero load	Upper	23.200	X=3.566	1.35
	Lower		$X_{st}$ =2.639	
250g	Upper	21.400	X=3.380	1.29
	Lower		$X_{st}$ =2.615	

500g	Upper	20.350	X=5.758	1.22
	Lower		$X_{st}$ =4.687	

VI. LIMITATIONS AND REMEDIES

Although smart fluids have many potential applications but they are limited in commercial feasibility because of the following reasons:

- Settling stability of MR fluid.
- MR fluids of high quality are expensive.
- Durability of devices.
- Generation of heat in shock absorber because of coil.

Active suspension use electro-hydraulic actuators which are commanded to give a desired control force. The active suspension has high control performance over a wide frequency range. However, it is very expensive and cannot be used for commercial application as it requires a high power supply, many sensors, and servo-valves.

A semi-active suspension uses MR or ER dampers which are commanded by two nested controllers that are system controller and damper controller. A semi-active suspension contains the properties of both i.e. active suspension as well as passive suspension. It is much more effective and economical.If the system fails then the semi-active suspension can also work as a passive suspension. Various applications in the field of defence are yet to be worked on to become feasible.

VII. CONCLUSIONS

Magneto-rheological dampers (MR dampers) have a lot of potential use in applications where controllable damping force is necessary. These applications consist of dampers for automobiles (Acura MDX), heavy commercial and army vehicles (U.S. HUMMER VS, Rail vehicles),Motorbikes (Ducati Multistrada1200 S with DSS system), prosthetic knee and legs, special Kevlar armours and others.This suspension system when used in automobiles will provide better vehicle stability and ride comfort than the conventional passive systems. It applies a smart controllable approach to handle the vibrations caused due to change in road profile.

Passive type suspension systems have permanent damping properties and cannot be controlled according to the road profile, whereas the active suspensions systems cover all these limitations but are not cost effective. Semi active suspension system using MR dampers is becoming popular because it overcomes all the inherent limits of the above two and combines the advantages of both.These are few important applications of MR dampers and a lot of research is being carried out for its potential scope in various fields.

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