A Study on Employment of Magnetorheological Fluid in Automotive and Engineering Domain

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Abstract Recent years have seen the widespread commercialization of devices and systems based on magnetorheological (MR) fluid technology, with automotive applications being the most prominent and promising. The primary suspension in passenger cars, the suspension of the driver's seat in off-highway, construction, and agricultural equipment, and the steering-by-wire control of industrial, off-highway, and maritime vehicles are all examples of applications where MR fluid systems and devices have proved commercially successful. More than a hundred thousand MR dampers, shock absorbers, and brakes are in use on the roads today. Demand for MR devices is expected to grow by more than a million units each year, and that's just for automotive platform applications. MR Fluid may be optimized for many uses, has

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high strength, and lasts a long time. MR Fluid has advanced to a high level of development, with rich experience-based guidelines backing up the fundamental material data and device design and models at its disposal. This article provides a concise overview of how MR Fluid Technology is currently being used and developed in the automotive and transportation industries.

Keywords Damper · Magnetorheological fluid · Suspension · Structure · Seat

1 Introduction

Since the 1940s, when the first patent was granted to inventor Jacob Rabinow, magnetorheological (MR) fluids have primarily been a laboratory curiosity with limited practical applications. In the late 1980s and early 1990s, however, researchers began to view MR fluids as a viable business opportunity, particularly as other technologies converged to make their practical application feasible. Control options that were unavailable in Rabinow's day have emerged as a result of advancements in microprocessor and sensor technology as well as rising electronic content and processing rates. Power is now available in more compact containers than ever before because to advancements in battery technology spurred by the expansion of the mobile phone industry and to the discovery of new rare earth magnets [1].

Lord Corporation has put a lot of money into research and development over the past ten years. As a result, they now have the most patents in the world for MR fluids, devices, and systems. The company has made additives, lubricants, and suspension aids to stop iron bits from wearing down seals, gaskets, and metal parts. Through rigorous life cycle testing and the use of MR fluids, devices, and systems in commercial uses, the company has built up a body of scientific evidence that proves the effectiveness, durability, and performance of MR fluids, devices, and systems. The prime objective of this study is to overview of how MR Fluid Technology is currently being used and developed in the automotive, civil construction, medical, and transportation industries.

2 Magnetorheological Fluid

Fluids having magnetorheological (MR) properties undergo substantial changes in rheology when exposed to a magnetic field. When subjected to a magnetic field, these fluids undergo an instantaneous phase transition from a freely flowing liquid to a semi-solid with a tunable yield strength. MR fluids can be thought of as Newtonian liquids without an applied field. In most engineering contexts, the basic, field-dependent fluid features can be adequately described by means of a simple Bingham plastic model. 20–40% by volume of a carrier liquid (mineral oil, synthetic oil, water, or glycol) is occupied by relatively pure iron particles (3–10 microns in diameter). As

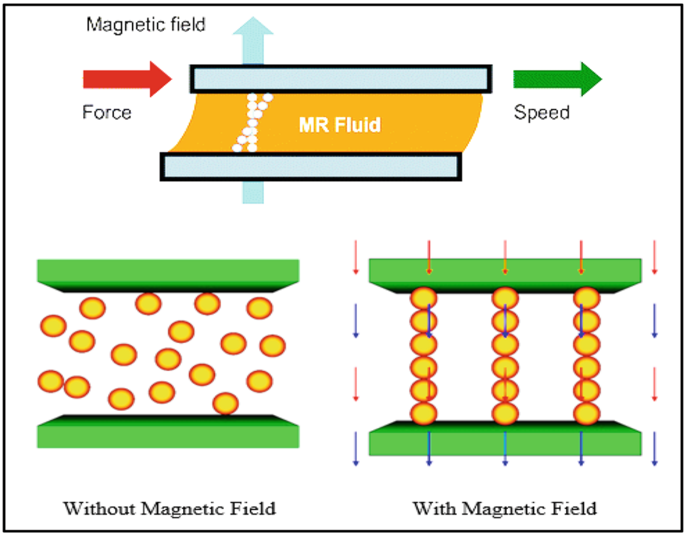

Fig. 1 MR fluid working principle

shown in Fig. 1, lord's cutting-edge MR fluids typically feature a number of patented additives to improve lubricity, adjust viscosity, and reduce wear. These additives are comparable to those used in commercial lubricants and work by discouraging gravity settling and promoting particle suspension [2].

When magnetic fields of 150–250 kA/m are put on MR fluids with iron particles, the highest yield strength is 50–100 kPa. MR fluids don't break down as quickly as other fluids when they come in contact with water or other contaminants. Also, because temperature has no effect on the way magnetic polarization works, the performance of MR-based devices is mostly untouched by temperature over a wide range, including the range for use in cars. In most applications, valve or direct-shear modes are used with MR fluids. Shock absorbers and dampers are two examples of valve mode devices. Braked, clutches, and variable friction dampers are all examples of equipment that operate in the direct-shear mode.

3 MR Fluid Applications

3.1 MR Dampers

One of the most common uses for MR fluid is in linear dampers, which play a role in the semi-active control. The device's off-state viscosity is crucial to its operation. MR dampers are seen as fail-safe devices because they provide a novel perspective on the problem of energy absorption in different systems and constructions [3]. One notable use is in suspension seats, where a small MR fluid damper is employed to dampen vibrations. Heavy-duty vehicles use MR fluid dampers similar to struts in passenger cars for primary suspension. Prosthetic devices sometimes have MR fluid dampers designed for specific purposes. MR dampers have a wide range of applications [4].

3.2 Automotive Industry

The market has taken to using MR fluid dampers as semi-active dampening elements that operate in real time. This suspension system operates in a manner distinct from that of the norm [5]. An electromagnet is used to generate the magnetic field. Suspension shock absorption can be optimized through algorithmic control of MR fluid viscosity. More than a million automobiles from companies including Ferrari, General Motors, Audi, Land Rover, and others are equipped with this technology since its introduction in 2002 as shown in Fig. 2. Semi-active vibration control systems were first utilized in the seats of 18-wheeler trucks in 1998. An MR fluid damper, microcontroller, sensor, current driver, and auxiliary cables make up a semi-active vibration control system [6].

There are currently over 5000 semi-active vibration control devices in heavy-duty trucks operating on American roads that are based on MR fluid. As shown in Fig. 3, drivers who have experienced these devices have nothing but admiration [8]. For hundreds of thousands to millions of kilometers, they perform admirably. Almost no failures have ever been documented in this industry.

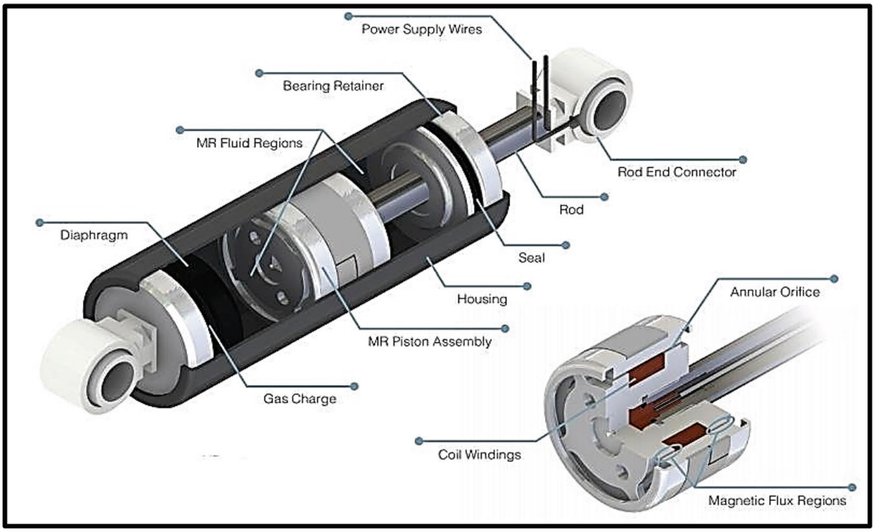

Fig. 2 LORD magnetorheological suspension

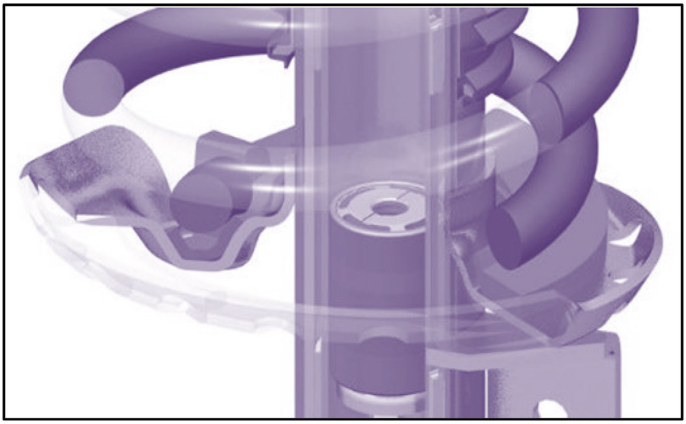

Fig. 3 MR fluid dampers in seat suspension. Reproduced with permission from Ramkumar et al. under license from Copyright Clearance Center [7]

3.3 Washing Machine

The MR fluid damper is used in the washing machine to decrease vibrations during spin. Semi-active control has a long way to go before it can be used in common household settings; so far, the topic has only been discussed in contexts where researchers have focused on tub dynamics at low spin, namely the main drum's resonance frequency as shown in Fig. 4. The high rotational velocity that causes vibrations is the major emphasis of this work [9].

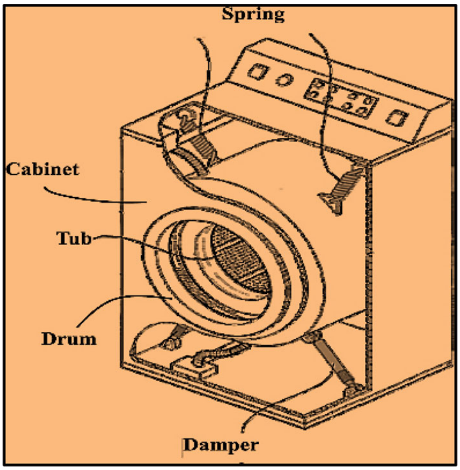

Fig. 4 MR Fluid dampers in washing machine

3.4 Prosthetic Leg

The Lord Corporation has also just brought to market a prosthetic knee equipped with an MR damper; this knee has the damper, sensors, control unit, and battery. The Smart Magnetic prosthetic leg was developed by Lord Corp. Cary, NC, a materials technology business, using a modified version of the magnetorheological technology originally implemented in the company's truck-seat damper. The gadget reaches the closest neurological human reaction time of movement thanks to its integration of MR, electronics, and software, allowing it to reply 20 times faster than previous state-of-the-art designs. In other words, the new prosthetic design is a more accurate representation of how humans think and move than prior designs.

The prosthetic leg's magneto rheological technology allows it to mimic a natural stride. Biedermann Motech, a German maker of prosthetic components, worked with the design engineers to create a device that helps amputees with legs above the knee move around more freely. As shown in Fig. 5, controllable MR technology adopted from the LORD motion master TM ride management system truck-seat damper improves the above-the-knee (AK) prosthetic's capacity to maintain gait balance, stability, and energy efficiency [4]. LORD MR Fluid has a response time of less than 10 ms and a range of resistance that is practically unlimited. This product would not be viable without the capacity to vary the amount of force used.

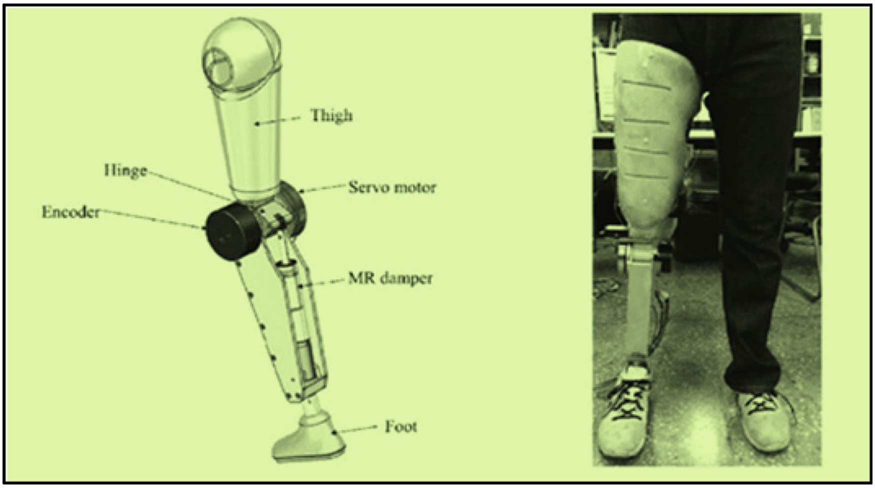

Fig. 5 Application in prosthetic leg

3.5 Hydraulic Valves

Actuators controlled by a hydraulic system can use MR fluid as their working medium when MR valves are in place. The MR valve in this setup is a proportional throttle valve with fixed components. The valve's construction may involve a magnetic core housed within a metal housing that also contains a hydraulic channel and an induction coil winding. There is a port there to let fluid in and out. Because of the magnetic field, MR fluid becomes more viscous as it flows through these valves. The resistance to flow of the fluid, caused by higher viscosity, raises the inlet pressure.

3.6 Artificial Muscles

When working with artificial muscles, the MR Fluid is employed to dampen vibrations. The robots must make touch with humans in a risk-free manner. Pneumatic-based artificial muscle is therefore of great interest. This actuator is portable, adaptable, and powerful. However, the artificial muscle's flexibility causes it to vibrate excessively when subjected to a heavy strain. MR fluid is needed for this. Therefore, it has been proposed to implement a way of MR brake control that takes into consideration the energy of the manipulator system. This technique allows MR brake to dissipate energy, producing the desired result.

3.7 Polishing Devices

The use of MR fluid as a polishing agent is one of its more peculiar applications. In an MR finishing slurry under computer control, optical surfaces are polished. As shown in Fig. 6, unlike conventional lap polishing, the form and viscosity of the fluid can be adjusted by adjusting the field strength [8]. The computer program estimates the shape and level of polish of the finished product.

3.8 MR Fluid in Defense

The development of a smart Kevlar vest layered with MR fluids is the subject of ongoing study. By passing a magnetic field across it, these vests can be toughened in the blink of an eye. The vest is demonstrated in Fig. 7 to be soft and pliable when not exposed to a magnetic field but to become rigid at the flip of a switch [10]. Armor suits made from MR fluids have been developed by defense research agencies to withstand the impact of grenades by stopping the shrapnel from penetrating the suit. The United States Army is investigating the use of magnetic resonance (MR)

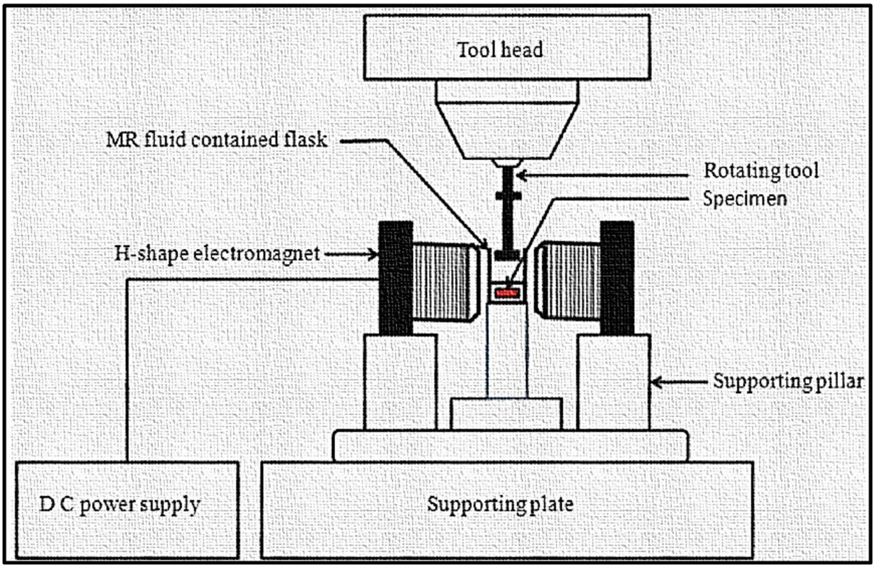

Fig. 6 Polishing device using MR fluid

dampers in military heavy vehicles, such as the HMMWV Hummer. More research is needed before an MR fluid vest can effectively deflect bullets in combat.

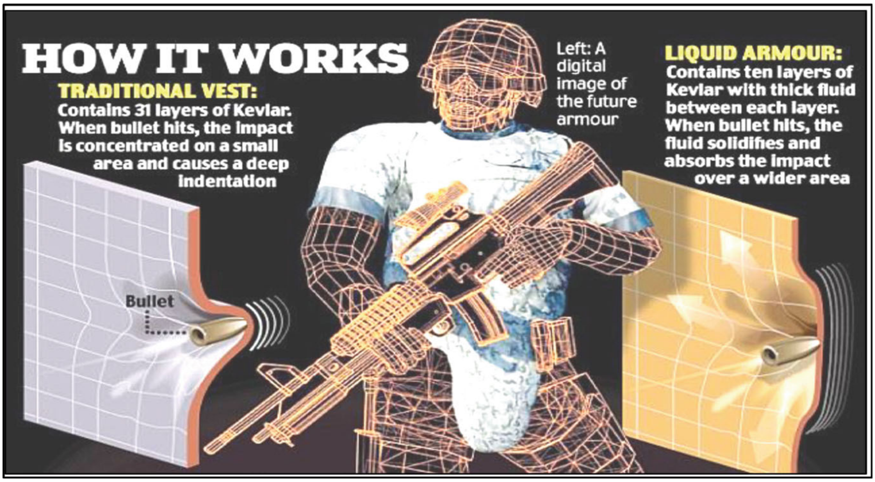

Fig. 7 MR fluid used in Kevlar vest

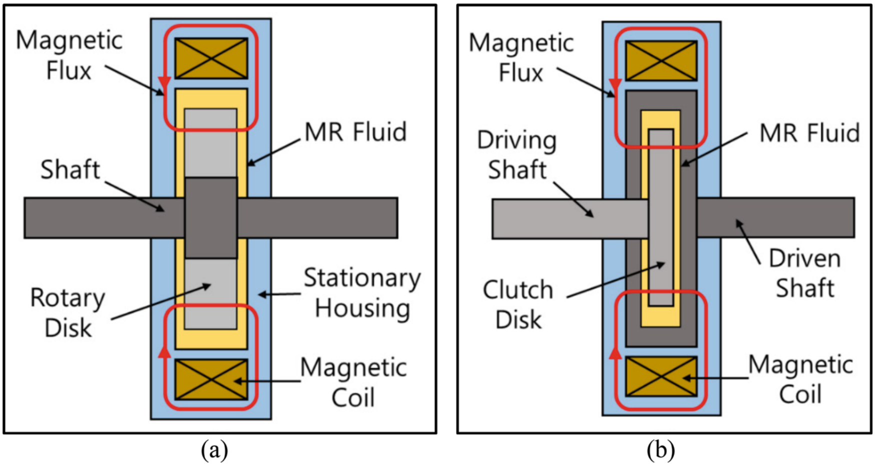

Fig. 8 **a** MR brakes, **b** MR clutches

3.9 MR Brake and MR Clutch

Actuators such as MR brakes and clutches are used to modulate the rotational torque of a machine. The MR brake slows or stops the rotating shaft so that the force of rotation can be transferred to another shaft. The MR fluid is placed in the gap between the revolving core and the stationary housing of an MR brake. One set of revolving cores, one separate revolving core, and a revolving housing make up an MR clutch. Space among cores and its housing, is filled with MR fluid. The magnetic resonance outcome is created in the MR fluid via shear mode or flow mode, and the core is built in the shape of a disc or drum. Figure 8 shows the basic layout of an MR brake and clutch. Review on MR brakes and clutches by Phu and Choi [11] and Hua et al. [12] focuses on structural configurations of MR brakes and clutches produced till the year 2021.

3.10 Robot Application

Figure 9 shows the results of research by Baser and Demiray [13] into the development of T-shaped multipole MR brakes for the exoskeleton robot ankle. To characterize the hysteresis, torque-to-volume ratio, torque-tracking, transient response, energy consumption, torque-tracking and damping performance, prototypes of the same size were built and subjected to experimental testing. When equated to the other designs, MR brake design with the T-shaped multipole had the best performance characteristics. A multi-disc MR brake consisting of '3' modules was developed by Kim et al. [14] for use with wearable robots. Each module has three discs and a coil to

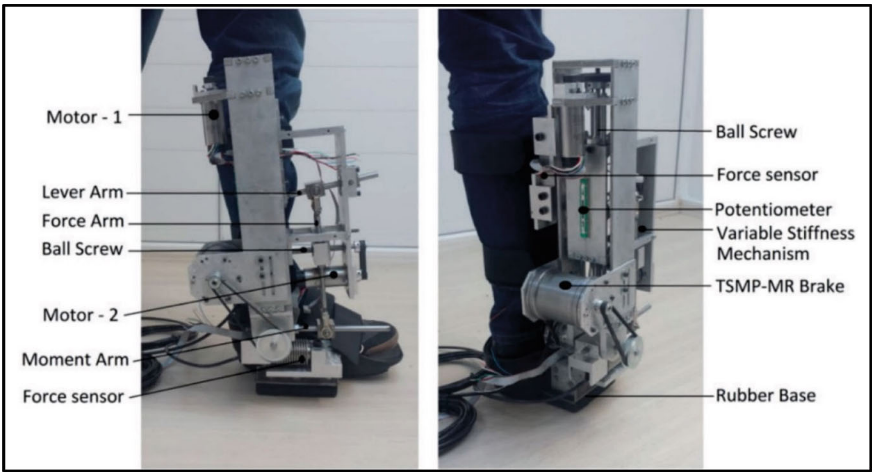

Fig. 9 MR brake to the ankle-exoskeleton robot

maximize actuation torque while minimizing size. The first prototype was built to test how well the manufactured MR brake worked, while the second was used to see how the response characteristics and generated torque varied with the voltage used. Open loop torque and crash safety were among the criteria Wang et al. [15] considered when assessing clutch actuators with high torque ratios. Series clutch actuators were developed and shown to be superior to MR clutches in order to address the drawbacks of the latter, most notably the MR clutch's comparatively low torque-to-weight ratio, which makes mixing into robots challenging. A lightweight type of MR clutch, dubbed a hybrid type MR clutch, was presented by Moghani and Kermani [16]. Their clutch combined electromagnetic coil and permanent magnet magnetization. The transmitted torque can be precisely measured by altering the magnetic field produced by the permanent magnet using the electromagnetic coil.

4 Conclusion

In conclusion, magnetorheological fluids and elastomers have found a wide range of uses as new technologies have emerged. These materials are one of a kind because their characteristics may be altered in response to a variety of stimuli. Magnetic fields can be used to manipulate the viscoelastic and rheological properties of magnetorheological fluids and elastomers. It was previously difficult to construct systems with adaptive properties using traditional materials, but that has changed because to the unique properties of these new materials. Dampers, shock absorbers, clutches, and brakes all make use of these clever materials. Magnetorheological dampers and shock absorbers are used for high-tension wire damping, building and bridge operation, and other damping applications. The key features of the MR fluid are its quick responsiveness, non-complex interaction between electrical input and mechanical output, integration, and controllability in complicated machinery. There have been several developments in the commercialization of MR fluids and MR fluid devices in recent years. In many advanced nations, there is intense competition to create the safer fluid. The suggested usage of MR Fluid centers on shielding soldiers from harm caused by weapon recoil. There is a steady stream of patent filings for innovative methods of using magnetorheological elastomers in automobiles.

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