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Automotive Applications of Magnetorheological Fluids

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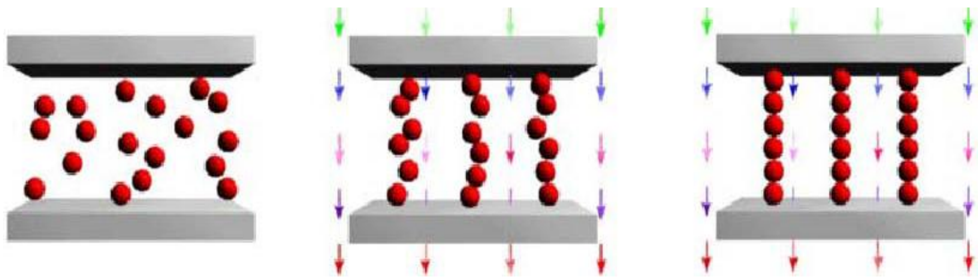
ABSTRACT

Magnetorheological fluids are one of the advanced materials that change its rheological properties (mainly viscosity and yield stress) under the influence of magnetic field. Magnetorheological fluids consist of micro sized magnetic particles immersed in carrier fluid, in absence of magnetic field, magnetorheological fluid behave like ordinary oil but as we apply magnetic field magnetic particles form a chain like structure with in milliseconds and increase its viscosity. Magnetorheological fluid have wide range of application like vibration isolation devices for civil and mechanical structures, semi active suspension system for automobiles, brakes, clutch and engine mounts. This paper briefly explains Magnetorheological fluids its properties, working modes, various automotive applications .

KeywordsComputation fluid dynamics, Earth Air Tunnel Heat Exchanger, Passive cooling.

I.INTRODUCTION

Magnetorheological fluid discovered by Jacob Rabinow at the US National Bureau of Standard in 1948[1]. A Magnetorheological fluid consists of micro-sized magnetic particles dispersed in non magnetic carrier fluid. MR fluids are one of the controllable fluids that show dramatic change in its rheological properties under the influence of magnetic field. Initially magnetic particles are amorphous state as shown in Figure 1(a). But in the presence of magnetic field MR fluids particle align or form a chains along the flux as shown in Figure 1(b) & 1(c). Response time of MR fluids is in milliseconds.



(a) (b) (c)

Figure 1 Activation of MR fluids: (a) no magnetic field applied; (b) magnetic field applied; (c) ferrous particle chains have formed [2]

1.1 Working modes of MR fluids Devices:

MR fluids devices have basic three modes valve mode, shear mode and squeeze mode.

Valve mode:- Valve mode, shown schematically in Figure 2, is one of the operating modes in the MR devices where the flow of the MR fluid between motionless plates or an orifice is created by a pressure drop. The magnetic field, which is applied perpendicular to the direction of the flow, is used to change the viscosity of the MR fluid in order to control the flow. Generally it is used in linear dampers.

Shear mode:- In shear mode shown in Figure 3, the MR fluids is contained between two parallel surfaces (poles) while an external magnetic field is applied perpendicular to the poles. A force is applied to one of the poles, making it move laterally, directly shearing the fluid layer. The force required to cause the fluid to shear depends on the intensity of the applied magnetic field and on the resulting shear stress developed in the MR fluid. Devices based on the shear mode essentially include brakes and clutches used in a broad range of applications.

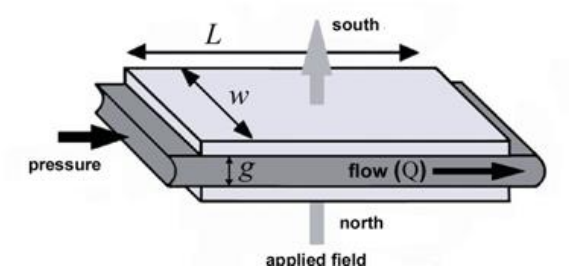


Figure 2 Valve mode [3]

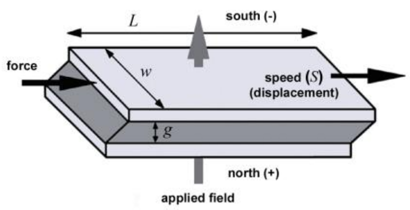


Figure 3 Shear mode [3]

Squeeze flow shown in Figure 4 of MR fluids is flow in which MR fluids are compressed between two parallel plates and then squeezed out radially. This mode is mainly for bearing application and some small amplitude vibration dampers.

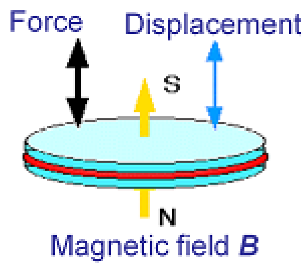


Figure 4 Squeeze mode

II.MAGNETORHEOLOGICAL DAMPER

Shock absorbers in most vehicles rely on a hydraulic fluid, a sliding piston and other parts that suffer wear and tear. If the shock absorbers of a vehicle's suspension are filled with magneto rheological fluid instead of plain oil, and the whole device surrounded with an electromagnet, the viscosity of the fluid, and hence the amount of damping provided by the shock absorber, can be varied depending on driver preference or the weight being carried by the vehicle - or it may be dynamically varied in order to provide stability control.

2.1 Working principle

MR damper are same as hydraulic damper, but they do not required any mechanical valve to control the flow of fluid. In MR damper a chamber filled with MR fluid and piston containing coils is inserted. As pistons moves fluid flows through the orifices easily, the coil generates magnetic field fluid become semi solid and restrict its motion which causes damping effect, its intensity is controlled by applied magnetic field. Operating principle of MR damper shown in Figure 5.

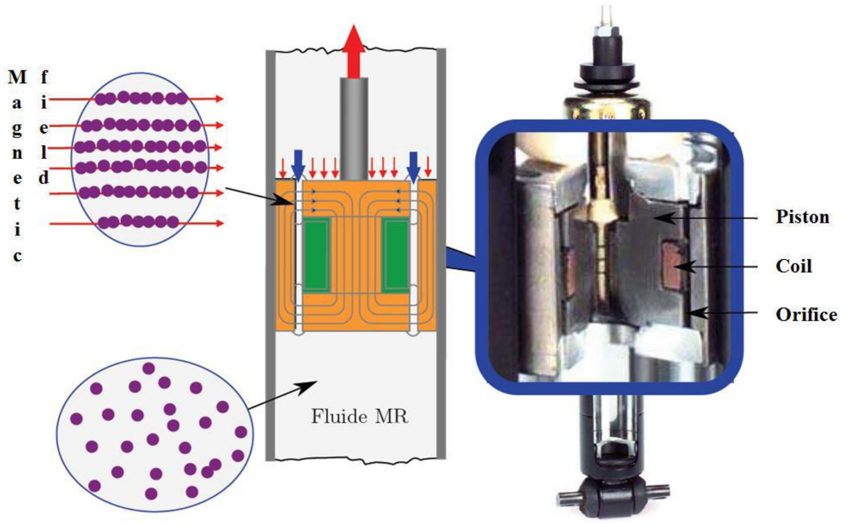


Figure 5 Operating principle of an MR damper [4]

2.2 Types of MR damper

There are three types of MR damper, monotube, twin tube and double ended.

2.1.1 Monotube MR damper

A mono tube MR damper shown in Figure 6, has only one reservoir for the MR fluid and an accumulator mechanism to accommodate the change in volume that results from piston rod movement. The accumulator piston provides a barrier between the MR fluid and a compressed gas (usually nitrogen) that is used to accommodate the volume changes that occur when the piston rod enters the housing.

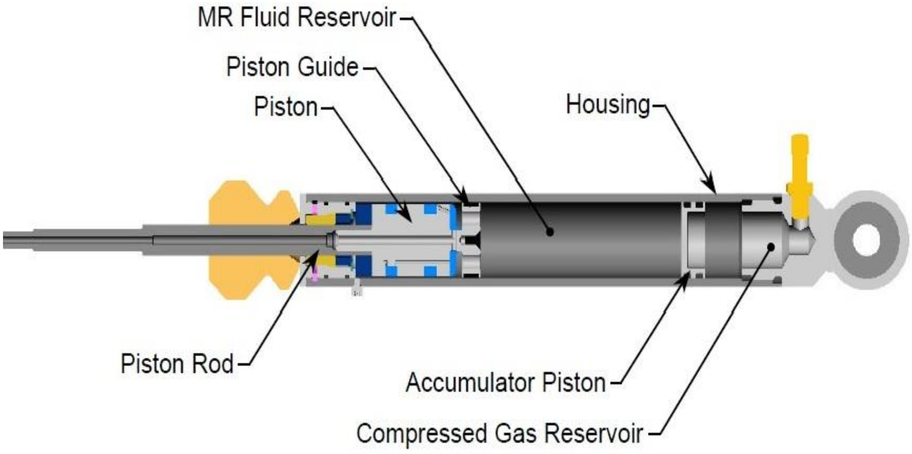


Figure 6 Mono tube dampers [5]

2.1.2 Twin tube MR damper:

The twin tube MR damper has two fluid reservoirs, one inside to the other shown in Figure 7. The inner housing works same as the housing of a monotube damper. MR fluid filled inside the inner housing with no air gaps. To accommodate changes in volume due to piston rod movement, an outer housing that is partially filled with MR fluid occurs. To regulate the flow of fluid between the two reservoirs a foot valve is attached to bottom. As the piston rod enters the damper, MR fluid flows from the inner housing into the outer housing through the compression valve that is attached to the bottom of the inner housing. The amount of fluid that flows from the inner housing into the outer housing is equal to the volume displaced by the piston rod as it enters the inner housing. As the piston rod is withdrawn from the damper, MR fluid flows into the inner housing through the return valve.

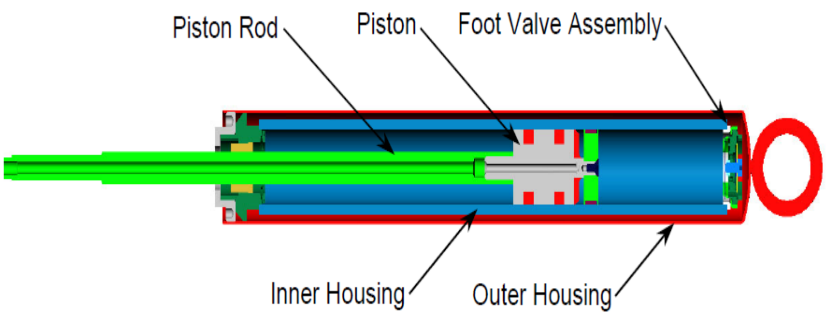


Figure 7 Twin Tube MR Damper [5]

2.1.3 Double ended damper

The final type of MR damper is called a double-ended damper since a piston rod of equal diameter protrudes from both ends of the damper housing. Figure 8 shows a section view of typical double-ended MR damper. Since there is no change in volume as the piston rod moves relative to the damper body, the double-ended damper does not require an accumulator mechanism. Double-ended MR dampers have been used for bicycle applications gun recoil applications, Commercial applications and for controlling building sway motion caused by wind gusts and earthquakes.

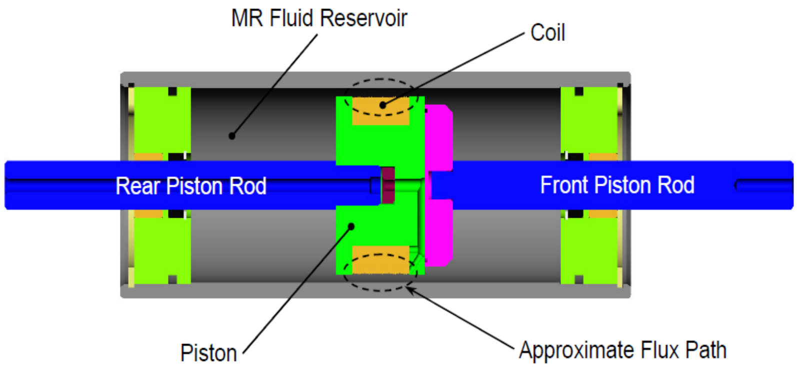


Figure 3.8 Double Ended MR Damper [5]

2.1.4 A disc type Magnetorheological fluid damper

A disc type Magnetorheological fluid damper works of shear mode operation, a simple symmetrical disk-type MR fluid damper as shown in Figure 9 was designed and built. It consisted of a moving disk, a ball bearing, two magnetic poles, a coil wound circumferentially and a damper housing, which form the magnetic path with two equal axial gaps. The moving disk was mounted on an additional journal in the outer race of the ball bearing. When the journal is whirling, the moving disk shears the MR fluid in the axial gaps and produces a resisting fluid force to dissipate the vibration energy from the rotor system.

III. MR MOUNTS

Vibration and noise control is the most promising area of research. Traditional mounts have narrow range of frequencies of vibration, hydraulic mounts have wide range of frequency and better amplitude response than traditional mounts. MR mounts basically similar to hydraulic mounts whose damping coefficient changes. Replacing the hydraulic fluid inside the mount with MR fluid improves its vibration isolation capabilities. The effect of the MR fluid is the most beneficial at frequencies higher than the notch frequency of the mount. When the MR fluid is activated inside the mount, it acts like a valve and facilitates the control of the fluid flow through the inertia track of the mount.MR mounts works on squeeze mode, its damping characteristics explain experimentally by Ha et al [5]. In which they observed that resonant frequency increases on increasing the magnetic field. Figure 10 shows a MR engine mount.

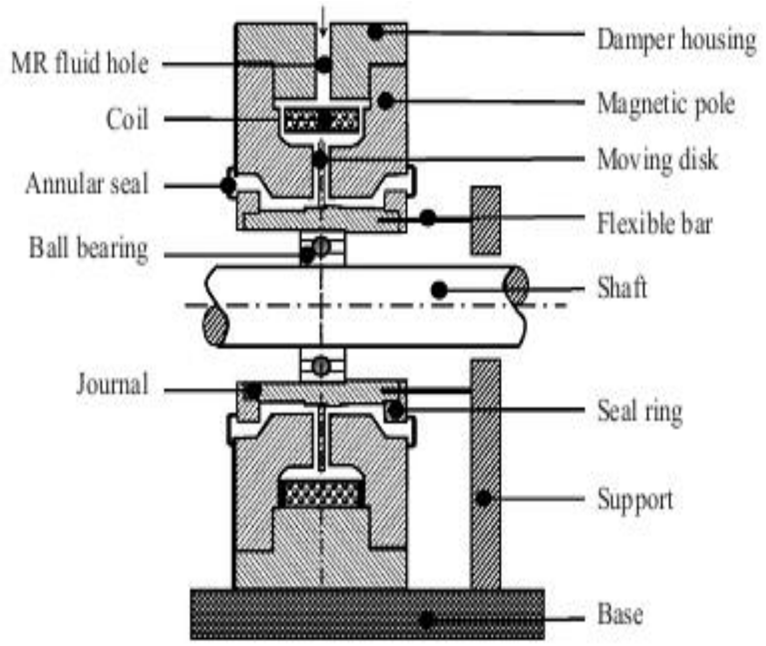


Figure 9 Cross-section of the disk-type MR fluid damper [6]

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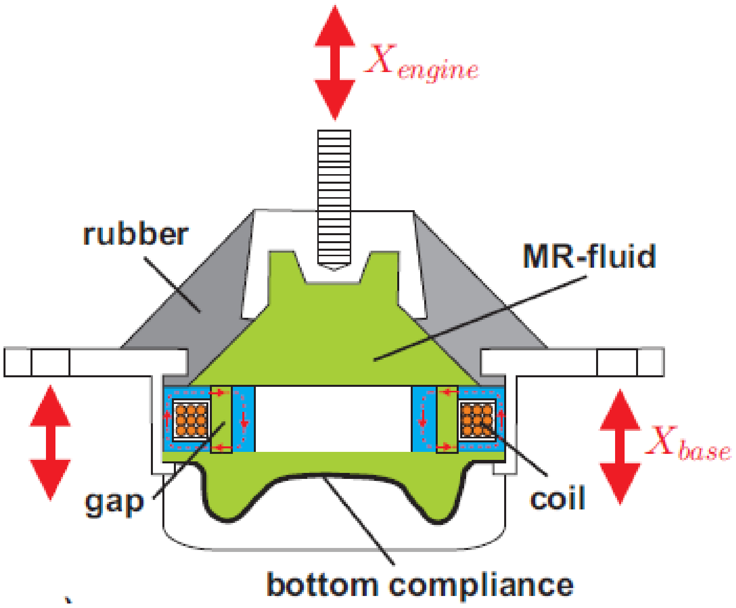


Figure 10 A MR Engine Mount [7]

Later Ciocanel, Elahinia et al [6] suggest a new MR mount model which works on both squeeze and valve (flow) mode respectively. They concluded that combining of both mode increases the effectiveness of the mount. The mount consists of an upper chamber and a lower chamber connected through inertia tracks located at the center of the mount, as shown in Figure 11. Inside the upper chamber a plate is connected to the rod that connects the mount to the engine. This plate is set parallel to the coil housing and separates the bottom chamber and upper chamber. Squeeze mode and flow mode is controlled by central coil and outer coil respectively.

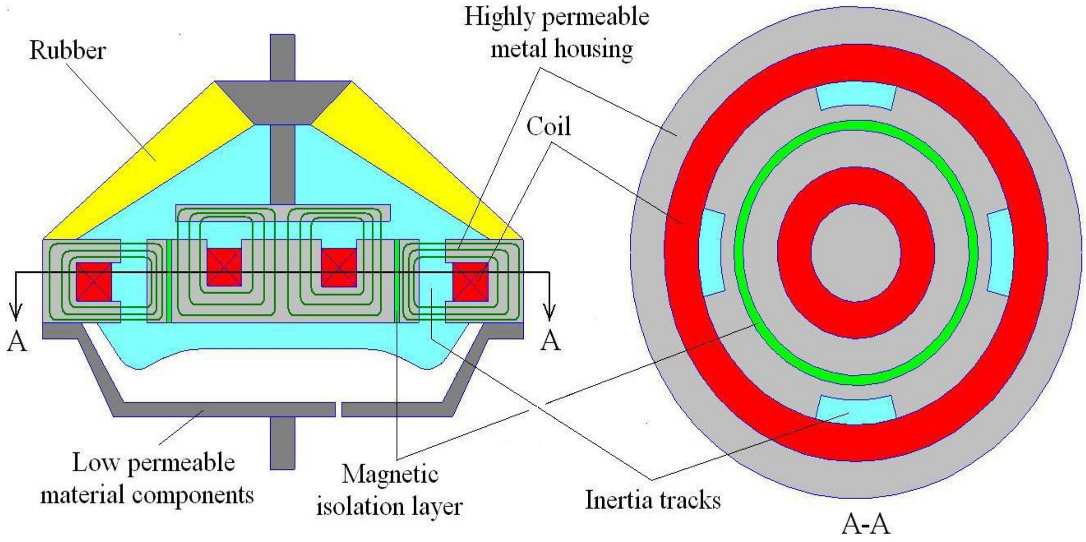


Figure 11 Schematic Diagram of Combined Mode Mount [8]

IV. MRF BRAKES

A MR brake operates on shear mode. In shear mode MR fluid is placed between two non rotating plates of cylindrical walls. Advantage MRF brakes that its braking torque increase quickly as we apply magnetic field. Cylindrical MR brake has four main parts viz. rotor, stator MR fluid, magnetic coil and Housing shown in Figure12.

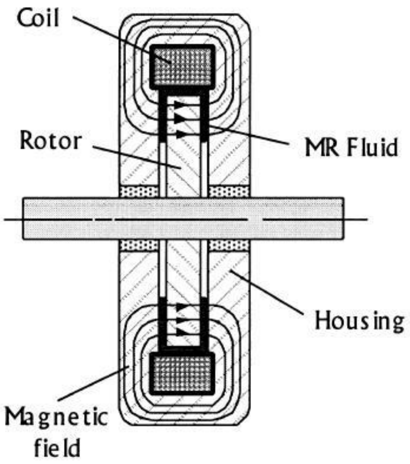


Figure 12 MRF Brake [9]

Operating principle: In MRF brakes MR fluid is filled in between rotor and stator (housing) and coils are placed parallel to axis of rotor as shown in Figure In absence of magnetic field rotor rotates freely in MR fluids, as brakes apply a magnetic field is generated through coils, due which rheology of MR fluid changes that causes breaking torque. Magnetic field controls the intensity of breaking torque.

MRF brakes can be classified in following categories [7]

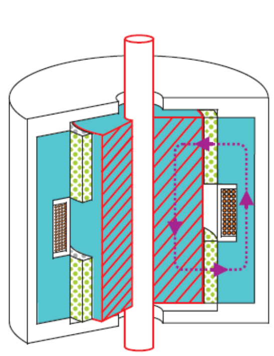
a) Drum

b) Inverted drum

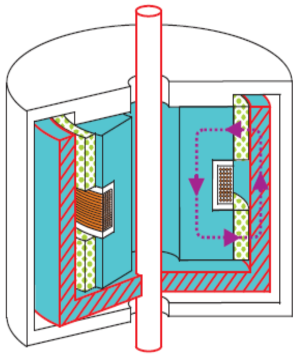
c) T-shaped

d) Disk

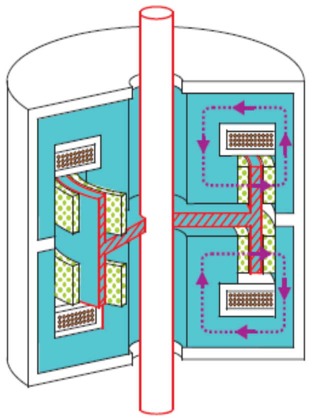
e) Multi-disk



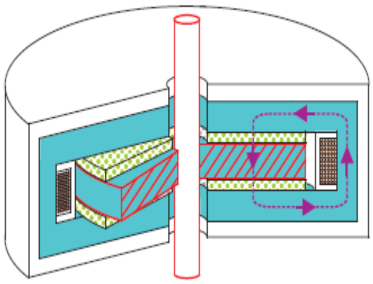
(a) Drum



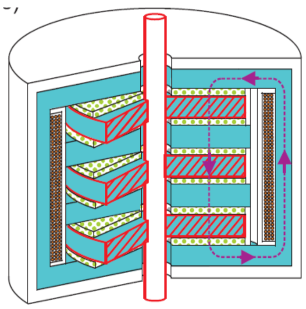
(b) Inverted Drum



(c) T - shaped



(d) disk



(e) Multi-Disk

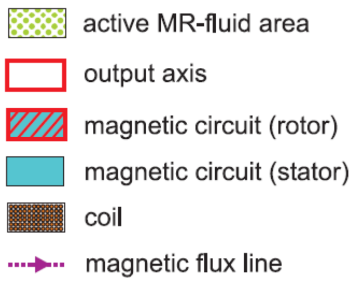


Figure 13 Types of MRF Brakes [7]

Drum type of brake are easy to construct. A solid drum type rotor is followed by MR fluid and stator and coil is enclosed in housing as shown in Figure 13(a). And magnetic field is applied radially for breaking operation. Figure 13 (b) shows inverted drum type has a hollow cylindrical rotor. And other assembly is placed inside it. T-shaped MRF brakes are complex in geometry, it contain two coils instead of one and a special T type rotor

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shown in Figure 13 (c) which doubles the working area in comparison to drum and inverted drum types, results increase in effectiveness of brake. Disk type brake has single disk rotor which is surrounded by MR fluid from both side and coil is winded across its circumference. Figure 13 (d) and (e) shows disk type and multi disk MRF brakes respectively.

V. MRF CLUTCH

MR clutch works on shear mode of MR fluid. MRF clutch produce much more torque with a small amount of power input in comparison to conventional clutch. MRF brakes and clutch are simple to construct and gives better response, durability which make them an attractive application in automotive industry. The MRF clutch can perform high speed torque response depending on the rapid response of MR Fluids. The magnetic field in the MR clutch is usually generated by an electromagnet with a coil. The current in the coil determines the magnetic flux density in the MR fluid and the corresponding torque which is transmitted. This means that without any coil current the clutch works in the disengaged operational state, where only a drag torque due to the base viscosity of the MR fluid and the seal friction is transmitted. In the engaged state, the transmitted torque can only be maintained by the continuous supply of electric energy to the coil. If the clutch is primarily operated in the engaged state, this concept is energy-inefficient.

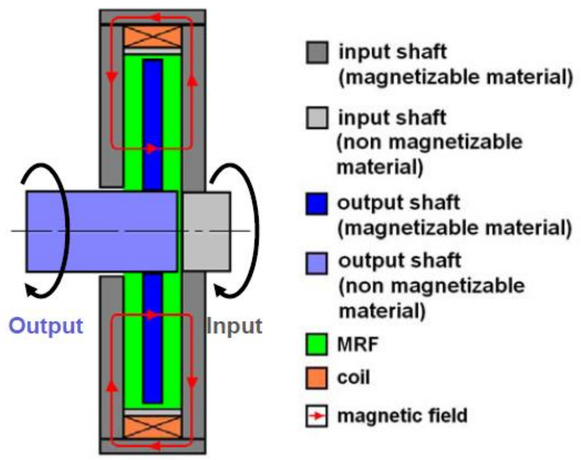

Figure 14 Disc type MRF clutch [10]

Two main type of MRF clutch are disc type and bell type. In the disk-type clutch (Figure 14), the shear gaps filled with the MR fluid are oriented perpendicular to the rotational axis of the clutch In the bell-type MR clutch, the MR fluid gaps are oriented parallel to the rotational axis (Figure 15). In bell type clutch both drive and driven shafts are surrounded by MR fluids and magnetic exciter or coil is winded over the driver shaft as shown in Figure Both type have different advantages and disadvantages. The disk-type clutch can be made more compact with a large number of parallel disks and corresponding shear gaps, which leads to a large transmittable torque. However, at high rotational speeds the torque is more prone to particle separation due to the centrifugal forces acting on the heavy iron particles in the MR fluid. In contrast, in bell-type MR clutches, the particles can move only over the small distance of the thin MR fluid gap.

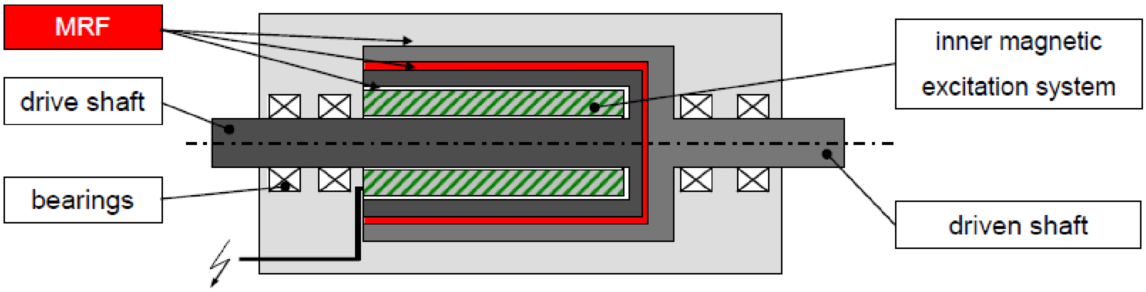

Figure 15 Bell type MRF clutch

VI.CONCLUSION

Magnetorheological fluids are advanced materials whose consistency is strongly influenced by magnetic fields. This behavior can be utilized for a large number of applications in various technological fields like vibration damping, clutches, actuators and Brakes, polishing etc. The basic properties of MR fluids which change their rheological properties in the presence of a magnetic field are described. Excellent features like fast response, simple interface between electrical power input and the mechanical power output, and controllability make MRF the next technology of choice for many applications. Direct shear mode (used in brakes and clutches) and valve mode (used in dampers) have been studied thoroughly and several products are already present in the market.

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