IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 1 Ser. V (Jan. - Feb. 2019), PP 79-86
www.iosrjournals.org

Comprehensive Study of Magnetorheological Fluid and its Applications in Automobiles: A Review

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Abstract: *Magnetorheological fluid (MRF) is a sort of non-Newtonian liquid whose properties can be controlled with the assistance of metal particles and magnetic field. These fluids can transmit force in a controlled way with the assistance of magnetic field, accordingly enhancing their execution particularly in areas where controlled fluid movement is required. The proposed idea of this paper is to study the various properties of the magnetorheological fluid, its behavior under various conditions and its application in automobiles in the brakes, clutches and vibration dampers.*

Keywords:*MR Fluid, magnetic field, conventional hydraulic braking, MR braking, MR clutch, MR damper*

Date of Submission: 22-02-2019 Date of acceptance: 08-03-2019

I. Introduction

Magnetorheological (MR) liquids are a class of new smart materials whose rheological qualities change quickly and can be controlled effectively within the sight of a connected magnetic field. Magnetorheological (MR) fluid technology has been demonstrated for various industrial applications like shock absorbers, actuators, etc. MR brake is a device to transmit torque by the shear stress of MR fluid. The common magneto-rheological fluid comprises 3 sections: soft magnetic particles, the carrier fluid, and added substances. Soft magnetic particles for the most part including Fe3O4, Fe, Co, Ni and so forth. Among them, the iron-cobalt alloy has the most astounding magnetic saturation and its magnetic saturation can achieve 2.4T, yet it is costly. The carrier fluid is a vital segment of magneto-rheological fluid, it is a media of soft magnetic particle suspension. Synthetic oil, Mineral oil and water and so forth can be carrier fluid. Additives incorporate dispersant and anti-sedimentation agent and so forth. The fundamental role of additives is to enhance the sedimentation stability, dispersion, zero viscosity and shear yield strength of magneto-rheological fluid.

II. Magnetorheological Fluids

Properties of MR fluids

Magnetorheological materials (liquids) (MR) are a class of smart materials whose rheological properties (e.g. viscosity) might be quickly differed by applying a magnetic field. Under the impact of the magnetic field the suspended magnetic particles associate to frame a structure that opposes shear deformation or stream. This variation in the material shows up as a fast increment in apparent viscosity or in the improvement of a semisolid state. Advances in the use of MR materials are parallel to the improvement of new, more refined MR materials with better properties and stability. Many smart systems and structures would have a positive impact on the change in viscosity or other material properties of MR. These days, these applications incorporate brakes, dampers, clutches and damping systems in automobiles. Without a connected field, MR liquids are sensibly all around approximated as Newtonian fluids. For most engineering applications an elementary Bingham plastic model is viable at portraying the basic, field-subordinate fluid characteristics. Advances in the use of MR materials are parallel to the improvement of new, more advanced MR materials with better properties and stability. Many smart systems and structures would profit by the variation in viscosity or other material properties of MR.

Within the sight of a connected magnetic field, the iron particles get a dipole moment lined up with the external field which makes particles shape like linear chains adjusted to the magnetic field. This phenomenon can set the suspended iron particles and limit the fluid motion. Therefore, yield strength is created inside the fluid. The level of variation is connected with the intensity of the applied magnetic field and can happen in a couple of milliseconds. Magnetorheological materials show a few favorable circumstances over quintessential electrorheological materials. Rather than electrorheological materials, MR liquids are more valuable in light of the fact that the variation in their rheological properties is vast, bigger than in ER fluids, so an expansion of yield stress is 20-50 times more powerful. Not at all like ER materials, they are additionally less touchy to moisture and contaminants, and subsequently, MR materials are a possibility for use in filthy or defiled situations. They are additionally unaffected by the surface chemistry of surfactants as ER materials may be. The power (50 W) and voltage (12– 24V) requirements for MR materials actuation are generally little contrasted with ER materials.

Magnetorheological fluid Components

MRF Components – A Magneto-Rheological-Fluid is a fluid with rheological conduct which relies upon the power of a magnetic field. The rheological status changes reversibly from fluid to the solid. The Greek word "rheos" signifies flow and rheology is the science of deformation conduct of materials which can flow. Usually the rheological property of viscosity changes with other physical properties, for example, chemical composition, shear stress, and temperature. These features are not actually controlled in many applications since they are fixed by surroundings. On account of all liquids, the variation of viscosity with temperature is reversible however this does not enable the viscosity to be controlled effectively. On account of MR, the fluid viscosity turns out to be cleverly controllable utilizing the magnetic field. This variation of viscosity up to the strong condition is reversible and is the fundamental element of MRF innovation. The MRF impact is the distinction in rheological properties with and without a magnetic field.

There are fundamentally three components in an MR liquid: basic fluid, metal particles and stabilizing additives. The Base fluid has the role of the carrier and normally consolidates lubrication (in a mix with additives) and damping properties. For the most elevated MRF impact, the viscosity of the liquid ought to be small and practically autonomous of temperature. Along these lines, the MRF impact will be the prevailing impact when it is contrasted and the characteristic physical viscosity fluctuating with temperature and shear stress. Fundamentally in the off-state (with no magnetic impacts) MR fluids act like the base fluid as per their chemical compositions. There are diverse kinds of fluid which can be utilized as the carrier fluid, for example, hydrocarbon oils, mineral oils or silicone oils. Similarly, as with a particle suspended in a fluid, the base fluid will have a higher viscosity when the concentration of metal particles is extremely high. The liquid will seem, by all accounts, to be "thicker" [5]. So even in the off-express, the fluid with the powder will have a greater viscosity. Normally the dynamic viscosity at surrounding temperature is around 100mPa.

In the on-state (with a magnetic field set up) the Metal particles are guided by the magnetic field to form a chain-like structure. This chain-like structure limits the movement of the fluid [4] and in this way changes the rheological behavior of the fluid. The MR-impact is delivered due to this resistance from flow brought about by the chain-like structure. The metal particles are normally made of carbonyl iron, or powder iron, or iron/cobalt alloys to accomplish a high magnetic saturation. The measure of metal powder in MRF can be up to 50% by volume [1-16]. The particle size is in the μ−meter run and changes relying upon the manufacturing processes. The particle size can be picked to accomplish different purposes. On account of carbonyl iron, the molecule estimate goes between 1-10 μ−meter. Bigger particles and higher portions of powder in the MR liquid will give higher torque in the on-state, and yet the viscosity of the MR liquid in the off-state will likewise be higher under these conditions. The material property, particularly the permeability is likewise an essential factor for controlling the MR-effect. The additives incorporate stabilizers and surfactants. Additives are suspending agents, thixotropes, friction modifiers, and anti-wear parts. Profoundly viscous materials, for example, grease or other thixotropic added substances are utilized to improve settling stability.

Ferrous naphthenate or ferrous oleate can be utilized as dispersants and metal soaps, for example, lithium stearate or sodium stearate as thixotropic additives. Additives are required to control the viscosity of the fluid and the settling rate of the particles, the friction between the particles and to stay away from the in-use thickening for a characterized number of on leave cycles. Every one of the three segments characterizes the magneto-rheological conduct of the MR fluid. The total density relies upon the formulation and is roughly by 3-4g/cc. The difference in one of the MRF properties will prompt rheological changes (in the off-state) and to magneto-rheological changes in behavior (in the on-state). At long last a change off between the reachable exhibitions of each of the three parts in total is required so as to enhance a formulation.

There are a few similitudes between MR fluids and ferrofluids. The magnetorheological properties of the two sorts of liquid are distinctive in light of the fact that there is a distinction in both the quality and the amount of the metal powders. Regular to both is that they contain iron particles, a basic fluid, and additives. The primary distinction is the size, the amount and the quality of the iron particles. On account of MR liquids, the iron particles are extensive, bigger than 1μm. On account of ferrofluids, the iron oxide particles are a lot smaller, about 30nm. With MRF there is a difference in a state from liquid to solid when a magnetic field is turned on, though a ferrofluid stays fluid even in a high magnetic field. In the ferrofluid impact, the solid yield stress behavior is practically nonexistent, though it is the capacity to make the chain structure in MR fluids with mechanical resistance to flow which is of fundamental significance in the MRF impact.

Carbonyl iron-based MR fluids can create yield stresses of 100kPa, however, average yield stress for a ferrofluid is 10kPa. The viscosity dependency because of a magnetic field in a ferrofluid is an auxiliary impact. The primary ferrofluid impact is to guide and attract the fluid concurring the magnetic field intensity.

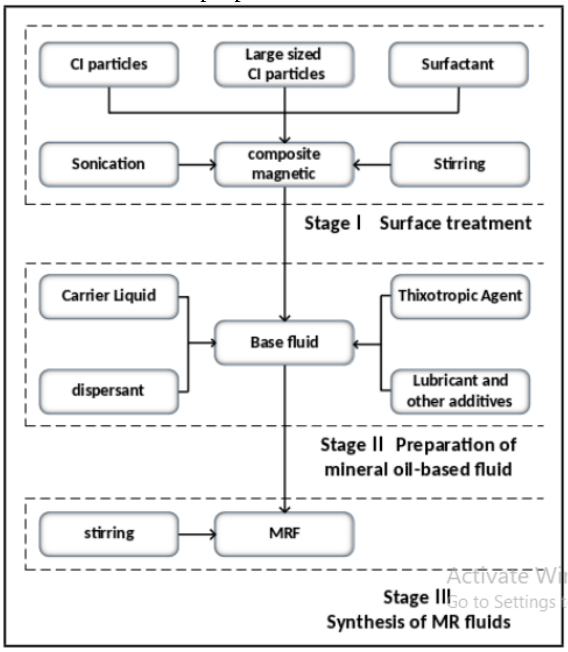
Ferrofluids are truly steady because of the particle sizes. The particles are also less abrasive than compared to MR fluids. The above portrayal shows the contrasts between the two kinds of liquid as far as functionality. It is additionally conceivable to characterize the distinction all the more precisely regarding an energy factor λ. This is characterized by an individual particle regarding Brownian thermal energy and magnetic polarization energy as follows:

$$\lambda = \frac{\mu_O \mathrm{P}_{mag}{}^2 V}{12 * k * T}$$

In this equation: P_{mag} is the polarization, V is the particle volume, k is Boltzmann's constant and T is the temperature. If the energy factor is greater than 1, the magnetization energy is greater than the thermal energy and the fluid will have the MRF functionality in an applied magnetic field. Else, the thermal energy is larger and the magnetic field would just guide the particles according to the flux density.

Preparation of MR Fluid

Table 1: Shows the preparation of MR Fluid flow chart.



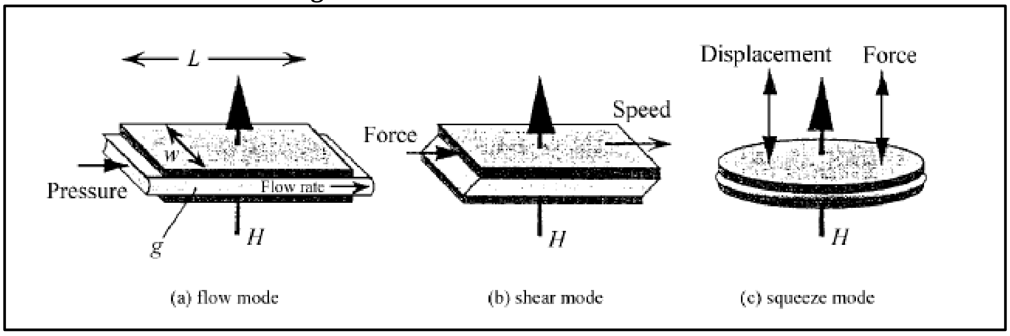
The preparation procedure is an imperative factor that influences the working of MR fluids. As appeared above the table, the planning procedure can be portrayed in detail as follows:

1. The surface treatment of CI particles: Firstly, put CI particles in a container of anhydrous ethanol, at that point add a surfactant. Furthermore, put the container in the ultrasonic dispersing instrument to make the mixture equitably. At that point, place the mixture in vacuum drying stove to keep low-temperature drying. Finally, crush the acquired dry CI particles in a mortar and afterward filter the particles through a standard sieve (100 mesh).
2. Preparation of mineral oil-based fluid: Take mineral oil into a container, include the dispersant, thixotropic agent, and strong lubricant in order while mixing at room temperature for 2 hours.
3. Synthesis of MR fluids: Put the 3 µm-CI particles and the 10 µm-CI particles after surface treatment into the acquired mineral oil-based fluid and blend well. As indicated by the previously mentioned procedure of MR fluids, four examples numbered A, B, C and D were made. The mass fraction of the all-out CI particles in each sample was 80% and the proportion of the 3 µm-CI particles to the 10 µm-CI particles are 9:1, 37:3, 19:1 and 39:1, respectively. That is, the 10 µm-CI particles in the proportion of the total CI particles is 10%, 7.5%, 5.0%, and 2.5%, separately.

Behavior of MR fluids

Methodology - The methods of activity for MR liquid gadgets are flow mode (settled plate mode, valve mode), shear mode (clutch mode), and squeeze mode (compression mode) and any mix of these three. In the flow mode, MR liquid is made to stream between static plates by a weight drop, and the flow resistance can be controlled by the magnetic field which runs typically to the flow course. Cases of the flow mode incorporate servo valves, dampers, shock ups, and actuators. In the shear mode, the MR liquid is situated between surfaces moving (sliding or turning) in connection to each other with the magnetic field streaming at right angles towards the course of movement of these shear surfaces. Cases of the shear mode incorporate clutches, brakes, hurling and bolting gadgets, dampers and basic composites. In the squeeze mode, the separation between the parallel shaft plates changes, which causes a squeezed flow. In this mode generally high powers can be accomplished; this mode is particularly appropriate for the damping of vibrations with low amplitudes (up to a couple of millimeters) and highly fluctuating loads.

Figure 1: Different modes of MR fluids.

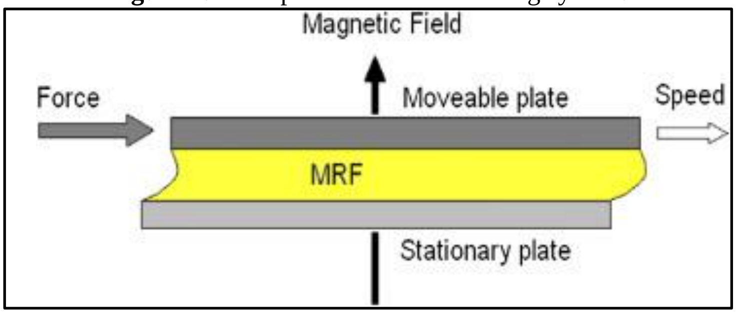


III. Applications in Automobiles

MR Fluid Braking System

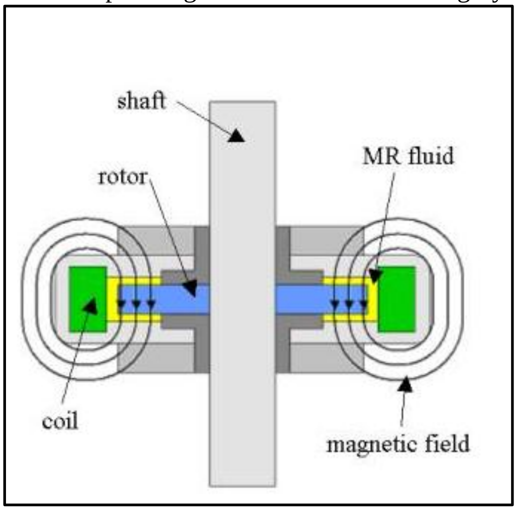
The proposed brake comprises of single rotating disc submerged in an MR liquid and encompassed electromagnet. In MR BRAKE, a portion of the traditional mechanical parts of the conventional brakes are supplanted by electromechanical parts. At the point when a magnetic field is applied to the MR Brake, the MR liquid hardens as its viscosity changes as a function of the magnetic field connected. This controllable viscosity produces a shear frictional force on the rotating plate creating braking torque. A straightforward case of such braking mechanism is the drum brakes utilized in trailers where less braking torque is required. These brakes are activated by an electromagnet introduced in the drum brake rather than a fluid powered system that attracts the magnetic rotating plate onto a stator. The friction created between the stator and the rotor brings about braking. A magneto-rheological brake is an abrasion based brake like a conventional hydraulic brake. Nonetheless, the procedure of friction generation in an MR is totally different from conventional braking system. In the CHB, when the breaking stress is introduced, the stator and rotor surface comes in contact and friction is created between the two surfaces, thereby producing braking torque. Yet, in the MRB, MRF is filled between the stator and the rotor, and because of controllable rheological properties of the MRF, shear friction is created.

Figure 2: Principle of MR Fluid braking system.



The MRB is a totally electronically controlled actuator and therefore, it can possibly additionally reduce the baking time (in this way, braking distance), and also less demanding mix of existing and modern control techniques, for example, anti-lock braking system(ABS), vehicle stability control (VSC), electronic parking brake (EPB), etc. The MRB configuration includes different vital outline steps, for example, designing of magnetic circuit and determination of material alongside other practical considerations, for example, heat dissipation and leakage sealing. Additionally, since CHBs utilize a very high pressurized brake fluid, there is the likelihood of spillage of the brake fluid that would cause deadly mischances, and this liquid is unsafe to the surroundings also which can be prevented in the case of MRB. Another issue seen in CHBs is that this kind of brake utilizes the friction between brake pads and the brake disc as its braking system, prompting the brake pads to wear. Because of both the material wear and the friction coefficient deviation in high speeds, the brake performs less efficiently at high speeds, and in addition to the expanded number of usage cycles another drawback of this sort of braking mechanism is that it is bulky in size, when both supplementary parts and brake actuators are taken into consideration.

Figure 3: Simple Diagram of MR Fluid Braking System.



MR Fluid Clutch

A conceptual drawing of a compact MRF clutch (CMRFC) comprises of an electric coil rolled around an output shaft and it generates magnetic fluxes. Multi-layered disks are fixed on the input/output shaft. The MRF is filled between these disks. It consists of a number of thin ferromagnetic layers (thickness 0.5mm), with 36 slots and teeth machined on the inner and outer diameter. Once stacked, the laminated core slots are filled with a conductive alloy, short-circuited around the ends by two rings. In this way, a kind of double 'squirrel cage' can be obtained: one positioned at the outer radius of the inner gap, and the second at the inner radius of the outer gap. This new design has two effects: (1) the ferromagnetic layers (laminations) allows to better address the magnetic flux density in the two cylindrical portions of the MRF gap; (2) the double-cage permits the circulation of the eddy currents and an extra torque can be obtained. Therefore, the device at the startup operates like an induction motor in which the rotating magnetic fields is obtained by the mechanical rotation of the four-pole PMs rotor. In fact, during the electro-mechanical transient phase, when the two clutch shafts rotate at different speeds, the permanent magnets induce eddy currents on the (double) squirrel cage.

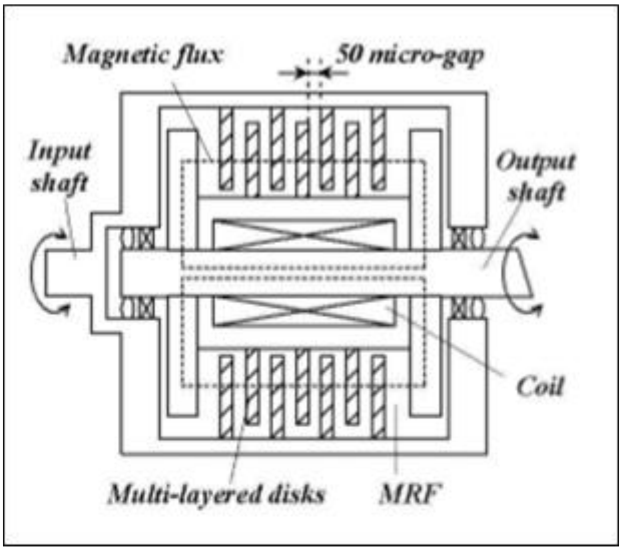
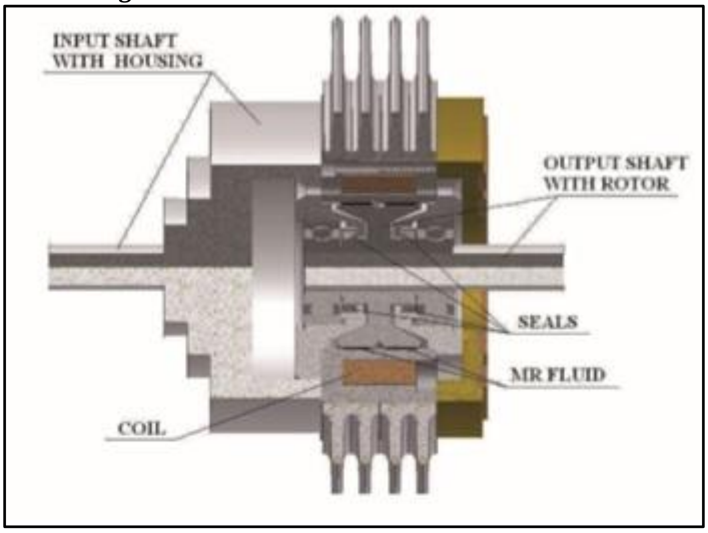


Figure 4: Basic diagram showing principle of MR Fluid clutch.

The interaction between the eddy currents and the magnetic induction produces an electromagnetic torque which, added to that of the MRF, helps the clutch engagement. When the relative speed between the clutch shafts is zero (engaged condition), the eddy currents, and consequently the electromagnetic torque, vanish and the torque transmission is assured by the MRF only. The proposed solution allows a smart increase of the clutch transmissible torque, especially during the starting phase when extra torque could be necessary to overcome possible static frictions.

Figure 5: Basic solid model of MR Fluid clutch.



MR Fluid Dampers

The magnetorheological (MR) damper is a standout amongst the most appealing new devices for structural vibration reduction. In light of its mechanical comprehensibility, high dynamic range, low power needs, greater force capacity and robustness, this device has been appeared to work well with application demands and restrictions to offer appealing methods for ensuring effective damping of vibrations in suspension of vehicles.

The principle distinction between their properties lies in the Rheological Properties of MR Fluids Recommended for use in Shock Absorbers is the extent of the attainable yield stress for liquids fluids for use in shock absorbers, the magnitude of yield stress is under 20kPa, for fluids utilized in couplings and brakes the yield stress can surpass 50kPa. In the fundamental components of a simple linear MR liquid damper just around 3 ml of MR fluid are required.

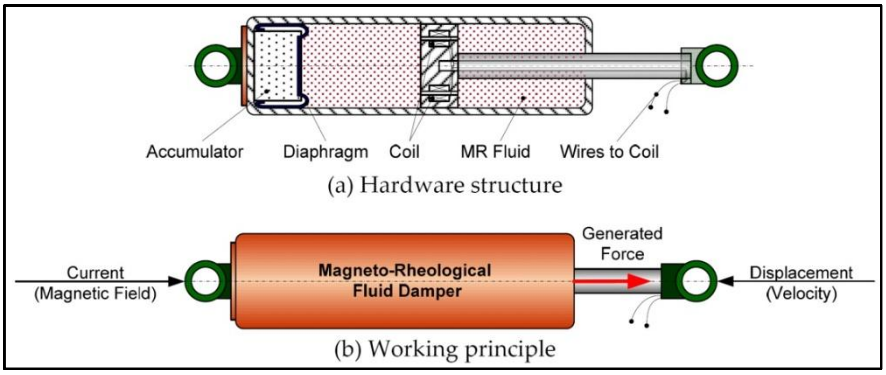
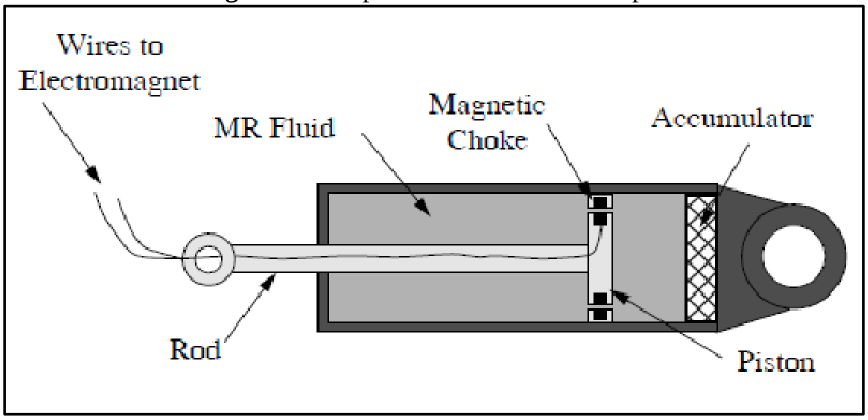


Figure 6: Structure and working principle of MR fluid damper

The dampers in flow mode comprised of a piston and a cylinder. The magnetic field is connected to control the flow of MR fluid, in the shear mode, the damper chiefly comprises of housing, electromagnet, shaft, blade MR liquid, and so forth. At the point when the shaft is exposed to torsional vibration then the shear in the MR fluid dissipates the vibrating energy, in squeeze mode, the damper works by moving a disc or baffle in an assembly of MR fluid in which the starting movement is axial and after that following movement is lateral. At the point when the magnetic field is intensified, a change from a viscous to a viscoelastic behavior was noticed which a solid impact on the energy had disseminated by the damper and on the damping force, the dampers can likewise be worked in mix of shear mode and squeeze mode in these dampers an annular space is given between piston and cylinder. The motion of the piston makes fluid flow and shear stress exists through the entire annular space. The magnetic coil is wound on the piston or on the internal surface of the cylinder. A damper with a single end piston rod requires volume compensation whereas a damper with double-ended piston rod does not require volume compensation. Further, the piston is upheld by a shaft on the two closures which gives great steadiness of the piston.

Figure 7: Components of MR fluid damper



IV. Conclusion

The magnetorheological liquid is smart material and it is anything but difficult to control, under the activity of an outside attractive field, it can accomplish the change between high return pressure viscoplastic colloid and Newtonian liquid in milliseconds and this progress is irreversible, consistent and controllable, so it has expansive application prospects. This paper basically presents the structure of MRF, magneto-rheological guideline and MRF application field. Residential and outside researchers accomplished numerous accomplishments around the component, testing, planning, application and different parts of MRF. In any case, MRF innovation and its applications still have numerous issues that need further research in following perspectives: low execution of MRF; simple to release, hard to seal when working; poor molecule sedimentation security and unsteadiness; gadget cooling impact isn't perfect; MRF control component, for example, brake, grip, yield torque isn't perfect, and so forth.. This innovation will be generally utilized in the field of mechanical designing subsequent to defeating the above inadequacies.

V. Future Scope

The advancement of smart materials at the nuclear scale is still some way off, despite the fact that the empowering advances are being worked on. These require novel parts of nanotechnology and the recently creating study of shape science. Around the world, significant exertion is being sent to create shrewd materials and structures. The mechanical advantages of such frameworks have started to be recognized and, demonstrators are under development for a wide scope of uses from space and aviation, to structural building and local items. In huge numbers of these applications, the money-saving advantage investigations of such frameworks presently can't seem to be completely illustrated. The general acknowledgment of smart materials and structures may in truth be more troublesome than a portion of the mechanical obstacles related to their advancement. The potential future advantages of smart materials, structures, and frameworks are stunning in scope. This innovation gives a guarantee of ideal reactions to an exceptionally complex issue territory by, for instance, giving early cautioning of the issues or adjusting the reaction to adapt to unexpected conditions, consequently upgrading the durability of the framework and improving its life cycle.

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Rudrajit Paul. "Comprehensive Study of Magnetorheological Fluid and its Applications in Automobiles: A Review." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 1, 2019, pp. 79-86