MAGNETIC PARTICLE BASED MR FLUID APPLICATIONS AND IT'S DEMERITS - A REVIEW

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Abstract : Magnetorheological (MR) fluids belong to a family of rheological materials that undergo rheological phase change under the application of magnetic field. This paper presents a review on applications and demerits of MR fluids in engineering applications. MR fluid confines its ability only to fewer applications because of its defects and failures. The most significant demerit is sedimentation of particles which origins the formation of hard cake, making re-dispersion of particles difficult. On the other hand clumping effect occurs when higher magnetic field is applied to the MR fluid for longer period of time resulting in the separation of magnetic particles from carrier fluid and this clumping problem leads to fluid particle separation (FPS).Another failure is oxidation of particles, which weakens the magnetizing ability of the particles.

***IndexTerms* - Magnetorheological fluids, hard cake, clumping effect, fluid particle separation (FPS).**

I. INTRODUCTION

MR fluids are composed of soft ferromagnetic (Fe, Ni, Co and several rare earth minerals [4]) or paramagnetic (Al, Na, Ca, O_2 and copper chloride) particles (0.03~10 μm) dispersed in a carrier fluid. Materials that can be magnetized by an external magnetic field and remain magnetized after the external field is removed is either ferromagnetic or ferrimagnetic. They have tendency to move from a region of weak magnetic field to strong magnetic field [4]. As long as the magnetized particles exhibit low levels of magnetic coercivity, many different metals or alloys can be used in the composition of MR fluids [8]. Usually, the MR particles are pure iron, carbonyl iron, or cobalt powder dispersed in carrier fluid where the suspension has rheological properties (viscosity and yield stress) that may be modified by an applied magnetic field [13]. In the absence of a magnetic field, the MR particles are randomly distributed in the fluid. However, under the influence of an applied magnetic field, the MR particles acquire a dipole moment aligned with the external field and form chains as shown in figure 1.This chain formation induces a reversible yield stress in the fluid. In addition, the yield stress (50 – 100Kpa) of the MR fluid is continuously and rapidly adjustable because it responds to the intensity of the applied magnetic field (150 – 280KA/m). As a result, MR fluid-based devices have inherent advantages such as continuously variable dynamic range and fast response.

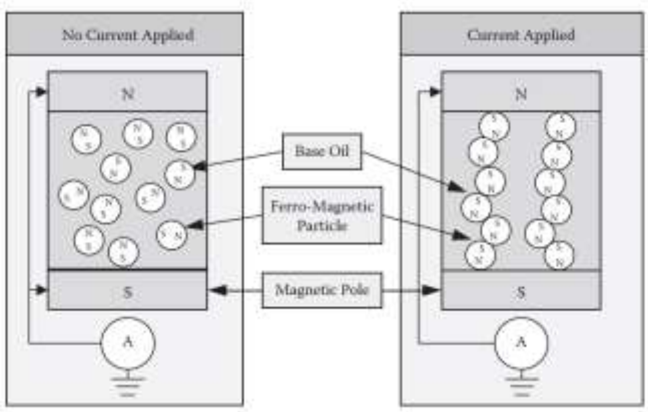


Figure 1.Microstructure of MR fluid [8].

2. MR FLUID COMPONENTS

2.1 Liquid carrier

The carrier fluid is a non – magnetic, organic, or aqueous liquid [8]. The major constituent of MR fluids is liquid carrier (50 – 80% by volume) [5].The preferred carrier fluid should be non – volatile, non- polar and does not include any significant amount of water [6]. Hydrocarbons such as mineral oils, paraffins, cycloparaffins, synthetic hydrocarbon oils and silicon oils are preferred class of carrier fluids.

Table 1: Properties of carrier fluids [5]

Properties	Mineral oil	Synthetic oil	Silicon oil
Viscosity @40 ^{0}C(Pa-s)	0.028	0.1068	0.110
Flash point ^{0}C	171-185	230	>300
Fire point ^{0}C	260-330	350	~500
Specific gravity	0.818 – 0.95	0.817	0.9124
Density at 25 ^{0}C (Kg/m^3)	825	873-894	760
Pour point ^{0}C	-25 to -50	-30 to -50	-50
Cloud point ^{0}C	-15	-20	-20
Market cost/ litre (Rs.)	~80	~800	~900

2.2 Magnetic Particles
Iron powder is the most commonly used particles in the MR fluid [9]. The concentration of magnetic particles in base fluid can go up to 50% [10]. MR fluid has high saturation magnetization and under the influence of a magnetic field, these iron particles are arranged to form very strong chains of "fluxes" with the pole of one particle being attracted to the opposite pole of another particle [9]. Low retentivity and coercivity, high saturation magnetization, high permeability, small remnance and high electrical resistivity are the preferred magnetic properties of MR fluids as it bounds smaller hysteresis loop [12].

2.3 Additives
The additives include stabilizers and surfactants .Additives are suspending agents, thixotropic, friction modifiers and anti-corrosion/wear components. Highly viscous materials such as grease or thixotropic additives are used to improve settling stability. Ferrous naphthanate or ferrous oleate can be used as dispersants and metal soaps (lithium stearate or sodium stearate) can be used as thixotropic additives. Additives are used to control the viscosity of the liquid and the settling rate of the particles, the friction between the particles and to avoid the in-use thickening for a defined number of off-duty cycles [11]. Based on total volume of MR fluid percentage of additive is 0.5 % to 7.5% [6]. Organomolybdenum additive provides durable MR fluid. [14].

3. OPERATION MODES OF MR FLUID [8]

3.1 Shear Mode
When MR fluid is used as a controllable actuator in application devices, the working behaviour of the fluid is classified into three different modes. In the shear mode, it is normally assumed that one of the two field activation parts is free to translate or rotate about the other. Applications include brakes, clutches and vibration isolation mounts for small magnitude excitation.

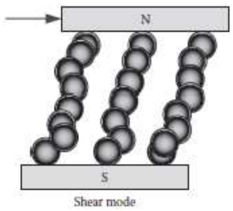


Figure: 2 Shear Mode

3.2 Flow Mode
In the flow mode it is assumed that two field activation parts are fixed. There are essentially two control volumes in this mode, and the actuating force is controlled by adjusting the pressure difference between the two control volumes. Applications include shock absorbers for vehicle suspension system, seat dampers etc. Another application of flow mode type damper is in medical devices, such as prosthesis (MR damper for leg).

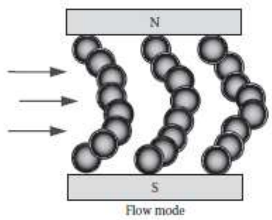


Figure: 3 Flow Mode

3.3 Squeeze Mode
In squeeze mode the activation gap is varied in the vertical direction. In this mode the MR fluid is squeezed by a normal force, hence both tensile and compressive forces can be controlled by the field intensity. Applications include vibration isolation systems for small magnitude excitations.

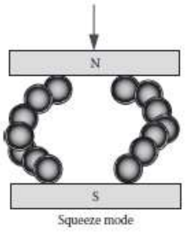
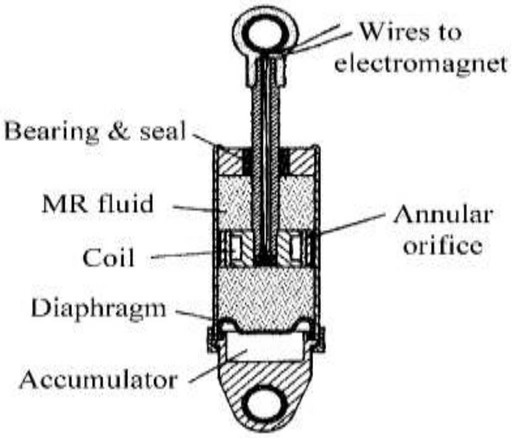


Figure: 4 Squeeze Mode

4 MR FLUID DEVICES

MR fluid based dampers as shown in figure have been commercialized for use in a semi active seat suspension system for large on and off highway vehicles [16]. MR fluid dampers are characterized by large damping force, low power consumption etc.



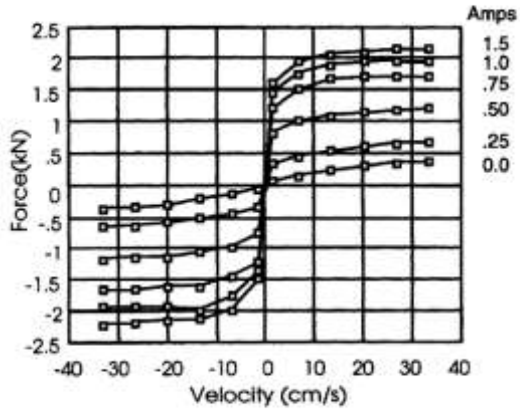


Figure 5. MR Fluid linear damper [17] Figure 6: Performance curves of linear MR damper [17]

The translation of the piston causes the flow of the fluid through axial opening in the coils. The control of the damping properties in the module relates to current feed of electrical coils arranged in the piston. Magnetic field generated by the coils influences the viscosity of the MR fluid flowing through the holes and causes resistance to the piston translation. A gaseous accumulator compensates a difference in the volume of the fluid at the front and backside of the piston. [18].

The controllable MR damper is capable of providing a wide dynamic range of force control for very modest force control and input power levels as shown in figure 5.The damper is 4.1cm diameter, has a 17.9 cm eye to eye length at mid stroke and has a ±2.9cm stroke. The MR fluid valve and associated magnetic circuit is fully contained within the piston. Current is carried to electromagnetic coil via the leads through hallow shaft. An input power of 5w is required to operate the damper at its nominal design current of 1amp. Although damper contains about 70cm^3 of MR fluid, actual amount of fluid activated in magnetic valve at any given instant is only about 0.3cm^3 [16].

5. SEMI ACTIVE SEAT SUSPENSION WITH MR DAMPER

Numerous heavy industrial vehicle types, extended driving hours, and exposure to severe working environments are transportation-related factors in industry and agriculture. The increased number of these vehicles inevitably results in increased demand for improved ride comfort. The ride vibration detected at the driver's seat significantly influences driver fatigue and safety. In fact, the ride vibration levels of commercial vehicles are 9 to 16 times higher than those of passenger cars, and most commercial vehicle drivers are exposed to this ride vibration for 10 to 20 hours a day [21]. Although ride comfort improvements have been attempted through appropriate suspensions, commercial vehicle drivers still suffer from the effects of low-frequency and high-amplitude ride vibration. To overcome this semi-active seat suspension with MR damper was introduced.

Semi-active seat suspension consists of spring and damper whose damping force can be adjusted in real time. MR damper fluid is an excellent semi-active control device, it possesses simple structure, large dynamic force, good durability, low energy consumption and strong reliability, which can be treated as a passive control devices even the control system failures. MR damper as a semi-active control device combines the reliability of passive control systems and the strong adaptability of active control system [19]. Proper tuning of the parameters of the feedback system enable optimization by elimination of resonance and retention of good high frequency isolation, greatly reducing the dangers of driving on bumpy roads by controlled damping [17]. Performance of controlled damping is shown by the curve.

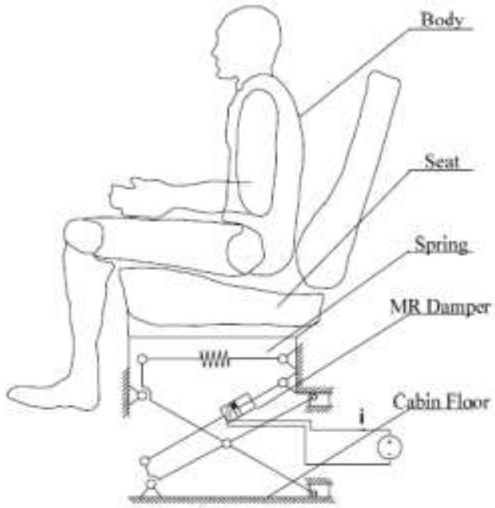


Figure.7. Physical model of semi active seat seat [17].

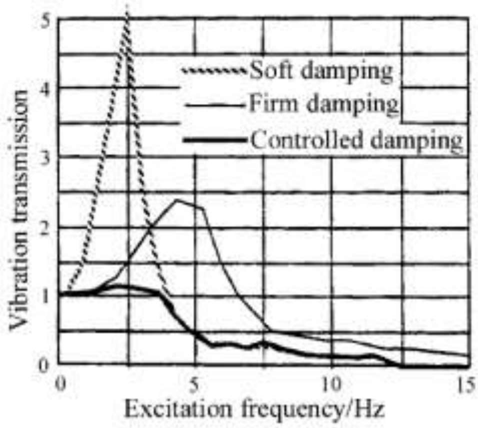


Figure 8: Performance for an MR semi – active controlled suspended Suspension with MR damper [19].

6 .MR DAMPER IN MEDICAL DEVICES.

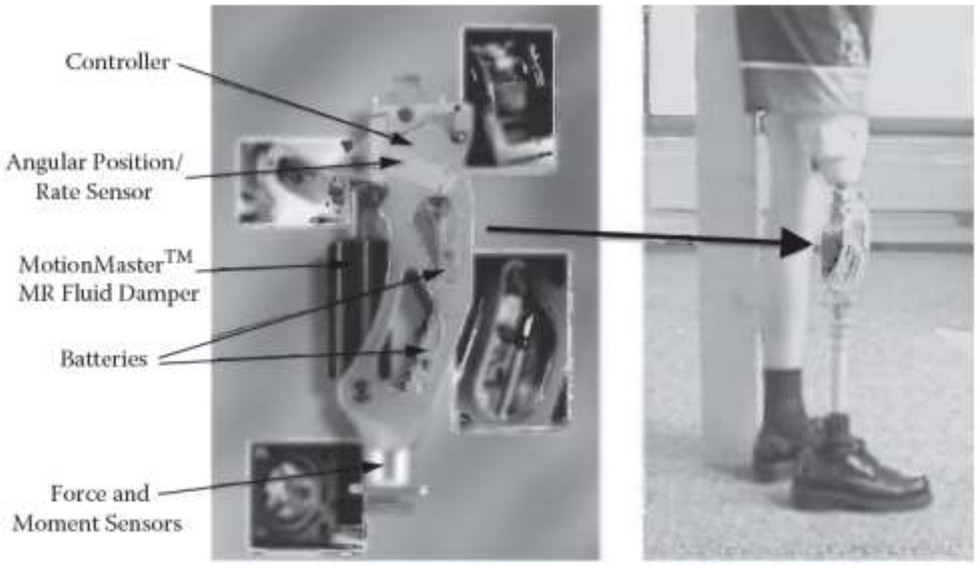


Figure 7: MR damper for leg [8].

7. SINGLE COIL MR VALVE

Figure shows the schematic configuration of a typical single-coil MR valve. The valve consists of valve coil, core, and housing. MR fluid flows from the inlet, through annular ducts between the core and the housing to the outlet. As the power of the coil is turned on, a magnetic field is exerted on the MR fluid in the annular duct between the magnetic poles. This causes the MR fluid to change its state into a semi-liquid or solid phase and hence stop the flow. Thus, this MR valve can be used as a relief valve, a pressure control valve, or a flow rate control valve.

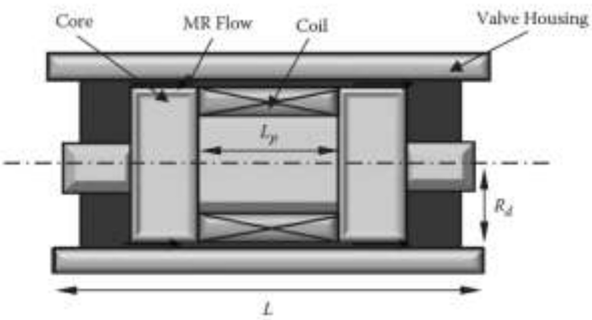


Figure 9: Single coil MR valve [8]

8. BI-DIRECTIONAL MR BRAKE

The Bi-directional MR brake consists of two coils, two rotors, one outer casing, and MR fluid filling the gap between the rotors and the casing. In order to avoid two magnetic fields interfering with each other, a non-magnetic partition is inserted at the middle location of the casing. Two powers to supply to the coils are distinct such that the current magnitudes of these coils can be controlled independently. Unlike other (conventional) MR brakes, which only have one rotor and one stator (casing), the casing in this brake is not stationary. Indeed, it is fixed to a driving shaft, which might be connected to a one-dimensional handle in haptic applications. Moreover, two rotors are fixed to their respective shafts, which are transmitted from a driving bi-output source so that they rotate counter to each other. This assures that there exist two relative shear motions between the surfaces of two rotors and the outer casing even when the casing is at a stop. Seung – Bo; Choi, Young-Min Han [8] clearly stated the working of bi-directional MR brake and also the total torque generated. Chiranjit Sarkar and Harish hirani [20] synthesized the CI based MR fluid and proved that CI based MR fluid shows better chain strength and less agglomeration as compared to MRF 241ES fluid.

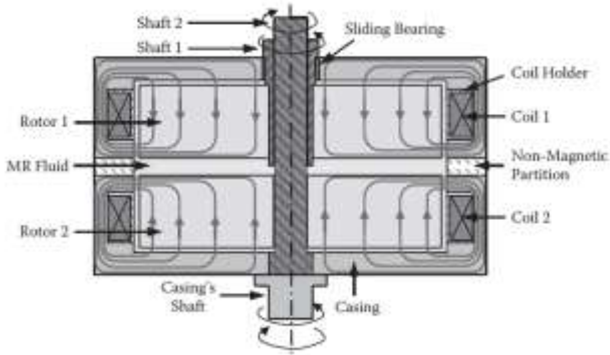


Figure 10: Bi directional MR brake [8]

9. DEMERITS OF MR FLUID

Conventional MR fluids have some disadvantages finding widespread commercial use, due to settling of particulates suspended in the fluid in the absence of constant mixing [22]. In time they settle into a hard cake making re-dispersion of particles difficult. The tightly hard cake is extremely hard to re-disperse due to strong aggregation and the remnant magnetization between the particles, which are not vanished even without magnetic field application. Higher the hardness of MR fluid the more difficult to re-disperse the fluid [10]. Re dispersion problem can overcome by adding a surfactant, such as lecithin was suggested to improve mix ability of the MR fluid. This decreases the permeability of the fluid and therefore reduces the settling rates of the particles [23].

The clumping effect occurs when higher magnetic field is applied to the magneto-rheological fluid for a longer period of time. As the clumping becomes apparent, the magnetic particles in the magneto-rheological fluid become entrapped in the chains that were formed under magnetic field. In this study, it is clearly showed that the clumping effect occur due to the rapid increments of both force and displacement transmission through the carrier fluid. Therefore, the magneto-rheological fluids become stiffer and have higher damping values [24]. Following figure shows the clumping process throughout three cycles of test.

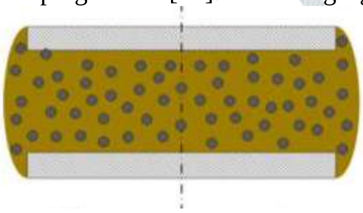


Fig.11.1 First cycle test

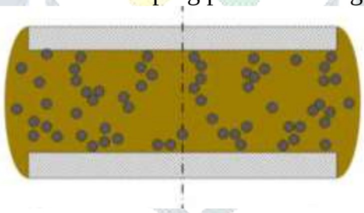


Fig.11.2 Second cycle test

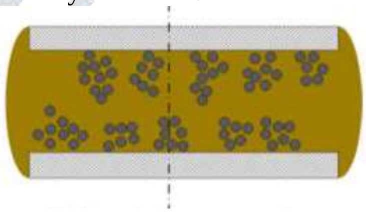


Fig.11.3Third cycle test

Separation of carrier fluid and iron particles was observed when magneto-rheological fluid being compressed between two parallel plates. The phase separation of the fluid was observed. Aggregations of the particles also were produced. Besides, resistance to compressive motion was increased. Therefore, FPS phenomenon occurred due to pressure build up, magnetic field distribution and changes of particles chain structure [25, 26].The concentration of magnetic particles in carrier fluid is up to 50% by volume [5].Particles suspended in carrier fluid can be iron, iron oxides and its alloys. However, most frequently used material of magnetic particles in magneto-rheological fluid is carbonyl iron powder (CIP) with iron content of 97–99 % [27]. Magnetic particles which are iron based particles always faced some challenges in magneto-rheological fluid technologies. Once expose to atmosphere, either spontaneously or in operating at high temperatures, oxidation of the particles will lead to lesser the magnetizing ability of the particles. Therefore, the magneto-rheological effect will be diminished [28]. Particles oxidation leads to increase the off-state viscosity of the magneto-rheological fluid over time. Besides, devices failures might occur. Perhaps, an unmanageable paste magneto-rheological fluid will be. The will be increased in off-state viscosity because of the increased in solid volume. The action between small particles might also generate colloidal forces of the magneto-rheological fluid [29].

10. CONCLUSION

Most of the MR fluid fails due to sedimentation of particles i.e., formation of hard cake, clumping effect, fluid particle separation and oxidation of particles, which constrained its usage in various applications. A further advancement of MR fluid is usages of nano particles, nano wires or nano powders as magnetic particles forming a nano fluid based MR fluid, which improves its stability and becomes more favorable for various applications like dampers, clutches, lubricants and bearings. The off-state (field off) viscosity of fluids containing only wires was found to be substantially greater than those MR fluids that contain only spherical particles. The fluids containing spherical nickel particles tended to settle rather quickly (< 20 minutes), while those containing only wires remained suspended even after several months. The yield properties improved with added magnetic nano particles and sedimentation of MR fluid also reduced.

REFERENCES

[1] Mahesh Chand, Ajay Shankar, Noorjahan, Komal Jain and R.P.Pant., Improved properties of bi dispersed magnetorheological fluids. Royal society of chemistry advances. 2014, 4, 53960-53966.
[2] R.C.Bell, E.D.Miller, J.O.Karli, A.N.Vavreck and D.T.Zimmerman., Influence of particle shape on the properties of magnetorheological fluids. Int.J. Modern physics. Vol 21, Nos.28 & 29 (2007) 5018 – 5025.
[3] SA Wahid, I Ismail, S Aid, MSA Rahim., Magneto- rheological defects and failures: A review. IOP conf. Material sci. & Engg.
[4] Yichuan Wang., Magnetic particles study and their application. Thesis, Feb 2014.
[5] Bhau K. Kumbhar, Satyajit R.Patil., A study on properties and selection criteria for magnetorheological (MR) fluid components. Int. J.ChemTech research. Vol.6, No.6 (2014)3303 -3306.
[6] Thomas J.Karol, Beth C.Munoz, J.Margida ., Magnetorheological fluid. US patent. Patent no.5906767, May 25, 1999.
[7] John M.Ginder, Larry D.Elie, and Lloyd C.Davis., Magnetic fluid – based magnetorheological fluids. US patent. Patent no. 5549837, Aug.27, 1996.
[8] Seung – Bo; Choi, Young-Min Han., Magnetorheological fluid technology, applications in vehicle systems.
[9] Kalurkar S.L, Darade P.D, Korade D.N., A review on magnetorheological fluid preparation and its testing using rheometer. IJESC, Vol.6, No.7 (2016) 8390 – 8393.
[10] Beth C.Munoz, Gary W.Adams, Van Trang Ngo, John R.Kitchin., Stable magnetorheological fluids. US patent. Patent no. 6203717, Mar. 20, 2001.
[11] A.G.Olabi, A.Grunwald, Design and application of magneto-rheological fluid. Elsevier, Science Direct, Material&Design 28 (2007) 2658 – 2664.
[12] Bhau K.Kumbhar, Satyajit R.Patil, Suresh M.Sawant., Synthesis and characterization of magnetorheological (MR) fluids for MR brake applications. Elsevier, Science Direct, Engg. Sci. and tech, an Int.J 18(2013) 432-438.
[13] Alan L.Browne, Nancy L.Johnson, Peter Maxwell Sarosi, John C.Ulieny., Magnetorheological fluids including shape memory alloys. US patent. Patent No. 0153816A1, Jun.20, 2013.
[14] Beth. C.Munoz, J.Margida, Thomas J.Karol., Organomolybdenum containing magnetorheological fluid. US patent. US patent No.575085, Jan 6, 1998.
[15] Deepak Baranwal, Dr.T.S.Deshmukh, MR-Fluid technology and its application – A Review. IJETAE Vol.2, 12 (2012) 2250 – 2459.
[16] Jolly, M.R., Jonathan, W.B., and Carlson, J.D.1999. Properties and applications of commercial magnetorheological fluids. J. of intelligent material systems and structures 10:5-13.
[17] J.Wang, G.Meng., Magnetorheological fluid devices: Principles, characteristics and applications in mechanical engineering.I.MechE, Vol 215 ,(2001) 165-174.
[18] A.Roszkowski, M.Bogdan, W.Skoczynski, B.Marek., Testing viscosity of MR fluid in magnetic field. Measurement Sci.review. 8(2008) 58-60.
[19] H.J.Yao, J Fu, M Yu, and Y X Peng., Semi-active $H\infty$ control of seat suspension with MR damper. J. of physics. Conf. series. 412 (2013) 1- 16.
[20] Chiranjit Sarkar and Harish hirani., Synthesis and characterization of antifriction magnetorheological fluids for brake. Defence science journal, Vol.63 (2013) 408-412.
[21] Queslati, F. and Sankar, S. 1992. Performance of a fail-safe active suspension with limited state feedback for improved ride quality and reduced pavement loading in heavy vehicles. SAE Paper 922474: 796–804.
[22] L.S.Chen and D.Y.Chen, Permalloy inductor based instrument that measures the sedimentation constant of magnetorheological fluids. Rev. Scien.Instru.74.3566 (2003).
[23] Powell LA, Hu W, Wereley NM. 2013. Magnetorheological fluid composites synthesized for helicopter landing gear applications. Journal of Intelligent Material Systems and Structures; **24**: 1043–1048.
[24] Adjerid K. 2011.A study on the dynamic characterization of a tunable magneto-rheological fluid-elastic mount in squeeze mode vibration. Blacksburg, Virginia: Virginia Polytechnic Institute and State University.
[25] Ismail I, Aqida SN.2014 Fluid-particle separation of magnetorheological (MR) fluid in MR machining application. Key Engineering Materials: Trans Tech Publ. p. 746-755.
[26] Ismail I, Mazlan SA, Zamzuri H, Olabi AG. 2012. Fluid–particle separation of magnetorheological fluid in squeeze mode. Japanese Journal of Applied Physics; **51**:067301.
[27] Wang Y. 2014.Magnetic particles study and their applications. York: University of York.
[28] Klingenberg DJ. 2001. Magnetorheology: Applications and challenges. AICHE Journal; 47:246-249.
[29] De Vicente J, Klingenberg DJ, Hidalgo-Alvarez R. 2011. Magnetorheological fluids: A review. Soft Matter; 7:3701-3710.