DESIGN AND PERFORMANCE ANALYSIS OF MR VALVE

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ABSTRACT

Magneto-Rheological Fluid (MRF) Technology has been successfully employed in various low and high volume automotive applications. Good understanding of specific design constraints is required to define and optimize a Magneto-Rheological device. An evolution of components based on MRF might be the next generation in design for products where power density, accuracy and dynamic performance are the key features especially, for products where there is a need to control fluid motion by varying the viscosity. Two aspects of this technology, direct shear mode (used in brakes and clutches) and valve mode (used in dampers) have been studied thoroughly in literature along with several application like direction control valve, pressure control valve. Outstanding features like fast response, simple interface between electrical power input and mechanical power output, and precise controllability make MRF technology attractive for many applications. Three types of fluid-Ferro fluid, Ferro oxide, and Iron powder with silicon oil and various weight ratios have been considered in this work. From various test like SEM, Viscosity of oil, Magnetic flux, Magnetic response by using MATLAB and FEMM, it has been seen that the MR Fluid (50ml silicon oil + 0.1g of iron powder) gives desirable performance. This paper presents the state of the art design and testing of a valve with a control arrangement based on MRF technology along with its salient features like fast response, leakage control, their simple and compact design.

Keywords; MR Valve, MR Fluid, FEMM V4

I INTRODUCTION

A magneto rheological fluid (MR fluid) is a type of fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its viscosity, to the point of becoming a viscoelastic solid. Importantly, the yield stress of the fluid when in its active ("on") state can be controlled very accurately by varying the magnetic field intensity. The fluid's ability to transmit force can be controlled with an electromagnet, which gives rise to its many possible

Control-based applications.MR fluid is different from a Ferro fluid which has smaller particles. MR fluid particles are primarily on the micrometer-scale and are too dense for Brownian motion to keep them suspended (in the lower density carrier fluid). Ferro fluid particles are primarily nano particles that are suspended by Brownian motion and generally will not settle under Normal conditions. As a result, these two fluids have very different application. While much of the fluids Success have been realized in devices intended for Automotive or civil engineering applications, recent studies [1] have investigated the fluid's promise in Impact or shock related applications. These emerging applications, and many current applications, subject the fluid to extreme flow conditions. Specifically, these flow environments or conditions include high shear and high velocity flow. The challenge in such devices becomes the lack of information regarding the behaviour of MR fluid under these adverse operating conditions. This chapter will review the fundamental behaviour of MR fluids and present some of the existing MR fluid devices. An introduction of some of the emerging applications of MR fluids then follows. An MR fluid is works in one of three main modes of operation, these being flow mode, shear mode and squeeze-flow mode [2]. These modes involve, respectively, fluid flowing as a result of pressure gradient between two stationary plates; fluid between two plates moving relative to one another; and fluid between two plates moving in the direction perpendicular to their planes. In all cases the magnetic field is perpendicular to the planes of the plates, so as to restrict fluid in the direction parallel to the plates. A. G. Olabi [1] in the year 1940s, Jacob Rabinov discovered the MRF effect at the US National bureau of Standards. At that time only W.Wislow was discovered ERF, since the both technologies were discovered in 1940 only. This two technologies required power, ERF required thousands of volts and some mA and the MRF required 2 to 24 volts and some amperes. The electro-rheological (ER) effect depends on an electrostatic field and the magneto rheological (MR) effect depends on a magnetic field. MRF products 20 to 50 times higher

Control effect than the equivalent ERF products. Recent five year MRF more publications than ERF Nowadays some industries application based on MRF, especially for automotive industries. Recently MRF had applied in dampers, clutches and active bearing. A. Grunewald [4] He presented this article about parametrical analysis with magnetic simulations, of a magneto-rheological valve and a magneto-rheological orifice. He had designed an orifice and valve and the performances have been evaluated experimentally. In this experimental testing the pressure drop of the orifice are 1.5MPa @ 4.5A at 0 cm^3/s, in the valve mode, using MRF132-AD, have been achieved. He said that this

Study show that excellent features like the fast response. This Magneto-Rheological Fluid (“MRF”) technology has been successfully employed in various low and high volume automotive applications. A.Roszkowski [3] in this paper he determine the coefficient of viscosity of a magneto rheological fluid for different values of magnetic field and also, he determine flow of the fluid through a capillary is stopped. He constructed a test stand with capillary viscometer. In final show the measurement of the viscosity of the magneto rheological fluid was linearly dependent in a wide range of values of the magnetic induction. Zhang Jinqiu [5], this research is to improve the characteristic of a magneto rheological fluid. He investigated the dynamical simulation in MATLAB, the microstructure of MRF, mechanism of MRF and factors affecting characteristic of MRF. This experiment validated in rotary shear yield stress equipment. He experiment and study the characteristic of MR Fluids formulations influenced by nano. Here he take four different nano size particle (10nm, 20nm, 30nm, 50nm) from that each have different weight fraction (60%, 70%, 80%, 85%).in the addition of nano sized particles reduces sedimentation rate.

II PREPARATIONS OF MR FLUIDS

Ferro fluids are ultra-stable colloids of nano-sized sub-domain magnetic dipolar particles inappropriate carrier liquids, actually an achievement of colloid science. Macroscopically, these fluids manifest themselves as magnetizable liquid media due to the "integration" in the structure of the carrier of sub-domain permanent magnetic dipolar particles. The size of magnetic particles in a Ferro fluid is in the nanometer range (3-15 nm), consequently, the magnetic moment of micron particles in MRFs is field induced and their Brownian motion is negligible, while in the case of Ferro fluids the magnetic nano particles have permanent dipole moment and perform intense thermal motion. Particle aggregation processes are reversible and rather intense in MR fluids and are induced by the applied magnetic field, which is their key feature in developing field controlled flow behavior. Agglomerate formation in Ferro fluids is limited due to thermal motion of nano particles and their strict or electrostatic stabilization in the carrier liquid; therefore the field induced changes in flow behavior usually are not significant. Ferro fluids have friction-reducing capabilities. If applied to the surface of a strong enough magnet, it can cause the magnet to glide across smooth surfaces with minimal resistance.

2.1 Synthesis of Ferro Fluid

At nano scale, a specific difficulty associated with the preparation of magnetic fluids is that the nano particles have large surface area-to-volume ratios and thus tend to aggregate to reduce their surface energy. In particular, magnetic metal oxide surfaces have extremely high surface energies (>100dyn/cm) that make the production of nano particles very challenging. In addition, magnetic dipole-dipole attractions between particles enhance the difficulties experienced in the production of Ferro fluids. Long-range, attractive Vander Waals and magnetic forces are ubiquitous and therefore must be balanced by Columbic, satiric or other interactions to control the colloidal stability of dispersed nano particle system, even in intense and strongly non-uniform magnetic field. Ferro Fluids are colloidal systems composed of isolated particles with nanometer-sized dimensions that are stabilized by surfactant molecules and dispersed in solvent media. In the ideal case, these non-interacting systems derive their unique magnetic properties mostly from the reduced size of the isolated nano particles, and contributions from antiparticle interactions are negligible. The synthesis of Ferro fluids has two main steps: (a) the preparation of nano-sized magnetic particles and (b) the subsequent stabilization/dispersion of the nano particles in various non-polar and polar carrier liquids.

2.2 Materials Required

The materials required for making Ferro fluid preparation are mentioned below.

1. Ferric chloride
2. Ferrous chlorides
3. Aqueous ammonia solution
4. Concentrated hydrochloric acid
5. Magnetite
6. Stirrer

2.3 Particle size test of Ferro fluid

2.4 Iron oxide preparation

The classical way of preparing ceramic oxide compounds (ferrites) in which the oxides (or) carbonates of semiconductor components are mixed and annealed at high temperature (>1200oC) has some inherent disadvantages such as production of chemically in homogeneous coarse powders as a consequence of high sintering temperature.

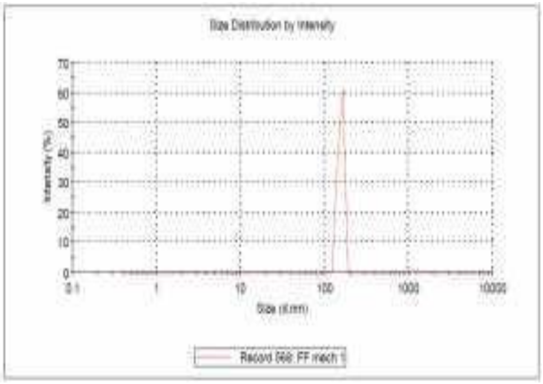


Figure 2.1 Particle Size Test of Ferro Fluid

Figure 2.2Iron Oxide in Furnace

To avoid such events, various chemistry based synthetic methods have been adopted namely sol-get techniques, co-precipitation method, hydrothermal synthesis, micro emulsion synthesis etc. to obtain ceramic products with superior microstructure. So, sol-gel combustion technology is applied to prepare homogeneous and sub-micron sized powder of oxide compounds. Reason for the combustion of sol-gel technique and self-combustion has been to use the heat generated by an exothermic combustion reaction to supply the high temperature needed for sintering the metal oxides, thus allowing a low cost preparation method. The main feature of SGS method is the intimate mixing of constituent ions, so that nucleation and crystallization can occur at relatively low temperature.

2.5 Materials required

The materials required for making iron oxide preparation are mentioned below.

1. Iron nitrate
2. Citric acid
3. Distilled water
4. Ammonium hydroxide
5. Beaker
6. Stirrer
7. PH paper

III EXPERIMENTAL APPARATUS

The scanning electron microscope (SEM) is a type of electron microscope that creates various images by focusing a high energy beam of electrons on to the surface of a sample and detecting signals from the interaction of the incident electrons with the sample surface. The type of signals gathered in a SEM varies and can include secondary electrons, characteristic x-rays, and back scattered electrons. In a SEM, these signals come not only from the primary beam impinging upon the sample, but from other interactions within the sample near the surface. The SEM is capable of producing high-resolution images of a sample surface in its primary use mode, secondary electron imaging. Due to the manner in which this image is created, SEM images have great depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample. This great depth of field and the wide range of magnifications are the most familiar imaging mode for specimens in the SEM. Characteristic x-rays are emitted when the primary beam causes the ejection of inner shell electrons from the sample and are used to tell the elemental composition of the sample.

To improve resolution is by reducing the size of the electron beam that strikes the sample:

$D_{min} = 1.29C_s1/4\lambda3/4[7.92\ (it/J_c)\ x109+ 1]3/8$ J_c = current density of the source,

λ = electron wavelength C_s= spherical aberration, i = current,

T = temperature

The resolution is increased by the following factors:

- Increasing the strength of the condenser lens
- Decreasing the size of the objective aperture
- Decreasing the working distance

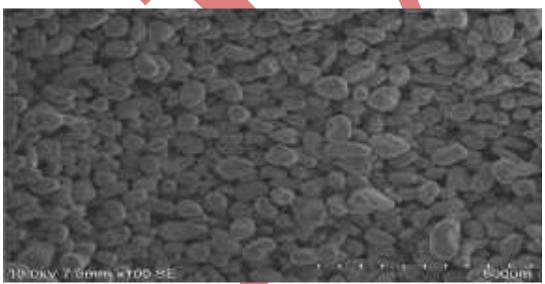
(WD = the distance the sample is from the objective lens)

The height over which a sample can be clearly focused is called the Depth of Field. The SEM has a large depth of field which produces the images that appear 3 dimensional in nature.

Depth of field is improved by:

- Longer working distance
- Smaller objective apertures
- Lower magnifications

3.1 SEM test results



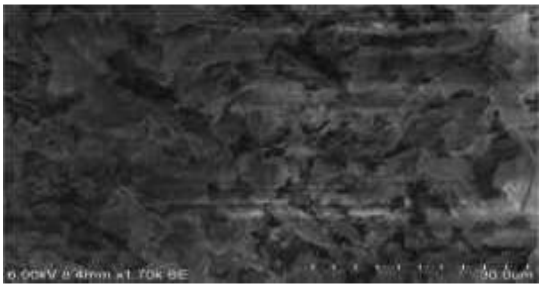


Fig 3.1 Test result for 500 micro meters Ferro fluid **Fig 3.2 Test result for 30 micro meters Iron oxide**

Iron powder is used as a magnetic particles which have less than 4 microns diameter and this range of size is considered perfect for MR fluids. Iron particles are sub-micrometer particles of iron metal. They are highly reactive because of their large surface area. In the presence of oxygen and water, they rapidly oxidize to form free iron ions. They are widely used in medical and laboratory applications and have also been studied for remediation of industrial sites contaminated with chlorinated organic compounds.

Fig 3.3 SEM Image-Before Grinding

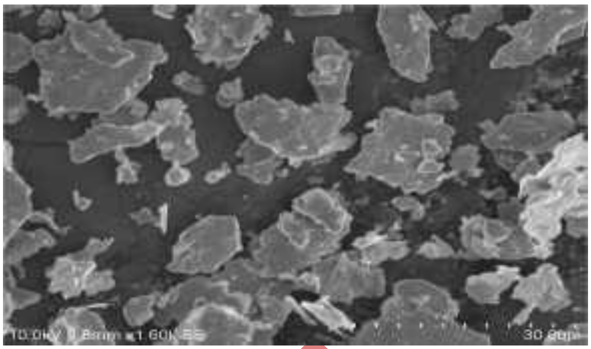


Fig 3.4 SEM Image-After Grinding

The carrier oil is chosen as silicone oil**.** Silicone oil is any polymerized siloxane with organic side chains. They are formed of alternating silicon-oxygen atoms, rather than carbon atoms.

Features of Silicone Oil

- Water clear fluid with viscosities ranging from 0.65 to 1, 00,000 centistokes.
- Exhibits very high flash points and is non-greasy and odorless.
- Low –toxicity.
- Little change in physical properties over a wide temperature span.
- The very high viscosity-index, thermal and chemical stability and compressibility make this as a mechanical fluid.

The surfactants prevent the nano particles from clumping together, ensuring that the particles do not form aggregates that become too heavy to be held in suspension by Brownian motion. The magnetic particles in an ideal Ferro fluid do not settle out, even when exposed to a strong magnetic or gravitational field. A surfactant has a polar head and non-polar tail (or vice versa), one of which absorbs to a nano particle, while the non-polar tail (or polar head) sticks out into the carrier medium, forming an inverse or regular micelle, respectively, around the particle. Sterric repulsion then prevents agglomeration of the particles. While surfactants are useful in prolonging the settling rate in MR fluids, they also prove detrimental to the fluid's magnetic properties. The addition of surfactants decreases the packing density of the Ferro particles while in its activated state, thus decreasing the fluids on-state viscosity, resulting in a "softer" activated fluid. While the on-state viscosity (the "hardness" of the activated fluid) is less of a concern for some Ferro fluid applications, it is a primary fluid property for the Majority of their commercial and industrial applications and therefore a compromise must be met when considering on-state viscosity versus the settling rate of a Ferro fluid. Sonication is the act of applying sound (usually ultrasound) energy to agitate particles in a sample, for various purposes. In the laboratory, it is usually applied using an ultrasonic bath or an ultrasonic probe, colloquially known as sonication. In a paper machine, an ultrasonic foil can distribute cellulose fibers more uniformly and strengthen the paper. Sonication can be used to speed dissolution, by breaking intermolecular interactions. It is especially useful when it is not possible to stir the sample, as with NMR tubes. It may also be used to provide the energy for certain chemical reactions to proceed. Sonication can be used to remove dissolved gases from liquids (degassing) by sonication the liquid while it is under a vacuum.

Figure 3.5 Sonicator

Figure 3.6 Redwood Viscometer

Redwood viscometer is an instrument used to measure the viscosity of a fluid. Viscometers only measure less than one flow condition. This viscometer is used to measure the viscosity of the fluid at various ranges of temperatures. There are two cylinders in the viscometer. The inner cylinder is filled with MR fluid to the marker level and the outer cylinder is filled with water. The surrounding water is heated with an electrical heating coil. The heat is transferred to the inner cylinder by rotation of the blades of the agitator. The heat is uniformly transferred to the fluid and the surrounding water.

The Hall co-efficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, since its value depends on the type, number, and properties of the charge carriers that constitute the current. The Hall Effect comes about due to the nature of the current in a conductor. Current consists of the movement of many small charge carriers, typically electrons, holes, ions or all three. When such a magnetic field is absent, the charges follow approximately straight, 'line of sight' paths between collisions with impurities, phonons, etc. However, when a perpendicular magnetic field is applied, their paths between collisions are curved so that moving charges accumulate on one face of the material. This leaves equal and opposite charges exposed on the other face, where there is a scarcity of mobile charges.

Fig 3.7 Hall Effect Apparatus

IV MR FLUID VALVE

Different types of control arrangements have been evaluated, the MRF control valve. In case of MRF control valve, the direction of the fluid flow is perpendicular to the external magnetic field. The external magnetic field causes chain-like structures of the MRF particles to form in the gap area. The resistance to flow caused by the particle-structure for the fluid to pass is the reason for the magneto-rheological pressure drop. Fig10.2. shows a cross-section of the MRF control valve. Main assembly components are: coil, housing and internal shaft with attachments. Fig10.3 depicts the flow direction and the orientation of the magnetic field in the gap area. The MRF effect in both layouts has been evaluated theoretically and experimentally. In this study, fluids MR have been used. The yield stress is the magnetic field dependent rheological feature of the MRF. Both fluids show high yield stress in response to the applied magnetic field. In the case of silicon-based MRF, yield stress of about 45 kPa at magnetic field intensity of 200 kA/m is achievable.

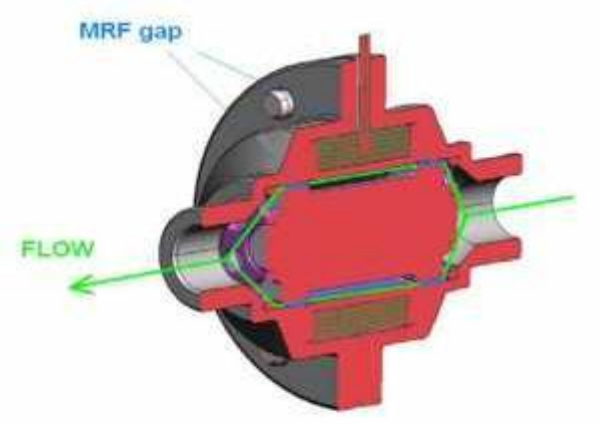


Figure 4.1 MRF Control Valve with Flow Direction

A coil in an appropriate ferromagnetic housing needs to be defined as the source of the magnetic field. The magnetic field is the result of electric power flow, current I [A] and voltage U [V], through the coil. The coil is wound around the bobbin and the magnetic field is guided through the MRF gap perpendicularly to the fluid flow. All ferromagnetic components, the housing, the internal shaft and the MRF, have to be considered for the evaluation of the magnetic circuitry. For the parametrical calculation it was necessary to perform a trial and error series of operations to find out how many turns the coil needs to have in order to provide the required field strength and how much space this coil will need. To perform these calculations, layout Geometries had to be assumed initially, i.e. the outer diameter of the housing, and then tuned to the optimum. Finally, magnetic field simulation must be used to confirm the magnetic field calculations.

Flux density has been plotted as a colour density plotted. To make a colour density plot of flux, only a black-and-white graph of flux lines is displayed. Maximum flux density value 1.689 e^{-2} Tesla this value from Fig 10.6. Flux density is known as the amount magnetic flux to a unit area taken perpendicular to direction of magnetic flux. Maximum field density value 1.387 e^{4} A/m this value from Fig 10.7

Simulation result by using FEMM software-v$_4$

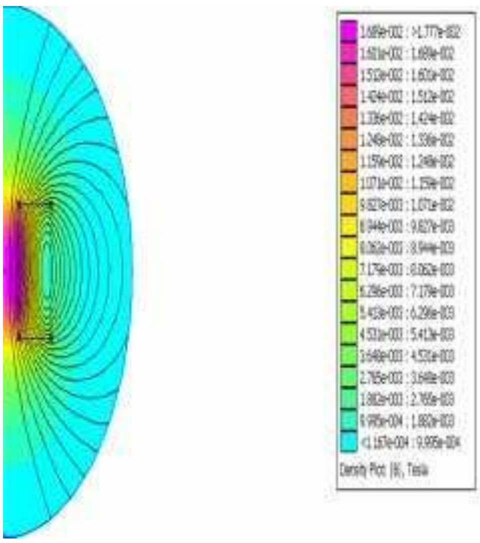


Figure 4.2 Flux Density

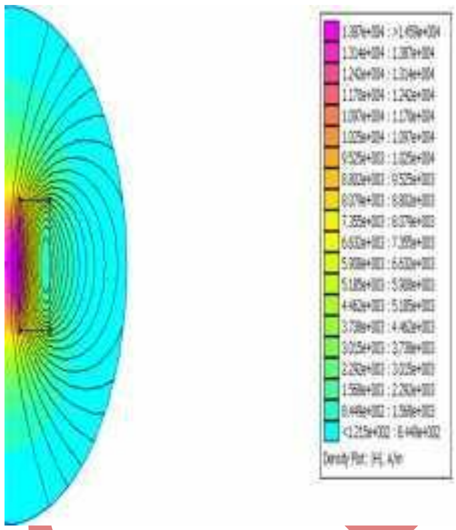


Figure 4.3 Field Density

Current density is knows as amount of current flowing through cross section area in a time interval. Maximum field Density value 7.363 e^1 MA/m^2 this value from Fig 10.8.In this case, FEMM determines which side of the boundary will be plotted based on the order in which points are added. For example, if points are added around a closed contour in a counter clockwise order, the plotted points will lie just to the inside of the contour. In closed contour line induced high magnetic flux value. If the points are added in a clockwise order, the plotted points will lie just to the outside of the contour. In this clockwise order between contour line gaps have high that time inducing magnetic flux value also decrease.

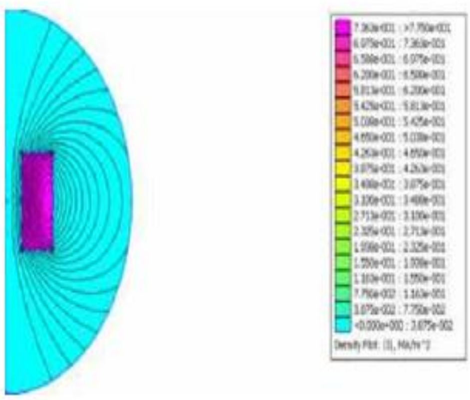


Figure 4.4 Current Density

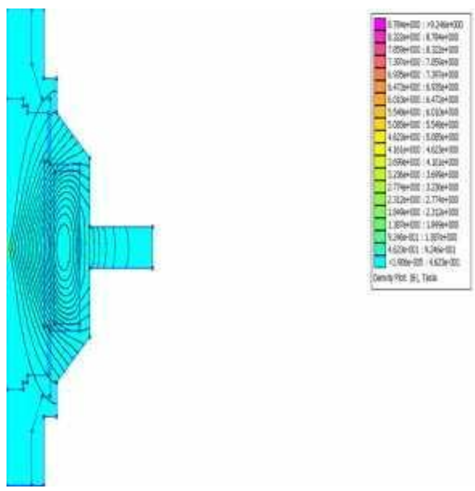


Figure 4.5 Flux Density, B Tesla

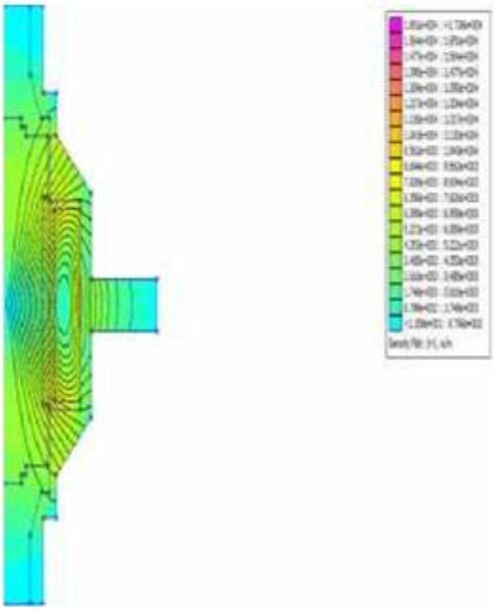


Figure 4.6 Density Plot H, A/M

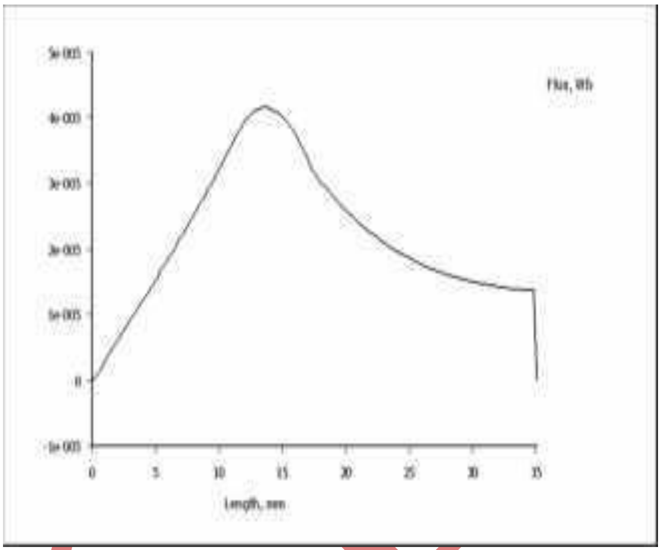


Figure 4.7 FEMM Magnetic Flux Graph

Result of circuit properties:

Total current = 1 Amps

Voltage Drop = 3.34138 Volts

Flux Linkage = 0.0229377 Weber

Flux/Current = 0.0229377 Henries

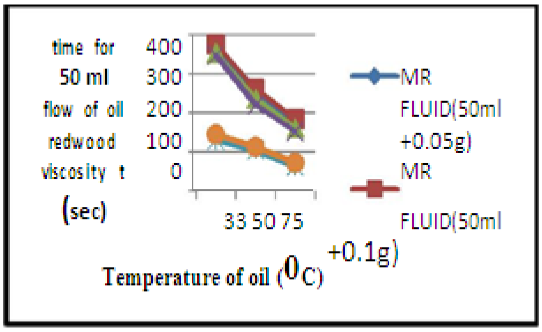
Voltage/Current = 3.34138 Ohms

Power = 3.34138 Watt

Since the problem is linear and there is only one current, the Flux/Current result can be unambiguously interpreted as the coil's inductance (i.e. 22.9 mH). The resistance of the coil is the Voltage/Current result (i.e. .34 Ω). FEMM magnetic flux graph length in mm is represented in X- axis and magnetic flux in Web is represented in Y- axis. Through the magnetic flux graph we can find out the Maximum magnetic flux value $4e^{-5}$Web that is the value in corresponding length of 15mm.

V RESULTS AND DISCUSSIONS

The redwood viscometer is used to measure the viscosity of the fluid at various ranges of temperatures. The readings for the flow of 50 cc oil are taken for different temperatures and the values are noted down. Kinematic viscosity and density of the oil are calculated by applying the formula for the readings taken.



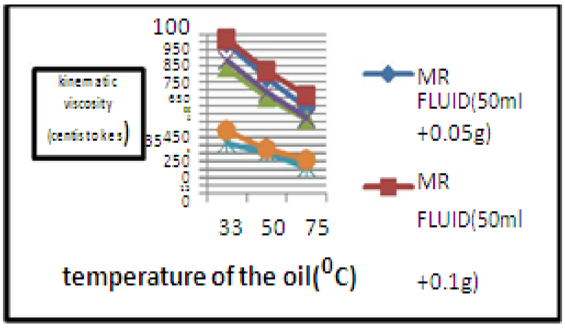


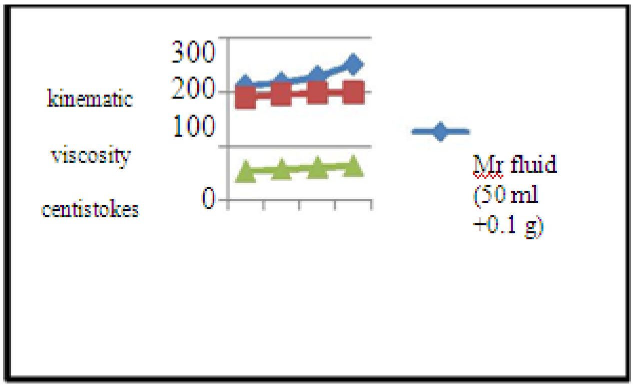
Figure 5.1 Temperature of Oil vs. Time **Figure 5.2 Temperatures vs. Viscosity of Oil**

The above graphs (Figure5.1) show that the time taken for the flow of various types of oil decreases with increase in temperature. Iron powder with silicon oil exhibits greater property than other fluids (i.e.) Ferro oxide and Ferro fluid mixed with silicon oil.

In (Figure 5.2), the viscosity of the oil decreases with increase in temperature. The iron powder mixed with silicon oil exhibits greater viscosity than other fluids (i.e.) Ferro oxide and Ferro fluid mixed with silicon oil.

The viscosity of the various types of fluids is found in Hall Effect apparatus. By varying the magnetic field the variation of viscosity of the fluid is noted. The Ostwald viscometer is placed in-between the two magnets, which produce the require magnetic field. The electric

Current and the magnetic field are varied and the viscosities are found out. The distance between the magnets can be varied according to the requirement.



Magnetic Field

Figure 5.3 Magnetic Fields vs. Viscosity of the Fluid

The below MATLAB simulation shows a result of MR fluid used in valve and the response time is shown in the graph. From the above simulation results, it is found that the response time of valve using MR fluid is better than ordinary fluid using valve. Above mention a graphs X- axis time in sec, and Y – axis reluctance mm/ web. In simulation software by using various input condition 500 web, 1000 web, 1500 web, 2000 web through this condition in various time response in corresponding field and the value of time response 43 sec, 37 sec, 25 sec, 18 sec. Reluctance is means that some iron particles are non- magnetize that time not supporting to the flow resisting.

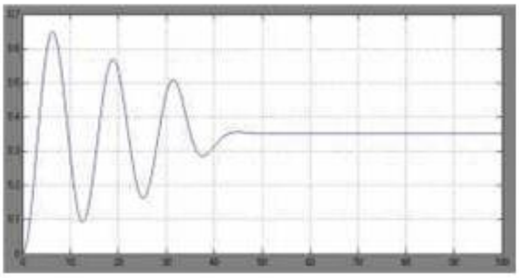


Figure 5.4 Valves with Response Time of 43 Sec

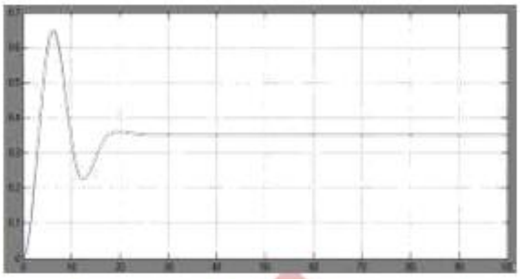


Figure 5.5 Valves with Response Time of 37 Sec

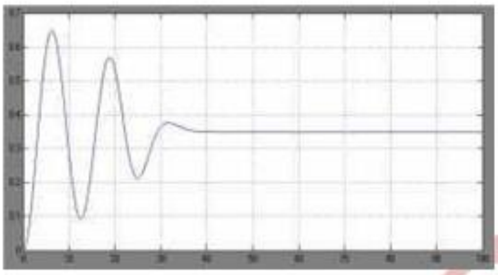


Figure 5.6 Valves with Response Time of 25 Sec

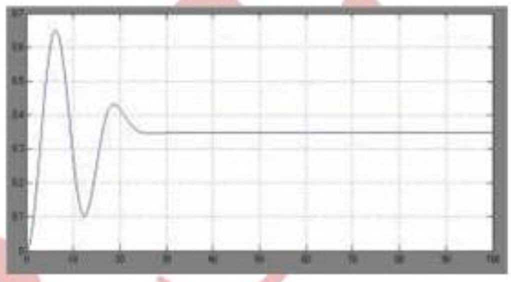


Figure 5.7 Valves with Response Time of 18 Sec

VI CONCLUSION

The results presented in this project show the good efficiency of the MR fluid (50ml Silicon oil + 0.1g of Iron powder) in the presence of magnetic field. The capillary tube viscometer has been used to measure the viscosity of the magnetic fluid under the applied magnetic field. Through the experimental investigation, the effect of the magnetic particle concentration, the applied magnetics strength and the orientation on the viscosity of the magnetic fluid have been analyzed. The viscosity is improved by comparing with the conventional fluid. Thus the MR fluid is efficient than ER fluid used in valve. In simulation software by using various input condition 500 web, 1000 web, 1500 web, 2000 web through this condition in various time response in corresponding field and the value of time response 43 sec, 37 sec, 25 sec, 18 sec, MR valve controls the leakage, and MR valve designs are very simple and compact.

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