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Instrumentation required for formulation of M.R. fluids used for automotive applications

Bhau K. Kumbhar[1], Aatishkumar J. Gupta[2], Abhishek P. Bodade[2], Adhiyash R. Mestry[2], Jay S. Doshi[2]

[1] Assistant Professor, Automobile Engineering Department, Saraswati College of Engineering, Maharashtra (MH), India.

[2] Student, Automobile Engineering Department, Saraswati College of Engineering, India

Abstract:- Magneto-rheological (MR) fluids consist of stable suspensions of magnetic particles in a carrier fluid, usually silicone oil. Magneto-rheological effect represents a reversible increase, due to an external magnetic field of effective viscosity. MR fluids and devices have the potential to revolutionize the design of automotive brakes, actuators, valves, active shock and vibration dampers, and other components used in mechanical systems. New MR fluids need to be developed, because the present ones are either too costly or do not offer substantial benefits over the existing technology. This can be done by lowering their production cost through improved manufacturing processes and by using localized components. Also, the instruments which have to be used for evaluating the properties of the MR Fluids have been covered in detail in this paper.

***Keywords*—** MR fluid; Automotive Applications, Characterization Techniques

Introduction

Magneto-rheological (MR) fluids, consisting of magnetisable particles dispersed in nonmagnetic liquids, show rapid but reversible change in their rheological properties following the application of an external magnetic field. The change from a free-flowing liquid state to a solid-like state is reversible and is dependent on the presence of a magnetic field. Iron powder is one of the more popular materials used as particle inclusion because of its high saturation magnetization, which is a favourable property as far as MR fluids are concerned. When MR fluids are exposed to an external magnetic field, the original particles become magnetized and acquire dipole moments which aggregate to form chains in the field direction. The fluid structure depends on the volume fraction; dilute suspensions form weakly interacting single particle chains, while in more concentrated suspensions, the particle chains cross-link laterally into a dense network. This structure is responsible for the unique rheological properties of MR fluids: the quick formation of a network in response to an external field creates a rapid liquid-to-solid transition. The mechanical properties of the MR fluids can be used in the construction of magnetically controlled devices such as the MR fluid brake or clutch.

Objectives

The proposed work in this paper is to carry analytical and experimental evaluation of magneto rheological brake, and fluid, designed especially for application in two wheelers. As far as the instruments used for evaluating the properties of MR fluids are concerned, no specific research has been carried out which describes their construction, working and the different properties that they measure, along with their cost and availability, in detail. This paper aims to do the same.

Following are the objectives of the dissertation work.

1. To characterize the MR fluids.
2. To compile a list of instruments used for testing MR fluid properties.
3. Elaborating on the construction, working, availability and cost of the aforementioned instruments.
4. Testing the MR fluids for their rheological and magnetic properties.
5. Comparing the commercially available samples with the locally synthesized fluid.

LITERATURE REVIEW

In [1], research is carried out on a low sedimentation MRF based on plate like iron particles which states that plate-like able against particle sedimentation. In the near future, the durability and temperature dependence of the proposed MR micron-sized iron particles play an important role in improving the stability against rapid sedimentation and in enhancing the yield stress value. It indicates that by using the proposed MRF, the field-dependent damping force is very stable against particle sedimentation. In the near future, the durability and temperature dependence of the proposed MRF will be investigated using devices such as dampers or brakes as a second phase of this work. [2] States that the core shell CI–PANI particles can be used as a dispersed phase in a MR fluid. PANI coating contributes to reduced sedimentation, and thus to improved suspension stability. The efficiency increases at elevated temperatures. The CI–PANI suspension exhibits strong elastic behaviour within the linear viscoelastic region due to the robust chain structure under an applied magnetic field. [3] focuses on the rheological properties of a honge oil based magneto-rheological fluid used as a carrier liquid which states that viscosity was increased from about 8 per cent to 15 percent (at different magnetic fields) when volume of suspension was increased from 20 per cent to 30 percent whereas this increase was 4 per cent to 9 per cent (at different magnetic fields) when volume of suspension was increased from 30 percent to 40 percent and the yield stress also increases. [4] States that the nanowire based suspensions make for a more efficient MR fluid (higher yield stresses) at low magnetic fields allowing for more sensitive control of the fluid properties. The sedimentation velocity and the percentage of sedimentation are both greatly reduced compared to conventional MR fluids. A disadvantage of the suspensions is that the maximum volume fraction of nanowires is much less than the desired 30-40 vol. % achievable with spherical particles. As per [5] on increasing the current, the magnetic induction and magnetic flux of the coil are increased which attracts the prepared MR fluid and increases the viscosity of the nano-Fe_2O_3 Fluid. MR fluid was prepared using Fe_2O_3 nano powder, silicone oil and grease. [6] Deals with literature review on MR fluid's and to explore the effect of different configurations of magnetisable particles and carrier fluid and a comparison of different concentrations (65%, 50% and 35% by weight) of magnetisable micro-meter sized particles is studied over here. Rheometer is the instrument which gives shear rate versus shear stress graph of MR fluid. In this paper the shear stresses of those MR fluids samples have been studied using ANTON PAAR MCR-102 Rheometer.

INSTRUMENTS USED FOR MRF CHARACTERIZATION:

The testing of MRF's involves finding out parameters such as viscosity (OFF state & ON state), shear stress, yield stress as well as the magnetic properties that have been mentioned beforehand like retentivity, coercivity etc. which are required for plotting a hysteresis loop. The measurement of these parameters is done by varieties of instruments/techniques which are listed below;

- Parallel plate rheometer
- Scanning electron microscopy
- Transmission electron microscopy
- Vibrating sample magnetometer

Each of these instruments will measure different properties of the MRF under different conditions. For example, a rheometer can only give us rheological values whilst for magnetic properties we will have to rely on data provided by the vibrating sample magnetometer.

The following section does not cover the setup used for testing the braking torque, which is one of the most important characteristics provided by the fluid sample.

PARALLEL PLATE RHEOMETER

A **rheometer** is a laboratory device used to measure the way in which a liquid, suspension or slurry flows in response to applied forces. It measures the *rheology* of the fluid. There are two distinctively different types of rheometers. Rheometers that control the applied shear stress or shear strain are called rotational or shear rheometers, whereas rheometers that apply extensional stress or extensional strain are extensional rheometers.

Since our brakes will be operating in shear mode, we will be using a shear rheometer for testing purposes. Parallel plate rheometer falls under this category.

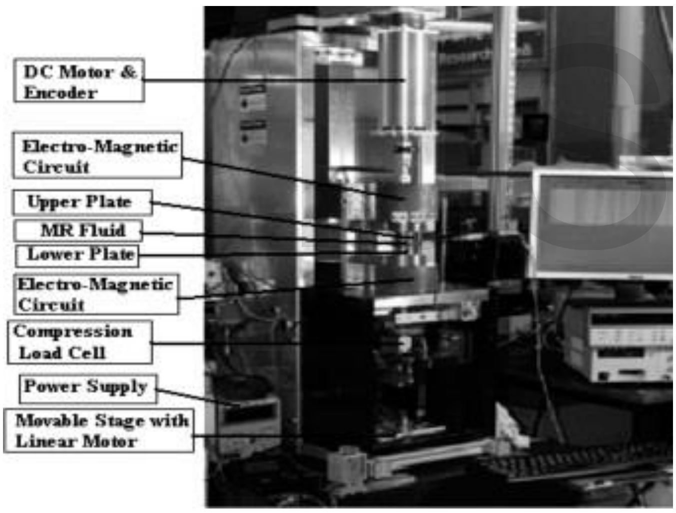

FIGURE 1 PARALLEL PLATE RHEOMETER [7]

Notable manufacturer/model:

BROOKFIELD, **DV3T**, retailing for US$ 5600-6000 on Alibaba.

SCANNING ELECTRON MICROSCOPY

A **scanning electron microscope** (**SEM**) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition. SEM can achieve resolution better than 1 nanometre. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

The most common SEM mode is detection of secondary electrons emitted by atoms excited by the electron beam. By scanning the sample and collecting the secondary electrons that are emitted using a special detector, an image displaying the topography of the surface is created

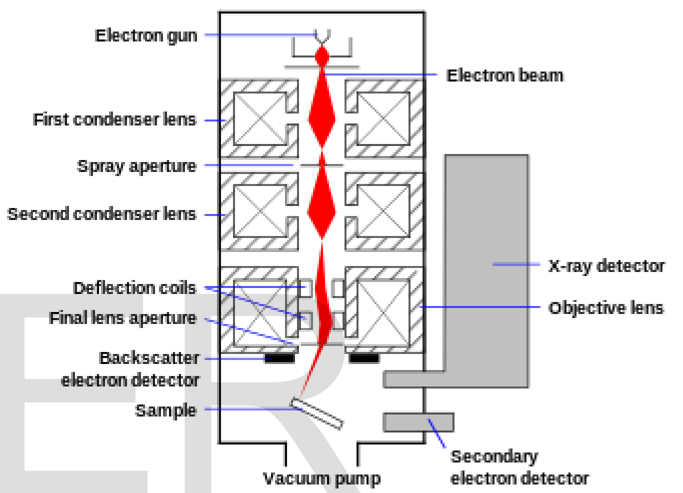

FIGURE 2 THEORETICAL DIAGRAM OF SEM

Working process:

In a typical SEM, an electron beam is thermionically emitted from an electron gun fitted with a tungsten filament cathode. Tungsten is normally used in thermionic electron guns because it has the highest melting point and lowest vapour pressure of all metals, thereby allowing it to be electrically heated for electron emission, and because of its low cost. The electron beam, which typically has an energy ranging from 0.2 keV to 40 keV, is focused by one or two condenser lenses to a spot about 0.4 nm to 5 nm in diameter. The beam passes through pairs of scanning coils or pairs of deflector plates in the electron column, typically in the final lens, Which deflect the beam in the x and y axes so that it scans in a raster fashion over a rectangular area of the sample surface.

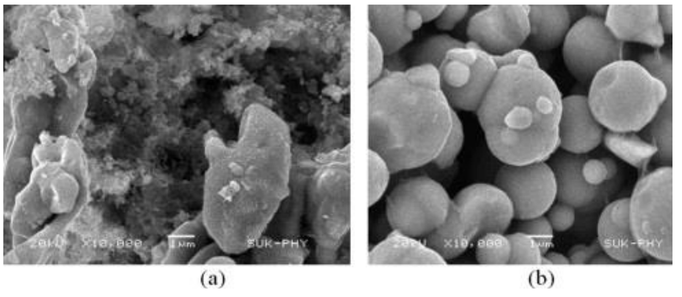

FIGURE 3 IMAGE AS OBSERVED ON SEM [7]

When the primary electron beam interacts with the sample, the electrons lose energy by repeated random scattering and absorption within a teardrop-shaped volume of the specimen known as the interaction volume, which extends from less than 100 nm to approximately 5 μm into the surface. The energy exchange between the electron beam and the sample results in the reflection of high-energy electrons by elastic scattering, emission of secondary electrons by inelastic scattering and the emission of electromagnetic radiation, each of which can be detected by specialized detectors. The beam current absorbed by the specimen can also be detected and used to create images of the distribution of specimen current. Electronic amplifiers of various types are used to amplify the signals, which are displayed as variations in brightness on a computer monitor. Each pixel of computer video memory is synchronized with the position of the beam on the specimen in the microscope, and the resulting image is therefore a distribution map of the intensity of the signal being emitted from the scanned area of the specimen.

Notable manufacturer/model:

Hitachi High-Technologies, Formed in 2001, manufactures a variety of science and technology related products. They currently manufacture three scanning electron microscope models:

- **S-3700N**, an analytical style SEM ideal for studying large, heavy and tall samples
- **S-3400N**, a user-friendly, more compact model that utilizes new technology in electron optics
- **SU1510**, a compact, high performance SEM that can handle large samples and provides high-resolution imaging

FEI manufacture a variety of models which are listed below.

- **NovaNano SEM**
- **QUANTA SEM**
- **Inspect family**
- **QEMSCAN**

TESCAN's latest 2016 models are listed below;

- **XEIA**
- **GAIA**
- **MAIA**

Some other manufacturers are *ZEISS, PHENOMWORLD* & *JEOL.*

TRANSMISSION ELECTRON MICROSCOPY

Transmission electron microscope (TEM), is a type of electron microscope that has three essential systems: (1) an electron gun, which produces the electron beam, and the condenser system, which focuses the beam onto the object, (2) the image-producing system, consisting of the objective lens, movable specimen stage, and intermediate and projector lenses, and (3) the image-recording system, which converts the electron image into some form perceptible to the human eye. In addition, a vacuum system, consisting of pumps and their associated gauges and valves, and power supplies are required.

Working process:

The beam of electrons from the electron gun is focused into a small, thin, coherent beam by the use of the condenser lens. The beam then strikes the specimen and parts of it are transmitted depending upon the thickness and electron transparency of the specimen. This transmitted portion is focused by the objective lens into an image on phosphor screen or charge coupled device (CCD) camera. The image is then passed down the column through the intermediate and projector lenses, is enlarged all the way.

The image strikes the phosphor screen and light is generated, allowing the user to see the image. The darker areas of the image represent those areas of the sample that fewer electrons are transmitted through while the lighter areas of the image represent those areas of the sample that more electrons were transmitted through**.**

Notable manufacturer/model:

TEMs are manufactured by companies such as *ZEISS, JEOL*, *PHILIPS* and *HITACHI* and are extremely expensive.

Examples of prices for new TEM models include $95,000 for a *JEOL* 1200EXII, $95,000 for a *PHILIPS* EM10 and $100,000 for a *HITACHI* 7000.

VIBRATING SAMPLE MAGNETOMETER

A vibrating sample magnetometer (VSM) operates on Faraday's Law of Induction, which tells us that a changing magnetic field will produce an electric field. This electric field can be measured and can tell us information about the changing magnetic field. A VSM is used to measure the magnetic behaviour of magnetic materials.

FIGURE 4 OPERATING PRINCIPLE OF VSM [7]

Working process:

A sample is placed inside a uniform magnetic field to magnetize the sample. The sample is then physically vibrated sinusoidally, typically through the use of a piezoelectric material. By measuring in the field of an external electromagnet, it is possible to obtain the hysteresis curve of a material. The vibrating sample magnetometer measures the magnetization of a small sample of magnetic material placed in an external magnetizing field by converting the dipole field of the sample into an AC electrical signal.

A typical measurement of a sample is taken in the following manner:

- The strength of the constant magnetic field is set.
- The sample begins to vibrate
- The signal received from the probe is translated into a value for the magnetic moment of the sample
- The strength of the constant magnetic field changes to a new value. No data is taken during this transition
- The strength of the constant magnetic field reaches its new value
- The signal from the probe again gets translated into a value for the magnetization of the sample
- The constant magnetic field varies over a given range, and a plot of magnetization (M) versus magnetic field strength (H) is generated.

CONCLUSION

Rheometer is used to check the rheological properties of the MR fluid. SEM & TEM are used for imaging. VSM is used for checking the magnetic properties.

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