

A Magneto-Rheological Clutch for Efficient Automotive Clutch

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ABSTRACT: Magneto rheological fluid is one of the smart materials which are gaining importance in current scenario. MR fluids find applications in dampers, brakes etc. nowadays. Viscosity of MR Fluids can be temporarily increased or decreased within a fraction of second, so that we can vary the torque whenever we require. This property makes MR Fluid a perfect material for clutch operations. Conventional friction clutch has high heat generation, frequent maintenance and replacement of clutch plates.

The aim of this work is to develop a magneto rheological clutch (MRC) system that has performance advantages over the conventional friction clutches. The proposed clutch system consist of rotating discs immersed in a MR fluid and enclosed in an electromagnet which the yield stress of the fluid varies as a function of the magnetic field applied by the electromagnet. The controllable yield stress causes friction on the rotating disk surfaces thus transferring the torque. This torque can be precisely controlled by changing the current applied to electromagnet.

KEYWORDS: Magneto rheological fluid; Magneto rheological clutch; Electro magnet

I. INTRODUCTION

Nowadays there are a lot of researchers are undergoing on developing smart materials. These smart materials can perform same function done by the conventional materials much smarter and economical. Magneto rheological fluids are such kind of smart material. It has a large area of application and lots of researchers are pursuing on that. MR fluid is very responsive to magnetic field, with an estimated time of less than 10 micro seconds and requires relatively low power to operate. Nowadays the traditional mechanical system are being replaced by improved electro mechanical systems that are able to do the same tasks faster, more reliably and more accurately. A conventional clutch system has a number of limitations including: (1) delayed response time, (2) frequent replacement of clutch plate due to frictional wear, (3) high temperature situations, (4) difficult in replacement. Here we are fabricating a clutch for an automotive which works using this magneto rheological fluid. In this clutches the conventional friction pads are replaced with magneto rheological fluids and some electro magnets to give magnetic fields to the fluid.

The concept behind the project is that the magneto rheological fluid has the ability to change its viscosity on the application of a magnetic field. So when we give a magnetic field the fluid gets solidified and it makes a rigid joint between the input and output shafts and transfer the torque. And if there is no electric field, the fluid is purely a liquid and input shaft freely rotates in that fluid.

In this project we are studying how effectively the torque is transmitted between the shafts and how much load is taken. We are conducting a load test for that. By using this MR clutches we are increasing the response time of the clutch and

thus it is useful in heavy speeds. And also by using MR clutches the conventional pedal clutches can be replaced by small switches or buttons which can be easily mounted on steering wheel or nearby

ILMR FLUID

MR fluids are created by adding micron-sized iron particles to an appropriate carrier fluid such as oil, water or silicon. Their rheological behavior is nearly the same as that of the carrier fluid when no external magnetic field is present. However, when exposed to a magnetic field, the iron particles acquire a dipole moment aligned with the applied magnetic field to form linear chains parallel to the field. This reversibly changes the free flowing liquid to semi-solids that have a controllable yield strength, which depends on the magnitude of the applied magnetic field. The magnetic field dependent fluid characteristics of MR fluids can be described by a simple Bingham plastic model. As illustrated in Fig.1, in this model, the total shear stress is given by

$$\tau = \tau_y(H) + \eta \dot{\gamma} \quad (1)$$

Where τ_y is the yield stress due to the applied magnetic field H , η is the constant plastic viscosity, which is considered equal to the no-field viscosity of the fluid, and $\dot{\gamma}$ is the shear-strain rate. Here, the plastic viscosity is defined as the slope between the shear stress and shear-strain rate as shown in fig.1, which is the traditional relationship for Newtonian fluids.

True behavior of MR fluids exhibits some significant departures from the Bingham model in the absence of a magnetic field (i.e., $\tau_y \propto H^2$). However, if used properly Eq. (1) provides a useful basis for the design of MR fluid-based devices, and the simple Bingham model is still very suitable for the initial design phase.

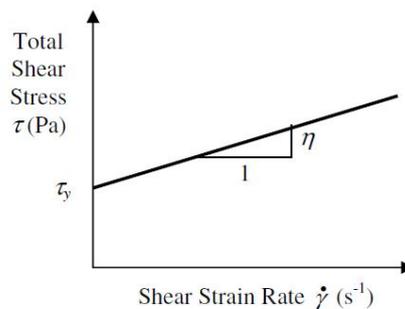


Fig.1: Bingham plastic model.

Material whose rheological properties can be varied by application of magnetic fields belong to a specific class of so called smart materials because they can respond, via solid state electronics and modern controlled algorithms, to change in their environment. These materials in the fluid responds to applied magnetic fields and are thus referred to as magneto rheological materials. Such materials can be utilized in devices or can be incorporated in traditional composites to form advanced intelligent composite structures, whose continuum magneto-rheological response can be actively controlled in real time. Applications that can benefit from materials whose rheology can be continuously, rapidly and reversibly varied are numerous.

The viscosity of controllable fluids in the absence of a field is most significantly a function of the carrier oil, suspension agents, and particle loading. Rheological figure of merits of controllable fluids benefit from low fluid viscosity, but be balanced with other fluid requirements such as temperature range and particle resuspendability. Because of the inclusion of the suspension agents and changes in particle microstructure during shear, most MR fluids exhibit significant shear thinning.

III. DESIGN OF MR CLUTCH

A basic configuration of MR Clutch for automotive is shown in fig 2. In addition, some of the key practical design considerations were also included during the design process, e.g. sealing of the MR fluid and the viscous torque generated within the MR Clutch due to MR fluid viscosity.

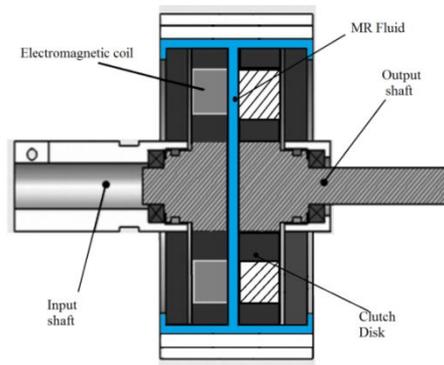


Fig.2: Basic configuration of MR Clutch

(a) Magnetic circuit design

The main goal of the magnetic circuit analysis is to direct the maximum amount of the magnetic flux generated by the electromagnet onto the MR fluid located in the gap. This will allow the maximum torque to be generated. The magnetic circuit in the MR clutch consists of the coil winding in the electromagnet, which is the magnetic flux generating “source” and the flux carrying path. The path provides resistance over the flux flow, and such resistance is called reluctance (R). The total reluctance of the magnetic circuit is the sum of the reluctances of the wire and the gap, which consists of the MR fluid and the clutch disk. Then, the flux generated (φ) in a member of the magnetic circuit can be defined as

$$\phi = \frac{ni}{R} = \frac{mmf}{R} \tag{2}$$

Where,

$$R = \frac{l}{\mu A} \tag{3}$$

In Eq. (2), where ‘n’ is the number of turns in the coil winding and ‘i’ is the current applied; in Eq. (3), μ is the permeability of the member, A is its cross-sectional area, and l is its length. Recall that in order to increase the torque, the flux flow over the MR fluid needs to be maximized. This implies that the reluctance of each member in the flux path of the flux flow has to be minimized, which in turn implies that l can be decreased or/and l and A can be increased. Since the magnetic fluxes in the gap (φ) can be directly calculated as the ratio between the mmf and the total reluctance of the magnetic circuit.

(b) Material selection

The material selection is another critical part of the MR clutch design process. Materials used in the MR clutch have crucial influence on the magnetic circuit (i.e. via μ) as well as the structural and thermal characteristics. Here, the material selection issue is discussed in terms of the magnetic properties and structural and thermal properties.

A magnetic property that defines a material’s magnetic characteristic is the permeability (μ). However, permeability of ferromagnetic materials is highly non-linear. It varies with temperature and applied magnetic field. Considering the cost, permeability and availability, low carbon steel, AISI 1018 was selected as material in the clutch.

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In terms of structural considerations, there are two critical parts: the shaft and the clutch disk. The shaft should be non-ferromagnetic in order to keep the flux far away from the seals that enclose the MR fluid (to avoid from MR fluid being solidified). Stainless steel is a suitable material for the shaft due to its high yield stress and availability. For the clutch disk material, already chosen AISI 1018 has a high yield stress. The remaining parts are not under any considerable structural loading.

Thermal properties of the materials are another important factor. Due to the temperature dependent permeability values of the ferromagnetic materials and the MR fluid viscosity, heat generated during shearing should be removed as quickly as possible. In terms of material properties, in order to increase the heat flow from the clutch disk, a material with high conductivity and high convection coefficient has to be selected as materials for the non-magnetic clutch components. Aluminium is a good candidate material for the thermal considerations.

(c) *Sealing*

Sealing of the MR clutch is another important design criterion. Since MR fluid is highly contaminated due to the iron particles in it, the risk of sealing failure is increased. In addition, in the case of dynamic seals employed between the static casing and the rotating shaft, MR fluid leakage would occur if the fluid was repetitively solidified around the vicinity of the seals.

In this work, the dynamic seals were kept away from the magnetic circuit by introducing a non-ferromagnetic shaft and clutch disk support outside the circuit which holds the magnetic clutch disks. Also the surface finishes were improved and the tolerances were kept tight for better interface between the seals and the counterpart surfaces.

(d) *Applied current density*

Coil is another important design criterion, as it is the source (i.e. mmf) in the magnetic circuit. The current density that can be applied to the electromagnet coil is limited, which depends on the cross-sectional area of the coil, its material, and the saturation flux densities of the magnetic materials used in the MR clutch. When the saturation flux value of a magnetic material has been reached, it will behave as non-magnetic material (i.e. μ_r becomes 1), affecting the corresponding reluctance in the magnetic circuit. Thus, it is beneficial to keep the flux in the unsaturated region for that material.

In order to maximize the amount of applied current density, the dimensional space of where the coil is located is also optimized along with the other dimensional parameters. In addition, a wire size that can generate the highest current density was selected: AWG 21 (\varnothing 0.77 mm).

IV. WORKING

These materials in the fluid responds to applied magnetic fields and are thus referred to as magneto rheological materials. Such materials can be utilized in devices or can be incorporated in traditional composites to form advanced intelligent composite structures, whose continuum magneto-rheological response can be actively controlled in real time. Applications that can be benefit from materials whose rheology can be continuously, rapidly and reversibly varied are numerous.

The most common MR materials are of liquid state. The controllable rheological response of such fluids results from the polarization induced in the suspended particles by application of an external magnetic field. The interaction between the resulting induced dipoles causes the particles to form columnar structures, parallel to the applied field. These chains like structure restrict the flow of the fluid, thereby increasing the viscous characteristics of the suspension. The mechanical energy needed to yield these chains like structures increase as the applied magnetic field increase

resulting in a field dependent yield stress. In the absence of an applied field, the controllable fluids exhibit Newtonian like behaviour.

MR fluid is filled in the casing and the fluid is there between the disc and the aligned electro magnets. The electro magnets are arranged so that the field of the magnet is directly focussed towards the fluid area. The electro magnet in the assembly is worked by using a 12 volt battery.

MR fluid is composed of particles suspended in a carrier fluid such as oil. When a magnetic field is applied the magnetic particles will align and form chains and solid like structures within the fluid.

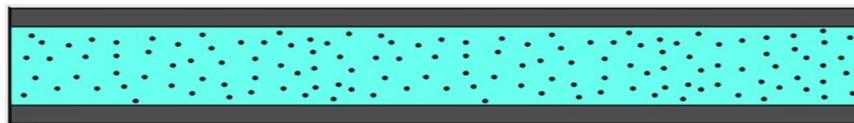


Fig.4

In disengaged phase the MR fluid filled between the shafts are not magnetically excited and the magnetically polarisable particle will be dispersed in carrier fluid in random manner as shown in fig.4. So whenever the shaft is rotating the fluid could not provide the resistance to shear due to low viscosity and is sheared off easily. Thus the power from the shaft will not be transmitted to the output shaft.

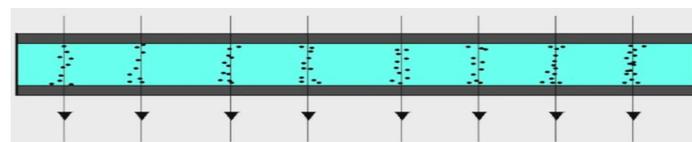


Fig.5

During engaged phase MR fluid is excited by passing current through the electromagnetic from a battery. Magnetic field will be generated in the region of MR fluid. This causes suspended magnetically polarisable particles in MR fluid to become magnetic dipoles and attract each other and align according to the magnetic field as shown in fig.5. This results in an immediate stiffening of the MR material and helps in transferring torque.

V. EXPERIMENTAL SETUP

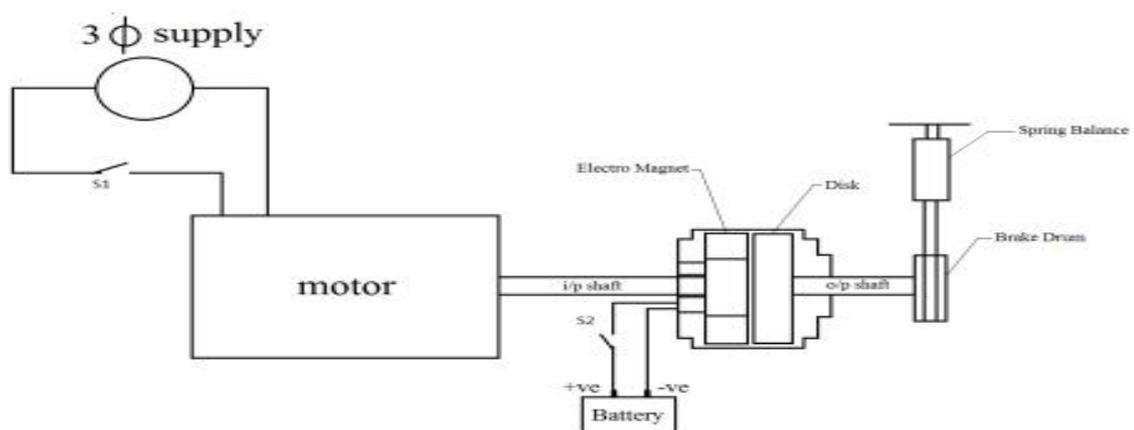


Fig.6

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Schematic diagram of experimental setup is shown in fig.6. it consist of a 3phase motor to represent an engine of automobile. An electromagnet is connected to the end of motor shaft and a battery is provided to excite it. output shaft is connected with a rotating drum and spring arrangement to calculate the load taken. Switch s1 is provided to start and stop the motor and switch s2 is provided to engage and disengage the clutch by exciting and de-exciting the magnetic field.

VI.CONCLUSION

By this project, a magneto rheological clutch design has been introduced as a viable alternative to the current conventional friction clutches. Since the MRC is an electromechanical device, it has several advantages over conventional one, such as reduced actuation delay, ease of software control, temperature reduction. The design process was started with an analytical model of the MRC. Then the MRC device was designed with a focus on magnetic circuit optimization and material selection. From that design considerations we develop a working model of MRC. And it is found that the MRC have quicker response time than that of conventional clutches.

The exploitation of hybrid magnetic circuits offers the possibility to reverse the operational states of MR clutches. If the clutch is engaged in the usual operational state, this engagement can be maintained simply by the supply of electric energy. Only for a short disengagement of the clutch, electric energy in terms of the coil current has to be supplied.

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