"I admit that I have read this report and found that it is suffice from the aspect of scope and quality to pass the

Bachelor Degree of Mechanical Engineering (Automotive)

Signature : ....................................................

Supervisor Name : DR KHISBULLAH HUDHA

Date : 7/5/2007

# DESIGN AND FABRICATE A HIGH TORQUE MAGNETO-REOLOGICAL FLUID CLUTCH

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# DECLARATION

"I admit this report is done all by myself except statement that I have already stated on each one of them"

Signature :..............................................
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# ABSTRACT

This project explains about the design of the high torque magneto-reological fluid clutch. The design is to compare the high torque transfer between two designs of double plate with the solid surface plate and another one is the hollow surface plate. Electromagnetic finite element analysis is performed to design and optimize the clutch. This paper includes the study of the magneto-reological fluid behavior, the advantages of the fluid and application to the clutch system for the automotive vehicle. The explanations also about the state on design the clutch, selecting material and fabrication process.

# ABSTRAK

Projek in menerangkan tentang mereka bentuk klac cecair magnetoreological yang berdaya kilasan tinggi. Reka bentuk ini adalah bagi membandingkan pemindahan daya kilasan yang tinggi di antara dua reka bentuk plat berkembar di mana salah satunya adalah plat yang berpermukaan rata dengan plat yang berpermukaan berlubang. Analisis unsur elektromagnatik digunakan bagi mereka bentuk dan mengoptimumkan klac. Dalam laporan in juga menerangkan tentang sifat-sifat kelakuan cecair magnetoreological, kelebihan cecair tersebut dan penggunaan dalam sistem klac untuk kenderaan automotif. Penerangan juga melibatkan peringkat mereka bentuk klac, memilih bahan dan proses pembuatan klac tersebut.

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| SYMBOL | DEFINATION |
|---|---|
| G | material modulus |
| H | magnetic field |
| L | length |
| F | Force |
| g | gap |
| w | width |
| Q | volumetric flow rate |
| A | area |
| V | volume |
| S | relative pole velocity |
| $F_\eta$ | viscosity force |
| $F_\tau$ | stress force |
| $\Delta P_\eta$ | sum of a viscous component |
| $\Delta P_\tau$ | sum yield stress component |
| $\lambda$ | control ratio |
| ¡c | clutch torque |
| $\tau$ | fluid stresses |
| $\tau_y$ | yield stress |
| $\eta$ | plastic viscosity |
| $\dot{\gamma}$ | fluid shear rate |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

In this chapter, it will discuss about the objective of the project, scope of the project, and problem statement. Depend on the project title is design and fabricate a high torque magneto-rheological fluid clutch, the two model design have been made for an experiment to compare the high torque transformation. The magneto-rheological fluid clutch is one of the new technologies of clutch that been use in the automotive industries. This technology of clutch will provide more efficiency a high torque transformation between engines to driveline because the properties of the magneto-rheologocal fluid that will discuss in the next chapter. For overall in this project, the two model of high torque magneto-rheological fluid clutch are designed for make an experiment to compare the high torque transformation between the driver and the driven shaft. The knowledge and the information about the properties of fluid and the mechanism of the clutch are important to make the design in this project that will be discuss in the next chapter.

## 1.2 Objective

The objectives of this project are:

- To design 3D model of high torque magneto-reological fluid clutch using CAD software.
- To make analysis of the design using Maxwell ANSOFT software to optimize the design of high torque magneto-reological fluid clutch.
- Fabricate the magneto-reological fluid clutch design prototype.

## 1.3 Scope of Project

The scopes of this project are to design 3D model of the double plate prototype magneto-reological fluid clutch using the CAD software such as Solid Work and make a comparison between the two design of double plate with is one is the solid surface and the another one with hole on the surface. This comparison is to know the high torque transfer between the two designs. Electromagnetic finite element analysis is performed, using Maxwell ANSOFT software, to optimize the design of the double plate prototype magneto-reological fluid clutch. Fabricate the two design of magneto-reological fluid clutch prototype.

## 1.4 Problem Statement

The most common problem with conventional clutch is mechanical friction. The friction material on a clutch disc is very similar to the friction material on the pads of a disc brake, or the shoes of a drum brake after a while, it wears away. When most or all of the friction material is gone, the clutch will start to slip, and eventually it would not transmit any power from the engine to the wheels.

The clutch only wears while the clutch disc and the flywheel are spinning at different speeds. When they are locked together, the friction material is held tightly against the flywheel, and they spin in synchronize. It is only when the clutch disc is slipping against the flywheel that wearing occurs. So if the driver slips the clutch a lot, they will wear out the clutch a lot faster. Another problem sometimes associated with clutches is a worn throw out bearing. This problem is often characterized by a rumbling noise whenever the clutch engages.

## 1.5 Engagement Problem

Internal combustion engines cannot descend below a minimum critical speed called idle speed. A conventional clutch behavior can be thought as composed by two running modes with is a sliding mode where the torque is generated by the friction of the clutch disk against the flywheel and the pressure plate, and a non-sliding mode where the clutch behaves as a simple connecting link. The steady stage response of the conventional clutch is about 0.5-2 seconds. During the sliding phase the clutch torque ¡$_c$ is proportional to the normal force $F_n$ exerted by the washer spring on the friction surfaces. The amount of normal force is controlled by acting on the washer spring's end either through a hydraulic system connected to the clutch pedal or a hydraulic actuator, in the case of manual transmissions or automated manual transmission vehicles respectively.

During a standing start the normal force is gradually increased from zero to a maximum value whose amount gives the spottiness of the movement. Under the clutch torque action the driveline, and thus the vehicle, accelerate; since clutch torque ¡$_c$ is usually higher than the engine torque ¡e the engine slows down and the clutch sliding speed is gradually reduced to zero. Once the sliding phase over, the clutch acts as a linking element; ¡$_c$ equals ¡$_e$ minus the engine inertial reaction torque. This sudden torque change excites the driveline generating highly uncomfortable longitudinal oscillations.

Usually an experienced driver can avoid, or at least minimize the occurrence of this situation but the concurrent increase in engine torque output and reduction of the transmission stiffness, due to tougher NVH (Noise, Vibration, and Harshness) standards, make the driver's task harder and reduce the perceived comfort. Being the magneto-reological clutch an inexpensive upgrade from a classical manual clutch system the importance of developing oscillation-preventing control strategies becomes evident.

# CHAPTER 2

# LITERATURE REVIEW

This chapter presents a review of the technical literature relating to the issues in developing a model magneto-reological fluid clutch. This chapter also will be review about the magneto-reological fluid behavior, the application, the state of the fluid and the advantages. All of this information is useful in state to know the characteristic before it can be applied to other applications. In this chapter also, it state about the conventional clutch, the system of the clutch, the application and the types of the clutch. Clutch is useful to the vehicle as the part to connect the two rotation component between the engine and driveline. This will made the vehicle move out easily on the road. However using the conventional clutch it has several problems that need to solve with develop the new technology of clutch using the other method such as magnetic, electrical, fluid, eddy current and etc.

## 2.1 History of Magneto-rheological Fluid

Magneto-rheological (MR) fluids are materials that respond to an applied magnetic field with a change in rheological behavior. Typically, this change is manifested by the development of a yield stress that monotonically increases with applied field. Interest in magneto-rheological fluids derives from their ability to provide simple, quiet, rapid response interfaces between electronic controls and mechanical systems. That magneto-rheological fluids have the potential to radically change the way electromechanical devices are designed and operated has long been recognized.

The initial discovery and development of MR fluids and devices can be credited to Jacob Rabinow at the US National Bureau of Standards (Rabinow, 1948) in the late 1940s. Interestingly, this work was almost concurrent with Winslow's ER fluid work. The late 1940s and early 1950s actually saw more patents and publications relating to MR fluids. Except or a flurry of interest after their initial discovery, there has been scant information published about MR fluids. Only recently has resurgence in interest in MR fluids been seen (Jolly M. R, Jonathan W. B, and Carlson.D. J) .

While a number of MR fluids and various MR fluid-based systems have been commercialized including a MR fluid brake for use in the exercise industry (Jolly M. R, Jonathan W. B, and Carlson.D. J), a controllable MR fluid damper for use in truck seat suspensions (Carlson, Catanzarite and St.Clair, 1995; Lord, 1997) and an MR fluid shock absorber for track automobile racing. The magneto-rheological response of MR fluids results from the polarization induced in the suspended particles by application of an external field. The interaction between the resulting inducted poles causes the particles to form column structures, parallel to the applied field.

## 2.2 Magneto-rheological Fluid

Magneto-rheological (MR) fluids are oils that are filled with iron particles. Often, surfactants surround the particles to protect them and help keep them suspended within the fluid. Typically, the iron particles comprise between 20 and 40 percent of the fluid's volume. The particles are tiny, measuring between 3 and 10 microns. However, they have a powerful effect on the fluid's consistency. When exposed to a magnetic field, the particles line up, thickening the fluid dramatically. The term magneto-rheological comes from this effect. Rheology is a branch of mechanics that focuses on the relationship between force and the way a material changes shape. The force of magnetism can change both the shape and the viscosity of MR fluids.

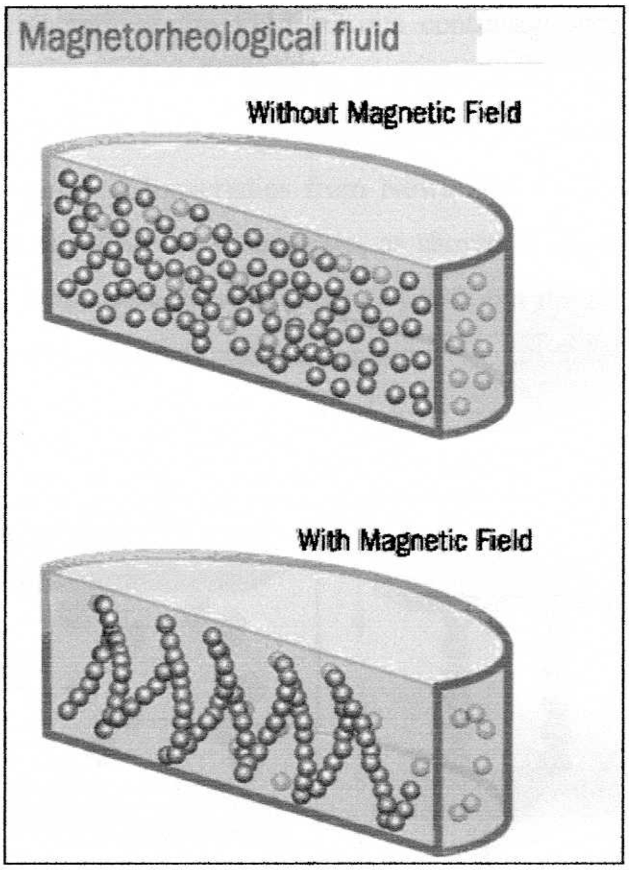


**Figure 2.1:** The particle in the magneto-reological fluid without and with magnetic field

MR fluids are suspensions of micron-sized, magnetic able particles in a carrier fluid. Normally, MR fluids are free flowing liquids having a consistency similar to that of motor oil. However, when a magnetic field is applied, their rheology changes, virtually instantly, to a consistency similar to peanut butter. MR fluids have been used in a variety of applications. Altering the strength of an applied magnetic field precisely and proportionally controls the consistency or yield strength of these fluids, which behave as Bingham plastics when in the presence of a magnetic field. MR fluids can be used in valve mode, with fluid flowing through an orifice as in a shock absorber or in shear mode for a brake or clutch with the fluid flowing between two surfaces that move relative to each other.

In the absence of a magnetic field applied across the gap the fluid occupies, the fluid flows freely or allows free movement. Upon application of a magnetic field, the particles align along the flux path generated by the magnetic field. The formation of these particle chains restricts the movement of the fluid within the gap since the fluid's yield strength is increased. Altering the inter-particle attraction by increasing or decreasing the strength of the field permits continuous control of the fluid's rheological properties and hence the damping or clutch or braking force.

Magneto-rheological fluid is one of the controllable fluids, which changes its damping and rheological characteristics from Newtonian fluid, in which the shear yield stress is proportional to the shear strain, as shown in Figure 2(a), to Bingham fluid, in which the shear yield stress is generated with out the shear strain as shown in (1) Figure2.2 (b) when magnetic field is applied

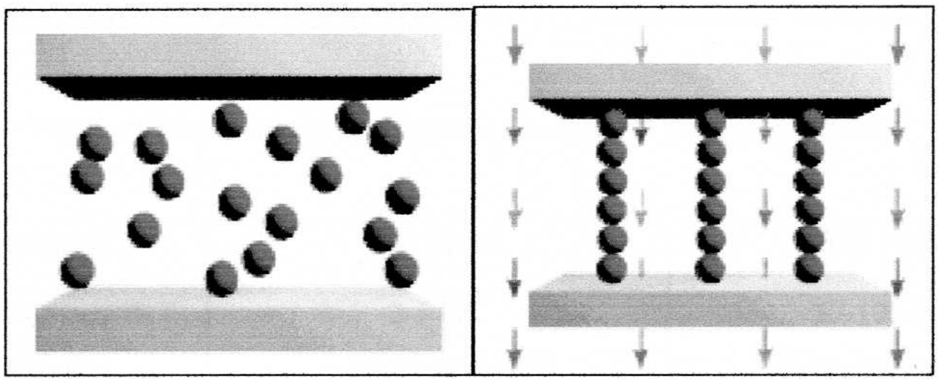

**Figure 2.2:** (a) Newtonian fluid (b) Bingham fluid. (Park Y., Jung B)

$$\tau_y = \tau_{y(H)} + \eta \gamma \quad (1)$$

It has several advantages such as high yield strength, low viscosity, robustness to impurities and wide temperature range of stability. If designing a device by using this material, it can not only design a simple structured device which generates semi active force but also expect a rapid response. In order to design a device using MR fluid, it must select its parameters by making use of magnetic analysis of the magnetic circuit to prevent the magnetic saturation.

The others advantage of MR fluids are the several useful material that use for some application in mechanical device. This material behavior is the combination between the chemical engineering developments to the mechanical engineering application. In chemical engineering research, the fluid development found the stronger of MR effect, higher stability against sedimentation and wider operation temperature range. With this fluid development make the rheological behavior to the shear, valve and squeeze mode to apply it in to the mechanical device such as vibration isolation for bridges, buildings and vehicles, brake, torque transfer devices and actuators. With this several advantages make the technology of the MR fluid product be more commercial for the engineering industries.

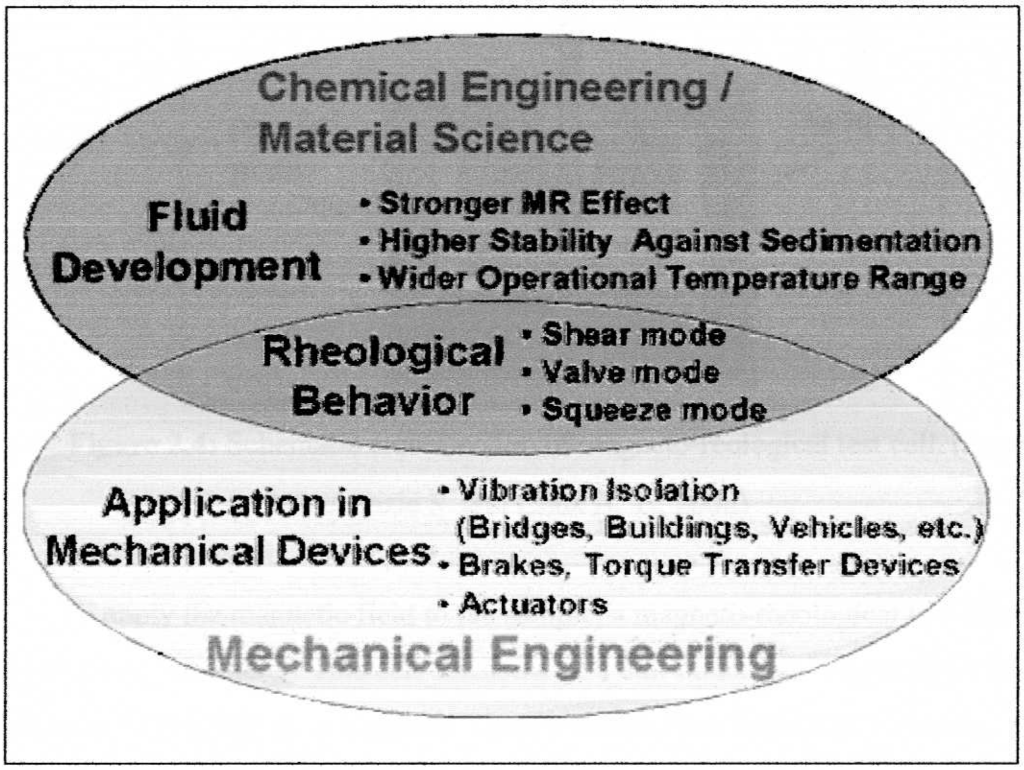


**Figure 2.3:** The advantages of MR fluid diagram

## 2.4 The Magnetoreological Cell Experiment

This experiment is to test the yield strength of the magneto-rheological fluid by MR fluid sample consisted of particles of carbonyl-iron powder with average particle size 4 μm, dispersed in a 0.1 Pas silicone oil with a volume fraction of 30%. This is standard volume fraction for testing, as a clear difference in flow properties can be observed between the field-on and field-off states (See H., Machanzie S. and Chua B. T., 2006).

The measuring geometry comprised of stainless steel, parallel plates of diameter 20 mm. The MRF sample was sandwiched between the plates and the upper plate was brought down towards the bottom plate to compress the sample. In all tests, the initial gap used was1.0 mm. During the compression, no torsional motion was applied to the sample.

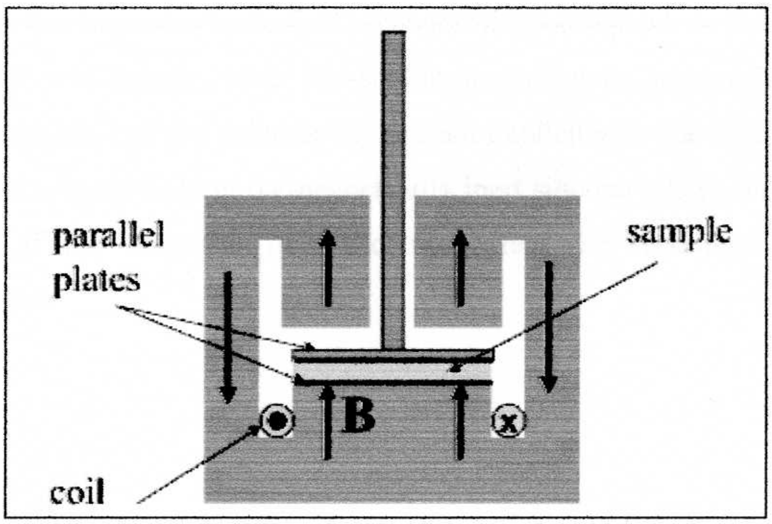


**Figure 2.4:** Schematic cross-section of magneto-reological test cell. (See H., Machanzie S. and Chua B. T., 2006)

To apply the magnetic field to the sample, a magneto-rheological test cell was attached to the rheometer. This cell consisted of a unit under the bottom plate, which housed the lower half of a magnetic circuit constructed from iron elements. This contained a coil of 495 windings through which a dc electric current was passed to generate the magnetic field. On the upper side, there was a removable cylindrical block which sat on the bottom stage and completely enclosed the two plates, with a central hole to pass the rheometer shaft. This block was also made up of iron elements and constituted the upper half of the magnetic circuit, thus enabling a uniform magnetic field to be applied perpendicularly across the plates see the schematic in Figure 2.4. The magnetic flux density across the plates was controlled by the rheometer software which adjusted the electric current through the coil, taking