Effect of Multilayered Disc size & Micro Sized Gap on MRF Clutch

P.L.Mane[1], V.Murali Mohan[2], R.D.Wategaonkar[3],
Automobile[1], Mechanical [2], Automobile3, Rmcet,Devrukh,india[1],Famt,Ratnagiri,india[2],Rmcet,Devrukh,india[3]
Email: autorocks.mane@gmail.com[1], vmm.famt@gmail.com[2], vategaonkar_rahul@rediffmail.com[3]

Abstract- Clutches plays a vital role in power transmission in mechanical engineering field. A well known application is in the automotive vehicles where it is used to connect the engine and the gear box. Positive clutches and friction clutches are the basic types utilized in early days. Friction clutches are widely used in all the automobiles. In recent days, lot of development has been done in mechanical power transmission sector. Magnetic clutches, Megnetorheological (MR) fluid clutches, Electro rheological (ER) Fluid clutches are some the innovative clutches developed in recent years. Smart materials have the ability to change its physical properties by applying external energy sources as per requirement. Magneto Rheological (MR) fluids and Electro rheological (ER) fluids also comes under smart materials. MR fluid is the suspension of Magnetizable soft iron particles in a carrier fluid. Application of magnetic field across the MR fluid gives drastic change in viscosity within few milliseconds. Previous researches gives some basic idea regarding the design, size and capacity of MR fluid based clutches. In present work theoretical and simulation calculations have been made and accordingly MR clutch assembly is prepared. Variation of torque transmission capacity is analyzed analytically and simulation. It is observed that the size of multilayered disc as well as gap size between plate play vital roles in Torque Transmission by MR Fluid based clutches.

Index Terms- MR Fluid, MR Cutch, Clutch design

1. INTRODUCTION

Clutches plays a vital role in power transmission in mechanical engineering field. A well known application is in the automotive vehicles where it is used to connect the engine and the gear box. Positive clutches and friction clutches are the basic types utilized in early days. Friction clutches are widely used in all the automobiles. In recent days, lot of development has been done in mechanical power transmission sector. Magnetic clutches, Megnetorheological (MR) fluid clutches, Electro rheological (ER) Fluid clutches are some the innovative clutches developed in recent years. Smart materials have the ability to change its physical properties by applying external energy sources as per requirement. Magneto Rheological (MR) fluids and Electro rheological (ER) fluids also comes under smart materials. MR fluid is the suspension of Magnetizable soft iron particles in a carrier fluid. Application of magnetic field across the MR fluid gives drastic change in viscosity within few milliseconds. Previous researches gives some basic idea regarding the design, size and capacity of MR fluid based clutches. In present work theoretical and simulation calculations have been made and accordingly MR clutch assembly is prepared. Variation of torque transmission capacity is analyzed analytically and simulation. It is observed that the size of multilayered disc as well as gap size between plate play vital roles in Torque Transmission by MR Fluid based clutches.

2. LIMITATION OF FRICTION CLUTCH

Friction clutches transmit power as a function of frictional torque generated between two mating surfaces. In order to generate frictional torque, force is provided by means of springs. Due to continuous applied force all parts of such clutches experience high stresses all the time. Slip between two surfaces generates heat which reduces strength of materials. Frictional slip also produces wear of mating surfaces which reduces power transmission capacity with the time of usage. Degradation of friction surfaces results into reduction in frictional torque generation and change in relative velocity profile.

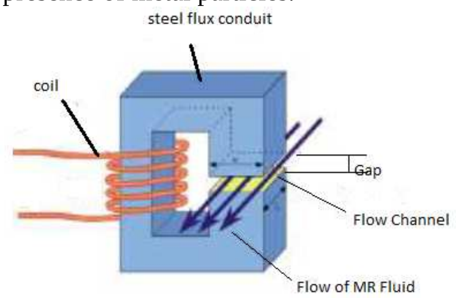
3. AIM AND OBJECTIVE BEHIND PRESENT RESEARCH WORK

Conventional clutches have some disadvantages like wearing of plates, heating of parts, high applied stresses during non working time also. The objectives of the present Work is to study effect of multilayered disc size and gap size between the plate on torque transmission capacity of clutch and reducing overall size of system.
MR fluid makes dramatic changes in their viscous and elastic properties in milliseconds when subjected to magnetic field. Variation in resistance to shear offered by MR fluid is rapid and almost reversible. These properties of MR fluid can be implemented in variable Torque transmission clutch. Torque

transmission occurs due to viscosity of MR fluid which is induced due to its own composition and change in viscosity after application of magnetic field. The primary objective is to provide magnetic field by high power permanent magnets. Variation in magnetic field could be achieved by varying axial distance. Solenoid coil was the option in case uses of permanent magnets are not suitable. The aim of the present study is to provide appropriate size of disc and appropriate size gap between disc by providing analytically found data and simulated data base for the present configuration.

4. WORKING PRINCIPLE OF MR FLUID

Typeset sub-subheadings in medium face and capitalize the first letter of the first word only. Section numbers to be in roman. The MR fluid is a smart fluid whose properties can be controlled in the presence of magnetic field. In the absence of magnetic field, the rheological properties of the MR fluid are similar to that of base fluid except that it is slightly thicker due to the presence of metal particles.



In the absence of magnetic field, these metal particles align themselves along the direction of flow (figure 1) however when a magnetic field is applied each metal particles becomes a dipole aligning itself along the direction of magnetic field (figure 1). Thus a chain Like structure is formed along the line of magnetic flux which offers mechanical resistance to the flow resulting in an increase in the viscosity of fluid .This mechanical resistance created due to the chain column imparts yield strength to the fluid, making it stiff like a semi-solid. This stiffness and hence the yield strength depends on the strength of the magnetic field and also the quality and quantity of metal particles.

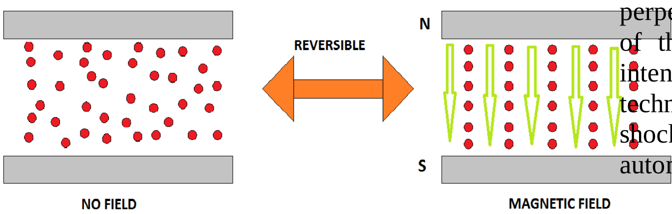


Fig 1: Orientation of iron particles in MR fluid

The MR effect is reversible. When the magnetic field is removed the fluid returns to its original condition. The MR fluids with their controllable properties are found to be useful in the implementation of smart fluid concept. Where the fluid motion is controlled by varying its viscosity with the help of magnetization .The simpleness of MR fluid technology, the controllability and the quick response of the rheological properties makes it a smart fluid with application areas where fluid motion is controlled by varying the viscosity.

4.1 Modes of operation of MR fluid

4.1.1. *Shear mode*

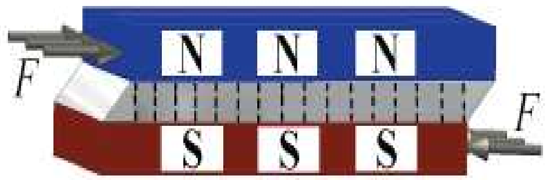


Fig 2: shear mode

In this mode, the fluid flows between surfaces having relative motion and a magnetic field is applied perpendicular to the direction of flow. Shear mode of MRF technology is used in various types of brakes and clutches of the vehicles. In this mode, the total shear force developed is a summation of the force developed due to the viscosity of the fluid (Fv) and the force developed due to the magnetic field (Fm).
$\Sigma F = Fv + Fm$.[5][6].

4.1.2. *Squeeze Film Mode*

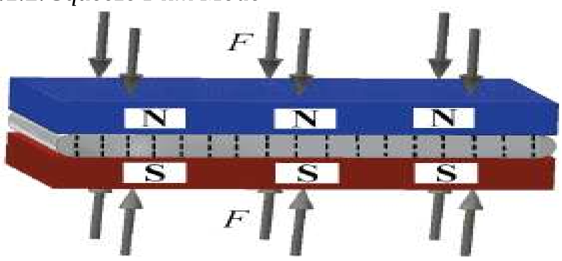


Fig 3: Squeeze film mode

In this mode of MRF operation, fluid flow through the two fixed surfaces and magnetic field is applied perpendicular to the direction of flow. The resistance of the fluid can be controlled by controlling the intensity of magnetic field. This mode of MRF technology is used in various types of dampers and shock absorbers and has vast application in automobile industry.

4.1.3. *Pressure driven flow mode*

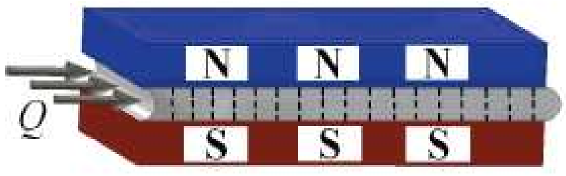


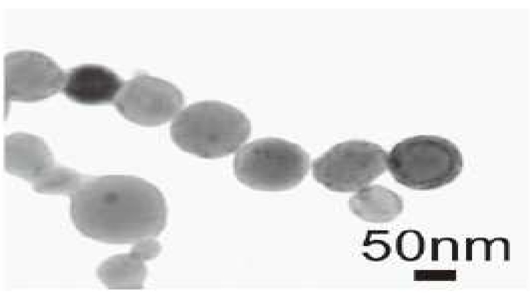
Fig 4: pressure driven flow mode

In this mode magneto rheological fluid flow between Fixed Pole. When magnetic field is generated the viscosity of fluid changes apparently, at that time pressure difference between input and output valve is altered. This type of fluid is used in shock absorber and vibration damper.

4.2 composition of MR Fluid

Megnetorheological fluids are the suspension of micron sized, Magnetizable particles (mainly iron) suspended in an appropriate carrier liquid such as mineral oil, synthetic oil, water or ethylene glycol. The carrier fluid serves as dispersion medium which enables homogeneity of iron particles in fluid [10].
MR fluid has basically three main constituents.
1) Magnetizable particles (mainly soft iron)
2) Carrier fluid
3) Additives

4.2.1. *Magnetizable particles*
Fe and iron particles are used for this purpose. These metals have high saturation magnetizations as compared with ferrites and secondly they can be produced easily with very narrow size distributions. However there were some major drawbacks like poor resistance to oxidation and subsequent loss of magnetic properties which restricted their use in most commercial applications. Only by maintaining these fluids in an inert atmosphere can give an extended lifeTime. After doing thorough literature survey Fe iron particles are used as main constituent [7]. For present study Fe particles were used around 5nm size.



(a) TEM image of Fe nano-seized particles

Fig. 5: Image of MR fluid under Microscope

4.2.2. *Carrier fluid*
The carrier fluid serves as a dispersion medium and ensures the homogeneity of particles in the fluid. Similarly, the carrier liquid should be non reactive toward the components or materials used in the device. When selecting a carrier liquid, it is important to consider the boiling temperature, vapor pressure at elevated temperatures and freezing point. As per the properties of commercially available MR fluids (Lord Corporation) Hydrocarbon oil, water, silicone oil, mineral oil, ethylene glycol could be used as carrier fluid. Amongst all the carrier fluids silicone oil with 70% by volume gives high shear strength and negligible sedimentation rate. By taking all previous researches in consideration silicone oil is selected as carrier fluid.

4.2.3. *Additives*
A variety of additives (stabilizers and surfactants) are used to prevent gravitational settling, to promote stable particles suspension, to enhance lubricity and to change initial viscosity of the MR fluids. The stabilizers serve to keep the particles suspended in the fluid, while the surfactants are absorbed on the surface of the magnetic particles to enhance the polarization induced in the suspended particles upon the application of a magnetic field.
These are the materials used to add in very small quantities in the overall mixture in order to improve some properties.

5. EFFECT OF MULTILAYERED DISC SIZE & MICRO SIZED GAP ON MRF CLUTCH

5.1) ***Effect of multilayered disc size on MRFc***

The present research work dealt with optimization of geometric buildup of a multi-plate MR clutch. The simulation process showed that the transmissible torque of an MR clutch can be enhanced by reducing the magnetic resistance of flux-guide parts with using only small numbers of plates. Increasing the number of plates, the previously mentioned effect is getting negligible because the high magnetic resistance of the several gaps filled with MR fluid. Increasing the number of the plates is a more efficient way to enhance the transmissible torque. To conclude, the transmissible torque is approximately proportional to the number of plates, but because of power consumption of magnetization, the number of plates cannot be raised unlimitedly.

5.1.1. *Analytical Method of Torque Calculation*

- *Shearing stress* (τ):

τ = [shearing stress due to viscosity] + [shearing stress due to external magnetic field]

$$\tau = \tau_n + \tau_h$$

$$\tau = \eta \gamma + H^{\beta}$$

Where,

η =dynamic viscosity coefficient

- *Shear Rate*

Where, $\gamma = \dfrac{r\omega}{g}$

r = Radius of mating surface.
ω =Rotational speed between mating surface.
g =Thickness of gap with MR Fluid.
κ & β =Stand for constant.
H =Magnetic field intensity.

If working surface placed at radius relation to rotational axis;
Then, Torque Transmitted (T);

Therefore, $T = F \cdot r$

Value of generated force (F);

$$= F_n + F_h$$

$$= \tau_n \text{ A} + \tau_h \text{ A}$$

$$= \frac{\eta.\omega.r}{g} \text{ A} + \tau_h \text{ A}$$

Where,

F_n =Force caused due to viscosity of MRF.
F_h = Force caused due to Magnetic field.
A =Value of shear area.

Then, **Torque Transmitted (T);**

$$= \frac{\eta.\omega}{g} \text{A}.r^2 + \tau_h \text{A}r$$

$$= \frac{\eta.\omega}{g} \text{A}.r^2 + \kappa \text{ H}^{\beta} \text{ A } r$$

The result of the analytical investigation is depicted in Fig. 6 with continual line.

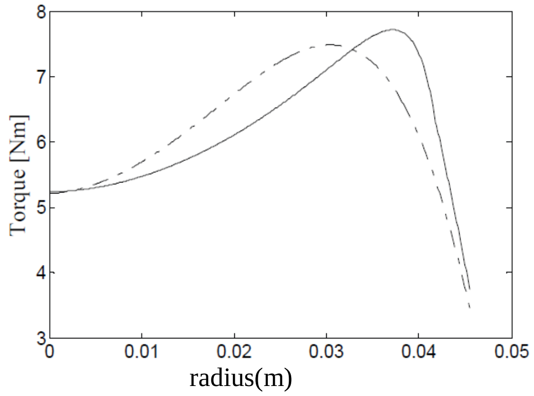


Fig 6: Analytical results

5.1.2. *Simulation Results*

To check our findings we carried out simulations by COMSOL Multiphysics software on the same configuration. In Fig. 7 one can see the relevant parts of the magnetic circuit where the darkness of picture is proportional to the intensity of magnetic flux density. Assuming *J*=4·106 A/m2 constant magnetization current density and *h*=1 mm fluid gap thickness, magnetic flux density was computed along the MRF gap assuming an inner radii of 16, 20, 24, 28 and 32 mm, respectively.

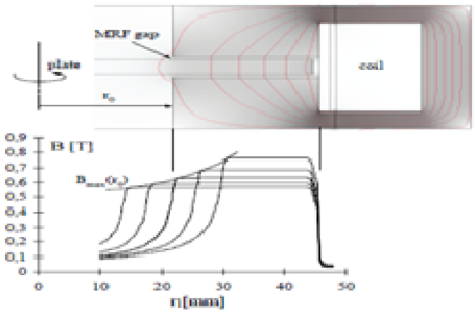


Fig 7: Magnetic flux density variation along radius

The relationship between the torque transmitted and inner radius of the plate gained by simulation is depicted with a dotted line in Fig. 6. According to the more accurate simulation procedure the optimal inner radius of plate happened at r0 ≈ 0.6r1. The reason for the difference between graphs can originate in many things. Analytical method can consider neither real geometry of flux guides, nor real material properties. It neglects also the resistance of MRF. The only advantage is the fast and globally appropriate solution. If accurate results are needed, the simulation procedure is firmly recommended.

5.2) *Effect of gap size on MRFc*

5.2.1. *Basic structure*

As shown in the figure 8, multi-layer structure is utilized to amplify output torque of the device. However, to make effective use of the viscous change of the MRF, we need to impress a sufficient magnetic flux on the MRF layers.6) because the MRFs have low magnetic permeability, it is necessary to reduce thickness of the total gap of the MRF layers for reduction of the magnetic resistance. Therefore, we suggest to utilize narrow gaps of 10 ~ 100 mm for the MRF layers.

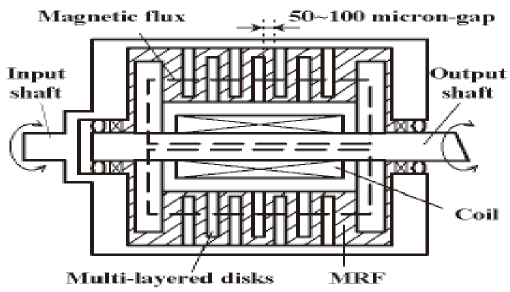


Fig 8: Basic structure of MRFc

5.2.2. *Basic design Method and goal*

We formulated design methods to estimate static torques of the CMRFC. An analysis is performed as follows;
(1) Geometric design of a CMRFC with 3-D CAD software.
(2) Magneto static analysis to estimate magnetic flux density with CAE (FEM) software,
(3) Decision of a yield stress of the MRF based on the results of the process (2) and the characteristics data of yield stress vs. magnetic flux density of the MRF.
(4) Calculation of a transmission torque based on the results of the process (3) and size-parameters.

5.2.3. *Effect of Gap size*

As a basic model, we decide 50 mm as a gap size for the MRF layers. However, more detailed analysis is needed because the gap size relates with other factors, for example required processing accuracy, assembling accuracy, cost and so on. It is hard task to accurately maintain 50 mm-gaps for multi-layered disks. Then we analyzed more detailed Condition on the gap-size with same conditions for other design parameters (the number and diameter of the disks, and so on).

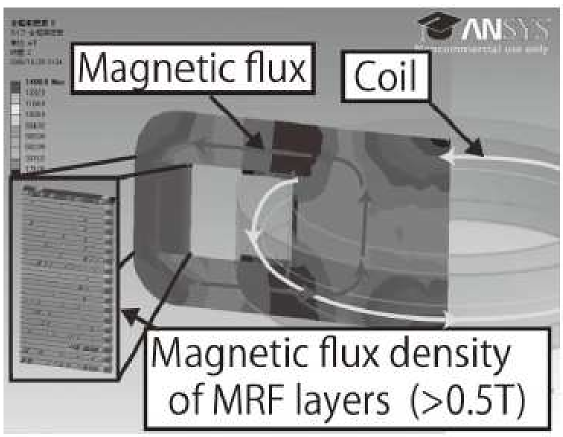


Fig 9: Magneto static analysis of MRFC

Figure 10 shows analytic results for each gap-size. The horizontal axis indicates electric current applied to the coil [A], and vertical axis indicates output torque of the devices [Nm]. As shown in this figure10, the increasing gap-size causes the reduction of the maximum torque; however, due to the nonlinear magnetic characteristics of the materials, the gap-effect becomes small in high current region. For example, torque ratio of 50 mm-gap to 100 mm-gap at 0.4 A of the electric current is about 1.6; however, that at 1.0 A is about 1.1. If we consider total cost / performance factors, it would be better to use 100 mm-gap or larger gaps in the practical devices. In this paper, we decided to develop two types CMRFC by applying 50 mm-gap and 100 mm-gap, and test their static torque experimentally.

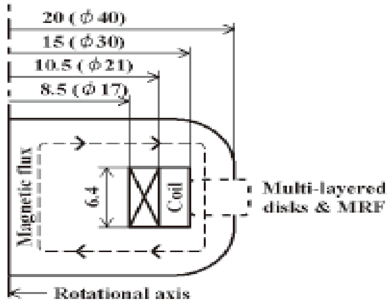


Fig10: Magnetic core

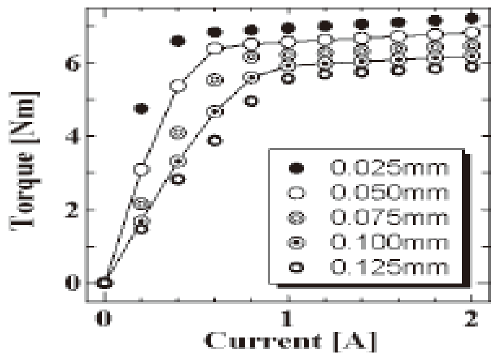


Fig 11: Effect of Gap size

According to the result of the magneto static analysis, we decided to use 9 input disks and 8 output disks for the target device. Therefore, the number of the MRF layer is 18. The diameter of each disk is 40 mm and the length of the MRF layer on the disk is 5 mm from the outer edge of it. We decided 50 mm as a gap size for the MRF layer in the first trial of the analysis. More detailed discussion on the gap size is conducted in the next session. The other geometric information for the magnetic core (yoke) is shown in Fig10.

Table 1: Specification of MRFC

Total thickness [mm]	32
Outer diameter [mm]	52
Diameter of disks [mm]	40
Number of disks	9(input)+8(output)
Number of MRF layers	18
Gap size of MRF layers [μm]	50 / 100 (2types)
Number of turns of coil	191
Idling torque [Nm]	0.15
Torque at 1A [Nm]	>5.0
Mass [g]	237

5.3 ***MR fluid using nano-sized Fe particles***

The majority of existing MRF is composed of micron-sized Fe particles suspended in a nonmagnetic carrier fluid. The particles may lead to unwanted abrasion of the components in contact with the fluid. Also, they are susceptible to settling in the absence of frequent mixing due to predominant gravity forces. Nanoparticles dispersed fluid would be desirable. Figure 9 (a) shows TEM image of the spherical Fe nanoparticles used in this study. The Fe nanoparticles were synthesized by the arc-plasma method.13) the diameter of the Fe nanoparticles estimated from their specific surface area was 104 nm. The saturation magnetization of the Fe nanoparticles was evaluated to be ~190 emu/g from their magnetization curve. After the surface modification with silane coupling agent, the Fe nanoparticles were dispersed in silicone oil (KF96-50cs, Shin-Etsu chemical, Japan), and the solid concentration of the Fe nanoparticles was set to 20 vol%. We call this new material “nano-MRF” in this paper. Figure 5.7 shows the photograph of the Fe nanoparticles dispersed system. Thanks to the hydrophobic surface and surface effect of the nano-sized particles, we cannot find significant particle-settling for more than several months.

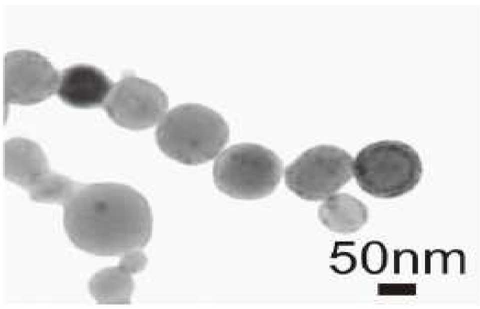


Fig 12:TEM image of Fe particles

Fig 13: TEM image & appearance of Fe nano sized MR fluid.

5.3.1*Results*

Static torque tests were conducted. Rotational speed of the output shaft was controlled at 3.0 rad/s accurately. An electric current was applied at a constant value and an average

Transmission torque was measured. The experimental results are shown in Fig.14 (a) and 14(b). Black circles mean transmission torque of experimental results. White circles mean the results of the analysis mentioned in the previous section. As shown in the figure14 (b), the Experimental result for 100 mm-gap indicates good similarity to the analytical result. Meanwhile, the result for 50mm gap has error of 10-20 % between analytic and experimental results. This would result from insufficient filling of the MRF (or particles) against 50 mm-gaps.

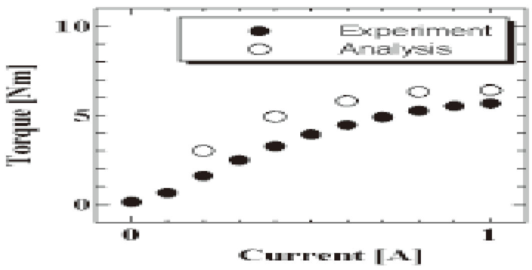


Fig 14(a):50µm gap

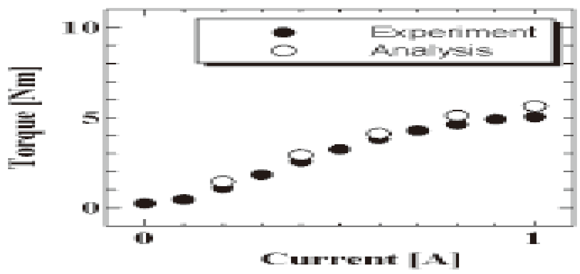


Fig 14(b):100 µm gap

In order to test viscosity-change characteristics of the nano- MRF, we filled the fluid in the 5Nm-Class

CMRFC with 50 mm-gap and tested torque response of it. The experimental setup and conditions are described in the previous sections. Figure 15 shows an experimental result of static torque tests. Black circles mean transmission torque of experimental results. White circles mean the estimated torque from magneto static analyses. An off-state torque at the electric current of 0.0 A is 0.28 Nm, and maximum torque at 1.0A is about 2.7 Nm. The off-state torque is about double of that with the MRF-140CG., Lord Corp. The maximum torque is about half of that. The MRF-140CG includes Fe particles of 40%vol. This value is just double of the new MRF. Therefore, the filling rate of particles would be strongly related to the viscosity-change of the MRF.

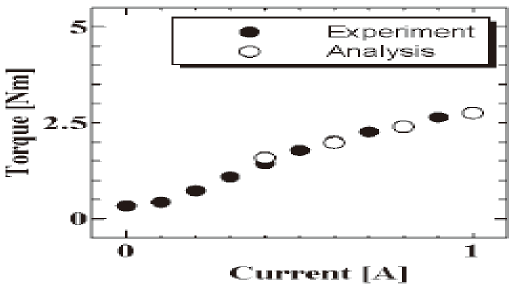


Fig15: static torque of nano MRF filled in MRFC with 50micron gap

6. CONCLUSION

In this report MR fluid is one of the smart materials prepared by suspending Magnetizable particles in dispersion medium like oil or water. In present work it is observed that the viscosity of such colloidal solution is getting varied with respect to magnetic field within fraction of seconds.

Properties of MR fluid are discussed briefly in present report. From above research it can be concluded In present research work developed two types of compact MR fluid clutches (CMRFC), which performs about 5Nm torque by applying 1 A current and have two different gap-size (50 mm and 100 mm). We tested their static torque. First, we used a conventional MR fluid as a working material of the CMRFCs. Then we used new MRF, which consist of nano sized Fe particles. According to the experimental results, gap size Affects not only magnetic property but also easiness of filling of MRF (or particles). We should consider the gap-size depending on the particle-size. The research clearly explains that size of multilayered disc affects not only magnetic properties of MR fluid but also Torque transmission capacity of MRF clutch.

REFERENCES

[1] J.Wang, G.Meng, (2001.) "Megnetorheological fluid devices: principles, charecteristics and applications in mechanical engineering", Proc. Instn. Mech. Engineers, Volume.215,

[2] M. Kciuk, R. Turczyn, (2006)"Properties and application of Megnetorheological fluids", Journal of Achievements in Materials and Manufacturing Engineering.

[3] 3)N.M.Wereley, A.Chaudhari, J.H.Yoo, S. John, S.Kotha, A. Suggs, R.Radhakrishnan, B.J.Love, T. S. Sudershan,(2006) "Bidisperse Megnetorheological Fluids using Fe particles at nanometer and micron scale", Journal of intelligent material systems and structures, Volume.17,.

[4] D. Torocsik, (2011)"Some design issues of multi-plate Megnetorheological clutches", Hungarian journal of industrial chemistry, Volume.39,.

[5] 5)Deepak Baranwal, Dr. T.S. Deshmukh (2012) “MR-fluid technology and its application- a review “International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 2, Issue 12, December.

[6] 6) Adam Rosiakowski, (2012) "Research on clutch with Megnetorheological fluid", Archives of Mechanical technology and Automation, Poznan university of technology, Volume.32,.

[7] 7) Mark R.Jolly,Jonathan W. Bender and J. David Carlson, “Properties and Applications of Commercial Megnetorheological Fluids", Thomas Lord Research Center Lord Corporation, 110 Lord Drive Cary, NC 27511.

[8] 8)G. Routhier and Y. St-Amant,(2011)"Torque Capacity Enhancement of Megnetorheological fluid clutch using the Squeeze strengthening effect", International Workshop on Smart Materials ,structures and NDT in Aerospace, Canada .

[9] 9)F.Bucchi,P.Forte,F.Frendo,(2013)"Magnetorheological clutch for efficient automotive auxiliary device actuation", The Italian research on smart materials and MEMS, Volume.23.

[10] 10) Horvath P (2011) “Optimization of a disc-type magneto-rheological clutch", Faculty of Mechanical Engineering, STU in Bratislava, Vol. 19.

[11] 11)Takehito Kikuchi et al, "Design and Development of Compact Megnetorheological Fluid Clutch (CMRFC) with Multi-layered Disks and Micro-sized Gaps”, Journal of the Society of Rheology, Japan, Vol.38, No.1.