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The Study of Magneto Rheological Fluids and Its Application in UAV

A.M. Anushree Kirthika

Dept. of Aeronautical Engineering, Veltech Dr RR & SR Technical University
Avadi, Tamilnadu, India,
E-mail: anushree.krithika@gmail.com

Abstract—*There are various developments in science and technology. These developments take place with innovation in materials, methods of operation and its application. A magnetorheological fluid consists of three main components namely soft magnetic particles, carrier liquids and additives. There should be replacement of existing devices with these smart system. This paper aims to study the properties, composition, principle of fluids and the application of MR Fluid in UAV for landing gear.*

Keyword: *Magnetorheological fluids, smart system*

1. INTRODUCTION

There are developments in technology which takes place with a innovation in materials , method of operation and the application of particular element or component in that field of study .This innovation in materials lead to change of properties. This change of properties lead to change of application and which changes its reliability, controllability on that processed product. One such development includes the magnetorheological fluids. The magnetorheological fluids with excellent properties are applied in various field of mechanical, automobile, civil, safety engineering, transportation and in life science.

The standard materials such as steel, aluminum, gold is all highly used in industries for various purposes, but these materials do not have very special properties. Due to such issues, Research are done for new materials with better properties.

There are materials which can change shape and size on heating where there is change from liquid to solid at most in an instantaneous time limit when placed near a magnet. These materials are called as smart materials which posses one or more properties that can also be altered on application of process.

The day to day usage of materials have physical properties which cannot be significantly altered; for example, if oil is heated in a pan. Then it will become even lighter and thinner, while the smart materials on application of particular method may turn from a liquid state which flows easily to a solid. Each individual type of smart material consists of different property which can be altered such as viscosity, volume, conductivity. The special property that can be altered determines what type of application it can be used for [1].

Magnetorheological materials (fluids) are a class of smart materials whose rheological properties (e.g. viscosity) can be varied by applying a magnetic field, the suspended magnetic particles interact to form a structure that resist shear deformation or flow.

This change in material appears to be as a rapid increase in viscosity or in the development of semisolid state. These advancement in the magnetorheological materials lead to better properties and stability .The various range of applications include dampers , clutches ,brakes and also in prosthetic legs.

2. PROPERTIES OF MAGNETORHEOLOGICAL FLUIDS

Typical magnetorheological fluids are the suspensions of magnetizable particles such as iron suspended in carrier liquid such as mineral oil, synthetic oil, water or thylene glycol. The carrier fluid is exactly as a dispersed medium and ensures the homogeneity of particles in the fluid There are huge range of additives such as stabilizers and surfactants which are used to prevent gravitational settling and promote stable particle suspension , enhance lubricity and change initial viscosity of the magneto rheological fluids .The stabilizers are used to maintain the particles suspended in the fluids while the surfactants are absorbed on the surface of the magnetic particles to enhance polarization induced in the suspended particles upon the application of magnetic field.

Table 1: Properties of carrier fluids

PROPERTY	MINERAL OIL	SYNTHETIC OIL	SILICON-E OIL
VISCOSITY	0.028	0.1068	0.1100
FLASH-POINT	171-185	230	>300
SPECEFIC GRAVITY	0.818-0.95	0.817	0.9124
DENSITY	825	873-894	760

Table 2: Properties of MR Fluids

PROPERTY	TYPICAL VALUES
INITIAL VISCOSITY	0,2-0,3[Pa.s] at 25℃
DENSITY	3-4[g/cm^3]
MAGNETIC FIELD STRENGTH	150-250[KA/m]
YIELD POINT (τ_0)	50-100 [KPa]
REACTION TIME	Few milliseconds
TYPICAL SUPPLY VOLTAGE AND CURRENT INTENSITY	2-25 V ,1-2A
WORK TEMPERATURE	-50 TO 150 [℃]

The diameter of the magnetizable particle range from 3 to 5 microns. As the size increases, the stable suspension of particles also increases. A commercial product such as carbonyl iron are of size greater than 1 or 2 microns. It is difficult to manufacture smaller particles but it is easier to suspend it. Small ferromagnetic particles are available as oxides such as in the case of pigments commonly found in magnetic recording media. Magnetorheological fluids made from such pigments are stable due to the diameter of particles which are about 30 nanometers.

Due to low saturation magnetization, fluids made from these particles are generally limited in strength of 5KPa.These have a large plastic viscosity due to large surface area.

In the absence of an applied magnetic field , MR fluids are approximated to Newtonian Liquids .In most of the engineering applications a simple Bingham plastic model is effective at a particular field dependant fluid characteristics.

A Bingham plastic is a Non-Newtonian fluid whose yield stress must be exceeded before the flow can begin.

Hence the rate of shear vs shear stress curve is linear. In this model, the total yield stress is given by (1.1)

$$\tau = \tau_0(H) + \eta\dot{\gamma}. \quad \ldots\ldots (1.1)$$

Where

τ_0 = Yield stress caused by applied magnetic field [Pa]

H = Magnetic field strength [A/m]

$\dot{\gamma}$ = Shear rate [S^{-1}]

$\boldsymbol{\eta}$ =Plastic Viscosity, [Pa.S]

Generally, MR fluids are free flowing liquids which have a consistency similar to a motor oil as in Fig. 1.

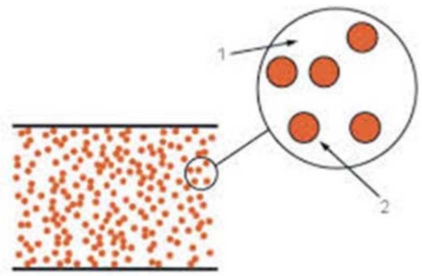


Fig. 1: MR fluid without outer magnetic field

In the Fig. 1 there are two representations namely 1 and 2

1 –carrier liquid

2- suspended magnetizable particles

However, in the presence of applied magnetic field, the iron particles acquire a dipole moment aligned with the external field which causes particles to form linear chains aligned with the magnetic field as in Fig. 1.2.

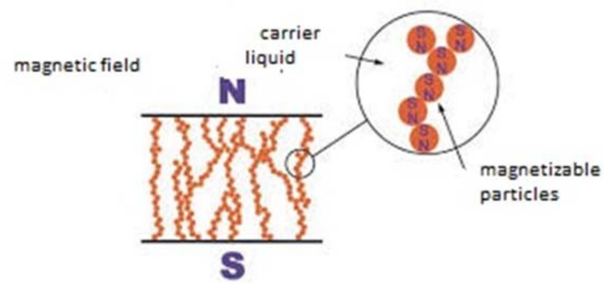


Fig. 2: MR fluid model in outer magnetic field

The phenomenon can solidify the suspended iron particles and restrict the fluid movement. There is also development of yield strength within the fluid. The degree of change is related to the magnitude of the applied magnetic field. Thus, this takes a very few milliseconds of time. [Typical magnetorheological materials can achieve a yield strength of up to 50-100KPa at magnetic field strength of about 150-250KA/m.]

In low magnetic field , the wall roughness which is in contact with the fluid is important for yield strength .The shear modulus of MR fluid shows a large increase in applied magnetic field for low strains prior to yield.].MR materials reach a saturation point where increase of magnetic field strength of the MR material .This phenomenon occurs around 300KA/M. Study of the magnetic saturation on strength basis can be done also by FEA.

The MR effect is immediately reversible if the magnetic field is reduced or removed .From study it shows that the response time is very fast and about 6.5 ms.MR materials are stable in temperature which ranges from -50 to 150°C. There are typically very small changes in the volume fraction and therefore small changes in the volume fraction and therefore small reduction in yield strength at such temperature. The change in property of MR fluids when placed in magnetic field is affected due to size distribution of suspended particles.

The advantage of MR fluid over ER fluid is given in table below.

Table 3: Comparison of MR and ER fluids.

S.NO	MR FLUID	ER FLUID	ADVANTAGE OF MR FLUID
1	Change in rheological properties is large	The change in rheological property is less.	Yield strength increases from 20 -50 times
2	MR fluids are less sensitive to moisture and contaminants	ER fluids are more sensitive to environment when compared with MR fluid.	It can be used in contaminant environment also.
3	These are unaffected by the surface chemistry of surfactants	These are more affected when compared to MR fluids.	Not affected by chemical reactions when compared with the ER fluid.
4	Power (50 W), voltage of about (12-24v) are the requirements of MR Materials.	Activation is more when compared to MR materials.	Activation of MR materials is small to that of ER materials.

In the above table comparison of the properties of MR and ER fluids are done for better understanding, where

MR – Magnetorheological fluids

ER – Electrorheological fluids

3. PRINCIPLE OF OPERATION

On application of magnetic field to the magneto rheological fluid causes the particles in the chain to align themselves into chains. The micro particles are magnetized to produce an orderly movement when an external magnetic field is applied. Hence the movement generated at the beginning of micro particles are magnetized. It finishes until it reaches a relatively stable state forming a fixed structure.

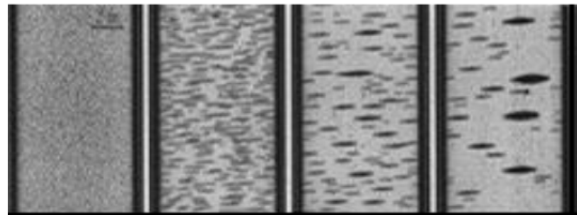


Fig. 3: Behavior of MR fluid under alternating magnetic field

There is gradual change in structure of particles when an alternating magnetic field is applied .The first leftmost picture shows the MR fluid which is after a time period of 1 second of exposure to fast changing magnetic field. The picture to right most end shows the fluid after a period of about 3 minutes,15 minutes and 1 hour of exposure. These particles also form little clumps that also help in little structural support.

4. BASIC SELECTION CRITERIA FOR MR FLUID COMPONENTS

Change in the composition and components, properties has wide range of variation in the MR effect. The selection criteria for various MR fluids are below as follows

4.1. Liquid Carrier

The viscosity of the fluid should be small and independent of temperature .The carrier liquid should be the major composition of MR Fluids .The commonly used carrier liquids are

1. Mineral and Synthetic oil

2. Silicone oil

4.1.1. Mineral and Synthetic Oil

The rate of change of viscosity is large in mineral oil Therefore this is one such limitation of mineral oil to be used as a carrier fluid in MR fluid at low temperature application. The various properties of synthesis oil are high flash point, high shear strength, high viscosity index, low friction and does not thicken at high temperature.

4.1.2. Silicone oil

There is good heat transfer characteristics , oxidation resistance , very low vapour pressure , high flash point .It is very difficult to seal silicone oil .There are small changes in physical properties over a wide range of temperature and a relative viscosity temperature slope and serviceability from -40 to 204°C.

4.1.3. Magnetic Particles

The size of magnetic particles is approximately of the order of 1µm to 10µm .As the size of magnetic particle increases, the attainable force also gradually increase but at the cost of increased off state viscosity (The viscosity without including the magnetic field) of MR fluid. The concentration of magnetic particles in base fluid can reach up to 50%. Low coercivity, high saturation magnetization, high permeability, small remnance and small hysteresis loop are other characteristics of magnetic materials used for chemically pure particles. The particles are mesoscale and spherical to eliminate the shape anisotropy.

4.1.4 Additives

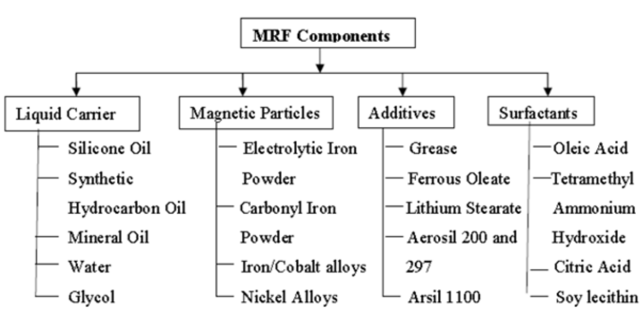
Highly viscous materials as grease, thixotropic additives are used for removal of settling stability. Ferrous naphthanate , ferrous oleate are also used as dispersants and metal soaps such as lithium stearate or sodium stearate as thixotropic.

Thixotropic is a property of gels that become liquids on stirring. Magnetic materials are coated with polystyrene (PS) for prevention of carbonyl iron (CI) particles from about to reach in contact with each other and thereby to decrease the (CI) particles density and thereby to improve sedimentation stability.

4.1.5 Surfactants

The surfactants serve to decrease the rate of ferroparticle settling which is a favorable characteristic for MR fluids. The ideal MR fluid never settles down but the development of such ideal fluid is difficult. The prolong settling of surfactants is achieved in two ways: by addition of surfactants and by addition of spherical ferromagnetic nanoparticles which suspends larger particles for a longer period. Addition of surfactants allows micelles to form around the ferroparticles.

Table 4: components of MRF



5. MODES OF OPERATION FOR MR FLUIDS

There are various modes of operation for MR fluids namely

1. Direct shear mode
2. Squeeze Film mode

5.1.1 Direct Shear Mode

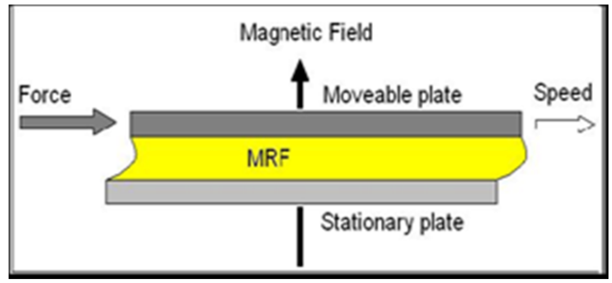


Fig. 4: Direct shear mode

In direct shear mode there is movement from two magnetic poles that are in relative movement with each other. There is shear which occurs in between them. The basic requirement of shear mode is that on movement of the relative plates, hence share the fluid between them as in fig4. Due to application of magnetic field there is alignment of MR particles in the direction perpendicular to the pole plates as such during the condition where there is sharing of motion between them attempts to bend the particle chain along the flux line .As the field intensity increases the MR fluid's resistance to shear process also increases. The direct-shear mode of MR fluids can be used in low force dampers.

5.1.2 Squeeze film mode

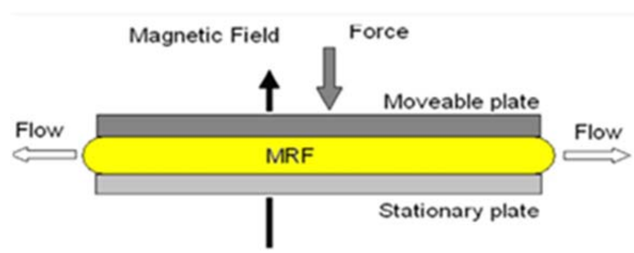


Fig. 5: Squeeze film mode

Squeeze film mode involves a layer of MR fluid where there are two magnetic poles as shown in the above Fig. 5.On application of force onto the plates such that parallel to the direction of flux lines that pressurizes the chain like structure of MR fluid particles . The ability of the MR fluid particle column to resist the buckling action is influenced by the intensity of induced fluid.

6. APPLICATION IN UAV

In general, there are wide range of application of MR fluids. These are used in dampers, shocks for racing cars. There are wide range of dampers such as mono tube damper etc.MR dampers are also used in suspensions, control by wire, feedback devices, pneumatic control, seismic mitigation and in human prosthesis.MR technology offers

1. Simple design
2. Damping

3 Motion and position control
4. Locking
5 High energy density

In UAV, the magnetorheological fluid can be applied in the case of shock absorber. Shock absorbers are designed in large commercial aircraft and now recent developments are being established for fixed wing type of UAV. The design of landing gear is also an important aspect. The landing gear when designed can be exposed to different loading which are due to two reasons that is change in aircraft center of gravity location and dynamic loading. Consider a tricycle configuration of landing gear which is found in most of the commercial jet aircraft. The wheel load geometry is illustrated and explained below with formulas for calculation of load in the nose and main landing gear with respect to CG location [8].

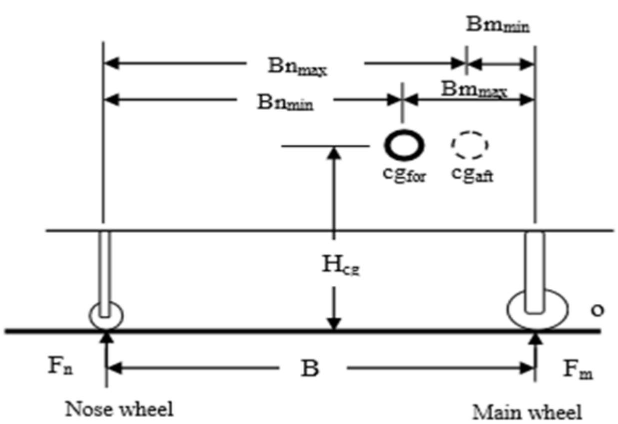


Fig. 6: Wheel load geometry

Along the x-axis, the aircraft center of gravity moves along two extreme limits “a” and “b”, where “a” refers to (Xcgaft) most aft location and “b” refers to (Xcgfor) most forward location. The main gear carries a load which is greater than the aircraft weight. The following equations govern the minimum and maximum static loads on each gear.

$F_{m_{max}} = \frac{B_{n_{max}}}{B} W$ …… (6.1)

$F_{n_{max}} = \frac{B_{m_{max}}}{B} W$ …… (6.2)

$F_{m_{min}} = \frac{B_{n_{min}}}{B} W$ …… (6.3)

$F_{n_{min}} = \frac{B_{m_{min}}}{B} W$ …… (6.4)

During the braking segment of landing operation, the equilibrium equation is obtained below.

$\sum M_0 = F_n B - W B_m - \frac{W}{g} |a_L| H_{cg} = 0$ …….. (6.5)

Where "a_L" refers to Braking Deceleration and “g” refers to Gravitational acceleration. The load acting in the nose gear is given below as

$F_n = W \frac{B_m}{B} + \frac{W |a_L| H_{cg}}{gB}$ ……. (6.6)

Where the first term refers to static load and second term refers to dynamic load. The total load on nose gear during landing is as follows

$F_n = F_{n_{max}} + F_{n_{dyn}}$ ……. (6.7)

Similarly, the dynamic load on main landing gear during take-off with an acceleration of “ a_T” will be determined as follows.

$F_{m_{dyn}} = \frac{a_T W H_{cg}}{gB}$ ……. (6.8)

Thus, the total load acting on the main landing gear is illustrated below.

$F_m = F_{m_{max}} + F_{m_{dyn}}$ …….. (6.9)

$= W \frac{B_{n_{max}}}{B} + \frac{W |a_T| H_{cg}}{gB}$ …….. (6.10)

The landing gear must be designed based on the maximum take-off weight of aircraft and not on the landing weight. Though the weight of aircraft during the phase of landing is very less when compared to MTOW [8].

The shock absorber data are generated based on the load acting on the gears. The diameter of the shock absorber is illustrated below [9].

D_s= 0.041 + 0.0025 $(P_m)^{0.5}$ ……. (6.11)

Where “ P_m ” refers to Load on main landing gear in pounds (lbs.) and “ D_s” refers to diameter of shock absorber in inches.

The shock absorbers are designed with a MR fluid in flow mode with a moving piston which is held together with an electromagnetic coil. The MR fluid will flow with an annulus between piston and body of cylinder. The design and components of landing gear with shock absorbers are shown below.

The basic elements are pneumatic chamber in the top, fluid flow control module in the middle, MR fluid chamber at the bottom. The top and bottom chambers are integrated to the flow control module. The flow control module will hold all the electromagnetic coil and elements for the magnetic flux path. The top and bottom chambers are fabricated with non-magnetic materials, so that the flux leakage will be minimized. The flow control module is manufactured with magnetic materials except the coil housing, coil cover and flow directing plates. All the items are properly machined with very close tolerances to maintain the geometric and positional requirements. The tyre is made up of standard aircraft quality to with stand the static and dynamic requirements [9].

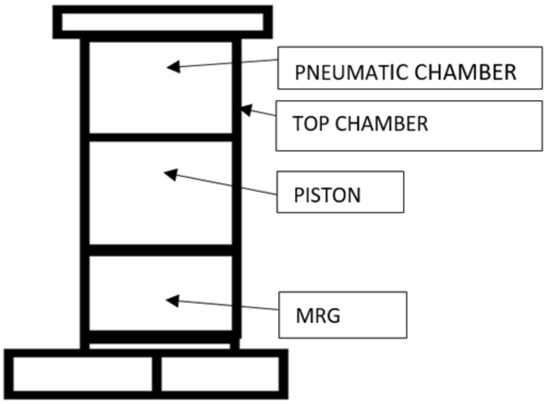


Fig. 7 Arrangement of landing gear

At the time of landing condition, due to vertical descent and weight of the aircraft, the piston rod will move inside pushing the MRG though the flow control module. The flow control module will regulate the flow of the MRG to the top chamber. As the flow of the fluid increases its volume in the top chamber, the piston in the top chamber will start compressing the gas inside the chamber and increases its pressure. The change in pressure also acts as a vertical force on the bottom piston. Once the gas is fully compressed, the movement of the pistons will be stopped. The pressure inside the top chamber is so high, that it is sufficient to float the UAV on the pneumatic pressure. As the gas is fully compressed, it will slowly expand and moves piston downward to a static position. Once fully compression is achieved, the magnetic flux will be switched off, so that the MRG will flow downward easily while the gas is in expansion condition.

Thus, the landing gear will settle in the static position. Once the takeoff is completed, air pressure pushes the piston to the bottom positon, thus the piston in bottom chamber will also be pushed down to the fully extended condition. The power-on condition will be only during landing condition. The velocity of the compression stroke will be regulated to achieve the desired damping properties. The diagram below illustrates the landing gear with piston in it.

Fig. 8 Assembly of landing gear

7. CONCLUSION

This paper deals with the basic principles, operation of magnetic field along with various properties. Science and technology shows a large variation in the view of developments in current new technology and research for past years.

Magnetorheological fluids can change their shape and form also from liquid to solid along with exposure to magnetic field. In the absence of Magnetic field the fluid behaves like a Newtonian fluid. The change in property of MR Fluid when placed in magnetic field is affected due to size distribution of suspended particle.

MR fluids provides more reliable control and can operate at very low voltage power supplies. MR technology can provide flexible, reliable control capabilities in designs also.MR fluid is less prone to contaminant and can be used in contaminated environment also.

As the size increases the stable suspension also increases.

These smart materials that are magnetorheological fluids are highly useful due to their properties and can be applied in various field such as dampers, MR fluid shocks for racing cars and in advance prosthesis also. The application of MR fluid in UAV for shock absorber has been explained along with the configuration of landing gear [9].

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