



## The Review of the Application of Magneto-Rheological Fluid and Engineering

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### ABSTRACT

Magneto-rheological fluid (MRF), as a smart material, with its fast response, simple operation, precise control and other fine features, has become an important branch of smart materials development. It has attached great importance from the domestic and abroad scientific community and caused a lot of manpower and resources used for the research and development of MRF materials and devices. This paper summarizes recent research status regarding the MRF, and describes the ingredients, features of MRF and its applications in engineering. Finally, it provides further problems to be solved and outlook for the prospect of the development of MRF technology.

**Keywords:** MRF, Polishing, Damper, Brake.

### 1. INTRODUCTION

MRF is a smart material with good development prospects. In the absence of a magnetic field, it showed good flow properties of liquid; but in the strong magnetic field, it will transform from liquid to solid in a very short period of time (in milliseconds), when removed the external magnetic field, it will appear Newtonian behavior again. This process of liquid - solid conversion is fast, easy control and low energy consumption, promoting it as an important branch of the development of smart materials, widely used in automobiles, machinery, aerospace, construction, instrumentation, precision machining, control engineering and other fields.

In 1840s, the second year after the invention of electro-rheological fluid (ERF), American scholars have invented MR material. At that time, widespread concern about ER, various ERF materials have been prepared, some of the ERF device also emerged. During this period, the MRF did not attract academic attention, caused the research about MRF delayed 40 years. Until the 1880s, along with small shear stress, high voltage power supply, security, tightness and some other problems of ERF materials, scholars began to focus on MRF. Compared to the ERF materials, the shear yield of MRF is great stronger, it doesn't pollute the environment, and requires for the power supply voltage and operating temperature range is wider. Since the 1990s, the research on MRF renewed to life. Especially since 1995, the international biennial conference about ER also changed name to the International Conference of ERF and MRF, which promote the research and development of MRF.

### 2. COMPOSITION AND PROPERTIES OF MRF

#### 2.1 Composition of the MRF

MRF mainly consists of three parts: magnetic particles, carrier liquid and additives.

**Magnetic particles:** under the applied magnetic field, the magnetic particles are magnetized, and showed the shape of chains along the magnetic field lines so that the MRF exhibits characteristics similar to solid, the magnetic particles should have a high permeability and low coercive force, the size should be moderate, not too small nor too big, the shape to spherical or ellipsoidal for the best. Magnetic particles' size is an important factor in controlling MR effect.

**Carrier liquid:** The effect of the carrier liquid is to disperse solid particles in the MRF uniformly, ensure that its overall behavior of multicomponent with two-phase, which presents Newtonian behavior at zero magnetic field, and act as Bin Han fluid properties in the magnetic field. The carrier liquid generally has many characteristics such as low viscosity, high boiling point, low freezing point, greater density, good stability of chemical and low cost. Now, the materials of MRF carrier liquid is usually mineral oil, silicone oil, water and other complex mixture materials .etc.

**Additives:** Additives role is to slow down or prevent the sedimentation of magnetic particles, to improve the stability of the mixture, properties of anti-corrosion and lubrication. Additives usually consist of two parts: (1) Active agent which can improve magnetic susceptibility, enhance MR effect; (2) Stabilizer which can prevent sedimentation of the magnetic particles, prevent failure of the MRF. The common used additives are oleic acid, alkylamine phosphate ester, coupling agents, polyethylene glycols .etc.

## 2.2 Properties of the MRF

MRF has many characteristics such as yield stress, stability, response time and operating temperature.

**Yield stress ( $\tau$ ):** For some non-Newtonian fluid, the small shear force exerted small deformation and fluid does not generate flow, when the shear force increases to a certain degree, the fluid began to flow. At this point, the value of the force is the yield stress. It is mainly related to the following factors: (1) Saturation magnetization ( $M$ ),  $\tau \propto M^2$ ; (2) Magnetic field intensity; (3) Volume fraction of MRF; (4) Particles' diameter.

**Stability:** The stability of MRF generally refers to reunite stability, sedimentation stability and thermal stability. Reunite stability ensures dispersion between particles; sedimentation stability prevents particles from sinking, and stables suspension; thermal stability guarantees MRF can effective at different temperatures and with a stable chemical composition.

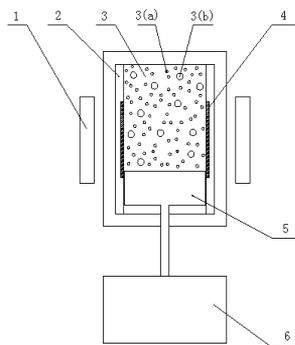
**Response time:** response time refers to the time of MRF in the magnetic field change from liquid into solid ( $\leq 6 \mu s$ ). It is mainly related to the volume fraction of MRF, viscosity and Magnetic field intensity.

**Operating temperature:** The range of operating temperature is mainly related to base liquid. Water-based MRF's operating temperature is much narrower than silicone-based.

## 3. APPLICATION OF MRF

### 3.1 Precision components processing

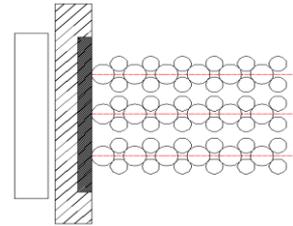
In some technical areas, the accuracy requirement of plane work piece is at the nanoscale, it's difficult for most of polishing apparatus to meet the accuracy, and apparatus which can reach the accuracy requirement, the polishing process can't be controlled easily. The magneto-rheological abrasive flow finishing (MRAFF) system blends abrasive particles with MRF, and its control device consists of a pair of electromagnets outside, which not only solve the problem of machining accuracy, but also make the polishing process can be controlled by an external device.



**Figure 1.** Apparatus of MRAFF

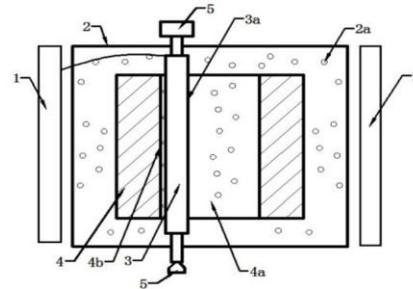
Apparatus is shown in Fig.1, where 1- electromagnets (generate magnetic field); 2-fixure; 3-polisher; 3(a) - magnetic particles; 3(b) -abrasives; 4-workpiece; 5-piston; 6- hydraulic control unit. The liquid in the polisher is the mixture of abrasives and magnetic particles, the abrasives are always non-magnetic (such as  $SiO_2$ ). Under the effect of magnetic field, magnetic particles were distributed along the

chain direction of the magnetic field lines, abrasives embedded in the magnetic chain to form body-centered cubic structure (as shown in Fig.2). When this structure contact with the surface of work piece, abrasives are withstood by magnetic chain to form flexible grinding, few layers of flexible grinding form a structure like brush. Then, the 'brush' will remove the extra materials on the surface of workpiece, and because of the mechanical mechanism, the effect of brush's removal is inversely proportional to the gap between abrasives and surface of work piece, that means it has a high material removal at the bumps, and low in the corresponding indentation. On the one hand, the 'brush' has viscoelasticity, so it will not damage the surface during the process; on the other hand, this process is adapted to the surface of work piece, which as long as the hydraulic unit controls the movement of the piston to polish the surface, a uniform surface and high-precision machining of a work piece will be got finally. Last but not list, the brush make free abrasives particles distributed in the polishing surface of the tool uniformly and stably, which traditional free abrasives machining technology can't do this.



**Figure 2.** body-centered cubic structure

Since the MRF can be used on plane for processing, then the field of machining and processing difficulties - surface also can use MRF to the polishing process, the device was shown in Fig.3.



**Figure 3.** MRF surface polishing system

Where: 1- electromagnet, 2- polishing pond, 2a- abrasive particles, 3- polishing shaft, 3a- centerline of shaft, 4-work piece, 4a- surface of work piece, 4b- centerline of work piece, 5- coordinate control device. The principle is similar to plane polishing process. Their differences are as follows: (1) one of the pole of device which generates magnetic field is polished shaft, the other pole is circumferentially disposed along the work piece, the purpose of design is to adjust the force of around the centerline of work piece; (2) under the control of the coordinate control device, the shaft not only do the polishing axis rotation, but also move in the XY plane; (3) according to program instructions, coordinate control device not only controls the rotation of the polishing shaft and the movement in XY plane at the same time, but also to maintain a minimum distance between centerline of shaft and

centerline of work piece, thereby ensuring the uniformity of polishing process; (4) the rotation of the shaft and its movement in XY plane can play a role of agitate the MRF, make abrasive particles distributed in the MRF uniformly, ensuring uniformity of polishing precision.

### 3.2 MRF damper

As shown in Fig.4, MRF has three working modes, they are: shear mode, squeeze mode and pressure-driven mode.

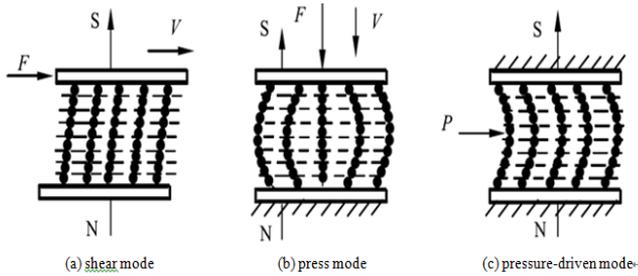


Figure 4. Three forms of work modes

Shear mode: As shown in Fig.4 (a), between two plates filled with MRF, F and V are force and velocity respectively. When under the magnetic field, magnetic particles were distributed along the chain direction of the magnetic field lines, thus limiting the flow of MRF, which generate shear yield stress.

Squeeze mode: As shown in Fig.4 (b), F act on the upper plate perpendicularly with a speed V downward movement, MRF was squeezed and flowed all-around, the direction perpendicular to the magnetic field direction. Mobile small displacements, MRF was able to have a great damping force.

Pressure-driven mode: As shown in Fig.4 (c), MRF flowed through the fixed plate under the pressure (P), the flow direction was perpendicular to the magnetic field direction. Then by changing the current of excitation coil to control MRF's pressure.

MRF damper is the application of pressure-driven mode, generally used as shock absorption, cushioning devices. MRF damper has a large output, low energy consumption, fast response and continuous performance characteristics, widely used in vehicles, machinery construction and medical fields.

As shown in Fig.5 is the structure of MRF damper, where: 1-cylinder, 2-damping channel, 3 MRF, 4- coil, 5-flux, 6-piston, 7-piston rod.

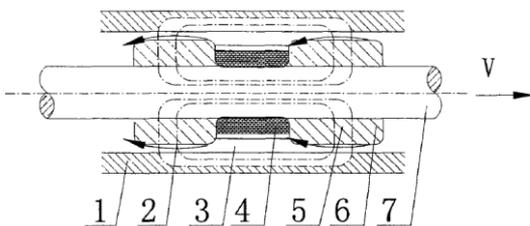


Figure 5. MRF damper

In operation, the magnetic field generated by the coil worked on the MRF, MRF formed chain structure under external magnetic field. The substance of chain structure is magnetized particles which movement is substantially parallel to the magnetic line. The magnetization motion made particles end to end, thus forming a chain structure, and even complex network structure. Movement of the piston caused

the MRF with a great speed through the gap between the piston and the cylinder wall, a pressure difference is generated across the gap, the cross section of the pressure differential acting across the piston, to produce a corresponding damping force and this force is controllable. As shown in Fig.6, there is an active and non-active region in the gap, MRF in activate region is affected by the magnetic field, MRF showed the characteristic of visco-plastic properties. By adjusting the strength of magnetic field, different shear yield stress can be obtained, so the control of the damping force can be achieved.

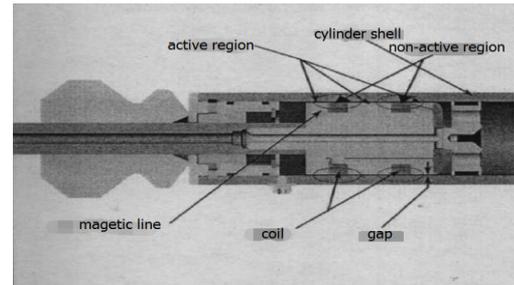


Figure 6. structure of gap

### 3.3 MRF Brake

The main function of the brake is to slow down or stop the machine or mechanism. Sometimes also used to adjust or restrict the movement speed of the machine or mechanism. Brake is important safety component to ensure normal work. MRF brake is the application of shear mode. Compared with the traditional brake, MRF brake has the following advantages: (1) by adjusting the magnetic field strength to control the size of the braking torque; (2) vibration, shock and noise are very small; (3) fast response; (4) small abrasion, long service life; (5) low energy consumption, simple structure. Usually, MRF brake has three forms, as shown in Fig.7, they were: disc, column and taper. They have differences in structure but with the same principle, so, this paper just introduces the disc MRF brake.

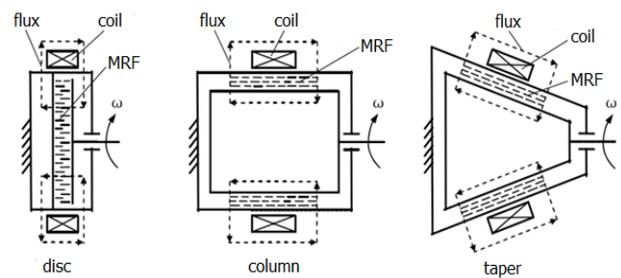


Figure 7. MRF brakes

Fig.8 is the structure diagram of disc MRF brake, in which: 1-shaft, 2-rotating disc, 3-coil, 4-flux, 5-MRF, 6-shell, 7-bearings. Disc drives shaft to rotate, when the magnetic excitation coil is not energized, MRF is NEWTON fluid, brake torque generated by the viscous force of MRF is almost 0, disc continues to rotate, brake doesn't work. When the coil is energized, current generates a magnetic field, under the action of the magnetic field, the magnetic particles in MRF attracted to each other along the magnetic field direction to form a chain structure, so that the MRF changes from fluid to solid, increasing the shear stress to produce torque to slow down or stop the machine or mechanism.

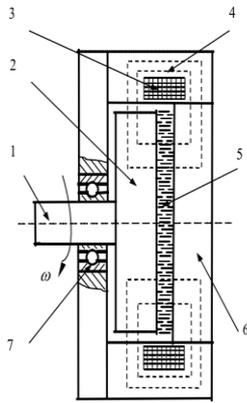


Figure 8. Disc MRF brake

### 3.4 MRF hydraulic device

In the hydraulic system, the magneto-rheological valve is another application in engineering, under the control of magneto-rheological valve, the MRF as the working medium can complete drive action. As can be seen from Fig.9, magneto-rheological valve worked as a non-moving elements proportional control valve in the hydraulic system, compared to traditional hydraulic proportional valve, MR valve is much cheaper and it has longer longevity.

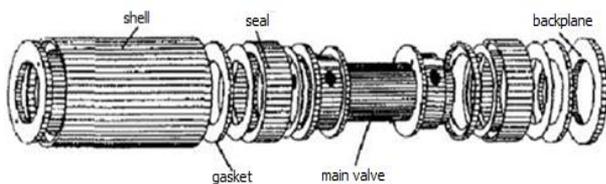


Figure 9. MRF hydraulic device

The working principle was shown in Fig.10, during normal operation, the current work through the coil of diagonal hydraulic valve (2, 3 or 1, 4), the resistance changed a lot, and it was controlled by the size of current, hydraulic cylinder piston moved in the chamber up and down, caused a difference of pressure, the piston moves in this difference, and achieve the purpose of positioning the actuator.

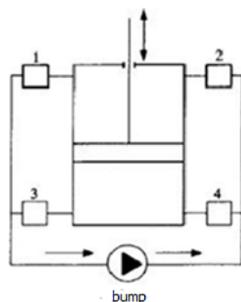


Figure 8. MRF hydraulic system

## 4. CONCLUSION

In order to make the MR device widely used in engineering, the MRF must be stable and reliable, but in practice, there are still exists many problems, one of the biggest problems is the stability of the settlement, which is

how to preserve the MRF. Three working modes of MRF, in which the shear mode (applied to the brake, clutch) and pressure-driven mode (damper) has been studied, and its related devices are gradually entering the market, but the research progress of the press mode is slow. MRF lose stability in high-speed rotation easily, resulting in the difference between the output torque and the ideal state in the clutch and brake. At the same time, the relevant technology is only reported in the literature is limited to general principle, key technology in the development process is still in the stage of secrecy. These factors have seriously affected the wide application of the magnetic rheological device.

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