A Pressure Control Valve Using MR Fluid

Shinichi YOKOTA*, Kazuhiro YOSHIDA* and Yutaka KONDOH*

* Precision and Intelligence Laboratory
Tokyo Institute of Technology
4259 Nagatsuta-cho, Midori-ku, Yokohama, 226-8503 Japan
(E-mail: syokota@pi.titech.ac.jp)

ABSTRACT

A novel control valve using MR fluid (MR valve) is proposed for fluid control systems. The MR or Magneto-Rheological fluid is a newly developed functional fluid whose apparent viscosity is controlled by the applied magnetic field intensity wider than that of Electro-Rheological fluid. The MR valve consists of a flow channel between a pair of magnetic poles and the differential pressure is controlled by the applied magnetic field intensity. It features simple, compact and reliable structure without moving parts.

An MR valve is fabricated. The magnetic poles have 20mm×30mm in face size and 3mm in gap length and are connected to an electromagnet. Through experiments on the static characteristics, it is found that the differential pressure is controlled by the applied magnetic field intensity under little influence of the flowrate, which corresponds to a pressure control valve. The differential pressure and output power changes of 0.68MPa and 20W are obtained with the input current and power changes of 710A-turns and 1.9W at the flowrate of 30cm³/s (1.8L/min).

KEY WORDS

MR Fluid, Control Valve, Functional Fluid, Static Characteristics, Actuator

1. INTRODUCTION

A novel control valve using MR fluid as a working fluid is proposed for fluid control systems. The MR or Magneto-Rheological fluid is a newly developed functional fluid whose apparent viscosity is controlled by the applied magnetic field intensity. Larger yield stress can be easily controlled with the MR fluid than with ER or Electro-Rheological fluid whose apparent viscosity is controlled by the applied electric field strength [1]. With application of the MR fluid, high level fluid power is expected to be controlled with simple, compact and reliable structure without moving parts. However, previous application researches have been focused on active dampers [1]-[3], brakes [1] and actuators [4]. There are few researches on application to fluid control components.

In this paper, firstly, a control valve using MR fluid is proposed for fluid control systems. Secondly, a 2-port control valve is fabricated. Then the static characteristics
among the differential pressure, flowrate and applied magnetic field intensity are experimentally investigated.

2. PROPOSITION OF CONTROL VALVE USING MR FLUID FOR FLUID CONTROL SYSTEMS

2.1 MR Fluids [1]
MR fluids are suspensions of micrometer-sized, magnetizable particles in oil. Without magnetic field, the particles flow freely as shown in Fig. 1(a). When magnetic field is applied, on the other hand, the magnetizable particles form clusters as shown in Fig. 1(b), which resist against flow increasing the apparent viscosity of the MR fluid.

Newly developed MR fluids feature 1) large yield stress 20 times larger than that of ER fluids, 2) sufficiently high response in millisecond order and 3) wide operable temperature range from -50 to 150°C. However, because of the high density of the magnetizable particles, the MR fluids have high density of 3 - 4x10³ kg/m³ and high base viscosity of 0.2 - 1.0 Pa·s to prevent sedimentation. The base viscosity is the viscosity without applied magnetic field.

2.2 Proposition of Control Valve Using MR Fluid
In this study, a control valve using MR fluid which has favorable features mentioned in section 2.1 is proposed for fluid control systems. The proposed control valve is called the "MR valve".

The principle of the MR valve is shown in Fig. 1. It has a flow channel to which magnetic field is applied vertically. The applied magnetic field intensity is controlled by the electric current of the electromagnet. The MR fluid flows through the flow channel as a working fluid.

Suppose that the differential pressure is maintained at constant. Without magnetic field as shown in Fig. 1(a), the apparent viscosity is low and the flowrate through the MR valve is high. When the magnetic field is applied as shown in Fig. 1(b), on the other hand, the apparent viscosity is high and the flowrate becomes low. However, for constant flowrate, the differential pressure is low in Fig. 1(a) and high in Fig. 1(b). In this way, the fluid power through the MR valve is controlled by the applied magnetic field intensity or the electric current of the electromagnet.

The proposed MR valve has simple structure without moving parts and controls fluid power through the MR valve directly by the electric current, hence it is expected to realize compact and reliable fluid control components. Also, as the simple structure is good for miniaturization, it is expected to be applied to the micromachines using fluid power which the authors have been developing [5].

Of course, some active dampers using MR fluid reported previously have MR valves in the components. However, the required performance for the active dampers are mainly on transient characteristics and are different from the MR valve for fluid control systems.

3. FABRICATION OF MR VALVE
To investigate the basic characteristics of the MR valve, a 2-port MR valve is fabricated as shown in Fig. 2. The fabricated MR valve consists of a flow channel, a pair of magnetic poles and an electromagnet. The magnetic poles have parallel plate faces with W=20mm in width, L=30mm in length and G=3mm in gap length. The magnetic material is mild steel and the nonmagnetic material is brass. Diameter and the number of turns of a wire for the electromagnet are 1mm and N=910, respectively. The measured electric resistance is 3.1Ω.

The MR valve is MRF-126QD developed by Lord Co., Ltd., USA. The density is 2.7x10³ kg/m³ and the measured base viscosity is 0.9 Pa·s at room temperature.

The magnetic flux density $B_0$ between the magnetic poles in air is measured by using a gauss meter. The marks in Fig. 3 show the relation between the magnetic flux density $B_0$ and the electric current $I$ of the electromagnet. The solid line in Fig. 3(b) shows the analyzed results as follows:

$$B_0 = \frac{\mu_0 H_0}{W} = \frac{NI}{\mu_0 G/W} = \frac{\mu_0 N I}{G},$$ (1)
where, $H_0$: the magnetic field intensity between the magnetic poles in air and $\mu_0$: permeability in vacuum. Equation (1) is obtained under assumptions that both magnetic leaks and reluctances of the core are negligible small and the magnetic flux density is homogeneous between the magnetic poles.

It is found that the magnetic flux density $B_0$ increases linearly with some hystereses for small electric current $I$, although there is saturation for large electric current $I$, which is caused by nonlinear characteristics of the magnetic material. There are some differences between the measured and analyzed results because of the magnetic leaks and reluctances of the core. For the same electric current $I$, the magnetic field intensity in MR fluid is slightly different from the value in air, however, in the experiments in chapter 4, for simplification, the magnetic field intensity is estimated as $H_0$ based on the results of Fig. 3(b) having the hystereses.

4. STATIC CHARACTERISTICS OF MR VALVE

4.1 Experimental Apparatus

With an experimental apparatus shown in Fig. 4, the static characteristics of the fabricated MR valve are experimentally investigated. In the experiments, the flowrate $Q$ through the fabricated MR valve is varied by manually adjusting the throttle valves A and B which divide an output flowrate of the gear pump. The upstream and downstream pressures $P_u$ and $P_d$ are measured by semiconductor pressure sensors and the differential pressure $\Delta P = P_u - P_d$ is calculated. The electric current of the electromagnet is $I = 0 - 0.78A$ ($I \cdot N = 0 - 710A\cdot$turns) and the magnetic field intensity $H_0$ is estimated based on Fig. 3(b) having the hystereses. The electric current $I$ is in no saturation range as mentioned in chapter 3. The flowrate

![Fig. 2 Fabricated MR valve](image-url)

![Fig. 4 Experimental apparatus](image-url)
4.2 Experimental Results

The obtained results are shown in Fig. 5. It is found that the differential pressure $\Delta P$ has little dependence on the flowrate $Q$ because the yield stress of the Bingham fluid characteristics is far larger than the shear stress caused by the base viscosity. It means that the differential pressure $\Delta P$ can be controlled by the magnetic field intensity or the electric current $I$ under little influence of the flowrate. The proposed MR valve has static characteristics corresponding to a pressure control valve. For the flowrate $Q = 30\text{cm}^3/\text{s}$, the differential pressure $\Delta P$ is varied from 0.007 to 0.69MPa by changing the electric current $I$ from 0 to 0.78A. The input power change of 1.9W produces the consumed fluid power change of 20W in the MR valve. For a 2-port control valve, the consumed fluid power in load connected serially to the control valve is controlled by the consumed fluid power in the control valve. So, with the fabricated MR valve, the output fluid power of 20W can be controlled by the input electric power of 1.9W.

Figure 6 shows the relation between the differential pressure $\Delta P$ and the applied magnetic field intensity $H_0$ for the same flowrate $Q$. It is clarified that, under these experimental conditions, the differential pressure $\Delta P$ increases linearly with some hystereses when the magnetic field intensity increases.

5. CONCLUSIONS

In this study, an MR valve with simple structure without moving parts is proposed for fluid control systems and the static characteristics are experimentally investigated. The following results are obtained:

1. The MR valve is proposed for fluid control systems.
2. The static characteristics are experimentally clarified.
3. The proposed MR valve has static characteristics corresponding to a pressure control valve.

The dynamic characteristics are under investigations through experiments.

REFERENCES