

Application Analysis of Magnetorheological Technology in Hydraulic Transmission and Control

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Abstract. This paper mainly explores the application of magnetorheological (MR) technology in hydraulic transmission and control. Starting with the overview of MR fluid (MRF), the effect, composition and working principle of MRF are analyzed. On this basis, the application measures of MR technology are studied from three aspects of MR pilot valve, MR servo valve and MR proportional valve, with a view to providing reference for relevant workers.

1. Introduction

The American scholar *Rabinow* first discovered the phenomenon of MR in 1940s, and applied for the patent of MRF transmission technology in 1951. MRF is a kind of intelligent controllable liquid. Under the action of magnetic field, MRF can complete the mutual transformation of quasi solid and fluid state, and the reaction time is only millisecond. This transformation has controllable and reversible characteristics, which makes MRF widely used in clutches, aerospace, automobile brakes, etc [1]. The application of MR technology in hydraulic transmission and control has a good effect.

2. The Overview of MRF

2.1 MRF Effect

The effect of MRF is explained according to the general magnetic domain theory. Every small particle suspended in MRF is regarded as a small magnet. The exchange coupling between adjacent atoms is strong, and the particles are arranged in a parallel state of magnetic moment to form a magnetic domain.

2.2 Composition of MRF

MRF is mainly composed of magnetic particles, additives and carrier liquid, among which magnetic particles, as one of the important components, have an important impact on the dispersion, oxidation resistance, friction and other properties of MRF. At present, magnetic particles are usually hydroxy iron powder and pure iron with magnetic saturation strength of about 2.0T and soft magnetic properties. The proportion of additives in the mixture is small, mainly because the density of the carrier liquid $\rho = 0.96g/cm^3$ is less than the density of hydroxy iron powder $\rho = 7.6g/cm^3$. If no stabilizer is added, the magnetic particles will settle [2]. For carrier liquid or mother liquid, kerosene, water, and synthetic oil are usually used to evenly disperse magnetic particles.

2.3 Working Mode

The working modes of MRF can be divided into three types, namely, extrusion mode, shear mode and flow mode. In the extrusion mode, two plates move relative to each other. MRF is between the two



plates and parallel to the moving direction of plates. When the magnetic field increases, MRF will become a quasi solid, and the apparent viscosity and yield stress will also increase. In the shear mode, the upper and lower plates move relative to each other. The magnetic field direction is perpendicular to the moving direction, and the yield strength of MRF increases with the increase of magnetic field strength. When MRF is sheared, it can bear more damping force and effectively restrain vibration [3]. In the flow mode, two plates are fixed, while MRF flows through the plate gap, and the flow direction is perpendicular to the magnetic field. After changing the magnetic field strength, the MRF yield strength can be adjusted, and the damping force can also be changed to achieve continuous control of the damping value. The application devices of different working modes are different, as follows:

Table 1 Analysis of working mode

Working modes	Applications
Extrusion mode	Rotating devices, linear dampers, etc
Shear mode	Brakes, clutches, dampers, locking devices, etc
Flow mode	Servo control valves, shock absorbers, dampers, etc

The grouping formula of pressure difference and yield stress viscosity without magnetic field is as follows:

$$\Delta P = \frac{12\eta QL}{s^3 h} + \frac{c\tau_H L}{s}$$

Where, ΔP is the yield stress; τ_H is the dynamic yield stress in MRF; Q is the volume flow rate; η is the viscosity; s is the plate gap; L is the plate length; h is the plate width; c is the coefficient.

There are active agents in MRF composition, and the magnetic domain micro particles will not hinder the hydraulic system, which can effectively reduce the impact of particles on the working system. Therefore, MRF can become the transmission medium of the system. Because of its good lubricity, it can lubricate the actuating elements and control elements.

3. The Application Analysis of MR Technology in Hydraulic Transmission and Control

MR technology is widely used in hydraulic transmission and control, and many scholars have done a lot of research on it, such as rotary controllers, MRF transmission devices, controllers and so on. In particular, the performance of developed MR valves is far superior to that of the traditional hydraulic valves, which will be introduced below.

3.1 MR Pilot Valve

MRF pilot valve is a kind of overflow valve, which has rheological property mainly through the magnetic fluid under the external magnetic field. If there is no current in the coil, MRF shows the characteristics of Newtonian fluid and only receives the resistance. If the coil is powered on, the external magnetic field will pass through damping gap through the magnetic conductive valve core, making MRF transform into a semi-solid.

The scholar Chen Wen[4] improved the MR pilot valve structure, as follows: The MR pilot valve uses ferronickel alloy, its magnetic permeability is 3000 – 55000, the saturation magnetic flux density is 0.64T, the resistivity is $1.53\Omega \cdot m$, and the coercive force is $3.2A \cdot m^{-2}$, which effectively ensures that the valve body and valve core of MR pilot valves can sense the change of external magnetic field sensitively and MRF can have MR effect in a short time. On the basis of Maxwell's equations [5], the secondary density was analyzed by simulation, the energized current was set to be 2A, the coil turns were set to be 200, the damping gap was 0.8mm, and the magnetic induction intensity was about 0.68T. After testing, it can be seen that the pressure drop speed in the inlet and outlet hydraulic oil and the damping clearance of middle ring is faster, and the pressure loss is less.

The maximum velocity of the magnetic fluid in the pilot valve is 16.3m/s, which can effectively improve the corresponding speed of the MR pilot valve. At this time, when the coil is powered on, the pressure reducing effect can be realized. When the coil current is adjusted, the MRF can sense the change of stress intensity and complete the voltage regulating operation.

3.2 MR Servo Valve

MR servo valve consists of three parts: bridge-type MR component integration block, electrical signal controller and power amplifier. The electrical signal controller can produce and amplify the control current signal needed in the system. The bridge-type MR component integration block will be controlled by the current signal in the electrical signal controller, and after the viscosity of the flow MRF is changed, the differential pressure can be provided for the system operation [6]. The inner part is composed of four MRF damper valves in parallel, which have four control units and constitute a four arm controllable hydraulic full bridge. When the control unit of the bridge arm in the bridge is changed, the hydraulic resistance of the hydraulic servo valve can be effectively adjusted so as to control the transmission of MR power. This shows that when $\Delta_i = 0$, the four damping valves get zero excitation current i_0 , the pressure and flow of the bridge arms at both ends are the same, and the load at both ends keeps the original position; when $\Delta_i \neq 0$, the load flow and pressure at both ends are different, and the load is pushed to move in different directions based on the magnitude of current. The amplification power element usually uses the hydraulic system slide valve element, which can be moved by the differential pressure valve core to change the opening of the valve port.

Under the action of magnetic field, MRF can be transformed into plastic fluid, and its theoretical model is as follows:

$$q = \frac{\pi D h^3}{12\eta} I \Delta p - \frac{\pi D N^\beta h^{2-\beta}}{4\eta}$$

Among them, N , D and h are the inner diameter, clearance height, coil turns and axial length of the servo valve body. η is MRF zero field viscosity and yield stress.

Under the constant magnetic field, the servo element can maintain the common liquid resistance characteristics. After the flow rate is determined, the greater the current is, the greater the working pressure difference will be, and the more sensitive the MR effect will be [7]. By adjusting the current, the viscosity of MRF can be changed, and then the flow of servo valve can be adjusted. The command signal is mainly electric signal, which is convenient for comparison, correction and measurement, and can reach the automatic control standard.

3.3 MR Proportional Valve

The corresponding magnetic field is added to the MR proportional valve. After MRF flows through the valve, the viscosity of MRF will increase under the influence of magnetic field, which will increase the resistance for MRF to flow through the valve. After the valve pressure is increased, the flow of liquid can be slowed down. According to this principle, the piston control scheme of hydraulic cylinder is designed. When there is current flowing through the diagonal hydraulic valve, the resistance of MRF will change, causing the piston pressure difference that allows the piston to move and perform the component positioning function.

4. Conclusions

In conclusion, as a controllable fluid, MRF can use the external magnetic field to increase the viscosity to slow down liquid fluidity. In the hydraulic system, the use of MR technology for control valve research and development has the advantages of long life, low cost and good prospects for development. Therefore, this paper mainly studies the three aspects of MR pilot valve, MR servo valve and MR proportional valve, and hopes to promote the further development of the hydraulic system.

References

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