Design and Simulation for Disk-Type Magnetorheological Fluid Transmission Device

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Abstract: The magnetorheological fluidtransmission device (MRTD) are chosen as study object for few mature magnetorheological fluid devices. Firstly, the working principle of MRTD introduced and a disk-type MRTD is designed based on the magneto-rheological Bingham model. Secondly, the magnetic circuit of MRTD is designed and the magnetic circuit materials in the device are selected. Finally, the magnetic circuit simulation are carried out based on finite element analysis software Ansoft Maxwell, thus, the distributions cloud picture of magnetic field under different excitation currents are obtained.The designed MRTD is able to meet the working requirements and provides reference and basis for optimal design of magnetorheological fluid devices.

1 INTRODUCTION

Magnetorheological fluids (MRF) are composed of micron sized ferromagnetic particles and additives with modification function dispersed in the carrier liquid to form a suspension system (Wang, 2015; (Liu, 2013; Cvek, 2020). This system can produce obvious magnetorheological effect under the action of magnetic field. When there is no external magnetic field, it behaves as Newtonian fluid state. When the external magnetic field is applied, the internal magnetic particles will form chains along the direction of the magnetic field within a few milliseconds, changing from a liquid state to a solid-like state, showing controllable shear yield strength (Zhu, 2020). As such transformation is reversible, rapid and controllable, MRF has been increasingly applied in automotive brakes, clutches, dampers, medical instruments, aerospace and other fields (Desai, 2020; Kim, 2018).

The magnetorheological fluid transmission device (MRTD) has attracted extensive attention from scholars at home and abroad because of its simple control, low energy consumption and short response time. Since Lord Company developed the first magnetorheological fluid brake in 1997, the transmission device has been studied deeply in foreign countries, and a series of achievements have been made. Gopalswamy (Gopalswamy, 1998) of General Motors in the United States successfully developed the magnetorheological fluid clutch. Kavlicoglu (GopKavlicoglu, 2007) from University of Nevada studied the response time and performance of the magnetorheological fluid limited slip clutch.of MRF limited slip differential clutch of response time and performance are analyzed. Great progress has also been made in the study of magnetic transmission in China. Meng Weijia (Meng, 2022) carried out the structural design and simulation experiment of the double-plate magnetorheological fluid clutch. Guo Jiangchuan (Guo, 2022) studied the influence of current, clearance and speed difference on the transmission performance of magnetorheological fluid clutch through experiments. Li Xing (Li, 2011) designed a disc-type magnetorheological soft starting device and optimized its structural parameters through magnetic field simulation analysis.

There are many patents related to MRTD or continuously variable speed device, but there are few mature products. In this paper, a disc MRTD is designed, of which the magnetic field are analyzed and simulated. Magnetic circuit design of MRTD is verified by magnetic flux density test-bed.

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2 MECHANISM ANALYSIS OF MRTD

2.1 Working Principle of MRTD

The working principle of the MRTD is shown in Figure 1. The driving and driven disks are filled with magnetorheological fluid and placed in a controllable magnetic field B. The magnetic field direction is along the axial direction of the device. Different magnetic field strengths are obtained by adjusting the size of the excitation current. The MRF will produce corresponding rheological effects and can transfer a certain amount of torque.

Under the action of magnetic field, the constitutive equation of MRF can be described by Bingham model, and its expression can be calculated as follows:

$$\tau = \tau_0(B)\,\mathrm{sgn}(\gamma) + \eta\gamma \quad |\tau| \ge \tau_0$$
$$\gamma = 0 \quad |\tau| < \tau_0$$

Where τ is the shear stress generated by MRF, τ_0 is the yield stress of MRF, γ is the shear stress of MRF and η is the viscosity coefficient of MRF. In the figure 1, r_1 and r_2 are the inner diameter and outer diameter of the driving and driven disks respectively. Take a micro ring with a radial width of d_r on the disk with a radius of r, then the micro torque transmitted by MRF on the micro ring surface can be expressed as follows:

$$dT = \tau \cdot 2\pi r^2 dr$$

Assume that the speed of the driving disk and driven disk is ω_1 and ω_2 respectively. The shear stressγcan be calculated as follows:

$$\gamma = r(\omega_1 - \omega_2)/h = r\Delta\omega/h$$

From this, it can be concluded that the torque transmitted by MRTD in the working area is:

$$T = \int_{r_1}^{r_2} \tau \cdot 2\pi r^2 dr = \frac{2\pi\tau_0}{3}(r_2^3 - r_1^3) + \frac{\pi\eta\Delta\omega}{2h}(r_2^4 - r_1^4)$$

2.2 Structure Design of MRTD

The designed MRTD is shown in Figure 2. MRTD is composed of 1- housing, 2-yoke, 3-coil, 4-magnetic separator ring, 5-driving disk, 6-bearing seat, 7-bearing, 8-nut, 9-input shaft, 10-oil seal, 11- driven disk, 12-hexagon socket bolt and 13-driven disk. The power is input from the driving shaft, the driving disk is fixedly connected with the driving shaft, and the driven disk is fixedly connected with the driven shaft. MRF is filled between the driving and driven disks, which is sealed by the fluorine rubber oil seal with high temperature resistance and good wear resistance. When the current is applied to the excitation coil, the working gap between the driving and driven disks produces a magnetic field, and MRF has a rheological effect. The power is transferred to the driven disk through MRF, and then output through the driven shaft. The torque can be adjusted by controlling the input current of different excitation coils.

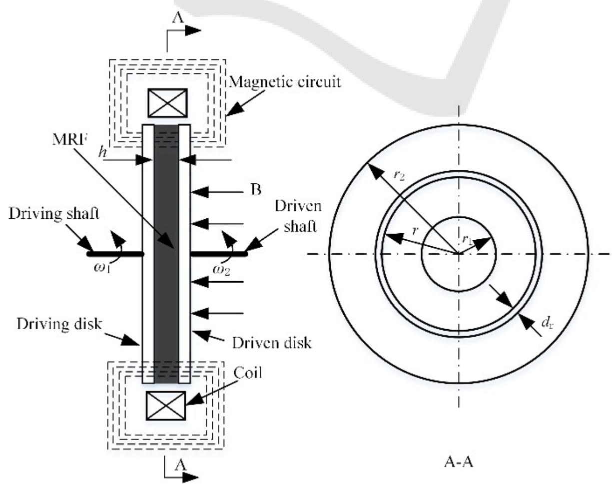


Figure 1: Working principle diagram of MRTD.

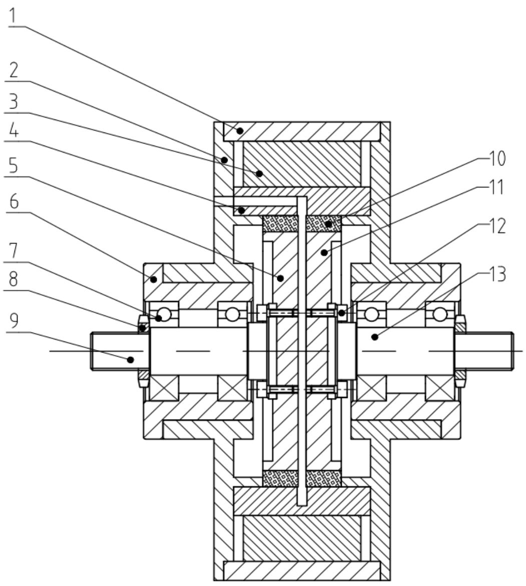


Figure 2: Working principle diagram.

3 MAGNETIC CIRCUIT ANALYZE AND SIMULATION OF MRTD

3.1 Magnetic Circuit Design of MRTD

The experiment and research show that the shear stress formed when the magnetic line of force passes through the shear direction of MRF vertically is much greater than that formed when the magnetic line of force passes through the shear direction of MRF in parallel. Therefore, the magnetic circuit design has a crucial influence on the torque that can be transmitted by the magnetorheological fluid transmission device. When designing the magnetic circuit, ensure that the magnetic force line passes through the working gap formed by the driving and driven disks vertically.

Magnetoresistance is a parameter in the magnetic circuit of MRTD. Applying current to the excitation coil can generate magnetic field in the working area, but when the magnetic flux passes through the gap in the magnetic circuit, the magnetic flux density will decrease, because a part of the magnetic flux is lost in the non gap, forming magnetic leakage, which leads to the formation of magnetic resistance in the magnetic circuit. According to Ohm's law of magnetic circuit, the magnetic resistance of magnetic circuit is expressed as:

$$R_m = \frac{F_m}{\Phi} = \frac{NI}{\Phi} = \frac{L}{\mu A}$$

Where R_m is magnetic circuit magnetoresistance (H^{-1}), F_m is magnetomotive force (A), Φ is magnetic flux (Wb), N is total coil turns, I is excitation coil current (A), L is magnetic circuit length (m), μ Is the magnetic permeability (H/m), and A is the sectional plane perpendicular to the magnetic line of force (m^2).

According to the above formula, in order to reduce the magnetic resistance of the magnetic circuit, materials with high permeability should be selected when designing the magnetic circuit of the device. Permeability reflects the transfer ability of materials to magnetic lines of force. When designing the magnetic circuit, materials with high magnetic permeability should be selected, so that when the excitation current and the number of winding turns are the same, the MRF placed in the working gap can obtain greater magnetic field strength. The drive device uses a coil with a certain number of turns as the magnetic field generator, which is used to meet the required magnetic field strength in the working area. The selection and design of excitation coil mainly consider the parameters such as heat loss, material, wire diameter and turns.

Table 1: Selection of magnetic conductive materials for main parts.

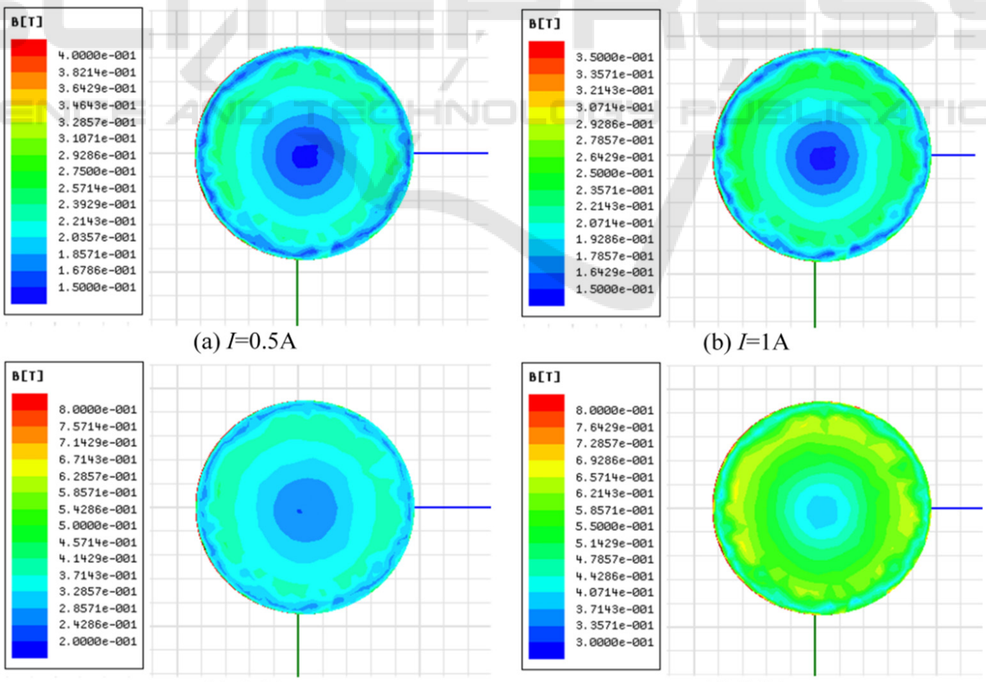
Part	Yoke	Driving and driven disks	Magnetic separator ring	Coil
Material	20#steel	20#steel	Aluminium	Copper wire

3.2 Selection of Magnetic Circuit Materials

The selection of magnetic circuit materials has a great influence on the magnetic field strength obtained in the working gap of MRTD. Compared with materials with smaller permeability, materials with higher permeability can produce larger magnetic field strength when the excitation current is smaller. Under the same excitation current conditions, materials with higher permeability can obtain greater magnetic field strength, thereby increasing the transmission torque of the transmission device. The material selection of the main parts of MRTD is shown in Table 1.

3.3 Magnetic Circuit Simulation of MRTD

The magnetic circuit design method is usually to convert or transfer the energy to the closed loop of limited magnetic flux designed by engineers, which is assumed to be linear when calculating the magnetic permeability of materials. This design method adopts a simple approximate calculation method, which easily ignores the influence of magnetoresistance, magnetic leakage, saturation magnetization effect and material nonlinearity. Therefore, Ansoft Maxwell is selected for magnetic field design and numerical simulation. Starting from the essential characteristics of ferromagnetic materials, the simulation can accurately obtain the magnetic field distribution of the device. The steps of Maxwell3D magnetic field simulation based on Ansoft software are as follows: establishing and simplifying geometric models, simplifying the import of geometric models, defining material properties, selecting magnetic field analysis mode, specifying boundary conditions, loading current excitation, setting solution options, numerical analysis and post-processing, etc.



(a) I=0.5A (b) I=1A

(c) I=2A (d) I=3A

Figure 3: Distribution of magnetic flux density under different current.

The number of turns of the excitation coil of MRTD designed in this paper is 1500 and the clearance between the master and slave discs is 2mm.When the excitation current is 0.5A, 1A, 2A, 3A, the magnetic induction intensity distribution cloud diagram of the working gap inside the device is shown in figure 3. When the excitation current is 0.5A, the magnetic induction intensity distribution cloud diagram of the working gap is shown in figure 3(a), and the average magnetic field is about 0.22T. When the excitation current is 1A, the magnetic induction intensity distribution cloud diagram of the working gap is shown in figure 3(b), and the average magnetic field is about 0.25T. When the excitation current is 2A, the magnetic induction intensity distribution cloud diagram of the working gap is shown in figure 3(c), and the average magnetic field is about 0.38T. When the excitation current is 3A, the magnetic induction intensity distribution cloud diagram of the working gap is shown in figure 3(d), and the average magnetic field is about 0.62T. At the same time, it can be seen that the magnetic field distribution in the working area at the working clearance of the transmission device is more uniform; When the number of turns of the excitation coil is a fixed value, the magnetic field strength in the working area increases with the increase of the excitation current; When the excitation current is 3A, the magnetic induction can reach 0.62T, which meets the requirements of experimental research.

4 CONCLUSION

In order to promote the development of magnetorheological fluid devices, a disk-type MRTD is designed, of which the magnetic field are analyzed and simulated. The simulation results show that the magnetic field distribution in the working area of MRTD is uniform. When the excitation current is 3A, the average magnetic field strength in the working area is 0.62T, meeting the design requirements. The research in this paper can provide reference and basis for the optimization design of high-power MRTD.

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CONFLICTS OF INTEREST

The authors confirm that this article content has no conflict of interest.

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