EXPERIMENTAL STUDY ON SEALING PERFORMANCE AND FLOW CHARACTERISTICS OF MAGNETIC FLUID IN EXTREMELY TINY CLEARANCE UNDER MAGNETIC FIELD

Y. Kato[1], M. Motozawa[2,a], W. Rakpakdee[2], M. Fukuta[2]

[1] *Graduate School of Integrated Science and Technology, Shizuoka University, Shizuoka, Japan*
[2] *Faculty of Engineering, Shizuoka University, Shizuoka, Japan, [a]motozawa.masaaki@shizuoka.ac.jp*

Abstract. Sealing performance and flow characteristics of magnetic fluid in extremely tiny clearance less than 30 µm under magnetic field are investigated experimentally. The extremely tiny clearance in the test section is set to 5, 10, 15, 20 and 30 µm, and magnetic field is applied to magnetic fluid flow at this clearance. The results show that maximum of 1.2 MPa of pressure resistance was obtained at 5 µm of tiny clearance from the sealing test and the relationship among frictional coefficient, magnetic field and *Re* is quite different between 5 and 30 µm of tiny clearance from the flow characteristic test.

1. Introduction

A magnetic fluid is a colloidal dispersion of ferromagnetic nanoparticles in carrier liquids such as water, kerosene and so on. It is well known that it has possibility to control actively flow characteristics by magnetic body force by application of the magnetic field because the magnetic fluid behaves liquid as if it has strong magnetism under the magnetic field. As popular application, the magnetic fluid is applied to sealing technologies. Generally, the clearance of magnetic fluid seal is hundreds of microns and the pressure resistance of single seal is not so large (tens kPa order) [1].

The sealing technologies are very important in many fields. For instance, regarding the sliding part in a compressor, as leakage of compressed gas directly affects the compressor performance, several sealing technologies are proposed [2]. Generally, the clearance of the sliding part of compressor is around few microns, and high-pressure resistance (e.g. MPa-order in some cases) is required. If the sealing technique of the magnetic fluid can be applied to the extremely tiny clearance (around few µm) and high-pressure condition (around 1 MPa), the application of magnetic fluid seal becomes expanding more. In addition, the flow characteristics of magnetic fluid may change in such extremely tiny clearance. However, there are few studies on the sealing performance and flow characteristics in tiny clearance.

In this study, we investigated the sealing performance (Exp. 1) and flow characteristics (Exp. 2) of magnetic fluid in extremely tiny clearance less than 30 µm experimentally. Experiment was carried out by a micro-channel flow path which has 5, 10, 15, 20 and 30 µm of clearance (i.e. channel height), and magnetic field is applied at this clearance.

2. Experimental apparatus and test magnetic fluid

Figure 1 shows the overview of experimental apparatus. Experimental apparatus consists of nitrogen cylinder, regulator, flow meter, and the test section. In case of the Exp. 2, the test fluid tank and electronic balance are installed at upstream and downstream of the test section, respectively. The detailed structure of the test section is shown in Fig. 2. The test section consists of bottom plate, middle part, sight glass, and glass holder. Flow path which has extremely tiny clearance is formed by sandwiching a thickness gauge as a spacer between the middle part and sight glass. The tiny clearances h (i.e. channel height) are set to 5, 10, 15, 20, 30 by changing thickness gauge, and channel width and length are 10 mm and 20 mm, respectively. Magnetic field can be applied at the center of the tiny clearance by embedding the magnet in a magnet groove under the tiny clearance.

For Exp. 1, magnetic fluid is provided at the tiny clearance, and pressure is applied to the clearance of the test section from the nitrogen cylinder. The maximum pressure, at which the seal breaks and leakage starts to occur, is measured. The magnetic field intensity is 0 and 300 mT. On the other hand, for Exp. 2, the test magnetic fluid is filled in the tank which is located at the upstream of the test section, and the test magnetic fluid flows through the channel in the test section by pressure applied by the nitrogen cylinder. The magnetic field intensities are 0, 54.4, 102.6, 136.3 and 330 mT.

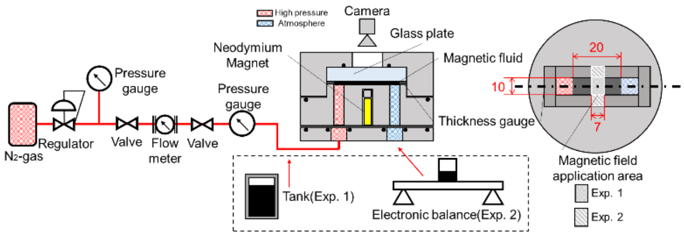

Fig.1. Experimental apparatus

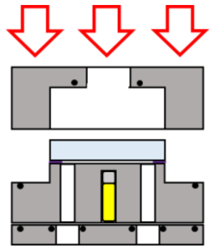

Fig.2. Detail structure of test section

Table 1. Physical properties of test magnetic fluids

Sample	Base	Viscosity Pa・s	Density kg/m³	Saturation magnetization mT	Experiment
A	Poly-□-Olefin	0.06	1267	48.5	Exp. 1
B	Alkyl benzene	0.65	1357	49.5	Exp. 1
C	Alkyl benzene	0.85	1339	50.2	Exp. 1
D	Kerosene	0.0055	1332	58.6	Exp. 2

Table 2 Pressure resistance (Exp. 1)

Condition	Sealing performance MPa	
	h=5 μm	*h*=10 μm
A-Mag	0.05	<0.05
A-Nomag	0.05	<0.05
B-Mag	0.4	0.1
B-Nomag	0.2	<0.05
C-Mag	1.2	0.2
C-Nomag	0.65	0.1

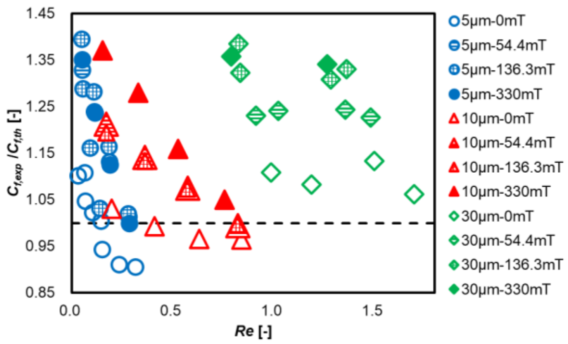

Fig. 3. Relationship between $C_{f.exp}/C_{f.th}$ and *Re* (Exp. 2)

Four test magnetic fluid samples A, B, C, and D, which have different base fluids and viscosities, are used. These test magnetic fluids were prepared by Ferrotec Material Technologies, inc., and their physical properties are listed in Table 1.

3. Results and discussion

Table 2 lists the pressure resistance obtained from Exp. 1. In this experiment, extremely tiny clearance is set to 5 and 10 μm. This table clearly indicated that the pressure resistance drastically increases in narrower tiny clearance, with increasing viscosity of test magnetic fluid, and by applying magnetic field. The maximum sealing performance of about 1.2 MPa at 5 μm of tiny clearance is obtained. Therefore, it was found that the sealing performance of the magnetic fluid is significantly improved in case of extremely tiny clearance such as 5 μm.

Figure 3 shows the relationship between the increasing ratio of experimental and theoretical pipe friction coefficient $C_{f.exp}/C_{f.th}$ and *Re* number obtained from Exp. 2. The theoretical pipe friction can be given by $C_{f,th}=96/Re$ and the tiny clearance is set to 5, 10 and 30 μm in this figure. The increasing ratio is close to 1 under no magnetic field. The tendency of the change in the increasing ratio is quite different between 5 and 30 μm of tiny clearance, but the maximum increasing rate is similar for each clearance. The increasing ratio at 30 μm of tiny clearance is gradually increases with decreasing *Re* number and increasing magnetic field intensity. On the other hand, this ratio in case of 5 μm sharply increases with decreasing *Re* number, and although this ratio increases by applying magnetic field, the increasing level does not change even if magnetic field intensity increases.

References:

[1] Mizutani et al., *Procedia CIRP*, 33, 2015, pp. 581-586.
[2] JSRAE, *Compressors for Air Conditioning and Refrigeration*, JSRAE Technical Books Series, 2018, p. 91