Study on Output Characteristic Considering Viscosity of Magnetic Fluid Differential Pressure Sensor

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Abstract —The magnetic fluid differential pressure sensor that mentioned in the paper utilize the liquidity and magnetic of magnetic fluid. Viscosity of magnetic fluid is subject to many factors, especially is subject to the magnetic field. Its viscosity would impact on output characteristics of the magnetic fluid differential pressure sensor. Considering coupling relationship between that the viscosity is subject to the impact of the external magnetic field and the magnetic field is subject to the impact of liquid flow, the coupling model of the sensor is deduced and then the output characteristic curve of the magnetic fluid differential pressure sensor is gaven.

I. INTRODUCTION

Viscosity is an inherent physical property of fluid. The viscosity of the fluid is used to characterize the physical quantity of fluid viscosity. As other fluid, the magnetic fluid also has viscosity. Its viscosity depends not only on the viscosity of liquid-based carrier liquid and on the volume components of magnetic particles in the solution, but also on the temperature, especially on the magnetic field. The magnetic fluid differential pressure sensor that mentioned in the paper utilize the liquidity and magnetic of magnetic fluid and base on the principle of electromagnetic induction. The property of magnetic fluid would impact on output characteristics of the sensor.

In this paper, the viscosity of magnetic fluid was measured. Based on the first law of thermodynamics, under the condition of considering the problems of magnetic field, flow field and mechanical field, the coupling model of the sensor is deduced and then the output characteristic curve of the magnetic fluid differential pressure sensor is given, the results indicate that the output characteristic curve is closer to the experimental results than without considering viscosity.

II. VISCOSITY MEASUREMENT

The viscosity of Fe_3O_4 kerosene -based carrier liquid is measured with the type of NDJ-1 rotational viscosimeter. The zero rotors are selected as the estimation of the measured viscosity is relatively low. From many measurements we found that viscosity had hardly changed under different shear rate, so we can consider this magnetic fluid as Newtonian fluid. Under the condition of room temperature (20℃), while the speed of rotor is 60 R.P.M, the measured results is shown in figure 1. The measured viscosity on average is 5.1mPa·s.

Shliomis had derived magnetic fluid viscosity and the angle relationship between the direction of magnetic fluid vortex vector and external magnetic field. While the external magnetic field vector H and magnetic fluid vortex vector ω made into angle β , as follows:

$$\frac{\Delta\eta}{\eta_c} = \frac{3}{2}\varphi\frac{0.5\alpha L(\alpha)}{1+0.5\alpha L(\alpha)}\sin^2\beta \tag{1}$$

$$\frac{\Delta\eta}{\eta_c} = \frac{3}{2}\varphi\frac{0.5\alpha B(\alpha)}{1+0.5\alpha B(\alpha)}\sin^2\beta \tag{2}$$

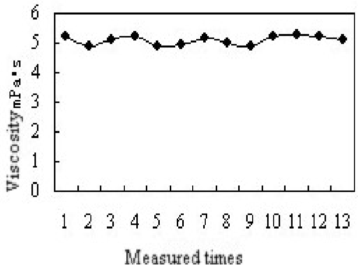

Fig.1 Measuement results

where, φ is the volume components of solid particles in magnetic fluid, η_c is kinematic viscosity of magnetic fluid-based carrier liquid, α is a parameter of langevin equation

$$\alpha = \frac{\mu_0 mH}{k_0 T} = \frac{\mu_0 M_d V_{p1} H}{k_0 T} \tag{3}$$

where, m is magnetic moment of single particle; T is absolute temperature; μ_0 is permeability of vacuum; H is magnetic intensity; k_0 is Boltzmann constant; M_d is saturated magnetizing strength of solid particles; V_{p1} is the volume of a solid particle.

Furthermore, $L(\alpha)$ is given in following equations:

$$L(\alpha) = \coth\alpha - \frac{1}{\alpha} \tag{4}$$

III. THE MAGNETIC -MECHANICS COUPLING MODLE

A. Modeling

The first law thermodynamics can be expressed as: The difference between the rate of system heat-trapping from outside and the rate of system does work to outside, and this difference is equal to the changes of the system energy. The mathematical expression is:

$$\dot{Q}-\dot{W}=\frac{\mathrm{d}E}{\mathrm{d}t} \tag{5}$$

where, $\dot{Q}$ --power; E-- sensitive energy of the system.

For the magnetic fluid differential pressure sensor, it has no thermal transmission between the system and outside. So $\dot{Q}=0$.

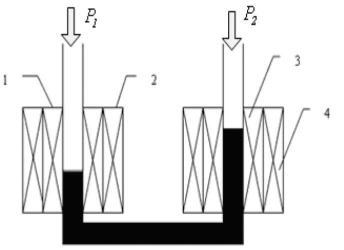

Fig.2 Mutual inductance sensor of differential pressure with magnetic fluid

In the system of the magnetic fluid differential pressure sensor, the radius of the U-pipe is R, l_1 and l_2 is the length of magnetic fluid in the coil winding on the both sides of the U-pipe respectively; l_3 is the length of magnetic fluid in a horizontal lateral. The total length of the magnetic fluid is L. The turns of excitation coils is N, and the length is l, the current through the coil is I. the pressure on the two side of the U-pipe is p_1, p_2 respectively. When the pressure is equal on both sides, there is $l_1=l_2=\frac{1}{2}l$, set the gravitational potential energy to zero.

We can get the following equition from the first law thermodynamics:

$$-\Delta p\pi R^2 v+\frac{\partial}{\partial t}\frac{1}{2}\rho\pi R^2 L v^2+\frac{\partial}{\partial t}\frac{1}{4}\rho\pi R^2 \mathrm{g}(l_2-l_1)^2$$
$$+\frac{\partial}{\partial t}\frac{1}{2}\int_{V_1} H_1\cdot B_1 \mathrm{d}V_1+\frac{\partial}{\partial t}\frac{1}{2}\int_{V_2} H_2\cdot B_2 \mathrm{d}V_2$$
$$+2\pi R(l_1\tau_1+l_2\tau_2+l_3\tau_3)v=0 \tag{6}$$

where, L is the total length of the magnetic fluid; $L=l_1+l_2+l_3$; V_1 is the volume of the magnetic in left side of the U-pipe; V_2 is the volume of the magnetic in right side of the U-pipe.

The equation (6) is the mathematics mode of magnetic-mechanics coupling.

B. Solution

Through the analysis of solution, for the integration of the equation (6) within the time Δt we can get:

$$W_P+W_g+\Delta W_{\mathrm{m1}}+\Delta W_{\mathrm{m2}}+W_\mu=0$$

After finishing avaliable：

$$\Delta p=\rho g(l_2-l_1)+\frac{2\eta_0 l_3}{3\eta_0 l_3-\eta_{\mathrm{H}_1} l_1-\eta_{\mathrm{H}_2} l_2}(H_2B_2-H_1B_1)$$

Comparition of the output characteristic curve from magnetic-mechanics coupling modle with the output characteristic curve without considering viscosity and experimental results, as the Fig.3 shows:

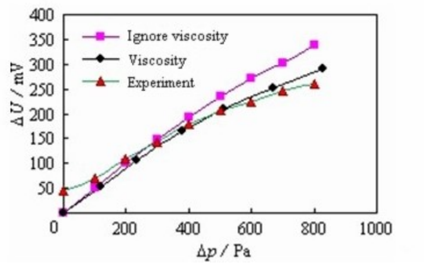

Fig.3 Comparison of the differential pressure sensor's output characteristic

Fig.3 shows: (1) When the pressure difference is the same,the output voltage obtained without considering viscosity is greater than the value obtained from the coupling model; (2) When the output voltage is the same, the value obtained with regardless of viscosity is smaller than the value obtained from magnetic -mechanics coupling modle; (3)There is zero error in experimental results, the magnetic -mechanics coupling modle is more close to the experimental results when the pressure is greater than 300Pa. It is because that with the flowing of the magnetic fluid, the pressure will does work to overcome viscosity, considering this part of work, the output characteristic curve can bet more accurate.

IV. CONCLUSIONS

Considered the problems of magnetic field, flow field and mechanical field, and the coupling relationship between them, the magnetic -mechanics coupling have been obtained. The results indicate that the output characteristic curve is closer to the experimental results than without considering viscosity.

V. ACKNOWLEDGMENT

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