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Magnetic Fluid Acceleration Sensor

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Abstract: - A kind of vertical acceleration sensor with magnetic fluid (MF) is presented in the paper, which is using the magnetic and fluid characteristic of MF. The magnetic field of the permanent magnet in the MF acceleration sensor is analysed which based on the Finite Element Method (FEM). Then the magnetic fluid deformation under static state is obtained. Through calculation and compare to magnetic forces of permanent magnets magnetized by two different ways, the magnet magnetized by the way of radial direction is selected. Finally, the experiment result is showed.

Key-Words: - magnetic fluid, acceleration sensor, permanent magnet, magnetic field, surface tension, static analysis

1 Introduction

Vertical acceleration sensor is usually used to detect the ground and structural deformations occurring in the earthquakes or other incidents. It is of vital significance to study this kind of sensors with high sensitivity, durability, and low cost.

Magnetic fluid is one kind of stable colloid which is mixed up by the ferromagnetic particles, the base fluid as well as the surface active agent, and one kind of new function material, which not only has the fluidity of liquid but also has the physical property of certain solid magnetic materials[1]. Since it was developed successfully in 1965, magnetic fluid has obtained important application in many domains because of its unusual characteristic. Magnetic fluid sensor technology taking this as the foundation has also aroused widespread interest of the international area of technology[2-4]. Magnetic fluid acceleration sensors have overcome the difficult problem of contact attrition among ordinary sensors, which don't need any mobile mechanical element. Moreover, they may enhance sensors' service life, anti-overload capacity, and guarantee precision.

2 Structures and Principle of Magnetic Fluid Acceleration Sensor

Magnetic fluid acceleration sensors use the differential transformer type. Fig.1 shows a draft of the structure. Magnetic fluid membrane 4 is controlled by ring magnet 5. On static conditions, the deformation Δw of membrane caused by the gravity has relation with the magnetic field force and the gravity received by the magnetic fluid, when the system receives the acceleration on the vertical direction, the shape of the membrane changes. Place 3 coils outside the magnetic fluid membrane, pours into the alternating current in the primary coil 1, produces an alternation magnetic field, when the system receives the function of acceleration on the vertical direction, the deformation of the membrane changes, then the induction voltage difference of the two coils 2 and 3 changes along with it. The voltage output is functions of the system acceleration.

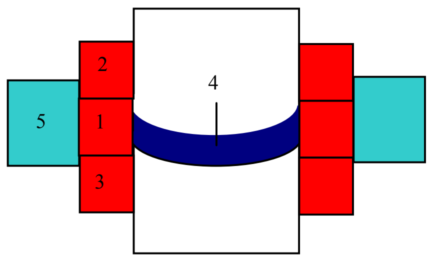

Fig.1 Sketch of acceleration sensor

3 Analysis and Design on Magnetic Fluid Acceleration Sensor

3.1 Finite Element Computation Model of Permanent Magnets with Axisymmetrical Field

When Permanent magnets work in return track, which is a straight line. Then the relation between B and H on operating points of permanent magnet is

$$H = H_C - \frac{1}{\mu}B$$

Where H_C is computation coercive force.

Use the vector magnetic potential as solution function, and then, according to the Maxwell equation, boundary value problem of permanent magnets may be indicated as followings[5]

$$\begin{cases} \nabla \times (\frac{1}{\mu}\nabla \times \boldsymbol{A}) = \boldsymbol{J}_C \\ \nabla \times (\boldsymbol{H}_C - \frac{1}{\mu}\nabla \times \boldsymbol{A}) = 0 \end{cases} \quad (1)$$

Equivalent variation of the boundary value problem above can be shown as

$$W(\boldsymbol{A}) = \int_{V_1} \frac{1}{2\mu}(\nabla \times \boldsymbol{A})^2 d\tau + \int_{V_2} \frac{1}{2\mu}(\mu \boldsymbol{H}_C - \nabla \times \boldsymbol{A})^2 d\tau - \int_{V_2} \boldsymbol{J}_C \cdot \boldsymbol{A} d\tau = \min \quad (2)$$

In the two-dimensional field, it may be expressed as

$$W(A) = \int_{V_1+V_2} \frac{1}{2\mu}[(\frac{\partial A}{\partial x})^2 + (\frac{\partial A}{\partial y})^2]dxdy - \int_{V_2} (H_C \cos\theta \frac{\partial A}{\partial y} - H_C \sin\theta \frac{\partial A}{\partial x})dxdy - \int_{V_2} J_C A dxdy + \int_{V_2} \frac{\mu}{2}(H_C)^2 d\tau = \min \quad (3)$$

Where θ is the included angle between magnetization direction and x axis, and the last item in the formula above is constant, which does not play a role to ask extreme value.

3.2 Magnetic Force which Magnetic Fluid in the Unit Volume Receives in the Magnetic Field

At present, there are two kinds of principles reasoning out body force formula that magnetic fluid receives in the outside magnetic field. One kind uses molecular electric current model, and the origin of body force that the magnetic fluid receives in the outside magnetic field results from the function that molecular annular electric current i receives in the magnetic field .In the uniform magnetic field, electric current loop only receives the moment of force but no resultant only in the non-uniform magnetic field, that is, there is magnetic gradient in the outside magnetic field, can the electric current loop receive exogenous process. Another kind is the general form of the magnetic force derived from thermodynamics free energy based on the energy method by Cowley and Rosensweig. The basic thought is connect thermodynamics work with mechanical work of surface tension, and the magnetic fluid body force can be obtained. Magnetic force in the unit volume, which is caused by magnetic gradient derived from the two methods provided above, is as the following

$$\boldsymbol{F} = \mu_0 \boldsymbol{M} \bullet \nabla \boldsymbol{H}$$

In magnetic fluid, vector $\boldsymbol{M}$ and $\boldsymbol{H}$ is parallel. There is no conduction current in magnetic fluid, namely $\nabla \times \boldsymbol{H} = 0$, and then $\boldsymbol{F}$ can be obtained

$$\boldsymbol{F} = \mu_0 M \nabla H \quad (4)$$

3.3 Permanent Magnet Design

Annular permanent magnet uses the NdFeB. Magnetic force acting on magnetic fluid depends on the magnetic gradient, and NdFeB can be magnetized by two kinds of way: on the transverse direction (Fig. 2) and on the radial direction (Fig. 3).

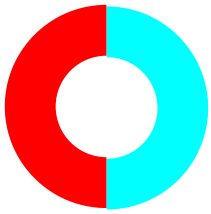

Fig.2 transverse direction magnetized magnet

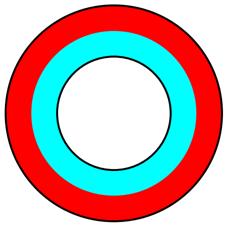

Fig. 3 radial direction magnetized magnet

In order to assure the uniformity of the magnetic force received by magnetic fluid membrane on radial direction, we have calculated the magnetic field and the force on the radial direction to the same size of permanent magnet magnetized by the two kinds of condition: on the transverse direction and on the radial direction. Table 1 and Fig.4 shows compare of the magnetic forces in the unit volume under the two different magnetized ways.

Through comparing the ununiformity of the magnetic force in two kinds of models, magnetic force of the transverse magnetized magnets differs nearly 10^4 times in the mutually perpendicular direction, which causes thickness non-uniformity of the magnetic fluid membrane. By experiment, if use this kind of magnetized magnet, the magnetic fluid in tube can not form non-hole membrane until the boundary thickness of magnetic fluid added to 5mm, and therefore, magnets magnetized by radial direction way are to be used.

Table 1 Compare of Magnetic Forces Under Two Ways of Being Magnetized

	magnetic force in the unit volume			ununiformity
	Max.	Min.	average	
Radial direction magnetized ($10^3N/m^3$)	2997.1	1555.4	1930.7	19.13%
Transverse direction magnetized f_x ($10^3N/m^3$)	1418.2	14.021	47.43	328.15%
Transverse direction magnetized f_y ($10^3N/m^3$)	4.3897	0.1441		

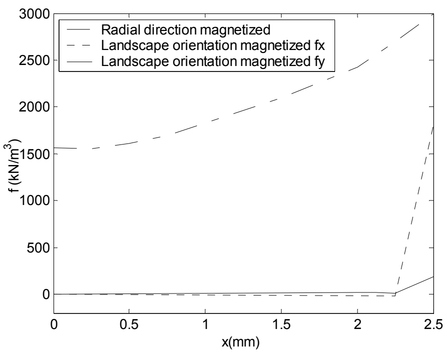

Fig.4 Magnetic force of FM under the two different ways of being magnetized permanent magnet

3.4 Survey of Magnetic Fluid Surface Tension

Liquid surface layer forms fluid film similar to tensioned rubber membrane because of the molecular force, and also has the tendency of voluntary contraction. If make a line segment with the length of L in the liquid level, there is a tension F acting on L in the two side liquid level of the line segment, whose direction is vertical with that of the line segment and whose size has direct ratio with the length of the line segment L

$$\boldsymbol{F} = f \bullet L$$

where f is called the liquid surface tension coefficient, which is equal to interaction force between liquid level molecules on both sides of the unit length straight line.

With curve fitting, Fig. 5 shows relations between surface tension in the unit length and magnetic field based on the experiment under transverse magnetic field(TM) and longitudinal magnetic field(LM).

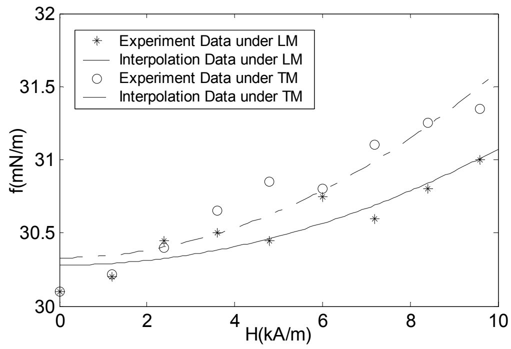

Fig. 5. Relations between surface tension of magnetic fluid and magnetic field

3.5 Static Analysis

Supposing there is a circular thin plate even to the edge, with the same outline to magnetic fluid, stressed by even pulling force D in the edge and even pressure q in the surface. When the thin plate deflection w is very small, the balance equation of the thin plate is

$$\nabla^2 w(r) = -\frac{q}{D} \tag{5}$$

The boundary of the thin plate bending is zero

$$w(R) = 0 .$$

The static state deformation of magnetic fluid membrane is decided by the balance of the magnetic force, the gravity and the surface tension[6,7]. Under the static state, magnetic fluid membrane deformation w can be comparative with the thin plate as the equation (5)

Where q: pressure in unit area of thin plate surface, i.e. gravity $q = \rho g h$.

D: pulling force in unit length of thin plate side, magnetic force $\boldsymbol{F}$ and surface tension $\boldsymbol{T}$.

In cylindrical coordinate system, the analytic solution of the equation (5) is

$$w(r) = \frac{q}{4D}(R^2 - r^2)$$

R=2.5mm, when the thickness of magnetic fluid membrane h=1mm, the deformation in the membrane center place w=0.28mm.

4 Experiment Result

Experiment of the MF acceleration sensor is performed in laboratory. The sketch of experiment is

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shown as Fig.6 and the experiment result is shown as Fig.7.

Fig.7a is the wave of oscillating signal, Fig.7b is the frequency spectrum of oscillating signal, Fig.7c is the wave of sensor output, and Fig.7d is the frequency spectrum of sensor output. It can be seen that the sensor's output accord with the input signal. The results reflect the oscillation actually and accurately.

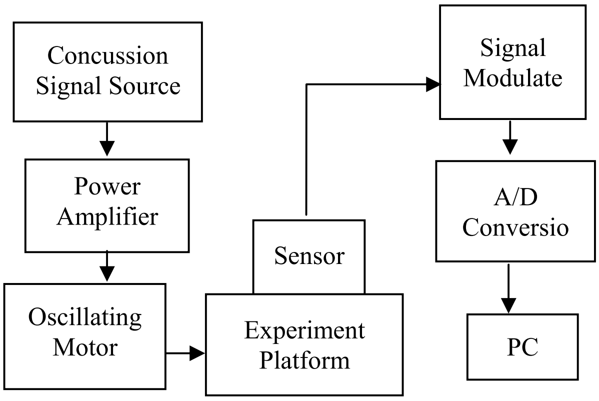

Fig.6 Sketch of Experiment

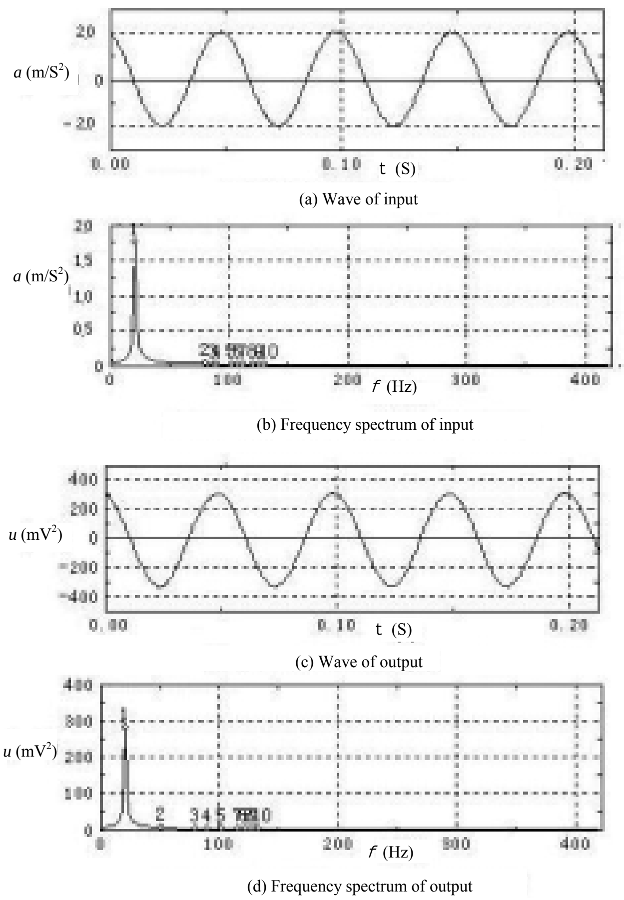

Fig.7 Experiment Result

5 Conclusion

Magnetic fluid acceleration sensors have overcome the difficult problem of contact attrition among ordinary sensors, which don't need any mobile mechanical element.

Through carrying on calculation and compare to magnetic forces permanent magnets magnetized by two different ways, the magnet magnetized by the way of radial direction acts on magnetic fluid more even comparatively, and this kind of magnets was used.

Through static analysis to the sensor system, we have obtained the static deformation of magnetic fluid without acceleration.

The experiment result shows that the magnetic fluid acceleration sensor's output accord with the input signal.

References:

[1] S. Chikazumi, S.Taketomi; Physics of Magnetic Fluids, *Journal of Magnetism and Magnetic Materials* , Vol. 65, 1987, pp:245-251

[2] Takahara, Ishihara Toshihisa, Sugltanl Tatsuo, Inoue Hideo, Vehicle acceleration sensor applied with Magnetic Fluid, *SAE Special Publications* Feb 1992, pp:33-39

[3] Y.Kamanaru, T.Fumino, J.Kanamoto, S.Notsu, Characteristics of level and two axis attitude detector using magnetic fluid, *IEEE Transaction on Magnetics*, Vol.23, 1987, No.5

[4] N.C. Popa, I. Potencz, L. Brostean; Some Aplications of Inductive Transducers with Magnetic Liquids, *Sensors and Actuators* A Vol.59, 1997, pp. 197–200.

[5] Qingxin Yang,Weili Yan, Guizhi Xu. Numerical Solution of the Magnetic Field of Permanent Magnet in MRI System. *Proceeding of the 2nd International Conference on Electromagnetic Field Problems & Application*. Beijing,1992,pp14-16

[6] V.Ido, K. Tannaka.Fluid transportation mechanisms by a couple systems of elastic membranes and magnetic fluids. Journal of Magnetism and magnetic materials, Vol.252, 2003:344-346

[7] B.P.Bhatt. Magnetic-fluid-based Smart Centrifugal Switch. Journal of Magnetism and magnetic materials, Vol.252, 2003:347-349