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Applications of Electromagnetic Phenomena in Electrical and Mechanical Systems
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A study of magnetic tilt sensor

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ABSTRACT : In order to exploit a small and lightweight magnetic tilt sensor with low power consumption and having high and wide-range sensitivity, this paper examines magnetic and non-magnetic materials, shapes and other factors that contribute to the construction of the sensor. At first, we examined a contribution of the materials to the sensitivity and dynamic range of the sensor. Secondly, we simulated the operational characteristics of the magnetic tilt sensor by means of the finite elements method. As a result, it was verified that a combination of magnetic fluid and glass ball yielded a wider dynamic range with relatively high sensitivity. This is because the magnetic permeability of magnetic fluid is relatively small compared with those of the other ferromagnetic materials. Also, a global magnetic field distribution change caused by the movement of glass ball is larger than that of the ferromagnetic materials.

1 INTRODUCTION

Tilt sensors are widely used in construction, building industries, in vessels, vehicles and so on. Because of the fluidity as well as advantageous magnetization characteristics of magnetic fluid, many tilt sensors using magnetic fluid have been proposed. The merits of this sensor are as follows: 1) small and light weight; 2) there are few mechanical elements or parts for the driving unit; 3) structure is simple so that maintenance is easy; and 4) the fluidity of the liquid is used which makes it possible to sense a horizontal tilt [1]. On the negative side - wave occurs on the liquid surface due to the vibration around the sensor. In order to address this, Fukamati proposed the direct current biased magnetic fluid angle sensor which was able to control by putting a direct current magnetic field on the liquid surface [2]. Further, a limit of sensitivity exists because the permeability of magnetic fluid is essentially small. To overcome this fault, Oka proposed a tilt sensor using not only the magnetic fluid but also ferromagnetic materials [3].

All magnetic tilt sensors utilize the fluidity of magnetic fluid that is caused by a change of an angle. The change of the magnetic fields distribution leads to the change of coil inductance. Thus, mechanical change of an angle is converted into the change of electric signal. This is the common principle of the tilt sensor utilizing magnetic fluid. The typical performance requirements of any types of magnetic tilt sensors include high sensitivity, linearity and low power consumption. In this paper, we examine, both experimentally and numerically, the influence of materials applied in the sensor on its performance.

2 TESTED SENSOR

2.1 Materials

For the purpose of this research, we selected four kinds of materials having different magnetic characteristics, i.e. ferromagnetic material (iron ball), diamagnetic material (glass ball), paramagnetic material (air) and magnetic fluid. Specification of the tested magnetic fluid is listed in Table 1.

Table 1- Specification of the tested magnetic fluid

Trademark	M300
Solvent	Water
Saturation induction	320 mT
Viscosity (20°C/50°C)	21/12 mPs
Manufacturer	Sigma high chemical company

2.2 Sensor

Fig.1 shows a schematic diagram of the tested magnetic tilt sensor.

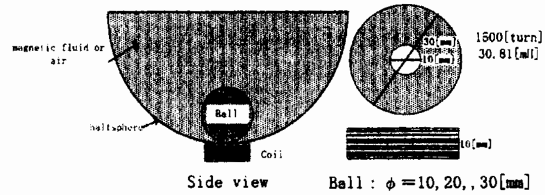

Figure 1 A schematic diagram of the tested sensor.

The construction of the magnetic tilt sensor was as follows. An iron ball was inserted into the container containing air, a container was filled with magnetic fluid and an iron ball was inserted in it. Then the container was filled with magnetic fluid and a glass ball was inserted in that. The diameters of the tested iron or glass ball were 10 mm, 20 mm and 30 mm.

3 EXPERIMENT

3.1 Phase change

The impedance of the single coil Z is given by equation (1) denoting R, X and Z as the electrical resistance, reactance and impedance, respectively.

$$
\begin{aligned}
Z &= V / I \\
&= R + jX \\
&= R + j\omega L , \qquad (1)
\end{aligned}
$$

Impedance Z consists of the real and imaginary parts and it is possible to examine a phase change caused by mechanical tilting. Fig.2 shows the oscillograms of the sensor constructed with the iron ball and air when changing the angles from 0 to 45 degree.

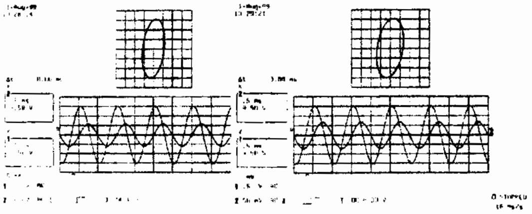

Figure 2 Oscillograms of the current and the terminal voltage of a tested sensor.

From the oscillograms in Fig.2 it is hard to see the phase change. This was due to the fact that the reactance was so large that the resistance was negligible. In the other words, reactance dominates this system, so that the magnetic field applied in the sensor occupies the main part of the electrical circuit impedance of the sensor.

3.2 Experimental results

Fig.3 shows the experimental results. Sensitivity is based on the impedance at 0 degree of each device. Sensitivity is defined by $S=Z_\theta/Z_0$, where Z_0 and Z_θ are the impedances at the angles $\theta=0$ and θ, respectively.

From the results in Fig.3, it is visible that the sensitivity reaches saturation at 1 kHz in each device. Therefore, we carried out the experiments only at 1 kHz.

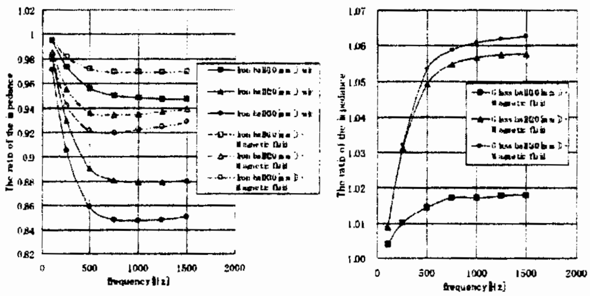

Figure 3 Frequency characteristics of the sensors.

Fig.4 and Fig.5 show the sensitivity for constructions based on a combination of an iron ball and air and on a combination of a glass ball and magnetic fluid.

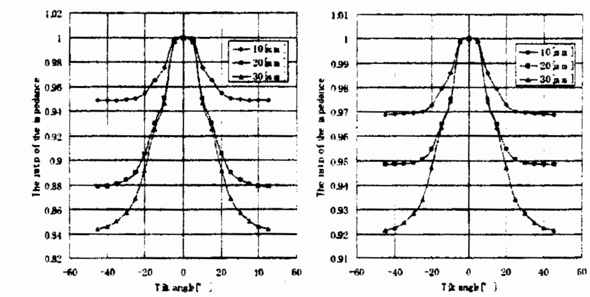

Figure 4 The sensitivity of the sensors. Left: an iron ball and air; and right: an iron ball and magnetic fluid.

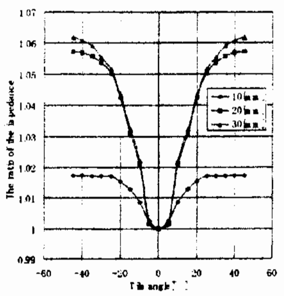

Figure 5 The sensitivity of the sensor constructed by a combination of glass ball and magnetic fluid.

The permeability of magnetic fluid is extremely small as compared with that of the iron ball. In the other words, the field effect caused by iron ball is very large but extremely localized near the iron ball surface. Since the magnetic fluid occupies the major space of the sensor, the sensibility of the sensor is dominated by the magnetic fluid even if its permeability is small. As shown in Fig.5 when a glass ball is used instead of an iron ball, the sensing range becomes wider than that of the sensor with the iron ball. This means that this solution can cope with a delicate change in an angle because the difference of permeability between the glass ball and the magnetic fluid is relatively small.

Table 2 summarizes the global characteristics for various material combinations which allows for material selection depending on the desired sensor characteristics.

Table 2 - Global characteristics depending on the materials.

Combination	Sensitivity	Dynamic range
Iron ball and air	High	Narrow
Iron ball and magnetic fluid	Middle	Middle
Glass ball and magnetic fluid	Low	Wide

4 SIMULATION

Figs. 6 and 7 show the magnetic flux distributions by means of the axisymmetrical finite elements method. In these figures, an iron or glass ball having 30mm diameter was used because it gave a high sensitivity. The magnetic flux distributions in Fig. 6 did not take into account the conductivity of the magnetic fluid. In Fig. 7 the conductivity of the magnetic fluid was taken into account.

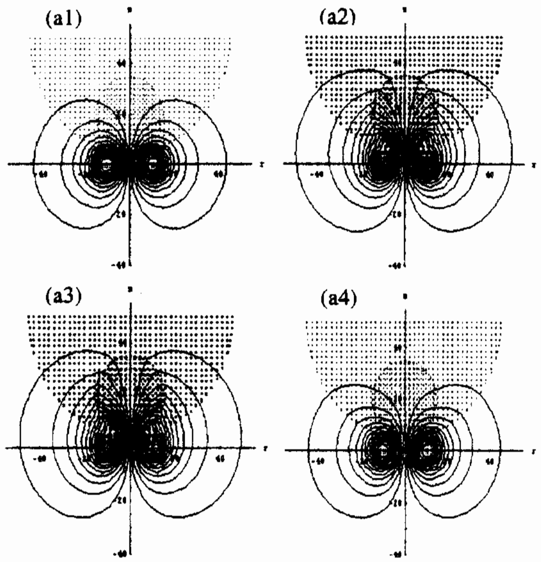

Figure 6 Magnetic flux distributions when sensor is constructed by iron or glass ball with the diameter 30mm when conductivity is ignored: (a1) Only coil; (a2) Combination of an iron ball and air; (a3) Combination of an iron and magnetic fluid; (a4) Combination of a glass ball and magnetic fluid.

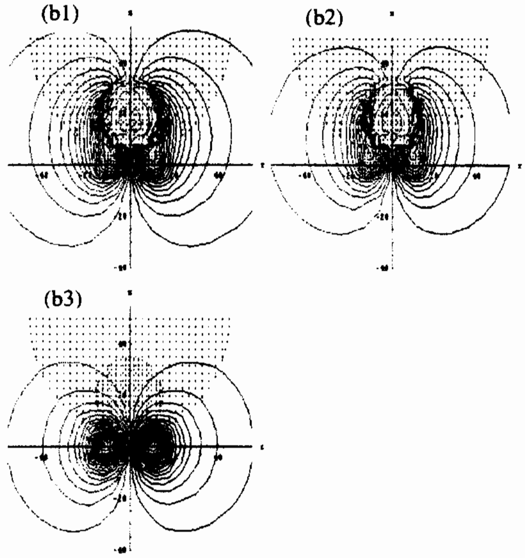

Figure 7 Magnetic flux distributions when sensor is constructed by iron or glass ball with the diameter 30mm when conductivity is taken into account: (b1) Combination of an iron ball and air; (b2) Combination of an iron ball and magnetic fluid; (b3) Combination of a glass ball and magnetic fluid.

By observing the magnetic flux distributions in Figs. 6 and 7, it is obvious that the magnetic flux distribution greatly depends on the combination of the materials. It is clear that tilting is detected with an iron ball due to the absorption of the magnetic flux. Also, tilting is detected with a glass ball due to the reduction of the magnetic flux. This result proves the change of the impedance shown in the Figs.2 and 3.

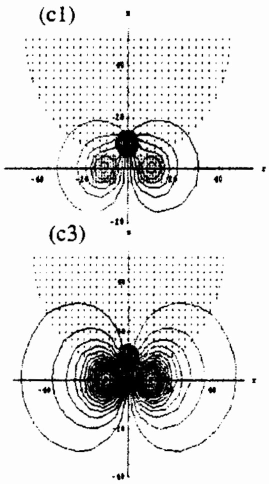

Figure 8 Magnetic flux distributions when sensor is constructed by an iron or glass ball having a diameter 10mm: (c1) Combination of an iron ball and air; (c2) Combination of an iron ball and magnetic fluid; (c3) Combination of a glass ball and magnetic fluid.

Figs. 8 and 9 show the magnetic flux distributions when employing the iron or glass ball with 10 and 20 mm diameters, respectively. Comparison of the distributions in Figs. 6 or 7 with those in Figs. 8 or 9 reveals the the disorder of the magnetic flux distribution becomes small. This proves the decline of the dynamic range and the sensitivity shown in Figs. 4 and 5.

Fig.10 shows the impedance changes when changing the diameter of an iron or glass ball.

5 CONCLUSIONS

The experiments carried out on the sensors constructed of iron balls, glass balls, air and magnetic fluid demonstrated that sensitivity and dynamic range are greatly dependent on the materials.

By observing the computed magnetic flux distributions, it is possible to understand the global sensor characteristics. Also it was shown that realization of the sensor having both the high sensitivity and the wide dynamic range is difficult when using a single coil.

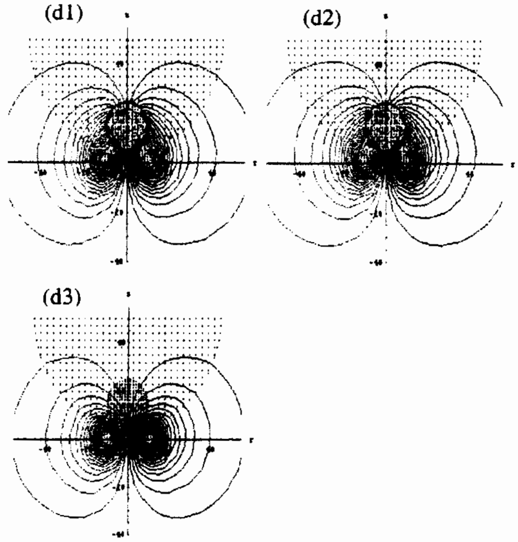

Figure 9 Magnetic flux distributions when sensor is constructed by an iron or glass ball having a diameter 20mm: (d1) Combination of an iron ball and air; (d2) Combination of an iron ball and magnetic fluid; (d3) Combination of a glass ball and magnetic fluid.

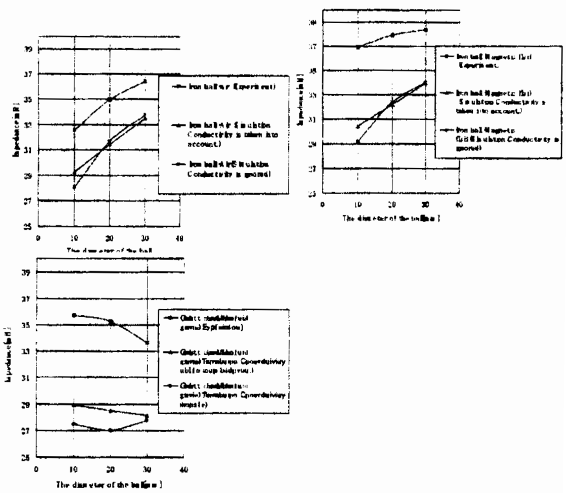

Figure 10 Impedance change when the diameter of the ball is changed.

REFERENCES

1. Yoshihisa Senoo, Seiji Hayano, Yoshifuru Saito., A study of Characterristics of the Magnetic Tilt Sensor, *Magnetic Society of IEEJ*, MAG-99-139.

2. Junichi Fukamachi, Seiji Hayano, Yoshifuru Saito., A Two Dimensional Tilt sensor With Three Coils Using Magnetic Fluid, *Magnetic Society of IEEJ*, MAG-98-266.

3. Hideo Oka, Junzo Iwata, Fundamental Characteristics And Analysis Of An Inclinosensor Using Magnetic Fluid, *Magnetic Society of IEEJ*, MAG-85-66.