Applications of Electromagnetic Phenomena in Electrical and Mechanical Systems
S. Yamada, A. Nafalski and S.C. Mukhopadhyay (eds.)

Float type tilt angle sensor using magnetic fluid -key idea and considerations-

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ABSTRACT: The tilt angle sensor utilizing magnetic fluid has been developed. But static friction between the container and movable element causes dead zone as well as noise signals. This paper proposes a float type tilt sensor in order to overcome these problems. Some configurations of float type tilt angle sensors are discussed along with the experimental as well as numerical approaches. As a result, employing a wooden cone as a float yields considerable advantage to the sensibility as well as dynamic range of tilt angle.

1 INTRODUCTION

Tilt angle sensors are widely used for controlling the tilt angles of mechanical devices as well as measurement devices, etc. In modern smart machines, the sensor devices are essentially required to be downsizing. Because of the fluidity as well as magnetization characteristics of magnetic fluid, different types of tilt sensors using the magnetic fluid have been investigated. The principle of the tilt angle sensors using magnetic fluid is to sense the change of magnetic flux distribution caused by fluidity of the magnetic fluid essentially accompanying mechanical tilt [1]. The change of magnetic field distribution leads to change of the electrical impedance of the sensor coil so that information on the mechanical tilt angle can be converted into electrical quantities. Our target is the development of a magnetic fluid based tilt angle sensor having much higher sensibility, reliability, and compact in shape [2]. We are now developing the sensor utilizing a float. As a wooden ball or cone is employed as a float, static friction between the container and movable element can be removed. Thus, we propose, in this paper, the float type tilt angle sensor using magnetic fluid.

Sensitivity and dynamic ranges of the float type magnetic tilt sensor depend on the material as well as shape of the float. This means that we have to take materials, shapes, and operating principle into account to design the sensor. As an initial test, we have experimentally examined the dependency of float materials to the sensibility and dynamic range. As a result, using wooden ball/cone as a float yields considerable advantage to the sensibility as well as dynamic range to the tilt angle. We have succeeded in obtaining higher sensitivity around the tilt angle 0 degree. Furthermore, it is revealed that combination of the magnetic fluid and wooden cone accomplished much wider dynamic range with higher sensibility.

2 MATERIAL AND EXPERIMENTAL DEVICE

2.1 Materials

We have previously proposed the tilt angle sensor composed of the magnetic fluid and iron ball sinking in it. In such a case, static friction between container and ball causes sensor signal noise and dead sensitivity. Therefore, we propose float type of sensor not to make such friction. Utilizing the bubble in the magnetic fluid is one of the best ways to obtain high sensitivity, however, unstable to keep its shape. In this paper, we consider wood as floats materials. Specification of the tested magnetic fluid is listed in Table 1.

Table.1. Specification of the tested magnetic fluid

Trade mark	M300
Solvent	Water
Maximum flux density	3.20 mT
Viscosity(20℃/50℃)	21/10 mPa·s
Manufacturer	Sigma high chemical company

2.2 Sensor structure

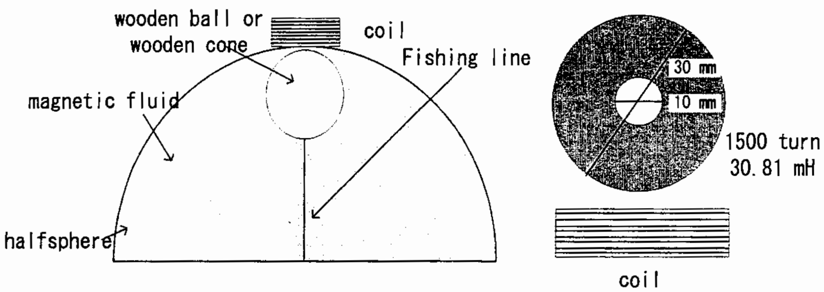
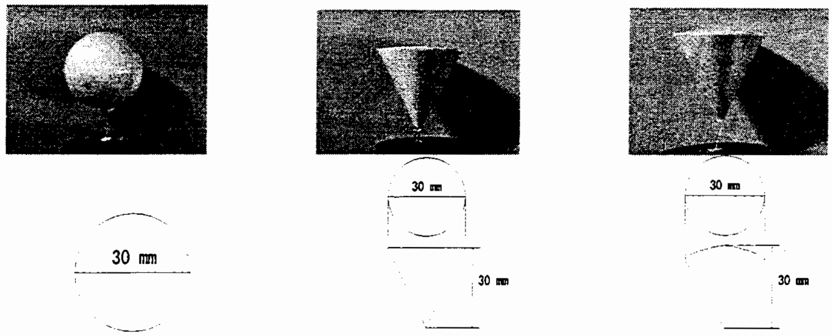


Fig.1. Schematic diagram of the tested sensor

Figure 1 shows schematic diagram of the tested sensor. Fig.2 shows the tested floats. The diameter of the ball in Fig. 2(a) is 30 mm. The corn shown in Fig.2(c), "cutting type", is made from the wooden corn shown in Fig. 2(b) along the spherical surface. We have experimentally investigated the cases of 1) Combination of the wooden ball and magnetic fluid, 2) Combination of the wooden cone and magnetic fluid, 3) Combination of the cutting type wooden cone and magnetic fluid. The distance from the sensor coil to floats was set up to 1mm, 3mm and 5mm.



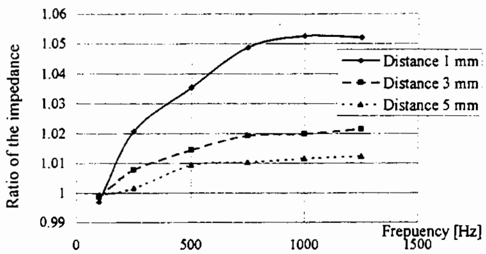
(a) wooden ball (b) wooden cone (c) wooden cone(cutting type)

Fig.2. Tested floats

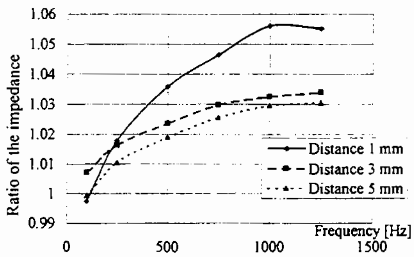
3 EXPERIMENT

3.1 Frequency characteristics

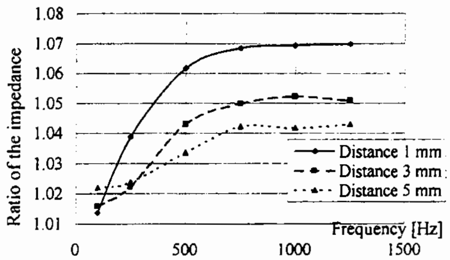
Figure 3 shows the frequency characteristics of the sensors, even though a small measurement error is observed. Sensibility is based on the impedance at 0 degree of each device. Sensibility S is defined by $S=Z\theta/Z0$, where Z0 and $Z\theta$ are the impedances at the angles $\theta=0$ and θ, respectively. From the results in Fig.3, it is revealed that sensibility has saturated from 1 kHz in every device. Therefore, we have carried out the experiments at only 1 kHz.



(a)



(b)

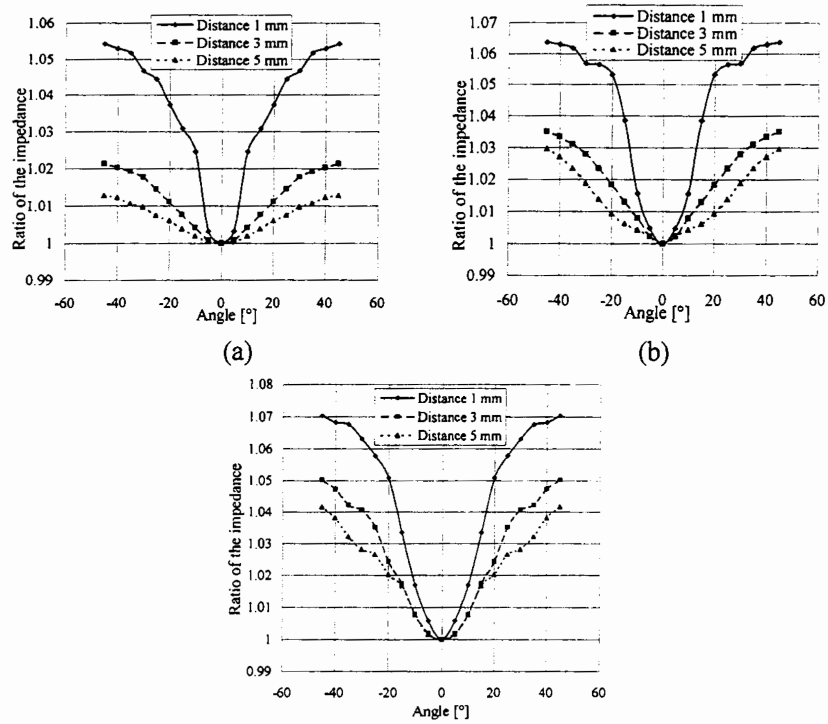


(c)

(a) Combination of wooden ball and magnetic fluid
(b) Combination of wooden cone and magnetic fluid
(c) Combination of wooden cone (cutting type) and magnetic fluid

Fig.3. Frequency characteristics of the tested sensors

3.2 Sensitivity



(c)

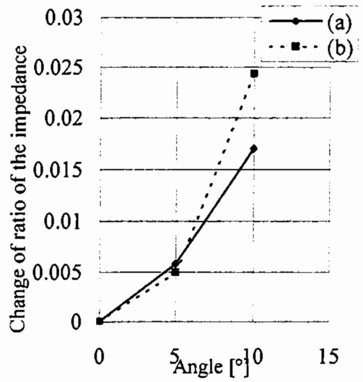
(a) Combination of wooden ball and magnetic fluid
(b) Combination of wooden cone and magnetic fluid
(c) Combination of wooden cone (cutting type) and magnetic fluid

Fig.4. Sensibility of the tested sensors

Figure 4 shows sensibility of the tested sensors under various combination and distance between the coil and the float. When the distance from the coil to the float is 1mm, has considerably good sensitivity. This is because the rate of change of flux density becomes high when the float approaches the coil. In case of the long distance between the float and coil, the magnetic fluid can not flow. Therefore, the sensitivity becomes higher in case of short distance. Namely, a combination of wooden cone (cutting type) and magnetic fluid has higher sensibility when a distance with the coil is 1mm. It has been reported in our previous report that the combination of iron ball and air yields the highest sensitivity [3]. In Table 2 and Fig.5, combination of the wooden cone (cutting type) and magnetic fluid is compared with that of the iron ball and air. According to the comparisons in Table1 and Fig.5, sensitivity of the combination of wooden cone (cutting type) and magnetic fluid is higher around the tilt angle 5 degree.

Table.2. Comparison of the change of impedance ratio

	Change of the impedance ratio	
Tilt angle [°]	Combination of wooden cone (cutting type) and magnetic fluid	Combination of iron ball and air
0	0	0
5	0.005786	0.004974
10	0.016983	0.024355



(a) Combination of wooden cone (cutting type) and magnetic fluid
(b) Combination of iron ball and air

Fig.5. Change of the impedance ratio

4 SIMULATION

4.1 Simulation

In order to examine the experimental results shown above, numerical simulations by the finite element method has been carried out. The simulation is assumed to be an axisymmetrical problem in terms of the vector potential. The governing equation takes the eddy currents into account.

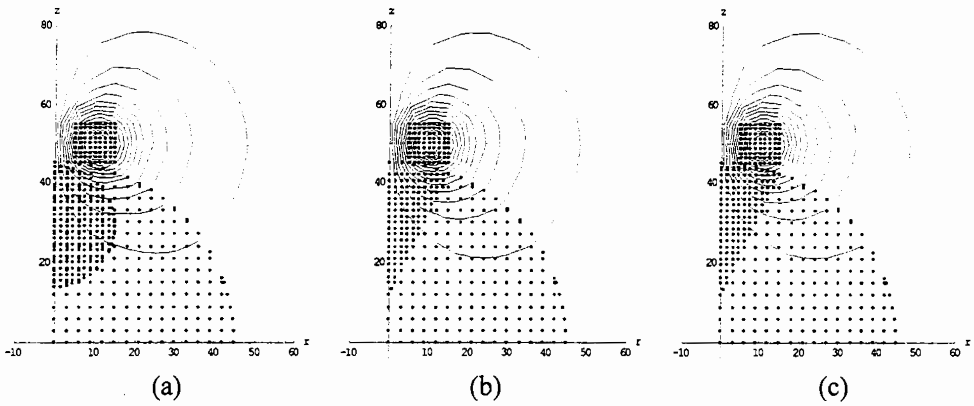
$$\frac{1}{\mu}\nabla^2 A_\vartheta - \kappa\frac{\partial}{\partial t}A_\vartheta = -J_\vartheta . \qquad (1)$$

where A_θ and J_θ denote the θ (circumference) component of vector potential and current density; μ, κ and t are permeability, conductivity and time, respectively. The parameters used for the simulation are listed in Table 3.

Table.3. Parameters used for the simulation

Material	Permeability μ [H/mm]	Conductivity κ [S/mm]	Current density J_θ [A/mm^2]
Wood	1.26×10^{-9}	0	0
Magnetic fluid	1.88×10^{-9}	0.88	3.93

Fig.6 shows the vector potential distributions by means of finite elements method taking unbounded effects into account by the Strategic Dual Image method [4]. The computed results in Fig. 6 are in case of 1mm distance from the coil to float.



(a) Combination of wooden ball and magnetic fluid
(b) Combination of wooden cone and magnetic fluid
(c) Combination of wooden cone (cutting type) and magnetic fluid

Fig.6. Vector potential distributions by the finite elements

Observing the vector potential distribution in Fig. 6 suggests that the magnetic field distributions of wooden corn sensor spread out widely. The magnetic flux concentrates on the magnetic fluid due to the differences in their permeability, therefore, the rate of volume difference float and magnetic fluid reflects on the sensitivity differences.

4.2 Results and discussions

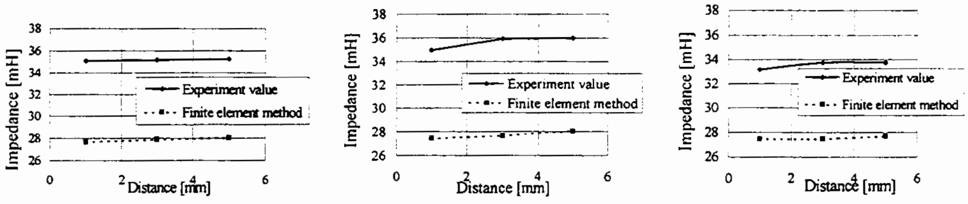
Tables 4 and 5 summarize the experimental and computed results of impedance. Fig.7 shows the impedance changes when changing the distance, from the coil to float. Comparison of the experimental with computed results shows that the tendency is similar. The impedance increases when the distance increases from the float to coil. This means that the magnetic fluid occupation to the coil stimulates the larger inductance.

Table.4. Experimental results of impedance

Distance	Combination of wooden ball and magnetic fluid [mH]	Combination of wooden cone and magnetic fluid [mH]	Combination of wooden cone (cutting type) and magnetic fluid [mH]
1 mm	35.09	34.96	32.36
3 mm	35.17	35.92	33.74
5 mm	35.25	35.98	33.76

Table.5. Computed results of impedance

Distance	Combination of wooden ball and magnetic fluid [mH]	Combination of wooden cone and magnetic fluid [mH]	Combination of wooden cone (cutting type) and magnetic fluid [mH]
1 mm	27.66	27.43	27.43
3 mm	27.88	27.67	27.45
5 mm	28.02	28.07	27.68



(a) (b) (c)

(a) Combination of wooden ball and magnetic fluid
(b) Combination of wooden cone and magnetic fluid
(c) Combination of wooden cone (cutting type) and magnetic fluid

Fig.7. Impedance changes

5 CONCLUSIONS

We have proposed, in this paper, the float type tilt angle sensor using magnetic fluid. In order to investigate the operating principle in detail, this paper has dealt with experimental verification in terms of frequency characteristics of the sensors and the sensibility to tilt angles. Further, we have carried out the finite element simulation. As a result of experiment, it has shown that the combination of wooden cone (cutting type) and magnetic fluid has high sensitivity around 0 degree. The rate of float to the magnetic fluid volume controls impedance differences. Also, it has been clarified that about 1mm distance from the coil to float is a limit of the sensitivity. The shape of float is one of the keys to the sensibility. Thereby, simulation and an experiment are necessary to work out an optimum tilt angle sensor utilizing magnetic fluid.

6 REFERENCES

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[4] Y.Saito, K.Takahashi, and S.Hayano, "Finite element solution of unbounded magnetic field problem containing ferromagnetic materials", *IEEE Trans. Magn.*, Vol.24, No.6, pp.2946-2948, 1988.