NEW TYPE OF SELF-SENSING MAGNETIC BEARING USING RESONANT CIRCUIT FOR LIQUID NITROGEN PUMP

Taro Okuhata
Kyushu Institute of Technology, 1- 1 Sensui, Tobata, Kitakyushu, Fukuoka 804- 8550, JAPAN

Naoki Isomura
Kyushu Institute of Technology, 1- 1 Sensui, Tobata, Kitakyushu, Fukuoka 804- 8550, JAPAN

Mochimitsu Komori
Kyushu Institute of Technology, 1- 1 Sensui, Tobata, Kitakyushu, Fukuoka 804- 8550, JAPAN
komori_mk@yahoo.co.jp

ABSTRACT
Self-sensing magnetic bearings don't have any position sensors. For this reason, self-sensing magnetic bearings are very promising for the maintenance free. They are useful for hydrogen pumps for rocket engines and hydrogen station of the fuel cars. Our self-sensing magnetic bearing gets the rotor position information from the middle point voltage. The control of levitation was performed by using this voltage. In this study, we propose a new type of self-sensing magnetic bearing technique and study the characteristics. And we verified that the self-sensing technique is useful in the extremely low temperature.

INTRODUCTION
Magnetic bearings have various kinds of advantages, such as non-contact and lubricant-free. Thus, they are applied to various fields, especially in the extremely low temperature. In this study, we make use of the advantage of this magnetic bearing and develop the maintenance free pump for using rocket engines and hydrogen stations of fuel cars. Therefore the control in cryogenic environment is necessary. The magnetic bearing needs displacement sensors controlling displacements. Reliable sensors are expensive for the system. Even if we use a sensor, there are faults that the device becomes complicated and large. In addition, there is a problem that the control isn't stable unless we can collocate the sensor and the actuator in the same place.

As a method to solve all problems, there is the self-sensing method. We used this method and proposed the self-sensing magnetic bearing which used an electromagnet. In this study, we made the prototype of self-sensing magnetic bearing and studied the characteristics.

STRUCTURE OF NITROGEN PUMP
Figure 1 shows the structure of liquid nitrogen pump using self-sensing magnetic bearings. This pump is used in cryogenic environment. The rotor is supported by four self-sensing magnetic bearings. Four magnetic bearings support a rotor in the radial direction, and one of them support in the thrust direction. An impeller and a motor are installed in the pump. Cryogenic liquid flows into the pump from the left hand side when the motor works. Then, the cryogenic liquid flows out from the upper part.

PRINCIPLE OF SELF- SENSING
In this study, a method using resonance circuits as a self-sensing displacement approximation process is adopted. Figure 2 shows a resonance circuit for sensing. Voltage v_0 is applied to coils. L_1 shows the inductance of upper coil, and L_2 the inductance of lower coil. L_1 and C_1 make LC resonant circuit and L_2 and C_2 makes another LC resonant circuit. Figure 3 shows the change of the middle point voltage v_2 for the frequency of v_0. In Figure 3, there are two frequencies, 7 kHz and 15 kHz, where v_2 changes according to displacement of the rotor. Since the higher frequency 15 kHz is better than 7 kHz, the frequency 15 kHz is adopted in our study.

SELF- SENSING SYSTEM
Figure 4 shows a block diagram of the self-sensing system. A sensing coil and a control coil are installed in each of the upper and lower electromagnet. In the upper electromagnet, the sensing coil and the control coil are

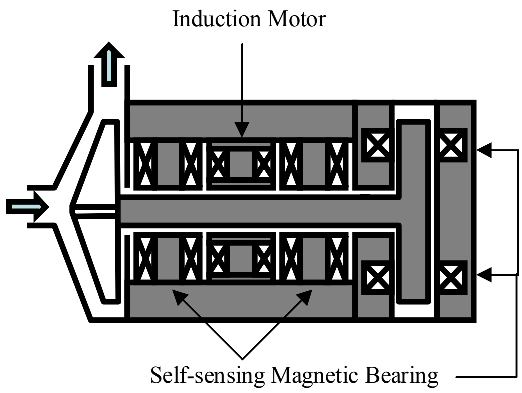


FIGURE 1: Structure of a liquid nitrogen pump

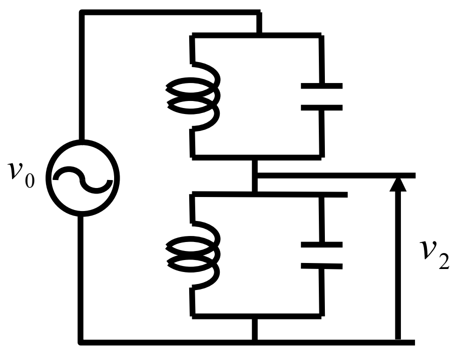


FIGURE 2: Resonant circuit for sensing

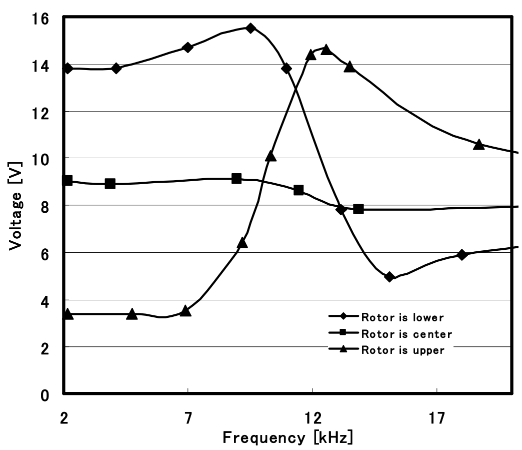


FIGURE 3: Change of middle point voltage to the frequency

connected in the same direction. In the lower electromagnet, the sensing coil and the control coil are connected in the opposite direction. The input signal is sinusoidal curve with bias current. The voltage between upper and lower coil changes depending on the rotor displacement. The middle point voltage passes through the BPF and the carrier signal is cut out by it. After carrying to the rectification circuit and the LPF, the sensing signal is passed through the computer through the A/D converter. The control signal is amplified and carried to the control coil. Therefore, in the upper electromagnet, the magnetic attractive force intensifies because two coils are connected in the same direction. In the lower electromagnet, the magnetic attractive force remits because two coils are connected in the opposite direction.

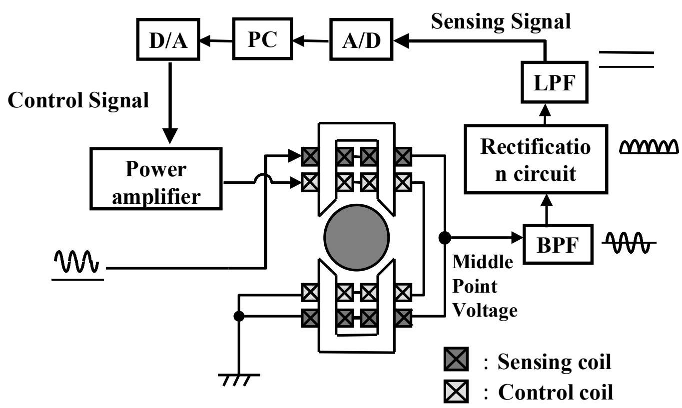


FIGURE 4: Self-sensing system

ATTRACTIVE FORCE

Figure 5 shows the principle of the magnetic attractive force. In Figure 5, the solid lines show the magnetic flux density B_s by sensing coil, the broken lines show the magnetic flux density B_c by control coil. The upper and lower electromagnets are regarded as a magnetic circuit. The magnetic flux density of upper coil is B_1, and the magnetic flux density of lower coil is B_2. The magnetic flux densities B_1, B_2 are written as

$$B_1 = B_s + B_c \tag{1}$$

$$B_2 = B_s - B_c \tag{2}$$

The direction of the control flux changes by changing the direction of the control current. Therefore, we can control the magnetic attractive force f. Generally, the magnetic attractive force f is

$$f = \frac{SB^2}{\mu_0} \tag{3}$$

The magnetic attractive force F of the all electromagnet is

$$F = \frac{S}{\mu_0}\left(B_1^2 - B_2^2\right) \tag{4}$$

Substituting Equations (1) and (2) in Equation (4) produces Equation (5).

$$F = \frac{S}{\mu_0} B_s B_c \tag{5}$$

Here, magnetic flux density B_s is constant. Equation (5) transforms to Equation (6).

$$F = \alpha B_c \tag{6}$$

$$\alpha = \frac{S}{\mu_0} B_s \tag{7}$$

Therefore, the magnetic attractive force of the electromagnet is proportional to the magnetic flux of the control coil [2].

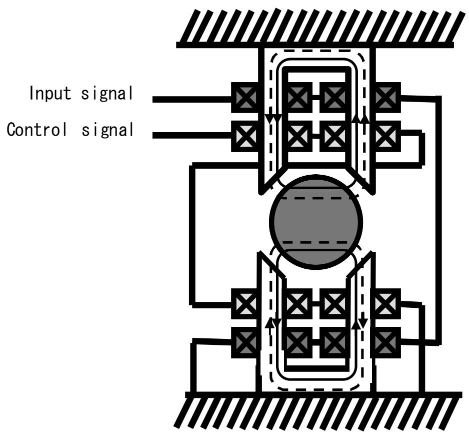
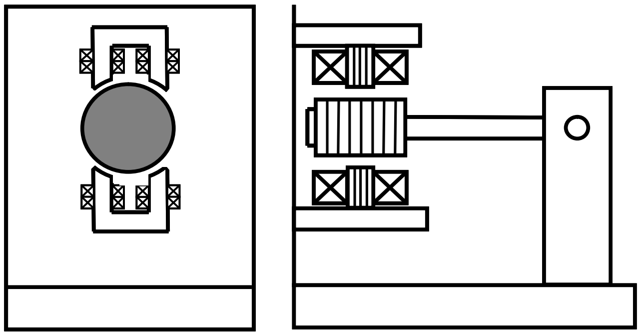


FIGURE 5: Principle of attractive forces

ONE AXIS EXPERIMENT

Experimental setup

Figure 6 shows the experimental setup for one axis control. Figures 6(a) and (b) show the front view and side view of experimental setup, respectively. The rotor is supported by a hinge, and it is possible to move freely only in the X direction. The self-sensing magnetic bearing is installed in the X direction. The sensing coil and the control coil are used in the self-sensing magnetic bearing. Figure 7 shows the relationship between inductance and displacement. The sensing coil and the control coil have 70 turns. We measured inductance of the upper and lower coil when the rotor was moved from -0.5 mm to 0.5 mm around the center of the electromagnets. In Figure 7, the inductances of the upper and lower coil are in proportion to the displacement.



(a) Front view (b) Side view

FIGURE 6: Experimental setup for one axis control

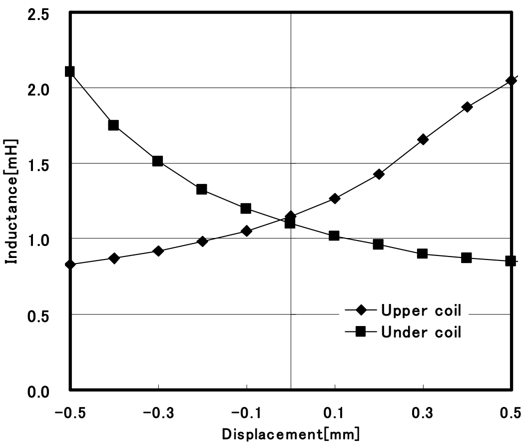


FIGURE 7: Change of the inductance

Middle point voltage

In the experiment, the rotor was set in the center of the electromagnets. Then, the change of the middle point voltage after passing through LPF was measured when the rotor was moved from -0.3 mm to 0.3 mm. The bias current of 0.7A was carried in the sensing coil.

Figure 8 shows the relationships between the middle point voltage and the displacement. In Figure 8, the control current is 0A, 0.3A and 0.5A. The frequency of sensing voltage is 15 kHz. The middle point voltage changes within ≈ 3V in proportional to the rotor displacement.

The change of the control current influences a little to the middle point voltage. If we can improve this problem, the characteristic of the sensing will be better [3], [4].

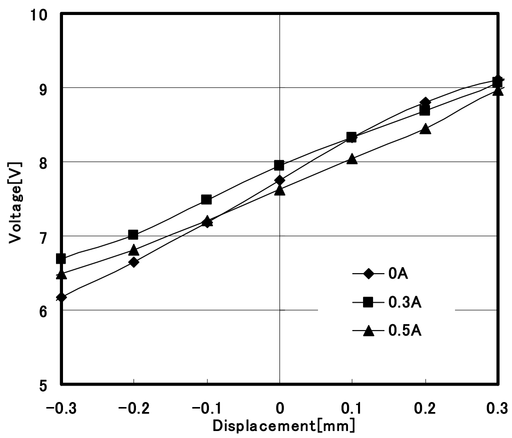


FIGURE 8: Middle point voltage (control current 0A, 0.3A, 0.5A)

Levitation experiment

In the air and liquid nitrogen, we performed the levitation experiment using the experimental setup in Figure 6. Impulse responses of the middle point voltage were measured. Figure 9 shows the result of impulse response in the air. Figures 9(a) and (b) show the rotor displacement and the control current, respectively. It is found that the vibration of the rotor disappears within about 0.2 s just after the impulse is applied.

Figure 10 shows the result of impulse response in liquid nitrogen. Figures 10(a) and (b) show the rotor displacement and the control current, respectively. It is found that the vibration of the rotor disappears within about 0.1 s just after the impulse is applied.

The vibration of the rotor in liquid nitrogen is stable compared with the result in the air. And the damping of vibration is larger than that in the air.

TWO AXIS EXPERIMENT

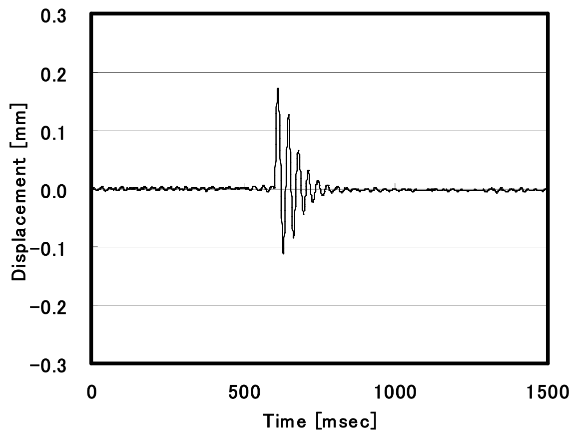
Experimental setup

Figure 11 shows the structure of electromagnet for two axis control. The experimental setup is the same as that of one axis control. In this case, the self-sensing magnetic bearing is installed in the X and Y directions.

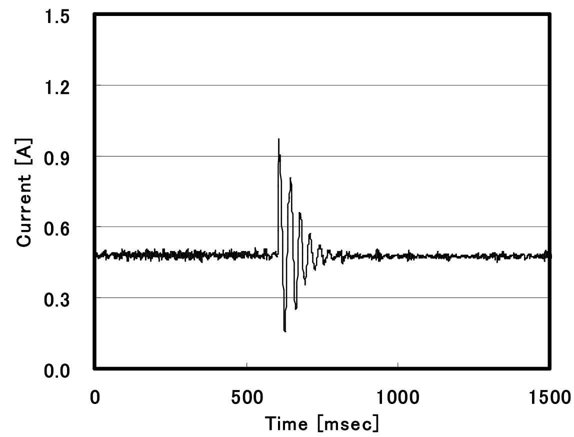
Levitation experiment

We performed the levitation experiment using the electromagnet in Figure 11. We measured the impulse response and step response of the middle point voltage. Figure 12 shows the result of impulse response in the air. Figures 12(a) and (b) show the rotor displacement and the control current, respectively. It is found that the vibration of the rotor disappears within about 0.15 s just after the impulse is applied.

Figure 13 shows the result of step response. Figure 13(a) and (b) show the rotor displacement and the control current, respectively. It is found that the vibration of the rotor disappears within about 0.2 s. As a result, it is confirmed that the rotor levitates in the stable condition. The rotor has some kinds of noise.

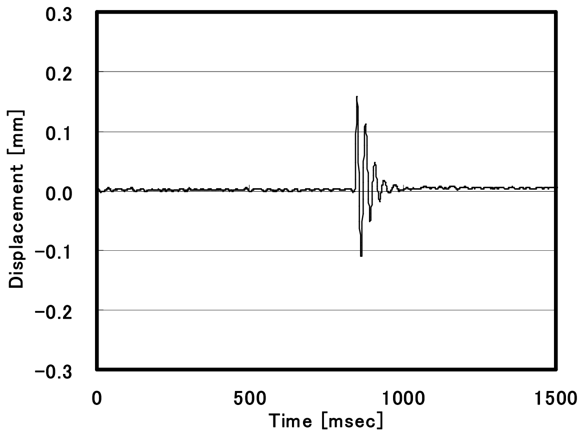


(a) Displacement

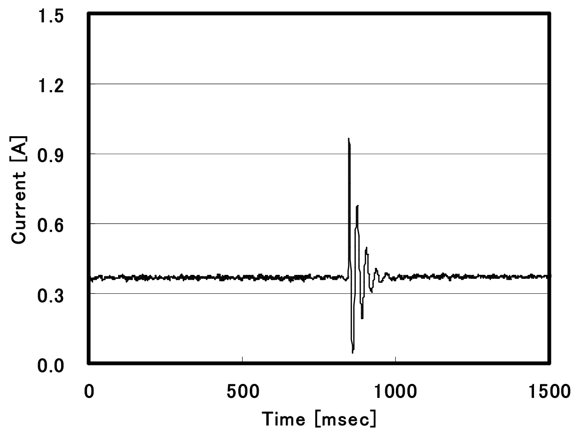


(b) Control current

FIGURE 9: Impulse response in the air

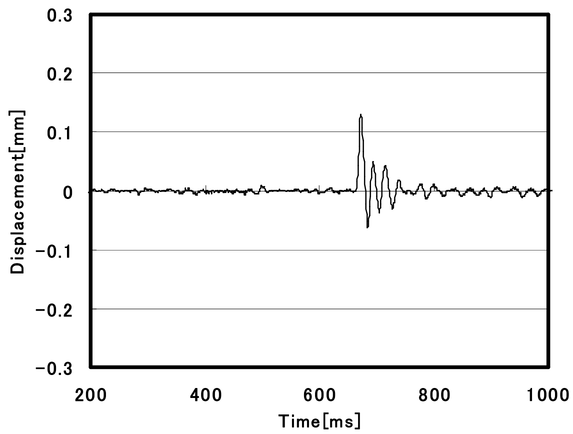


(a) Displacement

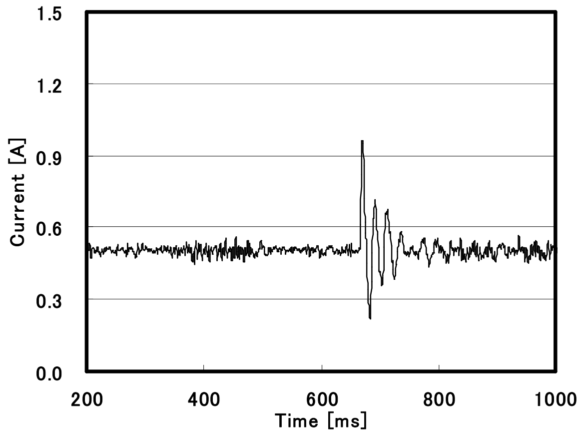


(b) Control current

FIGURE 10: Impulse response in liquid nitrogen



(a) Displacement



(b) Control current

FIGURE 12: Impulse response of the two axis control

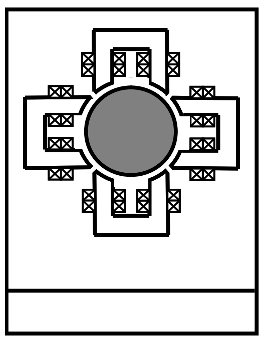
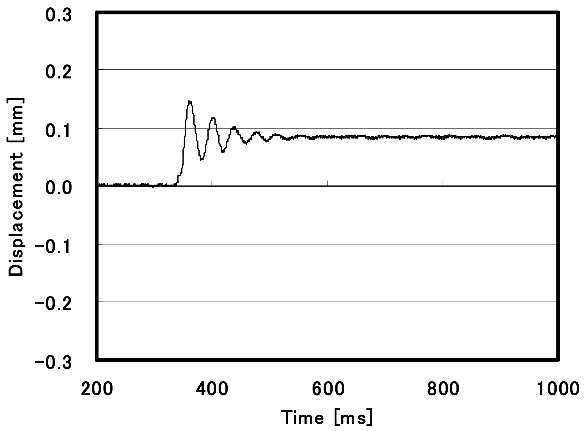


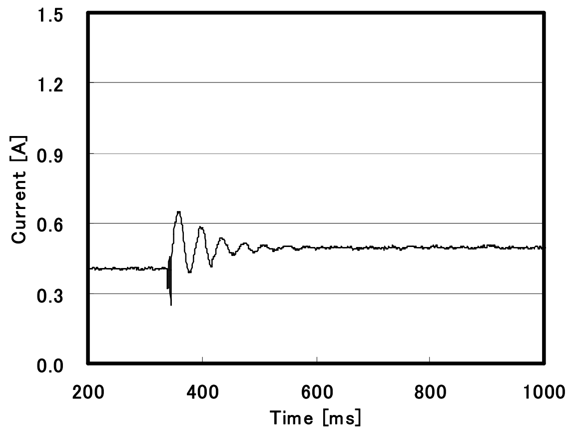
FIGURE 11: Structure of electromagnet for two axis control

CONCLUSION

We proposed a self-sensing magnetic bearing using LC resonance circuit. The middle point voltage is found useful as a sensing signal. We performed the levitation experiment using an experimental setup for one axis control in the air and liquid nitrogen. The vibration of the rotor in liquid nitrogen is stable compared with the result in the air. And the damping of vibration is large than that in the air. Therefore the self-sensing magnetic bearing is confirmed suitable for cryogenic environment. In addition, we performed the levitation experiment using an experimental setup for two axis control. As a result, it is confirmed the levitation of the experimental setup for two axis control is stable.



(a) Displacement



(b) Control current

FIGURE 13: Step response of the two axis control

References

1. Matsuda, K. Okada, Y. and Tani, J., Self-sensing Magnetic Bearing using the Principle of Differential Transformer, JSME Journal (c) Vol. 63, pp. 1441-1447 ,1997
2. Ebara, K. Nobe, T. Chiba, A. and Fukao, T., A Method of Rotor Position and Motor Flux Detection with Search Coils in Bearingless Motors, The 14th 「Dynamics Symposium Related to Electromagnetic Force」 (in Japanese), pp.397-402, 2002
3. Matsuda, K. Mito, K. Yamamoto, K. and Okada, K., Toward the Practical Use of Self-sensing Magnetic Bearing with nonlinear Compensation, JSME Journal (c) Vol. 71, pp.3494-3500, 2006
4. Morita, K. Yosida, S. and Ohniwa, A., Improvement of Sensing Characteristics of Self-Sensing Active Magnetic Bearings, IEEJ Trans. IA, Vol. 127, pp.471-477, 2007