Magnetic Suspension System Using Persistent Current Flowing in Superconducting Coil

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Abstract

Superconducting techniques are useful and applied to a superconducting magnetic suspension system. The system is composed of copper coils, a superconducting coil, a magnetically suspended object, a PID controller, a photo sensor, and power amplifiers. Control current flowing in copper coils and persistent current flowing in superconducting coil are used for suspending object and controlling object, respectively. Large gap trial for the suspension system is discussed, and static characteristics and dynamic characteristics of the suspension system are also discussed.

Keywords: Superconducting coil; Suspension system; Superconducting suspension

1. Introduction

Magnetic suspension techniques are very interesting because of mechanical contact-free. Generally, magnetic suspension techniques use electromagnets (EMs) in order to control the positions of suspended objects. These EMs usually need a lot of electric power and energy. In order to realize larger distance between EMs and suspended object, suspension systems need to generate much larger electromagnetic forces. Then, electromagnetic forces by permanent magnets (PMs) are tried to apply to reduce electric power (Kawamura and Takenaga, 2004), (Sawada and Kunimatsu, 2002). However, there is a technical limit for making much larger dimensions PMs in order to generate larger electromagnetic forces using PMs.

On the other hand, superconducting techniques are useful for various kind of levitation or suspension systems (Hull and Mulcahy, 1995), (Komori and Kobayashi, 1998). Especially, superconducting persistent current is suitable for suspension systems [5]. There is no electric power loss in superconducting coil because there is no electric resistance of superconducting coil.

2. Superconducting magnetic suspension system

An illustration of suspension system using superconducting persistent current in upper superconducting coil is shown in Figure 1. The suspension system is composed of upper copper coils, an upper superconducting coil, lower copper coils, a suspended object, an analog PID controller, a photo sensor and some power amplifiers. The critical current of the superconducting coil (100 turns) is 160 A (at 77K). The superconducting coil measures 10 mm in width, 103.4 mm in outer diameter and 60 mm in inner diameter. The copper coil (0.3 mm ×500 turns) measures 25 mm in

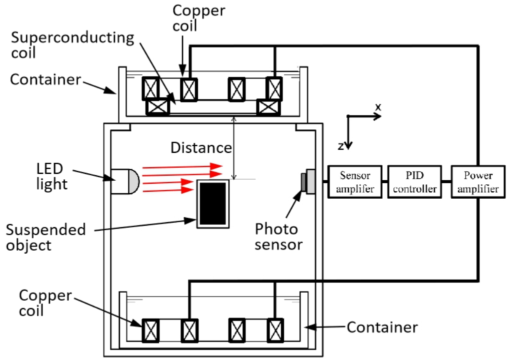
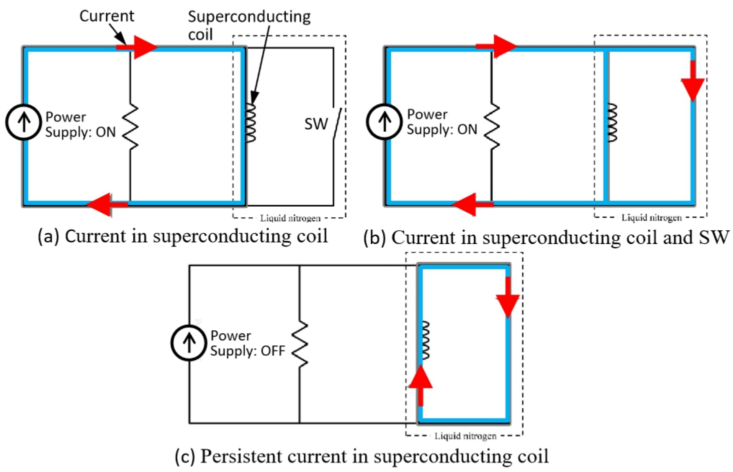


Figure 1 Schematic illustration of suspension system using persistent current in superconducting coil



(a) Current in superconducting coil (b) Current in superconducting coil and SW

(c) Persistent current in superconducting coil

Figure 2 Electric circuit for persistent current mode.

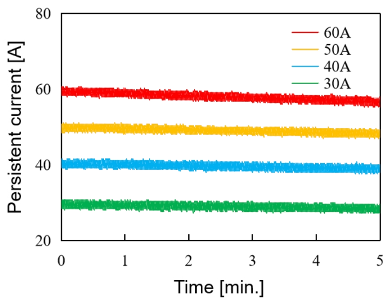


Figure 3 Relationship between persistent current and time for various initial currents of 30, 40, 50 and 60A.

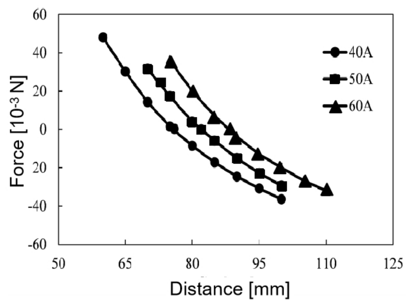


Figure 4 Relationship between suspension force and distance from a superconducting coil to the suspended object.

thickness, 96 mm in outer diameter and 60 mm in inner diameter. Two copper coils and the superconducting coil are installed in upper container. And two copper coils are also installed in lower container. The suspended object (96.3g, 30 ×40mm) has a PM (NdFeB, 70.5g, 20 ×30 mm) inside the plastic object. Detecting the displacement of suspended plastic object is carried out using a photo sensor.

Figure 2 shows the electric circuit for superconducting persistent current mode. After the persistent current (SW) becomes "OFF", the DC power applies a constant current to the superconducting coil in Figure 2(a). After the switch (SW) becomes "ON", constant currents flow through both the superconducting coil and the switch "SW" in Figure 2(b). Moreover, after the current from the DC power supply decreases, the constant current (persistent current) continues to keep the same current in the superconducting coil in Figure 2(c).

The relationships between superconducting persistent current and time for various initial currents in the time range from 0 to 5 min. are shown in Figure 3. Each persistent current from 30 to 60 A keeps the same current for more than 5 min. The persistent current at least for 5 min. is satisfactory to carry out some experiments.

The relationship between suspension force and distance for applied currents from 40 to 60 A is shown in Figure 4.

Each suspension force becomes smaller as the distance increases. The suspension force becomes larger with increasing applied current. Hereafter, persistent current 50 A is adopted in the experiments.

3. Experiments and discussions

Figure 5 shows the illustration of control forces given to suspended object. During experiments, these copper coils and superconducting coil are immersed in liquid nitrogen. Hereafter, the copper coils are used to control the displacement of suspended object and the superconducting coil is used to suspend the weight of object. In order to pass the same current through these coils, both upper two copper coils and lower two coils are connected in series. Thus in the case that polarities of upper coils and object are S and S respectively, the repulsive forces are produced. In the case that polarities of lower coils and object are S and N, the attractive forces are produced. These repulsive force and attractive force are forced to move the suspended object in the vertical direction.

The relationship between attractive force and applied current to copper coils is represented in Figure 6. In the experiment, the same current flows through these four copper coils in order to produce the same attractive force. Then, the total attractive force to the object is produced in the vertical direction. As shown in Figure 6, the attractive

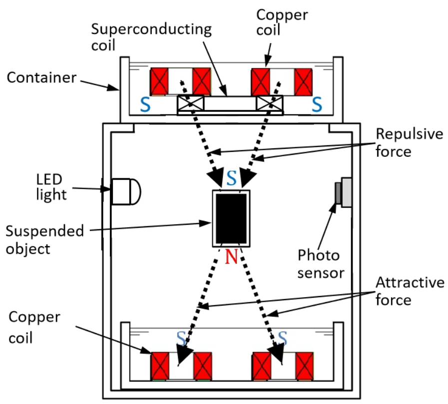


Figure 5 Schematic illustration of control force applied to suspended object.

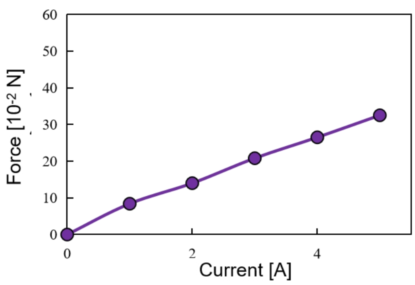


Figure 6 Relationship between attractive force and applied current to copper coils.

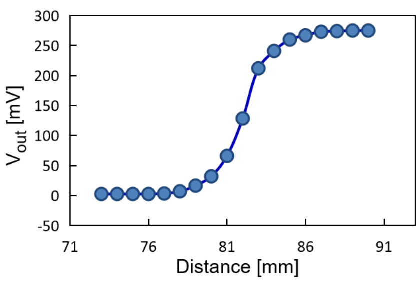


Figure 7 Relationship between output voltage and distance between superconducting coil and suspended object.

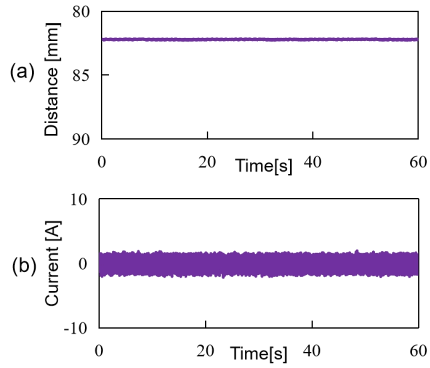


Figure 8 Relationships between (a) distance and time and between (b) current and time in the case of persistent current.

force is almost linear for applied current, which is applicable to controlling the suspended object.

Figure 7 represents the relationship between output voltage from displacement sensor and distance between suspended object and superconducting coil. The relationship near 82 mm is almost linear, which is corresponding to the sensor gain.

The results for the suspended object are represented in Figure 8. During the experiment, the superconducting persistent current of 50 A flows through the superconducting coil. The relationship between distance from superconducting coil bottom surface to suspended object and time is shown in Figure 8(a). The suspended object continues to keep the same distance for more than 60 s as shown in Figure 8(a). During the suspension, the displacement is less than 0.5 mm and small. Figure 8(b) represents the relationship between control current to copper coils and time. The amplitude of control current is less than 3 A. From the experimental results in Figure 8, it is found that the suspension system is working fine.

4. Summary

The suspension system using persistent current of 50 A is developed. The experimental results show that the object succeeds to be suspended at a distance of 82 mm and continues to keep the suspension for more than 60 s. During the suspension, the displacement is small and less than 0.5 mm and the amplitude of control current is less than 3 A.

As a result of experiments, it is found that the suspension system works well and seems to be very promising for some applications such a wind tunnel test equipment.

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