Basic Study on Superconducting Magnetic Bearing using Superconducting Bulk and Coil

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Abstract: Our group has developed a superconducting magnetic levitation (SML) with superconducting coil for magnetically levitated conveyers used for clean environments. In this paper, dynamic characteristics of the SML with superconducting coil are discussed. The damping for the SML with superconducting coil is compared with the SML without superconducting coil. The damping for the SML with PD control is also discussed.

Keywords: Superconducting Levitation, Superconductors, Diamagnetic Bearings, Magnetic Suspensions, Passive Magnetic Bearings

Introduction

Applying high *T*c superconductors to magnetic bearings as levitation mechanisms is very promising. Superconducting magnetic bearings are applied to some devices such as energy storage flywheel systems and motors [1], [2]. Magnetically levitated conveyers are very promising, because non- contact conveyer systems are needed for clean rooms for semiconductor industry, semiconductor devices, and other systems.

Our group has developed a superconducting magnetic levitation (SML) with superconducting coil for magnetically levitated conveyers used for clean environments. In this paper, dynamic characteristics of the SML with superconducting coil are discussed

System

Fig. 1 shows the SML with superconducting coil. The SML is composed of a levitated permanent magnet (PM) and a supporting superconductor with superconducting coil, a control coil and a Hall sensor. The dimensions of the superconductor are OD45mm x ID25mm x T20mm. The permanent

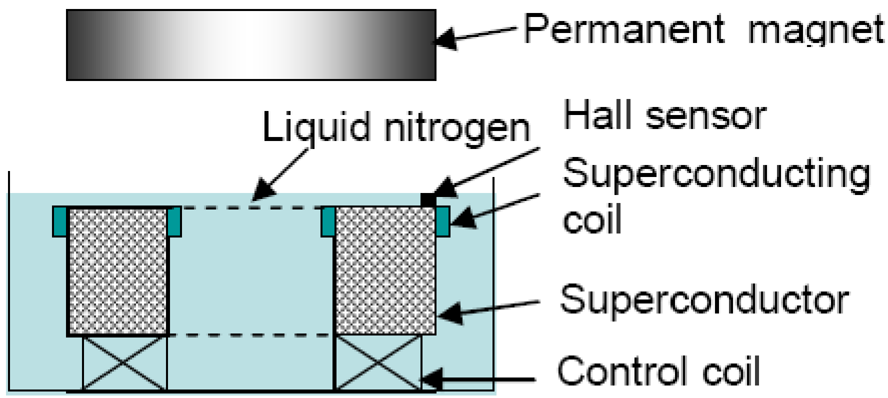

Fig.1 Superconducting levitation mechanism

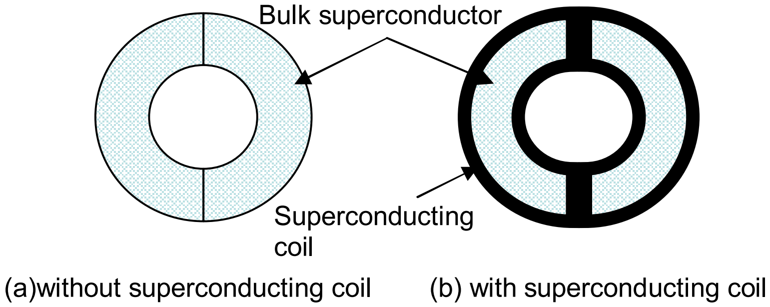

Fig. 2 Bulk superconductor and superconducting coil

magnet measures 50 mm in diameter, 10 mm in thickness and 0.15 kg in weight. The electromagnet ($\cong$700 turns) is set under the superconductor to produce magnetic field. The Hall sensor is put on the superconductor to detect magnetic field. The PM is used to produce magnetic field. In the system, field cooling process for the superconductor is carried out to make a stable magnetic levitation of the PM. Fig. 2 shows illustrations of (a) bulk superconductor and (b) bulk superconductor with superconducting coil. The superconducting coil is Bi-type superconductor with a width of 3.1 mm, a thickness of 0.22 mm, and a critical current of 80 A. The superconductor has ten turns around the superconductor. The superconducting coil has some bending parts. In order to reduce the resistance of bending parts, the bending parts are filled with solder. Fig.3 shows a photo of bulk superconductor and coil installed in a cryocooler.

The total system including the SML is shown in Fig. 4. A PD control is applied to the system for

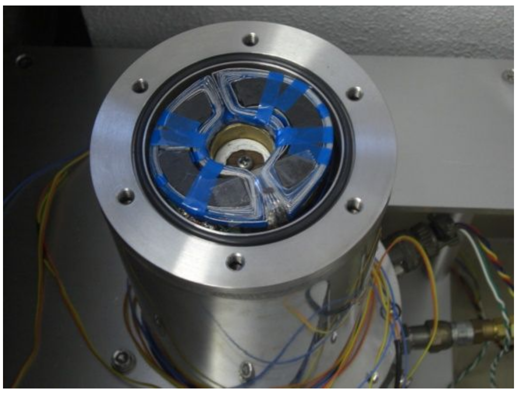

Fig. 3 Bulk superconductor and superconducting coil installed in cryocooler

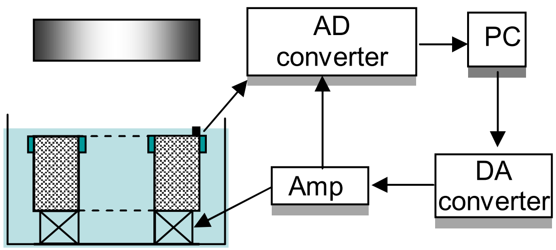

Fig. 4 Magnetic levitation system with control system

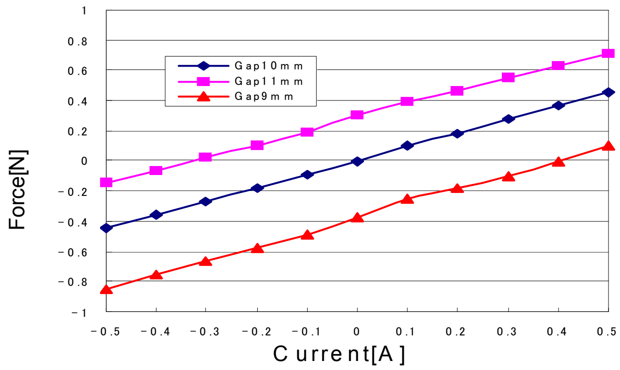

Fig.5 Relationship between force and coil current

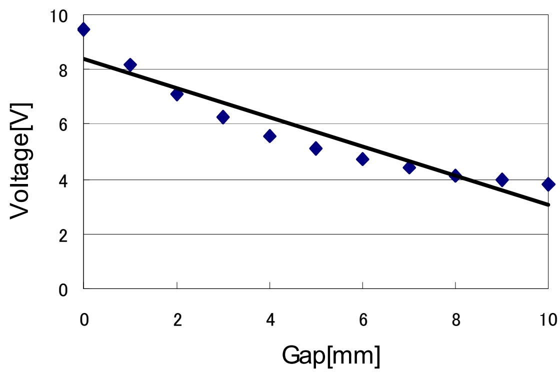

Fig.6 Relationship between Hall voltage and gap

suppressing PM vibrations. Control forces are produced by the electromagnet under the superconductor. The relationships between force and coil current for various gaps 9, 10 and 11 mm are shown in Fig. 5. In the experiment, the superconductor is field-cooled at a gap of 10 mm. The relationships for various gaps are almost linear. The minus and plus forces means repulsive and attractive forces, respectively. The force increases as the gap becomes large.

Fig. 6 shows a relationship between Hall voltage and gap. The gap means a distance between PM and bulk superconductor. As shown in Fig.6, the result shows a linear relationship. The Hall voltage is disturbed by a magnetic field produced by the control coil. Then, the gap between PM and bulk superconductor is detected by using the Hall voltage and the control coil current. The Hall sensor detects magnetic field as a function of gap with considering magnetic field by the control coil. The relationship between the gap and the Hall voltage is almost linear. The Hall voltage as a function of coil current is also measured, which shows a linear relationship.

Results and discussion

In order to suppress vibrations of the PM, the SMLs with superconducting coil and without superconducting coil are discussed. In the experiments, vibrations are detected by using the Hall sensor and a laser displacement sensor. The laser displacement sensor is used for correcting the Hall displacement. Impulse responses for the SML without superconducting coil and without control are

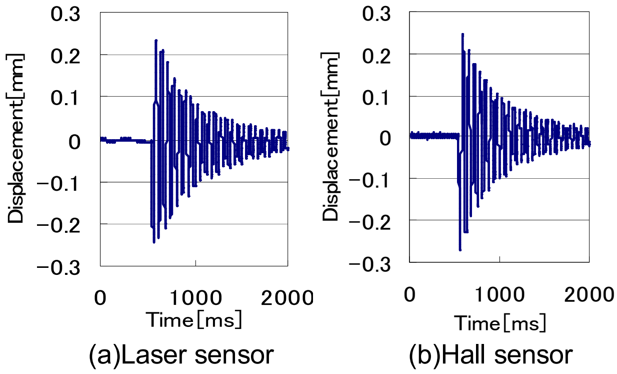

Fig. 7 Impulse response without superconducting coil (without control)

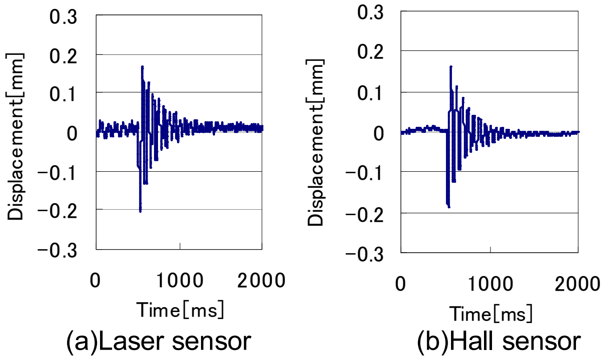

Fig. 8 Impulse response without superconducting coil (with control)

shown in Fig. 7, representing (a) the laser sensor displacement and (b) the Hall sensor displacement. The laser sensor displacement is almost the same as the Hall sensor displacement. These vibrations disappear within 2.0 s. This shows that the Hall sensor is useful for detecting the displacement of the PM. Impulse responses for the SML without superconducting coil and with control are shown in Fig. 8, representing (a) the laser sensor displacement and (b) the Hall sensor displacement. As shown in Fig. 8, the laser sensor displacement is almost the same as the Hall sensor displacement. These vibrations disappear within 1.0 s. This shows that the Hall sensor is useful for detecting the displacement of the PM. Hereafter, the Hall sensor is used for sensing displacement in this paper.

Impulse response for the SML without superconducting coil is shown in Fig. 9. The vibration in Fig. 9 continues for about 2.0 s. The impulse response for the SML with superconducting coil is shown in Fig. 10. The vibration in Fig. 10 disappears within 0.5 s. The damping for the SML with superconducting coil is larger than that for the SML without superconducting coil. This means that the superconducting coil is effective for suppressing vibrations.

Next, PD control is applied to the SMLs without superconducting coil and with superconducting coil. The impulse responses for the SMLs without superconducting coil and with superconducting coil are shown in Figs. 11 and 12, respectively. The vibration in Fig. 11 disappears within 0.3 s and that in Fig. 12 also disappears within 0.3 s. The damping for the SML with superconducting coil in

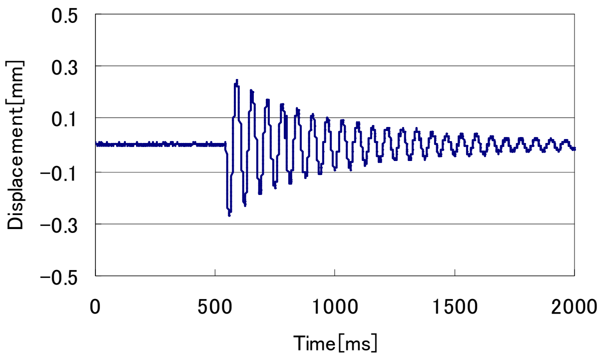

Fig. 9 Impulse response without superconducting coil (without control)

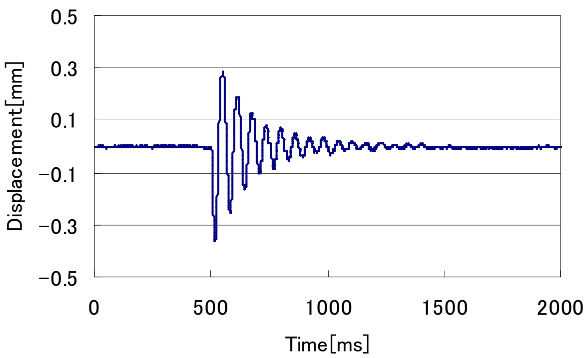

Fig. 10 Impulse response with superconducting coil (without control)

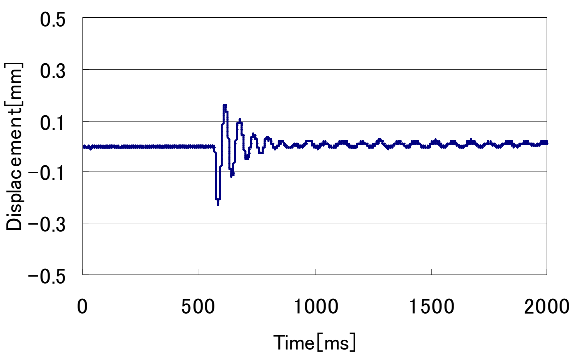

Fig. 11 Impulse response without superconducting coil (with control)

Fig. 11 is the same as that for the SML without superconducting coil in Fig. 12. This means that PD control is effective for suppressing vibrations for both the SMLs without superconducting coil and with superconducting coil. The damping for the SML in Fig. 10 is slightly smaller than those in

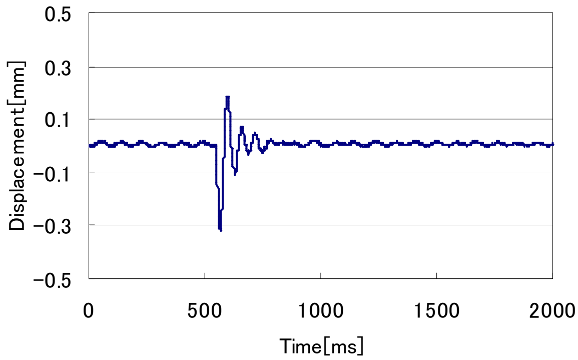

Fig. 12 Impulse response with superconducting coil (with control)

Figs. 11 and 12. This shows that the superconducting coil is effective for passively suppressing vibrations.

Summary

The SML with superconducting coil is developed. The Hall sensor as a displacement sensor is installed in the SML. The damping for the SML with superconducting coil is larger than that for the SML without superconducting coil. This means that the superconducting coil is useful for suppressing vibrations. The damping for the SML with superconducting coil is slightly smaller than those with PD control. The experimental results show that the superconducting coil is effective for passively suppressing vibrations.

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