§8. Fundamental Study on Application of Magnetic Levitation to Laser Fusion Research Using YBCO Bulk Superconductor

Tsuda, M., Yagai, T., Hamajima, T. (Tohoku Univ.),
Ishiyama, A. (Waseda Univ.),
Noguchi, S. (Hokkaido Univ.),
Yanagi, N., Mito, T., Iwamoto, A.

Accurate control of levitation height as well as stable levitation of a spherical cryogenic target is very important in a magnetic levitation type laser fusion system. Active magnetic levitation system composed of HTS bulk and electromagnets is effective for controlling levitation height. The characteristics of magnetic levitation of disk-, ring- and sphere-shaped HTS bulks, such as stability, levitation force and levitation height, have been already investigated experimentally and numerically by many research groups. The required accuracy of levitation height control in the laser fusion system, however, is much higher than those of the previous works; the required accuracy of levitation height is much less than 1 mm. Therefore, we investigated the suitable active magnetic levitation system and control method for the accurate control of levitation height of a spherical YBCO bulk.

Levitation height of an HTS bulk in an active magnetic levitation system is closely related to magnetic field distribution around the HTS bulk. This means that electromagnet size and arrangement are very important to achieve such the accurate control of levitation height. To investigate the suitable electromagnet size and arrangement for the accurate control of levitation height, we developed a numerical simulation code based on the finite element method and the boundary element method. To verify the validity of developed simulation code, we analyzed and measured levitation height of a ring-shaped YBCO bulk with inner diameter of 23 mm and outer diameter of 46 mm in a model levitation system composed of copper electromagnet 58 mm in inner diameter, 110 mm in outer diameter and 12 mm in height. Since good agreement of levitation height between experiment and analysis was obtained, we investigated the suitable electromagnet system for the accurate control of levitation height using the simulation code.

To realize the accurate control of levitation height, the changing ratio of levitation height to operating current of electromagnet should be as small as possible. We numerically investigated influence of inner and outer diameters and air gap between electromagnets on the changing ratio. In this simulation, we assumed that the diameter and equivalent critical current density of a spherical YBCO bulk are 15 mm and 4×10^7 A/m^2, respectively. It was clarified in the simulation that the smaller diameter and air gap were effective for reducing the changing ratio. One of the suitable electromagnets for the accurate control of levitation height was 22 mm in inner diameter, 74 mm in outer diameter, and 12 mm in height. Considering these parameters, we constructed a model levitation system to investigate the accuracy of levitation height control. The experimental setup is shown in Fig. 1. As shown in Fig. 1, the two electromagnets were arranged in the vertical direction; the air gap between the two electromagnets was 2 mm. The lower electromagnet was used for field-cooling and levitation processes and the upper one was mainly used for the accurate control of levitation height. Programmable Logic Controller (PLC) was adopted for the accurate control of levitation height and laser displacement gage was used for levitation height measurement.

The experiment proceeds through the following steps: 1) the spherical YBCO bulk is field-cooled at 5 A of the lower electromagnet; 2) operating current of the lower electromagnet is increased to 15 A and keep the current constant; 3) operating current of the upper electromagnet is increased and levitation height is controlled by PLC; 4) levitation height is measured by the laser displacement gage for ten minutes after the bulk reached the target height of 23 mm.

One of the experimental results of levitation height as a function of time is shown in Fig. 2. Averaged error between the target and measured levitation height was 20 μm. Considering some errors related to experimental conditions, we conclude that accurate control of levitation height of spherical YBCO bulk can be realized by our developed electromagnetic system and control method.

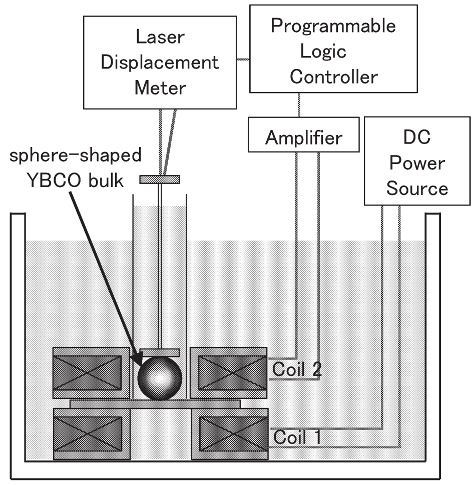

Fig. 1. Schematic drawing of an active magnetic levitation system for accurate control of levitation height.

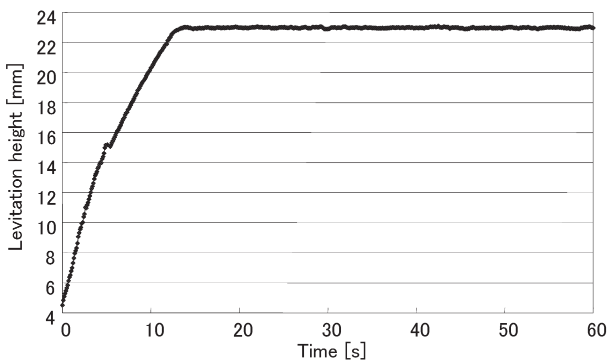

Fig. 2. Measured levitation height of a spherical YBCO bulk in active magnetic levitation system controlled by Programmable Logic controller.