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

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Stable levitation and precise levitation height control of a spherical cryogenic target are required in a magnetic levitation system for laser fusion system. The spherical target is surrounded by HTS thin layer of less than 100 μm. Large levitation force enough to levitate the target has to be generated in such the HTS thin layer. The characteristics of magnetic levitation, such as stability, levitation force and levitation height, have been already investigated both experimentally and theoretically. The most of investigations, however, are about disk- and ring-shaped HTS bulks and the characteristics of magnetic levitation in a spherical target with a concentric spherical HTS thin layer have not been investigated yet. The characteristics of magnetic levitation are closely related to supercurrent distribution. The supercurrent distribution strongly depends on the size and shape of HTS region. It is very difficult to produce the spherical target with a concentric spherical HTS thin layer. Furthermore, it is expected that the supercurrent distribution in the HTS layer of a spherical target would be similar to that of a spherical HTS bulk. Therefore, we investigated supercurrent distribution and the characteristics of magnetic levitation of a spherical YBCO bulk.

Since supercurrent distribution and levitation force strongly depend on equivalent critical current density of HTS bulk, it is very important to estimate the equivalent critical current density as accurate as possible. The equivalent critical current density can be estimated by both measurement and numerical analysis of levitation force using an active magnetic levitation system composed of HTS bulk and electromagnet. Therefore, we prepared a spherical YBCO bulk sample and three sets of copper coils. Then we measured levitation force of the spherical YBCO sample using the active magnetic levitation system shown in Fig.1. The diameter and weight of the YBCO sample are 15mm and 11g, respectively. The inner and outer diameters and height of copper coil are 20mm, 72mm and 12mm, respectively. In numerical analysis, we adopted the FEM-BEM coupling method to evaluate levitation force of the YBCO sample. We calculated the levitation force as a function of the equivalent critical current density and compared them with that of experiment. From the experimental and numerical results, the equivalent critical current density of 4×10^7A/m^2 was obtained. To validate the obtained equivalent critical current density, we measured levitation height of the YBCO sample using laser displacement meter. Good agreement between experiment and analysis was obtained. This means that the estimated equivalent critical current density is reliable.

Using the estimated equivalent critical current density, we simulated supercurrent distribution within the spherical YBCO sample. The computed supercurrent distribution at the coil current I_{coil} of 0 A (just after field-cooling process), 5 A (levitation height = 0 mm), 15 A (levitation height = 3.75 mm), and 45 A (levitation height = 44.2 mm) are shown in Fig.2. As shown in Fig.2, supercurrent flows only outermost layer of the spherical YBCO sample; the layer thickness of supercurrent region of about 0.8mm is independent of coil current and levitation height. This means that the thickness of the concentric spherical YBCO layer of 0.8mm is enough to levitate the sample of weight of 11g.

Accurate evaluation of supercurrent distribution within a concentric spherical HTS thin layer of a very small cryogenic target is necessary for the precise estimation of levitation force and the investigation of relationship between HTS layer thickness and levitation force. A strong nonlinearity of the *E-J* power law in the HTS layer, however, results in bad convergence of the nonlinear equation solvers, i.e., the Newton-Raphson method. Consequently, the unsuitable and/or undulating supercurrent distribution is sometimes observed. Therefore, we developed a new method combined a line search with the Newton-Raphson method. It was observed in the analysis by the developed method that the convergence was considerably improved and the supercurrent distribution was suitably smooth.

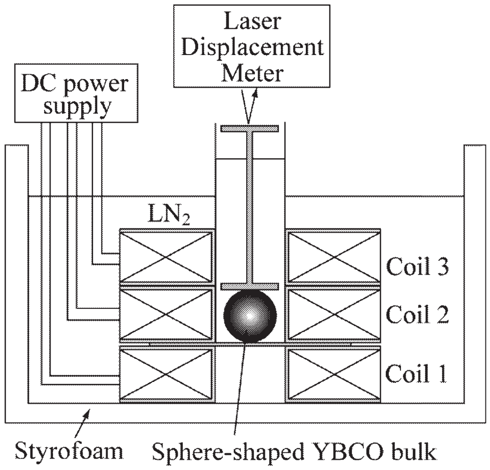
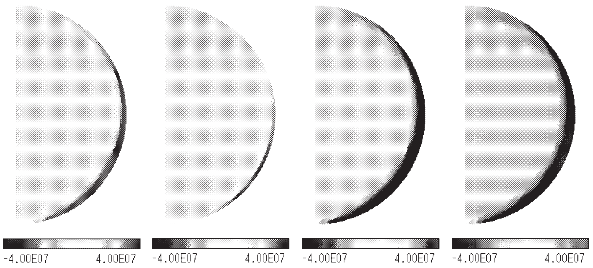


Fig. 1. Schematic drawing of an active magnetic levitation system.



I_{coil}=0A **I_{coil}=5A** **I_{coil}=15A** **I_{coil}=45A**

Fig. 2. Supercurrent distributions of a spherical YBCO sample in an active magnetic levitation system.