Physica C 494 (2013) 270–275

Contents lists available at SciVerse ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

The levitation characteristics of the magnetic substances using trapped HTS bulk annuli with various magnetic field distributions

S.B. Kim [a,*], T. Ikegami [a], J. Matsunaga [a], Y. Fujii [a], H. Onodera [b]

[a] Graduate School of Natural Science and Technology, Okayama University, 3-1-1, Tsushima-Naka, Kita-ku, Okayama 700-8530, Japan
[b] Japan Science and Technology Agency–Core Research for Evolutional Science and Technology (JST–CREST), Tokyo 102-0076, Japan

ARTICLE INFO

Article history:
Accepted 21 May 2013
Available online 29 May 2013

Keywords:
Magnetic levitation
HTS bulk
Spherical solenoid magnet
Reapplied field method

ABSTRACT

We have been investigating the levitation system without any mechanical contact which is composed of a field-cooled ring-shaped high temperature superconducting (HTS) bulks [1]. In this proposed levitation system, the trapped magnetic field distributions of stacked HTS bulk are very important. In this paper, the spherical solenoid magnet composed of seven solenoid coils with different inner and outer diameters was designed and fabricated as a new magnetic source. The fabricated spherical solenoid magnet can easily make a homogeneous and various magnetic field distributions in inner space of stacked HTS bulk annuli by controlling the emerging currents of each coil. By using this spherical solenoid magnet, we tried to make a large magnetic field gradient in inner space of HTS bulk annuli, and it is very important on the levitation of magnetic substances. In order to improve the levitation properties of magnetic substances with various sizes, the external fields were reapplied to the initially trapped HTS bulk magnets. We could generate a large magnetic field gradient along the axial direction in inner space of HTS bulk annuli, and obtain the improved levitation height of samples by the proposed reapplied field method.

1. Introduction

Because the non-contact levitation system does not have a mechanical friction, there is no energy loss and the maintenance is rarely needed. The trapped HTS bulks by FC method have a trapped magnetic field and exhibit diamagnetic behaviors, so those trapped HTS bulks were expected to be used for superconducting permanent magnets and magnetic levitation system [1]. The levitation systems to levitate the ferromagnetic samples using the trapped HTS bulks are very similar to the levitation principle of Mixed-m system composed of the ferromagnetic substance, diamagnetic material and the superconducting magnet [2–5]. In the Mixed-m system, the ferromagnetic substance suffers two forces, attractive force by the superconducting magnet and repulsive force by the diamagnetic material, and levitates. The diamagnetism is the property of an object which causes it to create a magnetic field in opposition to apply magnetic field, and it is generally quite a weak in most materials. However, HTS materials have a strong diamagnetism and pinning force to trap the magnetic flux. By using these characteristics, the ferromagnetic substance which dropped to inner space of HTS bulk annuli suffers attractive force and repulsive force and levitates. It means that the HTS bulk plays the roles of the diamagnetic substance and the superconducting magnet at the same time [6,7]. We have been developing the levitation system using trapped HTS bulk annuli magnetized by FC method, and we confirmed that the good homogeneity along the radial direction and large magnetic gradient along the axial direction were very effective for the levitation of the ferromagnetic samples with various sizes. In this paper, the reapplied field method that the external fields were reapplied to the initially trapped HTS bulks was proposed in order to improve the levitation height and force.

2. Magnetic levitation system using trapped HTS bulk annuli and the spherical solenoid magnet

In our levitation system, the three-stacked HTS bulks annuli with 20 mm ID, 60 mm OD and 15–20 mm thickness are prepared as shown in Fig. 1. The three-stacked HTS bulks annuli were fixed by installing bakelite in the upper and lower sides in experiment. The three-stacked HTS bulks annuli fixed were put into the room temperature bore of the superconducting magnet, and then it was magnetized by the superconducting magnet with FC method (LN_2). The trapped magnetic fields of stacked HTS bulks annuli were used for the levitation system after pulling out of the superconducting magnet, and stacked HTS bulks annuli were still placed in liquid nitrogen to keep the superconducting state during experiment. The levitation height of iron samples as the ferromagnetic substances was measured after dropping a sample to inner space of HTS bulk annuli as shown in Fig. 1c.

* Corresponding author. Address: Department of Electrical and Electronic Engineering, Okayama University, 3-1-1, Tsushima-Naka, Kita-ku, Okayama 700-8530, Japan. Tel.: +81 862518116; fax: +81 862518259.
E-mail address: kim@ec.okayama-u.ac.jp (S.B. Kim).

0921-4534/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physc.2013.05.020

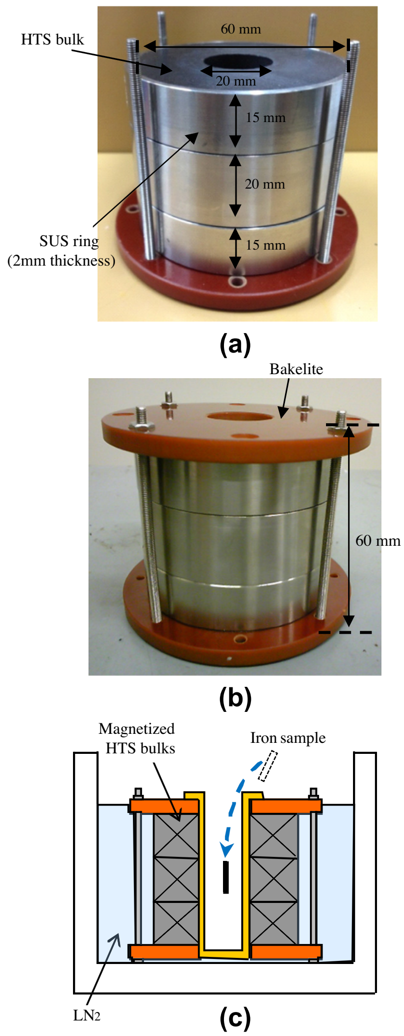

Fig. 1. (a) Photographs of the three-stacked HTS bulks annuli, (b) stacked HTS bulks annuli fixed by two bakelites and (c) schematic drawing of levitation system for the ferromagnetic substance using stacked HTS bulk annuli.

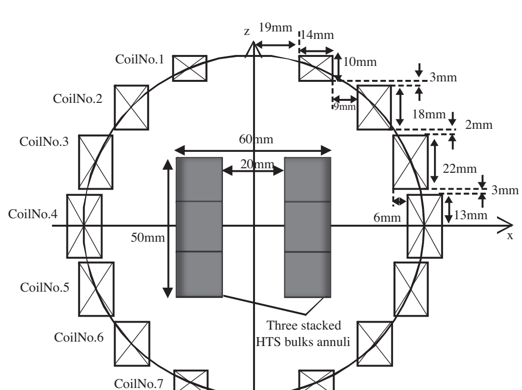

Fig. 2. To-scaled schematic drawing of fabricated spherical solenoid magnet composed of seven solenoid coils, and the 3-stacked HTS bulk annuli.

In the proposed magnetic levitation system, the magnetic field gradients in axial and radial directions were very important. So, we designed and fabricated the spherical solenoid magnet as a new magnetic source instead of superconducting magnet, and it composed of seven solenoid coils with different inner and outer diameters as shown in Fig. 2. The fabricated spherical solenoid magnet can easily make the homogeneous and various magnetic

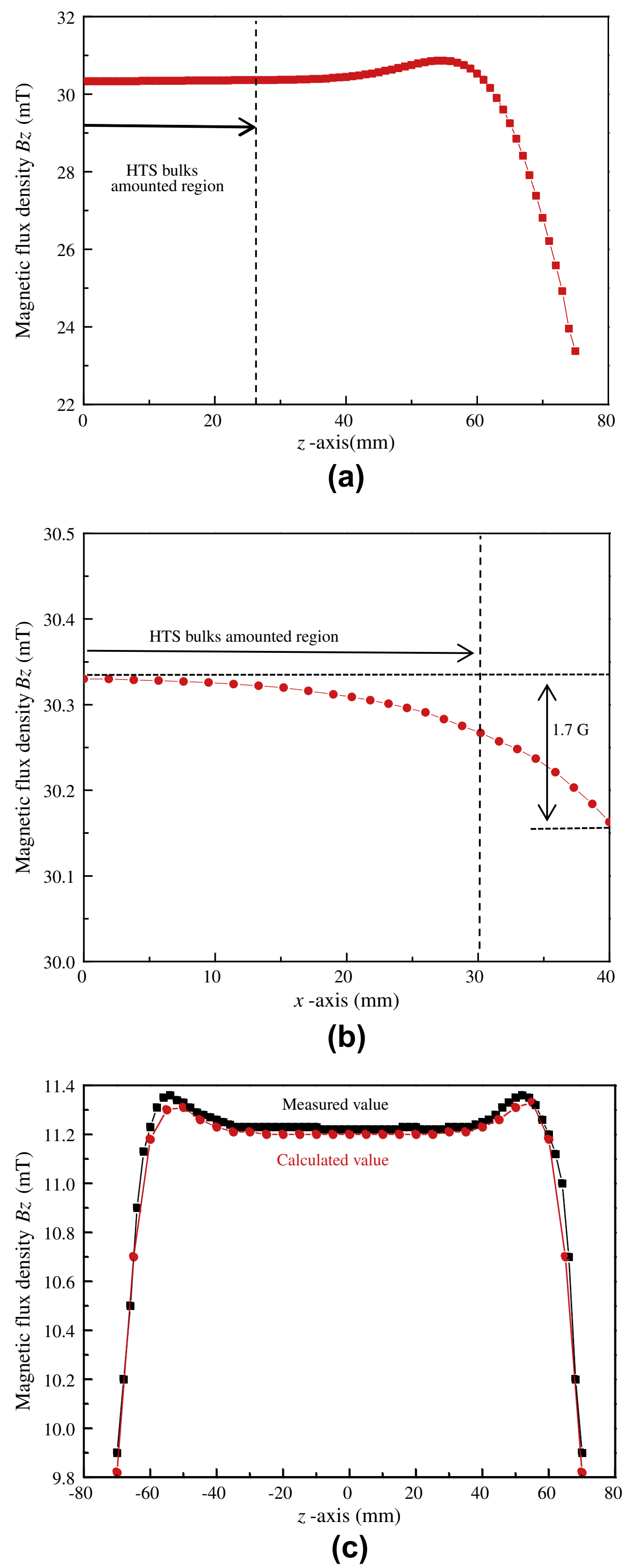

Fig. 3. Calculated B_z profiles (a) along the axial direction, (b) along the radial direction, and (c) measured and calculated values.