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Pulsed field magnetization characteristics of a holed superconducting bulk magnet

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ABSTRACT

We have proposed a holed superconducting bulk magnet to trap the magnetic field efficiently in the high-performance material excited by pulsed field magnetization. Previously, a single pulsed field was applied with varying amplitudes of the magnetic fields and temperatures to a GdBCO bulk material with four 2-mm-diameter holes, and the time responses of flux density on the bulk surface and trapped field distributions were measured. The experimental results suggested that the number of holes was too high because a large distortion appeared in the trapped field distributions. In this paper, we processed only a single hole with a different hole size and investigated the magnetization characteristics. After estimating the trapped field performance by applying a single pulsed field with varying its amplitude and temperature in the original material, a 1-mm-diameter hole was drilled; then the hole was extended to 2 mm in diameter, and the same experiments were carried out in each sample. A total magnetic flux of both 1-mm-diameter hole and 2-mm-diameter hole samples was about 10 percent higher than that of a four-hole sample at a low temperature. On the other hand, the value of a 2-mm-diameter hole sample was the same as that of a four-hole sample at a high temperature. The experimental results suggested that about 1 mm in diameter was proper for the hole size.

1. Introduction

A superconducting bulk magnet generates a strong magnetic field in a compact system with a low running cost, and various industrial applications, such as a superconducting generator for a wind turbine, a superconducting motor for an electric ship-propulsion system, a magnetic drug-delivery system, and a magnetic separation system [1–5], have been investigated. Although a large-size and high-performance REBCO bulk superconductor can trap a high magnetic field by field cooling (FC), it is difficult to activate it with pulsed field magnetization (PFM) due to the strong magnetic shield. Then, several methods of improving the PFM process [6–8] and adding mechanical processing to a bulk [9–12] were proposed to enhance a trapped field. We proposed intentionally weakening the magnetic shield in part of the sample by drilling small holes and supplying the magnetic flux in the bulk without generating heat; consequently, the trapped field was improved [13]. To investigate the validity of our proposed method, four 2-mm-diameter holes were drilled in a growth sector region (GSR) of a GdBCO bulk 60 mm in diameter and 20 mm thick, and a single pulsed field was applied with varying amplitudes and temperatures. The experimental results indicated easy flux penetration in a low applied field and flux flow suppression in a high applied field, while there was a distortion at a holed portion in a trapped field distribution. Moreover, the maximum trapped field and a total magnetic flux were decreased compared with an original bulk due to too many holes.

To investigate the influence of hole size on pulsed field magnetization characteristics, we compare a 1-mm-diameter hole sample and a 2-mm-diameter hole sample in this paper. After the trapped field characteristic was measured in an original GdBCO sample, a 1-mm-diameter hole was drilled at a GSR of the same material and the magnetization performance was investigated. Then the hole was extended to 2 mm in diameter, and trapped field distributions, total magnetic flux, and time responses of the flux density were compared between the samples.

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2. Experimental

A 60-mm-diameter and 20-mm-thick GdBCO bulk superconductor was attached to the second stage of the two-stage-type GM refrigerator with a cooling capacity of 5 W at 20 K. The bulk was cooled to 20, 30, 40, and 50 K, regulating with a thermo-controller, and a single pulsed field was applied with varying amplitudes of $\mu_0 H$ = 3.1–7.0 T for each temperature, where the rising time of the pulse was 10 ms. Four Hall sensors (BHT-921, BELL) were adhered at the positions illustrated in an inset of Fig. 1 on the bulk surface, and the time variation of magnetic flux density was monitored with a sampling rate of 100 µs. After magnetization, a three-dimensional Hall sensor (HGT-3030, Lake Shore Cryotronics, Inc.) was scanned with a 2-mm pitch on the magnetic pole surface, where a gap between the sample and the pole surface was 4 mm.

After investigating the magnetization characteristic in the original material, a 1-mm-diameter hole was drilled at the rim of the sample in a GSR as shown in an inset of Fig. 1, and it was filled with solder. Using the processed sample, the above experiment was performed. Then the hole was extended to 2 mm in diameter and the same experiment was carried out. After this, an original material, a 1-mm-diameter hole sample, and a 2-mm-diameter hole sample are called "case 0," "case 1," and "case 2," respectively. A sample with four 2-mm-diameter holes used in our previous study [13] is called "case 3."

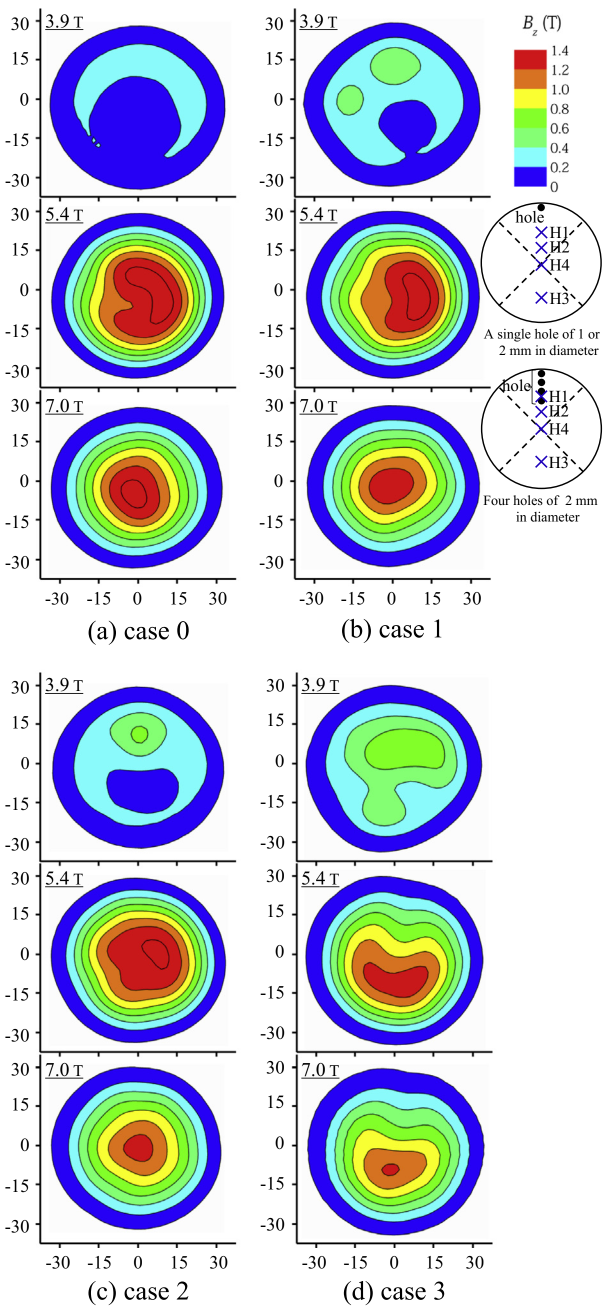

Fig. 1. Trapped field distributions for the applied fields of 3.9, 5.4 and 7.0 T at 20 K.

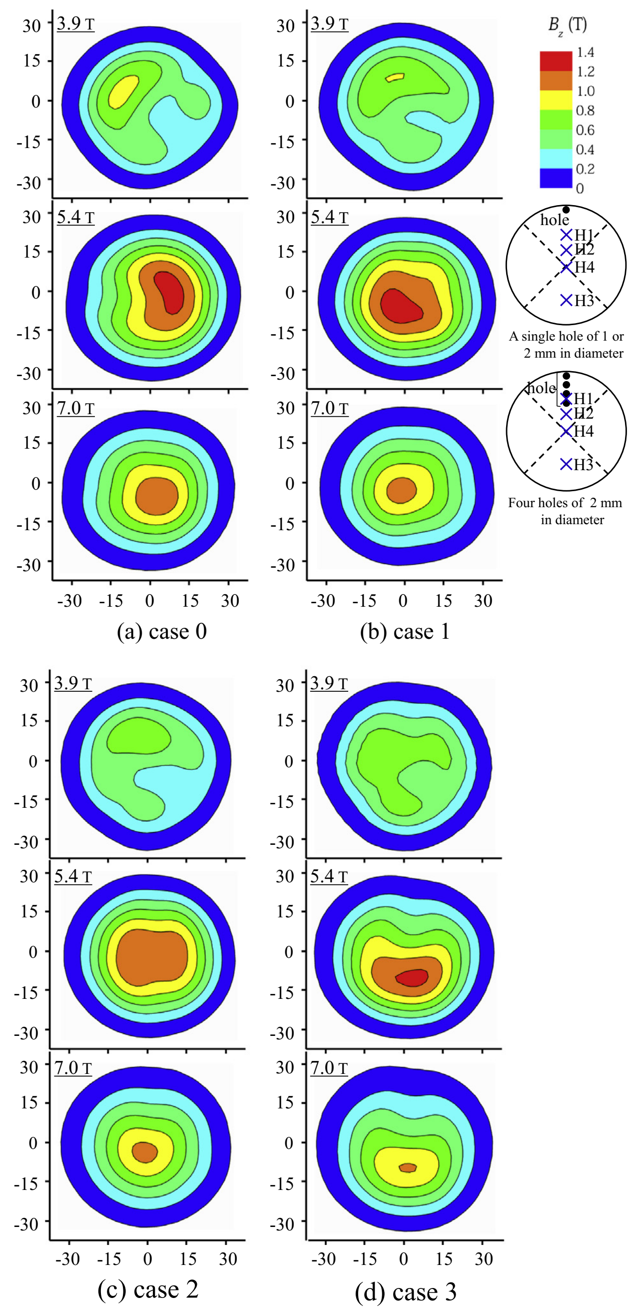

Fig. 2. Trapped field distributions for the applied fields of 3.9, 5.4 and 7.0 T at 40 K.