FEASIBILITY STUDY OF A PERMANENT MAGNET MADE FROM HIGH-T_C BULK SUPERCONDUCTOR

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Abstract

A field trapping experiment using magnetic fields up to about 1.5 T was performed using high-T_c bulk superconductors. The distribution of the trapped field and its decay process was monitored by an array of Hall sensors for different shapes of the bulk superconductors. The observations are reported on in this paper.

INTRODUCTION

Applications of bulk high-T_c superconductors have been investigated in various fields. High-T_c superconductors are attractive since they can trap higher magnetic fields than conventional permanent magnets. The trapping experiment was done with fields up to 1.5 T, which can be easily produced by conventional magnets. However, achieving the desired field distribution and understanding the characteristics of the trapped field and its decay process would open up the possibility of high-T_c bulk superconductor applications in the design of magnets for particle accelerators.

EXPERIMENT

Material

A cylindrical sample of melt textured Gd-based high-T_c superconductor made by the QMG[1] process was used for this study. Samples of different thickness, 3 mm, 5 mm and 10 mm, were used to examine the field trap dependence on the material thickness and the ramp-down speed of the external field. The diameter is 30 mm for all samples.

Probes

An array of thirty-six Hall probes placed on a G10 board was used to map the field and also to observe the decay process of the trapped field as is shown in Fig.1. The squares indicate the positions of thirty-six probes, which were used to monitor the trapped filed decay in the early experiment. Twelve probes, which are indicated by solid squares, were used for the experiment comparing the decay of the trapped field for three different samples.

Procedure

A static external field up to 1.5 T was applied using a conventional dipole magnet. The sample temperature was lowered to 77 K by submerging it in liquid nitrogen in a Styrofoam container as in previous experiments [2,3]. The external field created by the dipole magnet was measured using NMR at different excitations and the Hall probes were calibrated at 77 K using the NMR data. A thermometer was placed on the top surface of the sample in order to monitor the temperature during the experiments. The following series of procedures was carried out:

- Place the HTS magnet inside the gap of the dipole magnet.
- Apply an external field by ramping up the dipole magnet.
- Fill the Styrofoam container with liquid nitrogen.
- Wait until the temperature reaches 77 K.
- Turn off the external field by ramping down the dipole magnet.

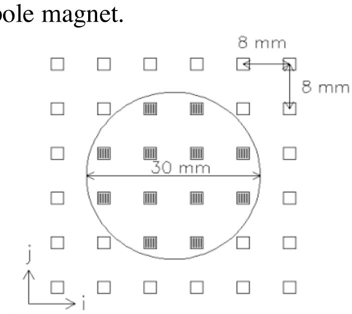

Figure 1: Top view of Hall array.

Trapping of 1.5 T by 10 mm thick sample

Trapping by the 10 mm sample was monitored with thirty-six probes. Fig.2 shows the external field and trapped field measured by one of the probes located near the center of the sample as a function of time. The external field started decreasing at t=0. By the time the external field reaches zero the sample loses almost 40% of the initial field even in the central part. The trapped field decays exponentially after the external field reaches zero, as mentioned later in this report. Fig. 3 shows the field distribution for t=20 s, 50 s and 800 s, respectively. As is reported the trapping effect weakens near the edge of the sample.

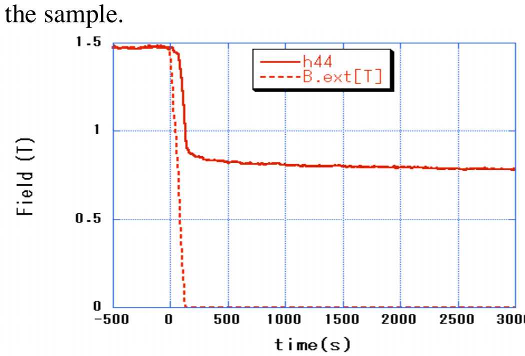

Figure 2: Trapped field by the Hall probe located at the position $(i,j)=(4,4)$ where i and j run from 1 to 6, respectively, as indicated in Fig.1.

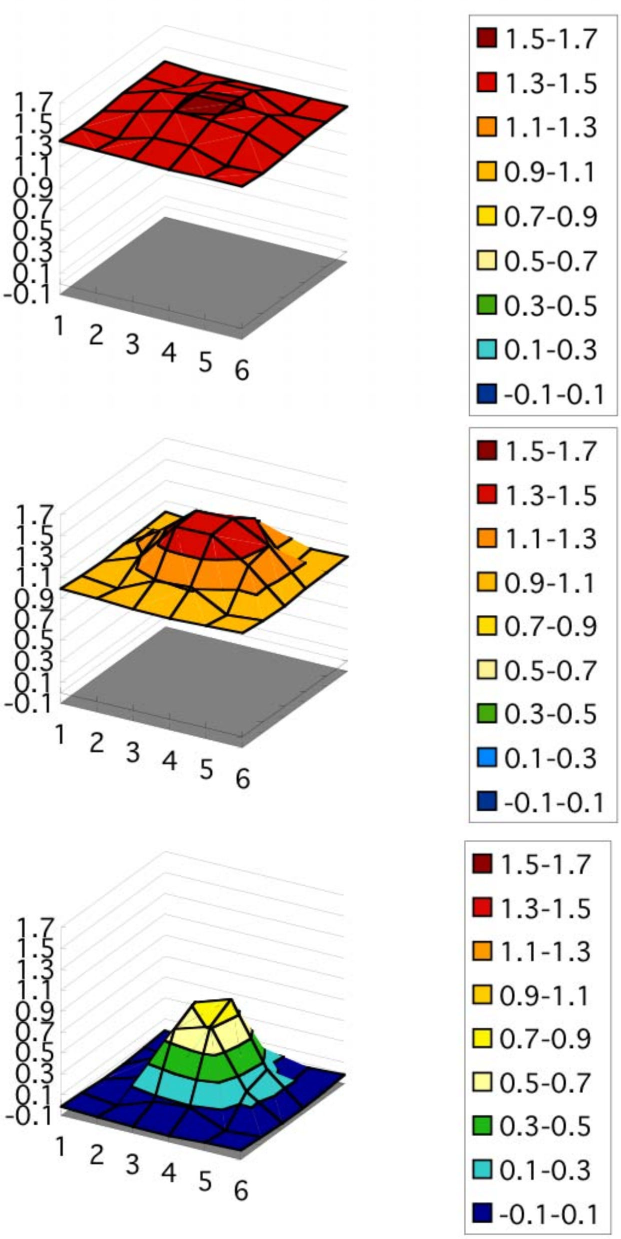

Figure 3: Field distribution at t=20 s, 50 s and 800 s when the initial external field is 1.5 T, from top to bottom.

Dependence on the initial external field

The twelve Hall probes in the central region shown by solid squires in Fig.1 were used to study the trapping effect dependence on the initial external field for different sample thickness. Fig. 4 shows the trapped field monitored by the probe *(i,j)*=(4,4) for ~1 hour after the external field was reduced at a rate of ~0.012T/s down to 0 T for three samples of different thicknesses. Thicker samples maintain more field for the cases where the initial external field B_{init} is higher than 1 T. When B_{init} is ~0.4 T the samples did not show any difference in the trapped field. When B_{init} was increased to ~0.77 T, the 3-mm thick sample did not hold as much field as the other two samples. One of the factors that determine the maximum trapped field is the thickness of the sample. Similar results with different material are presented in other report [4].

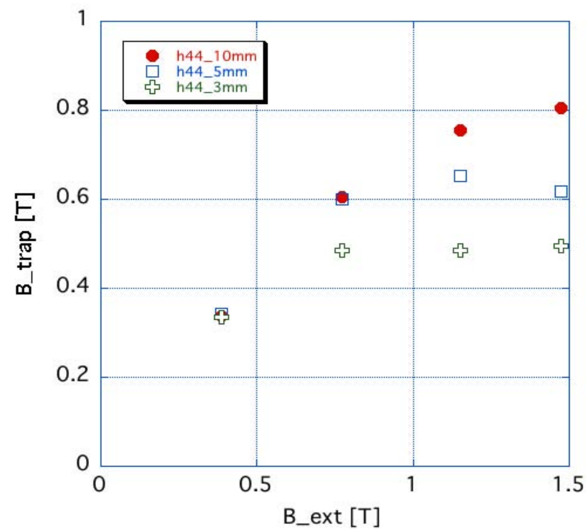

Figure 4: The trapped field monitored by the probe near the center of the sample is plotted against the initial external field.

Ramp-down speed dependence

Next, the external field was decreased with a different ramp-down speed. The ramp-down speed was normalized to the first experiment, ~0.012T/s, and plotted with the trapped field in Fig. 5 for the case where B_{init} was ~1.15 T. There seems to be no clear dependence on the ramp-down speed for all the samples of different thickness.

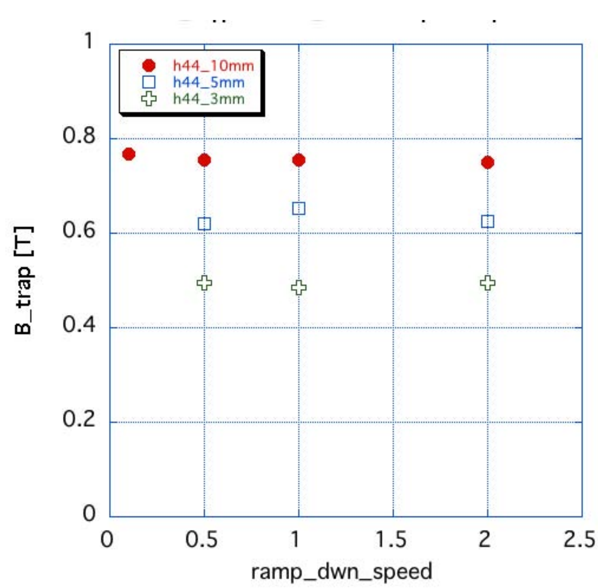

Figure 5: Trapped field as a function of the normalized ramp-down speed for different samples.

Decay constant

The trapped field decays exponentially though the decay 'constant' is not really constant as seen in Figs. 6 and 7. The logarithm of the trapped field is plotted as a function of time. If the decay follows a simple exponential curve with a decay constant, these plots should show linear behavior. However, the constant seems to become smaller as time proceeds. The decay curve is fitted to the following equation for three periods and the decay constant values are summarized in Table 1:

$$B_{trap} = a \times \exp(-t/\tau). \tag{1}$$

The negative value in Table 1 indicates an increase in the trapped field. This is probably an artificial effect which arises from the large (compared to the actual trend of the curve) fluctuation in the data. The current supply used for the Hall probes might have caused the fluctuation.

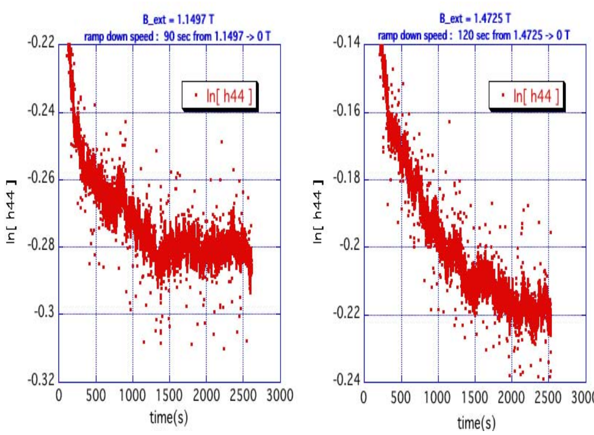

Figure 6: Log(B_{trap}) vs. time when B_{init} = 1.15 T (left) and 1.5 T (right) monitored by the Hall probe located at the position *(i,j)*=(4,4) near the center of the sample.

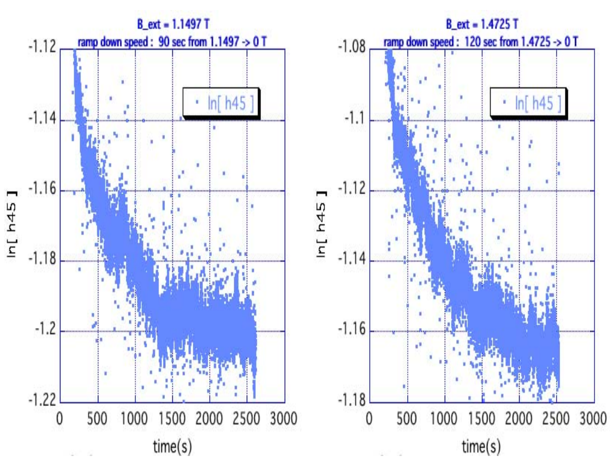

Figure 7: Log(B_{trap}) vs. time when B_{init} = 1.15 T (left) and 1.5 T (right) monitored by the Hall probe located at the position *(i,j)*=(4,5) closer to the edges of the sample.

Table 1: Decay constant (in hours) for different periods.

B_{init} (T)	Probe (i,j)	Periods (s)		
		600-1200	1200-1800	1800-2400
1.15	(4,4)	13.5	-70.1	-54.8
1.15	(4,5)	8.2	93.0	270.6
1.50	(4,4)	6.2	17.3	31.0
1.50	(4,5)	5.7	15.6	26.5

SUMMARY

The characteristics of a melt textured Gd-based high-T_c superconductor made by the QMG process were studied.

Cylindrical samples of 30 mm diameter and of different thicknesses, 3 mm, 5 mm and 10 mm, were used to examine the field trapping dependence on the material thickness. When the external field is about 0.4 T, the 3 mm sample held the same field as the 10 mm sample. The difference in thickness becomes clearer when the external field exceeds 1 T.

Ramp-down speed of the external field was varied in order to see the effect on the trapped field. There seems to be no clear dependence on how rapidly the external field disappears.

The trapped field decays exponentially but the decay constant changes as a function of time. The decay slows down significantly after about 1 hour when the external field is 1~1.5 T. The fact that the trapped field has weak dependence on the ramp-down speed of the external field makes application to accelerator components more feasible.

Slowing down of the decay process should also help in designing accelerator components using high-T_c bulk superconductors.

Trapping higher fields in larger samples and creating a field of desired distribution is needed for realizing high-T_c bulk superconductors for accelerator applications.

REFERENCES

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