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Study on the magnetic field homogeneity of stacked HTS bulk magnets including the deteriorated HTS bulk by crack for compact NMR relaxometry

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Abstract

We have been studying the compact magnet for NMR device that consists of a stacked high temperature superconducting (HTS) GdBCO bulk annuli trapped by a field cooling (FC) method. It was difficult to trap the uniform magnetic field above 4.7 T (200 MHz-class NMR magnet) and field homogeneity under 0.01 ppm/cm^3 at liquid nitrogen temperature (77.4 K) because of the low *Jc-B* characteristics of present HTS bulks. On the other hand, the strength and homogeneity of the magnetic field required for NMR relaxometry device are 1.5 T and 150 ppm/cm^3 respectively. Therefore, we have been investigating the development of the compact magnet for NMR relaxometry device. In our previous study, we obtained the trapped magnetic field over 1.5 T at 77.4 K using the stacked HTS bulk magnet with 80 mm height, and 150 ppm/cm^3 field homogeneity was obtained using the fabricated field compensation methods on inner diameter of 20 mm HTS bulk magnet. However, it is expected that the asymmetric problem of the magnetic field uniformity will be occurred by the crack in the HTS bulks with long-term operation. Therefore, in this study, the field homogeneity of HTS bulk magnet by the arrangement of the HTS bulk with crack was investigated using 3-D FEM analysis. We examined the effects of the stacking position of HTS bulk with the crack and the allowable range of degradation of HTS bulk to achieve the target field homogeneity of 150 ppm/ cm^3.

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1. Introduction

A new type NMR magnet consisted of the stacked HTS bulk annuli where magnetic fields were trapped by field cooling method using cryocooler had been suggested and fabricated by Nakamura at RIKEN in Japan [1], [2]. Furthermore, the NMR relaxometry device was produced by Stelar s.r.l., and its field homogeneity is 150 ppm/cm^3 [3]. In this study, the proposed HTS bulk magnets for compact NMR relaxometry were magnetically charged by superconducting magnet (SCM) at liquid nitrogen, so these HTS bulk magnets does not need a power supply and additional coolant supply system. Therefore, this is not only economical but also compact. The strength and homogeneity of the magnetic field required for the NMR relaxometry device were 1.5 T and 150 ppm/cm^3 respectively, these values were much lower than a conventional NMR device. In our previous study, we obtained the trapped magnetic field over 1.5 T at 77.4 K using the stacked HTS bulk magnet with 80 mm height, and 150 ppm/cm^3 field homogeneity was obtained using the fabricated field compensation methods on inner diameter of 20 mm HTS bulk magnet [4-7]. However, it is expected that the asymmetric problem of the magnetic field uniformity will be occurred by the crack in the HTS bulks with long-term operation. In this study, the field homogeneity of HTS bulk magnet by the arrangement of the HTS bulk with crack was investigated using 3-D FEM analysis. Furthermore, the calculated field homogeneities due to cracked HTS bulk were compared with HTS bulk magnet including the degraded HTS bulks using various *Jc-B* characteristics.

2. Analytical results of stacked HTS bulk magnet with iron rings

In this study, GdBCO oxide superconducting bulks were used, and the scaled schematic draws of SCM, passive field compensation by iron rings and packaged HTS bulk were shown in Fig. 1. The SCM have a 100 mm room temperature bore size and 10 T was used in experiment and analysis. The magnetic field homogeneity at the center region of SCM is 610 ppm/cm^3. The iron rings were symmetrically placed to the upper, bottom and central positions in the axial direction in order to compensate the magnetic field of SCM and HTS bulk magnet. In this study, the currents in the HTS bulk during the field cooling process were induced by the Bean's critical state model and n-value model, and the trapped magnetic fields of HTS bulks were calculated by their currents. Fig. 2 shows the calculated magnetic field distributions and the field homogeneity along the *z*-axis of the analytical model shown in Fig. 1. The compensated magnetic field strength was decreased from 1.6 T to 1.57 T because the applied magnetic field of SCM was concentrated in the iron rings. However, the spatial field homogeneity at center region along ±5 mm in the *z*-axis direction was improved from 610 ppm/cm to 19 ppm/cm. We obtained the trapped magnetic field above 1.5 T and 55 ppm field homogeneity using packaged HTS bulk magnet with iron rings when the height and ID of HTS bulk magnet are 80 mm and 20 mm at 77.4 K.
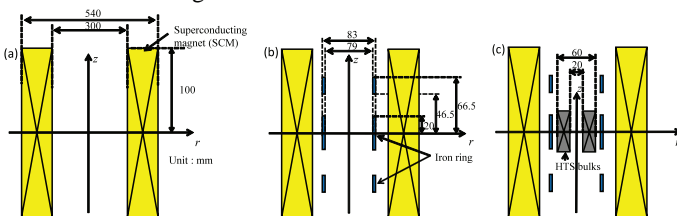

Fig. 1. Scaled schematic draws of (a) SCM, (b) SCM and iron rings and (c) SCM and packaged HTS magnet with iron rings
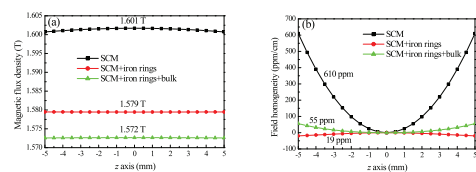
Fig. 2. The calculated (a) magnetic field distributions and (b) the field homogeneity along the *z*-axis of the analytical model shown in Fig. 1 (@ apply field of 1.6 T and 77.4 K).

3. Analytical results of stacked HTS bulk magnet including the cracked HTS bulk

In this study, the field homogeneity of HTS bulk magnet included cracked HTS bulk was investigated using 3-D FEM analysis. Fig. 3 shows the scaled schematic draw of 16-stacked HTS bulk magnet model and packaged HTS bulk magnet with iron rings. A HTS bulk with crack was placed in the 16-stacked HTS bulk magnet. The field property in the HTS bulk magnet was studied analytically as a function of stacking position of cracked HTS bulk. The cracked HTS bulk was simulated by including a 0.1 mm slit in HTS bulk. Simulated cracked HTS bulk was shown in Fig. 4. The cracked HTS bulk was placed to the stacking positions of Bulk 1, 3, 5, and 7.