PERFORMANCE OF HTS-MAGNETIC SHIELD FOR HIGHLY-SENSITIVE CURRENT MONITOR WITH HTS-SQUID

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Abstract

The HTS magnetic shield has been developed for the dc beam current monitor in the RIKEN RI beam factory. The one is made of high temperature superconducting materials, Bi-2223, coated on the cylindrical MgO substrate. Performance as the magnetic shield has been measured at 106k environment.

1 INTRODUCTION

Development of high temperature super conducting (HTS) magnetic shield for the purpose of observing somatosensory evoked magnetic field coming from human brain is now current topics in the worldwide. It is seemed that the HTS magnetic shield is effective in the dc beam current monitor using the HTS-SQUID. The HTS material composed of $Bi(Pb)_2$-Sr_2-Ca_2-Cu_2-Ox (Bi-2223) coated on a cylindrical MgO substrate has been studied to develop the HTS-magnetic shield aiming at 106K environments. After the physical and chemical testing the HTS-magnetic shield with the sizes of 148 mm in diameter and 250 mm in length, has been fabricated.[1] An attenuation factor of the HTS-magnetic shield has been measured by using a precise X-Y-Z stage and a LN2 dewer to make the 106K environment. A Helmholtz coil as an external magnetic field source is equipped outside the LN2 dewer. A magnetic field inside the HTS-magnetic shield was measured by using the 2D HTS-SQUID supported by the movable rod. Schematics of the HTS magnetic shield (outer cylinder) and the HTS-sensor (inner cylinder) are illustrated in Fig.1. The brief description and measurement results of the performance of the HTS-magnetic shield are presented in this report.

2 HTS-MAGNETIC SHIELD

The super conductive magnetic shield is based on the Meissner effect of the super conductive layer in the MgO substrate. The homogeneity of the surface of the HTS-magnetic shield is important to make the homogeneous magnetic shield. Because the Bi-2223 is dip-coated material the surface condition is dependent on the manufacture process in the factory. A small piece of Bi-2223 HTS plate made by dip coating method on the 99.9% MgO substrate has been tested to make the complete HTS-magnetic shield. The X-ray spectrometer has been used to examine the surface composition of the HTS material coated on the MgO substrate. The developed HTS-magnetic shield has cylindrical structure with the sizes of 148 mm in diameter and 250 mm in length. The HTS material is composed of dip-coat layer of Bi-2223 with 300 μmm in thickness outside the MgO cylinder. The dc current monitor comprises the inner current detector, called HTS-sensor, and the HTS-magnetic shield. The diameter (D) and length (L) of the HTS-sensor are 98 mm and 250 mm, respectively.

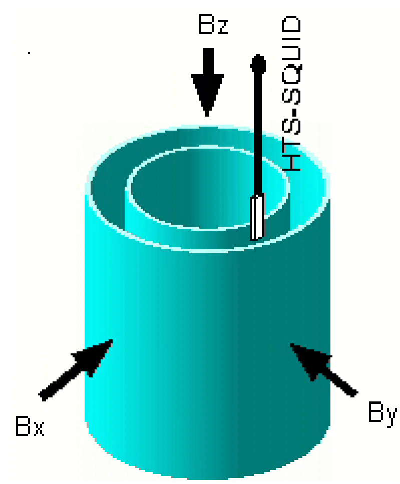

Fig.1: Schematic of the HTS magnetic shield (outer cylinder) and HTS-sensor (inner cylinder). The HTS-SQUID measures attenuated magnetic field. The Bx, By, Bz represent the external magnetic fields, respectively.

When the charged particles (ions or electron) is being passed in the inner side of an HTS-sensor, a shielding current caused by the image current flows in the opposite direction on the surface of the HTS-sensor. The HTS-sensor is patterned on the surface of cylindrical MgO substrate by using the dip-coating method. Since the outer surface is patterned to have a bridge circuit, the current arisen from the charged particles concentrate on the bridge circuit and generates an azimuthally magnetic field ϕ around the bridge circuit.[2] A HTS-SQUID is set near the bridge circuit. The HTS-SQUID detects the azimuthally magnetic field. The magnetic shield plays the role of magnetic field attenuation around the HTS-sensor and the HTS-SQUID to identify the external magnetic field as the expected external noise and the internal magnetic field due to the incident beam current.

A magnetic shield combined with a Permalloy shield using the cylindrical TMC-V material is also examined. It is expected that the combination of the HTS shield and the Permalloy shield is effective to attenuate the external magnetic field very well.

3 MEASUREMENT SYSTEM

A measurement system has been constructed aiming at not only the evaluation of the attenuation factor of the magnetic shield but also a current-sensitivity of the HTS-sensor. The measurement system is composed of a X-Y-Z stage driven by the stepping motors, the HTS-SQUID in x-z or y-z directions, Helmholtz coil as an external field source, and a current source for making the external field. The field map in the area of Helmholtz coil has been measured by using the 3D hole probe.[3] The figure of X-Y-Z stage in case of the vertical external field is shown in Fig.2. The HTS-sensor and HTS -magnetic shield are installed in the LN2 dewer as shown in Fig.2. A supporting base made of G10 holds both the HTS equipments in the LN2 environment.

Fig.2: Measurement system of the HTS-magnetic shield and HTS-sensor. The whole system is constructed on the floor base and the position of the HTS-SQUID is controlled by the X-Y-Z stage driven by the pulse motor.

Table 1: Specifications of X-Y-Z stage

Drive axis	4-axis
Minimum displacement	2μm/pulse
Driving stroke	X-axis=200 mm (+/-100 mm) Y-axis=100 mm (+/- 50 mm) Z-axis=150 mm (+/- 75 mm)
Control	Remote control (X and Z), Computer control is available

Table 2: Specifications of Helmholtz coil

Coil	48turns/coil	0.185Ω/coil
Magnetic field	23G	@15A
Coil temperature	23 degree	@15A

The HTS-SQUID is button type with the sizes of 17 mm in OD and 4 mm in height. Both the sensors are supported by the G10-rod as shown in Fig.3 and inserted into either the inner side of the HTS-sensor and HTS-magnetic shield as shown in Fig.1 or the inner side of the HTS-sensor. The positioning of the sensor is determined by the X-Y-Z stage because the supporting rod is fixed to that stage. The detectable flux direction is determined by the positioning of the HTS-SQUID. In order to determine the sensor direction the G10-rod is semi-fixed on the rotatable substrate. The supporting base and whole mechanical parts except a mechanical drive parts are made of SUS316L. The specifications of X-Z stage are tabulated in Table 1. The y-axis is set manually to move the HTS-SQUID. The specification of HTS-SQUID is tabulated in Table 3.

A flux locked loop method is employed in the HTS-SQUID circuit in order that the wide dynamic range and high resolution of the flux sensitivity are required. The flux locked loop make a linear operation to the HTS-SQUID circuit so that it can cancel the external magnetic flux density, B, with the aid of flowing the bias current in the feedback coil. The voltage appeared on the resistance, if it is appeared in the figure, is to be measured aiming at obtaining the calibrated external magnetic field.

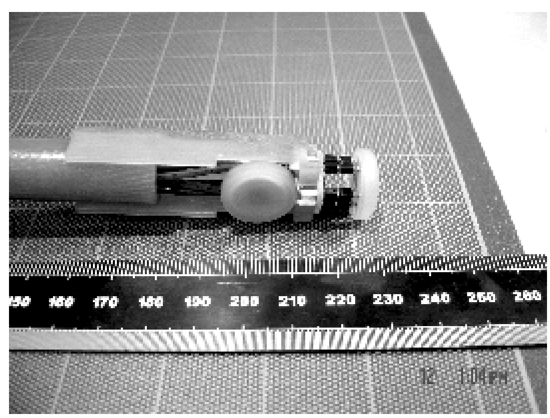

Fig.3: Button type HTS-SQUID's are attached to the G10-rod with the x and z directions. Both sensors are installed in the top of the G10-rod by using the pin-socket mechanism.

Table 3: Specifications of HTS-SQUID Sensor

Resolution	1pT / Hz $^{1/2}$
Sensitivity	0.48 μT / V
Sizes	17 mm^2 x 4 mm
Flux sensitive area	0.08 mm^2
Modulation frequency	40 kHz
Dynamic range	50 dB

4 MEASUREMENT RESULT

In order to measure the field distribution inside the HTS-magnetic shield, we made the *X-Z* stage that can be moved by 4 stepping motors in *X-Z* plane. The *X-Z* stage is remotely controlled by a personal computer (PC). The Helmholtz coil, which can produce flatten 0.001 Tesla magnetic fields, is equipped on the *X-Z* stage. The specification of the Helmholtz coil is represented in the Table 2.

The attenuation factor $S(z)$ is expressed by

$$S(Z) = B(Z) / B_0 , \quad (1)$$

where the $B(z)$, B_0 the magnetic field measured at the inside the HTS shield, the external magnetic field, respectively. Then the numerical attenuation factor in the center of cylindrical HTS-magnetic shield is

$$S(Z) = B(Z) / B_0 = \exp(-KL/2D), \quad (2)$$

where the D and L are the diameter and the length of the cylinder, respectively. The factor K is called as shield factor depend on the direction of the external magnetic field, B_0 (7.6 for *vertical* and 3.6 for *transverse*).

Fig.4-(a) and (b) show the measurement results in *vertical* at B_0=Bz and in *transverse* at B_0=By, respectively. The triangle mark represents the result of attenuation factor measured at the center of the HTS-magnetic shield. The attenuation factor is linearly decreased in proportion to the distance, Z, from the center of HTS-magnetic shield. The plus mark represents the result of attenuation factor measured at the inner side of the HTS-magnetic shield and the HTS-sensor as shown in Fig.1. As shown in the Fig.4-(a), the attenuation factor is nearly constant between the center of the HTS-sensor and the position where is 20 mm apart from the center, Z=0. The diamond mark represents the attenuation factor measured at the center of the HTS-magnetic shield. This is the case that the Permalloy shields with double layers are set outside the HTS magnetic shield. On the other hand, the attenuation factor in the case of transverse field attenuation, B=By, is shown in the Fig.4-(b). The measurement results suggest that magnetic shield in the transverse direction is to be reinforced compared with the vertical one.

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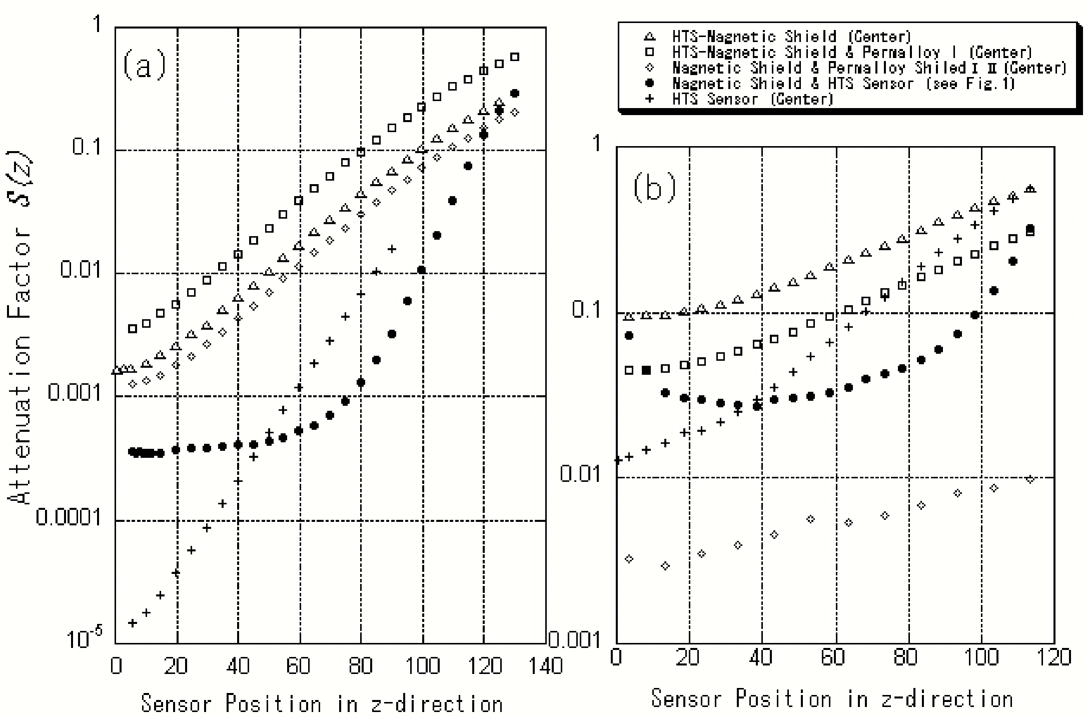

Fig.4 Measurement results of attenuation factor of the magnetic shield with the external magnetic field in the vertical direction (left-a) and the transverse direction (right-b), respectively.

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