Bi2212 HTS Tubular Bulk with Conical Shape for Current Lead

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Abstract. Current leads using HTS material have been developed for application in a large scale superconducting magnet system. Tokai University and NIFS have developed Bi2212 tubular bulk which was prepared by a diffusion process. 8 kA of maximum transport current was achieved by a tubular bulk with a cylindrical shape. The maximum current was estimated to be 2 kA at 50 K for this tubular bulk. A current lead can be designed with this bulk the warm end of the HTS part being at 50 K and the cold end at 4.2 K. Under this condition, the cross section of the cold end of the bulk can be reduced. This type of HTS bulk has a great potential for flexible design since the Bi2212 layer can be reacted on the surface of any shapes of substrate. If a conical shaped HTS bulk was made, it could be an advantage for heat leakage to the cold end. To confirm this effect, we have made two types of conical bulk. The transport current of the specimen exceeds 7 kA at 4.2 K and 4 kA of stable current flow was achieved with a warm end temperature of 50 K.

1. Introduction

The performance of high-Tc superconductors (HTS) has been improving and many practical applications have been introduced using HTS. Typical composition of HTS materials are Bi-Sr-Ca-Cu-O system, Y-Ba-Cu-O system etc. Each system has its own characteristic, i.e. the Bi2-Sr2-Ca-Cu2 oxide (Bi2212) system has a high transport current density at lower temperature, the critical temperature of Bi2-Sr2-Ca-Cu2 oxide (Bi2223) is much higher than liquid nitrogen temperature, and the Y-Ba-Cu-O (YBCO) system is useful under high magnetic field conditions. The common advantage of using a HTS system is a low heat load to the lower temperature region since it has a low thermal conductivity compare with a metallic low-Tc superconductor or copper. From these reasons, they are expected as a current lead between a low-Tc superconductor and a current carrying material as copper at room temperature. The heat load could be reduced to about 1/4 of a conventional helium gas cooled copper current lead by using HTS and the total geometrical scale of the current lead could be smaller.

Yamada et al. has developed Bi2212 bulk material by using diffusion reaction [2, 3]. 35 kA/cm² of maximum transport current density was achieved at the diffusion layer of tubular bulk. To obtain high transport current, increasing of the cross-sectional area can be efficient since the diffusion layer is
A tubular bulk seemed to be appropriate to maximize the surface area. Furthermore, the substrate of the Bi2212 HTS could be made in any shape because it is made by using a cold isothermal pressing method. This is a special advantage of this bulk technique. Another benefit of the Bi2212 is no need to add Pb material at all. In this paper, an optimal design using Bi2212 was considered and the results of transport current performance test are shown.

2. Tubular bulk with cylindrical shape
At the first phase of the development of large scale Bi2212 bulk samples, we had investigated characteristics of tubular bulk pieces with cylindrical shape. The bulk used for a transport current performance test was 200 mm in length and 37 mm/29 mm in outer/inner diameter, respectively. AlO₂ fiber was wound around the outside surface of the bulk to strengthen it mechanically. The filament winding method was adopted and the winding angle was decided as ±40 degree according to the relationship between the angle and the thermal contraction of each direction [4].

The bulk was immersed into liquid helium up to the warm end section at first. 8 kA of maximum transport current was achieved without voltage generation exceeding 500 μV. Hereafter define quench current as the current when the voltage generation exceeds 500 μV. Then lower the flow level of the liquid helium at the same level of the cold end, the warm end section was heated by using resistive heaters. The quench current decreased when the temperature rise of the warm end increased. 3kA of quench current was observed at a warm end temperature of 40 K [5]. From the result of this test, the maximum current at 50 K was expected to be 2 kA with the chosen size of the HTS tube. On the other hand, the cross sectional area of the cold end can be reduced since it has enough area to transport 8 kA. 14 mm/6 mm in outer/inner diameters were thought to be needed at least [6].

3. Bulk with conical shape
Based on the result of the cylindrical bulk, we made a new type of tubular bulk which had a conical shape. There were two types of conical bulk; the first one had 37 mm/29 mm in diameter at the warm end and that of 27 mm/19 mm at the cold end (hereafter 37mm-27mm cone). This sample was made to confirm the validity of conical shape and its workability. The second one had 47 mm/39 mm in diameter at the warm end, and the same sized cold end with the first one (47mm-27mm cone). The second one was expected to improve the transport current especially at the warm end. Each sample was connected to end caps made of copper as shown in figure 1. A gap between the HTS bulk and the groove of end cap was filled up with a solder. Voltage taps were attached on the surface of the end caps and several points on the surface of the HTS. The transport current tests were carried out in the same manner as with the cylindrical ones.

**Figure 1.** Schematic of HTS sample setting.

**Figure 2.** Quench current of the Bi2212 tubular bulk with conical shape (37mm-27mm cone) under condition of longitudinal temperature distribution.
Figure 2 shows the quench current of the HTS bulk as a function of the temperature of the warm end shown in figure 1. When the whole HTS section was immersed into the liquid helium, 7 kA of maximum transport current of 7 kA was achieved. As the temperature of the warm end section increased, the quench current decreased gradually. The quench current at 50 K was a little bit smaller than 2 kA which was much less than we had expected. To recover this drop of the quench current at higher temperature, the cross section of warm end of the bulk should be extended. 47mm-27mm cone was fabricated and the test was carried out again.

During the transport current test, the voltage generation was much higher than usual. There might occurred a problem concerning a connection between HTS and the copper end caps. Therefore, we could not discuss the quench current, therefore we show the transport current with voltage generation here. Figure 3 shows the current profile and the temperature change at the warm end, HTS part, and cold end. No temperature rise due to the current flow was observed for any region of the specimen. Figure 4 shows V-I curve at a ramp up process in the figure 3 for the overall region which includes HTS and end caps as shown in figure 1. The voltage generation in the contact regions between HTS and end cap are also shown. There was no propagation of voltage. Furthermore, the voltage generation in the HTS region was less than 25 μV. These data show that the current transport behavior is quite stable in the HTS region even when the current exceeded to 4 kA.

4. Design optimization
To confirm the effect of the conical HTS and for a practical use of the Bi2212 bulk, we considered a conceptual design of a current lead. From the result of the transport current tests, a nominal current would be 2 kA and a warm end of the HTS should be cooled lower than 60 K. The calculation model of the current lead consists of 3 parts as shown in figure 5; conventional heat exchanger part (normal resistive current feeder), HTS part, and low Tc superconductor part (Nb/Ti, for example). The heat exchanger part was assumed consisting of 114 bundle copper wires being 1.5 mm in diameter. The HTS part was divided virtually into 10 cylindrical sections for its longitudinal direction to perform the calculation one dimensional. The warm end of the HTS part was assumed to be cooled by 60 K helium gas with 0.9 g/s of mass flow rate. The cold end was connected to NbTi/Cu low Tc superconductor which was in the liquid helium. Thermal conductivity of the HTS part was obtained from the measurement of the Bi2212 plate with 2 mm thickness which has the same composition and manufacturing procedure of the tubular one [7]. An effect of Ag deposition on the surface of the bulk was also taken into account. CURLEAD analysis code [8] was used for the calculation.
Figure 6 shows the results of the calculations. We fixed the outer/inner diameter at the warm end to 48 mm/39 mm. The outer/inner diameters at the cold end of the cylindrical and conical model were set to 47 mm/39 mm and 27 mm/19 mm, respectively. Then the length of the HTS part was changed to obtain an effect for the heat leakage to the cold end. As result, the heat leakage of the conical shaped HTS was almost 2/3 of that of the cylindrical one. The heat leakage would be less than 1 W if the length of the HTS part was longer than 150 mm.

![Figure 5.](image1)  
**Figure 5.** Calculation model for current lead using HTS tube with conical shape.  

![Figure 6.](image2)  
**Figure 6.** Heat leakage to the cold end of the current lead using conical/cylindrical shaped HTS as a function of length of the HTS part.

5. Conclusions

Bi2212 HTS prepared by a diffusion process has a great potential since its outward form can be made in any shape. Tubular bulk with conical shape is useful for a current lead application since the shape has an advantage for both transport current and heat load to a cryogenic system.

By using a Bi2212 tubular bulk with the size 47 mm/39 mm, 27 mm/19 mm, 150 mm in warm end outer/inner diameter, cold end outer/inner diameter and length, respectively, 4 kA of stable transport current without heat leakage over 1 W could be achieved.

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