Critical current measurement of HTS tape relating with cable structure for a DC power cable

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Abstract.

In the 200 m high temperature superconducting (HTS) cable test facility at Chubu University, a coaxial power cable is used and composed of two BSCCO (Bi-2223) superconducting layers. The tapes are wound closely to reduce effects on the critical current of BSCCO at self-field. Accordingly, each superconducting layer has a different number of BSCCO tapes. Previously, we have investigated dependence of the critical current ($I_c$) on the gap in order to optimize the HTS DC cable design. We have been studying the effect on the performance of HTS tapes for the superconducting DC power cables by critical current measurements. In the present experiments several HTS tapes are used and set as a similar structure in the cable with a two-layer structure. The critical current of HTS tapes are measured against the gap between the tapes in the same layer. The experiments show the improvement of the critical current by optimizing the tape arrangements due to magnetic field interaction between the tapes. We will present the experimental results and discuss the design of the HTS DC cable.

1. Introduction

DC superconducting power transmission system has been studied at Chubu University by using HTS tapes [1]. In the 200 m HTS cable system, called as CASER-2, a coaxial cable is used as shown in Fig. 1, which is made of BSCCO tapes by Sumitomo Electric Industries (SEI) [2]. There are 23 tapes with a two-layer structure for the inner HTS conductor and 16 tapes with a mono-layer structure for the outer one in consideration of the gap effect on the critical current of the tapes in the cable, which affects the rated current of the cable. In order to optimize the structure of a HTS power cable, we have been studying the effects of tape arrangements on the critical current to improve the superconductivity characteristics of HTS tape in the cable. Previous study shows strong dependence of the critical current of BSCCO tape on the gap. The critical current of the middle tape in three straight tapes in parallel increases by 10% for a two-layer structure [3].

We continue to measure the critical currents of BSCCO tape due to HTS tape arrangements to study the effect on the performance of BSCCO tapes for the superconducting DC power cables relating with cable structure [4]. As shown in Fig. 1b, the tapes are wound crossly and there are small gaps due to the shape of the former which may degrade the performance of the
Figure 1: (a) The coaxial HTS power cable for CASER-2 and (b) A diagram of the tapes winding arrangement in the CASER-2 power cable. The insert of (a) shows gaps between HTS tapes.

In this work more HTS tapes are set as a similar structure in the cable with a two-layer structure by considering the winding directions. This paper presents the $I_c$ measurements of BSCCO tape relating with the cable structure by varying the transport current independently.

2. Experiments

BSCCO tapes are used with a cross section of 4.5 mm wide and 0.35 mm thick by SEI [5],[6]. The $I_c$ of BSCCO tape is about 160 A at 77 K, self field. Figure 2a shows the tape arrangements with a two-layer structure for different winding directions. $d$ is the lateral space gap between the tape edges in the same layer. The gaps are set to be 0.4 mm and 2.0 mm. Five tapes are used with a length of 27 cm and are insulated from each other by an insulating tape. Figure 2b shows a current loop applied to the five tapes conductor. Different currents are applied to the tapes by two power-supplies. The critical current of the middle tape #3 in the lower layer is measured by changing the lateral space gaps for different transport current in the neighboring tapes.

The experimental setup for the critical current measurement is similar to previous experiment [3] in which the tapes are immersed into liquid nitrogen at 77 K. Three voltage taps are attached on BSCCO tapes with distance of 8 cm and 10 cm for parallel tape conductor and 2 cm and 3 cm for cross tape conductor. The transport current is measured by a current shunt resistor. The voltage signals are measured by a KEITHLEY 2700 digital multimeter. The $V - I$ characteristics of HTS tapes are obtained by the four-probe method.

3. Results and discussion

Figure 3 shows $E-I$ curves of middle tape #3 for single and five parallel tape conductors with different gaps by dividing the measured voltages to the distance between the voltage taps. The
transport currents in the neighboring tapes are 120 A. $E$-$I$ curves are quite different between small and large gaps and the critical current of tape #3 in the five tapes is larger than that of a single tape. The critical current is determined on the criterion of 1 $\mu$V/cm. Figure 4 presents the dependence of the critical current of middle BSCCO tape #3 in five parallel tapes conductor on the neighboring current $I_2$. When the neighboring current is larger than 80 A, the critical current becomes larger than that of a single tape. When the neighboring current is larger than 100 A, the critical current for large gap of 2.0 mm becomes larger than that for small gap of 0.4 mm. The measured critical currents of middle tape #3 increases 10% for 2.0 mm gap in the five parallel tapes arrangement and thus the critical current of BSCCO tape is improved when there are gaps between the tapes in the same layer.

We calculate the magnetic field distribution by the commercial finite element method code (ANSYS) \[4, 7, 8\]. Figure 5a-f present the magnetic flux lines around the five tape conductors with increasing gaps between the tapes. The transport current of 160 A is assumed to be uniformly distributed in the BSCCO filaments area. The cross section of the transport current area is assumed to be 4.5 mm $\times$ 0.25 mm for BSCCO tape by subtracting the reinforcing copper layer \[6\] and thus the current density is 142 A/mm$^2$. The magnetic flux density in the BSCCO filament area is reduced by increasing the gaps between the tapes. When the gap is 2.0 mm, about half of the tape width, neutral zone is formed in the intermediate tape in the second layer as in Fig. 5f. Therefore, the critical current in the five tape conductors is improved when there exists a gap of 2.0 mm as shown in Fig. 3 and 4.

As shown in Fig.1b, the tapes for HTS conductor are wound crossly between each layer. Five long tapes are wound around a supporter with a similar pitch as the CASER-2 power cable. Figure 6 presents the dependence on the gaps of the increase of $I_c$ and the n-value of BSCCO tape in the five tapes conductor for different neighboring currents by comparison of the parallel and cross arrangements. The $I_c$ of BSCCO tape is measured to be 161 A. The $I_c$ and the n-value of BSCCO tape become larger than those of the single one. The increased $I_c$8 of BSCCO tape by about 10% is measured for the parallel arrangement. However, the cross arrangement leads to the decrease of the $I_c$ and the n-value of BSCCO tape. Therefore, the performance of HTS power cable can be improved by the parallel arrangement.

4. Conclusion
We investigated the critical current of BSCCO tape relating with the cable structures of gaps and winding methods for the five tapes conductor with a two-layer structure. The critical current
Figure 5: Magnetic flux lines around five tape conductors with increasing gaps between 0.4 mm (a) and 2.4 mm (f) by a step of 0.4 mm.

Figure 6: The dependence of increase of $I_c$ and $n$-value of BSCCO tape on the gaps between the tapes for parallel and cross tapes conductor. Left: $I_2 = 160$ A; Right: $I_2 = 140$ A.

of BSCCO tape is improved when gaps exist for the five parallel tape conductor. The critical current and the $n$-value of BSCCO tape for the parallel arrangement become larger than those for the cross arrangement. Therefore fewer BSCCO tapes can be wound in parallel with gaps for a DC power cable with a two-layer structure.

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