Critical current measurements of a tape in the hybrid multi-stacking high $T_c$ superconducting tapes

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Abstract.

A new 200 m high $T_c$ superconducting DC cable test facility was successfully constructed in 2010. This cable is composed of two superconducting layers of the DI-BSCCO® tapes spirally and closely surrounding a copper former. The number of the tapes in each layer is different due to their different radii. We have investigated the effect of the way of the tape winding on the critical current ($I_c$) of the tapes in order to optimize the cable configuration for the DC transmission.

This paper presents the measurements of $I_c$ of DI-BSCCO® in a hybrid multi-stacking configuration composed of YBCO and BSCCO tapes by controlling the transport current in each tape independently. The $I_c$ measurements were performed with the standard four-probe method at the liquid nitrogen temperature. The magnetic field distribution around the tapes was calculated by the finite element method to demonstrate the effects of the self field from the adjacent tapes. The enhancement and degradation of $I_c$ in the hybrid multi-stacking tapes were observed in contrast to that of single tape. Through the experiments, we started to investigate optimized tape configuration of the DC power cable to enhance the superconducting characteristics.

1. Introduction

Since the enhancement of the performance of the high $T_c$ superconducting (HTS) tapes with high engineering critical current density $\sim 10$ kA/cm$^2$ the HTS power cables for power transmissions are extensively studied around the world [1, 2]. The performance of the DC transmission through HTS cable has been studied and tested at Chubu University since 2006 [3] and a new 200 m HTS DC cable test facility, named as CASER-2 [4], was successfully constructed in the spring of 2010. The HTS cable is installed into a vacuum insulated cryogenic pipe and operated at about 77K. This HTS cable, which was made by Sumitomo Electric Industries Ltd (SEI), is composed of two superconducting (SC) layers of the DI-BSCCO® tapes spirally and closely surrounding a copper former. There are 23 tapes for the inner SC layer and 16 tapes for the outer SC layer due to their different radii, respectively.

In order to optimize the structure of HTS cables, we started to study the effects of tape arrangements on the critical current $I_c$ to enhance the SC characteristics of the HTS tape in the cable. Lim et al. studied the magnetization loss of hybrid multi-stacked wire using YBCO and
BSCCO wire [5]. This paper presents the measurements of \( I_c \) of DI-BSCCO® in the multi-stacked tapes composed of YBCO and BSCCO tapes by controlling the transport current in each tape independently.

2. Experiments

The YBCO (Y-123) tapes were prepared by the method of Trifluoroacetates-Metal Organic Deposition (TFA-MOD) [6] by SWCC and the DI-BSCCO® (Bi-2223) tapes (Type HT-CA) were prepared by the powder in tube (PIT) with the controlled over pressure sintering technique by SEI [7, 8]. Table 1 shows the specifications of the YBCO tape and the BSCCO tape. The cross sections of the YBCO tape and the BSCCO tape are 4.9 mm × 0.13 mm and 4.5 mm × 0.36 mm, respectively. The thickness of the BSCCO tape includes the thickness of the reinforcing copper layer, which is 0.05 mm on both sides of the silver-sheathed multi-filamentary Bi-2223 matrix area to improve the mechanical strength of the tape [8]. The \( I_c \)s of YBCO tape and BSCCO tape are 141 A and 160 A in the self field at 77 K, respectively.

|            | YBCO tape | BSCCO tape |
|------------|-----------|------------|
| Thickness  | 129.7 µm  | 0.36 mm    |
| Width      | 4.9 mm    | 4.5 mm     |
| Hastelloy  | 100 µm    | \( I_c \) (77 K) 160 A |
| IBAD/GZO   | 1.2 µm    | Type HT-CA |
| CeO₂       | 1 µm      |            |
| YBCO       | 1.5 µm    |            |
| Ag         | 26 µm     |            |
| \( I_c \) (77 K) | 141 A     |            |

3. Results and discussion

By normalizing to the distance between the voltage taps, we obtain the \( E - I \) characteristic curves of the BSCCO tape. Figs. 2a - 2c show the comparisons of the \( E - I \) characteristic curves of the BSCCO tape for single and triply stacked HTS tapes with the different currents of \(-100\) A, 0 A, and 100 A applied for the adjacent YBCO tapes, respectively. The significant difference

![Figure 1](image-url)
of $I_c$ of the BSCCO tape between the triply stacked tapes and single one is shown when the currents in the adjacent YBCO tapes are changed. Even if no current in the adjacent YBCO tapes, the $I_c$ of the BSCCO tape becomes larger than that of the single one due to the magnetic shielding on the self-field of the middle BSCCO tape by the YBCO tapes.

Figure 2: The $E - I$ characteristic curves of the BSCCO tape for single and hybrid triply stacked configurations with the different currents (a) $-100$ A, (b) 0 A, (c) 100 A applied to the adjacent YBCO tapes.

$I_c$ is determined according to the criterion of 1 $\mu$V/cm. Fig. 3 presents the dependence of $I_c$ of the BSCCO tape on the currents in the adjacent YBCO tapes for triply hybrid multi-stacked tapes. The $I_c$ of the BSCCO tape is measured to be 165 A, which is a little larger than that in the specification from SEI. When no current is applied to the adjacent YBCO tapes, the $I_c$ of the BSCCO tape becomes 15% larger than that of the single one. In the case of antiparallel current feeding to the YBCO tapes against the BSCCO tape, the sharp increase of $I_c$s of the BSCCO tape is seen and is about 30% in contrast with that of the single one. However, the parallel current feeding leads to the decrease of the $I_c$ of the BSCCO tape when the current in the adjacent YBCO tapes becomes larger than 50 A.

We calculate the magnetic field distribution by the commercial finite element method code (ANSYS) [10, 11, 12]. To illustrate the effect of the self-field by the adjacent YBCO tapes, we
present the magnetic field distribution for triply stacked tapes in Figs. 4a and 4b and single one in Figs. 4c and 4d. The transport current is assumed to be uniformly distributed in the BSCCO matrix area and the YBCO coated film. Hence the cross section of the transport current area is assumed to be 4.5 mm × 0.25 mm for the BSCCO tape without the reinforcing copper layer [8] and 1.5 μm × 4.9 mm for the YBCO tapes. The current is set 160 A for the BSCCO tape and −100 A for the YBCO tapes. The magnetic flux density in the BSCCO filament area is reduced comparing with that of the single one as shown in Figs. 4a and 4c. Since the $I_c$ of the BSCCO tape is affected by the magnetic field especially for the perpendicular component to the tape wide surface [7], Figs. 4b and 4d present the perpendicular component of the magnetic flux density distribution. As seen in the figures, the perpendicular component of the magnetic flux density is reduced, which would result in the enhanced $I_c$ in Figs 2 and 3.

4. Conclusion
We investigated the dependence of $I_c$ of the BSCCO tapes on the current in the adjacent YBCO tapes in the triply hybrid multi-stacked tapes experimentally. Enhancement of $I_c$ of the BSCCO tape in the triply stacked tapes composed by the BSCCO and the YBCO tapes is observed experimentally. In conjunction with the magnetic field distribution calculated by the finite element method, the effects of the self field from the adjacent tapes lead to the reduction of the magnetic flux density in the antiparallel current feeding to the triply stacked tapes. Therefore, the enhancement and degradation of $I_c$s of the BSCCO tape are observed in contrast with that of the single one.

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