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Development of a 66 kV-5 kA Class HTS Power Cable With IBAD/PLD REBCO Tapes

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Abstract

High temperature superconducting (HTS) cables are able to achieve large power capacity and low-loss power transmission. In the Japanese national project, Fujikura Ltd. worked on developing a 66 kV-5 kArms HTS power cable using high critical current (I_c) $REBa_2Cu_3O_x$ (REBCO, RE = rare earth) tapes. One of the technical targets in this project is to reduce AC loss to less than 2 W/m at 5 kArms. The REBCO tapes with 240 A/4mm-width of I_c at 77 K, self field, which were fabricated by Ion-beam-assisted-deposition (IBAD) and Pulsed Laser Deposition (PLD) method, were applied to a HTS power cable in order to achieve extremely low AC loss. As a result, we have succeeded in developing a 20 m-long 66 kV-5 kArms HTS power cable. The measured AC loss was achieved 1.4 W/m at 77 K and 1.0 W/m at 67 K at 5 kArms.

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Keywords: High temperature superconductors; Yttrium barium copper oxide; Superconducting cables; AC loss

1. Introduction

$REBa_2Cu_3O_x$ (REBCO, RE = rare earth) tapes have advantages for high temperature superconducting (HTS) power cables because of their high critical current (I_c). REBCO tapes have been commercialized with over five hundred amperes per centimeter width at 77 K with good longitudinal homogeneity [1]-[3]. The AC loss in REBCO tapes of a HTS power cable subjected to a parallel magnetic field is extremely small because of the thin-film structure of the REBCO superconducting layer [4]. It is reported that AC loss of a HTS calbe using REBCO tapes was achieved 1.83 W/m at 5 kA at 63.8 K [5]. However, the operating temperature with higher temperature are expected to make HTS cables practical.

In the Japanese national project, Fujikura Ltd. developed a 66 kV-5 kArms REBCO power cable using high I_c and good homogeneity tapes. One of the technical targets in this project was to reduce AC loss to less than 2 W/m at 5 kArms. REBCO tapes with 240 A/4 mm-width of I_c at 77 K, s.f., which were fabricated by Ion-beam-assisted-deposition (IBAD) and Pulsed Laser Deposition (PLD) method, were applied to the HTS power cable in order to achieve extremely low AC loss. This paper describes the verified test results of the 66 kV-5 kArms REBCO power cable for AC loss reduction using high Ic and good homogeneity tapes.

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2. Design and fabrication of the REBCO power cable

Fujikura has developed REBCO coated conductors that were manufactured by the ion-beam-assisted deposition (IBAD) and pulsed laser deposition (PLD) methods. These conductors are 4 mm wide with a 0.1-mm-thick Hastelloy® substrate and a 0.02 mm thick copper stabilizer. Critical current at 77 K, s.f., which is defined with 10^{-6} V/cm is more than 240 A per 4 mm in width.

A 20 m long HTS cable was manufactured by Fujikura Ltd. as shown in Fig. 1. The specifications of the HTS cable are shown in Table 1. The cable core consists of a former made from stranded copper wires, an HTS conducting layer, an electric insulation layer, an HTS shielding layer, a copper shielding layer and a core protection. The cryostated pipe has an adiabatic multilayer applied between two stainless steel corrugated pipes.

Fig. 2 shows measurement results of total I_c of all REBCO tapes before and after fabrication the cable core. It was almost same as total I_c of all REBCO tapes. In addition, the designed load factor of the HTS conductor was approximately 50%, and the designed load factor of the HTS shield was approximately 55%.

Table 1. Specifications of the HTS cable

Items	Specifications
Former	Stranded copper wires (140mm^2) 20 mm ϕ
HTS conductor	4 layers, All 4mm-w tapes (I_c = 14 kA) I_c = 240 A/4 mm-w (77 K, s.f.)
Electric insulation	Craft papers (6 mm-t)
HTS shield	2 layers, All 4 mm-w tapes (I_c = 12.7 kA) I_c = 240 A/4 mm-w (77 K, s.f.)
Copper shield	Copper tapes (100 mm^2)
Core protection	Nonwoven tapes 45 mm ϕ
Cryostat	Double corrugated SUS pipes Vacuum thermal insulation
Jacket	Polyethylene 114 mm ϕ

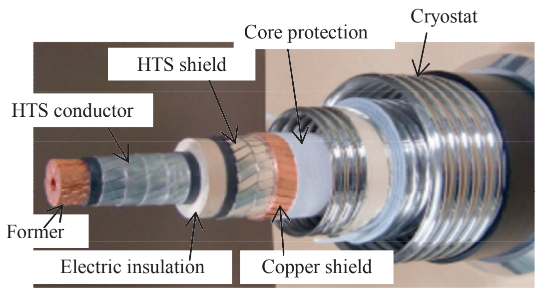

Fig. 1. Photograph of the REBCO power cable

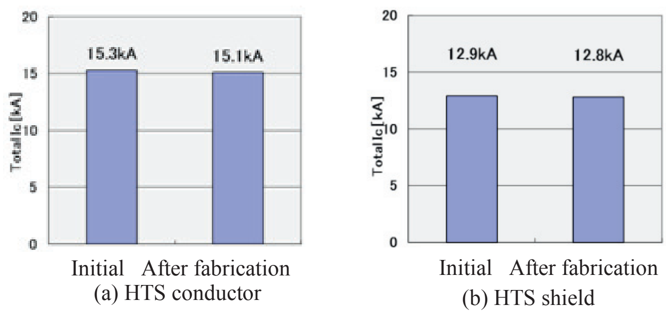

Fig. 2. Measurement results of total I_c of all REBCO tapes before and after fabrication cable core

3. Experimental results

The verification system was constructed at Sakura plant in Fujikura Ltd. in January 2013. The system includes the 20 m long HTS cable, a combined terminal vessel, and a cooling system. Schematic and photograph of the current loading test line is shown in Fig. 3. Both ends of the HTS cable were connected in one terminal vessel instead of two isolated vessels in order to shorten the connecting wire to suppress its impedance(resistance and inductance). Fig. 4 shows the cooling system of the verification system. The cooling system was employed the circulation system for cooling the HTS cable and heat exchange system for cooling the liquid nitrogen by the sub-cooled liquid nitrogen. It was possible to change the operating temperature from 67 K to 77 K by the cooling system. The cooling capacity of the cooling system was 2 kW.

Fig. 5. shows the current waveforms when the AC current of 5 kA was applied to the HTS cable. The induction rate of shield current to conductor current was approximately 98%. In addition, the long-term (20 cycles) test was successfully conducted, one cycle was set of 8-hour current loading and 16-hour unloading.

AC current was supplied to the HTS cable conductor of the current loading test line and the loss component of the tap voltage was measured using a lock-in amplifier. The frequency of the AC current was 60 Hz in this test. Fig. 6. shows the measurement portion of AC loss of HTS cable, Fig. 7. shows the measuremental results of total AC loss of the HTS cable conductor and the shield layer. The AC loss at 67 K was measured in the current loading test line, the AC loss at 77 K was measured by another short sample. The measured AC loss was achieved 1.4 W/m at 77 K and 1.0 W/m at 67 K at 5 kArms. These results indicate that the HTS cable with high I_c REBCO tapes can achieve extremely low AC loss.

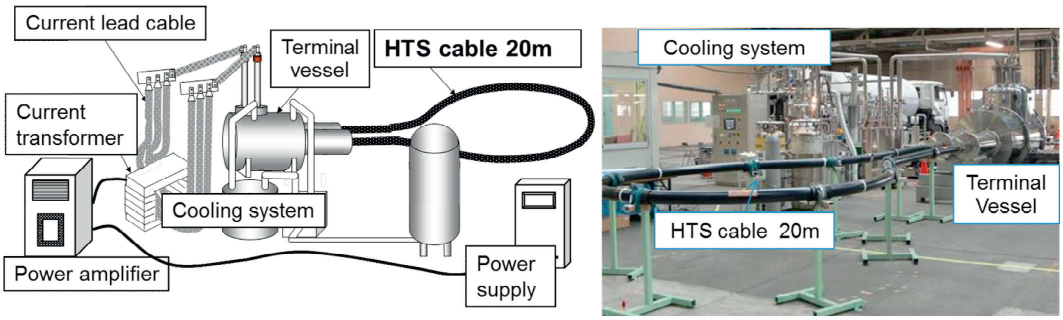

Fig. 3. Schematic and photograph of the current loading test line

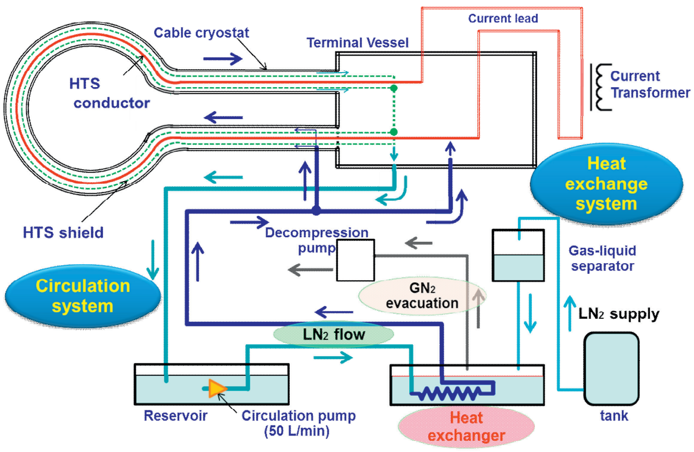

Fig. 4. Schematic of the cooling system

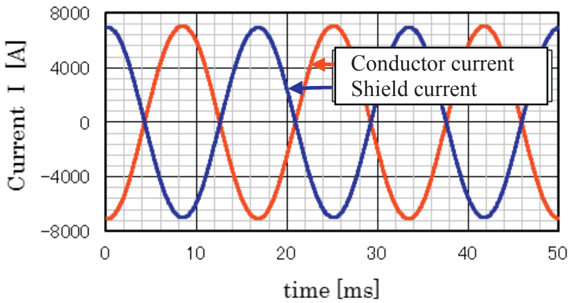

Fig. 5. Measurement results of conductor current and shield induced current at 5 kArms at 67 K

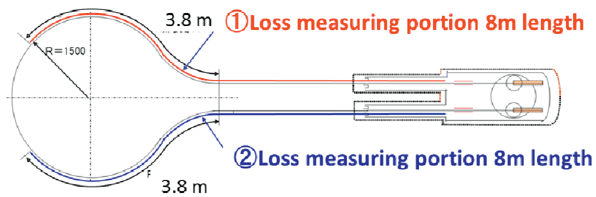

Fig. 6. Measurement portion of AC loss of HTS cable

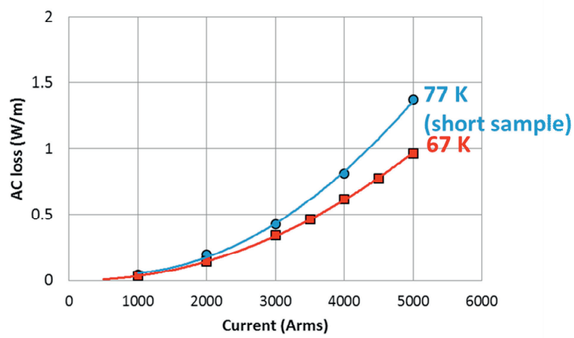

Fig. 7. Measurement results of total AC loss of HTS cable conductor and shield layer

4. Conclusion

In the Japanese national project, we succeeded in developing the 20 m-long 66 kV-5 kArms HTS power cable using REBCO tapes with 240 A/4mm-width of I_c at 77 K, self field. One of the technical targets in the project was to reduce AC loss to less than 2 W/m at 5 kArms. As a result, the measured AC loss could be achieved 1.4 W/m at 77 K and 1.0 W/m at 67 K at 5 kArms. These results indicate that the HTS cable with high I_c REBCO tapes can achieve extremely low AC loss. From a practical perspective, it is remarkable achievement to reduce AC loss at 77 K.

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References

[1] K. Kakimoto, M. Igarashi, S. Hanyu, H. Kutami, Y. Iijima, T. Saitoh, et al., Physica C 471 (2011) 929.
[2] M. Igarashi, K. Kakimoto, S. Hanyu, Y. Iijima, M. Itoh, T. Saitoh, et al., Physics Procedia 36 (2012) 1412.
[3] Y.Iijima, S.Fujita, M. Igarashi, M. Daibo, N.Nakamura, S.Hanyu, et al., "Development of Commercial RE123 Coated Conductors for Practical Applications by IBAD/PLD Approach", submitted for Physica Procedia.
[4] N. Amemiya, Z. Jiang, M. Nakahata, M. Yagi, S. Mukoyama, N. Kashima, et al., IEEE Transactions on Applied Superconductivity 17-2, (2007) 1712.
[5] M. Ohya, H. Hirota, T. Masuda, N. Amemiya, A. Ishiyama, T. Ohkuma, Physics Procedia 36 (2012) 849.