Development of REBCO Superconducting Transformers and Motors in Japan

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***Abstract*—In Japan we started a national project to develop superconducting power machines and devices with REBCO superconducting tapes two years ago. In this workshop we will report the progress of the development of transformers and motors. In this extended abstract we report on transformers.**

I. Introduction

The target transformer is a 66/6.9kV-20MVA one for a substation in a power grid. Superconducting transformers are expected to give us the merits of compactness, lightweight and high efficiency. To produce such merits, it is necessary to reduce a 1-turn voltage, which is the important parameter for the design of a transformer, in comparison to conventional transformers. It corresponds to increasing the turn number of windings and reducing the cross-sectional area of an iron core. By making the most use of low loss and high J_c properties of superconducting tapes, the superconducting windings will be compact even if the turn number increases. We proposed a new idea to reduce the ac loss in REBCO superconducting thin tapes and verified it even in coil configuration. In addition, in order to satisfy the dielectric strength regulated in Japanese standards on transformers, we got the data on the basically required insulation distance in the peculiar system which are mainly composed of REBCO thin tapes and subcooled liquid nitrogen. Further we verified the applicability of the method of enhancing the current capacity by forming transposed parallel conductors with REBCO thin tapes though the tapes are bent edgewise at transposition points.

As for motors, we successfully fabricated a7.5 kW motor with a superconducting rotor with REBCO tapes. The rotor was cooled down to 40K by forced-flowed helium gas. 6-pices of field coils were racetrack-shaped 19-layer solenoidal ones. The armature winding was wound with copper wires. We carried out the factory test in the same way as conventional motors. We confirmed 11kW power output applying the field current up to 70A beyond the design one of 60A. In this extended abstract we describe only on the transformers.

II. Ac Loss Reduction

It is possible to easily reduce the ac loss in a short sample by scribing a superconducting layer including a stabilizing layer into multifilamentary structure by using laser or chemical etching. However, in coil configuration, all of the filaments are connected at the terminals. So shielding current is induced and it generates much coupling current loss. It may result in no effect of scribing. Hence we introduced a new special winding process so as to suppress shielding current.

To verify the validity of the proposed method, we made test coils using YBCO tapes fabricated IBAD-PLD method. We scribed the 10mm wide tapes by laser into multifilamentary structure so that the filaments were arrayed in parallel from end to end of a tape. All filaments in a tape are insulated with each other on the identical substrate since the buffer layer of $Gd_2Zr_2O_7$ and CeO_2 with a thickness of about 1 mm in total is an insulator electrically. We made 3-, 5-, 10- and 20-filament tapes. The photograph of the scribed YBCO tapes into 10- and 20-filament structure is shown in Fig. 1. We also confirmed that the actual resistances between the filaments were larger than 10 k! /cm.

First we investigated the ac loss properties of the short scribed tapes by a pickup coil method. The straight sample tapes 60mm long were stacked into 3 layers and inserted into the center of a saddle-shaped pickup coil [1]. The observed ac losses in magnetic field perpendicular to the wide surface of the tapes at 77K are shown in Fig.2. The ac loss was reduced in proportion to the filament width. Next we fabricated a 16-layer solenoidal coil with a 3-filament YBCO tape. The number of turn per layer was 6. The photograph of the coil is shown in Fig. 3 The total length of a tape was about 24 m. We also fabricated one more coil with the identical dimensions and structure using a non-scribed tape for comparison. Applying ac transport current at 0.01 to 400 Hz, we measured the ac losses of the coils in liquid nitrogen at 77 K by electrical and thermal methods. The observed ac losses are shown in Fig. 4. We can see that the ac loss of the coil wound with a 3-filament tape is reduced to 1/3 as compared with a non-scribed one. Fig. 5 shows the frequency dependences of the observed ac loss in the coil wound with a 3-filament tape with a current amplitude as parameter. No frequency dependence was observed. It proves that the ac loss is only the sum

Fig. 1. Scribed tapes with 10 and 20 filaments.

Fig. 3. 16-layer solenoidal test coil.

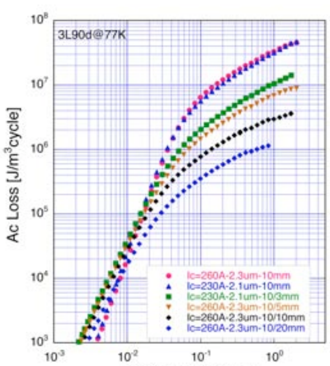


Fig. 2. Ac losses in scribed short sample tapes.

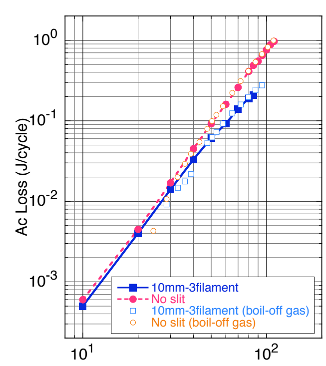


Fig. 4. Ac losses in the test coils wound with scribed and non-scribed tapes.

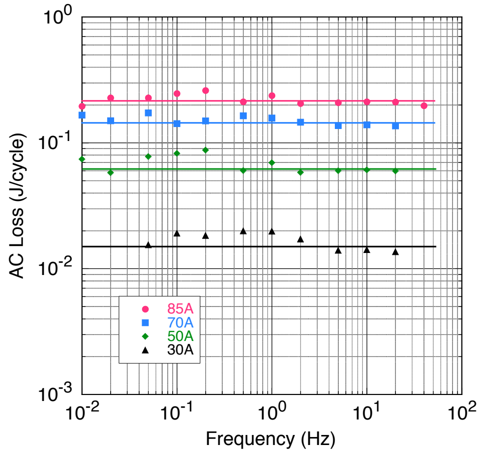


Fig. 5. Frequency dependences of the ac losses in the test coil wound with 3-filament tape..

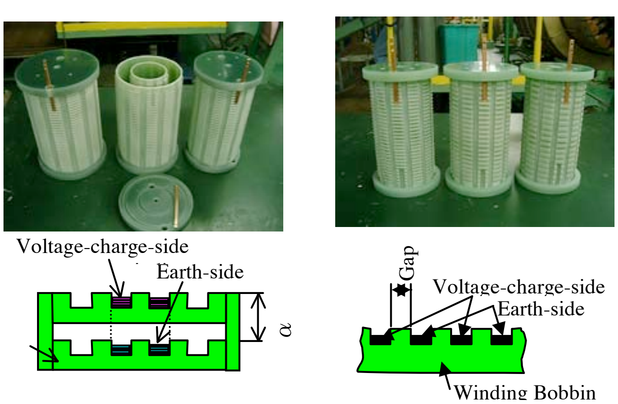
of hysteresis loss in each filament.

III. Insulation Distance Required for 66kV Superconducting Transformers

According to the domestic standards on transformers in Japan, LIWL and AC withstand voltage for 66/6.9kV power transformers are regulated as 350 kV and 140 kV respectively. We aim at getting hold of the required insulation distance in the peculiar system that is mainly composed of REBCO superconducting thin tapes and subcooled liquid. To make a dielectric breakdown test, we made model coils so as to simulate the actual situation (1)between primary and secondary windings, henceforth called as between , and (2)between turns. The photographs of the respective model coils and schematic illustrations are shown in Fig. 6.

The dielectric tests were carried out in subcooled liquid nitrogen at 66 K. Fig.7 shows the observed dependences of the breakdown voltage on insulation distance in the case of the model coils between . We can see from that the insulation distance between   is required to be more than 45 mm to satisfy the regulated AC withstand voltage of 140 kV. On the other hand, with respect to dielectric impulse voltage test, no breakdown was observed in case that insulation distance was more than 30 mm.

In the case of the model coils between turns, we also made the dielectric breakdown test and concluded that 1 mm is enough for intervals between turns from the viewpoint of dielectric strength.



(a) (b)

Fig. 6 Photos and schematic illustrations of the model coils, which simulate the situation (a) between   and (b) between turns, for the breakdown test.

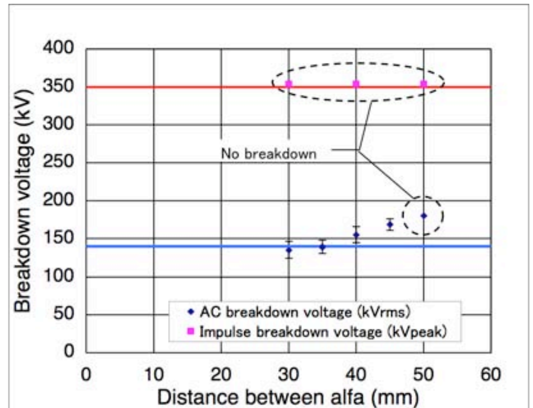


Fig. 7. Insulation distance dependences of the breakdown voltage in the model coils which simulated the situation between .

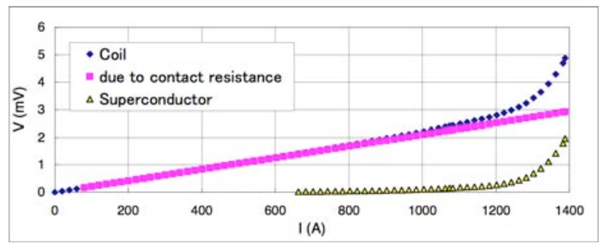


Fig. 8. *V-I* characteristics of the test coil with a 24-strand parallel conductor.

VI. Large Current Capacity

The secondary current amplitude of a 66/6.9 kV-20MVA transformer is 2.37 kA. We have to realize it without increment of ac loss density. We decided to adopt the configuration of parallel conductors by which we successfully enlarged current capacity without additional ac loss due to forming those with Bi2223 wires. As a first step of development, we fabricated a test coil forming two pieces of 12-strand parallel conductors, i.e. a 24-strand parallel conductor with REBCO tapes 5 mm in width during the winding process. The 12-strand parallel conductors were co-wound side by side into a one-layer solenoid. So the constituent strands, i.e. REBCO tapes were transposed 11 times in each parallel conductor so as to be inductively equivalent with each other. Fig. 8 shows the observed V-I characteristics of the test coil. The critical current, I_c, at 77 K was 1.4 kA. No degradation of I_c was observed as can be seen by referring to the I_c -B curve of a single tape. I_c at 64 K was more than 2kA.

In addition we investigated the 50Hz ac transport property at 66 K. No phase shift among each branch current was observed and the quite stable operation up to 1kArms was verified. The result suggests the applicability of the method of enhancing current capacity by forming a parallel conductor with REBCO tapes.

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References

[1] M. iwakuma et al, *SUST*, vol. 16, pp.545-556 , March 2003.