Resistance Increase Behavior of HTS Wire with Stabilizer Layer on Applied Over-currents

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YBCO-coated conductors, called "second-generation wires," show a remarkably greater increase in the amount or speed of their resistance than BSCCO wires when a quench occurs. This is probably because of the specific resistance at their stabilizer layer, which also affects their voltage grade. YBCO coated conductors with copper as a stabilizer layer have a voltage grade of 1.5-2 V/cm, and those with stainless steel as a stabilizer layer have a voltage grade of about 0.5-0.6 V/cm. The voltage grade of YBCO coated conductors is important in selecting and applying superconducting wires to power instruments later. In this study, two kinds of YBCO-coated conductors with different stabilizer layers and one kind of BSCCO wire were prepared. Among them, based on the YBCO coated conductors that had a stainless steel stabilizer layer with a low voltage grade, five kinds of experimental samples for joining were prepared with the remaining two kinds of wires. Using the prepared samples, the current application properties and the resistance increase in the flux-flow and the quench states of the single wire and the joined wires were compared.

Keywords: Quench, Flux-flow, Voltage grade, YBCO coated conductor, BSCCO wire

1. INTRODUCTION

High-temperature superconducting wires are applied to such high-power instruments as current lead wires, superconducting cables, and superconducting magnets because of their high critical properties. The current representative high-temperature superconducting wire is the (Bi,Pb)-St-Ca-Cu-O(BSCCO) wire, which is also called the "first-generation wire" and is manufactured using the PIT technique. Despite their high critical properties, however, BSCCO wires show limitations in their application because of their mechanical properties and weaknesses under a magnetic field[1,2]. Thus, second-generation high-temperature superconducting wires, called "Y-Ba-Cu-O (YBCO) coated conductors," were developed. It can be said that YBCO coated conductors, which overcame the weaknesses of BSCCO wires and have different critical properties based on the appropriate selection of materials for their stabilizer layer, have wider applications than BSCCO wires[3,4]. They also have different voltage grades based on the material used for their stabilizer layer[5]. YBCO coated conductors with stainless steel as a stabilizer layer have a low voltage grade of about 0.5-0.6 V/cm. This problem must be overcome to allow for the use of YBCO coated conductors in high-power instruments. In this study, an attempt was made to improve the voltage grade of YBCO coated conductors and to increase the stability of the application of the fault current to them so as to improve their applicability to high-power instruments. To do this, their resistance properties were examined based on their critical temperature, and were compared with those of BSCCO wires. After analyzing the over-current application properties of each wire, the state of increase in their resistance at the flux flow and their complete quench states were compared with those of single wires by combining prepared wires based on YBCO coated conductors with stainless steel as their stabilizer layer.

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2. EXPERIMENTAL SET UP

Figure 1 shows a specific resistance increase curve based on the temperature of the wires in the experiment. On the basis of the critical temperature, the resistance of the BSCCO wires was found to have been 0.03 [mΩ/cm] at 90 K, and of the YBCO coated conductors with copper as a stabilizer layer, 0.1814 [mΩ/cm] at 90 K. The YBCO coated conductors with stainless steel as their stabilizer layer had a resistance of 1.2276 [mΩ/cm] at 90 K. There were significant differences in the resistance values compared with the critical temperatures of the superconducting wires, which had different values based on the material used for their stabilizer layer and their area.

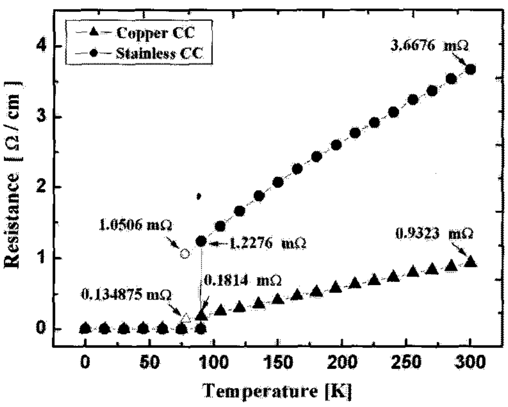

Fig. 1. Resistance variation of YBCO coated conductor with temperature.

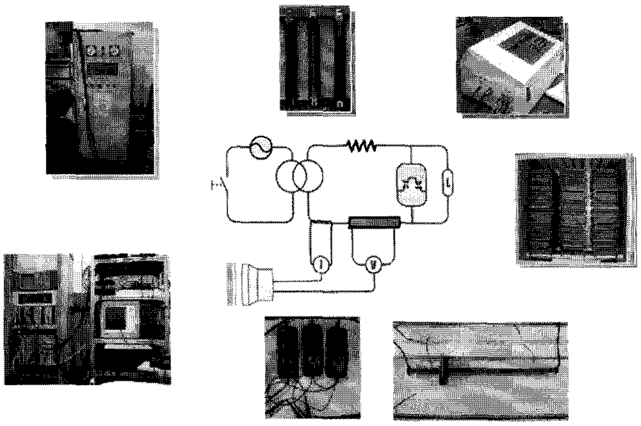

Fig. 2. Schematics diagram of the experimental circuit.

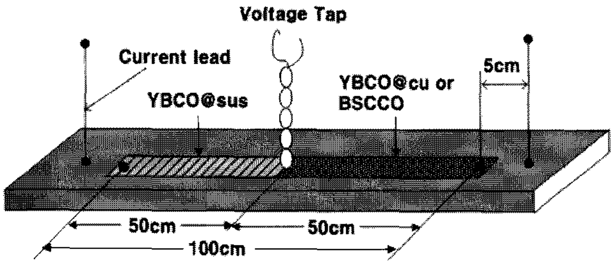

Fig. 3. Shape of former straight state of YBCO coated conductor.

Figure 2 shows the composition of the experiment device. The standard resistance (R_0) of 0.1 Ω was used to control the applied current and to protect the device against a fault current. To simulate a fault, SW_1 and SW_2 were activated through a phase controller that was in good order. For the YBCO coated conductors, the applied voltage was restricted between 20 V_{rms} and 45 V_{rms}, with a fault cycle at about 6.5, in consideration of the voltage grade for the single and combined wires. Figure 3 shows the combined experimental samples while the conditions of the wires were maintained. The amounts of the voltage and the current were measured in terms of the applied voltage using the four-terminal method, in which fast wires were stuck onto the former and current and voltage terminals were installed on the surface of the wires. The full length of the single and combined wires was fixed at 100 cm, and the length of the single wires for the combination was fixed at 50 cm.

3. RESULTS AND DISCUSSION

3.1 Tendency of the resistance of the single wires to increase

Figures 4, 5, and 6 show the changes in the resistance due to the occurrence of a voltage and a current in the application of an over-current to the 50 cm-long single wires. First, the BSCCO wires shown in Fig. 4 showed a tendency to slowly increase in their resistance over the general applied voltage. This probably resulted from the low specific resistance of silver, which was the material of their stabilizer layer, and their greater area compared to that of the YBCO coated conductors. This was because the Joule's heat that occurred based on the time and the applied voltage in proportion to the area of the wires was accumulated. The YBCO coated conductors with copper as a stabilizer layer, shown in Fig. 5, had a higher resistance value than the BSCCO wires and showed a tendency to rapidly increase in resistance. This may be attributed to copper's higher specific resistance than silver and to the smaller area of the YBCO coated conductors with a copper stabilizer layer than that of the BSCCO wires. The YBCO coated conductors with a stainless steel stabilizer layer, shown in Fig. 6, showed a remarkably higher resistance than the wires with a copper stabilizer layer and the BSCCO wires. They had a smaller area than the BSCCO wires and a greater area than the wires with a copper stabilizer layer. They also showed better specific resistance properties than the other two kinds of wires. Therefore, making the increase in the resistance of the wires small or significant produces remarkable differences in the specific resistance at their stabilizer layer rather than in their area.

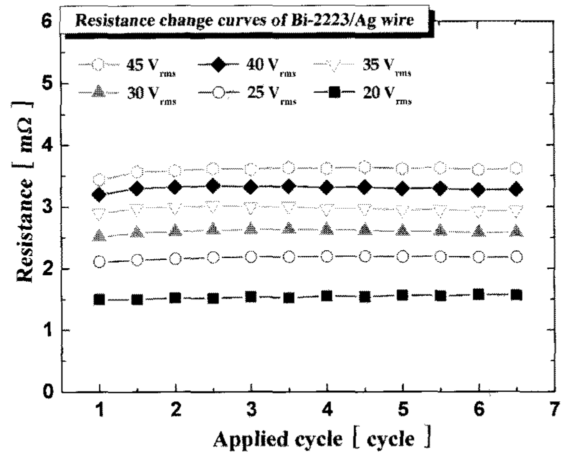

Fig. 4. Resistance characteristics of the Bi-2223/Ag tape.

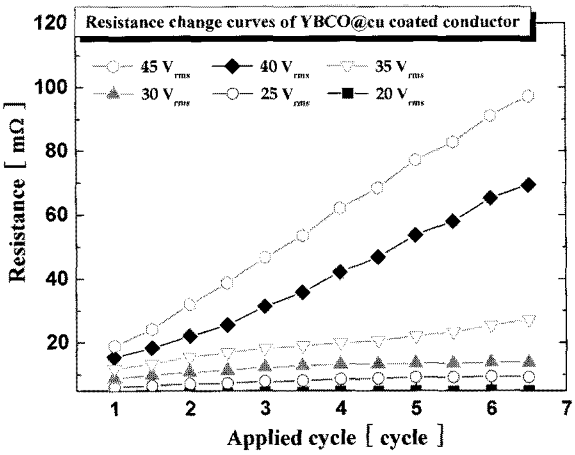

Fig. 5. Resistance characteristics of the YBCO coated conductor having copper as a stabilizer layer.

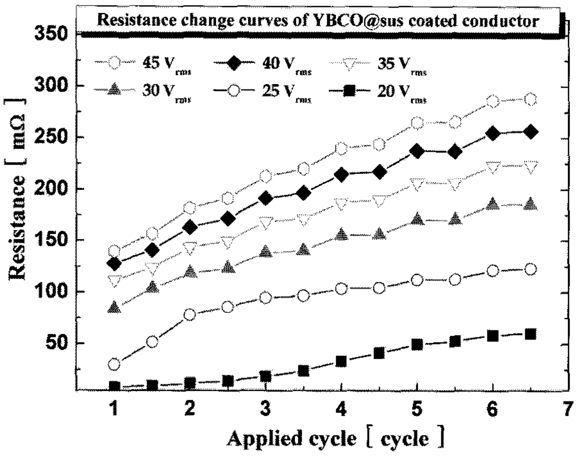

Fig. 6. Resistance characteristics of the YBCO coated conductor having stainless steel as a stabilizer layer.

3.2 Tendency of the resistance of various combined wires to increase

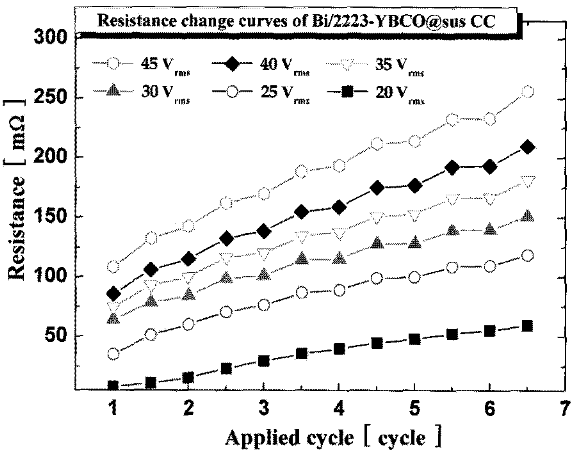

Fig. 7. Resistance characteristics for combination of the Bi-2223/Ag and YBCO coated conductor having stainless steel as a stabilizer layer.

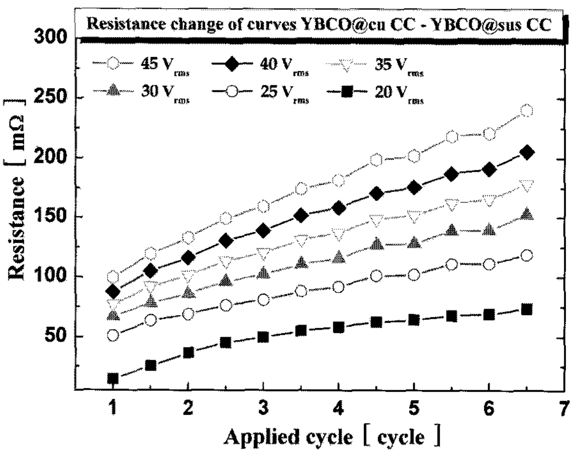

Fig. 8. Resistance characteristics for combination of YBCO coated conductor having copper as a stabilizer and YBCO coated conductor having stainless steel as a stabilizer layer.

Figure 7 shows the resistance occurrence via the overcurrent application when the BSCCO wire was combined with the YBCO coated conductor with a stainless steel stabilizer layer. The results in Fig. 7 show that the tendency of the increase in the resistance is identical to that for the single use of YBCO coated conductors. The value of the after-quench resistance was small, though. The combination of two kinds of YBCO coated conductors in Fig. 8 also shows the same tendency of resistance increase and the same resistance value as that in Fig. 7. This is because there were great differences in the specific resistance values in the stabilizer layers of the two kinds of wires and the YBCO coated conductors with stainless steel stabilizer layers, which had a high specific resistance share in the resistance that occurred after the quench. As for the value of the increase in the resistance after the complete quench, however, that of the single wires was greater than that of the combined wires. While the YBCO coated conductors with high-specific-resistance stainless steel stabilizer layers shared all the resistance, some resistance was taken by the remaining part of the wires that were combined to recover the occurring resistance.

3.3 Resistance properties of the combined wires in the flux-flow and complete quench states

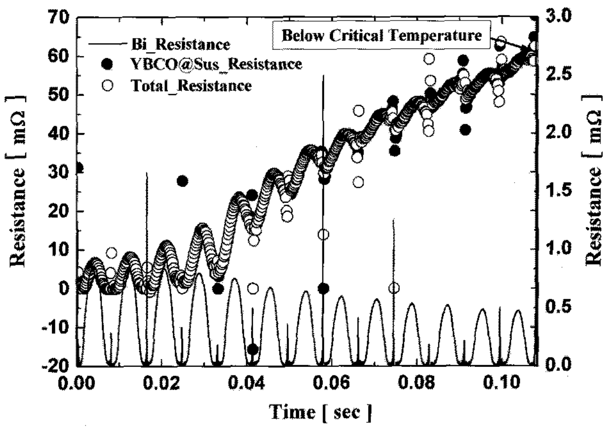

Fig. 9. Voltage-current and resistance characteristics for combination of Bi-2223/Ag and YBCO coated conductor having stainless steel as a stabilizer layer in flux-flow state.

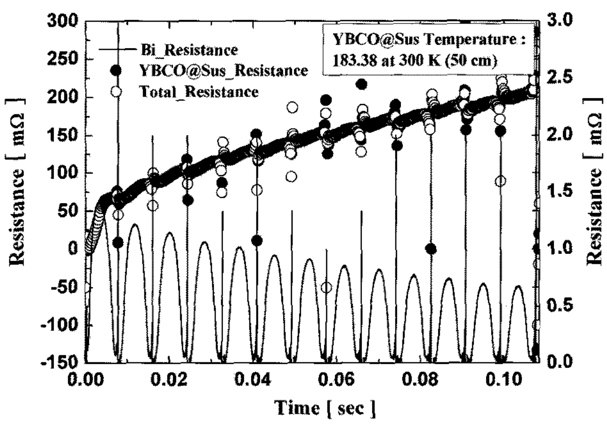

Fig. 10. Voltage-current and resistance characteristics for combination of Bi-2223/Ag and YBCO coated conductor having stainless steel as a stabilizer layer in complete quench state.

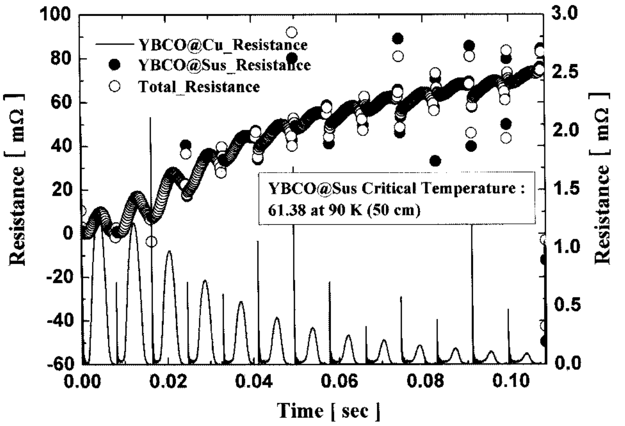

Fig. 11. Voltage-current and resistance characteristics for combination of YBCO coated conductor having copper as a stabilizer layer and YBCO coated conductor having stainless steel as a stabilizer layer in flux-flow state.

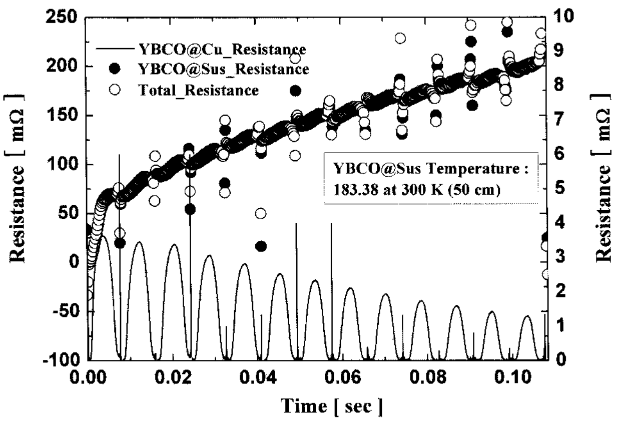

Fig. 12. Voltage-current and resistance characteristics for combination of YBCO coated conductor having copper as a stabilizer layer and YBCO coated conductor having stainless steel as a stabilizer layer in completeness quench state.

To find out why the combined wires had a lower resistance than the single wires, the resistance properties of the combined wires were examined in the flux flow and complete quench states. Figures 9 and 10 show the results, including those for the BSCCO wires. The results show that the occurring resistance of the BSCCO wires that were combined decreased over time and reduced the general occurring resistance below the resistance value that occurred in the single wires. The same tendency can be seen in the results shown in Figs. 11 and 12 for the combined YBCO coated conductors with copper stabilizer layers, although there are some differences in the values of the occurring resistance.

4. CONCLUSION

In this study, the resistance increase properties of YBCO-coated conductors that were expected to be applied to a power apparatus instrument were examined in single and combined wires. Before and after the combination, the specific resistance properties of their stabilizer layer had marked effects on their general current application properties. In particular, the resistance tendency of the combined wires was determined from the degrees of the differences in their specific resistance values at their stabilizer layers. As for the combined wires in which the individual wires were shorter than the single wires, the YBCO coated conductors with relatively high-specific-resistance stainless steel stabilizer layers had a greater voltage share than the BSCCO wires or those with copper stabilizer layers. When the combined wires were used, however, the resistance of the wires with relatively low specific resistance values was recovered, and a smaller general resistance occurred with them than with the single wires. This will make up for the low voltage grade of YBCO coated conductors. The results of the experiment in this study can be used as basic data to improve the voltage grade of YBCO coated conductors and can be useful reference data for their application to high-power instruments.

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