# Fault Angle Dependent Resistance of YBCO Coated Conductor with Stainless Steel Stabilizer Layer

Ho-Ik Du*, Min-Ju Kim, Seung-Gyu Doo, Yong-Jin Kim, and Byoung-Sung Han
*Department of Electrical Engineering, Chonbuk National University, Deokjindong 1-ga, Deokjin-gu, Jeonju-si, Chonbuk 561-756, Republic of Korea*

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To manufacture YBCO-coated conductors as superconducting fault current limiters, it is important to conduct researches on their durability. To test their durability, it is necessary to investigate their properties before and after the quench in more severe conditions than in general operating conditions. In this study, their voltage-current and resistance properties were measured before and after a fault current was repetitively applied to them. For the applied voltage, the voltage grades of the YBCO coated conductors were considered. The current amplitude was controlled using protective resistance on an experimental track, and the time and number of applications were fixed to produce the quench occurrence at the fault angles of 0 °, 45 °, and 90 °. The operating conditions of the YBCO coated conductors as the main components of superconducting fault current limiters were determined using their voltage properties. The voltage properties of the YBCO coated conductors that were analyzed in this research will be used as important data for their practical application to superconducting fault current limiters.

*Keywords*: YBCO coated conductor, Superconducting fault current limiter, Fault angle, Quench, Voltage grade

## 1. INTRODUCTION

Y-Ba-Cu-O(YBCO)-coated conductors are fast becoming important materials for superconducting power machines due to the flexibility of their application to power instruments via their stabilizer layers. Among the different kinds of YBCO-coated conductors, those with stainless steel stabilizer layers are considered the main components of superconducting fault current limiters (SFCLs). The advantages of YBCO coated conductors are their ability to solve the problems associated with simultaneous quench and volume increase, due to their use of YBCO thin films[1-3] as the main device for SFCLs, and their overcoming of the mechanical weaknesses of (Bi,Pb)-St-Ca-Cu-O(BSCCO) bulk[4,5]. The objective of this study is to determine the durability of YBCO-coated conductors so as to prove their suitability as the main device for SFCLs. To do this, YBCO-coated conductors with a critical current of 70 A and a voltage grade of 0.6 V/cm were connected to a spiral former for the conduct of a current application test for the fault angles of 0 °, 45 °, and 90 °. From the results, the resistance of the YBCO-coated conductors was detected to examine the effects on the fault angles after the quench. For the flux flow state, wherein the resistance occurred but did not increase in the YBCO coated conductors, the 190 K state[6,7], wherein the temperature of the coated conductors whose resistance increased was determined to have been at a stable point, 250 K was the expected coated conductor occurrence temperature when the complete quench occurred. Tests were repetitively conducted 30 times at 20-second intervals to measure the voltage after the quench by the number of tests. Finally, the voltage-current and resistance properties at around 250 K, which was the most severe condition, were considered.

*Author to whom corresponding should be addressed: electronic mail: dudoc@chonbuk.ac.kr

## 2. EXPERIMENTAL SET UP

Table 1 shows the resources of the YBCO coated conductors used in this study. The coated conductor with a stainless steel stabilizer layer was manufactured by the U.S. AMSC, and had a critical current of 70 A, a critical temperature of 90 K, and a voltage grade of 0.5-0.6 V/cm. The YBCO superconductor was deposited on the metal board with a silver coating to improve its stability in current application. With 20 ㎛ coated copper as the stability layer material, the surface of the wire had a completely silver color. To observe the temperature properties of the YBCO coated conductors by the resistance occurrence, the changes in temperature from the resistance changes shown in Fig. 1 were measured. Considering the resistance value compared with the measured temperature, the measured resistance on the superconducting wires in the application of the over-current was changed into the critical temperature. The results were used as the standard data for the definition of the flux-flow, 190 K, and the 250 K states. Figure 2 shows an outline of the experiment device for the application of a current to the YBCO coated conductors used in this study.

Table. 1. Properties of YBCO Coated Conductor.

| YBCO coated conductor(Producer : AMSC) | |
|---|---|
| Stabilizer | Stainless steel |
| Length of pattern/ pattern/width/thickness | 200 ㎝/4.4 ㎜/0.2 ㎜ |
| Stabilizer layer/Over layer/Substrate layer | 20 ㎛/Ag2 ㎛/Nickel50 ㎛ |
| $I_c$ & $T_c$ | 70 A (1 μV/㎝, @77 K), 90 K |
| Rated voltage | 0.6 V/㎝ (@300 K) |
| Resistance | 3.7 mΩ/㎝ (@300 K) |

 

The fault was simulated using $SW_1$ and $SW_2$, and the amount of the current was controlled using the standard resistance $R_0$ and the source of the voltage. The YBCO-coated conductors were connected to the spiral former shown in Fig. 2. The spiral former is expected to be used in its basic form in manufacturing fault current devices using YBCO coated conductors.

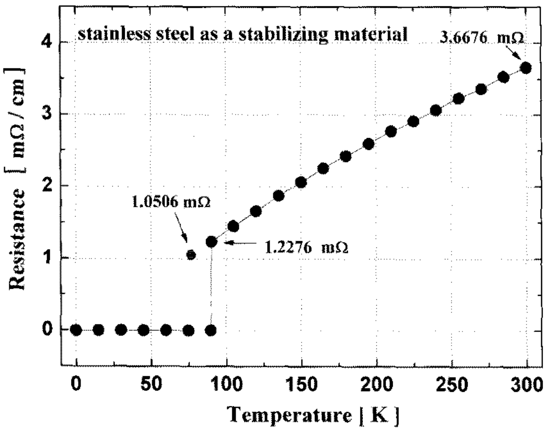


Fig. 1. Resistance variation of YBCO coated conductor with temperature.

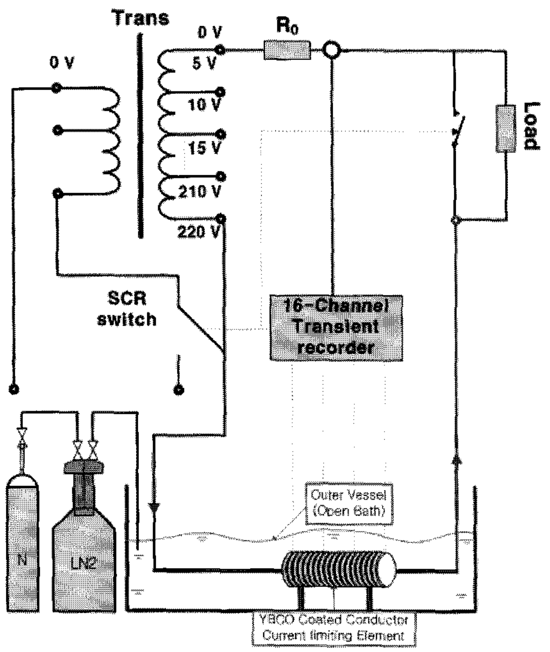


Fig. 2. Schematic diagram of the experimental circuit.

## 3. RESULTS AND DISCUSSION

### 3.1 Tendency of the YBCO coated conductors to increase in resistance by fault angles

To observe the tendency of YBCO coated conductors to increase in resistance by fault angles, Figures 3, 4, and 5 show the resistance increase curves by the applied current at 0 °, 45 °, and 90 ° fault angles. The results show that the biggest resistance increase curve and the fastest quench transfer occurred at the 0° fault angle, with generally no significant difference. This was probably because the peak value was greatest at the first cycle.

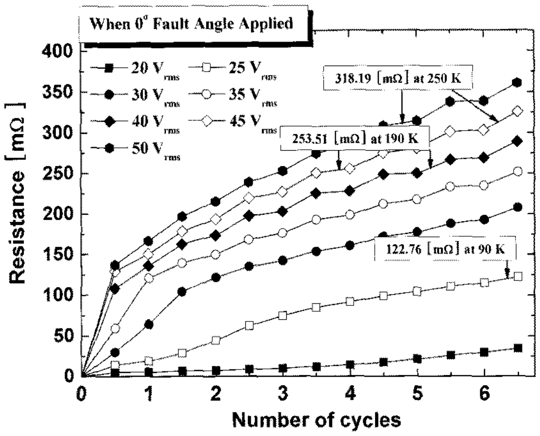


Fig. 3. Resistance change curves by applied voltage-current at 0 ° fault angles.

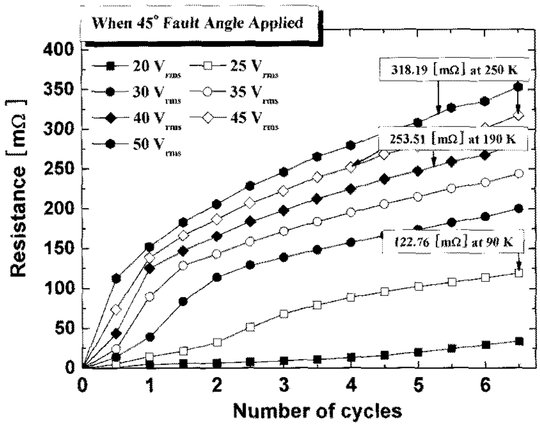


Fig. 4. Resistance change curves by applied voltage-current at 45 ° fault angles.

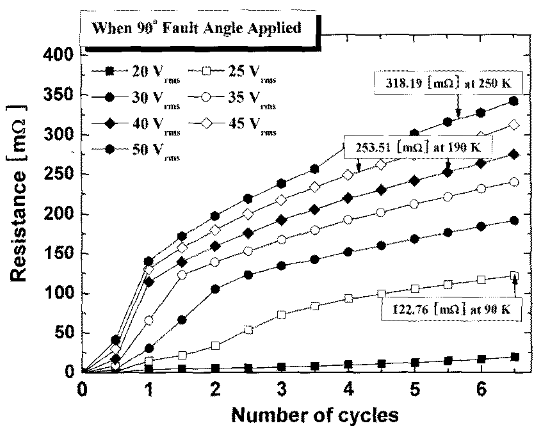


Fig. 5. Resistance change curves by applied voltage-current at 90 ° fault angles.

### 3.2 Occurrence voltage of the YBCO coated conductor by fault angles from the repetitive tests

To make SFCLs useful, researches on their durability are important, as with other power instruments. This is because the long-term stable operation of a SFCL can make its functions of system protection correct for its system input. To test its durability, its current-voltage and quench properties were measured before and after a more severe quench of the YBCO coated conductors than in their normal operating conditions. The measurement was carried out in three conditions. For the flux-flow state that had little increase in the quench occurrence resistance in the stable state, with a temperature of 190 K for the YBCO coated conductors after the quench and 250 K for the complete quench, tests were repetitively carried out 30 times in 20-second intervals. Figure 6 shows the curve of the resulting voltage occurrence at the 0 °, 45 °, and 90 ° fault angles in the flux-flow state of the 20 $V_{rms}$ applied voltage and the 200 $A_{rms}$ applied current, from the current application test for the YBCO coated conductors in this study. After the repetitive quench, the properties of the voltage that occurred at the 0 °, 45 °, and 90 ° fault angles did not change. Rather, it was found that as the number of tests increased, the occurrence voltage decreased. This was probably because the Joule's heat, which increased the resistance, was fully cooled by liquid nitrogen. This property is a typical tendency of the flux-flow state. The curve in Fig. 7 shows the results of the measurement of the occurring voltage for each fault angle at 190 K, which was defined as the stable temperature for YBCO coated conductors. In this case, the occurring voltage was found to be great for the 0 ° fault angle, as can be seen in Fig. 6. The changes in the occurring voltage by the number of tests were smaller than in the flux-flow state, though. This was because the Joule's heat from the resistance that occurred in the YBCO coated conductors did not cool completely but was accumulated. Figure 8 shows the results of the measurement of the occurring voltage by the fault angles at 250 K, which was defined as the complete quench state. With the greater accumulation of Joule's heat in this state than in the stable state, there was only a slight change in the voltage based on the number of tests.

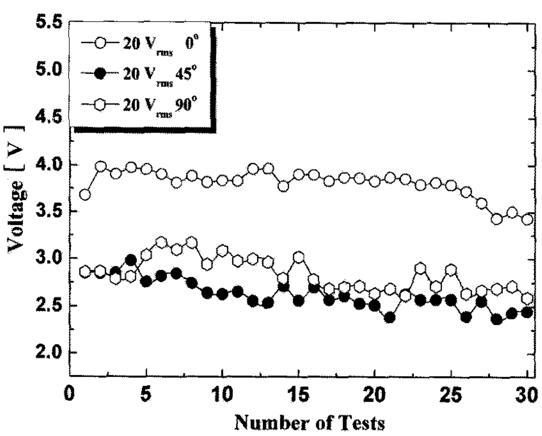


Fig. 6. Voltage occurrence at 0 ° 45 ° 90 ° fault angles in the flux-flow state of 20 $V_{rms}$ applied.

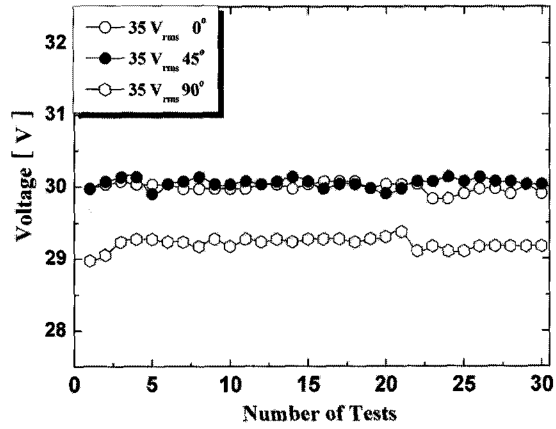


Fig. 7. Voltage occurrence at 0 ° 45 ° 90 ° fault angles in the stable state(at 190 K) of 35 $V_{rms}$ applied.

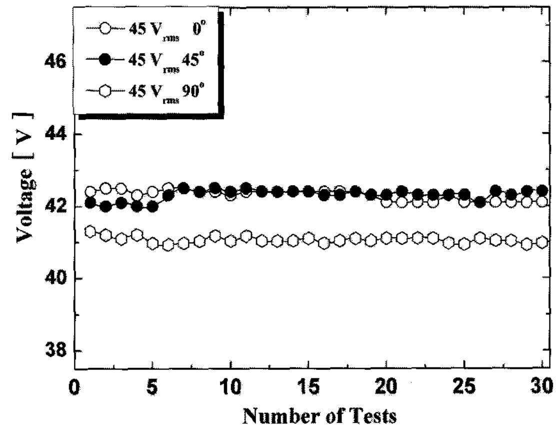


Fig. 8. Voltage occurrence at 0 ° 45 ° 90 ° fault angles in the meta-stable state (at 250 K) of 45 $V_{rms}$ applied.

### 3.3 Change in the voltage-current-resistance by the fault angles at 250 K

The effects of the fault angles were examined from the changes in the voltage, current, and resistance by the fault angles at 250 K in the complete quench state, among the test conditions in the previous section.

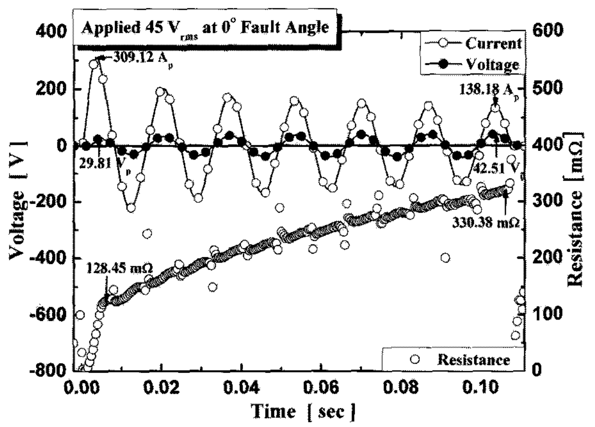


Fig. 9. Voltage-current-resistance characteristics at 0 ° fault angle in the meta-stable state (at 250 K).

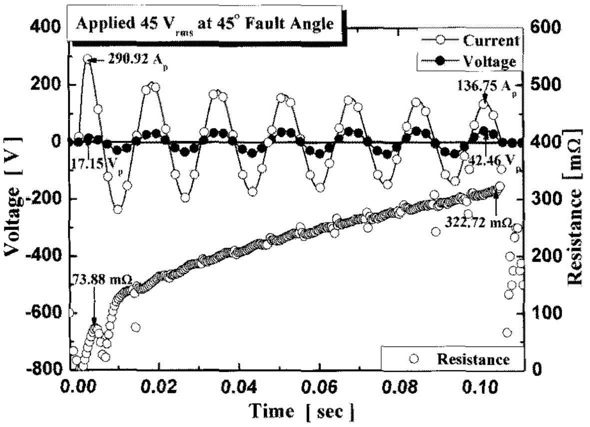


Fig. 10. Voltage-current-resistance characteristics at 45 ° fault angle in the meta-stable state (at 250 K).

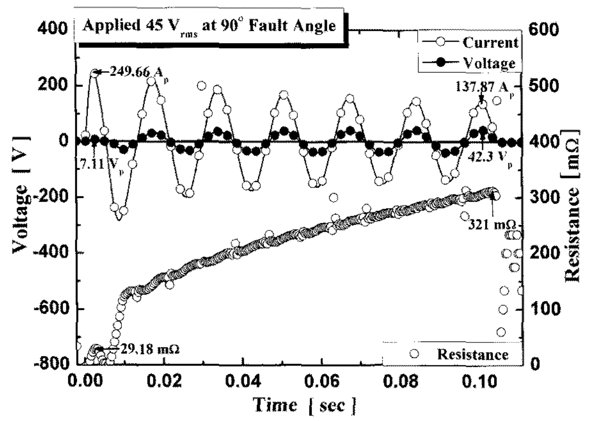


Fig. 11. Voltage-current-resistance characteristics at 90 ° fault angle in the meta-stable state (at 250 K).

Figures 9, 10, and 11 show the curves of the properties when 45 $V_{rms}$ / 450 $A_{rms}$ was applied at the 0 °, 45 °, and 90 ° fault angles. The applied voltage and current were at the temperature state of 250 K. The voltage and resistance were greatest at the 0 ° fault angle based on the first cycle, but had almost the same value at the final cycle. The current was smaller at the first cycle, as the angle increased due to the effects of the fault angles. The current wave forms after the fourth cycle demonstrated, however, that the increase in the current was small at the first cycle because of the above-mentioned fault angle, and not that the increase in the fault angle led to the improvement of the current limitation rate.

## 4. CONCLUSION

YBCO-coated conductors are expected to be applied as current limiters for SFCLs in various systems. In this study, YBCO-coated conductors with stainless steel stabilizer layers, which are highly applicable as current limiters, were used to prove the stability of YBCO coated conductors that operate constantly even in severe conditions of repetitive quench by fault angles. When a fault current was applied at the fault angles of 0 °, 45 °, and 90 ° in three conditions of the flux-flow state, the stable state of the coated conductors (190 K), and the complete quench state of the coated conductors (250 K), it was proven that the fault angles had no great effects on the voltage-current-resistance properties. The results show that fault angles and repetitive quench had no effects on the physical properties of the superconductors of YBCO coated conductors. This is important in the application of YBCO coated conductors to various systems.

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