Journal of the Korean Institute of Electrical and Electronic Material Engineers, Vol. 17, No. 6, p. 678, June 2004.

논 문 17-6-17

Analysis on Current Distribution in Bi-2223/Ag Tapes with Applied Alternating Over-critical Current

Seong Woo Yim[1,a], Hye-Rim Kim[1], and Si Dole Hwang[1]

Abstract

Generally, Bi-2223/Ag tapes have a broad S/N transition region and their sheath is a good electric conductor. In this study, the current distribution between superconductor and metal sheath in HTS tapes were investigated. AC with its peak value above 10 times I_c was applied to HTS tapes for around 6 cycles and V-I characteristics were measured. Using the resistance of the sheath and V-I curves, the current distribution between superconductor and metal sheath was calculated. When 150 A_p was applied, more than 2/3 of the current flows through superconductor. However, in the case of 304 A_p, most of the applied current came to flow through the metal sheath at the 6th cycle.

Key Words : HTS tape, Over-critical current, Current distribution

1. INTRODUCTION

Although the coated conductors, which is called as next generation high-T_c superconductor (HTS) tapes, are attracting peoples attention, still yet, HTS tapes fabricated by powder in tube (PIT) method assume the role of the main material for HTS applications such as cables and transformers. Those HTS tapes by PIT method have a merit of high critical current and mechanical strength. In particular, they can guarantee higher safety against the over-critical current. The Joule heat of the tapes generated by the over-critical current do not increase fast due to the low n value and large heat capacity of HTS material[1,2]. In addition, because of the existence of metal sheath, which is a good conductor, the current exceeding the critical current is distributed into superconductor and metal sheath, keeping the thermal equilibrium.

The clear analysis of current distribution in HTS tapes is important for the prediction and analysis of the problems such as the damage of the tapes when the quench happens in HTS tapes[3,4].

In this study, we analyzed the current distribution based on the over-critical current characteristics of HTS tapes. Firstly, V-I curves of HTS tapes in which the maximum magnitude of the applied current amounts to 10 times I_c were investigated. Secondly, resistance increase data of HTS tapes were acquired from the V-I curves. Finally, the current distribution in the HTS tapes with applied over-critical current was calculated and analyzed using equivalent equations and experimental data.

2. EXPERIMENTAL SET UP

A commercial HTS tape fabricated by PIT method was prepared for the experiments, and its properties are presented in Table 1. The tape

---

1. Korea Electric Power Search Institute, Advanced Technology Center
(103-16 Munji dong Yusung gu Daejon)
a. Corresponding Author : yimsw@kepri.re.kr

접수일자 : 2004. 2. 12
1차 심사 : 2004. 3. 13
2차 심사 : 2004. 4. 26
심사완료 : 2004. 5. 7

has critical current of 57 A and critical temperature of 106 K. The schematic diagram of experimental set-ups for the tests of the over-critical current characteristics is shown in Fig. 1. The current was fed through a voltage power supply, and the amplitude of current was regulated through a transformer. To make the unloaded state, a fault current controller was inserted in the circuit. Non-inductive resistors were used as a load bank in order to suppress the phase difference between voltage and current due to inductive component during current flowing. Various magnitudes of AC, 60 Hz for about 6 cycles, were applied. The applied current was increased by 50 A each, and the signals of voltage and current were measured. 4 probe method was used for detecting voltage signal. The length of HTS tapes prepared for the test was 110 cm, and the distance between voltage taps was 100 cm. In order to minimize the induced voltage due to the self field, the voltage taps were attached on the surface of the tape closely and twisted together at the center part. However, since the voltage generated by the over-critical current was considered to be high enough and resistive components were dominant, a cancel coil for removing the inductive components was not used.

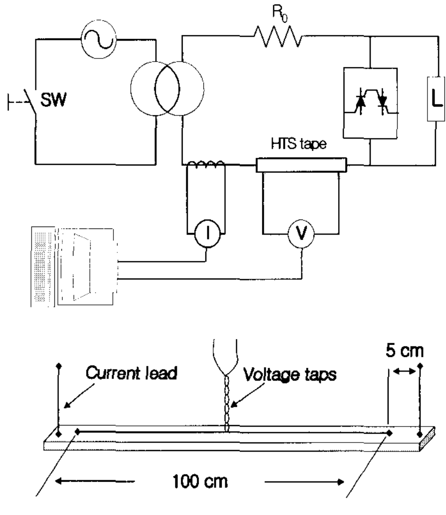


Fig. 1. Experimental set-ups for investigation of the over-critical current characteristics.

Table 1. Properties of the HTS tape.

Critical current [1μV/cm criterion, at 77K, 0T]	57 A
Critical temperature	106 K
Dimension	3.81 × 0.193 [mm^2]
Superconductor / Metal	Bi-2223 / Ag-alloy

3. RESULTS AND DISCUSSION

Although the applied current is not over the critical current of HTS tape, AC transporting current makes small resistive loss. For example, the detected voltages in Fig. 2 include the resistive component and inductive component due to inductance and induced voltage. As the applied current is close to the critical current, the resistive component becomes dominant.

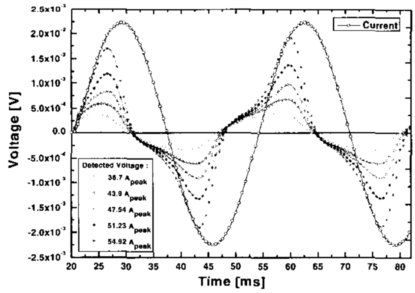


Fig. 2. Detected voltage across the HTS tape in the current range under the critical current (57 A).

Prior to investigating the over-critical current characteristics and the current distribution between superconductor and metal sheath of the HTS tape, the resistance of HTS tape with temperature variation from room to cryogenic temperature was measured and shown in Fig. 3. The resistance was measured for 100 cm of the HTS tape, considering the distance of voltage taps. In Fig. 3, at the transition period of superconducting/normal state, the resistance at 108 K, which was the point where the resistance was beginning to decrease, was 12.7

mΩ/m. The resistance of metal sheath at 77 K, calculated under the assumption that it varied linearly with temperature, was 8.67 mΩ/m.

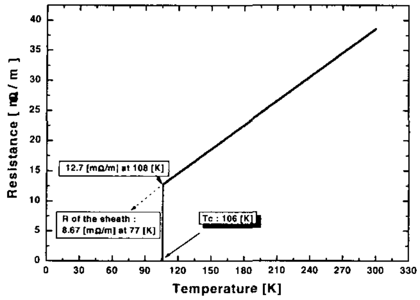


Fig. 3. Variation of resistance of the HTS tape with temperature.

In Fig. 4, there is a *V*-*I* curve of HTS tape in which the peak value of the applied current is 150 A_p. Since the applied current alternated periodically, at every cycle, the heating and the cooling were repeated because the super-conductor was changed back and forth between the normal state and the superconducting state. However, in Fig. 4, the increase of peak voltage was not over 30 mV until 6 cycles. Judging from this result, it could be thought that the Joule heat did not increase much during the duration of applying current.

If the magnitude of the applied current is large enough to make the Joule heat increased with time, I_c of an HTS tape decreases gradually as the cycles of AC go on.

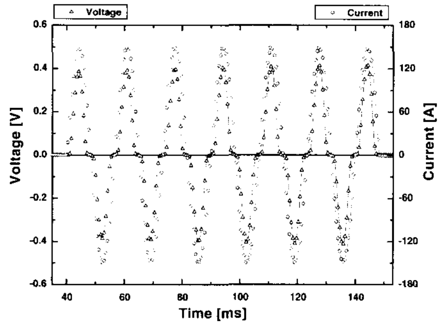


Fig. 4. *V*-*I* curve of the HTS tape with applied current of 150 A_p.

This results in increasing the resistance of the tape.

We obtained the *V*-*I* curves, with the magnitude of the applied current increased by around 50 A up to 507 A_p. The resistance acquired from the variation of the currents and voltages is presented in Fig. 5.

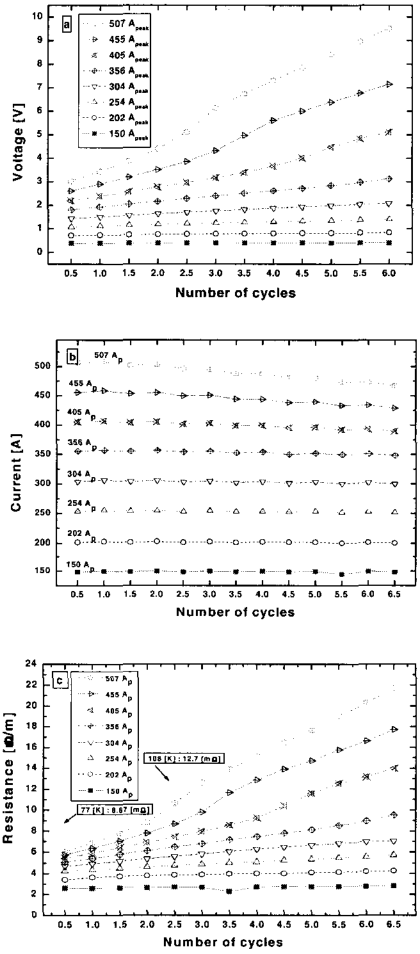


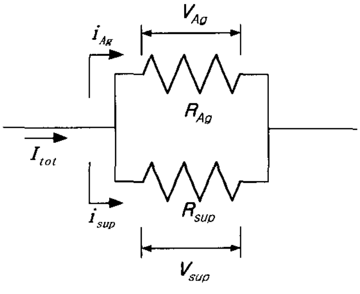
Fig. 5. Variation of a) voltage b) current c) resistance of the HTS tape with the magnitude of the applied current.

As estimated from the resistance variation of the HTS tape with temperature, which is presented in Fig. 2, the temperature of HTS tape is still not over 77 K until 304 A_p is fed for 6.5 cycles.

However, when 356 A_p is applied, at 5.5 cycles, the resistance of the HTS tape is beyond 8.67 mΩ/m, which is the resistance of metal sheath at 77K. That is, before reaching this point, it can be thought that the accumulated Joule heat is exceeding the evaporation heat of liquid nitrogen. In the case of applying 405 A_p, 12.7 mΩ/m was generated at the same cycle. As the higher current was applied, the time to reach that point comes gradually faster. Considered that the resistance of metal sheath is 12.7 mΩ/m at 108 K, one can think that HTS tape lost the superconductivity completely and most of the applied current comes to flow through metal sheath, when the resistance increase is over this point.

When the applied current is beyond its critical current, an HTS tape can be expressed as equivalent circuit and equations shown in Fig. 5.

Because the sheath of HTS tape came in contact with liquid nitrogen directly, we assumed the temperature of HTS tape did not exceed 77 K, as long as the resistance of the tape was not over 8.67 mΩ/m, which was the resistance of the sheath at 77 K.



$V_{Ag} = V_{sup}$

$I_{tot} = i_{Ag} + i_{sup}$

$R_{tot} = R_{Ag} \times R_{sup} / (R_{Ag} + R_{sup})$

Fig. 6. Equivalent circuit and equations of the HTS tape with applied over-critical current.

If this assumption is effective, in Fig. 5, it can be thought that the region where the current do not exceed 304 A_p maintains the temperature of 77 K. Applying the results of that region to equivalent equations in Fig. 5, the current distribution between superconductor and metal sheath was calculated as presented in Fig. 7.

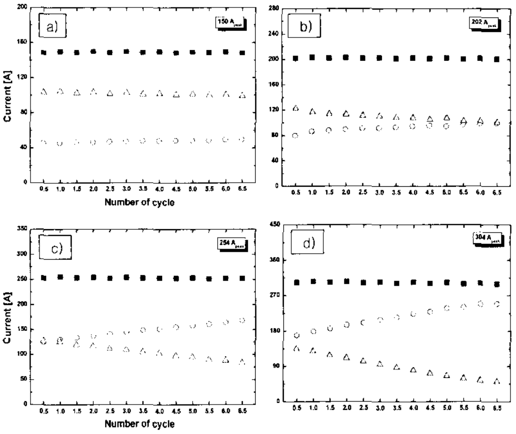


Fig. 7. Variation of current distributions between the superconductor and metal sheath inside HTS tape with its magnitude and duration of the applied current. (-■-: total current, -△-: current flowing through superconductor, -○-: current flowing through the sheath).

Fig. 7 a) shows the current distribution between superconductor and metal sheath when 150 A_p was applied to the HTS tape. Although the peak value of the applied current amounts to 3 times critical current, more than 2/3 of the applied current still flows through superconductor. Therefore, it can be inferred the Joule heat of the HTS tape is not so high that the accumulated heat is suppressed by liquid nitrogen completely. In the case of applying 202 A_p, as shown in Fig. 7 b), the proportion of current distribution varied gradually with time. After 6 cycles, the amount of the current flowing through both materials is to be almost about the same.

When 254 A_p was applied to the HTS tape, the result in Fig. 7 c) shows that the amount of current flowing through the metal sheath is larger than the one flowing through superconductor. The difference become more as the applying of current proceeds. When 304 A_p was applied as shown in Fig. 7 d), most of the applied current is flowing through the metal sheath when 6 cycles lapse. It can be seen from Fig. 7 that more current flows through the metal sheath as the applied current increases.

4. CONCLUSION

Current distribution between superconductor and metal sheath in HTS tape due to the applied over-current beyond its critical current was investigated. The tested tape had the critical current of 57 A and critical temperature of 106 K. Using the *V-I* curves of HTS tape for the over-critical current from 150 A_p to 507 A_p, data of resistance increase of the tape with magnitude and duration of the applied current was acquired. From the results, we analyzed current distribution between superconductor and metal sheath under the assumption that the HTS tape was cooling enough until the tape resistance reached the resistance of the sheath at 77 K. With increasing amount and duration of the current, the current flowing though the metal sheath became larger than the one flowing through superconductor gradually. When 150 A_p was applied, more than 2/3 of the current flows through superconductor and, in the case of 304 A_p, most of the applied current came to flow through the metal sheath. These results will be available to the quench detection and protection of HTS power machines that is made of HTS tapes against such as fault current.

ACKNOWLEDGEMENT

This research was supported by a grant from ETPS funded by KEPCO and by a grant from Center for Applied Superconductivity Technology of the 21st Century Frontier R&D Program funded by the Ministry of Science and Technology, Republic of Korea

REFERENCES

[1] C. L. Wu, Z. M. Bai, J. H. Li, and J. X. Wang, "Minimum quench energy studies on Bi-2223/Ag tape operating at nitrogen atmosphere", Physica C, Vol. 386, p. 162, 2003.

[2] M. Polak, J. Kvitkovic, E. Demencik, L. Jansak, and P. Mozola, "Temperature of Bi-2223/Ag samples in the resistive section of I-V curves", Physica C, Vol. 401, p. 160, 2004.

[3] Y. Wang, L. Xiao, L. Lin, S. Dai, and M. Qiu, "Current distribution in high-T_c composite tape", IEEE Trans. on Appl. Supercond., Vol. 11, No. 1, p. 1824, 2001.

[4] J. Duron, F. Grilli, B. Dutoit, and S. Stavrev, "Modelling the E-J relation of high-T_c superconductors in an arbitrary current range", Physica C, Vol. 401, p. 231, 2004.