Excess current experiment on YBCO tape conductor with metal stabilized layer

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Abstract. Excess current experiments were performed using YBCO tape conductors with a metal stabilized layer on the superconducting layer. The purpose of this research is to obtain the stable criteria of energy dissipation when YBCO tape is forced to flow excess current higher than its critical current. This situation should be considered in power applications. In the experiments short-length samples were immersed in liquid nitrogen and several cycles of 50Hz sinusoidal current were supplied to the samples by an induction voltage regulator. The critical current of the samples was about 110 A. With pulse length as long as 60 ms, YBCO tapes were able to be energized up to twelve times as the critical current without electrical or mechanical deformation. Prior to the excess current experiments, temperature dependency of resistance of the sample was measured so that the temperature rise was estimated by the generated resistance. It is found that YBCO tapes with a copper stabilized layer can be transiently heated to over 400K without degradation.

1. Introduction

Several high temperature superconducting (HTS) apparatus are used at lower temperature such as 20 K since critical currents of HTS wires are higher at lower temperature [1][2]. On the other hand, HTS coils for electrical power apparatus such as transmission cables, transformers and fault current limiters (FCL) are used in liquid nitrogen from the viewpoint of electrical insulation and cooling costs [3]. In these apparatus, the rated current in the normal operating state is set below the critical current of the coil. However, a current exceeding the critical current can be flowing in the coil when a fault occurs in a transmission line.

We performed excess current experiments using an YBCO tape conductor with a metal stabilized layer on the superconducting layer in order to obtain the stable criteria of energy dissipation when excess current higher than the critical current is forced to flow through YBCO tape.

2. Sample preparation

2.1 Specifications of YBCO tape conductor

A schematic view of an YBCO tape conductor is shown in Fig.1. The conductor consists of a metal substrate (Ni-W), intermediate layers (CeO$_2$, YSZ, Y$_2$O$_3$), YBCO superconducting layer and metal protective layer (Ag). The metal protective layer is soldered with a copper stabilized layer. Specifications of the conductor are shown in Table 1. V-I characteristics of the conductor were...
measured in liquid nitrogen. The conductor showed a good superconducting performance and critical current and n-value of the conductor were 110 A and 32 at 77 K and a self magnetic field, respectively.

2.2 Measured sample
A 50 mm long YBCO tape conductor was wound with a G-10 bobbin and both terminals were soldered with copper electrodes as shown in Fig. 3. The sample was immersed in liquid nitrogen and excess currents were applied to the sample.

![Fig. 1 Schematic view of YBCO tape conductor](image1)

| Table 1 Specifications of YBCO tape conductor |
|---------------------------------------------|
| Width | 5 mm |  |
| Thickness |
| YBCO layer | 1 μm |
| Ni-W substrate | 75 μm |
| Cu stabilized layer | 75 μm |

![Fig. 2 V-I characteristics of YBCO tape conductor at 77 K and a self magnetic field.](image2)

![Fig. 3 Measured sample](image3)

3. Excess current experiments

3.1. Test procedure
Using the circuit shown in Fig. 4, excess currents were applied to the sample. Sinusoidal waveform currents of 50 Hz were supplied to the sample using an induction voltage regulator (IVR). Controlling a pair of thyristors as shown in Fig. 4, the wave number of the operating current was adjusted. In the tests, currents and terminal voltages of the sample were measured. Gradually increasing the current amplitudes supplied to the sample, the waveforms of operating currents and voltages, and energy-resistance characteristics of the sample were investigated.

3.2. Test results
Waveforms of current, voltage and electrical resistance generated in the sample are shown in Fig. 5 when an excess current of 380 A (Ip/Ic = 3.5) was applied to the sample. The electrical resistance was calculated using a relational expression of V/I. The calculated resistance was compared with the temperature dependence of the sample resistance (R-T curve), which was measured before the excess
current applying tests. The R-T curve is shown in Fig. 6. The solid line shows a measured R-T curve of the sample and a black circle shows the calculated resistance. An inflection point in the R-T curve probably shows the critical temperature of the sample. Since the black circle stands on the left side of the inflection point, the sample was in a flux-flow state during the current operation. Under this condition, a current in the sample should flow in an YBCO layer at lower current and share between the YBCO layer and the Cu stabilized layer at a higher current.

A test result in an excess current of 1,000 A (Ip/Ic = 9) is shown in Fig. 7. In this figure the resistance increased in a monotone way, which means that the sample temperature would maintain an upward trend. The white circle in Fig. 6 shows the calculated resistance in an excess current operation of 1,000 A. The sample temperature reached 270 K soon after the excess current operation. Almost all of the current probably flowed in the Cu stabilized layer.

V-I characteristics of the sample in the liquid nitrogen were measured with respect to each excess current operation and whether the sample would deteriorate was investigated. The applied energy dependence of the sample on ultimate temperature is shown in Fig. 8. The horizontal axis represents the time integration of the square of the current. The white circle shows that degradation of the sample performance did not occur and the black circle shows that degradation occurred after an excess current operation. The sample did not deteriorate even when 34 kA’s of the integration of I² for 60 ms was applied to the sample and the sample ultimate temperature reached approximately 480 K.

![Fig. 4 Experimental circuit](image)

![Fig. 5 Current, voltage and resistance waves (Ip/Ic=3.5)](image)

![Fig. 6 Temperature dependence of sample resistance](image)

![Fig. 7 Current, voltage and resistance waves (Ip/Ic=9)](image)
After 36 kA²s of the integration of $I^2$ for 60 ms was applied to the sample and the ultimate sample temperature reached 580 K, the critical current of the sample decreased to almost zero and the sample deteriorated. Investigating the sample, a burnout of the sample was observed as shown in Fig. 9. As a result, resistance to the applied energy to an YBCO tape conductor, i.e. a resistance to the temperature rise of an YBCO tape conductor was confirmed. Therefore, an YBCO tape conductor is suitable as a conductor for electrical power apparatus such as transmission cables, transformers and FCLs.

4. Conclusions
Excess current applying tests were performed using an YBCO tape conductor with a metal stabilized layer on the superconducting layer in order to obtain the stable criteria of energy dissipation when an excess current higher than its critical current is forced to flow through an YBCO tape. When energy of 34 kA²s was applied, i.e. the ultimate temperature was approximately 480 K, the sample did not deteriorate. As a result, it was confirmed that an YBCO tape conductor would be suitable as a conductor for electrical power apparatus such as transmission cables, transformers and FCLs.

References
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