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AC loss characteristics of YBCO conductors carrying transport currents in external AC magnetic fields

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Abstract

In this work we present dependence of AC losses in a YBCO tape conductor carrying an AC transport current in an external AC magnetic field on the angle between the direction of the external field and the tape face of the conductor. The losses were measured by a calorimetric method whose validity was proven by simultaneous electric and calorimetric measurements of the losses in the same part of the conductor. The experiment was conducted at 77 K. The measured data show that the AC losses are dominated by the normal component of the external magnetic field to the tape surface. It is also shown that the AC losses sharply drop when the external magnetic field is parallel to the tape surface, which is due to extremely high aspect ratio of the YBCO conductor.

Keywords: Thin film; AC losses; Calorimeters

1. Introduction

AC superconducting power apparatuses such as power cables and transformers are most promising applications of high temperature superconductor (HTS) because costs to cool the AC losses in the HTS conductors in those apparatuses are much low compared with low temperature superconductor AC power apparatuses. However, even in HTS, AC losses in superconductors are the major losses dissipated in the apparatuses and dominate the efficiency and the economic feasibility of the apparatuses. Therefore, it is important to have correct and accurate data of the AC losses.

YBCO coated tape conductors potentially have high critical current density (more than 10^6 A/cm^2 at 77 K) and are valuable HTS conductors for power applications. A YBCO tape conductor usually has very high aspect ratio and its AC losses strongly depend on the angle between the face of the tape conductor and an external magnetic field.

Superconductors used in the apparatuses are exposed to external AC magnetic field and, therefore, it is necessary to have data of the AC losses in the superconductors carrying AC transport current in AC magnetic fields with various directions.

AC losses in superconductors are composed of two kinds of AC losses, magnetization losses due to the external magnetic field and the transport current losses due to the transport current. Methods to measure the total AC losses that are the addition of the magnetization and transport current losses are categorized in two methods, electric [1–3] and calorimetric ones [4]. Generally, electric methods have high sensitivity and resolution and can measure the components of magnetization losses and transport current losses separately. However, data obtained by the electric method can be wrong if electromagnetic environment around the sample conductors is not well defined. Therefore, in the case of using an electrical method it is necessary to prove its validity. On the other hand, calorimetric methods are less sensitive and

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have lower resolution but give actual losses regardless the electro-magnetic environment around the sample, although a proper method for calibration is necessary.

We have developed an electric method to measure the AC magnetization and transport current losses in a short sample of HTS tape subject to the external AC magnetic field perpendicular to the tape face [1]. Applying this electric method to the calibration, we measured the dependence of the total AC losses in a YBCO tape conductor on the angle between the direction of the external magnetic field and the tape face by a calorimetric method. The angular dependence of the AC losses was studied already by electric measurement [3]. We conducted the calorimetric measurement to make sure the validity of the results obtained by the electric measurement. We also investigated the loss characteristics in the case that the external magnetic field is almost parallel to the tape face, a difficult case for the electric measurement. The calorimetric method used in this work was similar to the method developed by Ashworth [4] except the calibration method.

2. Experiment

2.1. Sample arrangement and experimental set-up

Fig. 1 illustrates an arrangement of a measurement sample to measure the AC losses by the calorimetric method together by the electric method. A rectangular pick-up coil is for the magnetization loss measurement and the calibration and spiral voltage leads is for transport current loss measurement [5]. A thermo-couple is placed on the face of the sample HTS tape to measure the temperature rise and the part of the tape where the thermo-couple is placed is covered by polystyrene thermal insulator. This arrangement is similar to that used to the measurement of the AC losses in a Bi/Ag sheathed tape [6]. Specifications of a YBCO tape to measure the losses are listed in Table 1. The measurement sample is mounted on a rotating axis and placed in a gap of a dipole copper coil to apply AC external magnetic field to the tape. The angle between the tape face and the direction of the external magnetic field is changed by rotating the rotating axis. An AC transport current of the same phase of the external magnetic field is applied to the tape. The measurement sample together with the copper coil are immersed in liquid nitrogen bath. Current leads to the tape are so arranged that electro-magnetic interaction between the power supplies for the transport current and the copper dipole coil is avoided.

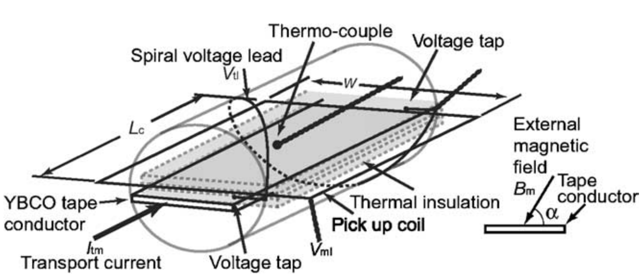

Fig. 1. Sample arrangement to measure the AC losses by electric and calorimetric methods.

Table 1
Specifications of YBCO tape

Conductor dimension width	10.0 mm
Critical current I_c at 0 T and 1 μV/cm (77 K)	51.7 A
n value at 0 T	33.1
Thickness of Ag layer	50 μm
Thickness of YBCO layer	1.0 μm

2.2. Measurement method

Total AC losses in an HTS tape carrying AC transport currents in external AC magnetic fields were measured simultaneously by electric and calorimetric methods at the same part of the tape to prove the validity of measurement methods in the case that the external fields were perpendicular to the tape surface. After verifying the methods, the angular dependence of the total AC losses on the direction of the external magnetic field was measured by the calorimetric method. In the following the both methods used in this work are explained.

2.2.1. Electric method

In the experiment, the same electric method explained in Ref. [1] was used. AC magnetization losses are measured by mean of standard digital lock-in technique using the rectangular-shaped pick-up coil. The magnetization losses Q_m [J/m/cycle] are given by the following equation [7]:

$$Q_m = \pi w V_{ml} B_m / 2L_c f, \quad (1)$$

where L_c and w were the length and width of the pick-up coil, respectively. V_{ml} is the magnetization loss voltage component of the pick-up coil that is the component in phase with the external magnetic field. B_m is the amplitude of the external field and f is frequency. The magnetization losses can be measured by this method only in the case that the external fields are perpendicular to the tape face.

The transport current losses are measured by the four terminal method. The inductive voltage is greatly reduced by use of the spiral leads arrangement. The transport current losses Q_t [J/m/cycle] is given by

$$Q_t = I_{tm} V_{tl} / 2Lf, \quad (2)$$

where I_{tm} is the amplitude of transport current and V_{tl} is the loss component of the voltage between the voltage taps that is in phase with the transport current. L is the distance between the voltage taps. The transport