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Dependence AC magnetization losses in thin film superconductor tape on J_c distribution along tape width

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Abstract

Analytical formulas derived by Norris [J. Phys. D 3 (1970) 489] and Brandt et al. [Phys. Rev. B 48 (1993) 12893] are often used to calculate the AC transport current and magnetization losses in HTS strip conductors. In those formulas, homogeneous distribution of critical sheet current density σ_c in the strip is assumed. However, it is considered that σ_c in actual HTS strips are distributed inhomogeneously and that deviations of the measured AC loss data of actual HTS strips from those formulas are due to the inhomogeneous σ_c distributions. We derived a semi-analytical method to calculate the transport current and magnetization losses in an HTS strip with inhomogeneous σ_c distribution. The validity of the semi-analytical method is shown by comparing the experimental and analytical data.

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Keywords: HTS strip; Transport current loss; Magnetization loss; Semi-analytical method; AC losses

1. Introduction

AC losses in superconductors are the major losses in the AC HTS apparatuses and dominate their efficiency and the economic feasibility. Therefore, it is important to understand and estimate the AC loss characteristics. YBCO conductors are strip-shaped and their YBCO layers are very thin and of high aspect ratio in the range of 10^4. Therefore, it is considered that electromagnetic behaviors of YBCO conductors can be treated as thin strip type II superconductors. Formulas to calculate transport current losses Q_t and magnetization

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losses Q_m caused by AC magnetic field applied perpendicular to the strip face are analytically derived for thin strip type II superconductors assuming that critical sheet current density σ_c is homogeneous. The Norris strip model [1] is for Q_t and the Brandt model [2] for the Q_m. It was shown by the measurement of actual YBCO strips that the both of transport current and magnetization losses were hysteretic in the range of power frequency as is indicated in the analyses but that the loss data were deviated from those models due to assumption of homogeneous σ_c distribution [3–7].

Measured transport current losses in Bi/Ag-sheathed tapes were also observed to deviate from the Norris elliptical model in which the Bean model with constant critical current density J_c is assumed in an elliptical type II superconductor. This deviation of Bi/Ag-sheathed tapes is explained by assuming inhomogeneous J_c distribution in the elliptical cross section of the tape [3,8]. It was also shown that the deviation of the measured transport current losses in YBCO conductors from the Norris strip model was explained by a model of elliptical superconductor with high aspect ratio and inhomogeneous J_c distribution [3,7,9]. However, this model could not explain the deviation of the measured magnetization losses from the Brandt model. In this work we derive a semi-analytical method to calculate the AC transport current and magnetization losses in type II strip superconductors with inhomogeneous σ_c modifying the Brandt model which cannot treat a strip with inhomogeneous σ_c distribution.

By this method, both of the AC transport current and magnetization losses in a real YBCO strip conductor can be estimated by assuming a proper σ_c distribution in the direction of the width of the strip. In this paper the validity of the method is demonstrated by comparing the calculated data with the Norris and Brandt analyses and experimental data. There are works of numerical analyses of the AC losses in superconductor strips using FEM [10,11]. However, those methods are time consuming and sometime have a problem of the accuracy of the calculated results due to limited size of memory of a computer because very fine meshes are necessary for accurate calculations of the strip with high aspect ratio. On the other hand our semi-analytical method much less time consuming for the calculation and gives highly accurate results.

2. Measured results of actual YBCO conductors

We measured the transport current and magnetization losses of two kinds of YBCO coated conductors which are fabricated with IBAD/PLD and IBAD/MOD methods. The specifications of the YBCO conductors are listed in Table 1. The transport current losses were measured by a four terminal/lock-in amplifier method using a one-turn spiral loop. The magnetization losses were measured by mean of a standard lock-in technique using a plane rectangular pick up coil. The external AC magnetic field was oriented perpendicular to the tape face of the YBCO conductor. An inductive component of the signal voltage from the pick-up coil was reduced by means of a compensation coil located in the magnet considerably far away from the sample and the angle of the compensation coil to the external magnetic field was adjustable.

Figs. 1 and 2 show the results of transport current and magnetization losses in PLD sample and MOD sample, respectively. In case of MOD sample, DC external magnetic field is applied to the sample to reduce the critical current for the measurement purpose, because the YBCO conductor fabricated by MOD method had a high critical current. The critical current of this sample was 102.3 A at 77 K and 60 mT. It was demonstrated in our previous work that the pattern of σ_c distribution of YBCO was not changed even when it was exposed by the DC magnetic field [3]. We assumed this was the same as in the case of MOD

Table 1
Specifications of YBCO strips

Conductor dimension width	10.0 mm	10.0 mm
Critical current I_c at 0 T and 1 μV/cm (77 K)	51.7 A	25.2 A
Thickness of Ag layer	50 μm	10 μm
Thickness of YBCO layer	1.0 μm	1.5 μm
Process	IBAD/PLD	IBAD/MOD