§28. Analysis on Time Evolution of Shielding Current Density in High-Temperature Superconductor

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1. Introduction

The critical current density is one of the most important parameters for engineering applications of a high-temperature superconducting (HTS) film. Ohshima et al. developed a contactless method for measuring the critical current density j_C of an HTS film. While bringing a permanent magnet closer to an HTS film, they measured the electromagnetic force acting on the film. As a result, they found that the maximum repulsive force is approximately proportional to j_C. This tendency implies that j_C can be determined by measuring the electromagnetic interaction between the magnet and the film. This method is called the permanent-magnet method.

In order to simulate the permanent-magnet method, the time evolution of the shielding current density has to be determined numerically. Although the implicit method has been so far applied to the initial-boundary-value problem of the shielding current density, it costs enormous CPU time. In order to resolve this difficulty, the authors proposed the modified constitutive-relation method and demonstrated its high performance in 2009.

The purpose of the present study is to numerically investigate the permanent-magnet method by means of a non-axisymmetric code in which the modified constitutive-relation method is implemented. Especially, the present study focuses on the influence of a film edge on the accuracy of the permanent-magnet method.

2. Non-axisymmetric Code

We assume that an HTS film of thickness b is exposed to the time-dependent magnetic field $\boldsymbol{B}/\mu_0$. Under the thin-layer approximation, there exists a scalar function $S(\boldsymbol{x}, t)$ such that $\boldsymbol{j} = \nabla \times [(2S/b)\boldsymbol{e}_z]$ and its time evolution is governed by the following integrodifferential equation:

$$\mu_0 \partial_t \left(\hat{W} S \right) = -\partial_t \left\langle \boldsymbol{B} \cdot \boldsymbol{e}_z \right\rangle - (\nabla \times \boldsymbol{E}) \cdot \boldsymbol{e}_z . \qquad (1)$$

Here, $\boldsymbol{E}$ denotes an electric field and $\langle \ \rangle$ is an average operator over the thickness. In addition, $\hat{W}$ is an operator defined by

$$\hat{W} S \equiv \iint_{\Omega} Q(|\boldsymbol{x} - \boldsymbol{x}'|) S(\boldsymbol{x}', t)\, d\boldsymbol{x}' + \frac{2}{b} S(\boldsymbol{x}, t). \qquad (2)$$

For the *J-E* constitutive relation, the power law is assumed.

By numerically solving the initial-boundary-value problem of (1), we can investigate the time evolution of the shielding current density.

3. Numerical Simulation of Permanent Magnet Method

On the basis of the modified constitutive-relation method, a non-axisymmetric numerical code has been developed for analyzing the time evolution of the shielding current density. By means of the code, we have investigated the permanent magnet method.

Conclusions obtained in the present study are summarized as follows:

1) Regardless of the magnet position, the critical current density is proportional to the maximum repulsive force (see Fig. 1).
2) The constant proportionality between F_M and j_C remarkably changes near the film edge (see Fig. 2). This tendency implies that the accuracy of the permanent magnet method is degraded near the film edge.

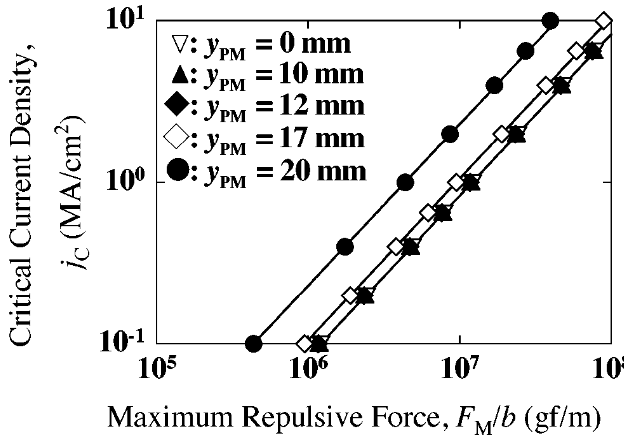

Fig. 1. Dependence of the maximum repulsive force F_M on the critical current density j_C.

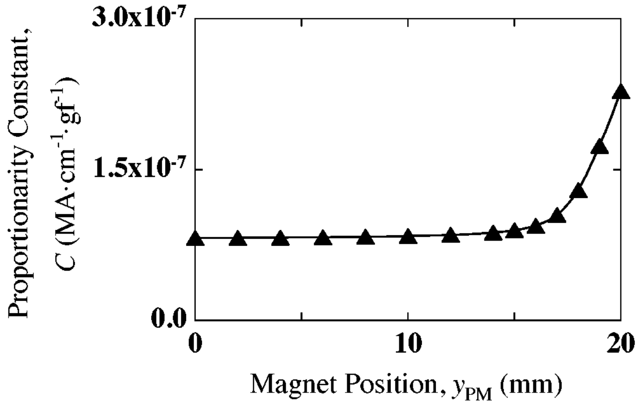

Fig. 2. Dependence of the proportionality constant on the magnet position y_{PM}.