

§34. High-Performance Analysis of Shielding Current Density in High-Temperature Superconducting Film

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Introduction Hattori *et al.*¹⁾ proposed a high-speed contactless method for measuring the distribution of the critical current density j_C in a high-temperature superconducting (HTS) film. While moving a permanent magnet along an HTS film, they measured the electromagnetic force F_z acting on the film. As a result, the j_C -distribution can be successfully determined from the measured F_z -distribution. The proposed method is called the scanning permanent-magnet method (SPMM).

The purpose of the present study is to numerically investigate the applicability of the SPMM to the crack detection in an HTS film.

Governing Equations A schematic view of the SPMM is shown in Fig. 1. A permanent magnet is moved along an HTS film at a constant speed. Specifically, the magnet movement is assumed as $x_A = \pm(vt - l/2) \equiv x_{\pm}(t)$, where v is a scanning speed. Furthermore, the HTS film is assumed to contain a crack whose cross section is a line segment connecting two points, $(x_c \pm L_c/2, y_c)$, in the xy plane. In the following, \mathbf{j} and \mathbf{E} denote the shielding current density and the electric field, respectively.

Under the thin-plate approximation, there exists a scalar function $T(\mathbf{x}, t)$ such that $\mathbf{j} = (2/b)[\nabla \times (T\mathbf{e}_z)]$, and its time evolution is governed by the following equation^{2) 3)}:

$$\mu_0 \partial_t (\hat{W}T) + \mathbf{e}_z \cdot (\nabla \times \mathbf{E}) = -\partial_t \langle \mathbf{B} \cdot \mathbf{e}_z \rangle. \quad (1)$$

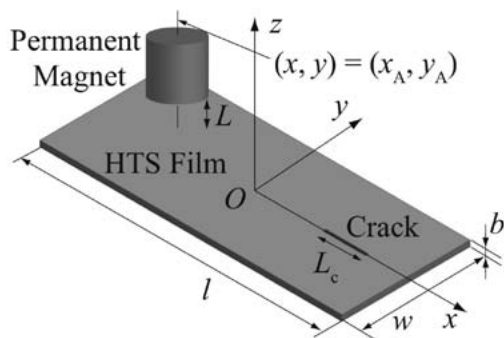


Fig. 1: A schematic view of the scanning permanent-magnet method.

Here, \mathbf{B}/μ_0 is the magnetic field generated by the permanent magnet. In addition, $\langle \rangle$ denotes an average operator over the thickness and \hat{W} is an operator defined by

$$\hat{W}T \equiv \frac{2T(\mathbf{x}, t)}{b} + \iint_{\Omega} Q(|\mathbf{x} - \mathbf{x}'|) T(\mathbf{x}', t) d^2 \mathbf{x}',$$

where $Q(r) = -(\pi b^2)^{-1}[r^{-1} - (r^2 + b^2)^{-1/2}]$. As the J - E constitutive relation, the following power law^{4) 5)} is adopted:

$$\mathbf{E} = E(|\mathbf{j}|)[\mathbf{j}/|\mathbf{j}|], \quad E(j) = E_C (j/j_C)^N,$$

where E_C denotes the critical electric field and N is a positive constant.

By solving the initial-boundary-value problem of (1), we can determine the time evolution of \mathbf{j} . Throughout the present study, the parameters are fixed as follows: $v = 2$ mm/s, $b = 1$ μm , $L_c = 2$ mm, $(x_c, y_c) = (3$ mm, 0 mm), $N = 20$, and $E_C = 1$ mV/m.

Numerical Simulation On the basis of the virtual voltage method^{2) 3)}, a numerical code was developed for analyzing the time evolution of \mathbf{j} . By means of the code, we investigate whether or not the SPMM is applicable to the crack detection.

As a measure of the crack detection, we define the following defect parameter: $d \equiv \text{sgn}(\Delta F_z^+ \cdot \Delta F_z^-) |\Delta F_z^+ \cdot \Delta F_z^-|^{1/2}$. Here, ΔF_z^+ and ΔF_z^- denote a change in F_z due to a crack for $x_A = x_+(t)$ and that for $x_A = x_-(t)$, respectively. The defect parameter d is calculated as functions of the scanning position x_A . The results of computations show that $|d|$ takes a large value only for $x_A \approx x_c$ and that it rapidly decreases with an increase in $|x_A - x_c|$. In other words, a crack can be found in the region where $|d|$ exceeds a small positive constant. On the basis of this result, we can approximately determine the region D_c in which a crack is contained. The boundary ∂D_c of D_c is depicted in Fig. 2.

- 1) Hattori, K. et al.: Physica C 71 (2011) 1033.
- 2) Kamitani, A. et al.: Physica C 494 (2013) 168.
- 3) Kamitani, A. et al.: IEEE Trans. Magn. 49 (2013) 1877.
- 4) Brambilla, R. et al.: IEEE Trans. Appl. Supercond. 22 (2012) 8401006.
- 5) Kameni, A. et al.: IEEE. Trans. Magn. 48 (2012) 591.

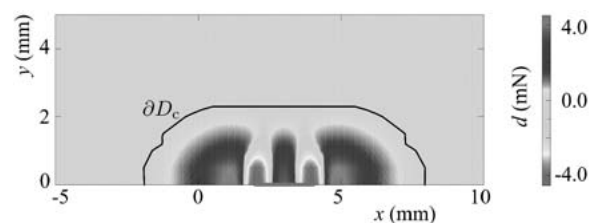


Fig. 2: The boundary ∂D_c and the gray-scale plot of the defect parameter d . In this figure, a crack is denoted by a thick line segment on $y = 0$ mm.