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

Kamitani, A., Takayama, T. (Yamagata Univ.),
Ikuno, S., Itoh, T. (Tokyo Univ. of Technology),
Nakata, S. (Ritsumeikan Univ.),
Saitoh, A. (Hyogo Univ.),
Tamura, Y. (Konan Univ.),
Fujita, Y. (Nagoya Univ.),
Nakamura, H.

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, $\boldsymbol{j}$ and $\boldsymbol{E}$ denote the shielding current density and the electric field, respectively.

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

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

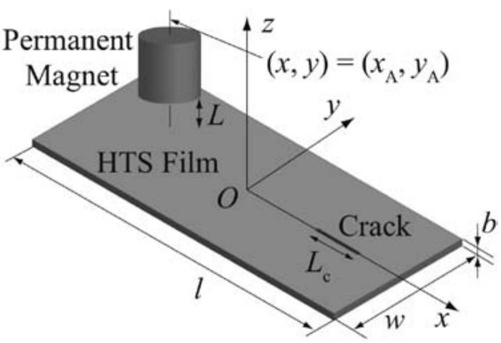

Fig. 1: A schematic view of the scanning permanent-magnet method.

Here, $\boldsymbol{B}/\mu_0$ 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

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

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

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

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 $\boldsymbol{j}$. Throughout the present study, the parameters are fixed as follows: $v = 2$ mm/s, $b = 1\ \mu$m, $L_c = 2$ 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 $\boldsymbol{j}$. 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: $d \equiv \mathrm{sgn}(\Delta F_z^+ \cdot \Delta F_z^-)|\Delta F_z^+ \cdot \Delta F_z^-|^{1/2}$. 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 $x_A \cong x_c$ 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.

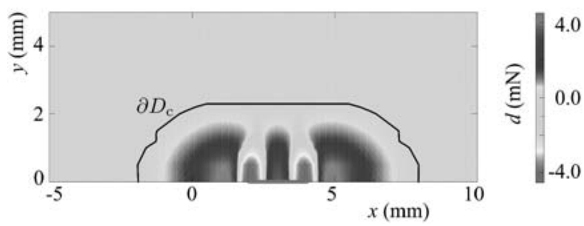

Fig. 2: The boundary ∂D_c and the gray-scale plot of the defect parameter d. In this figure, a crack is denoted by a thick line segment on $y = 0$ mm.