§27. 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. (Univ. Hyogo),
Tamura, Y. (Konan Univ.),
Saito, S. (NIT, Kushiro College),
Fujita, Y. (Nagoya Univ.),
Nakamura, H.

Introduction After discretized with the implicit scheme and the finite element method (FEM), an initial-boundary-value problem of the shielding current density is transformed to a problem in which nonlinear algebraic equations have to be solved at each time step. Although this method can be also applied to the shielding current analysis in an HTS film containing cracks, it is extremely time-consuming. This method is called a virtual voltage method[1].

The purpose of the present study is to develop a fast and stable method for analyzing the shielding current density in an HTS film containing cracks and to numerically investigate the scanning permanent-magnet method (SPM) [2].

Numerical Methods Under the thin-plate approximation, the shielding current density $\boldsymbol{j}$ can be written as $\boldsymbol{j} = (2/b)\nabla \times (T\boldsymbol{e}_z)$. Here, b denotes the film thickness. In addition, $T(\boldsymbol{x}, t)$ is a scalar function and its time evolution is governed by the following equation:

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

where $\boldsymbol{E}$ and $\boldsymbol{B}/\mu_0$ are the electric field and the magnetic field applied to the HTS film, respectively, and $\langle\ \rangle$ denotes an average operator over the thickness. Moreover, the power law is assumed as the J-E constitutive relation [1, 3].

After spatially discretized with the FEM, the initial-boundary-value problem of (1) reduces to the semi-explicit differential algebraic equations (DAEs). Although the DAEs can be solved with standard ordinary-differential-equation (ODE) solvers, much CPU time is required for its numerical solution. In order to shorten the CPU time, a high-speed method is proposed. In the method, the block LU decomposition is incorporated into function evaluations in ODE solvers.

Let us compare the speed of the proposed method with that of the virtual voltage method. The dependence of the CPU time τ_{CPU} on the number n of nodes is depicted in Fig. 1. As expected, the proposed method is faster than the virtual voltage method for the case with $n \gtrsim 10^3$. Especially, for the case with n = 3007, the execution of the virtual voltage method was forced to be terminated because the CPU time had exceeded the upper limit, 8.64×10^4 s. Hence, for this case, the proposed method is over 5.3 times faster than the virtual voltage method. From these results, we can conclude that the proposed method could be effective especially for a large-sized shielding current analysis in an HTS film containing cracks.

Application to SPM On the basis of the methods explained above, a high-speed numerical code has been developed for analyzing the time evolution of $\boldsymbol{j}$. By using the code, we numerically investigate whether or not two cracks can be distinguished by the SPM.

Dependences of the defect parameter d on the scanning position x_{A} are numerically determined for a = 10 mm and for a = 20 mm, and they are depicted in Fig. 2. Here, a is a distance between two cracks. This figure indicates that $|d|$ does not vanish even at x_{A} = 0 mm for the case with a = 10 mm. In contrast, $|d| \cong 0$ mN is fulfilled there for the case with a = 20 mm. In other words, two cracks are regarded as a single crack for the case with a = 10 mm, whereas they are completely distinguishable for the case with a = 20 mm. This result implies that multiple cracks will remarkably affect resolution of the SPM.

1) Kamitani, A. et al.: IEEE Trans. Magn. 49 (2013) 1877.

2) Hattori, K. et al.: Physica C 471 (2011) 1033.

3) Brambilla, R. et al.: IEEE Trans. Appl. Supercond. 22 (2012) Art. No. 8401006.

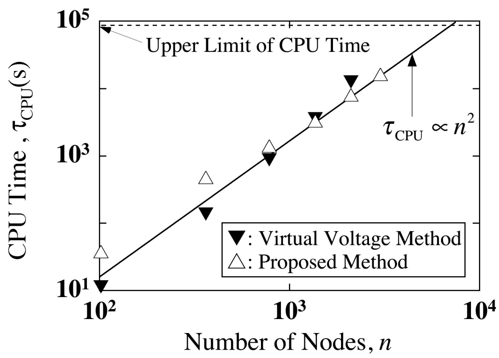

Fig. 1: The CPU time τ_{CPU} as functions of the number n of nodes for the case where one crack is contained in the HTS film.

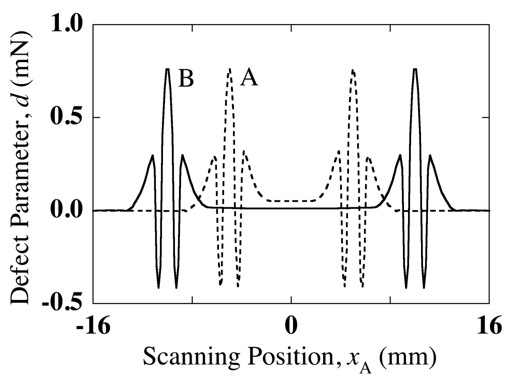

Fig. 2: Dependences of the defect parameter d on the scanning position x_{A}. Here, A: a = 10 mm and B: a = 20 mm.