WBP6-1

Numerical Study to Reduce the Effect of the Screening Field for Compact HTS NMR Magnets

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High temperature superconducting (HTS) magnets wound with REBCO tape are used in many applications such as NMR and MRI. We have been developing compact NMR relaxometry devices using stacked HTS double pancake coil operated by persistent current mode (PCM) with superconducting joint between REBCO wires at liquid nitrogen temperature. The required strength, homogeneity and temporal stability of magnetic field of proposed NMR relaxometry devices are 1.5 T, 150 ppm/cm^{3}and 0.01 ppm/h respectively. However, the screening current is induced in the REBCO tape by the radial component of the self-field of HTS NMR magnets, and the screening field induced by the screening current affects the strength, homogeneity and temporal stability of compact HTS NMR magnets. In this study, we carried out numerical analysis using two coil models to reduce the effect of the screening field which affects compact HTS NMR magnets. In the numerical study, the current vector potential, Ohm's law, Faraday's law and Biot-Savart's law are adopted to formulate electromagnetic analysis, and thin film approximation, three-dimensional shape and magnetic coupling between tapes are considered. An n-value model was adopted for superconducting current-voltage characteristics. We used the nonlinear finite element method and the high-speed multipole method as the analysis method to calculate the magnetic field distribution. We could reduce the effect of the screening field of compact HTS NMR magnets by the optimizing coil shape and designed HTS coil for compact HTS NMR magnets will be presented.

Keywords: HTS magnets, compact NMR relaxometry, screening current, screening field

WBP6-2

Numerical Simulation on Coupling Current for Multifilamentary HTS Wire

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Since a high temperature superconductor (HTS) wire such as Bi-2223 ($Bi_2Sr_2Ca_2Cu_3O$) and REBCO(($(RE)Ba_2Cu_3O$) tapes indicates good superconducting characteristics under high magnetic field, ultra-high field magnets wound HTS wire are applicable to a nuclear magnetic resonance (NMR) spectrometer and magnetic resonance imaging (MRI). The large and long-time-constant screening current is induced in the HTS wire, which is the tape shape and not twisted, and the magnetic field generated by screening current deteriorated the field quality such as temporal stability and spatial homogeneity. Because NMR and MRI requires highly accurate field on temporal stability and spatial homogeneity, it is necessary to investigate the influence of the screening current-induced field. REBCO tape is thin tape with high aspect ratio, therefore, the screening current is remarkably induced. In REBCO tape, the screening current can be reduced by dividing the superconductor layer. However, filaments are electrically connected because they are covered with copper due to strength and thermal stability. On the other hand, a Bi-2223 is a multifilamentary wire, therefore, the screening current is smaller than that in a REBCO tape. However, in a Bi-2223 tape, a coupling current flows because of electrical bridge by the silver between the filaments. In this study, we discuss coupling current distribution from numerical simulation on the multifilamentary HTS coil which is given the local electrical contact between filaments.

Keywords: High Temperature Superconductor, Screening Current, Multifilamentary Wire, Nuclear Magnetic Resonance

WBP6-3

Analysis of Magnetization and Loss on a Twisted Superconducting Tape Wire in a Constantly Ramping Magnetic Field

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Rare earth based copper oxide superconductor tape wires operating at high magnetic fields are being developed for an application to superconducting (SC) coils for magnetic resonance imaging (MRI). Inside a SC coil, screening current flows on a wide tape surface due to the perpendicular component of an applied field, resulting in disturbing the spatial and temporal stability of the magnetic field. In order to generate an uniform magnetic field inside a MRI magnet, the cabling method with multi-filamentarization [1] and/or twisting [2] has been developed to suppress the influence of the screening current together with maintaining the high critical current density in a magnetic field. To date the detailed analysis of electromagnetic fields has been conducted for twisted multi-filamentary coated superconductors in ac magnetic fields [3].

We suppose excitation/demagnetization of a SC coil, and thus we address electromagnetic field response in a magnetic field ramping steadily. We here leave the effect of the multi-filamentarization and focus on the twisting of a SC tape wire. It is known that the coupling loss can be reduced by decreasing the twist pitch length L_p [4], and hence theoretical study on a twisted strip will be valuable.

We obtain the analytic formulae of magnetization and loss power with the use of the perturbation method with respect to the twist wavenumber $k=2\pi/L_p$. We also confirm that the zero-th order solution of the Maxwell equation gives the same formulae obtained with the approximation that a twisted strip is regarded as the summation of tilted flat tape. For a loosely twisted tape wire, it is plausible to neglect the small correction of the higher order in k.Then both magnetization and loss power do not depend on L_p, and they get smaller than that of a flat tape by a geometric factor $B(2n+1/2n,1/2)/\pi$ owing to twisting alone, where B and n denote the beta function and the power of SC nonlinear resistivity, respectively.

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[1] N. Amemiya *et al.*, Supercond. Sci. Technol. **17**, 1464 (2004).
[2] M. Takayasu *et al.*, Supercond. Sci. Technol. **25**, 014011 (2012).
[3] N. Amemiya *et al.*, J. Appl. Phys. **100**, 123907 (2006).
[4] M. N. Wilson, Superconducting Magnets (Clarendon, Oxford, 1983).

Keywords: twisted tape wire, loss power, sweeping magnetic field

WBP6-4

Electromagnetic Coupling of Multi-Filamentary Superconducting Tape Wires in Ramping Magnetic Fields

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The rare earth (RE)-based copper oxide superconducting (SC) wire materials are the promising candidate of the application to NMR and MRI magnets. The key issues inherent in their tape shape are considerable irregular field and the loss power in the case of excitation/demagnetization of a SC coil. Dividing tape wires in width direction is called multi-filamentation and is effective to resolve these issues arising from the screening current. However, multi-filamentary SC tape wire may be electromagnetically coupled each other when they are short-circuited by normal stabilizers. In the present work, we suppose excitation/demagnetization of a SC coil, and we theoretically investigate the loss power and electromagnetic coupling of a multi-filamentary tape wire in ramping magnetic fields.

We focus on the steady state with a constant ramping speed after magnetic fluxes reach the center of the tape surface. The (electric field)-(current density) characteristic in SC filaments is considered to be the nonlinear power law behavior, and the normal state resistivity between the SC filaments is assumed. We numerically solved the Maxwell equation in the steady state to obtain the instantaneous loss power of the multi-filamentary tape wires. Although the dependence of the loss power on the field-sweep rate shows closely resemble behavior of the multi-filamentary SC wire in ac magnetic fields, we clarified that the mechanism of the electromagnetic coupling in a SC wire with ramping fields is essentially different from that in ac magnetic fields.

This work is based on the results obtained from a project commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Keywords: superconductor, striated tape wire, ramping magnetic field, electromagnetic coupling

WBP6-5

TDGL simulation on the motion of flux lines with different kinds of pins in thin superconducting wire in transverse magnetic field

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We numerically investigate the vortex dynamics in a thin superconducting wire exposed to a transport current and a transverse magnetic field. By using the Euler method, we numerically solve the time-dependent Ginzburg-Landau (TDGL) equations for a superconducting wire, of which diameter is smaller than the London penetration depth. In this way, Vector potential $\boldsymbol{A}$ depends on only the external magnetic field $\boldsymbol{B}$. We show the three-dimensional dynamics of vortices by plotting the contour surfaces of the superconducting electron density $|\Psi|^2$.

In this study, The parameters using in the original TDGL equations is normalized using the coherence length ξ and the upper critical field B_{c2}.

We assume thin superconducting wire in vacuum and only consider the cubic space of each length of 10ξ for superconducting region and outside is vacuum. In addition, 8 spherical or 4 cylindrical pins of diameter ξ were introduced in parallel with the external magnetic field inside the space. In the region of the pins, we define the order parameter Ψ as 0. Thereafter, different conditions for the distance from the center of the pins d were defined as shown in Fig. 1.

We defined the boundary condition that the electric current density J does not flow from the sides. J and B are applied to the y axis and the z axis, respectively. Hence, Vector potential can be given by $(A_x, A_y, A_z)=(0,Bx,0)$ for the transverse magnetic field in the cubic space. The electric current density and the magnetic field at each time were kept constant at a normalized value as usual. Calculation were made for all combinations of current density J=0.01,0.02,…,0.38, and external magnetic field B=0.1,0.2,…,0.6.

Fig. 2 shows the E-J property and it is possible to confirm the rise of the electric field E. Critical current density J_c is defined using a resistance standard as indicated by a red straight line in Fig. 2.

Fig. 3 shows magnetic field dependence of critical current density. It is confirmed that the peak appears in the J_c-B property. For cylindrical pins, it is suggested that the peak appears at B=0.4 for d=3.6,4.0 and 4.6 and at B=0.5 at d=3.0. Here, in order to estimate the magnetic flux line lattice spacing a_f corresponding to the value of B, it was confirmed that a_f was approximately 3.9 at B=0.4. and 3.6 at B=0.5, respectively. These values of d are closed to the simulated results.

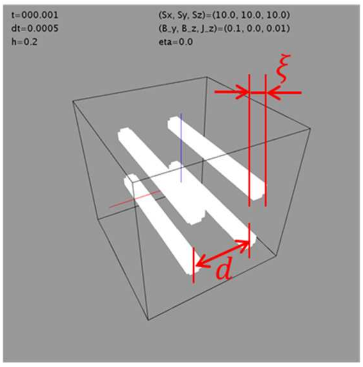

Fig. 1: Geometry of the superconducting wire

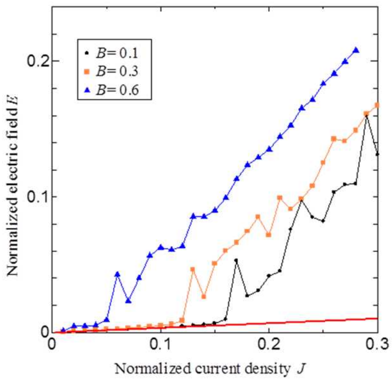

Fig. 2: E-J property of d = 3.0

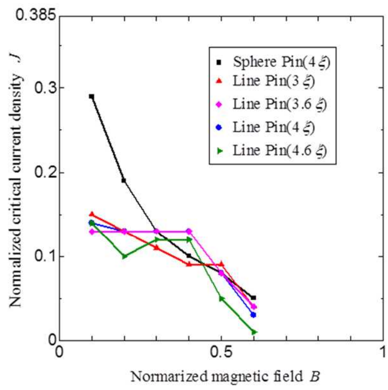

Fig. 3: J_c-B property. The contents of parentheses correspond to d

Keywords: Critical current density, time-dependent Ginzburg-Landau equations