

Research Article

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Eddy current modeling in linear and nonlinear multifilamentary composite materials

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Abstract: In this work, a numerical model is developed for a rapid computation of eddy currents in composite materials, adaptable for both carbon fiber reinforced polymers (CFRPs) for NDT applications and multifilamentary high temperature superconductive (HTS) tapes for AC loss evaluation. The proposed model is based on an integro-differential formulation in terms of the electric vector potential in the frequency domain. The high anisotropy and the nonlinearity of the considered materials are easily handled in the frequency domain.

Keywords: Eddy current, multifilamentary composite materials, anisotropy, nonlinearity, numerical modeling

PACS: 85.25.Am, 84.71.Mn, 74.25.N-, 02.60.Cb, 02.70.Bf

1 Introduction

Electromagnetic field modeling in composite materials such as carbon fiber reinforced polymers (CFRPs) or multifilamentary high-temperature superconductive (HTS) tapes, is in many cases a challenging task. Numerical modeling is then often necessary [1, 2], where the conventional numerical tools have difficulties to provide accurate solutions in reasonable computing times due to multi-scale dimensions, nonlinearities and high anisotropies. In these cases, specific modeling approaches meeting a better compromise between accuracy and computing time are needed.

In previous works, we have developed an electromagnetic model, based on an integro-differential formulation, for a rapid eddy current computation in carbon fiber reinforced composite polymers for nondestructive testing (NDT) applications [2]. In this work, this model is extended to model eddy current losses in multifilamentary HTS composite tapes submitted to external sinusoidal time varying magnetic fields. Indeed, both materials have similarities in their geometrical structures, constituted of filaments embedded in a matrix. In the case of CFRPs, the filaments are carbon fibers embedded in a polymer matrix resulting in poor conductivities and high anisotropies, whereas in the HTS tapes, the filaments are made of a nonlinear conductive material (HTS) and the matrix is made of a high conductive material. A numerical scheme is proposed to take into account the nonlinearity of the constitutive law, relating the electrical current density to the electrical field, in the frequency domain rather than in the time domain as it is commonly done. This ensures the stability and the rapidity of convergence of the numerical scheme. The proposed approach is validated by comparison to theoretical and experimental results. For loss computation, it is particularly shown that the nonlinearity of the HTS tapes can be avoided by considering a high anisotropy factor as reported in [3].

The modeled system and the electromagnetic formulation are presented in the next sections. Numerical results and validation are given in the last section.

2 The modeled system

The modeled system (Figure 1) consists of a multifilamentary composite sample of length L_c , width W , and thickness T_c , constituted of filaments embedded in a matrix. The sample is submitted to an external sinusoidal time varying magnetic flux density (\vec{B}^e). The whole system is characterized by the vacuum magnetic permeability (μ_0). To avoid the modeling at the filament scale, a homogenized nonlinear electrical conductivity tensor is defined for the sample, given by (1), where σ_{ij} and σ_T denote the

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Eddy Currents In Linear And Nonlinear Media

Clarence W. de Silva



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Non-linear Electromagnetic Systems Paolo Di Barba, A. Savini, 2000 This text is a collection of contributions covering a wide range of topics of interdisciplinary character from materials to systems from microdevices to large equipment with special emphasis on emerging subjects and particular attention to advanced computational methods in order to model both devices and systems The book provides the solution to challenging problems of research on non linear electromagnetic systems and is expected to help researchers working in this broad area *Electromagnetic Modeling by Finite Element Methods* João Pedro A. Bastos, Nelson Sadowski, 2003-04-01 Unlike any other source in the field this valuable reference clearly examines key aspects of the finite element method FEM for electromagnetic analysis of low frequency electrical devices The authors examine phenomena such as nonlinearity mechanical force electrical circuit coupling vibration heat and movement for applications in the electrical mechanical nuclear aeronautics and transportation industries Electromagnetic Modeling by Finite Element Methods offers a wide range of examples including torque vibration and iron loss calculation coupling of the FEM with mechanical equations circuits converters and thermal effects material modeling and proven

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Numerical Methods for Energy Applications Naser Mahdavi Tabatabaei,Nicu Bizon,2021-03-22 This book provides a thorough guide to the use of numerical methods in energy systems and applications It presents methods for analysing engineering applications for energy systems discussing finite difference finite element and other advanced numerical methods Solutions to technical problems relating the application of these methods to energy systems are also thoroughly explored Readers will discover diverse perspectives of the contributing authors and extensive discussions of issues including a wide variety of numerical methods concepts and related energy systems applications systems equations and optimization partial differential equations and finite difference method methods for solving nonlinear equations special methods and their mathematical implementation in multi energy sources numerical investigations of electrochemical fields and devices and issues related to numerical approaches and optimal integration of energy consumption This is a highly informative and carefully presented book providing scientific and academic insight for readers with an interest in numerical methods and energy systems *Mathematical Models of Hysteresis and their Applications* Isaak D. Mayergoyz,2003-10-01 This new edition has been significantly revised and updated to reflect advances in the field since the publication of the first edition such as the systematic experimental testing of Preisach models of hysteresis The author has however retained the two most salient features of the original the emphasis on the universal nature of mathematical models of hysteresis and their applicability to the description of hysteresis phenomena in various areas of science technology and economics and its accessibility to a broad audience of researchers engineers and students Provides a unique emphasis on the development of universal mathematical models of hysteresis Accessibility to a broad audience using simple and complex mathematical tools application to various areas of science Presents new theoretical and experimental results

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specialists in different scientific area present their results in the two sections Section 1 Induction and Microwave Heating of Mineral Materials and Section 2 Microwave Heating of Organic Materials

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Numerical Mathematics And Advanced Applications: 3rd European Conf, Jul 99, Finland Pekka Neittaanmaki,Pasi Tarvainen,Timo Tiihonen,2000-09-05 This volume contains major lectures given at ENUMATH 99 the 3rd European Conference on Numerical Mathematics and Advanced Applications The ENUMATH conferences were established in 1995 to provide a forum for discussing current topics in numerical mathematics They convene leading experts and young scientists with special emphasis on contributions from Europe Recent results and new trends are discussed in the analysis of numerical algorithms as well as their application to challenging scientific and industrial problems The topics of ENUMATH 99 included finite element methods a posteriori error control and adaptive mesh design non matching grids least squares methods for partial differential equations boundary element methods and optimization in partial differential equations Apart from theoretical aspects a major part of the conference was devoted to numerical methods in interdisciplinary applications such as problems in computational fluid electrodynamics telecommunications software as well as visualization

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