Research Article

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Eddy current modeling in linear and nonlinear multifilamentary composite materials

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, nolinearity, 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 multiscale dimensions, nonlinearities and high anisotropies. In these cases, specific modeling approaches meeting a better compromise between accuracy and computing time are needed.

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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_r, width W, and thickness T_z, constituted of filaments embedded in a matrix. The sample is submitted to an external sinusoidal time varying magnetic flux density (B^{ex}). 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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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 **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 methods for hysteresis implementation into FEM codes Providing experimental results and comparisons from the authors personal research Electromagnetic Modeling by Finite Element Methods supplies techniques to implement FEM for solving Maxwell s equations analyze electrical and magnetic losses determine the behavior of electrical machines evaluate force distribution on a magnetic medium simulate movement in electrical machines and electromagnetic devices fed by external circuits or static converters and analyze the vibrational behavior of electrical machines **Scientific and Technical Aerospace Reports** ,1995 **Applied Mechanics Reviews** ,1966 **Applications of High-Tc Superconductivity** Adir Luiz,2011-06-27 This book is a collection of the chapters intended to study only practical applications of HTS materials You will find here a great number of research on actual applications of HTS as well as possible future applications of HTS Depending on the strength of the applied magnetic field applications of HTS may be divided in two groups large scale applications large magnetic fields and small scale applications small magnetic fields 12 chapters in the book are fascinating studies about large scale applications as well as small scale applications of HTS Some chapters are presenting interesting research on the synthesis of special materials that may be useful in practical applications of HTS There are also research about properties of high Tc superconductors and experimental research about HTS materials with potential applications The future of practical applications of HTS materials is very exciting I hope that this book will be useful in the research of new radical solutions for practical applications of HTS materials and that it will encourage further experimental research of HTS materials with potential technological applications **Vibration** Clarence W. de Silva,2006-09-14 Maintaining the outstanding features and practical approach that led the bestselling first edition to become a standard textbook in engineering classrooms worldwide Clarence de Silva s Vibration Fundamentals and Practice Second Edition remains a solid instructional tool for modeling analyzing simulating measuring

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