

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

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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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Table of Contents Eddy Currents In Linear And Nonlinear Media

1. Understanding the eBook Eddy Currents In Linear And Nonlinear Media
 - The Rise of Digital Reading Eddy Currents In Linear And Nonlinear Media
 - Advantages of eBooks Over Traditional Books
2. Identifying Eddy Currents In Linear And Nonlinear Media
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Eddy Currents In Linear And Nonlinear Media
 - User-Friendly Interface
4. Exploring eBook Recommendations from Eddy Currents In Linear And Nonlinear Media

- Personalized Recommendations
 - Eddy Currents In Linear And Nonlinear Media User Reviews and Ratings
 - Eddy Currents In Linear And Nonlinear Media and Bestseller Lists
5. Accessing Eddy Currents In Linear And Nonlinear Media Free and Paid eBooks
 - Eddy Currents In Linear And Nonlinear Media Public Domain eBooks
 - Eddy Currents In Linear And Nonlinear Media eBook Subscription Services
 - Eddy Currents In Linear And Nonlinear Media Budget-Friendly Options
 6. Navigating Eddy Currents In Linear And Nonlinear Media eBook Formats
 - ePub, PDF, MOBI, and More
 - Eddy Currents In Linear And Nonlinear Media Compatibility with Devices
 - Eddy Currents In Linear And Nonlinear Media Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Eddy Currents In Linear And Nonlinear Media
 - Highlighting and Note-Taking Eddy Currents In Linear And Nonlinear Media
 - Interactive Elements Eddy Currents In Linear And Nonlinear Media
 8. Staying Engaged with Eddy Currents In Linear And Nonlinear Media
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Eddy Currents In Linear And Nonlinear Media
 9. Balancing eBooks and Physical Books Eddy Currents In Linear And Nonlinear Media
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Eddy Currents In Linear And Nonlinear Media
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Eddy Currents In Linear And Nonlinear Media
 - Setting Reading Goals Eddy Currents In Linear And Nonlinear Media
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Eddy Currents In Linear And Nonlinear Media

- Fact-Checking eBook Content of Eddy Currents In Linear And Nonlinear Media
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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