

## Research Article

Hocine Menana\*, Mohamad Farhat, Melika Hinaje, Kevin Berger, Bruno Douine, and Jean Lévêque

# 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 ( $\mu_0$ ). To avoid the modeling at the filament scale, a homogenized nonlinear electrical conductivity tensor is defined for the sample, given by (1), where  $\sigma_{ff}$  and  $\sigma_T$  denote the

\*Corresponding Author: Hocine Menana: Group of Research in Electrical Engineering of Nancy (GREEN), University of Lorraine Vandoeuvre-Lès-Nancy, France; Email: [hocine.menana@univ-lorraine.fr](mailto:hocine.menana@univ-lorraine.fr)

Mohamad Farhat, Melika Hinaje, Kevin Berger, Bruno Douine, Jean Lévêque: Group of Research in Electrical Engineering of Nancy (GREEN), University of Lorraine Vandoeuvre-Lès-Nancy, France

# Eddy Currents In Linear And Nonlinear Media

**Andrzej Krawczyk, Sławomir Wiak, Ivo  
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