

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

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

*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

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

Y Pai

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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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web jul 7 2019 step two mix the mash now dump the cracked grains into a 30 gallon container and stir in 25 lbs of sugar when the sugar is dissolved completely add 15 to 20 gallons of cold water until the mash mix reaches 30 gallons by total volume chopped corn with sweet feed and yeast pack

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web cheesecloth narrow mouthed preferably glass jug big enough for fermentation sieving siphoning and distillation equipment for the next phase with just these basic tools you can make a really good moonshine 5 gallon moonshine mash recipe

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web step 1 cook the grains bring 5 gallons of water to a boil in a pot big enough to hold the water and the grain once the water starts to boil lower the heat and add the cracked corn and the sweet feed then continuously stir for 30 minutes note if you don't stir continuously you run the risk of letting the grains scorch on the bottom of the pot

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web aug 6 2022 moonshine mash is a popular way to make an alcoholic beverage using a few basic ingredients start by mixing the cornmeal sugar water and yeast together then ferment the mash so it becomes alcoholic and distill it so it tastes great as a drink you can then sip moonshine mash on its own or add it to cocktails or other drinks for

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web jun 16 2015 step 1 research and purchase ingredients basic moonshine mash recipe 5 gallons of malt grains rye barley or a combination of grains 1 package of bread yeast 10 pounds sugar any kind 5 gallons warm water

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web may 29 2023 directions 1 in a large pot or boiler add 5 gallons of water and heat to around 140 160 f 2 add your grains to the water and stir to combine 3 allow the mixture to sit for 1 2 hours to activate the enzymes in the grains 4 after 1 2 hours add 10 pounds of sugar to the mixture and stir until dissolved

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web step 1 choosing type of mash to make moonshine there are different types of moonshine mash you can choose from when trying to make a batch of this liquor at home basically there are three key ingredients distillers yeast granulated sugar and water

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web nov 9 2023 creating a mash the first thing you ll need for making moonshine is a mash this part of the process will depend on the flavor you want weigh and measure out all your ingredients place your mash pot on your heat source and turn it on pour in 5 gallons of water and boil it to 165 f once it reaches 165 f turn off your heat source

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web 1 make the mash the process begins by heating 5 gallons of water to 165 f when the temperature reaches this point turn off the heat and add the full amount of corn to the water it s important to stir the corn consistently for 5 minutes