

Modeling of Diffusion Layer Thickness Variation of Laminate in Case of a Current Supply

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This paper presents the modeling of the diffusion layer thickness variation impact on eddy currents signals. The numerical modeling of laminate with the diffusion layer is realized using finite elements code developed under Matlab environment. The solving of the 2D electromagnetic equation, in (r, z) plane, is performed by considering magnetic permeability variation of diffusion layer. A comparison between the simulation results and experimental signals shows a good agreement.

Index Terms—Laminated material, diffusion layer thickness, finite elements, eddy currents signals, experimental results.

I. INTRODUCTION

THE Multilayer materials are appreciated for their modular properties that conventional materials cannot offer. However, knowledge of their behavior is necessary to be able to fully realize their potential [1]. Many others have proposed a multi-layer approach in order to simulate complex heterogeneous material, where the properties vary from the surface to the depth [2]. In this work the goal is the modeling of a multilayer material, taking into account the variation of diffusion layer thickness and evaluate the impact on the eddy current signals under several excitation frequencies. A comparison with experimental results is performed [3]. The magnetic permeability variation according to diffusion layer thickness is computed and highlight the non-linear nature of the studied problem.

II. ELECTROMAGNETIC EQUATION AND RESOLUTION METHOD

A. 2D Electromagnetic equation

The modeling of the electromagnetic problems is based on Maxwell's equations. From Maxwell's equations, in case of 2D axisymmetric problem, the electromagnetic phenomenon in (r,z) plane is governed by equation below:

$$\frac{\partial}{\partial r} \left(\frac{\nu}{r} \frac{\partial (rA_\phi)}{\partial r} \right) + \frac{\partial}{\partial z} \left(\frac{\nu}{r} \frac{\partial (rA_\phi)}{\partial z} \right) - j \frac{\sigma \omega}{r} (rA_\phi) = -J_s \quad (1)$$

where A is the magnetic vector potential, ν is the magnetic reluctivity, J_s (A/m²) is the source current density and σ (S/m) is the electrical conductivity.

B. Finite elements formulation of 2D electromagnetic equation

The finite elements formulation of the 2D electromagnetic equation (1), with Green theorem and by considering homogeneous boundaries conditions, becomes:

$$\iint_{\Omega} \nu \left(\frac{\partial \phi_i}{\partial r} \frac{\partial A}{\partial r} + \frac{\partial \phi_i}{\partial z} \frac{\partial A}{\partial z} \right) \frac{drdz}{r} + j\omega \iint_{\Omega} \sigma \phi_i A \frac{drdz}{r} = \iint_{\Omega} \phi_i J_s \frac{drdz}{r} \quad (2)$$

ϕ_i is the projection function at node "i", ϕ_j is the shape function at node "j".

After arrangements we obtain the algebraic system to solve:

$$[M][A] + j\omega[L][A] = [F] \quad (3)$$

[M], [L] and [F] are the matrices of the first and the second terms of (2) and a vector of the right hand of (2).

III. SIMULATION AND RESULTS

A. Geometry description and physical parameters

The geometric configuration of the studied system consists of two coils, transmitter and receiver, placed above a multi-layer area (Fig. 1). The first coil consists of 100 turns and excited by a signal of amplitude about 3mA. The second have 300 turns.

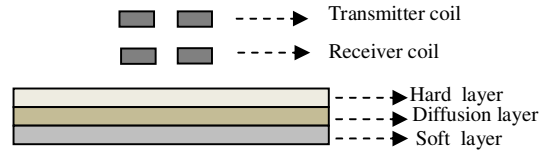


Fig.1. Geometric characteristics of the problem

TABLE I
PHYSICAL AND GEOMETRY PROPERTIES

Material	Electrical conductivity (S/m)	Magnetic Permeability	Width (mm)	Length (mm)
Hard layer	6.67 10 ⁶	230	22 10 ⁻³	42
Diffusion layer	3.57 10 ⁶	variable	6-18 10 ⁻³	42
Soft layer	6.67 10 ⁶	450	1	42
Transmitter coil	59 10 ⁶	1	2	2
Receiver coil	59 10 ⁶	1	2	2

B. Solving geometry and boundary conditions

The described geometry in Fig.2 represents the domain resolution of the electromagnetic problem obtained by considering symmetry of the physical phenomenon.

The meshed domain of the investigated problem is represented in Fig. 3. The number of nodes is 20,576 and the number of triangle is about 41,059.

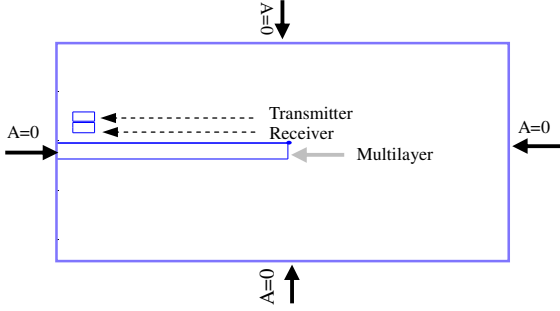


Fig.2. Studied domain and boundary conditions

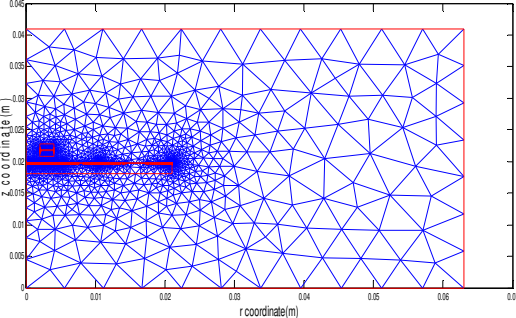


Fig.3. Meshed domain representation

C. Magnetic vector distribution

The magnetic vector potential distribution is shown in Fig.4. Then the voltage U around detection coils is computed using the relationship below [3]:

$$\vec{B} = \vec{\nabla} \wedge \vec{A} \quad (4)$$

$$U = -\frac{d}{dt} \iint_s \vec{B} \cdot d\vec{S} \quad (5)$$

In Fig. 4 a, Fig. 4.b, Fig. 4.c and Fig. 4.d are plotted the obtained results of the induced voltage variation with diffusion layer width for different values of the frequency.

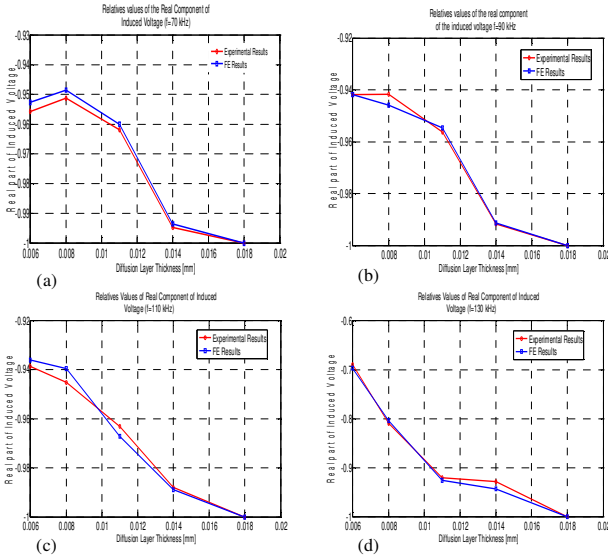


Fig.4. Relative values of the real component of the induced voltage:

- a) $f=70$ kHz b) $f=90$ kHz
c) $f=110$ kHz d) $f=130$ kHz

The numerical calculation is realized for different thicknesses of diffusion layer, which varies in the interval $[6-18] \mu\text{m}$ under

different excitation frequencies. The comparison with experimental results [3] show a good agreement between results (Fig.4 and Fig.5) of the voltage for frequencies $f=70$ kHz, $f=90$ kHz, $f=110$ kHz, $f=130$ kHz.

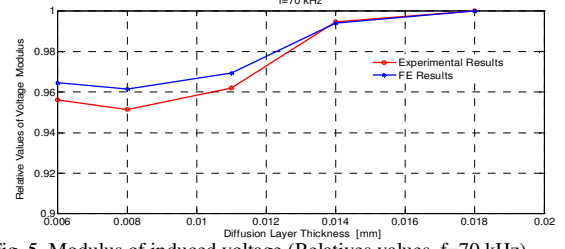


Fig. 5. Modulus of induced voltage (Relative values, $f=70$ kHz)

The voltage decrease with increasing diffusion layer thickness (Fig.6) while permeability increases with increasing diffusion layer thickness (Fig.7).

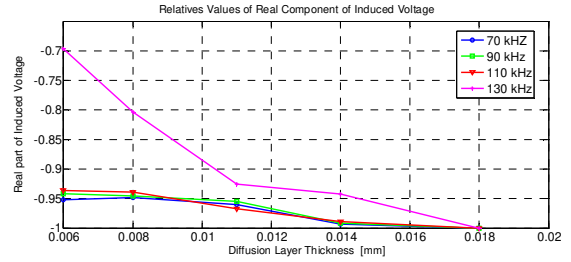


Fig.6. Induced voltage variation with diffusion layer thickness

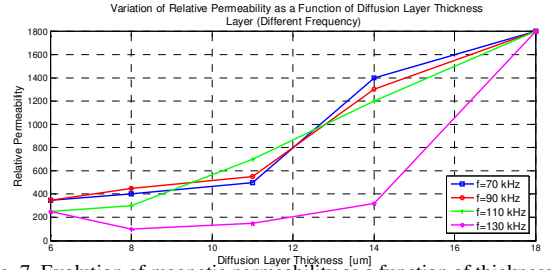


Fig. 7. Evolution of magnetic permeability as a function of thickness for different values of frequency

We see that the material has the same behavior for different values of frequencies. Note that beyond the frequency of 130 kHz the behavior changes.

IV. CONCLUSION

In this paper, the modeling of multi-layer material is performed using FEM code. The impact of diffusion layer thicknesses is investigated because of its importance in the industrial process. The calculated and measured eddy currents profiles were compared. A good agreement between simulation and experimental data is highlighted. The future of the study will be the use of the homogenization technique with magnetic non-linearity.

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