Simulation of Electromagnetic Systems by COMSOL Multiphysics

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Abstract. Non-destructive techniques are used widely in the metal industry in order to control the quality of materials. Eddy current testing is one of the most extensively used non-destructive techniques for inspecting electrically conductive materials at very high speeds that does not require any contact between the test piece and the sensor. The present work aims at identifying the Non-destructive testing (NDT) by eddy currents (EC) in its various modeling as well as experimental aspects, the benchmark problems TEAM Workshop 15-1 have been considered to validate a COMSOL-Multiphysics 3D-resolution using a 3D electromagnetic formulation with Whitney edge elements. Our calculations' findings using COMSOL Multiphysics software are highly reliable and in harmony with the experimental data, this definitely permits us to examine numerous other cases in a perfect way and create a database ready for a study pertinent to inverse problems. The realized experimental setup can be used for Automatic sorting of defective materials in some industrial applications, which can reduce losses and costs and increase quality and efficiency.

Keywords: Non-destructive control · Eddy current · Edge element method 3D · Defective materials · COMSOL Multiphysics

1 Introduction

The modeling of an actual configuration of CND-CF can not generally be obtained analytically and uses numerical methods. Among them, the finite element method (FEM) which allows to take into account complex geometries of probes and parts [1].

Today a wide range of digital tools is available. It is based on the implementation of theoretical models using different mathematical tools including finite element technique. Numerical simulation makes it possible to study the functioning and the properties of a modeled system as well as to predict its evolution. It is very interesting to have a simulation environment that includes the possibility of adding different physical phenomena to the studied model. It is in this philosophy that Comsol Multiphysics has been developed. It is a modular finite element numerical computation software

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allowing to model a large variety of physical phenomena characterizing a real problem. It will also be a design tool thanks to its ability to manage complex 3D geometries [2].

2 Use of COMSOL Multiphysics in ECT

The release of the software used for the study is the 5.3 a release.

2.1 Formulation

The system of equations in magnetic vector and electric scalar potential to solve is:

$$\begin{aligned}&\iiint_D [\nabla\times(\nu\nabla\times\vec{A})-\nabla(\nu\nabla.\vec{A})]dxdydZ + j\omega\iiint_D [\sigma(\vec{A}+\nabla V)dxdydz = \\ &\iiint_D \vec{J_s}dxdydz \\ &\iiint_D \nabla.[-j\omega\sigma(\vec{A}+\nabla V)dxdydz = 0\end{aligned} \quad (1)$$

$\vec{A}$ and V are respectively the magnetic vector potential and electric scalar potential, ν is the magnetic reluctivity and σ the electrical conductivity of the conductive plate [3].

2.2 Geometry

Geometric and electromagnetic characteristics are shown in Table 1.

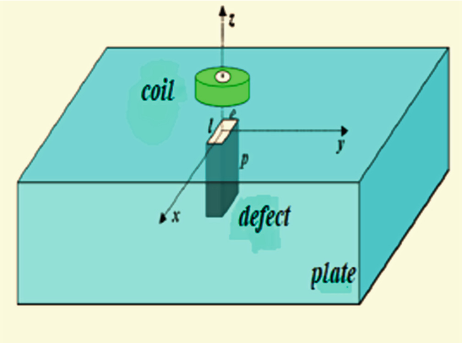

Fig. 1. Sensor-crack system.

Table 1. Geometric and electromagnetic characteristics of the system

Conductive plate	Length: 120 mm
	Width: 103 mm
	Thickness: 20 mm
	Electrical Conductivity: 3.85×10^7
	Magnetic Permeability: $4\pi \times 10^{-7}$
Defect	Length: 14 mm
	Width: 1 mm
	Depth: 5 mm
Coil	Coil inner radius
	Coil outer radius
	Coil length
	Lift off
	Resonance frequency: fc = 717k

2.3 Boundary Condition

In all the boundaries of the study domain, the magnetic induction B is supposed tangent and then the magnetic insulation condition (nxA = 0) is imposed (default condition in COMSOL Multiphysics).

2.4 Mesh

The mesh is generated with tetrahedral elements. The entire mesh consisting of 25214 domain elements, 4091 boundary elements, and 419 edge elements (Fig. 2).

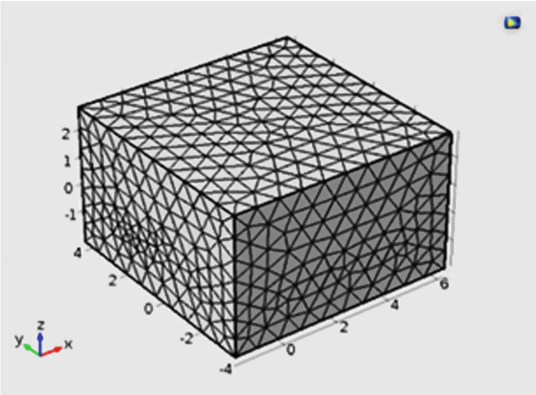

Fig. 2. Mesh

2.5 Resolution

The impedance variation ΔZ is a complex number. The real part is computed with the Joule Losses (J_L) in the conductive media and the imaginary part is computed with the magnetic energy (W_M) in the whole meshed domain (Fig. 3).

$$Z = R + Xi$$

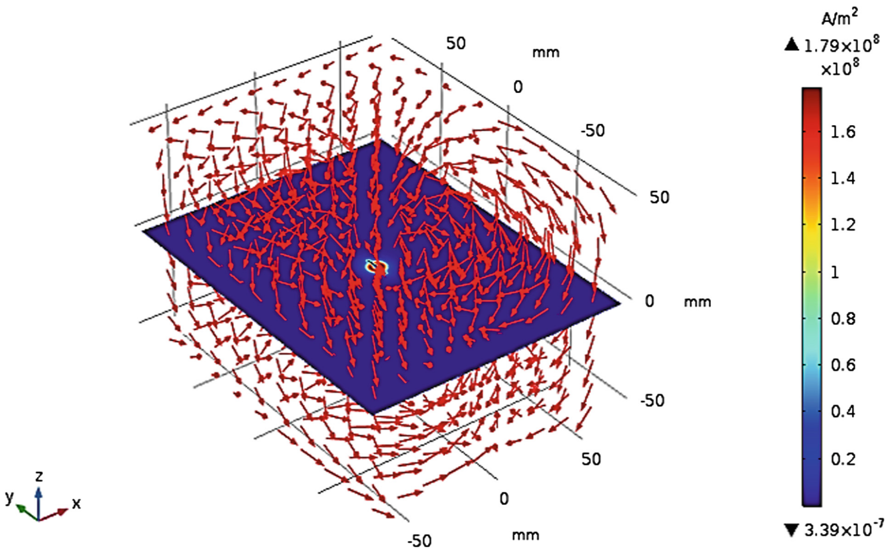

Fig. 3. Distribution of the vectors of magnetic induction B in 3D.

3 Experimental Procedures (Team Workshop Problem 15)

The experimental arrangement is shown schematically in Fig. 1. Here, a circular air-cored coil is scanned, parallel to the x-axis, along the length of a rectangular slot in an aluminum alloy plate. Both the frequency and the coil lift-off are fixed and ΔZ is

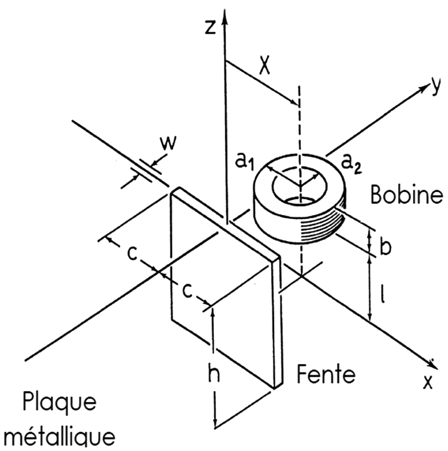

Fig. 4. Detail of TEAM Workshop Pb N ° 15-1

Table 2. Parameters of the Problem Benchmark TEAM Workshop Pb N ° 15-1

Bobine	
Rayon externe (a_1)	$12,40 \pm 0,05\ mm$
Rayon interne (a_2)	$6,15 \pm 0,05\ mm$
Hauteur (b)	$6,15 \pm 0,1\ mm$
Nombre de spires (N)	*3790*
Lift-off (l)	$0,88\ mm$
Spécimen	
Conductivité (σ)	$(30,6 \pm 0,20).10^6\ S/m$
Épaisseur	$12,22 \pm 0,02\ mm$
Défaut	
Longueur ($2c$)	$12,6 \pm 0,02\ mm$
Profondeur (h)	$5,00 \pm 0,05\ mm$
Largeur (w)	$0,28 \pm 0,01\ mm$
Autres	
Fréquence	$900\ Hz$
Épaisseur de peau(δ) à 900 Hz	$3,04\ mm$

measured as a function of coilcenter position. The parameters for this test experiment are listed in Table 2 (Fig. 4).

4 Validation

In this section we compared the experimental results with the numerical results of 3D simulations (Figs. 5 and 6).

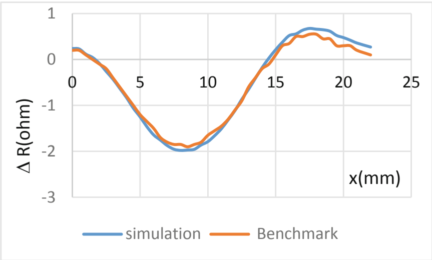

Fig. 5. Variation of the resistance according to the displacement of the sensor

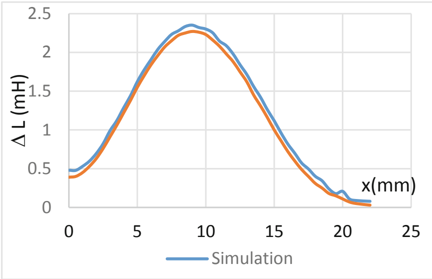

Fig. 6. Variation of inductance as a function of sensor displacement

5 Conclusion

This work presents a simulation of a 3D ECT problem with the COMSOL Multiphysics 5.3a software. The use of the software to solve this type of problem is detailed and explained. The results of our COMSOL Multiphysics calculations are in very good agreement with the experimental data, this definitely permits us to examine numerous other cases in a perfect way.

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