AENSI Journals
Australian Journal of Basic and Applied Sciences
ISSN:1991-8178
Journal home page: www.ajbasweb.com

Numerical Simulations of Eddy Current Testing For Plated Aluminum Parts

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ARTICLE INFO
Article history:
Received 15 April 2014
Received in revised form 22 May 2014
Accepted 25 October 2014
Available online 10 November 2014

Keywords:
Non destructive testing, eddy current, finite element method, aluminum parts, numerical simulations.

ABSTRACT
Eddy current testing is a non-destructive inspection method applied to conductive materials. Its effects on aluminum are more effective than other materials. Modeling is a good tool for understanding and analyzing impedance responses due to flaws. In this paper, discretization by finite element method is used to solve the electromagnetic field equations in terms of magnetic vector and electric scalar potentials in order to calculate the probe impedance. Simulation by finite elements method was realized to calculate the electromagnetic energy of the interaction between coil and tested part. The real and imaginary components of the probe impedance were deduced from calculated energy that allows determining the characteristic parameters of a crack in aluminum parts.

To Cite This Article: Salim Bennoud and Mourad Zergoug., Numerical Simulations of Eddy Current Testing For Plated Aluminum Parts. ***Aust. J. Basic & Appl. Sci.,*** *8(19): 47-50, 2014*

INTRODUCTION

Amongst all of the available methods of non-destructive testing (NDT), electromagnetic NDT methods are often the most suitable for the inspection of metallic structures or components (Bennoud, S. and M. Zergoug, 2012).Eddy current testing (EC) is an electromagnetic NDT method applied to conductive materials. Various advantages such as high sensitivity, rapid scanning, contactless inspection, and versatility contribute to its wide utilization (Ladislav Janousek, 2005).

The eddy current method has been shown to be one of the most effective techniques for the detection and characterization of surface and near-surface defects in conductive mediums (Helifa, B., *et al*., 2006). Modeling is a good tool for understanding and analyzing impedance responses due to various flaws, such as cracks and near surface voids or inclusions, in NDT by EC. Small impedance variations due to flaw and inspection process must be captured in a model. It is therefore important to use accurate numerical methods (Rosell, A. and G. Persson, 2011).

In the last years, an important progress was made in the development of software for the eddy current testing simulation. The modeling approach can be divided into analytical and numerical models.

The Dodd and Deeds analytical models have proved to be successful in predicting experimental data from eddy current measurements (Dodd, C.V., 1974). The conductor can have any number of layers and the geometries studied fall into two major categories: planar and coaxial cylindrical layers.

Numerical simulations in general are more powerful than simulations using an analytical approach. Modeling and simulations of non-destructive testing by eddy current using the numerical models of the finite element method (FEM) in order to establish codes able to solve Maxwell's equations have been developed in different papers (Nagata, S. and M. Enokizono, 2005; Palanisamy, R. and W. Lord, 1980; Correia, J.P.M., 2008; LIU Xu-dong, 2007; Rosell, A., Gert Persson, 2012; Rao, B.P.C., 1996; Baharom, M.Z., *et al*., 2012). In this study, a code to solve electromagnetic problems by employing the finite element method was developed. This computer code is based on the discretization in three dimensions of the Maxwell's equations in harmonic mode by the finite element method based on the combined potential formulations.

Simulation tools make it possible to study the interactions between probe and tested part and play an increasing role in designing control systems and demonstrating their performance. Electromagnetic modeling can simulate the interaction between probe and tested part and can define probe design adapted to a given problem. Thus it is possible to envisage the consequences of various choices (geometrical configuration, choice of materials…) while limiting the number of prototype to be constructed.

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Problem Modeling:

The resolution of the NDT by EC problems returns actually to the resolution of the Maxwell's equations. These equations are as follows:

$\nabla \times B = \mu (J + dD / dt)$ (Ampere-Maxwell theorem) (1)

$\nabla \times E = - dB / dt$ (Faraday's law) (2)

$\nabla . B = 0$ (law of conservation of magnetic flux) (3)

$\nabla . E = \rho / \varepsilon$ (Gauss theorem) (4)

Where: μ and ε are respectively the permeability and the permittivity of the medium. ρ represents the volume density of electric charges (C/m3). E is the electric field (V / m). B is the magnetic induction (Wb/m2 or T). j is the conduction current density (A/m2). D is the electric induction (C/m2). The constitutive relations are given in the following forms:

$B = \mu H$, (5)

$D = \varepsilon E$, (6)

$j = \sigma E$. (7)

H is the magnetic field (A / m). σ is the conductivity of the medium (S / m). As magnetic induction is with null divergence, a potential magnetic vector, noted *A*, can be introduced such as:

$B = \nabla \times A$ (8)

The field *E* can be expressed according to the magnetic potential vector *A* and of the electric potential *V* such as:

$$E = -\frac{\partial A}{\partial t} - \nabla V \quad (9)$$

The local form of the Ampere's theorem and the law of conservation are written:

$$\nabla \times \left(\frac{1}{\mu} \nabla \times A\right) + \sigma \frac{\partial}{\partial t}(A + \nabla V) = J \quad (10)$$

$$\nabla . \sigma \left(\frac{\partial A}{\partial t} + \nabla V\right) = 0 \quad (11)$$

The principal objective of the modeling of the NDT by EC is to determine the response of the coil. (Studied materials are supposed linear and isotropic). Assuming probe traversed by a sinusoidal current *I*, of pulsation *ω*, it is possible to determine impedance *Z* of this probe by calculation of average magnetic energy (*W*) stored in all space and of the Joule losses (P_j) in the conducting mediums defined by the following relations:

$$P_j = I^2 Re(Z) \quad (12)$$

$$w = I^2 \frac{Im(Z)}{2\omega} \quad (13)$$

$Z = Re(Z)+Im(Z)=1/I^2 \ (P_j+j\,2\,W\,\omega)$ (14)

The system that we propose to study is represented in Figure 1.

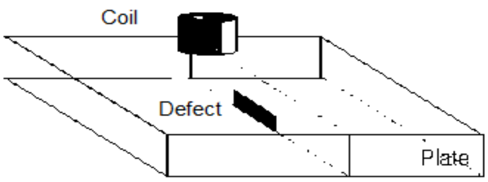

Fig. 1: Studied system.

The procedure of NDT-EC was applied to some plated aluminum samples, the method of eddy current requires a reference like standard (the state or sought discontinuity must be defined). All the deviations of this standard below a tolerance indicated will then be regarded as unacceptable.

Application And Discussion:

For the validation of our code, we use a representation in two dimensions of crack of 10mm of length and 0.2 mm of width of a sheet 40mm*40mm of aluminum 2024, of 2.5mm depth, of conductivity 17 MS/m, and permeability 1. The resolution of the system of equations was performed by 3D finite element method. First, the magnetic vector potential is calculated. After analyzing the distribution of the electromagnetic field, we calculate the electromagnetic energy and we deduce the real and imaginary components of the impedance of the sensor and this in order to carry out the simulation of the NDT by eddy currents of the studied system.

First we validate the 3D model from measurements on standard parts. Once validated the model we apply it to the CND by establishing standard curves for different morphologies of the crack. First, the model from

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measurements on standard parts is validated (Figure 2). Once the model is validated, it applies to establishing curves for different morphologies of crack (Figure 3). The impedance value can be affected by the defect depth, the defect length, and the area of the tested part.

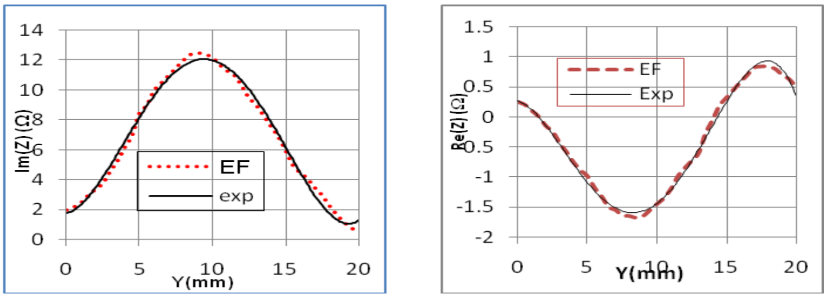

Fig. 2: Real and imaginary components of the validation of impedance.

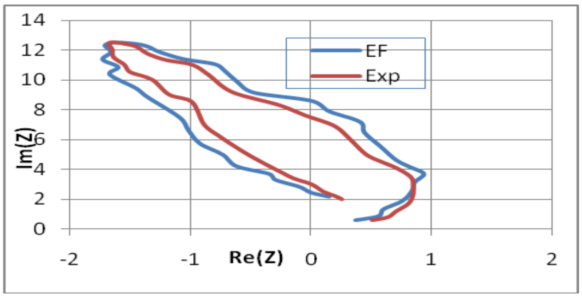

Fig. 3: Variation of the components of the transverse impedance according to the frequency of 20 Khz.

Conclusion:

The NDT by eddy currents is an electromagnetic technique largely used to inspect aeronautical parts, for the detection and the classification of the cracks, corrosion and other material discontinuities during manufacture as in service. Technical advances in numerical simulation methods of NDT allowed simulation to take an important place in the recent developed research. Eddy current testing can be used such as perfect tool to characterize defects in materials. Factors such as the type of material, surface finish and condition of the material, the design of the probe, and many other factors can affect the sensitivity of the inspection. Suggested methodology can be applied to various coils and for various materials.

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