Eddy-current non-destructive testing system using a magnetic sensor based on GMR

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Abstract—Detecting the cracks is a major challenge in the development of Eddy Current (EC) Non-Destructive Testing (NDT). In fact, the detection sensitivity of EC-NDT depends on the interaction between the crack characteristics and the EC formed in the materials. The induced currents are primarily generated along a single direction in the tested sample. This paper presents an excitation method for generating an alternating magnetic field and, consequently, eddy currents. This method significantly improves the detection of cracks of two different kinds of material (non-magnetic conductive material and ferromagnetic material). The magnetic flux density signature of the defect is studied using a 2D Finite Element Model (FEM).

Keywords—Eddy Current; Non-destructive testing; Giant Magneto Resistance; Finite Element Method.

I. INTRODUCTION

The detection of profound defects in structures and materials is an important case for NDT by CF. The detection depends not only on the sensitivity of the magnetometer but also on the interaction between the defects and the EC flowing in the tested structures and the nature of material. The NDT-EC systems developed in has a preferential direction for detecting cracks. In fact, the inducer was directed to induce a current perpendicular to the defect length [1][2][5].

Most of the developed EC-NDT systems use inducers that create a uniform distribution of the EC in the tested structure, the deformation of these EC give us information about the stats of the tested structure [1][3][6].

An GMR magnetometer is used as a sensing element; the benefits of such an excitation method are to improve the detection sensitivity of the EC system and to simplify the characterization of the defects in different types of material nature existing in the industry world like steel (ferromagnetic) and aluminum (non magnetic conductive) [4][7].

We have used a 2D numerical model based on the Finite Element Method (FEM) to simulate the NDT inspection process and to predict the corresponding signal sensed by the GMR magnetometer (calculate the interaction of magnetic induction between the tested structure and the GMR) using a ferromagnetic and non magnetic conductive plate to investigate the effect of the material proprieties (electrical conductivity and magnetic permeability) in the sensitivity and the quality detection [8][9].

II. PROBLEM MODEL

A. Geometries of problem

The problem is consist an aluminum plate and a wire inductor to create a magnetic field as shown in fig.1. The GMR is moving according to the wire to detect the variation of magnetic induction such as the length of that wire and the plate, h the high of plate, ld the profounder of defect and Ld larger of defect.

![Fig. 1 Geometric problem.](image)

The physical characteristics its depends on material nature we choose in our modilization two types of materials as shown in Tab. 1, the first is aluminum this mateirial features of his non magnetic confuctivity nature, the second is steel is ferromagnetic nature because of his high magnetic permeability μ_S=4000.

<table>
<thead>
<tr>
<th>Table 1. Geometric and physical characteristics</th>
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<tr>
<td><strong>Physics characteristics</strong></td>
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<tr>
<td>Courant excitation: 0.18 A</td>
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<tr>
<td>Frequency: 500Hz</td>
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<tr>
<td>Material 2: Steel</td>
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<tr>
<td>σ_s: 1.12.10 MS/m</td>
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<tr>
<td>Ld: 0.5 cm</td>
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The excitation for the inductor is 0.18 A with reference value of frequency of 500Hz, the lift-off between the GMR and the plate is 1mm.

B. Mathematic Modelization problem

The numerical model base on potential magnetic vector A model represented in PDE (Partial Derive Equation) in 2D problem, the FEM applied to solve the equation using a software (COMSOL Multiphysics 4.3).

The PDE of the problem based on Maxwell's equations such as :

\[ \text{Curl}(E) = -\mu \frac{\partial H}{\partial t} \]  
\[ \text{Curl}(H) = J_{\text{ind}} + J_s \]  
\[ \frac{1}{\mu} \text{Curl}(A) = H \]  

These equations using to modulate the reaction between the plat and the inductor such as, \( E \) (V/m) is the electrical field, \( H \) (A/m) is the magnetic field, \( \mu \) is the absolute magnetic permeability, \( J_{\text{ind}} \) (A/m²) and \( J_s \) respectively is the induced current density created in the plat and the current density of the source.

The \( J_{\text{ind}} \) is depend on the skin thickness \( \delta \), the equation who show the effect of the skin thickness and the material proprieties is :

\[ J_{\text{ind}} = J_0 e^{-z/\delta} \]  
with:
\[ \delta = 1/(\pi f \mu \sigma)^{1/2} \]

By the combination between the equations (1), (2) and (3) we have :

\[ \text{Curl} (\text{Curl}(A_z)) + j \omega \sigma A_z = J_{\text{ind}} + J_s \]  

Such as \( \omega \) (rad/s) and \( \sigma \) (S/m), respectively, the frequency of the supply and the electrical conductivity of the plate.

The modelization of the inductor using a Boit-Savart equation:

\[ H = (I/2\pi(y^2+x^2))(ye_x-xe_y) \]  

The equation (3) and (5) combination:

\[ \text{Curl}(A_z) = (I/2\pi(y^2+x^2))(ye_x-xe_y) \]  

Such as the \( e_z \) is the vector unit of Z axe and \( I \) is the current in the inductor.

The finite element method formulation using to resolve the equation (6):

\[ -\frac{1}{\mu} \int \int \nabla A dxdy + j \omega \int \int \sigma A dxdy = \int \int a J_{\text{ind}} \]

The diagram of the formulation in each domain are shown in Fig. 2.

![Fig. 2 Formulation in domain](image)

Fig. 2 Finite element algorithm diagram.

The mesh of the domain show in the fig. 3, the number of element descretization is 11238 with concentration the mesh in the inductor to give precision results.
III. RESULTS AND DISCUSSIONS

The results show the variation of the module of the induced current distribution in different cases at frequency 500Hz, the first case is using a aluminum (non magnetic conductive material and ferromagnetic material) plate and the second case using a steel plate.

The distribution of the induced current in the aluminum plate is uniform according to equation (5), the distribution of the induced current in steel plate is irregular because of the high magnetic permeability of steel ($\mu_r=4000$).

![Fig. 3 Mesh operation in domain](image)

![Fig. 4 The module of the induced current, (a) Aluminum plate, (b) Steel plate.](image)

![Fig. 5 Real part of the magnetic induction Bx (a)aluminum plate (b)steel plate.](image)

![Fig. 6 Imaginary part of the magnetic induction Bx (a)aluminum plate (b)steel plate.](image)

![Fig. 7 Imaginary part according with the real part of the magnetic induction Bx (a)aluminum plate (b)steel plate.](image)

![Fig. 8 Real part of the magnetic induction By (a)aluminum plate (b)steel plate.](image)
The effect of the frequency values and the material properties in the sensibility of detection of defects as shown in Fig. 7, for the aluminum plate and according in equation (5).

IV. CONCLUSION

In this paper we have modulate a method of detecting of defects and buried in two kind of materials (ferromagnetic and conductive material). This method use a magnetometer as detector and a source of original excitement with different frequencies to generate a magnetic field with perpendicular wire inductor. The results show that this method allows to describe easily of the fault detected by analyzing the magnetic field induced in the test piece with the components of the magnetic induction curves.

References


