

USING A MOUSE POINTER AS A POSITIONING DEVICE IN EDDY CURRENT TESTING

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Abstract – The use of Eddy currents is a well-known non-destructive technique used in the characterization of cracks in conductive non-magnetic materials. In this paper some experimental and finite element modelling tests with a new probe installed in a mouse pointer device connected to a PC are reported. This probe combines good sensitivity performances at low frequencies by using a giant magnetoresistor (GMR) magnetic sensor with an hand-held device capable of transferring easily its position to the PC.

Keywords: Non-destructive Testing; Eddy Currents; Measurement System.

1. INTRODUCTION

Eddy current testing is one of the several methods that use electromagnetic theory to examine the properties of materials. It is a particularly attractive method because it offers very high sensitivity in detection of cracks and other inhomogeneities [1-3]. The principle of eddy current inspection is to bring a coil to the specimen to produce a time-varying excitation magnetic field that generates eddy currents in the material. These loop currents are proportional to the conductivity distribution and create a secondary magnetic field that contains the information about the defects in the specimen. The resulting magnetic field can be measured using different types of probes like, for example, a magnetic sensor (Giant Magnetoresistor, Hall sensor, SQUID) or detection coils that sense the e.m.f. induced by the time varying magnetic field.

Local signals are produced and in order to obtain the electromagnetic properties of the material under test either a scan of the surface must be done or an array of probes must be used. Since XY-positioning systems are expensive, we, at the Instituto de Telecomunicações - Instrumentation and Measurement Group are developing a scanning probe installed on a mouse device connected to a personal computer (PC) [4, 5]. This paper describes the implementation of the system and some experimental and simulation results.

2. EXPERIMENTAL SETUP

A. Block Diagram

Fig. 1 shows the experimental setup of the measuring system implemented to detect defects in a plate using eddy current testing. The Eddy Current Probe (ECP) scans a conductive aluminum aircraft plate and the magnetic fields of the induced currents are measured using a multifunction data acquisition board (NI USB-9215) connected to the USB port of a PC. This board has four 16-bit resolution simultaneously sampled analog input channels with an input range of $\pm 10V$. The maximum sampling rate is 100 kHz per channel. In order to obtain higher resolution, two high precision instrumentation amplifiers with variable gain are placed before the A/D converter. A signal generator with a power amplifier able to convert voltage to current excites the probe. The excitation current is sampled by the data acquisition board already described using a 10Ω resistor (R_s).

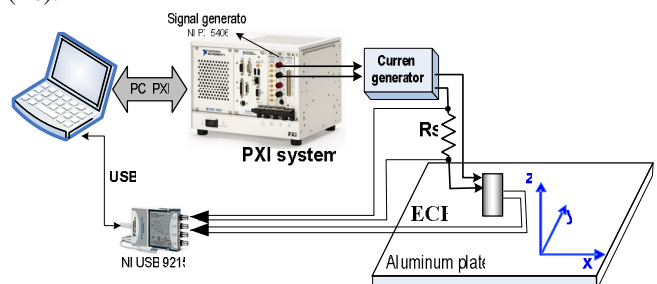


Fig. 1. Block diagram of the experimental setup.

B. ECT Probe

The Eddy Current Probe (ECP), which will be attached to a mouse, is represented in Fig. 2.

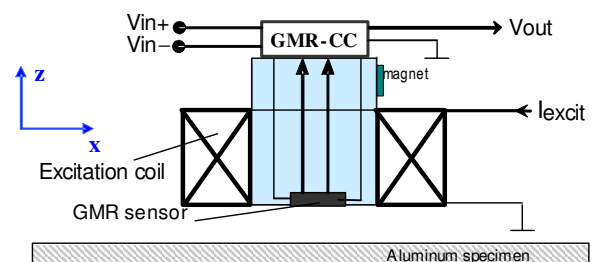


Fig. 2. Eddy current probe geometry.

It includes the excitation coil required to induce eddy (or Foucault) currents on the specimen under test, wound around an acrylic cylinder. These induced currents generate a magnetic field around the inspection area and the parallel component will be detected by the probe. The magnetic sensor located on the coil axis uses a Giant Magnetoresistive (GMR) magnetic field sensor which can detect minor changes on magnetic fields. This sensor is based on the effect found in metallic thin layer that consists on a resistance decrease due to an applied magnetic field.

GMRs measure the magnetic field and their sensitivity does not depend on the frequency used. They provide a combination of high sensitivity and an outstanding high dynamic range. Thus, low frequency excitation can be used enabling high penetration depth of fields in the material [6].

The sensor used (AA002 from NVE) includes four GMR resistors configured in a Wheatstone bridge [7]. Two of these resistors are sensing elements and the other two shielded from the applied magnetic field act as reference elements. This imbalance leads to the bridge output. This configuration, better than the usage of a standalone GMR, provides higher precision and accuracy to the sensor.

The GMR sensor is mounted in order to put its plane parallel with the aluminum plate under inspection. Thus the excitation magnetic field on the coil axis, being perpendicular to the sensing axis of the GMR sensor package, has no effect on the sensor. On the top of the cylinder a small but powerful magnet is placed to bias the sensor, so that the operating point of the sensor is on the linear portion of the characteristic curve.

The Conditioning Circuit (GM-CC) used to pre-amplify the GMR bridge sensor output in Fig. 3. The precision, low power instrumentation amplifier (INA118 from Burr-Brown) has a variable controlled gain resistance (RG). Its high common mode rejection is ideal because a common DC voltage is present in the two output pins. In this project the gain is fixed around 100 which provides a wide 70 kHz bandwidth. Both the sensor and the instrumentation amplifier power supply were protected with a coupling capacitor in order to reduce the noise.

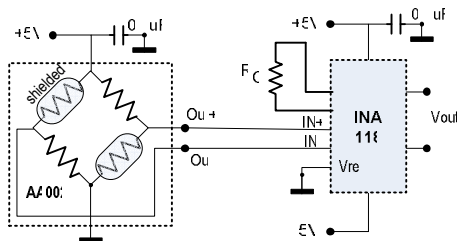


Fig. 3. GMR sensor with pre-amplification.

C. Current Generator

In order to guarantee an excitation current delivered to the excitation coil of the probe with constant amplitude and independent of the inductance's impedance (impedance depends on the frequency of the applied signal) a current source was implemented based on a power operational amplifier from National Semiconductors (LM 675) with

3 A maximum output current capability [8]. The circuit is represented on Fig. 4. It also includes an operational amplifier with negative feedback and the input is the voltage supplied by the signal generator (NI PXI-5406) integrated in the PXI chassis represented in the block diagram of the setup system depicted on Fig.1. The power amplifier has unity gain and acts as a voltage to current converter, as shown in Fig. 4. For power supply decoupling, 0.1 uF capacitors are used.

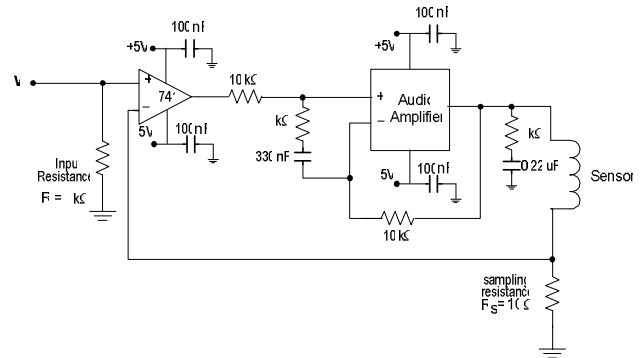


Fig. 4. Current source schematic.

The circuit has been tested using as load, ECPs having giant magnetoresistances or detecting coils as sensing elements. For the first case, a sweep frequency from 100 Hz to 1 kHz was used. When tested with inductive probes the frequency range is [1 kHz; 40 kHz].

Fig. 5 presents the oscilograms of the input voltage delivered to the circuit and the corresponding output voltage obtained (upper and lower signals, respectively) using an inductive probe and performing a frequency sweep from 1 kHz to 20 kHz. The circuit has a unity gain because the operational amplifier delivers a voltage to the load equal to the input voltage. So, the current which flows in the sampling resistor (R_s) will be the same as the one in the inductance and will be independent of its impedance.

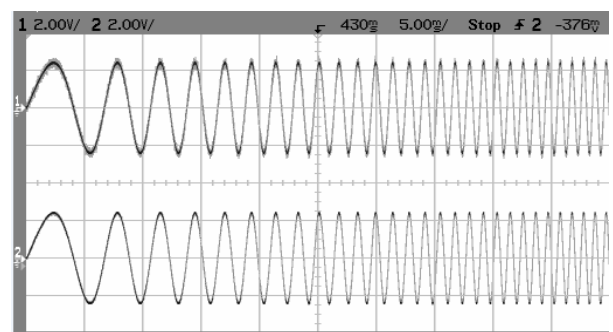


Fig. 5. Oscilograms obtained when a frequency sweep is performed.

3. MEASUREMENT TECHNIQUE

3.1 Data Acquisition

Two analog input channels of the data acquisition card (NI USB-9215) are used. One to measure the output signal (V_{out}) of the conditioning circuit (GMR-CC) represented in Fig. 3 and another to observe the voltage drop on the

sampling resistance (R_S) in order to measure the amplitude of the excitation current.

While the current source is permanently supplying the excitation current to the ECT, data is acquired only when a command is given. This procedure is initiated by clicking the mouse button of the probe set-up.

3.2 Retrieving the Position

After assembly the probe it was necessary to implement a system which locates the probe position at real time. Besides, as the ECT produces local signals, a scan of the surface is necessary in order to obtain the electromagnetic properties of the material under test. The cheapest and easiest solution is to attach the probe to an optical mouse. Using a program specially made in LabVIEW for this purpose, it is possible to correlate the cursor position in the screen to the real position of the mouse (Fig. 6).

When the mouse key is pressed two actions take place. One is retrieving the cursor's position and the other is to initiate an acquisition procedure.

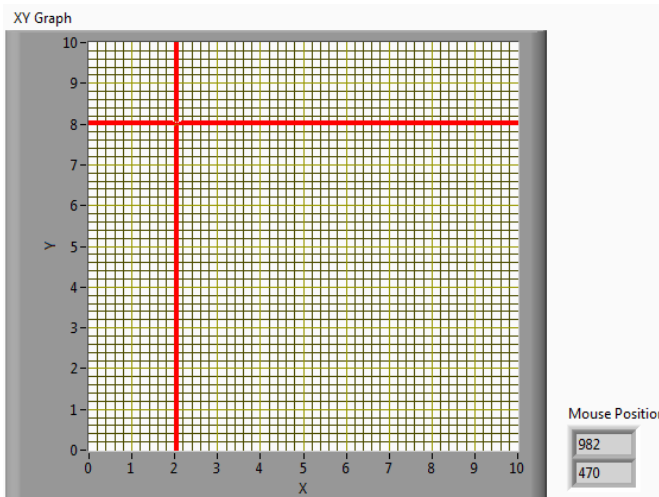


Fig. 6. Graphical display of the mouse position.

4. SIMULATION RESULTS

To clarify the nature of the eddy current density distribution when a plate of duralumin 2024 T3 with 1 mm thickness and a long rectangular crack in the center (1 mm x 23 mm) crossing through the plate thickness is scanned in a direction orthogonal to the crack, a commercial finite element program (FEM) from Opera® software was used [9]. The conductivity of the material simulated is $\sigma = 1.75 \text{ MSm}^{-1}$.

The excitation magnetic field is generated by a 100 mA, 5 kHz current that runs in a 240-turn copper coil having 16 mm of height, with internal and external diameters of 15.8 and 17.4 mm respectively. The FEM model uses 330837 second order tetrahedral elements with 389242 edges. The applied magnetic field is calculated using the Biot-Savart law. The metallic plate (40 mm x 60 mm) is enclosed in a spherical volume of free space with a diameter

1.5 times greater than the maximum plate dimension. An animation of the coil moving along the crack axis was developed. Fig. 7, Fig. 8, Fig. 9 and Fig. 10 present four simulations taken out of that animation. The point of view is underneath the plate and the excitation coil is moving from the right to the left side (in Fig. 10 the top of the coil when positioned at the left edge of the plate can be seen).

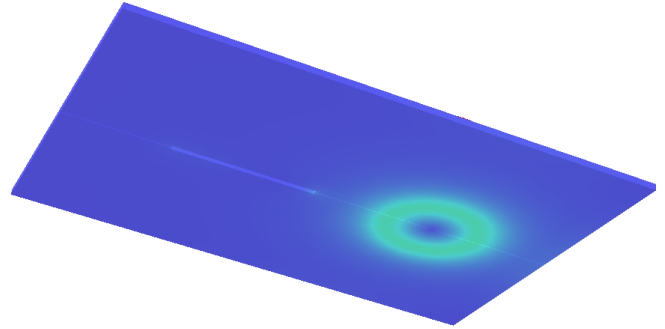


Fig. 7. 3D display of the current density when the excitation coil is outside the vicinity of the crack.

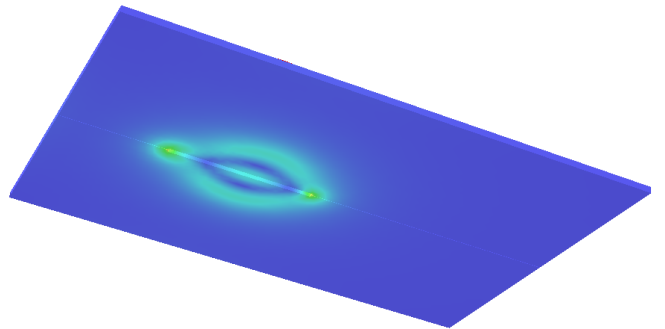


Fig. 8. 3D display of the current density when the excitation coil is on the middle of the crack.

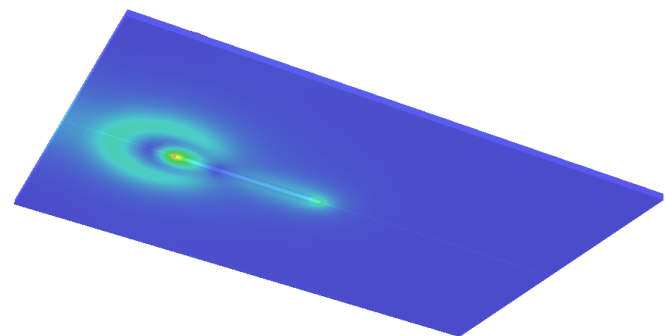


Fig. 9. 3D display of the current density when the excitation coil is leaving the crack region.

The figures show how the currents were distorted due to presence of the void space. It is possible to see that the current density attains maximum values at the slot ends. On the other hand, the current density near the lateral faces of the slot is much lower. These facts indicate that the determination of the length of the slot shall be easier than the determination of its thickness.

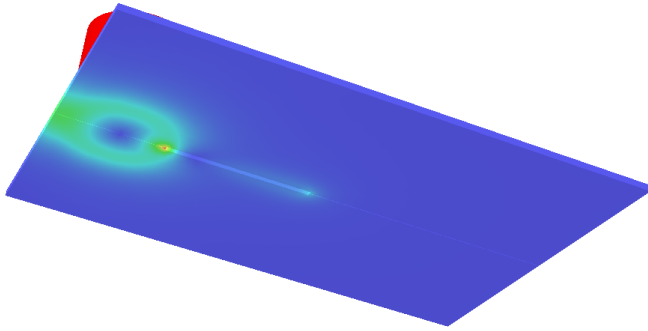


Fig. 10. 3D display of the current density when the excitation coil is leaving the crack region.

5. EXPERIMENTAL RESULTS

The experimental results obtained with the setup described in the previous sections for the simulations carried out are presented in Fig. 11. An aircraft plate of thickness 1 mm, made out of an aluminum alloy (Al 2024 T3) with a conductivity of 1.75 MSm^{-1} was used. On this plate there are artificial defects with different depths and widths. The mouse with the probe scanned the surface along a straight line parallel to a crack that perforates the plate (23 mm by 0.5 mm). The line scanned had 40 mm in length and was 3 mm away from the crack. A frequency of 200 Hz was used.

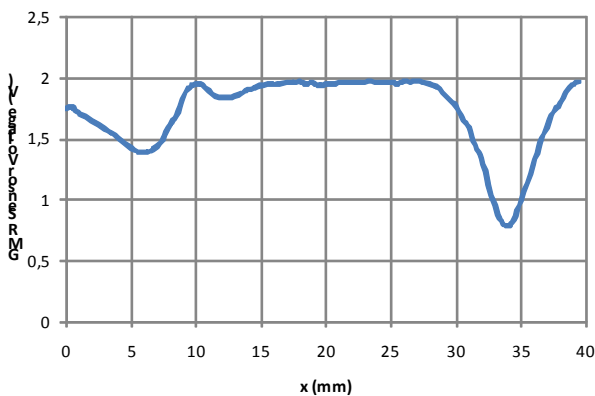


Fig. 11. Measured sensor voltage along a line parallel to a crack.

Two voltage deeps near the ends of the crack at $x = 7 \text{ mm}$ and $x = 33 \text{ mm}$ are visible in Fig. 11. The uncertainty associated with the location of the crack ends is $\pm 1.5 \text{ mm}$, as the maximum current density occurs not on the crack ends exactly but shifted as it is clearly shown in the bright yellow spot on Fig.9.

6. CONCLUSIONS

This paper presents a computer based system that enhances the performance of eddy-current inspection of non-magnetic metallic sub-surface cracks by scanning the surface with an ECT probe built-in an optical mouse. To clarify the results obtained finite element modeling was used to compute the eddy current density distribution in the material.

The probe uses a magnetic sensor based on GMRs. Thus high sensitivity is obtained without the higher frequencies required when detecting coils are employed. Thus sub-surface inspection is easier and can be carried out much deeper as higher field penetration can be obtained.

In the authors opinion and although only preliminary results have been obtained the scanning performed with the new ECP installed in the mouse is a very innovative idea that can be further explored. It is inexpensive and the use of GMRs allows it to surpass some drawbacks presented by the purely inductive probes.

ACKNOWLEDGMENTS

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