ECT CHARACTERIZATION OF A LINEAR DEFECT FROM MULTIPLE ANGLE MEASUREMENTS

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*Abstract-*This paper presents the characterization of a linear defect using the eddy current test (ECT) method with spatially uniform sinusoidal excitation. The eddy current probe includes a planar coil and a giant magneto-resistor sensor (GMR). To increase accuracy on the geometrical characterization of defects, measurements are performed at several rotation angles. The experimental magnetic field data obtained by scanning a given area is used to obtain the spatial eddy current distribution. For each scanning angle the eddy current map is obtained using an algorithm based on an image reconstruction technique solving the Biot-Savart inverse problem.

I. Introduction

Nondestructive testing (NDT) is a large group of analysis techniques used to evaluate the properties of a material without causing damage to the part under test [1]. For the purpose of detecting defects in a metallic plate, the eddy current testing (ECT) is an effective technique of detection [2], location [3] and characterization [4] of defects in a wide range of industrial activity such as aeronautic, naval or railway. The technique requires an excitation coil with a time-varying current to produce a magnetic field that penetrates metallic plates, inducing eddy currents in the conductor that produces a secondary magnetic field which carries information regarding defect characteristics.

In this work, an eddy current technique with GMR as magnetic sensor to sense the secondary magnetic field is used due to its directional characteristics and high sensitivity in a large frequency range (direct current to 1 MHz) [5-6]. An inversion problem algorithm is used to improve the characterization of the eddy current in the metallic plate. This algorithm is based on image reconstruction methods and involves the application of regularization algorithms [7].

II. System description

The system block scheme used in this work is depicted in Fig.1.The calibrator FLUKE 5700A is used to excite the coil included in the probe with a sinusoidal current with constant amplitude. This probe also includes a GMR sensor AA-002-02 from NVE capable of measuring the magnetic field along its sensitive axis. The probe is fixed to a XY positioning system with 0.05 mm resolution. The support that attaches the probe to the positioning system allows the rotation of the probe with 1 degree of resolution. The positioning system is controlled by the PXI system through a RS232 interface. A PC also controls the PXI system with RS232 interface. A multifunction data acquisition board included in the PXI System is used to measure the magnetic sensor output voltage. Fig. 2 depicts the implemented ECT probe used in this work. The geometry of the excitation planar coil produces a uniform magnetic field on an area of 25x20 mm around the GMR sensor, inducing a uniform eddy current distribution on the plate. In the presence of defects in the material surface, the lines of current inside the material are deviated from their uniform direction and the magnetic field produced by these currents is sensed by the GMR sensor.
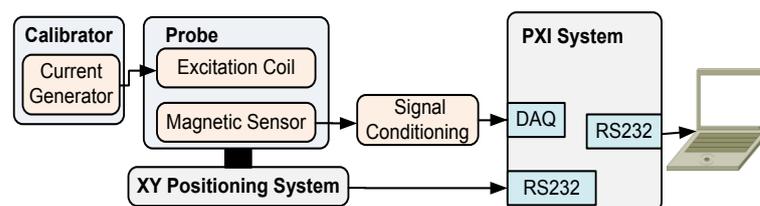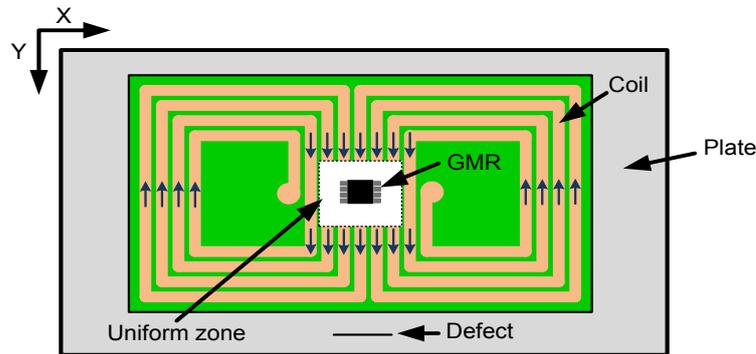

Fig. 1- Experimental Setup.

Fig. 2 – Schematic of the ECT probe.

III. Algorithm

The spatial eddy current distribution is obtained by processing a scanned area of magnetic field data from the GMR sensor. The minimization of the energy functional including a total variation term allows us to obtain the eddy current approximation by using a regularization algorithm. The solutions obtained by the total variation regularization algorithm were a minimizer of equation (1).

$$f(J) = \frac{1}{2}\|H - gJ\|^2 + \alpha TV(J) \tag{1}$$

where H is the observed data (magnetic field), J is the spatial eddy current distribution, g is the transformed kernel that maps the dipolar perturbation current density in the metallic plate into the measurable field component, $TV(J)$ is the discrete total variation norm and α the regularization parameter. This process uses an iterative algorithm called Two-step Iterative Shrinkage (TwIST) [8] that has a fast convergence rate for finding the problem solution.

The transformed kernel g depicted in Fig. 3 was based on the decomposition of the eddy current perturbation in unitary current dipoles using the Biot-Savart law and considering just the magnetic field axis sensed by the GMR. It maps the magnetic field of a unitary dipolar current.
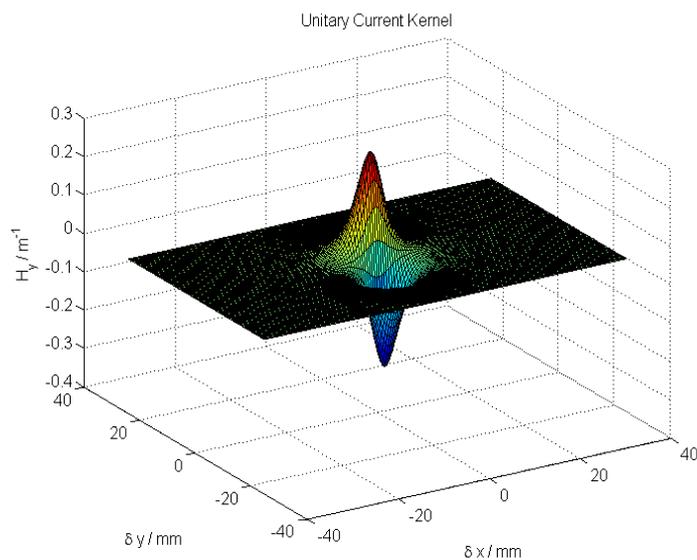

Fig. 3 – Graphic that maps the dipolar current kernel used in the transformation.

IV. Experimental results

The GMR sensor measures the magnetic field along its sensitive axis. This fact allows studying the magnetic field obtained with different angles of the GMR sensing axis in relation to a defect orientation. In this section, the angle between the longitudinal direction of a linear defect and the sensing axis of the GMR sensor is the angle present in the next result. Experimental results were obtained by scanning an aluminum plate with a linear machined defect with 2 cm length at a set of 6 rotation angles, from 0 to 90 degrees with 18 degrees steps. Fig.4 depicts the photographs of the defect scanned on the aluminum plate.
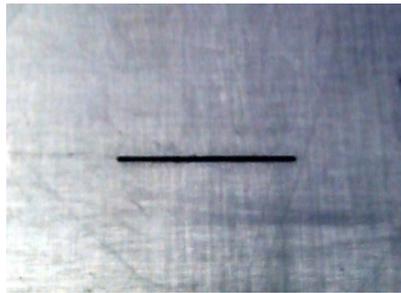

Fig. 4 – Linear defect machined with 2 cm of length.

Fig. 5 depicts the obtained results for 0, 36 and 90 degrees. The area scanned was 50×50 mm with steps of 1 mm that corresponds to the area where the perturbations of the magnetic field are present in the proximity of the defect. It is possible to observe that the different orientation of the GMR sensing axis in relation to the defect orientation clearly affects the measured results. Note that, due to the high sensitivity of the magnetic sensor, a three-parameter sine fitting algorithm was used to reduce the signal noise.
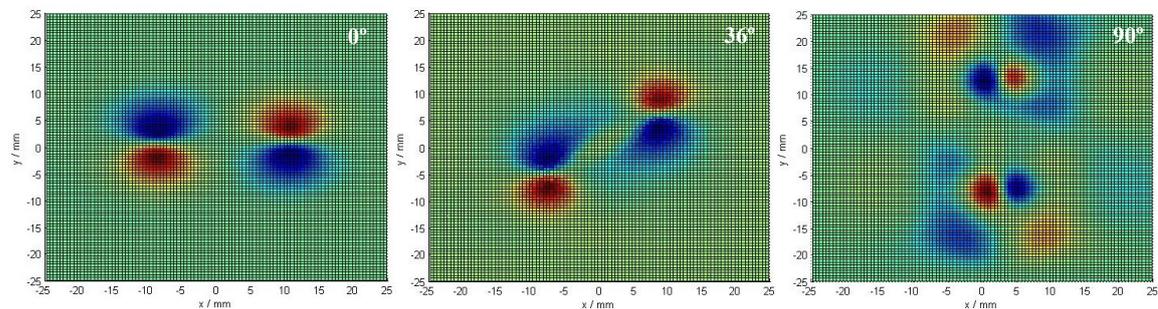

Fig. 5 – Magnetic field results obtained for three angles.

Fig. 6 depicts the normalized eddy current densities obtained by the inverse problem algorithm with total variation regularization for 0, 36 and 90 degrees of rotation angle.
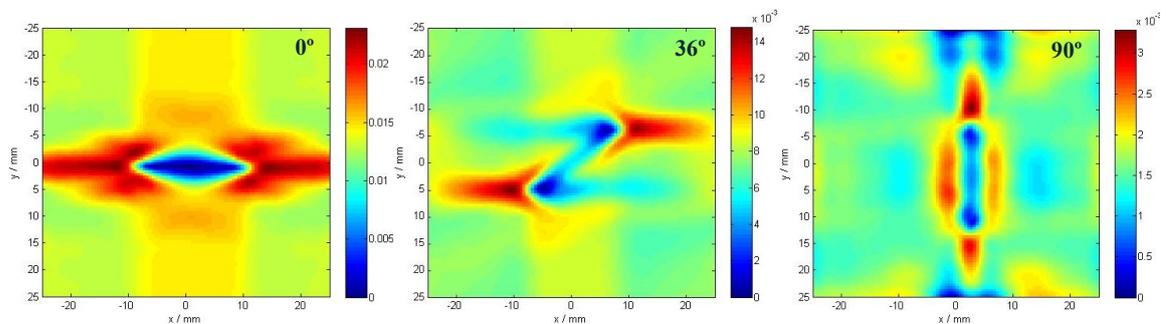

Fig.6 – Eddy current densities obtained for three angles.

The blue zone represented in Fig. 6 is a free-current zone, giving evidence of an obstacle that the electric current couldn't overpass. The dark red corresponds to a high current density in the ends of the defect.

Fig.6 was obtained by vector summing all the current densities after rotating the currents densities to the same angle.
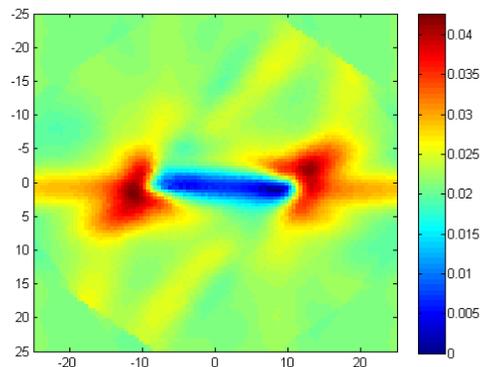

Fig.6 – Result obtained by the sum of EC densities.

It is visible in Fig.6 that the sum of all eddy current densities shows a better defect length measurement than with just one eddy current density map. However, it was also observed that the defect zone isn't parallel to the defect orientation when the orientation is 0 degrees. This may be associated to small image rotation errors when measuring the magnetic field.

V. Conclusions

The application of the total variation regularization allows us to obtain the reconstructed image of the eddy current distribution around a defect. The fact that the GMR has one single sensing axis allows the study the defect from different angles. As expected, the sum of all eddy current densities results in a well distinct area where the defect is defined. As future work the regularization parameters will be automatically calculated in order to reduce the human labor and the associated uncertainty. Also, it might be interesting to apply this method to different metals and defect shapes.

VI. Acknowledgments

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