Determining the 2D eddy current distribution with magnetic field measurements on two different directions

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Abstract

The magnetic field sensors based on the tunnel magneto-resistive effect (TMR) present enhanced characteristics such as the high sensitivity and a good linearity. They can distinguish the two orientations along a single direction of measurement and don't need a DC field to set the working point.
In this article we shall use TMRs to measure the small magnetic field in the context of an eddy current inspection of a planar aluminum material. The magnetic field disturbance due to the presence of a flaw is measured in two different directions, one parallel to the material surface and the other perpendicular to the surface. The measurements are performed in a rectangular zone, around a machined defect, and two data maps are obtained depicting two components of the perturbation field. Both maps are then subject to an inversion process, with regularization, in order to obtain the eddy current density. Both eddy current maps describe the same current, and must be fused to increase the accuracy of the current map. On the map the zones without any significant currents represent the defects with null conductivity.

Keywords: eddy currents; tunnel magneto-resistive sensors; inversion; regularization; data fusion.

1. Introduction

In this paper we use tunnel magnetoresistance sensors to inspect an aluminum plate, under eddy current method [1] with sinusoidal excitation at 5 kHz. For the purpose of this work we considered a thin plate with 1 mm of thickness that was inspected using a planar probe with two tunnel magneto-resistive (TMR) sensors. The aluminum plate contained a machined linear through defect with a length L=10 mm and width W=0.5 mm. The planar probe generates a uniform magnetic field inside a surface with area approximately equal to 4×4 cm^2. The probe generates a uniform eddy current at the aluminum surface that is directed across the linear effect. From now on we shall consider the defect oriented along the x-direction, and the applied excitation field is also oriented on the x-direction. The eddy currents are launched across the defect on the y-direction. Thus, the material surface is oriented parallel to the xy-plane. Two single-axis TMR sensors were used to measure the magnetic field along the y-direction, perpendicular to the defect and along the z-direction perpendicular to the xy-plane.

The general idea of the experimental side of this work was described in the last paragraph. In the next section we shall present and explain the two data field maps obtained directly from the experiments. In section 3 we preview the configuration of the current density on the material surface. The maps were inverted, by considering suitable transformation kernels.

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2. The acquired field maps

The measured field maps are represented in the next figures. Fig. 1 represents the amplitude of the field measured along the y-direction. Note that the excitation field is mainly directed along Ox, but a small part of the excitation also exists along Oy, and must be removed using adequate signal processing. Note that the real direction of the field By is positive on the first and third quadrants and negative on the second and fourth quadrants.

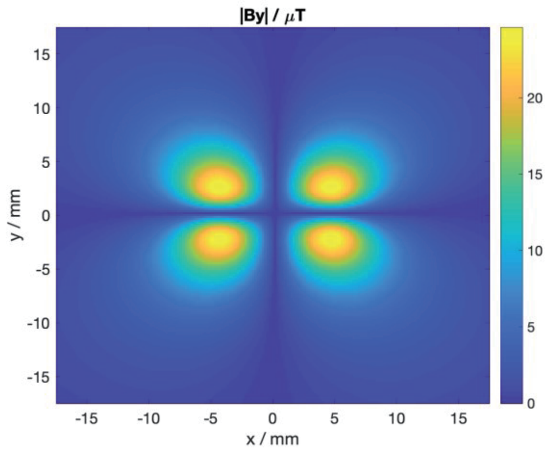

Fig.1 Map of the measured field component By.

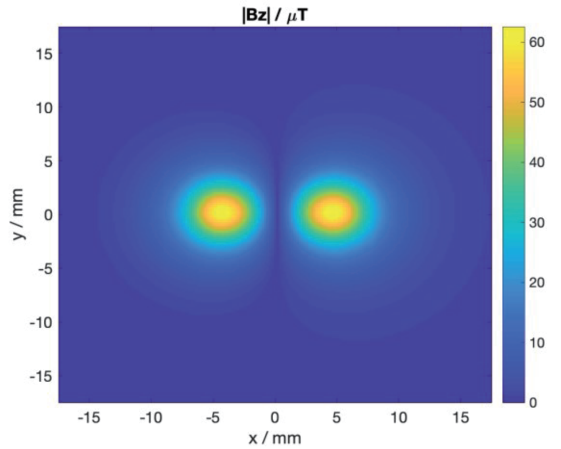

Fig.2 Map of the measured field component Bz.

Fig. 2 represents the field measured on the direction perpendicular to the plate surface. Two amplitude picks appear close to the defect tips, due to the higher current density. The eddy currents were launched in the positive Oy direction. Thus, in the presence of the defect the eddy currents curl anticlockwise around the right tip and clockwise around the left tip.

3. The field kernels used for inversion

The current density on the material surface is supposed concentrated on the surface and considered as the superposition of small square loops of current. Each square loop has dimensions exactly equal to the step used in the experiment to scan the plate.

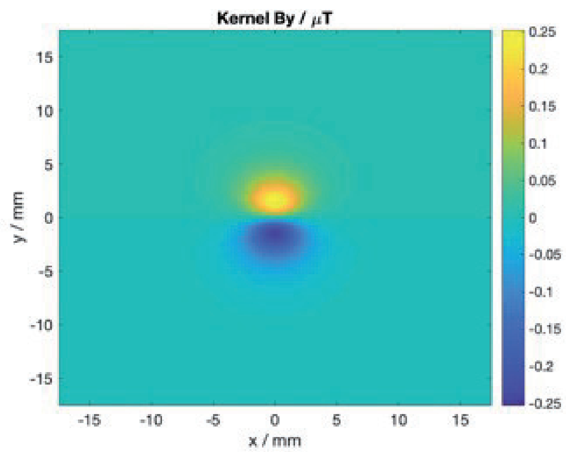

Fig.3 Map of the computed field kernel by.

Fig. 3 represents the magnetic field component **hy** produced, in the y-direction, by one loop of current. This is the direction of measurement of the TMS sensor. The kernel **hz** is not represented, but it is easy to understand that it consists of one positive pick in the middle of the map. The field that was effectively measured by the sensors may be arranged as a summation of the elemental fields of the small current dipoles.

$$\boldsymbol{H_y(i,j) = \sum_{k,l} h_y(i-k, j-l) I_d(k,l)} \quad (1)$$

In (1) I_d represents the current in the dipoles. From one single field map it is possible to invert the current map, using discrete Fourier transforms and a regularization method, such as the Tikhonov method.

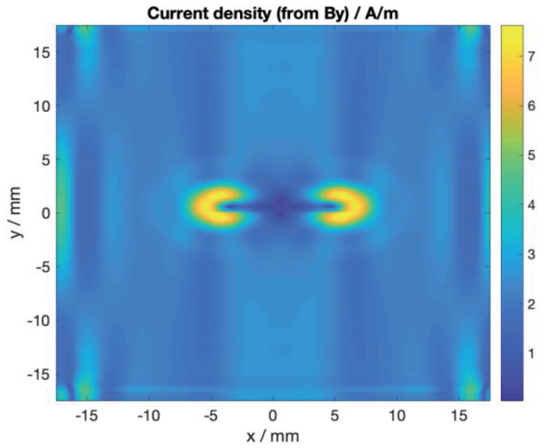

Fig.4 Current density reconstruction from map By and kernel by.

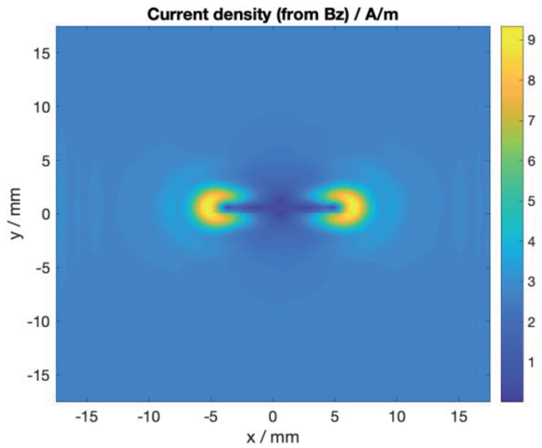

Fig.5 Current density reconstruction from map Bz and kernel bz.

Fig. 4 and Fig. 5 represent the current density obtained by the inversion of the two field maps, By and Bz.

4. Conclusion

To improve the image resolution, we decided to normalize the two amplitudes. Then we used an image fusion algorithm using discrete Fourier transforms [2]. This method benefits from the fact that we already computed those transforms in the inversion process. Then we also used mutual information concepts [3] to obtain the reduction of uncertainty of each one of the current density maps obtained separately.

By observation of the final result, it was easier to infer about the real length of the defect.

Acknowledgment

This work was developed at Instituto de Telecomunicações and was supported by the Portuguese Foundation for Science and Technology, project UID/EEA/50008/2019. This support is gratefully acknowledged.

References

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