15th IMEKO TC10 Workshop on Technical Diagnostics
Technical Diagnostics in Cyber-Physical Era
Budapest, Hungary, June 6-7, 2017

ECT with Uniform Current Distribution for the Inspection of Sub-surface cracks in Conductive Plates

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***Abstract* – This paper reports a study concerning the penetration of eddy current density in the material when sub-surface linear cracks exist. Simulations were performed for a set of different lengths and depths of the crack using a sinusoidal excitation current with uniform magnetic field distribution. The dependences between the length/depth of the crack and the magnetic field components (B_x and B_z) were analyzed.**

I. INTRODUCTION

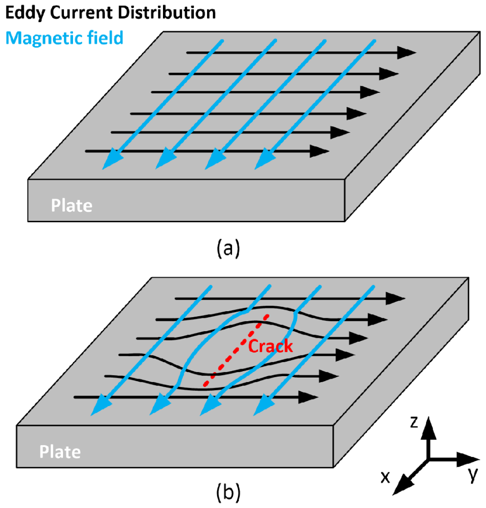
Eddy current testing (ECT) is an electromagnetic testing technique to detect and characterize surface and sub-surface cracks in conductive materials with a minimum preparation of the surfaces under inspection [1-3]. ECT requires a coil excited with a time-varying electric current to produce a time-varying magnetic field in the proximity of a conductive material. In that situation, electromagnetic forces are induced in the conductor and eddy currents are created inside the sample of the conductive material. In the vicinity of cracks, the eddy current distribution is perturbed and the resulting magnetic field changes. A magnetic sensor is used to measure the magnetic field perturbation, and it is chosen according to their characteristics, size and cost [4-5].

Due to the nature of the electromagnetic testing phenomena, the main disadvantage of this technique is related to its limited sub-surface crack detection at deeper levels [6]. Hence, it is essential to study the parameters that influence the penetration depth of the electromagnetic field into a conductive material. The eddy currents that flow in the metallic structure are sensitive to several factors, such as the material proprieties (conductivity and permeability), the test frequency, the lift-off effect [7], the edge effect [7, 8] and the dimensions of the crack. The flow of eddy currents in a conductor is maximum at the material surface and it is attenuated with increasing depth. For lower electrical conductivity or low magnetic permeability of non-ferromagnetic materials, the eddy current achieves deeper penetration. For a given material, the standard penetration depth (δ) defines the depth at which the current density decreases 1/e from the surface density amplitude [9, 10].

This paper presents simulation work to investigate the penetration quantities of eddy currents in the material when a coil is excited by a sinusoidal current with uniform magnetic field distribution to evaluate sub-surface cracks. The tests were performed for linear cracks with different lengths and depths.

II. CONDITIONS OF TEST

The simulations were computed for a 1050 aluminum alloy plate with 4 mm of thickness. Linear cracks with fixed width of 1 mm, different length and depth were studied. The tests were performed using a spatially invariant excitation field with sinusoidal excitation at a fixed lift-off value of 0.5 mm. This means that the eddy currents generated inside the conductor by induction were spatially uniform inside the restricted area, as depicted in fig. 1(a). The eddy currents close outside the indicated region. In the proximity of a crack, the eddy current distribution is perturbed and the magnetic field produced by the eddy currents changes, as depicted in fig. 1(b).



(a)

(b)

Fig. 1 - Representation of the uniform eddy current flow: (a) without defect presence; (b) with defect presence.

The components of the magnetic field (B_x and B_z) are obtained to evaluate the eddy current density depth profile in the conductive material for several linear crack sizes. The distance z considered between the obtained data and the sample plate was 2.2 mm.

III. NUMERICAL MODEL

The Finite Element Method software COMSOL® Multiphysics was used to evaluate the magnetic field components (B_x and B_z) in the proximity of a metallic plate containing sub-surface cracks. The physics used in this model was Magnetic Fields (AC/DC Module) with a frequency domain study type. A parametric sweep of the length and depth of the sub-surface defects were used in this study. The excitation was performed by imposing a uniform surface current density.

The type of mesh elements used in this model was tetrahedral. To obtain the magnetic field components, a series of points (straight line) was added at 2.2 mm above the surface of the plate. A small air block, as shown in fig. 2, was created surrounding the points where the magnetic field components were computed. The air block was meshed with high density elements in order to improve the accuracy of the results and minimize the error due to the interpolation. Fig. 2 depicts the defect, air block and the measurement points used in the model.

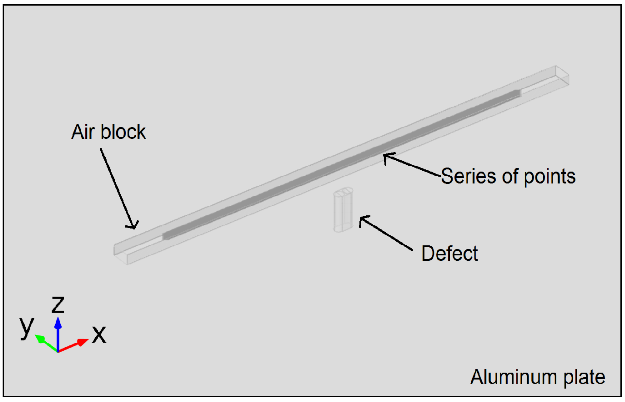


Fig. 2 - – Illustration of the defect, air block and series of points used in the model.

IV. RESULTS

The tests were performed for two crack depths (1 mm and 3 mm), and for fourteen different lengths (between 4 mm to 30 mm with steps of 2 mm) in order to study the eddy current density depth profile when sub-surface cracks exist in conductive materials. The simulations were carried out for fixed excitation current amplitude of 200 mA. For a standard depth of penetration equal to 4 mm, fig. 3 depicts the magnitude of the magnetic field component B_z obtained in a straight line of 40 mm above the cracks.

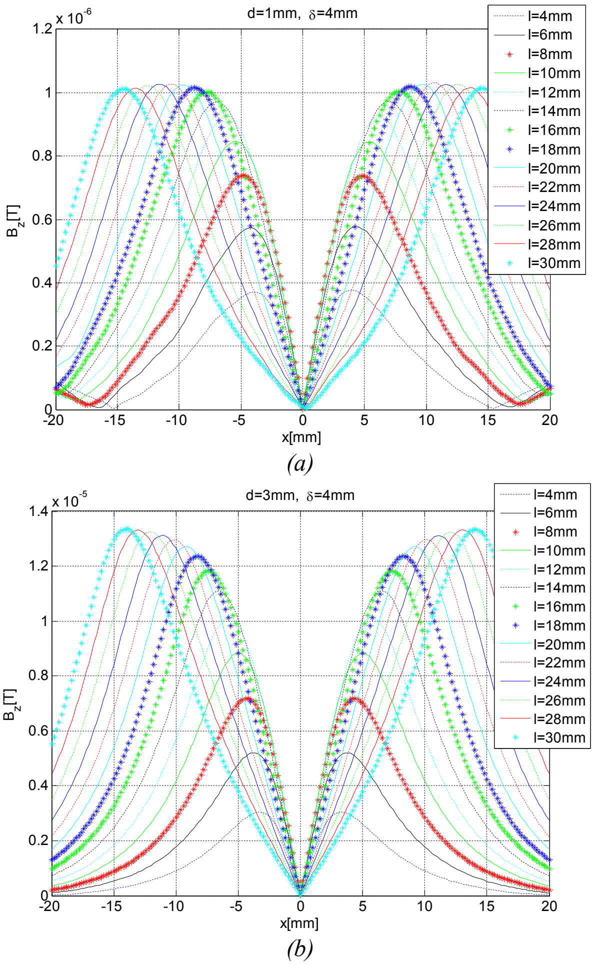
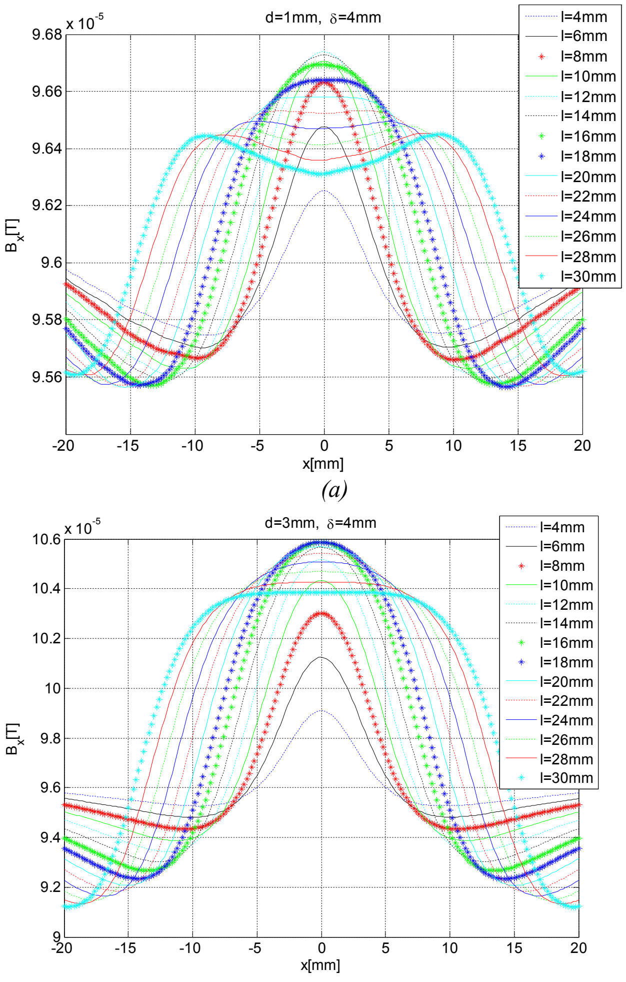


Fig. 3 - Simulated results of Bz obtained in a straight line above a set of different length (l); (a) Cracks depth equal to 1 mm; (b) Cracks depth equal to 3mm.

From fig. 3, it is possible to observe that the magnitude of B_z is directly related with the length (l) of the cracks, and with the depth (d) at the limit of the cracks. For long sub-surface cracks with 1 mm of depth, the magnitude of B_z tends to a constant value in the limit of the crack. This effect occurs due to the perturbed current flow change from going around the crack to crossing below it, because the current flow becomes the path of least resistance. So, this means that a higher current density region is created above the center of the defect for long sub-surface cracks. If the depth of the crack increases, this effect also occurs but the magnitude of B_z tends to a constant value for much longer cracks.

For the same excitation conditions, fig. 4 depicts the magnitude of the magnetic field component B_x obtained in a straight line of 40 mm above the cracks.



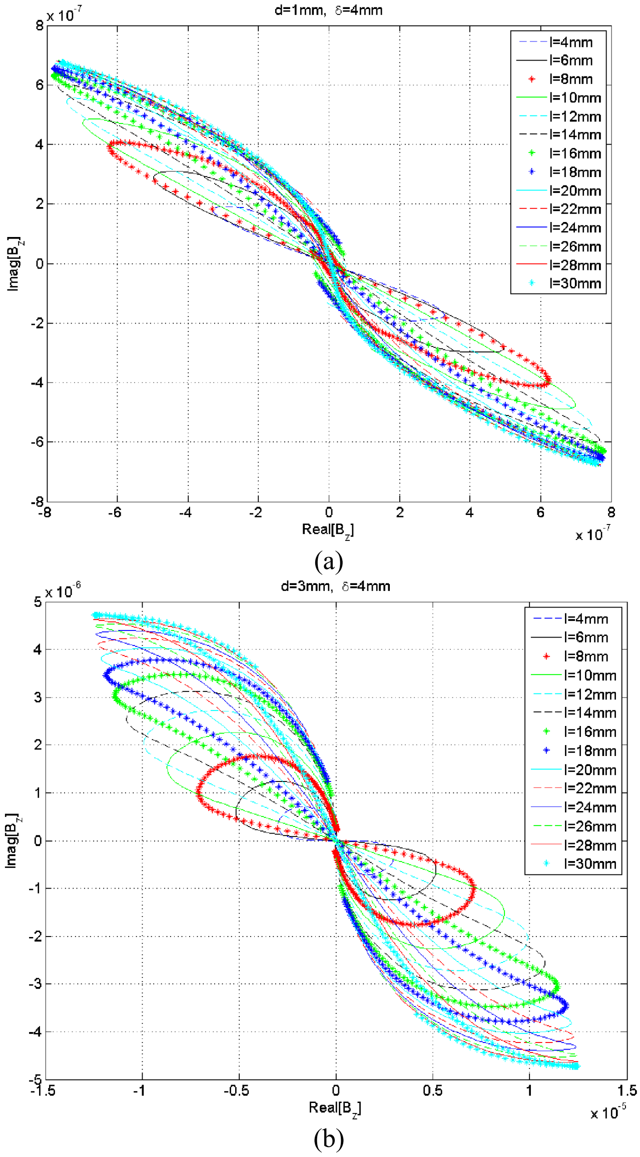
(a)

(b)

Fig. 4 - Simulated results of B_z obtained in a straight line above a set of length (l) of linear cracks; (a) Cracks depth equal to 1 mm; (b) Cracks depth equal to 3mm.

The obtained results indicate that the magnitude of B_x is directly related with the depth (d) of the crack in function of the length of the crack. Considering that the length of the crack increases, the magnitude of B_x in the center region of the crack increases for small sub-surface cracks. This means that a lesser current density region is created above the center region of the defect when the length of the crack increases. However, this effect is inverted for long sub-surface cracks. The point of inversion of the B_x curve matches with the constant value of B_z in the limit of the crack. As expected after analyzing B_z, this means that a higher current density region is created above the center of the defect after l=18 mm. This means that the intensity of currents that cross over or around a crack, depends on its length/depth ratio, and the components of magnetic field (B_x and B_z) provide complementary information to evaluate a crack in conductive materials.

Fig. 5 depicts the complex signatures (from B_z) obtained crossing the center of all sub-surface defect length, when an sinosidal excitation was applied with a frequency of 440 Hz (that corresponds to a standard depth of penetration equal to δ =4 mm). The results are presented for two crack depths (1 mm and 3 mm).



(a)

(b)

Fig. 5 - Simulated results of the complex signatures B_z obtained in a straight line above a set of length (l) of linear cracks; (a) Cracks depth equal to 1 mm; (b) Cracks depth equal to 3mm.

In both cases, the results show that the shape of the signature changes when defect length also changes. This feature can be used to classify sub-surface defect length in a range of known geometry defect.

As expected, the amplitude of the complex signatures for the sub-surface defect with 1 mm depth is smaller than the sub-surface defect with 3 mm depth. This is due to the reduced quantity of eddy currents that flow in the metallic structure at deeper levels. Comparing the two results (between 1 mm and 3 mm sub-surface defect depth), it is also possible to observe that the phase of the signature changes when defect depth also changes.

V. CONCLUSIONS

For sub-surface linear cracks, the penetration of eddy current densities in the material when a coil is excited by a sinusoidal current with uniform magnetic field distribution were studied and presented in this manuscript. The depth of the eddy current penetration is strongly dependent on the dimensions of the crack. The magnetic field components (B_x and B_z) provide complementary information, and both of them should be considered to evaluate cracks in metallic structures. The complex signatures can be used to classify sub-surface defect depth in a range of known geometry defect.

VI. ACKNOWLEDGMENTS

This work was supported in part by Project UID/EEA/50008/2013 - RELIM and the Project FCT PTDC/EEI-ELC/5811/2014. This support is gratefully acknowledged.

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