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EVALUATION OF SPATIAL COMPONENTS ON EDDY CURRENT TESTING RESPONSE SIGNALS OF SELECTED DEFECT PARAMETERS

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Abstract: *In this article, the presence of inhomogeneities in solid electrically conducting plate is inspected by non-destructive way with use of eddy current testing method where the perturbed electromagnetic field caused by the defect is detected. We perform three-dimensional finite element simulations of this structure with pre-defined material inhomogeneities and they are evaluated by an induction coil. This study is motivated by the novel eddy current testing technique which is based on sensing of all the three components of the perturbed field. Basically we performed parametric study to quantify the impact of various parameters - depth and electrical conductivity of the inhomogeneity. The analyses provide reference results to understand the effectiveness, feasibility and capability of this approach.*

Keywords: *spatial components, three-axes sensing, eddy current testing coil, material inhomogeneities*

INTRODUCTION

The importance of non-destructive testing (NDT) and evaluation (NDE) of the materials increase along with industrial development and the need of optimal and cost-efficient material consumption. The continuous assessment of material characteristics during the production process is used to increase the quality of the end product but also to avoid additional production costs. Controlling during the operation is valuable information. It can help to increase the overall reliability and maintain the required safety of the product. These requirements are followed by a strong demand on development of new NDT techniques which can overcome some of the limitations of already available techniques, [1].

Development of new testing techniques, which allow preventing functional losses, is still continuing and their number went up to over a hundred. Especially the electromagnetic methods are widely spread due to their simplicity and flexibility of application. Among these methods the eddy current testing (ECT) is predominant for examination of non (fero-) magnetic materials. It can be applied for detection of close-to-surface defect anomalies which lead to a change in electrical conductivity. The principle of this method lies in electromagnetic induction phenomena. When an alternating current is used to excite a coil, an alternating magnetic field is produced and magnetic lines of flux are concentrated at the center of the coil. Then, as the coil is brought near an electrically conductive material, the alternating magnetic field penetrates the material and generates continuous, circular eddy currents as shown Figure1.

As the penetration of the induced field increases, the eddy currents become weaker, therefore larger eddy currents are produced near the test surface.

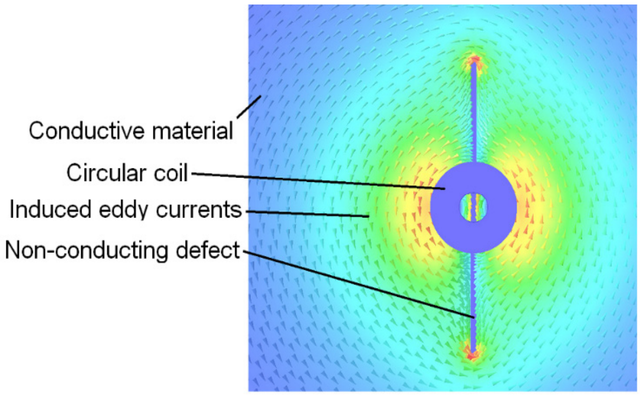

***Figure 1**. Distribution of the current field in a conductive material sample with non-conducting defect*

The induced eddy currents produce an opposing (secondary) magnetic field, Figure1. This opposing magnetic field, coming from the material, has a weakening effect on the primary magnetic field and the test coil can sense this change. In effect, the impedance of the test coil is reduced proportionally as eddy currents are increased in the test piece. Changes in the coil impedance (self inductance sensor) or in the induced voltage (mutual inductance sensor) due to a presence of discontinuity are sensed during mechanical movement of a sensor over an inspected region of a material. The main purpose is the detection and reliable characterization of defects or inhomogeneities.

Eddy current probe is the main link between an eddy current instrument and a component under the test. Success of eddy current testing for a specific inspection application depends on sensor, instrument and on selection of test parameters. The probe plays two important roles: it induces the eddy currents and it senses the distortion of their flow caused by the defects.

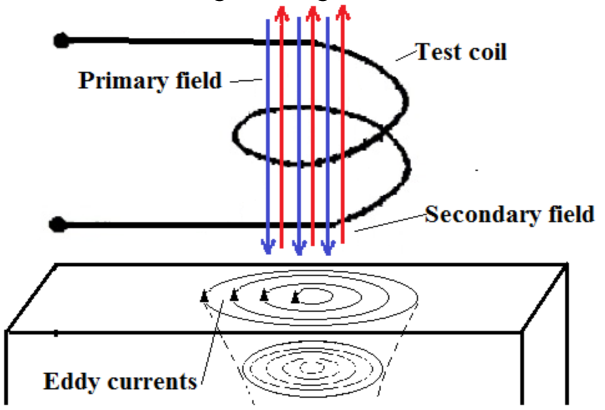

***Figure 2**. Basic principle of the ECT method*

The design and development of eddy current probes is very important as it is the probe that dictates the probability of detection, sensitivity, resolution and the reliability of characterization. Traditional eddy current testing methods based on excitation-detection coils is fundamentally limited by the lower sensitivity of the detection coils at low frequencies. Nowadays, different types of magnetic detection elements such as Hall sensors, SQUID, GMR, Fluxgate, AMR and others have been employed in order to increase the detection probability and the sensitivity. The main focus in these research areas nowadays is to increase the information value of the detected response signal to get more information about the dimensions of the material defect. For this purpose was used new approach where all the three (X, Y, Z) axes of electromagnetic field are sensed. These components are evaluated and analyzed by numerical simulations and their influence to different inhomogeneities parameters (depth, electrical conductivity) of all electromagnetic components is presented.

NUMERICAL MODELING

Definition of the problem

The model of the simulated problem was investigated by numerical way. Commercially available software for numerical analyses of electromagnetic fields OPERA 3D, based on the finite element method, is employed for the above-mentioned purposes.

The eddy currents are driven by a circular coil standard self-inductance probe, shown Figure3. The probe is positioned normally in a view of the plate surface with lift-off 1 mm. The coil is driven by the harmonic current with a frequency of $f = 10$ kHz and current density $J = 2$ A/mm^2.

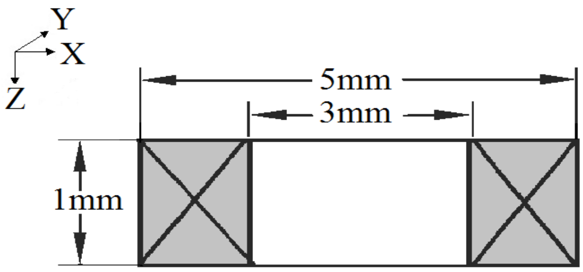

***Figure 3**. Dimensions of the coil*

Conductive plate specimen with a thickness of $h = 10$ mm and having the electromagnetic parameters of the stainless steel SUS316L is inspected in this study, shown Figure 4. The material has the conductivity of $\sigma = 1.35$ MS/m and the relative permeability of $\mu_r = 1$.

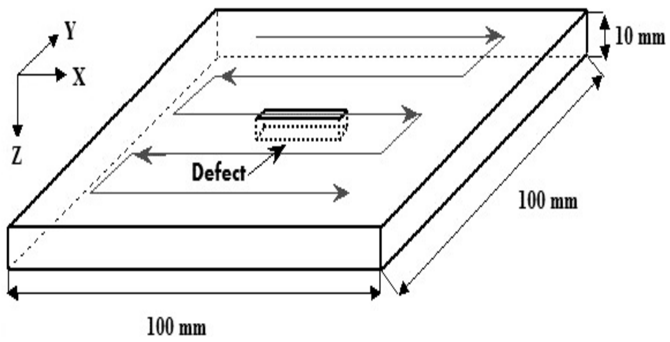

***Figure 4**. Dimensions of the inspected material*

The non-conductive defects with rectangular shape are modeled and positioned in the middle of the plate. The defects have a width of $w_c = 0.2$ mm, a length of $l_c = 10$ mm and their depth d_c and electrical conductivity are varied according to Table1. The electrical conductivity is changing from σ_d= 0% to 10% of the base material conductivity. These interpretations are used for modeling of the stress corrosion cracks. Only one parameter is varied in numerical simulations for one case, while other parameters are kept constant.

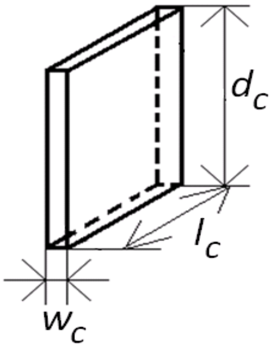

***Figure 5**. Dimensions of the simulated imhomogeneity*

***Table 1**. Change in parameters of the Defects*

Depth (d_c) [mm]	0	1	2	3	4	5	6	7	8	9
Conductivity [%]	0		1		2		5		10	

The inspection of the material is realized as a 2D scan. In order to assure a thorough inspection of the sample, the coil moves over the material surface in both X and Y axes as shown Figure 4. The three spatial components of the magnetic flux density vector B_x, B_y, B_z with respect to coordinate system are considered as response signals.

NUMERICAL SIMULATIONS RESULTS

Eddy current method does not provide a direct measure of the size or severity of the defects. The response signal is usually found by subtracting the reference signal from the one gained over a defect. A reference signal is collected over a defect-free region. Any flaws, defects, or conductivity and dimensional changes produce the changes in the response signal.

The peak value of gained differential response signals for all three spatial components of the magnetic flux density vector has been identified as an important characteristic of the response signals.

Figures 6-8 show the surface distribution of the maximum values of the differential response signals for all the three spatial components of magnetic flux density vector B. The surface distribution is different for different defect dimension and properties and it also influence the maximum value of each spatial component. The position of the maximum value depends on the analyzed defect parameter.

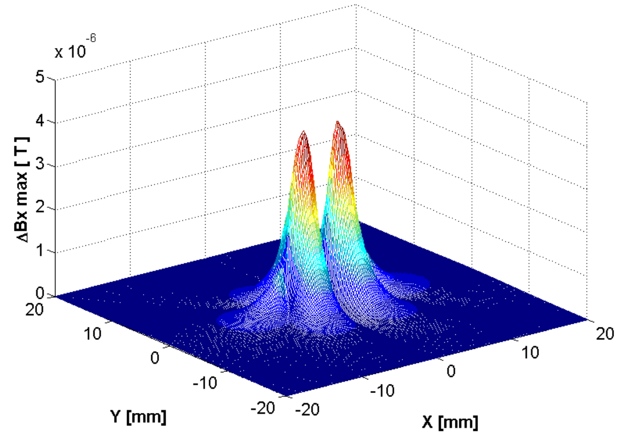

Figure 6. *Surface distribution of the differential signal Bx; defect 0.2x10x3mm, probe position x,y=[0,0]mm above a middle of defect*

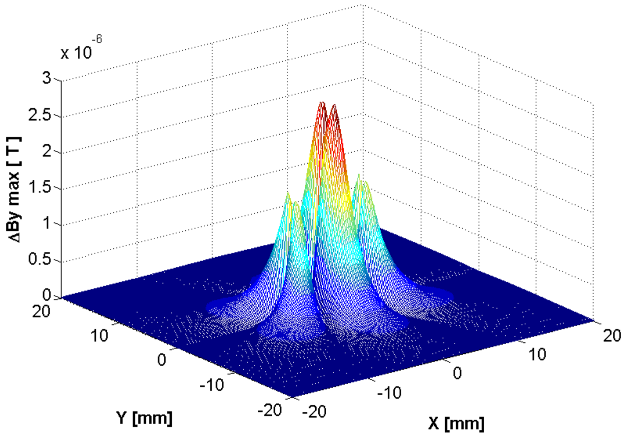

Figure 7. *Surface distribution of the differential signal By; defect 0.2x10x3mm, probe position x,y=[0,0]mm above a middle of defect*

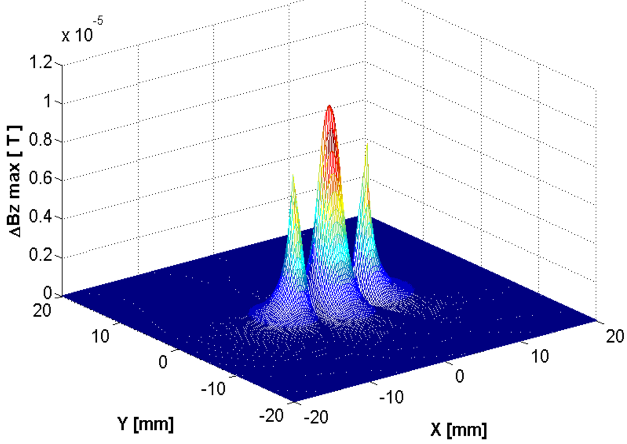

Figure 8. *Surface distribution of the differential signal Bz; defect 0.2x10x3mm, probe position x,y=[0,0]mm above a middle of defect*

Impact of defect parameters on response signals

The impact of defect parameters on responses is analyzed in this section. Real defects are mostly represented by fatigue cracks or stress corrosion ones. The area of fatigue crack is narrow and non-conductive, while the stress corrosion crack has more complicated structure, which is wider and particularly conductive. Hence, in numerical simulation the defect depth and electrical conductivity has been changed according to Table1.

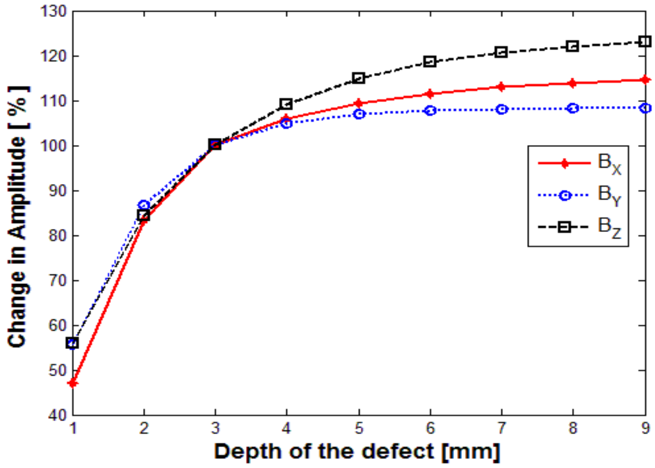

Figure 9. *The dependence of amplitude changes on depth of defect for each **B** component*

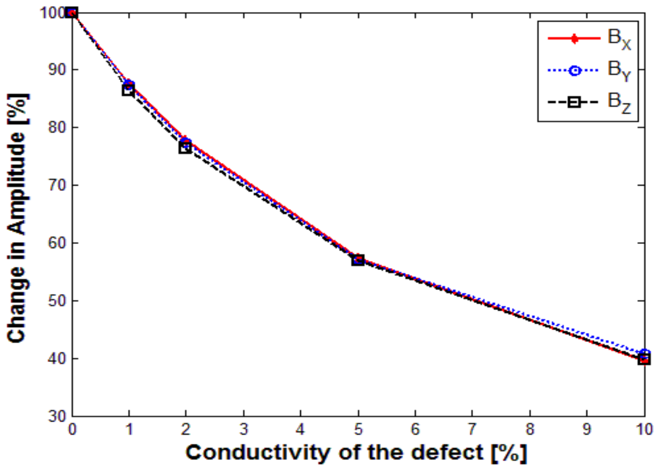

Figure 10. *The dependence of amplitude changes on conductivity changes for each B component*

Figure 9 and 10 demonstrate the parameters influence of real defects on each spatial component of the vector B. It can be clearly seen that these waveform varies for each component differently. With increasing depth of the defect the value of each component increasing, shown Figure 9. On the other hand with increasing the crack's partial conductivity the values for each component are decreasing and slowly settle down, Figure10.

Presented results clearly showed that each change in the defect parameters affect the distribution of eddy current density near defect, resulting in different values and different spatial components of the vector B. Spatial components of the vector B are not linearly dependent on each other and they reflect the specific parameter of the defect in slightly different way. These results confirm the expectation that in the investigation and identification of real defects *it would be beneficial to consider all three spatial components of the magnetic flux density vector.*

CONCLUSION

In the article the eddy current method of non-destructive evaluation was discussed. The exciting coil was used to perform simulated 2D scan above the inspected structure and surface distribution of all three spatial components of B vector was sensed and analyzed. The impact of various crack parameters on response signals was investigated by numerical way. From the presented results it is clearly obvious that all the three spatial components of the magnetic flux density vector significantly modify their distribution depending on the dimensions and electromagnetic properties of the crack and on the position of the excitation coil towards to defect. The obtained knowledge are of great asset to this work and it confirm the expected conclusion that for the investigation and identification of the real defects, it is necessary to take into account the spatial distribution of the sensed values of the field, because this significantly increases the information value of detected signals. Further work of the authors will be concentrated on realization of the simulation where the other parameters as width, length will change too. The unique response signal database from parametric analysis could be used in the future as a source of information for inverse problems solutions, where the geometry of the defect will be reconstructed.

ACKNOWLEDGEMENT

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