Finding a Crack Position in a Material on the Basis of Non-Destructive Testing with Eddy Currents

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Abstract — The purpose of this paper is to find geometry of a crack in a conductive plate, on the basis of non-destructive testing with eddy currents. Measured values of magnetic density in the centre of excitation coil are the input data. The position of a crack can be determined by taking into consideration the change in the magnetic density between the measured points. The depth is determined with use of the FEM model.

I. Introduction

The method of identifying and searching for a crack, with a non-destructive testing is all more widespread and important [1-4]. The position of a crack is determined on the basis of measurements. Measured values of magnetic density in the centre of excitation coil are the input data. The excitation coil is supplied with an alternating current. A program that defines a position of a crack in a material, is presented in the paper.

II. Measurements

The basis for geometry of a test case is geometry of the Team Workshop problem No. 8.

The test case is an aluminium plate with a crack, above which is an excitation coil. Plate with a crack and coil with marked dimensions are shown in Figure 1.

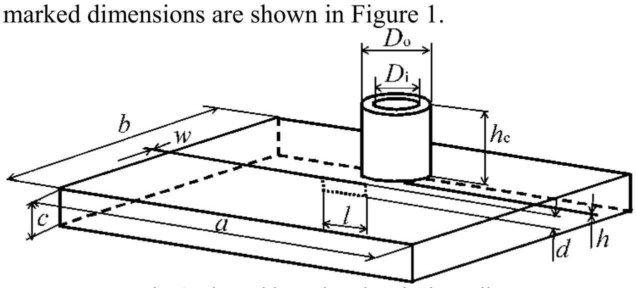

Fig. 1. Plate with crack and excitation coil

Plate thickness is c = 30 mm and dimensions a = 330 mm and b = 285 mm. The crack is in the middle of a plate. The position of a crack is determined with the help of a coil, that is placed at h = 7.8 mm above plate. The coil has 566 turns, inner diameter D_i = 36.8 mm, outside diameter D_o = 53 mm and height h_c = 56 mm. The coil is supplied with a sinusoidal current of 1 A and frequency of 500 Hz. The crack has a depth d = 10 mm, length l = 40 mm and width w = 0.5 mm. The measuring is only conducted with a z component (magnitude) of magnetic flux density in an axle of the coil at 0.5 mm above the plate.

Values obtained through measurements are shown in Figure 2.

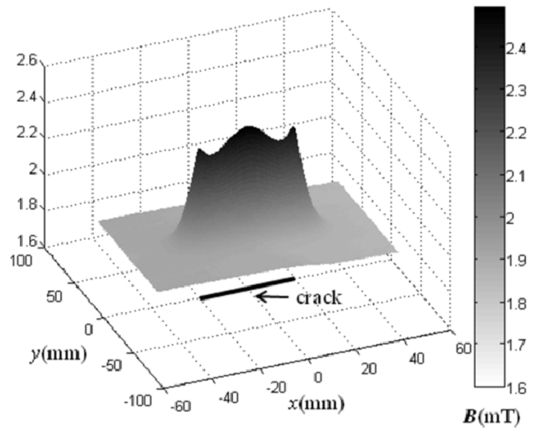

Fig. 2. Measured values above the crack size d = 10 mm and w = 0.5 mm

III. Determining a Crack Position and Length

The measured B_z are exemplified with plane, which shape is dependent from crack parameters (length, depth and width). That way the crack position is determined by considering the change in density – derivatives on the plane in measured points. In every measured point, the derivatives are calculated in the direction of neighbouring measured points, which are in eight directions.

During the measuring process, errors and discrepancies can occur which makes it difficult to determine a correct derivatives. Because of that, the approximation plane is calculated on the basis of each point and its eight neighbour points. The approximation plane is defined with (1).

$$F(x,y) = a_0 + a_1 x + a_2 y + a_3 xy + a_4 x^2 + a_5 y^2 + a_6 x^2 y + a_7 xy^2 \tag{1}$$

Coefficients $\boldsymbol{A}=(a_0, a_1, \ldots, a_7)^T$ are obtained with (2).

$$\boldsymbol{A} = \left(\boldsymbol{X}^T \cdot \boldsymbol{X}\right)^{-1} \cdot \boldsymbol{X}^T \cdot \boldsymbol{Y}^T \tag{2}$$

$\boldsymbol{X}$ is defined with (3) and $\boldsymbol{Y}$ with (4).

$$\boldsymbol{X} = \begin{bmatrix} 1 & x_1 & y_1 & x_1 y_1 & x_1^2 & y_1^2 & x_1^2 y_1 & x_1 y_1^2 \\ 1 & x_2 & y_2 & x_2 y_2 & x_2^2 & y_2^2 & x_2^2 y_2 & x_2 y_2^2 \\ & & & & \bullet & \bullet & \bullet & \\ 1 & x_9 & y_9 & x_9 y_9 & x_9^2 & y_9^2 & x_9^2 y_9 & x_9 y_9^2 \end{bmatrix} \tag{3}$$

$$\boldsymbol{Y} = \begin{pmatrix} B_{z1} & B_{z1} & \cdots & B_{z9} \end{pmatrix} \tag{4}$$

Approximated plane is shown in Fig. 3.

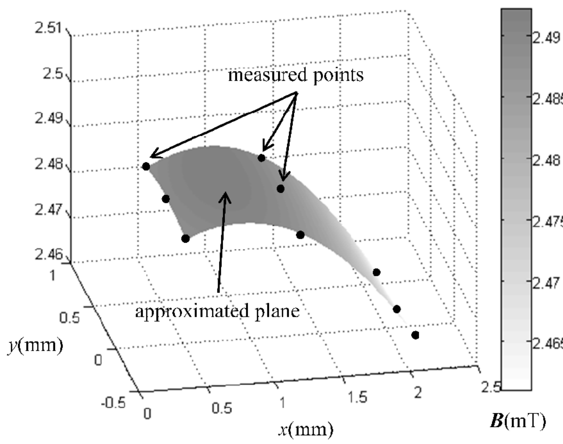

Fig. 3. Approximated plane

The derivatives from the center point towards to neighbouring eight points in the plane are analytically calculated and expressed as angles.

Obtained angles can be 0, positive or negative. If the magnetic density in neighbouring measured point does not change, then the angle equals 0. If it increased then the angle is positive and if it decreased the angle is negative.

In order to determine a crack, it is sufficient enough to know the maximum and minimum angle respectively derivative of the magnetic field density. The crack in the material occurs when the minimum angle is smaller than zero and maximum angle approximately equal to zero or when the minimum angle is smaller than zero and maximum angle is smaller than zero. During the calculation, a certain tolerance is taken into consideration since the plane of the measured values is not completely smooth.

Results obtained for the test example are shown in the Figure 4.

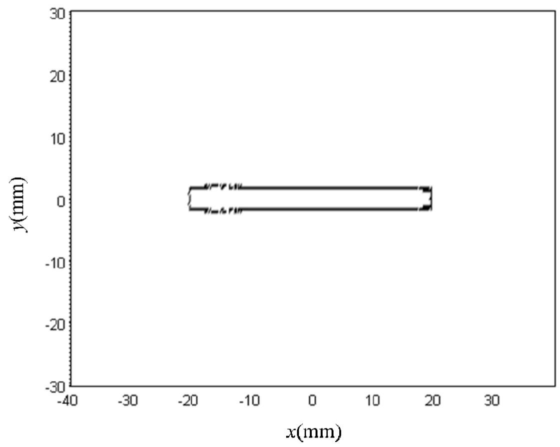

Fig. 4. Determined position of a crack

Based on a condition that $\varphi_{min} < 0$ and $\varphi_{max} \approx 0$ or $\varphi_{min} < 0$ and $\varphi_{max} < 0$ the course of a crack is obtained. The course of a crack is determined correctly. The obtained length of the crack on the Fig. 4 is 39.4 mm, which is correct value. The obtained width of the crack on the Figure 4 is not the width of the real crack.

Depth (*d*) and width (*w*) influence the course of density. The course of density above the crack can be more or less curved. The difference is mainly above and in the vicinity of a crack. The knowledge of this course, which is obtained from the measurement, makes it possible to determine *d* and *w*. A program has been developed that connects Finite elements model (based on the ***A***-*V*, ***A*** formulation) with the iterative method.

The secant procedure is used, where the direction of a derivative, expressed with quotient difference, approaches the result, written in (5).

$$x^{(k)} = x^{(k-1)} - \left(x^{(k-1)} - x^{(k-2)}\right)\frac{f\left(x^{(k-1)}\right)}{f\left(x^{(k-1)}\right) - f\left(x^{(k-2)}\right)} \quad (5)$$

Where *k* is iteration number.

In this case the function is $f(x) = f(d,w) = B_{calculated} - B_{measured}$. Because the function $f(d,w)$ is a function of two variables, it is alternately used to determine a new value *d* and *w*.

The crack is uniform and it would be sufficient enough to choose for the calculation of *d* and *w* only those points on one line transversely to the crack. Five points are chosen.

After 21 iterations we obtain the calculated depth d = 9.22 mm and calculated width is w = 0.66 mm.

IV. Conclusions

The length of the crack is found 39.4 mm. That is almost exact solution (the real crack is 40 mm long). The found depth is 9.22 mm, which deviates 7.8 % from the actual depth of 10 mm. The problem is poorly conditional in a sense of a search of the crack width, therefore the crack width 0.66 mm is only estimation.

The calculated example proves that good results can be achieved with a small number of points.

V. References

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