Detection of Surface Crack Using Eddy Currents

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***Abstract*—Induction eddy current testing of an axisymmetric workpiece is modeled. This problem is solved by a fully adaptive higher-order finite element method. Numerical computations are realized using own code Agros2D. The methodology is illustrated by a typical example whose results are discussed.**

I. Introduction

Due to the cost of new technologies and possible consequences of their failure, permanent monitoring of their integrity and functionality becomes more and more important. Non-destructive defectoscopy (NDD) plays an important role because there is no damage to the test sample and in most cases it is not necessary its disassembling into parts. NDD is a very popular technology for continuous monitoring equipment as well as for the evaluation of manufacturing processes.

The principle of non-destructive testing using eddy currents is based on the interaction of eddy currents and structure of the investigated body. Magnetic field generated by the source coil penetrates into the surface layer of the object to the effective depth. Eddy currents are affected by defects and other non-homogenities in the structure of the test sample. The electromagnetic field generated by the eddy currents can be detected by the same coil that is driven by eddy currents. Possible defects are then evaluated as changes of the impedance of the coil (see [1]–[3]). The impedance is not only influenced by the properties of the sample but also by the configuration of the coil and its distance from the surface.

II. Formulation of the Problem

The basic arrangement of the coils is depicted in Fig. 1. The investigated part is placed in the coil connected to a current source providing harmonic current of amplitude I and frequency f. The response from eddy currents induced in the sample is measured by the differential coil.

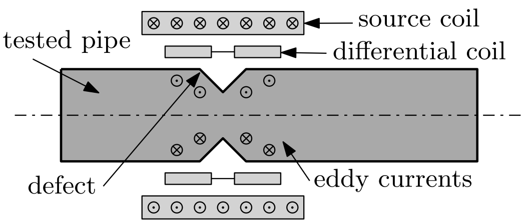

Fig. 1. Principal arrangement of system

III. Mathematical Model

The mathematical model of the problem is given by a nonstationary partial differential equation of parabolic type describing the distribution of the magnetic field in the domain. This equation for magnetic vector potential $\boldsymbol{A}$ has the form

$$\mathrm{curl}\ \left(\frac{1}{\mu}\mathrm{curl}\ \boldsymbol{A}\right) + \sigma\frac{\partial \boldsymbol{A}}{\partial t} = \boldsymbol{J}_{\mathrm{ext}}, \tag{1}$$

where μ denotes the magnetic permeability, σ is the electric conductivity and $\boldsymbol{J}_{\mathrm{ext}}$ stands for the vector of the external harmonic current density in the inductor. The solution to equation (1) is, in this case, practically unfeasible. The model should be simplified using the assumption that the magnetic field is harmonic. In such a case it can be described by the Helmholtz equation for the phasor $\underline{\boldsymbol{A}}$ of the magnetic vector potential $\boldsymbol{A}$

$$\mathrm{curl}\ \mathrm{curl}\ \underline{\boldsymbol{A}} + \mathrm{j}\omega\sigma\mu\underline{\boldsymbol{A}} = \underline{\boldsymbol{J}}_{\mathrm{ext}}, \tag{2}$$

where ω is the angular frequency. Eddy currents can be expressed in the form

$$\underline{\boldsymbol{J}}_{\mathrm{eddy}} = \mathrm{j}\omega\sigma\mu\underline{\boldsymbol{A}}.$$

The artificial boundary placed at a sufficient distance from the system is of the Dirichlet type ($\underline{\boldsymbol{A}} = \underline{\boldsymbol{0}}$).

IV. Numerical Solution

The continuous mathematical model given by the equation (2) is solved numerically. We used our own codes Agros2D [4] and Hermes2D [5]. While Hermes is a library of numerical algorithms for monolithic and fully adaptive solution of systems of generally nonlinear and non-stationary partial differential equations (PDEs) based on the finite element method of higher order of accuracy, Agros2D is a powerful GUI serving for pre-processing and post-processing of the problems solved. Both codes written in C++ are intended for the solution of complex coupled problems rooting in various domains of physics. They are freely distributable under the GNU General Public License v2.

V. Illustrative Example

The methodology is illustrated by an example of the defect of rectangular shape on the surface of an aluminum cylinder of diameter $\o = 35$ mm. The width of the crack $h = 3$ mm and depth $h = 1.25$ mm. Its arrangement is depicted in Fig. 2 (left part), while its right part depicts the measuring coil.

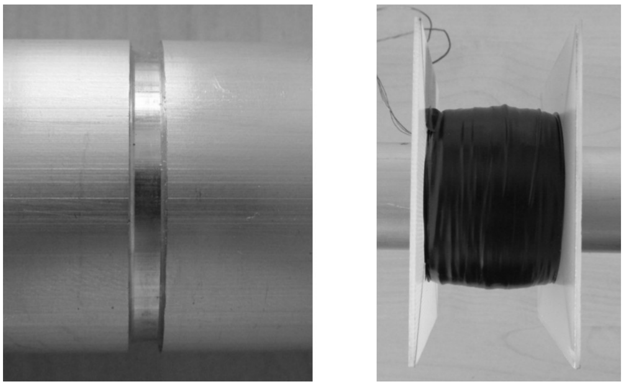

Fig. 2. Detail of defect and measuring coil

The cylinder is made of aluminum with electric conductivity $\sigma = 33 \times 10^6\,\mathrm{A/m^2}$. The coil with 400 turns is supplied with harmonic voltage $U = 2\,\mathrm{V}$ and frequency f between $1\,\mathrm{kHz}$ and $3\,\mathrm{kHz}$.

Figure 3 depicts the distribution of the magnetic field in the area of the defect.

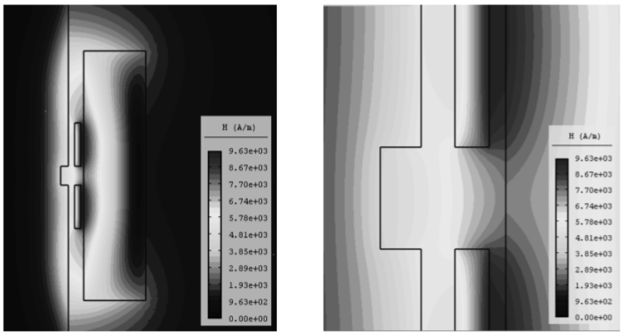

Fig. 3. Distribution of magnetic field in area of defect

VI. Experimental Verification

The principal scheme of the measuring chain is depicted in Fig. 4. The harmonic signal from function generator Tektronix AFG 3021 is amplified by power amplifier QSC RMX 850. The amplifier output is connected to the source coil, which generates in its surroundings a time-varying magnetic field.

The response to the excitation signal is measured by two coils in the differential connection (see Fig. 2 right) using amplifier AD620AN. The output signal is processed by the oscilloscope.

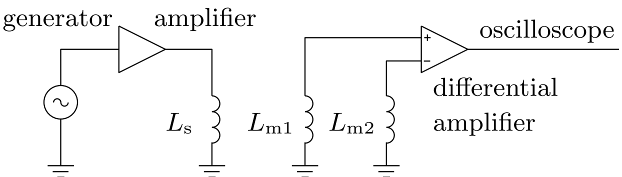

Fig. 4. Principal scheme of differential measuring chain

Figure 5 shows the dependence of the maximum current density in the measuring coil on the position. It is visible that the agreement between the numerical calculation and experimental measurement is very good.

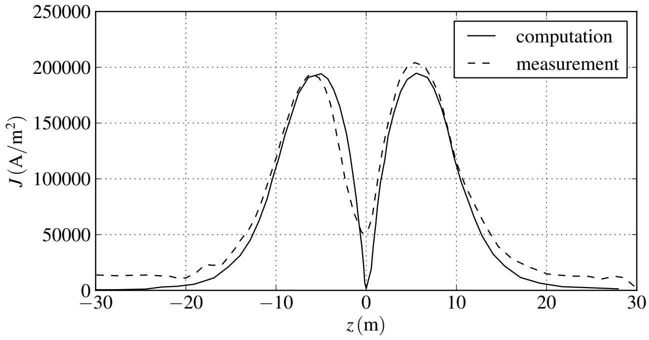

Fig. 5. Dependence of maximum current density in measuring coil on its position (origin is located in middle of defect)

VII. Conclusion

The numerical results are realistic and very well correspond with the measurement. The presented method is suitable for the detection of surface defects in the material.

Further work will be focused on creating an automated test environment using a computer.

Acknowledgment

This work was supported by the European Regional Development Fund and Ministry of Education, Youth and Sports of the Czech Republic (project No. CZ.1.05/2.1.00/03.0094: Regional Innovation Centre for Electrical Engineering - RICE), grant project GACR P102/11/0498 and grant SGS-2012-039 of University of West Bohemia.

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