INNOVATED EDDY CURRENT TESTING OF MATERIAL BY PROBE CREATED IN COMSOL MULTIPHYSICS SOFTWARE

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Abstract

This paper deals with Eddy Current Testing (ECT) based on swept frequency. This technique provides new possibilities in various fields of research. It connects successful electromagnetic method of non-destructive evaluation with technique using the fixed location of probe. The investigated plate is made of conductive material due to the requirement of this method. Concretely, an austenitic steel is employed in this study. This object contains three defects with rectangular shape, which are investigated by eddy current probe. The purpose of this work is a creation of numerical model of ECT probe in COMSOL Multiphysics for non-destructive testing of above mentioned material and a comparison of the signals obtained from different depths of defects.

1 Swept frequency eddy current technique

Eddy current testing is regarded as a successful method in a field of non-destructive evaluation of various conductive structures. This method is type of technique which investigates a object without damaging it. ECT is based on the phenomenon of electromagnetic (EM) induction using the formula,

$$\varepsilon = -\frac{\mathrm{d}\Phi_B}{\mathrm{d}t}, \tag{1}$$

where ε is the electromotive force and Φ_B is the magnetic flux density. The basis of ECT is a movement of investigated probe above material. It is considered to be a disadvantage for modern techniques. All methods of nondestructive testing involve the interaction of some form of energy with the inspected area and the monitoring of this interaction with measuring sensors. In the case of ECT the interaction is due to an inspection coil with a magnetic field coupling. This coupling is affected by the eddy current flow around the defect. In the standard approach, this is monitored by the change of induced voltage in the coil while the probe is moved above the inspected object with the defect. Principle of ECT is display in Fig. 1. [1], [2], [3].

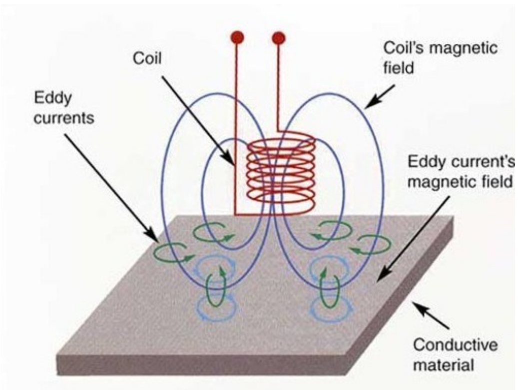

Fig. 1. Principle of Eddy Current Testing

Swept frequency eddy current technique (SFECT) connects this method with sweep frequency response analysis, which evaluates of material using the fixed location of probe. Consequently, it meets the substantial requirements of current approaches – the continuous monitoring of conductive material for a long time. SFECT evaluates the material based on the frequency responses of the sensor which are obtained in a wide frequency range. Frequency swept signals provide more complex information about the investigated objects, [4], [5], [6].

The resolving system created in COMSOL Multiphysics connects an analysis of EM field in frequency domain and circuit model. This model consists of the testing probe and feeding and measuring chains. Both equations - ordinary differential equation for the circuit model and partial differential equation for magnetic field are solved in the hard-coupled formulation.

The field equation (written in terms of the phasor $\underline{\boldsymbol{A}}$ of magnetic vector potential $\boldsymbol{A}$) reads

$$\Delta\underline{\boldsymbol{A}} - \mathrm{j}\omega\mu_0\gamma\underline{\boldsymbol{A}} = -\mu_0\underline{\boldsymbol{J}}_{\mathrm{ext}}, \tag{2}$$

where $\underline{\boldsymbol{J}}_{\mathrm{ext}}$ is the external current density, γ is the electrical conductivity of material, μ_0 is the relative permeability and $\boldsymbol{\omega}$ is the angular velocity. The distribution of the field quantities then gives the value of inductance and induced voltage for the circuit model.

2 Non-destructive testing by eddy current probe

The aim of this work is a evaluation of conductive material which consist three defects. Concretely, an austenitic steel SUS 316L is employed in this study. The material parameters of this object and its mesh are set to the same values during the all simulations. The conductivity of SUS316L is $\sigma = 1.4\text{x}10^6$ S/m and the defects are nonconductive. Values of relative permeability and relative permittivity is $\mu_r = \varepsilon_r = 1$.

Non-destructive testing by swept frequency eddy current technique is realized by eddy current probe with air core. This sensor contains two coaxial coils arranged one above the other. One of them - transmitting coil "Tx" excites of eddy current and it is located closer to the material. The second - receiving coil "Rx" is used to sense the responses. Dimensions and configuration of this probe are shown in Fig. 2.

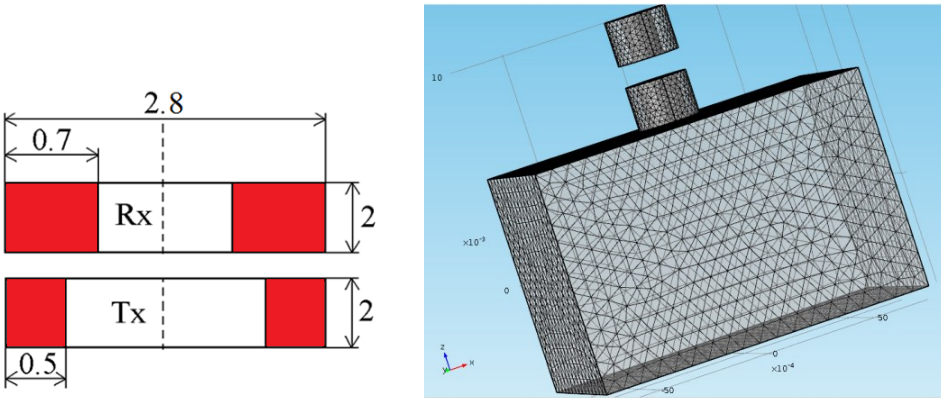

Fig. 2. Eddy current probe and its location above investigated material

Two measuring chains, it means a transmitting and receiving electrical circuits are created in COMSOL Multiphysics for each coil separately. The coil "Tx" is fed with a time-varying electrical current and generates a time-varying electromagnetic field. The voltage source represents the value of voltage $U = 1$V and impedance of power cable of high frequency generator is $Z_0 = 50\Omega$. This circuit model connects the mentioned chains with the high frequency representation of coil due to a large impact on the resulting signal.

3 Numerical simulations created in COMSOL Multiphysics

Non-destructive testing by the numerical simulations is performed in 3D COMSOL Multiphysics. Eddy current probe is employed for four simulations. One of them is realized in case of absent defect in investigated material. The remaining three simulations created by the presence of defects with different depth d = 1, 5 and 9 mm. The length of defects l = 10 mm and thickness w = 0.2 mm are the same for all numerical simulations. The resulting graphs display the voltage transfer u_2/u_1 in dependence on the excitation frequency frequencies $f \in$ <990 kHz, 1030 kHz>. The influence of one defect parameter – its depth is evaluated in this study. Different defect depths case the various deflection of resulting signals.

The evaluation of material without defect provides the highest deflection of signal and increasing of defect depth cases decreasing of resulting amplitude. All detections as shown Fig. 3 are successful and the difference in the displacement of resulting signals is visible.

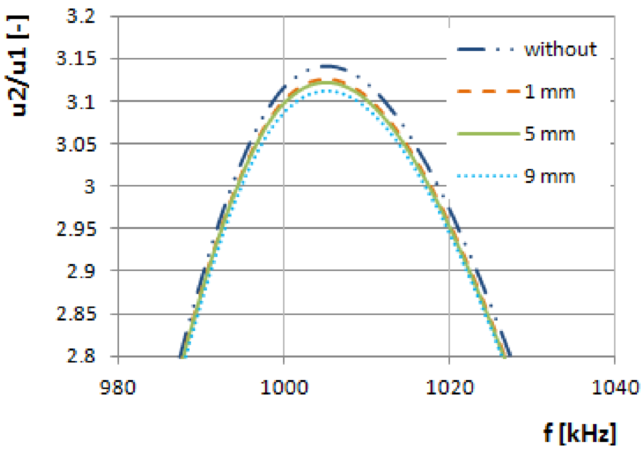

Fig. 3. Amplitude-frequency characteristics of ECT probe

4 Conclusion

Non-destructive testing by swept frequency eddy current technique represents the effective tool for evaluation conductive materials. This method meets of the requirements of current approaches due to fixed location of the investigated probe and possibilities of long-term monitoring.

This work deals with evaluation of austenitic steel with electro-discharge machined notches, which differ in their depth. The ECT probe created in COMSOL Multiphysics was positioned above material and frequency was changed. Resulting signals displayed amplitude frequency characteristic or the voltage-amplitude transfer u_2/u_1. Numerical simulations were realized in frequency range $f \in$ <990 kHz, 1030 kHz> and resonance frequency is f_R ~ 1 MHz. All defects were detected successfully and defect with the highest depth represented the smallest deflection.

This technique has a perspective in field of nondestructive testing, because it connects two effective methods, which are used in the different research areas.

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