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Impact of probe configuration on cracks depth resolution in pulsed eddy current non-destructive evaluation

***Abstract**. Pulsed eddy current non-destructive evaluation is concerned in the paper. Impact of eddy-current probe's configuration on response signals, especially on crack's depth resolution is numerically investigated. The induction coupling between a probe and a material affects information transfer between the probe and the material and consequently it influences the resolution of detected defects. Numerical simulations with various diameters of a coil are performed and evaluated to investigate impact of this parameter on resolution of defects with different depths.*

***Streszczenie.** Tematem artykułu jest defektoskopia bazująca na pulsujących prądach wirowych. Przeanalizowano wpływ geometrii próbki na rozdzielczość analizy głębokości szczelin. Przeprowadzono symulację numeryczną różnych średnic cewki czujnika. (**Wpływ geometrii próbki na możliwość wykrywania głębokości szczelin w defektoskopii bazującej na pulsujących prądach wirowych**)*

Keywords: pulsed eddy currents, probe configuration, response signal, depth of defect
Słowa kluczowe: prądy wirowe, defektoskopia, szczeliny.

Introduction

Different physical principles are utilised for the non-destructive evaluation (NDE) of materials. Eddy current testing (ECT) is one of the widely utilized electromagnetic methods [1], [2]. It originates from the electromagnetic induction phenomena and its principle underlies in the interaction of induced eddy currents with structure of an examined body.

Conventional eddy current technique employs harmonic continuous-wave excitation under only one or a few discrete frequencies. On the other hand, pulsed eddy current (PEC) instruments apply a broad-band pulse, or step excitation to a coil to generate a magnetic field pulse. This magnetic field pulse propagates into a conductive material, generating pulsed eddy currents that according to the Lenz's theorem oppose the exciting field. The net field which is the superposition of the exciting field and the field "reflected" by the induced eddy currents in the specimen can be detected by a coil.

The pulsed driving produces an inherently wideband frequency spectrum and accordingly permitting extraction of more selective information that cannot be obtained by performing the inspection using a single frequency [3]. This provides an opportunity for better resolution of defect signals from interfering signals and also more complex information about a specimen under inspection can be obtained. In view of further enhancing of PEC an optimal excitation system has to be designed. In PEC a test piece is coupled to an exciting coil through the electromagnetic induction. The induction coupling affects the information transfer and it relates especially to a lift-off (the distance between the coil and the surface of material under inspection), to dimensions of the coil as well as the coil's orientation. One should understand these relations in order to design high performance PEC probes.

Parametric study is carried out in the paper through numerical means. So called pancake eddy-current probe is used for the inspection. The probe is composed of only one circular coil that drives eddy currents in a specimen and pick-ups a response signal. Impact of selected parameters of the probe on the induction coupling between the probe and the specimen is investigated. The investigation is done indirectly through evaluation of the time constant of the coil coupled to the specimen. Influence of the coil diameter on the resolution of cracks with different depths is then evaluated.

Numerical simulation

A plate specimen having the electromagnetic parameters of a stainless steel INCONEL 600 with a conductivity of $\sigma = 1\ \mathrm{MS{\cdot}m^{-1}}$ and a relative permeability of $\mu_r = 1$ is used in this study. The dimensions of the material are length x width x thickness = 150 x 150 x 10 mm^3.

A circular coil shown in Fig. 1 drives the eddy currents in the specimen and pick-ups a signal. The coil is driven from a voltage source, while the voltage is changed in step from 0 to 10 V. The coil's current is considered as the response signal. Clearance between the coil and the plate surface, so called lift-off, is kept constant at 1 mm during the investigations.

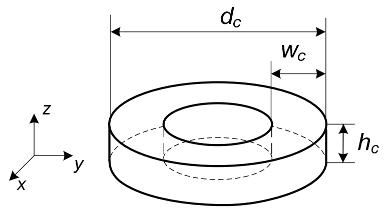

Fig.1. Configuration of the exciting coil

Coil orientation and dimensions

The influence of the exciting coil orientation regarding the plate surface on the induction coupling is investigated at first. Two particular orientations of the coil are considered here: a) normal position – the coil axis is perpendicular to the plate surface, b) tangential position – the coil axis is parallel to the plate surface. Particular results of time evolution of the coil current for the two orientations of the coil are shown in Fig. 2. The current response for the coil in free space is displayed in the figure as well. Dimensions of the coil for this case are according to Fig. 1 as follows: diameter d_c = 50 mm, width of winding w_c = 1 mm and height of winding h_c = 1 mm. It is clear from the presented results that the time constant of the coil coupled to the plate are different for the two orientations of the coil over the plate comparing to the self time constant of the coil (coil in free space). It means that the induction coupling is different for different orientation of the coil over the plate surface, while it is the strongest in the coil's normal position.

The investigations for the two orientations of the coil are also done for other coil's dimensions. Using transient analysis the time constant of response signals is computed and analyzed.

All the three coil's dimensions shown in Fig.1 are varied in wide ranges to study their impacts on the induction coupling. Figure 3 presents time dependences of the current for two values of the coil diameter d_c: 3 mm and 50 mm while the coil is in the normal position regarding the plate surface and the winding cross section is 1 mm^2.

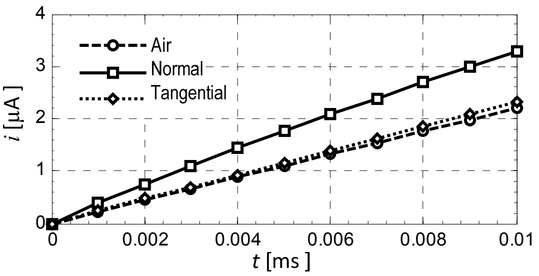

Fig.2. Time dependences of current for different orientations of the coil

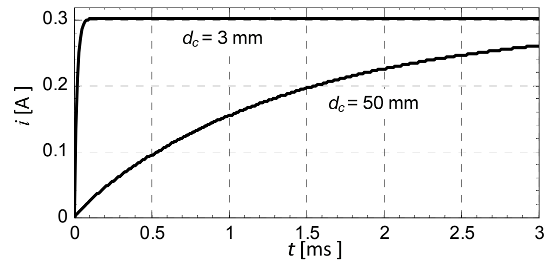

Fig.3. Time dependences of current for different diameters of the coil

Dependences of the response signals time constant on the coil diameter for different orientations of the coil are displayed in Fig. 4. With increasing the coil's diameter the time constant rises. For small diameters of the coil it is quite difficult to observe differences between plots for various positions of the coil; however, with increasing of coil's diameter the differences gets larger. It can be observed that for the larger coil's diameter the difference between the time constant for the normal position of the coil and the coil in air is larger comparing to the tangential position and the air. It means that the induction coupling is stronger for the normal position of the coil comparing to the tangential one while the coupling increases with increasing the coil's diameter.

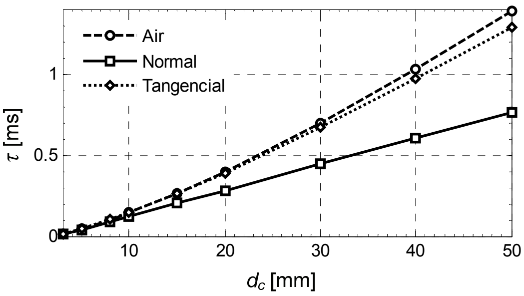

Fig.4. Time constant dependences on the coil diameter

Dependences of the time constant of response signals on the winding width w_c for different locations of the coil are shown in Fig. 5. The diameter of coil is set to d_c = 50 mm and the winding hight is kept at h_c = 1 mm in this case. One can observe that by increasing the winding width the time constant decreases and hence also the induction coupling.

The dependences of the time constant on the winding height h_c for various orientations of the coil are shown in Fig. 6. The other two coil's parameters are adjusted as follows: the diameter d_c = 50 mm and the winding width w_c = 1 mm for these investigations. The presented results demonstrate that increasing height of the coil's winding decreases the time constant and the induction coupling as well.

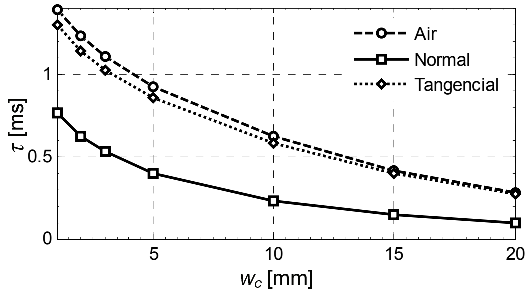

Fig.5. Time constant dependences on the coil winding width

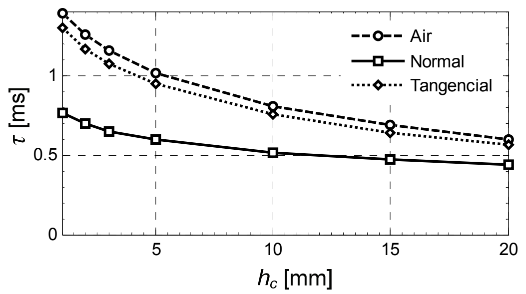

Fig.6. Time constant dependences on the coil winding height

It can be concluded from the results shown above that the coil oriented in the normal position with larger diameter and small winding cross section provides stronger induction coupling with the plate and accordingly more information can be gained about the inspected plate.

Resolution of the defect

The resolution of a defect with different depths according to the response signals is then investigated. Influence of the coil diameter on the resolution is studied. The defect has a shape of cuboid with a width of w_d = 0.2 mm, a length of l_d = 10 mm and its depth changes in a range d_d = 1÷10 mm with a step of 1 mm. The defect is situated in the middle of the plate and the coil is situated just over its centre as shown in Fig.7.

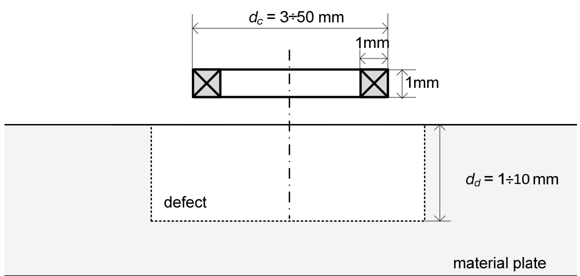

Fig.7. Configuration of numerical model and exciting coil

The exciting coil is positioned normally regarding the plate's surface. The width w_c and height h_c of the coil's winding according to Fig. 1 are kept constant each at a value of 1 mm, whilst the coil diameter is changed in the range d_c = 3÷50 mm. The coil current is sensed as the response signal (see Fig.3). However, the changes in signal due to different depths of the defect are relatively small and it is difficult to observe them from the response signals. Therefore, the difference signals obtained by subtraction of the response signals with crack and without crack are evaluated. The example of difference signal for a 2-mm-deep crack using a 3-mm-diameter coil is displayed in Fig.8.

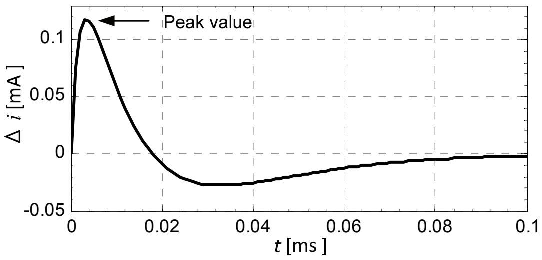

Fig.8. Difference signal for crack's depth 2 mm using 3-mm-diameter coil

One of the important parameter used for crack's characterization is the maximum value of the difference signal (called also peak value) as it strongly depends on the crack depth [4]. Figure 9 shows a dependence of the maximum value of the difference signal on the crack depth gained using 3-mm-diameter coil. The curve determines crack's depth resolution. It can be seen that the resolution of crack's depth from the response signal decreases when the crack gets deeper due to the skin-effect. It means that it is difficult to evaluate defect's depth from the response signal when the crack is deeper that approximately 4 mm.

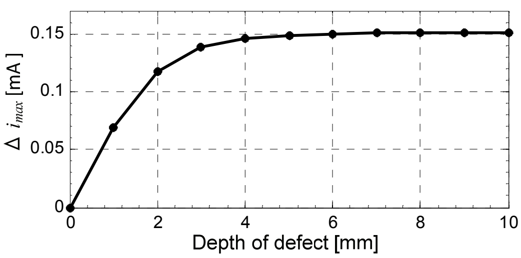

Fig.9. Dependence of difference signal's maximum values on the crack's depth for 3-mm-diameter coil

However, the resolution of the crack's depth from the response signal strongly depends on the coil's diameter. With increasing the coil diameter, the maximal value of difference signal decreases as it is shown in Fig. 10 for the 50-mm-diameter coil. Moreover, when comparing the dependences in normalized values shown in Fig.11, it can be seen that the resolution of defect does change so drastically within an investigate range comparing the results for the 3-mm and 50-mm-diameter coil. This finding could be essential for evaluation of deeper cracks. From previous work of authors it is known, that the best results in defect detection are obtained when the coil size is comparable to the crack dimensions. It is possible to catch the most useful information about a crack.

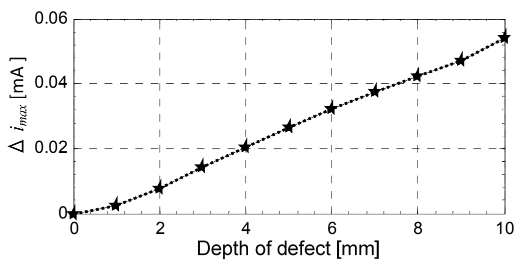

Fig.10. Dependence of difference signal's maximum values on the crack's depth for 50-mm-diameter coil

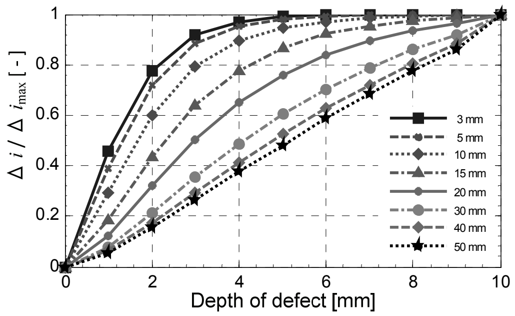

Fig.11. Dependence of normalized difference signal's maximum values on the crack's depth for varyous coil's diameter

Conclusion

The paper was focused on impact of exciting coils configuration on the response signal in pulsed eddy current non-destructive inspection. Especially, resolution of defects with different depths was concerned. It can be concluded from the results that the coil oriented in the normal position with larger diameter and small winding cross section provides stronger induction coupling with a conductive material sample. The induction coupling has impact on information transfer between a probe and an inspected material and thus it influences the resolution of detected cracks.

Cracks with different depths were inspected with coils having different diameters. Using a small-diameter coil the resolution of deeper defects is worse comparing to a larger-diameter coil where the investigated feature of response signal shows almost linear relationship to the crack depth within an investigated range. In the design of new ECT probe it is necessary to take into account size of expected cracks and appropriately select the dimension of the exciting coil.

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