<Original Paper>

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Parametric Study of Rectangular Coil for Eddy Current Testing of Lamination

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Abstract Eddy current testing (ECT) is an important nondestructive testing technology for the inspection of flaws in conductive materials. However, this widely used technology is not suitable for inspecting lamination when a conventional pancake coil is used because the eddy current (EC) generated by the pancake coil is parallel to the lamination and will not be perturbed. A new method using a rectangular coil placed vertical to the work piece is proposed for lamination detection. The vertical sections of the rectangular coil induce ECs that are vertical to the lamination and can be perturbed by the lamination. A parametric study of a rectangular coil by finite element analysis was performed in order to examine the capability of generating vertical EC.

Keywords: Eddy Current Testing, Rectangular Coil, Vertical Eddy Current, Finite Element Method

1. Introduction

Eddy current testing (ECT) is a nondestructive testing (NDT) technique that is based on the principle of Faraday's law of electromagnetic induction to inspect flaws in conductive materials [1]. If a flaw in the material perturbs the eddy current circulation, the magnetic coupling between the probe and the work piece is changed and a flaw signal can be read by measuring the variation of coil impedance or voltage [1,2].

Comparing with the other NDT methods, ECT has special advantages and characteristics, such as:

(1) Being sensitive to surface flaws and near-surface flaws.
(2) The contact of the probe and the measured work piece is not required and there is no need to use couplant which is necessary in ultrasonic inspection, allowing ECT be performed under high temperature.
(3) Suitable for automated testing and the saving, replaying, and processing of data are easy.
(4) The testing speed can be high.

However, ECT using conventional pancake coil is difficult to find lamination in conducting plate as the eddy current (EC) induced in the plate is parallel to lamination and will not be perturbed by lamination. This paper uses rectangular coil to detect lamination and makes use of the vertical sections of rectangular coil to generate EC that is vertical to lamination. The perturbation of vertical EC by lamination makes it possible to detect lamination. To improve the capability of generating vertical EC, the paper conducts parametric study of the rectangular coil by finite element (FE) analysis. The simulation software is self-developed and based on the A_r, $V-A_r$ formulation where A_r and V stand for the reduced magnetic vector potential and the electric scalar potential, respectively [3].

2. Vertical EC Method

Before introducing the vertical EC method, the principle of ECT is reviewed.

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2.1. Principle of ECT Using Pancake Coil

As shown in Fig. 1, according to the principle of electromagnetic induction, when an excitation coil with AC approaches the surface of a conductor, EC is generated inside the conductor because of the alternating magnetic field generated by the excitation current. The EC generates another alternating magnetic field which hinders the change of the magnetic flux through the excitation coil, changing the impedance and voltage of the coil. The physical properties of the conductor, such as conductivity, permeability, shape, size and flaws, determine the distribution and intensity of the EC, and then decide the change of the impedance and voltage of the coil. Therefore, flaws or the changes of the physical properties of the conductor can be speculated indirectly by observing the change of the impedance or voltage of the coil [4].

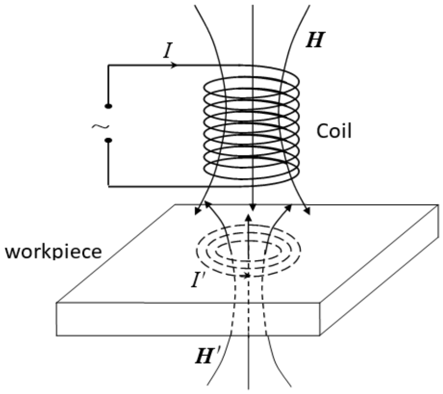


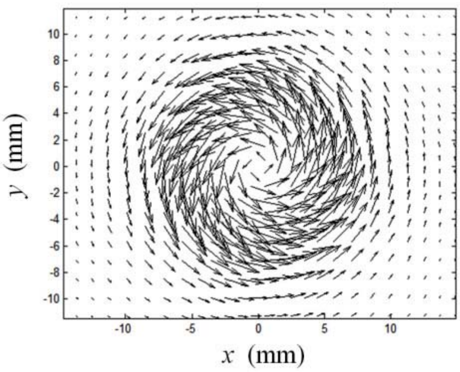
Fig. 1 Principle of ECT

Fig. 2 shows the EC in aluminum work piece excited by a pancake coil frequently used in ECT where z is normal to the surface. The EC is parallel to the surface of the material. If there is lamination of small thickness parallel to the surface, the EC will not be significantly perturbed, which makes the detection of lamination very difficult.

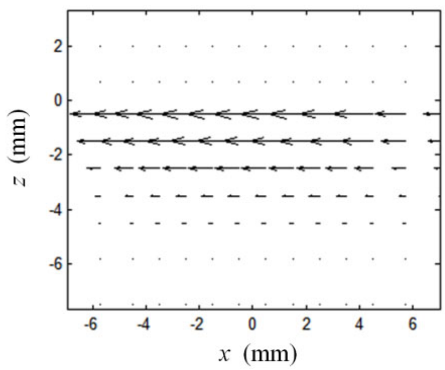
2.2. Vertical EC Method Using Rectangular Coil

A vertical current perpendicular to the surface of the work piece will make the detection of lamination possible.

If a rectangular coil is placed perpendicular to the surface of material, vertical current will be induced inside the material and will be much stronger right under the vertical section of the coil than other positions. When the coil scans over the surface of the material to right above a lamination, the vertical current will change direction and flow parallel to the lamination. A simulation has been done to prove the theory and the EC inside the material is shown in Fig. 3 where y is the direction perpendicular to the bottom section of the coil and parallel to the surface of the work piece.

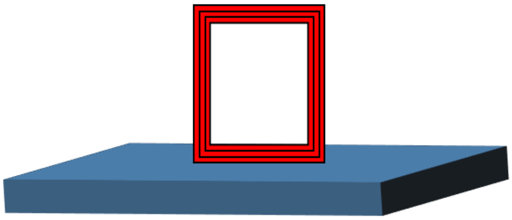


(a) x-y plane

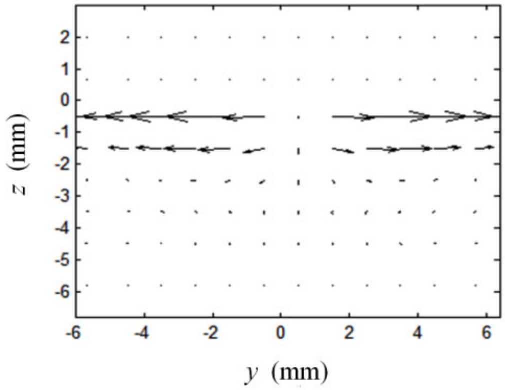


(b) x-z plane

Fig. 2 EC below a pancake coil



(a) a rectangular coil vertical to work piece



(b) EC below a vertical section of coil

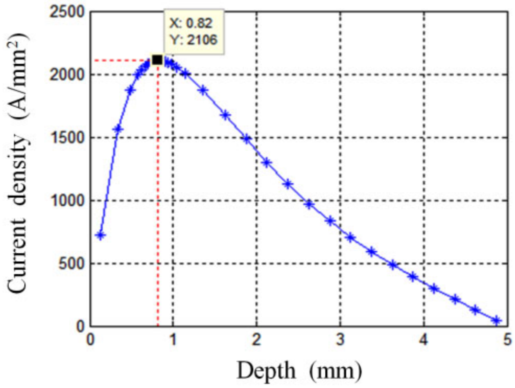
Fig. 3 The vertical EC perturbed by lamination

3. Parametric Study of Rectangular Coil

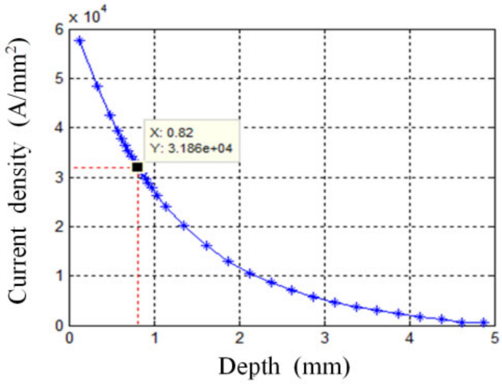
A rectangular coil is much more effective than a pancake coil in lamination testing. However, the EC induced by rectangular coil also has component parallel to lamination that is much larger than the vertical component, as can be seen in Fig. 4. As the parallel component of EC is useless in lamination testing, it is necessary to increase the vertical component. Changing the sizes of the coil might increase the value or percentage of the vertical current.

Two groups of simulations have been done to study the influence of the sizes of the rectangular coil to the vertical EC using FE method.

In the first set of simulations, the length of the bottom section varies from 4 mm to 10 mm while the length of the vertical section remains 4 mm. The maximum value of vertical current and its percentage in the EC are shown in Fig.



(a) amplitude of the vertical current density vs. depth



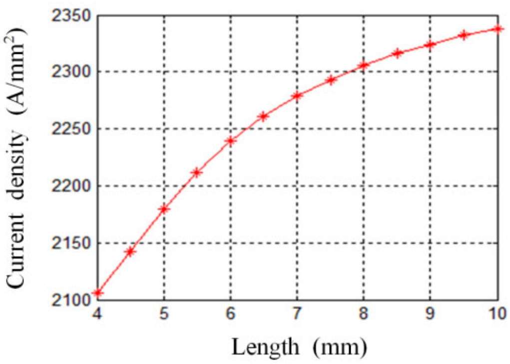
(b) amplitude of current density vs. depth

Fig. 4 EC density vs. depth

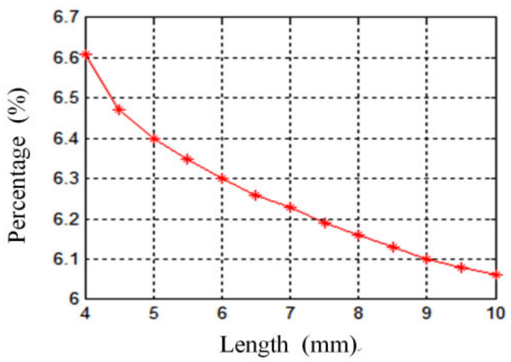
5. A rectangular coil has two vertical sections delivering current in opposite directions. The vertical ECs generated by the sections reduce each other. Elongate the bottom section to make two vertical sections apart from each other relieves the effect so that the vertical currents become bigger. On the other hand, elongating the bottom section increases the component of EC parallel to the surface and makes the percentage of the vertical component decreases.

In the second set of simulations, the length of vertical section varies from 4 mm to 10 mm while the length of the bottom section remains 4 mm. The maximum value of vertical current and its percentage in the EC are shown in Fig. 6.

Obviously, increasing the length of the vertical sections enlarges the vertical component

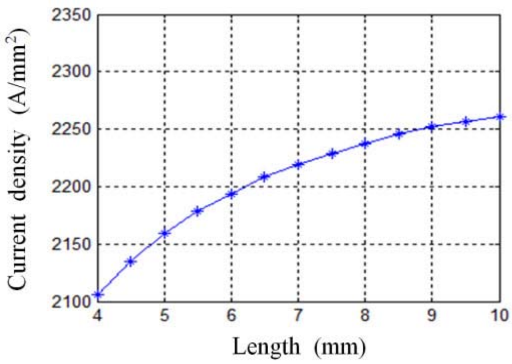


(a) maximum value of vertical current density vs. length of bottom section

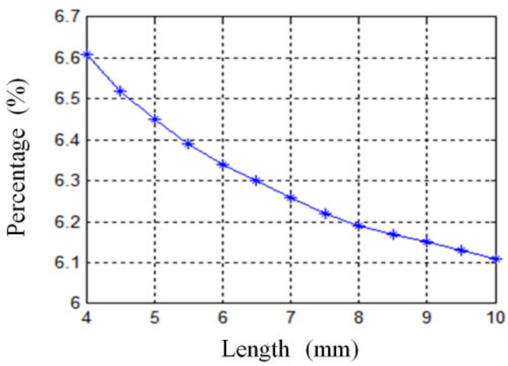


(b) percentage of vertical current in EC vs. length of bottom section

Fig. 5 Vertical current vs. length of bottom section



(a) maximum value of vertical current density vs. length of vertical section



(b) percentage of vertical current in EC vs. length of vertical section

Fig. 6 Vertical current vs. length of vertical section

of EC. However, the EC component parallel to the surface is also enlarged because the reduction of ECs generated by the top and bottom sections is weakened. The final effect is that the percentage of the vertical component is decreased.

Summarizing the simulation results, the maximum value of the vertical current increases when increasing either the length of the vertical section or the length of the bottom section of the rectangular coil. It's effective to elongate both the vertical and bottom sections if a higher maximum value of vertical current is desired. But at the same time, the percentage of vertical current in the whole EC decreases when each section of the coil becomes longer.

4. Conclusions

The vertical current induced by a rectangular coil placed vertically to the material can be used to detect lamination. A larger coil results in greater vertical current but smaller percentage of vertical current in the whole EC. A trade-off must be taken into account when designing coil.

Acknowledgment

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