CALCULATION OF ELECTROMAGNETIC FIELDS IN THE EDDY CURRENT CONTROL OF THE LEVEL OF ADHESION IN COATINGS

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Within the framework of the problems of nondestructive control of the level of adhesion in coatings by the method of eddy currents, we determined the component of the resultant electromagnetic field induced by an intermediate layer whose specific conductivity continuously changes from the coating to the base. The results of calculations of the magnetic field intensity are presented both for the cases where the conductivity of the coating is higher than that of the base metal and in the opposite case.

One of the principal characteristics of metal coatings is adhesion caused by the mutual diffusion of a coating material and a base metal. The possibility of measuring the required parameters by the methods of nondestructive control directly on workpieces and hardware is of great interest for technological needs. In this connection, the use of the eddy current method appears to be quite promising. There are two main types of problems that should be solved in the process of testing: to reveal stratifications in coated structures and to estimate the level of adhesion. The latter is necessary for measuring small changes in the output signal of an initial eddy current transducer caused by the diffusion layer. At the same time, this signal was affected by the changes in the other parameters of a laminated structure that were regarded as a noise and contributed to an error of the method.

The theory of eddy current control studies the influence of the parameters of piecewise homogeneous structures on the resultant field in the case where the source field is generated by a current loop with the alternative current $Ie^{iot}$ [1–4]. In this paper, we present the computation method and use it to find the component of the resultant field induced by the diffusion layer under the assumption that the values of specific conductivity and magnetic permeability undergo continuous changes in the diffusion layer from the coating to the base material.

The problem can be posed as follows: The source field is generated by a circular current loop of radius $a$ with a current $Ie^{iot}$ placed near a flat-laminated medium (Fig. 1). The wave number of the external medium is denoted by $k_0$. The thickness of the coating and base are $h$, the width of the diffusion layer is $d$, the wave numbers of the diffusion layers are $k_1$, $k_2$, and $k_3$, and the wave numbers of the intermediate layers are $k_0$. The currents $i_0$, $i_1$, $i_2$, and $i_3$ are the components of the resultant field induced by the diffusion layer.

Fig. 1. Current loop over a laminated structure.
by \( k_0 \). The laminated structure consists of three layers: the upper layer (the coating) 1 with a wave number \( k_1 \), the base 3 with a wave number \( k_3 \), and the diffusion (adhesion) layer 2 with a wave number \( k_2 \) that changes continuously from \( k_1 \) to \( k_3 \). The origin of coordinates \((x, y, z)\) is placed at the center of the loop (Fig. 1). Let the boundaries of the coating have the coordinates \( z_1 \) and \( z_2 \), and let the coordinate of the upper boundary of the base be \( z_3 \) (its lower boundary is infinity). The diffusion layer is located between the coordinates \( z_2 \) and \( z_3 \). We also introduce polar coordinates \((\rho, \varphi, z)\) by setting

\[
x = \rho \cos \varphi \quad \text{and} \quad y = \rho \sin \varphi.
\]

Suppose that the wave number \( k_2 \) obeys the law

\[
k_2^2 = A + \frac{B}{z^2},
\]

where

\[
A = \frac{k_1^2 \cdot z_2^2 - k_2^2 \cdot z_2^2}{z_2 - z_3} \quad \text{and} \quad B = \frac{(k_1^2 - k_2^2) \cdot z_2^2 - z_3^2}{z_2 - z_3},
\]

and that \( k_2^2 = k_1^2 \) for \( z = z_2 \) and \( k_2^2 = k_3^2 \) for \( z = z_3 \).

The wave number of the \( j \)th layer \((j = 0, 1, 2, 3)\)

\[
k_j^2 = \omega^2 \varepsilon_j \mu_j - i \omega \sigma_j \mu_j,
\]

where \( \omega = 2\pi f \) is the cyclic frequency, \( \varepsilon_j \) is the dielectric permittivity, \( \mu_j \) is the magnetic permeability, and \( \sigma_j \) is the specific conductivity of the \( j \)th layer.

For \( z > 0 \), the electric component of the electromagnetic field \( E_{1\varphi} \) generated by the current loop in the near zone is described by the formula (here, we set \( I = IA \))

\[
E_{\varphi} = \frac{i \omega \mu_0 a}{2} \int_0^\infty \exp \left[-\sqrt{k^2 - k_0^2} \cdot z \right] J_1(\lambda a) J_1(\lambda \rho) d\lambda.
\]

The other components of the electric field in the free space are equal to zero \((E_{\rho} = 0, \ E_z = 0)\). The source field induces in each layer a field that also has only one nonzero component \( E_{j\varphi} \neq 0 \).

In each layer, the component \( E_{j\varphi} \) satisfies the equation \([1]\)

\[
\frac{\partial}{\partial \rho} \left( \frac{1}{\rho} \frac{\partial}{\partial \rho} (\rho E_{j\varphi}) \right) + \frac{\partial^2 E_{j\varphi}}{\partial z^2} + k_j^2 E_{j\varphi} = 0,
\]

the boundary conditions in the interfaces of the layers \((z = z_1, z_2, z_3)\)

\[
\begin{align*}
E_{1\varphi} + E_{0\varphi} &= E_{1\varphi}; \\
\frac{1}{\mu_0} \cdot \frac{\partial}{\partial z} (E_{1\varphi} + E_{0\varphi}) &= \frac{1}{\mu_1} \cdot \frac{\partial E_{1\varphi}}{\partial z} \quad \text{for} \quad z = z_1,
\end{align*}
\]