THE CALCULATION MODEL OF ECT SIGNALS FOR SUPERFICIAL AND SUBSURFACE CRACKS CONTROL

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For the reliable control and effective diagnosing of the electric machine-building equipment and metal designs is widely applied eddy current method of non-destructive testing. In a base of this method lays the interaction external, in relation to object control, magnetizing electromagnetic field with induced in object eddy currents. In spite of on adequate consideration development of theoretical and applied aspects of modern methods and means of eddy current non-destructive testing, definition the functional dependences between condition of object and signals of the converter, and also restoration the parameters of defect or structure of the object on the measured data are developed weakly by virtue of the large complexity and a polysemy of a problem. For the decision of the similar problems are developed as analytical methods, thus a well-known numerical methods, which are based on the decision of the integral or differential equations of an electromagnetic field. The author in the paper [1] offers another approach to modeling the signals of eddy current transmitter (ECT), which is based on the decision of a task of interaction of separate coils of eddy currents of object with measuring winding of ECT. However, the present approach was already considered in the work [2], nevertheless was not applied to modeling signal ECT from defect in ferromagnetic materials.

On fig. 1 is shown the sketch of eddy current transmitter connecting type, which in common case placed in to ferromagnetic tube and simultaneously with that covers ferromagnetic cylindrical object. The tube and the cylinder present itself the multi-layer structure each groups,r in the accepted model, is divided between on equivalent near located short-circuited coils on which the nduced eddy currents I flows. ECT is shown like magnetizing winding W and measuring winding Wm. In the figure the cracks on a surface and in an internal layer of a tube and the cylinder are schematically shown.

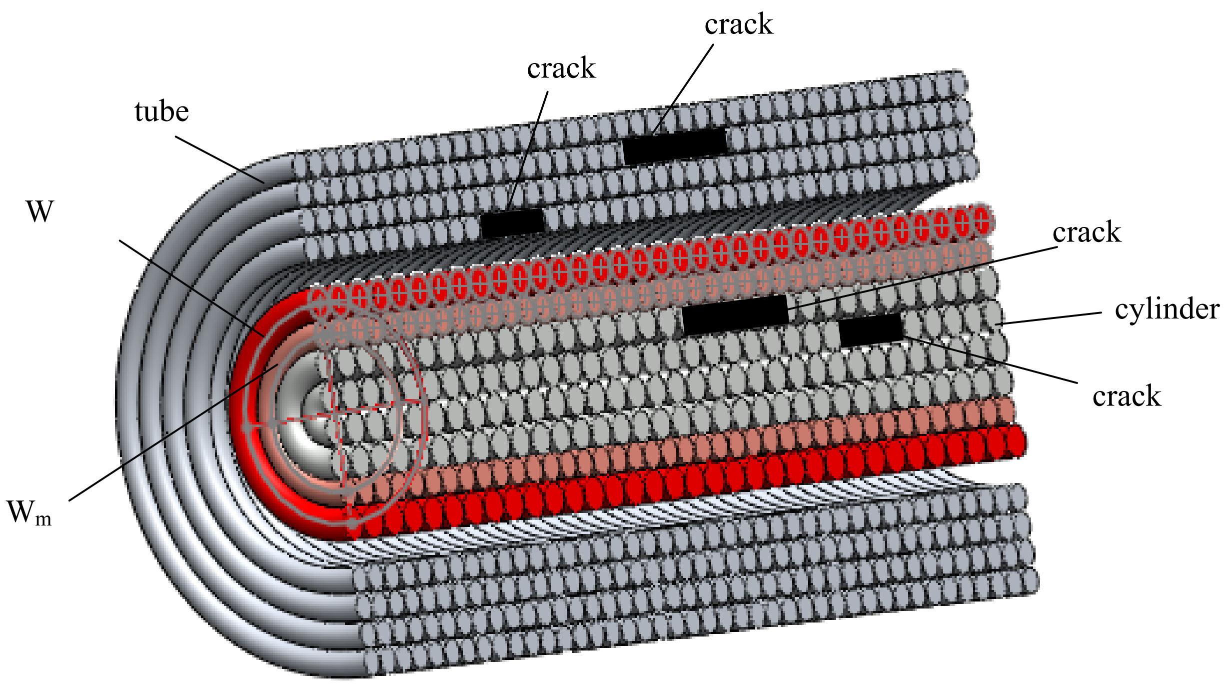

Fig. 1 - Appearance of ECT and the objects of the control

For given ECT is possible to make up the equivalent electric circuit (for example for the internal cylinder) which is shown on fig. 2. At the same time, the magnetizing winding represents by separated coils with resistances R_i and inductances L_i which are connected to corresponding sources of alternating current E_i. Similarly, measuring coils with resistance R_{mi} and inductances L_{mi} are connected to corresponding voltmeters with resistance R_v. Short-circuited coils of the object are shown like resistance R_{oi} and inductances L_{oi}. Here the magnetic communication between all coils of the system (for a case of interaction of the first coil of a magnetizing winding) like the mutual inductance M is shown.

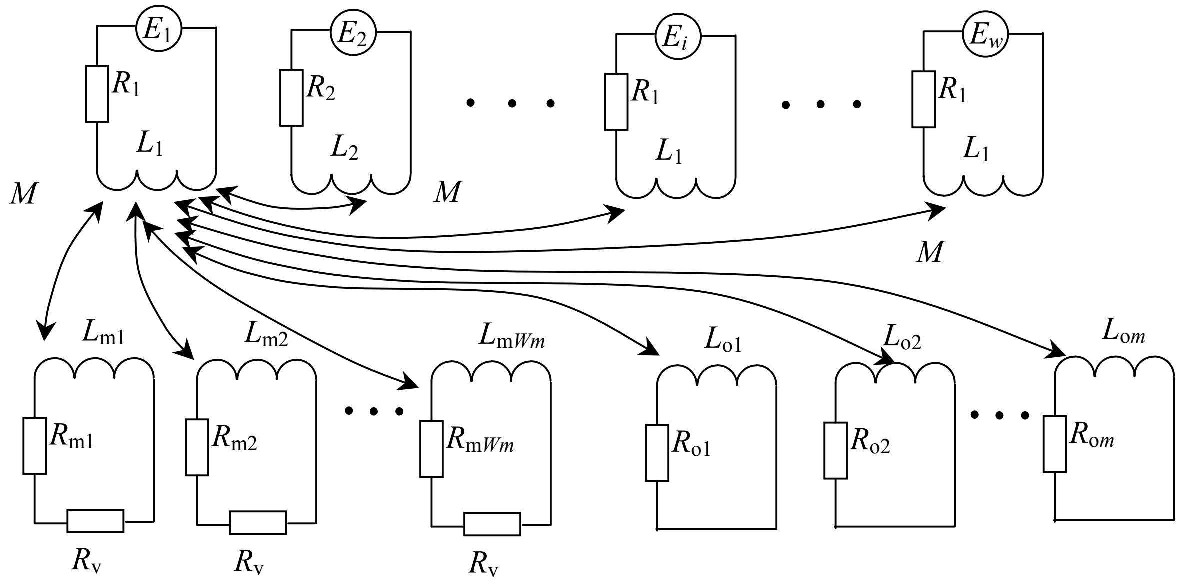

Fig. 2 – The electric equivalent circuit of ECT and the object of control.

In order to not tangled in indexation of windings, taking for the beginning of account the first coil of a magnetizing winding and using through numbering for the given equivalent circuit, equating the matrix equation in form:

$$\begin{bmatrix} A_{11}\ A_{12}\ A_{13} \ldots A_{1j}\ A_{1n} \\ A_{21}\ A_{22}\ A_{23} \ldots A_{2j}\ A_{2n} \\ A_{31}\ A_{32}\ A_{33} \ldots A_{3j}\ A_{3n} \\ \ldots \\ A_{i1}\ A_{i2}\ A_{i3} \ldots A_{ij}\ A_{in} \\ A_{n1}\ A_{n2}\ A_{n3} \ldots A_{nj}\ A_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \ldots \\ I_j \\ I_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ 0 \\ \ldots \\ 0 \\ 0 \end{bmatrix} \tag{1}$$

- where A_{11}, A_{22}, A_{ii}, A_{nn} the elements of the main diagonal of a matrix coefficients represents complex resistance of corresponding coils $R_{ij}+j\omega L_{ij}$; - A_{ij} the elements shown the magnetic communication between coils of system like $j\omega M_{ij}$; I_j - corresponding currents in magnetizing, measuring windings and the induced eddy currents in separate coils of the object.

Active resistances of the any elements of the system are founded from correlation:

$$R_{ij} = \frac{l_{ij}}{\sigma_{ij} S_{ij}} \tag{2}$$

where l_{ij} – length of any circuit; S_{ij} - net area; σ_{ij} – electric current conductivity.

Inductances are founded by formula:

$$L_{ij} = \mu_0 a_{ij} \left(\ln \frac{16 a_{ij}}{d_{ij}} - 2 + \frac{\mu_0 \mu_{rij}}{\mu_0} \frac{\xi}{4} \right) \tag{3}$$

where a_{ij} – radius of any circuit; μ_{ij} – magnetic permeability.

For finding of mutual inductance between any coils of the system authors received [1] the calculations:

$$M_{ij} = 2\pi\left(\frac{a_{\text{external}}\mu_0\mu_r}{2\pi}\sqrt{\frac{a}{a_{з\text{external}}}}f(\lambda_{з\text{external}}) - \frac{a_{\text{internal}}\mu_0\mu_r}{2\pi}\sqrt{\frac{a}{a_{\text{internal}}}}f(\lambda_{\text{internal}})\right) \quad (4)$$

$$f(\lambda_{\text{external}}) = \left(\frac{2}{\lambda_{\text{external}}} - \lambda_{з\text{external}}\right)K(\lambda_{\text{external}}) - \frac{2}{\lambda}E(\lambda_{\text{external}}) \quad (5)$$

$$f(\lambda_{\text{internal}}) = \left(\frac{2}{\lambda_{\text{internal}}} - \lambda_{\text{internal}}\right)K(\lambda_{\text{internal}}) - \frac{2}{\lambda_{\text{internal}}}E(\lambda_{\text{internal}}) \quad (6)$$

$$\lambda_{\text{external}} = \sqrt{\frac{4aa_{\text{external}}}{z_0^{\ 2} + (a + a_{\text{external}})^2}} \quad (7)$$

$$\lambda_{\text{nternal}} = \sqrt{\frac{4aa_{\text{nternal}}}{z_0^{\ 2} + (a + a_{\text{nternal}})^2}} \quad (8)$$

where a – any coil of the system, a_{external} and a_{internal} – radiuses of examined coil of the system, K and E – elliptic integrals.

For the description superficial and subsurface cracks is taking, that value of complex resistance $R_{ij}+j\omega L_{ij}$ in corresponding coils of object are equal to zero. Then formula (1) will become

$$\begin{bmatrix} A_{11}\ A_{12}\ A_{13}\ldots A_{1j}\ A_{1n} \\ A_{21}\ A_{22}\ A_{23}\ldots A_{2j}\ A_{2n} \\ A_{31}\ A_{32}\ 0\ldots A_{3j}\ A_{3n} \\ \ldots 0 \\ A_{i1}\ A_{i2}\ A_{i3}\ldots 0\ A_{in} \\ A_{n1}\ A_{n2}\ A_{n3}\ldots A_{nj}\ A_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \ldots \\ I_j \\ I_n \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ 0 \\ \ldots \\ 0 \\ 0 \end{bmatrix} \quad (9)$$

Using the presented method, was paid off the calculations of output signal of ECT for the superficial cracks, which diagrams are shown on the fig.2.

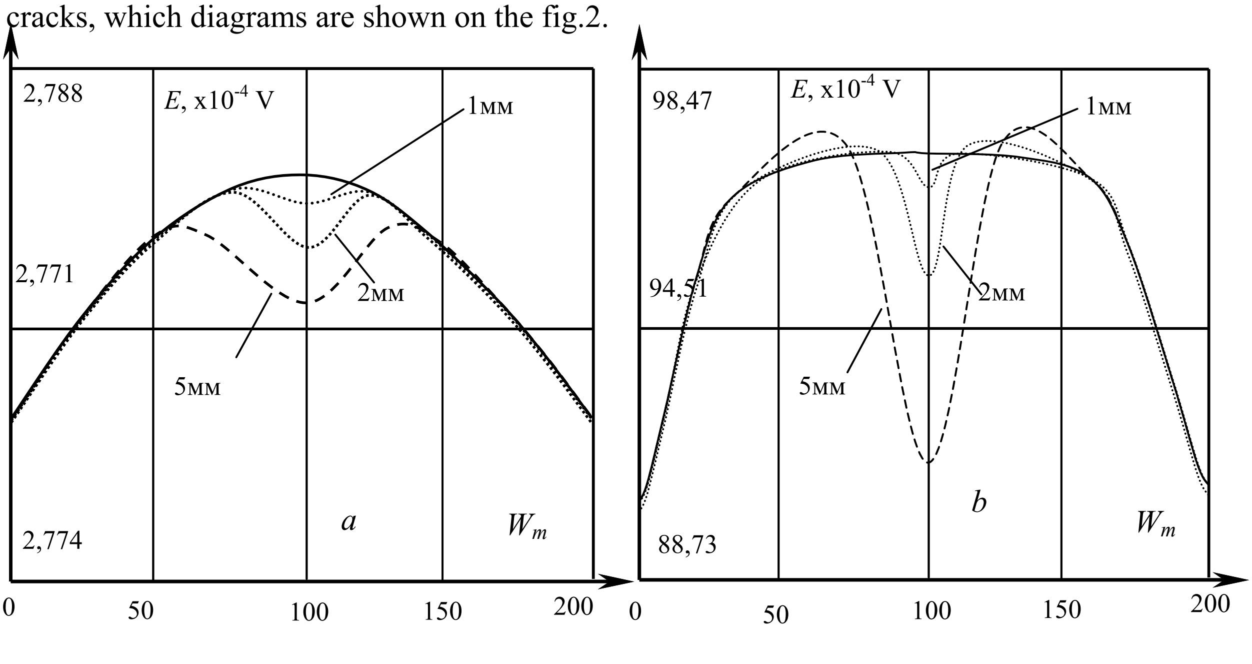

Fig. 2 – The diagrams of output signals of ECT for the superficial cracks for copper (*a*) and steel (*b*).

Look-and-feel of this model are, that every coil of measurement winding virtual to the displacement the thin spool along the axes of the object. So, on axes *x* marked the coils of measurement winding. On axes *y* marked the values of the voltage on the each coils of measurement winding. The graphs corresponding to size of the cracks.
On fig. 3 the diagrams of calculations of output signals of EDC for subsurface cracks (under 1 mm from the surface) are shown.

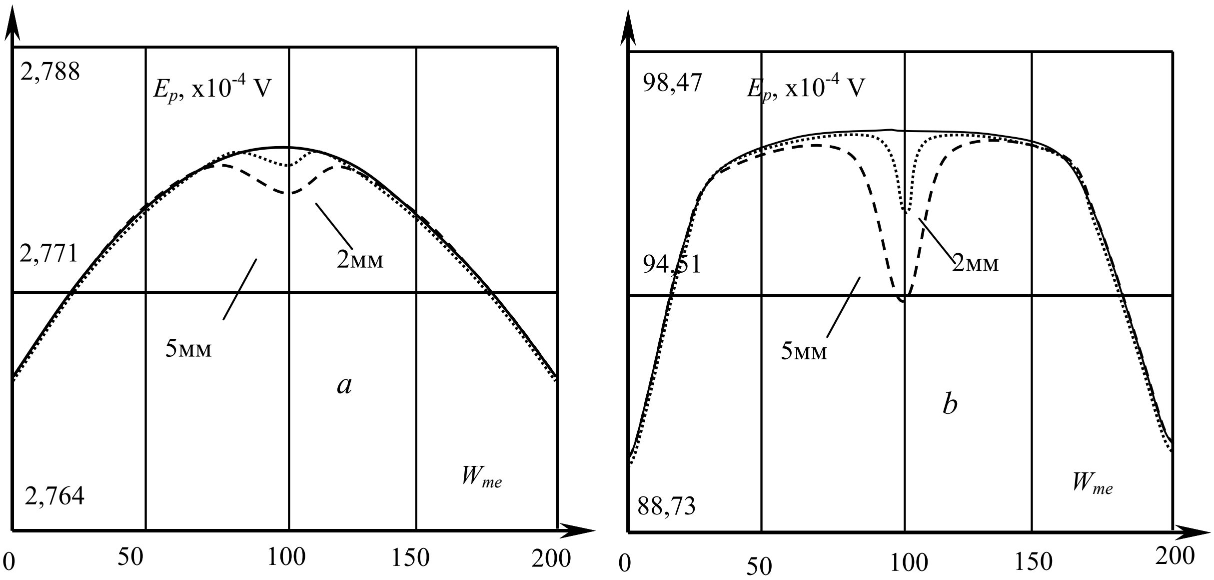

Fig. 3 - The diagrams of output signals of ECT for subsurface cracks for copper (*a*), steel (*b*).

Results of calculations shown, that the given method adequately describes output signal ECT from superficial subsurface cracks. The voltage on coils of a measuring winding under the form repeats the form of the induced eddy current in the object. Also, it is necessary to note, that sensitivity of the transmitter for cracks depends on a material of the object, the size of cracks and from its occurrence depth. Experimental researches have shown, that the offered method of calculation of output signal of ECT allows to receive a calculation signal of the transmitter with precision of 2-3 % for not magnetic materials and 7-10 % for ferromagnetic. Calculation of a signal on the offered algorithm is made in package MatLab and on time 1-2 minutes. Given fact allow to integrate this algorithm into systems of eddy current nondestructive testing over comparison of experimentally received signals of the transmitter with calculations, practically in real time. Comparison is made on a least-squares method with delivery result in the form of probability of an error. It essentially facilitates decision-making results by operator.

Literature: 1. Горкунов Б.М., Тюпа И.В., Тищенко А.А. Модель вихретокового преобразователя проходного типа с токопроводящим цилиндрическим образцом. //Технічна електродинаміка, тематичний випуск "Силова електроніка та енергоефективність", ч.5, 2007, Київ, С. 45-48. 2. M.J.Sablik, R.I. Beissner, and A. Choy. An alternative numerical approach for computing eddy currents – Case of the double-layered plate, IEEE. Tans. Magn., vol. MAG-20, pp. 500-506, 1984.