USING OF PARAMETRIC TRANSDUCERS IN PULSED EDDY CURRENT TESTING

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Introduction. Eddy current nondestructive testing (ECNDT) is one of the most common types of NDT, characterized by the simple interaction way of the testing object (TO) with the eddy current transducer (ECT), relatively low price, high efficiency, and reliability of the results. The current ECNDT development is focused on solving the tasks of improving the ECT, methods of excited eddy currents in the TO, developing new methods for processing information signals of the transducer, etc. [1, 2].

In the case of harmonic ECT excitation, the electrophysical characteristics of the materials and the geometric parameters of the TO are determined by the parameters of the ECT signals as amplitude, frequency and phase shift. The analysis of the ECT signals and the interpretation of the testing results are complicated by the action of a number of interfering factors, among which the most dangerous are the gap between the ECT and the TO, the variation of the material electromagnetic properties, the curvature and roughness of the TO surface, external and hardware noise and other. [1, 3].

Specialists from ECNDT periodically give attention to the idea of using ECT pulsed excitation, which has several advantages: increased depth of testing; additional informative parameters; the possibility of simultaneous analysis of the signal at several frequencies; the possibility of analyzing the ECT signal in the time domain [4, 5, 6].

In the practice of pulsed ECNDT, the following informative signals parameters are most often used: the variation of the time offset of crossing by signal of a certain level, the time slot certain nodal points, the peak values of amplitude and the surpassing the certain threshold values by the amplitude and times moments of these surpassing [7, 8, 9]. The disadvantage of such pulsed ECNDT implementations is the use of nodal points of the ECT signal. As result, there are the incomplete usage of signal information capabilities and difficulties in the exposure of the mentioned nodal points from the effects of noises. In this regard, the issues of increasing the informativity and accuracy of the ECNDT, based on the in-depth study of pulsed ECNDT, the search for new informational parameters and characteristics of ECT signals and the improvement of their analysis methods in ECNDT are very important.

The purpose of this paper is to analyze the informational parameters of the parametric ECT signals in the pulsed excitation mode in a case of testing the defects such as surface cracks.

The Structure of the Experimental Model. Fig. 1 shows the structure of the developed ECNDT system, which consists of the laid-on parametric ECT, generator (G), digital oscilloscope (DO), the digital interface (DI), personal computer (PC) with original algorithmic software (Soft). The algorithm of the software has provided the receiving ECT signals, obtaining the discrete amplitude and phase characteristics of the signals (ACS and PCS) by applying a discrete Hilbert transform (DHT) and analysis of obtained characteristics [10]. The usage of the DHT allows obtaining a large volume of data in a small time interval.

The pulse signal from the generator was transmitted to a parametric ECT ($U=5V$, pulse interval $T=5\mu s$, pulse duration $\tau=2\mu s$. ECT was connected to the measuring scheme, the output of which was formed the information signal of voltage. This signal has been considered as the reaction of the ECT to the front of the excitation pulse.
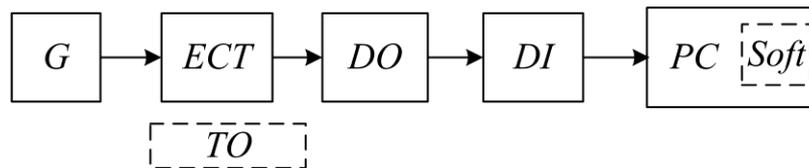
Fig. 1. Structure of the experimental setup

For experimental researches there were used the samples with a thickness of 5 mm, a length of 100 mm, a width of 30 mm. The sample S-1 is made of steel of St.20 ($\mu>1$), and S-2 is made of aluminum alloy D16 ($\mu=1$). There are three artificial defects imitating surface cracks, 0.2 mm in width and h = {0.2, 0.5, 1.0} mm in depth on one of the samples surfaces.

Technique of Experimental Data Processing. The task was solved by experiments based on:

− researching the parametric laid-on ECT with pulsed excitation mode and the subsequent analysis of it signals in the time domain[11];

− detection and analysis of informational parameters of ECT signals such damping decrement and oscillations frequency;

− the determination of the functional dependence of the ECT signal parameters on the TO characteristics.

The ECT signal model could be represented by an additive mixture of dumping harmonic oscillations and Gaussian noise:

$$u_{\text{ect}}(t,h) = A_m(h) \cdot e^{-\alpha(h)t} \cos(2\pi f(h) \cdot t) + u_n(t), \ t \in (t_1, t_2), \tag{1}$$

where $A_m(h)$ − the amplitude value of the information component of the ECT signal, $\alpha(h)$ − damping decrement, $f(h)$ − frequency of the signal oscillations, t − current time, (t_1, t_2) − time interval for analysis of the ECT signal, $u_n(t)$ − the noise component of the signal, which was considered as the realization of a Gaussian random process with zero mathematical expectation and dispersion σ^2.

The procedure for processing and analyzing the characteristics of the ECT signal obtained in pulsed excitation mode included the following steps:

− determination of the Hilbert-image of the sample capture $u_{\text{ect}}[j, h]$:

$$u_H[j,h] = \mathbf{H}[u_{\text{ect}}[j,h]], \tag{2}$$

where j − the number of the ECT signal in the digital representation, $\mathbf{H}$ − Hilbert-transform operator;

− determination of discrete ACS and PCS of ECT:

$$\Phi[j,h] = arctg \frac{u_H[j,h]}{u_{ect}[j,h]} + \mathbf{L}(u_H[j,h], u_{ect}[j,h]), \tag{3}$$

$$U[j,h] = \sqrt{u_{ect}^2[j,h] + u_H^2[j,h]}, \tag{4}$$

where $\mathbf{L}$ − the determination operator of PCS existing outside the unicity interval of the *arctan* function.

− smoothing of function (3) using the method of obtaining the linear regression of Bartlett-Kenosis [12] and determining the oscillations frequency of ECT signals by the linear trend of obtained function:

$$f(h) = \Delta\Phi_L(\Delta T, h) / (2\pi\Delta T), \tag{5}$$

where $\Delta\Phi_L(\Delta T, h)$ − the phase of the ECT signal accumulated in time interval $\Delta T = t_2 - t_1$ and obtained by the function of linear regression;

− application of exponential approximation to function (4) to increase the accuracy of determining the damping decrement of the ECT signal and to determine it using equation:

$$\alpha(\overline{w}) = \frac{1}{\Delta T} ln \frac{\hat{U}(t_1', \overline{w})}{\hat{U}(t_2', \overline{w})}, \tag{6}$$

where $\hat{U}(t_1', \overline{w})$, $\hat{U}(t_2', \overline{w})$ – the value of approximation curves at time moment t_2' and t_1', $\Delta T = t_2' - t_1'$;

− analysis of the obtained results by comparison with the calibration characteristic of the dependence of the measurable parameter TO from the informative parameter of the ECT signal;

− visualization of obtained results.

Results and discussions. The results of the analysis of the signal dumping in pulsed excitation mode of the ECT for the two samples are shown in Fig. 6 (curve 1 – is for S-1 sample; curve 2 – for S-2 sample). There is close to the linear the character of the received function dependence of the dumping of the ECT signal from the crack depth in TO. It has different values depending on the physical and mechanical characteristics of the TO material (including conductivity and magnetic permeability).

Comparative analysis of curves on Fig. 6 shows that such informative parameter like damping decrement can be used to testing and evaluate the crack depth in the TO. In the conducted experiments, the relative error of the determining the crack depth has not exceeded ±0.5%, and the average sensitivity for S-1 and S-2 was $S_{\alpha\_S1} = 0.2\ \mu s^{-1}/mm$, $S_{\alpha\_S2} = 0.1\ \mu s^{-1}/mm$ respectively, that is higher for non-magnetic material.

The results of determining the change in the ECT signal frequency in pulsed excitation mode as functions of the crack depth in the specimen S-1 and S-2 is shown in Fig. 7a and Fig. 7b, respectively. The obtained curves of the dependence f(h) are linear, and the values of the ECT signal frequency decrease with increasing the crack depth in both samples.
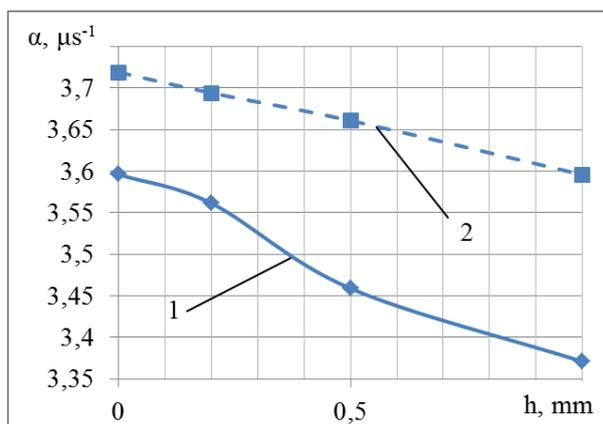

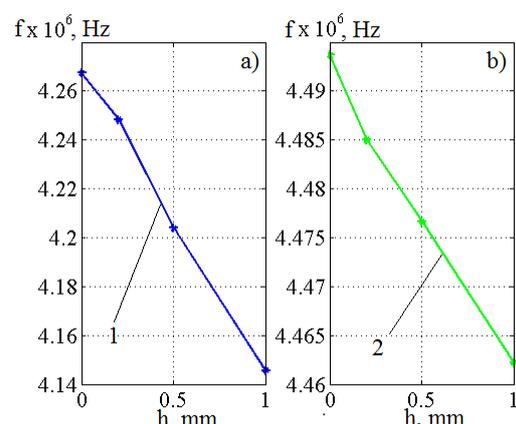Fig. 2. ECT signal dumping variation   Fig.3. ECT signal frequency variation
(curve 1 – for S-1; curve 2 – for S-2)

Detailed analysis of the curves from Fig. 7 showed that in this case the relative error of determining the crack depth h does not exceed ±2%, and the sensitivity to the crack depth h for S-1 with $\mu > 1$ ($S_{f\_S1} = 0.12\ MHz/mm$) is much higher than for the S-2 with $\mu = 1$ ($S_{f\_S2} = 0.03\ MHz/mm$).

The conducted researches have shown that in the case of using the parametric ECT in pulsed excitation mode for evaluation the crack depth in products made of magnetic materials, it is advisable to use as an informative parameter the signal frequency, and for products made of non-magnetic materials, the dumping of ECT signals.

Conclusions. It has been established that the signals of the parametric ECT that are obtained in pulsed excitation mode and have the form of damped harmonic oscillations can be used in the eddy current testing for estimating the depth of surface cracks. Also, it is established that in the pulsed mode of ECT excitation, the type of dependence of the dumping decrement and the oscillations frequency of this signal, from the change in the crack depth in the TO, is close to the linear one.

The provided experiments show that the change in the crack depth from 0 to 1 mm led to a relative change in the oscillations frequency of the transducer signal by ≈3% and ≈0.7% (for samples made of steel and aluminum, respectively) and the relative change in the dumping decrement - in 3.3% and 6.6% (for samples made of aluminum and steel, respectively). The error of determining the crack depth for mentioned samples did not exceed ± 2%.

The dependences of the damping decrement and the oscillations frequency of the signal from the crack depth indicated for the parametric laid-on ECT can be used for further researchers of this ECT type in order to evaluate the crack parameters in the surface and subsurface layer of the TO material with a dielectric coating.

The usage of the parametric type of the ECT in conjunction with the digital processing of information signals expands the capabilities of pulsed ECNDT. In particular, it allows realizing specific mode for estimating of surface cracks depth.

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