2018 IEEE 38th International Conference on Electronics and Nanotechnology (ELNANO)

Study of Parametric Transducer Operation in Pulsed Eddy Current Non-Destructive Testing

Kuts Y., Maievskyi S., Protasov A., Lysenko I., Dugin O.
Dep. of Non-Destructive Testing Devices and Systems,
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
Kyiv, Ukraine
j.lysenko@kpi.ua

***Abstract*—In this article is considered the experimental results of the using the parametric type of an eddy current transducer at two excitation modes - pulsed and harmonic. The flat samples from aluminum alloy and steel with artificial crack-like defects on them were selected as testing objects. The estimation of the amplitude, decrement and natural oscillation frequency of the eddy current transducer signal as informative parameters was performed according to the results of the analysis of experimental signals of the parametric transducer. The results of the comparative analysis of the eddy current transducer signals at harmonic and pulsed excitation are presented by estimating of changes in the signals amplitude values from the crack depth in the testing object. It is shown that the signals of parametric eddy current transducer in the form of damped harmonic oscillations obtained by pulse excitation of the transducer can be used in the eddy current non-destructive testing to estimate the depth of surface cracks. The types of the dependences of the attenuation and the natural oscillation frequency of the eddy current transducer signal from the change in the crack depth in the testing object were established using the experimental data. The analysis of the sensitivities of the informational parameters of the eddy current transducer at pulsed excitation to the crack depth in the testing objects is performed.**

Keywords— pulse eddy current; parametric type eddy current transducer; harmonic excitation; pulsed excitation; frequency; decrement; crack depth

I. INTRODUCTION

Eddy current non-destructive testing (ECNDT) is currently used in various fields of science and technology to solve the problems of defectoscopy, quality inspection of materials and products, monitoring characteristics of testing objects (TO) for various purposes. It is popular due to its high efficiency and reliability of the results. The current development of ECNDT is focused on solving the problems of improving eddy current transducers (ECT), methods of eddy current excitation in the TO, the development of new methods for transducer signals processing, etc. [1, 2].

Traditional ECNDT uses of a harmonic excitation signal and analysis of its informative parameters: the amplitude and initial phase of the received signals (or orthogonal component signals in the case of their representation on the complex plane) [1, 3]. There are more and more attempts at research and application other methods of ECNDT in order to implement multi-parameter testing and expansion of its functional capabilities, in particular methods based on impulse excitation of eddy currents. Most of the researches on pulsed ECNDT is based on the use of characteristic points as the signal information parameters. For example, it could be the moment the signal is crossing by a certain level, the time interval between certain nodal points, the maximum values of amplitude, etc. [4-7]. The use of only some values of the ECT signal indicates that the signal information capabilities are not fully utilized and the above-mentioned point characteristics are not protected from the effects of noises. In this connection, the topical issues are to increase informativity and reliability of ECNDT on the basis of further research of impulse ECNDT, search for new informational parameters and characteristics of ECT signals and improvement of methods of their analysis [8, 9].

The purpose of this article is a comparative analysis of the signal informational parameters of parametric ECT in different modes of excitation using the task of finding defects such as surface cracks.

II. EXPERIMENTAL TECHNIQUE

A. *The Structure of the Experimental Model*

Fig. 1 shows the structure of the developed ECNDT system. It consists of the overlay parametric transducer (ECT), generator (G), digital oscilloscope (DO), digital interface (DI), and personal computer (PC) with original algorithmic software (Soft). The algorithm of the software provided for the selection of ECT signals, obtaining amplitude and phase characteristics of signals by applying the discrete Hilbert transformation and further analysis of these discrete characteristics [10].

The signal characteristics obtained in this way can be used to determine experimentally new information characteristics - the coefficient of attenuation of signals and the frequency of the signal natural oscillations.

The experimental studies were provided with proposed parametric ECT. The construction of it is shown on Fig. 2. A polycore tip was used to ensure the wear resistance of the ECT.

978-1-5386-6383-7/18/$31.00

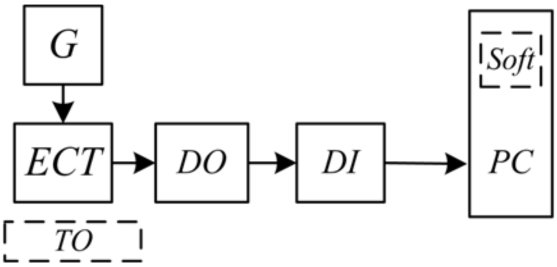

Fig. 1. Structure of the experimental setup

The parametric ECT received an exciting pulse signal from the generator (U = 5V, the repetition period T = 5μs, duration τ=2μs). ECT was a component of the measuring circuit, which formed an information signal in the form of voltage at the output. This signal was the ECT reaction to the front of the exciting pulse. A typical ECT signal has the form of damped harmonic oscillations (Fig. 3).

Under conditions of harmonic excitation, it is used a sinusoidal signal with amplitude U = 5V and frequency f = 4MHz.

B. Description of the Testing Object

Two plates (S-1 and S-2) were chosen for carrying out of experimental researches. They had the thickness of 5 mm, length 100 mm and width of 30 mm (Fig. 4).

Sample S-1 is made of steel of St.20 (μ> 1), and sample S-2 of aluminum alloy D16 (μ = 1). There are three artificial defects on one of the surfaces of both samples with the same interval. They imitate surface cracks, 0.2 mm in width and h = {0.2, 0.5, 1.0} mm in depth. The roughness of the working surface does not exceed 1.6 microns.

III. METHOD OF OBTAIN OF ECT SIGNAL INFORMATIONAL PARAMETERS

The task was solved by experiments based on:

- research of the parametric overlay ECT operation in conditions of pulse and harmonic excitation with further analysis of its signals in the time domain;
- identification and analysis of the informational parameters of the ECT signals: the peak value of the amplitude, the attenuation coefficient and the frequency of the proper oscillations for the pulsed mode of excitation; change in amplitude level - for harmonic;
- determination of the functional dependence of the parameters of the ECT signal on the characteristics of the TO.

An additive mixture of attenuating harmonic oscillations and Gaussian noise can represent the ECT signal model (Fig. 3):

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

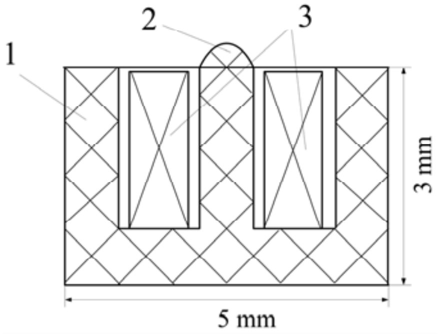

Fig. 2. The construction of a parametric eddy current transducer 1- ferrite core, 2- spherical ferrite tip, 3- coil of inductance with number of turns W = 18.

where: $A_m(h)$ is the amplitude value of the information component of the ECT signal, $\alpha(h)$ is the signal decrement, $f(h)$ is the frequency of the signal natural oscillation, t is the current time, (t_1, t_2) the time interval of the ECT signal analysis, $u_n(t)$ is 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.

A. Technique of Experimental Data Processing

The procedure for processing and analyzing the characteristics of ECT information signals with impulse excitation included the following steps:

- definition of the peak value of amplitude A of the signal $u_{ect}(t, h)$ (Fig. 3);
- definition of a Hilbert - image sample $u_{ect}[j, h]$:

$$u_H[j, h] = \mathbf{H}[u_{ect}[j, h]], \quad (2)$$

where j is the reference number of the ECT signal in the digital representation, **H** is the Hilbert transformation operator;

- determination of discrete PCS and ACS ECT:

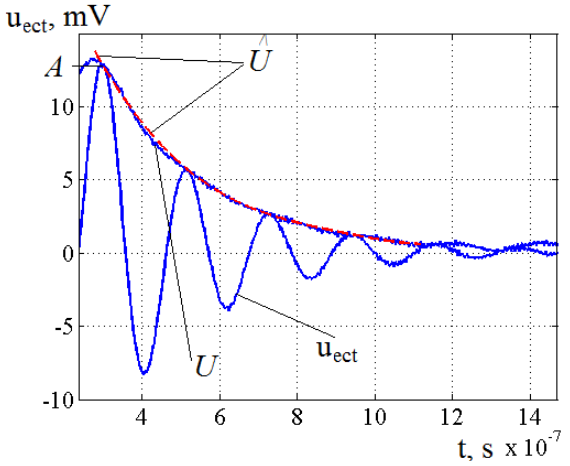

Fig. 3. The plot of signal received from a transducer excited by a pulse

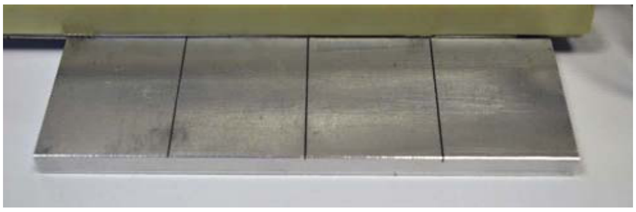

Fig. 4. The object of investigation

$$\Phi[j,h] = arctg\frac{u_{\mathrm{H}}[j,h]}{u_{ect}[j,h]} + \mathbf{L}\left(u_{\mathrm{H}}[j,h], u_{ect}[j,h]\right), \qquad (3)$$

$$U[j,h] = \sqrt{u_{ect}^2[j,h] + u_{\mathrm{H}}^2[j,h]}\,, \qquad (4)$$

where **L** is the operator of the deployment of PCS outside the interval of uniqueness of the *arctg* function;

- smoothing of function (3) by the method of determining the linear regression of Bartlett-Kenoy [10];
- determination of the frequency of ECT signals from the linear trend of the function (3):

$$f(h) = \Delta\,\Phi_L(\Delta T,\, h)\,/\,(2\pi\Delta T), \qquad (5)$$

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

- application of exponential approximation to function (4) to increase the accuracy of determining the attenuation coefficient of the ECT signal. The ACS section was taken into account, which corresponds to the first periods of the ECT information signal, that is, periods with the highest sharpness of the ACS (Fig. 3);
- determination of the attenuation coefficient of ECT signals by the formula:

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

$$\alpha + \beta = \chi. \qquad (1)$$

(1)

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

- comparison analysis of the results obtained with the calibration characteristic of the dependence of the measured TO parameter on the information parameter of the ECT signal;
- visualization of the obtained results.

Such a technique allows us to perform a correct comparative analysis of the informational parameters of the ECT signals in different modes of excitation.

IV. EXPERIMENTAL RESEARCH AND RESULTS DISCUSSION

ECT was located on the TO section with a crack. The general model of the obtained electric signal ECT was determined by the expression (1). The dimensions of the cracks were known. The process of signal formation was the same for all cracks. The dependences *A(h)* for both modes of excitation and *α(h)* and *f(h)* for the pulsed mode were determined at the stage of signals processing for the received samples.

Fig. 5a shows the experimental values of the amplitude level of the parametric ECT signal under conditions of continuous excitation. Fig. 5b demonstrates peak amplitude values of the signal from the same transducer in conditions of pulsed excitation. Curve 1 on Fig. 5 corresponds to the dependence *A(h)* for the sample S-1; curve 2 – to the dependence of *A(h)* for sample S-2. The analysis of these graphs shows a weak dependence the amplitude of the ECT with pulsed excitation on the crack depth *h* for both samples. At the same time, an increase of the crack depth leads to an increase of the amplitude values of the ECT voltage with harmonic excitation for both samples.

There is a slight change in the peak values of the ECT amplitude signal with the pulsed excitation in the range $h = 0 \div 0.5mm$ for the S-1 sample. However, the sensitivity in this case is lower than in the harmonic excitation waveform ($S_{A\_pulsed}=1.3mV/mm < S_{A\_harm}=0.3mV/mm$).

The analysis results of the attenuation of the ECT signal at its pulse excitation for the two samples are shown in Fig. 6 (curve 1 for sample S-1, curve 2 for sample S-2). These graphs show that the dependence of the transducer signal attenuation from the crack depth of the TO is linear and has different values, depending on the physical and mechanical characteristics of the TO material.

Comparative analysis of graphs in Fig. 6 shows that this informative parameter can be used in the testing and evaluation of the crack size. In this case, the relative error does not exceed ±0.5%, and the sensitivity is equal to $S_{\alpha\_S1}=0.2\ \mu s^{-1}/mm$, $S_{\alpha\_S2}=0.1\ \mu s^{-1}/mm$.

Fig. 7 shows the results of changes in the frequency of the signal natural oscillations of the ECT with pulsed excitation as a function of the crack depth in the specimen S-1 and S-2, respectively. As can be seen, the graphs of the dependence *f (h)* are linear, and the values of the frequency of the ECT natural oscillations decrease with an increase of the crack depth for both samples.

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

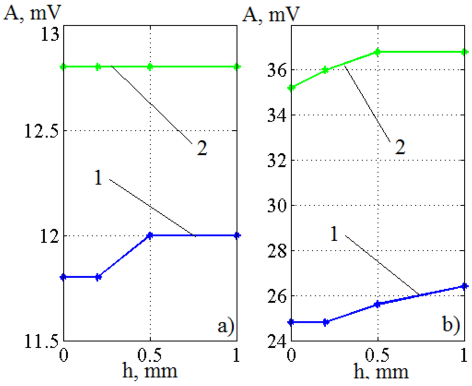

Fig. 5. The plot of signal received from a transducer excited by a pulse

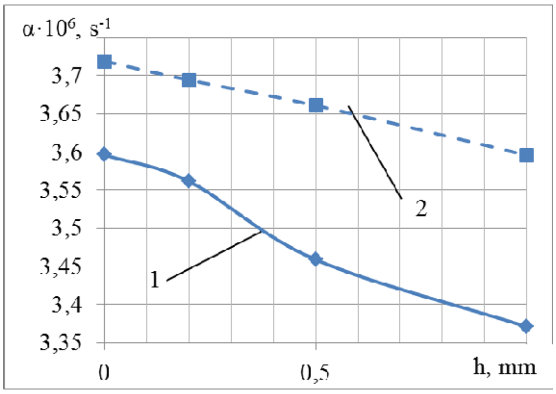

Fig. 6. Dependence of *α (h)* on impulse excitation of ECT

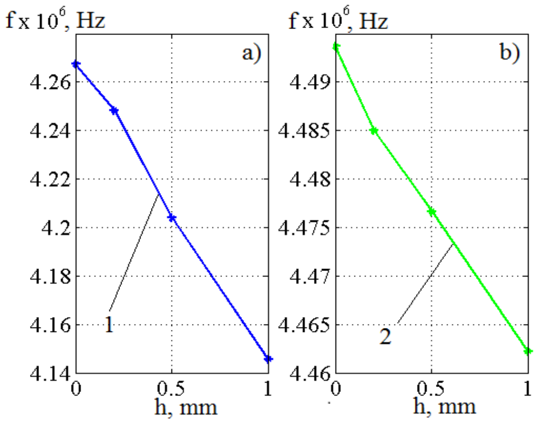

Fig. 7. Dependence *f (h)* on the pulsed excitation of the ECT (curve 1 for sample S-1, curve 2 for sample S-2)

V. CONCLUSIONS

It has been established that the ECT signals in the form of damped harmonic oscillations obtained by pulse excitation of the transducer can be used in the eddy current defectometry to estimate the depth of surface cracks.

Comparative analysis of the possibility of estimating the surface cracks depth was carried out using signals of parametric ECT in pulsed and harmonic modes of excitation. The analysis was carried out by estimating the change in the amplitude values of the ECT signals from the crack depth in the TO. It was shown that sensitivity for continuous ECT excitation is better

However, the use of this informative parameter under conditions of harmonic excitation in the defectometry problems has a significant limitation due to the considerable noise accompanying the process of evaluating the crack parameters.

It is established that in the pulsed mode of ECT excitation, the dependence of the attenuation and frequency of natural oscillations of the signal on the change in the crack depth is close to the linear one. The performed experiments showed that changes in crack depth in samples of steel and aluminum in the range from 0 to 1 mm led to a relative change in the frequency of the natural oscillations of the VSP by ≈3% and ≈0.7%, and a relative change in the decrement by 3.3% and 6.6%, respectively. The error determination of the crack depth did not exceed ± 2% for these samples.

The given dependencies for the parametric overlay ECT can be used for further studies of these type transducers in order to evaluate the parameters of cracks in the surface and subsurface material layer with a dielectric coating. The use of the parametric type of ECT in combination with the digital processing of information signals expands the capabilities of pulse ECNDT, in particular, allows you to implement a mode of evaluation of the depth of surface cracks.

REFERENCES

[1] Teterko A., Nazarchuk Z. Selektyvna Vykhrostrumova Defektoskopija [Selective Eddy Current Non-Destructive Testing]. Lviv: Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine (in Ukraine), 2004. – 247p.

[2] Bazhenov, V., Protasov, A., Gloinik, K. Increasing of operation speed of digital eddy current defectoscopes based on frequency synthesizer. MRRS 2017 - 2017 IEEE Microwaves, Radar and Remote Sensing Symposium, Proceedings 8075051, p. 155-158.

[3] Huang S., Wang S. New Technologies in Electromagnetic Non-destructive Testing. Singapore : Springer, 2016. – 222 p.

[4] Johnson M. J. Pulsed eddy-current measurements for materials characterization and flaw detection. The University of Surrey, Guildford, Surrey, UK, 1997 – 153p.

[5] Vasic D. Pulsed Eddy-Current Nondestructive Testing of Ferromagnetic Tubes / D. Vasic, V. Bilas, D. Ambrus // IEEE Trans. Instrum. Meas. – 2004. – vol. 53, no. 4. – pp. 1289-1294.

[6] Adewale I. Decoupling the Influence of Permeability and Conductivity in Pulsed Eddy-Current Measurements / I.D. Adewale, G.Y. Tian// IEEE Trans. Magn. – 2013. – vol. 49, no. 3. – pp. 1119-1127.

[7] Yating Y. Investigation on contribution of conductivity and permeability on electrical runout of eddy current displacement sensor / Y. Yating, D. Pingan, Y. Tuo // Proc. IEEE Instrum. Meas. Technol. Conf. – 2011.

[8] Kuts Y. Analysis of an Eddy-Current Transducer with Impulsive Excitation in the Nondestructive Testing of Cylindrical Objects / Y. Kuts, Y. Lysenko, A. Dugin, A. Zakrevskii // Materials Science. – 2016. – vol. 52, no. 3. - pp 431–437.

[9] Lysenko I. Using multidifferential transducer for pulsed eddy current object inspection / Y. Kuts; A. Protasov; I. Lysenko; O. Dugin; O. Bliznuk; V. Uchanin // IEEE 1st Ukraine Conf. on Electrical and Computer Engineering. – 2017. – pp. 826-829.

[10] Improvement of the Eddy Current Method of Non-Destructive Testing with Pulsed Mode Excitation / I. Lysenko, Y. Kuts, O. Dugin, A. Protasov // The e-Journal of Nondestructive Testing. – 2016. – № 7, Vol. 21.