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Using Multidifferential Transducer for Pulsed Eddy Current Object Inspection

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***Abstract* — In this article is considered of experimental results of using the multidifferential type of a transducer at two excitation mode - pulsed and harmonic. The research was carried out on the plates-type samples made of steel and aluminium alloy which had artificial defects like crack. It has been described the analysis procedure signals informative parameters from multidifferential type transducer. The signal amplitude, decrement and frequency of natural oscillations have been used as informative parameters of the transducer signal at the pulsed mode of excitation. The research of multidifferential type of the transducer at harmonic excitation mode was carried out on the frequency which was equivalent to natural oscillations frequency at the pulsed mode of excitation. It is given the experimental results of evaluation of the electric conductivity and cracks depth influence to signal informative parameters. The general character of dependencies of the signal amplitude, decrement and frequency at pulsed mode excitation of the transducer from crack depth in testing samples are found. Also, sensitivities of the signals informative parameters of multidifferential type transducer at both excitation modes to crack depth variation have been defined.**

Keywords* — *pulse eddy current; multidifferential type eddy current transducer; excitation harmonic mode; excitation pulsed mode; frequency; decrement; crack depth

I. INTRODUCTION

High effectiveness of the eddy current non-destructive testing (ECNDT) leads to its application in different areas of science and engineering. Traditionally ECNDT is based on eddy currents excitation by harmonic signals in a testing object (TO) and following analysis of the signal's informative parameters taking from a transducer. At uninterrupted impact on the TO the electrophysical characteristics of the TO and its geometrical parameters can be found using the amplitude and phase shift of a transducer signal [1]. In this case there are some negative factors which complicate to analyzing and interpreting a transducer signal. The most negative influence on a testing result have Such factors as an air-gap between transducer and TO, fluctuation of material's electromagnetic properties, bending and roughness of TO's surface, outer and instrumental noises [2]. In order to eliminate these factors the construction of transducers is improved [3]. We can find new manners of eddy currents excitation and new methods of signal processing [2].

Development of transducers with anaxial construction or double differentiation (multidifferential type) is important problem today [3, 4, 5]. Anaxial transducers are characterized by non-coincidence of the exciting and measuring coil axes. Such transducers have more complicated construction and need hard-working adjustment. On the other hand they have more selectivity and high sensitivity in comparison with traditional transducers.

One more direction of transducer development is application of the different modes of eddy currents excitation. One of them is connected with application of the pulsed mode transducer excitation. Different duration of a current pulse gives possibility to get information about the air-gap at low pulse duration and information about flaw in a TO at high pulse duration [6]. Application the combine mode of excitation (harmonic and pulsed) can be used for increasing number of testing characteristics at inspection of pipe walls [7]. In this case the transducer's signal attenuation and zero crossing time variation are additional informative parameters (IP).

Pulsed ECNDT is used for flows develop in the connecting holes of airplanes as well [8]. The result of parameter testing is based on analysis of the transducer's signal amplitude (analysis in time domain) and spectrum energy (analysis in frequency domain).

The present-day ECNDT with pulsed excitation is based on measuring the transducer's signal amplitude or duration. Signal has pulsed form and it arises at the time of interaction between nonstationary electromagnetic field and a TO. Traditionally pulsed excitation is used for transducers of the absolute type [6, 7]. Improvement of the pulsed transducers is possible on the way of the new IP searching, different distortions decreasing, realizing multiparameter inspection, enlarging functional possibility of transducers and raising testing reliability [9, 10].

II. OBJECTIVE AND METHODS

The aim of this work is to investigate the multidifferential type of transducers at harmonic and pulsed mode of excitation, analyze informative signals under offered processing technique and information comparison for two excitation modes.

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The paper contains experimental results of two samples testing using the multidifferential type of a transducer with pulsed excitation. The samples look like plates and have thickness 5 mm, length 100 mm and width 30 mm (Fig. 1). The first sample (S1) is made of steel St.20 and second sample (S2) is made of aluminium alloy D16. The both samples have 3 artificial defects. The defects were made by cutting the upper surface. Width of the defect is 0.2 mm and depths are h = {0.2, 0.5, 1.0} mm. Roughness of the working surface is within 1.6 mkm.

The mentioned problem is solved using experiments which based on:

- researching of the multidifferential overlay transducer operation at the condition of pulsed excitation and analyzing its signals in the time domain;
- discovering and analyzing of the signal's informative parameters received from a transducer;
- defining of the functional dependence of signal parameters on the TO's characteristics.

III. EXPERIMENTAL SETTING

A. The Structure of the Experimental Model

On the Fig. 2 is showing the structure of proposed ECNDT system. This system consists of a multidifferential overlay eddy current transducer (MdECT), generator (G), digital oscillograph (DO), digital interface (DI) and personal computer (PC) with original software (S). Received signals were analyzed using developed software. Algorithm of software is based on signal processing in time domain using Hilbert transform and analysis of signal's amplitude and phase characteristics [11, 12].

Multidifferential transducer was excited by a pulse from the generator (U=5V, pulse time T=0.1ms, duration τ=50μs). The signal from transducer looked like damped harmonic oscillations (Fig. 3).

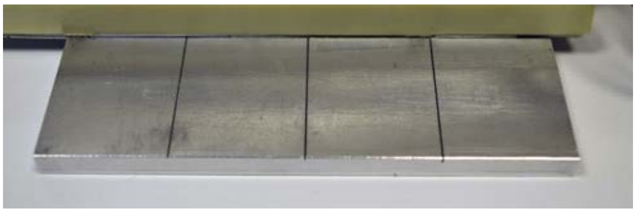

Fig. 1. The object of investigation

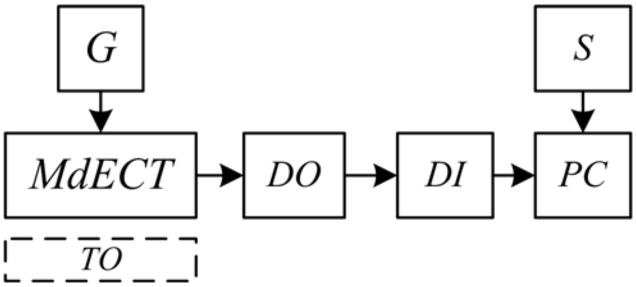

Fig. 2. Structure of the experimental setup

Informative signal model of the transducer is presented as an additive mixture of harmonic oscillation and Gaussian noise:

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

where $A_m(h)$ – amplitude component of the transducer informative signal, $\alpha(h)$ – signal decrement, $f(h)$ – signal frequency of natural oscillations, t – current time, $(t_1,\,t_2)$ period of the transducer signal analyses, $t \in (t_1,\,t_2)$, $u_n(t)$ – signal noise term which was considered like Gaussian random process realization with zero statistical expectation and dispersion σ^2.

B. Technique of Experimental Data Processing

The order of signal processing was following:

- investigation of the multidifferential transducer operation at pulsed excitation according to proposed in [9, 11] methods;
- determination of the frequency of signal natural oscillations by the formula:

$$f(h) = \Delta\Phi(h) / (2\pi\Delta T), \quad (2)$$

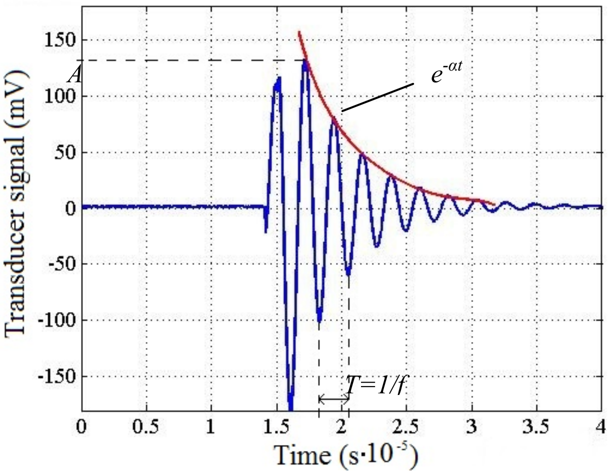

Fig. 3. The plot of signal received from a transducer excited by a pulse

where $\Delta\Phi(h)$– accumulated signal's phase within $\Delta T > T$, T – signal's period;

- investigation of the multidifferential transducer operation at continuous excitation on the frequency of natural oscillations;
- analysis of the signal's informative parameters received from a transducer: amplitude dependence $A(h)$, decrement $\alpha(h)$ and frequency of natural oscillations $f(h)$ on h.
- evaluation of sensitivity of the signal's informative parameters to changing h in a TO. Under sensitivity of the informative parameters we imply:

$$S_A = \partial A/\partial h,\ S_\alpha = \partial \alpha/\partial h,\ S_f = \partial f/\partial h. \qquad (3)$$

This method allows to accomplish correct comparable analysis of the multidifferential transducer sensitivity at different exciting modes regarding to the crack depth in a TO.

IV. EXPERIMENTAL RESEARCH AND RESULTS DISCUSSION

The eddy current transducer was placed on the TO's part which had a certain crack. The received signals looked like in the equation (1). Investigations were accomplished for two exciting modes – pulsed and continuous. Samples S1 and S2 were used. It was defined dependences A(h), α(h) and f(h) A(h), α(h) and f(h) for received selections of the transducer signals.

Received experimental data of A(h) for mentioned samples and at mentioned conditions are shown on Fig. 4 and Fig. 5. The curves 1 and 2 on these figures show for the S1 dependence A(h) at frequencies equal to 667 kHz and 434 kHz accordingly. The curves 3 and 4 demonstrate for the S2 dependence A(h) at frequencies equal to 787 kHz and 507 kHz accordingly. As we can see, the crack depth increasing leads to increasing of the transducer voltage amplitude. Sensitivity of the voltage amplitude to the crack depth puts in Table 1.

TABLE I. CRACK DEPTH SENSITIVITY (V/M)

Excitation	Sample 1		Sample 2	
	667 kHz	*434 kHz*	*787 kHz*	*507 kHz*
pulsed	29.8	62.3	14.5	20.4
harmonic	132	145	62	91

The Fig. 4 and Fig. 5 demonstrate dependences of the signal's amplitude on the crack depth. The dependences look like a linear function. Continuous excitation provides higher transducer sensitivity.

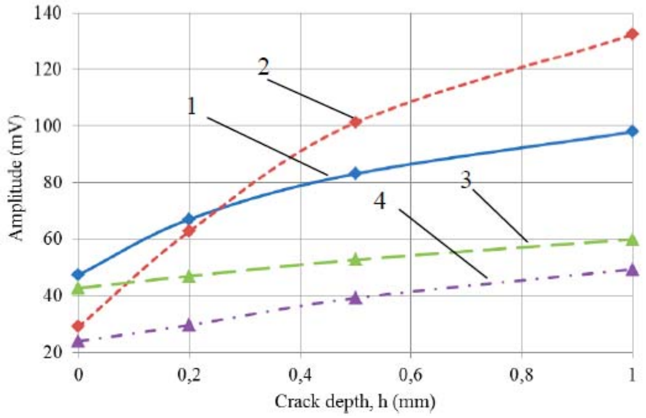

Fig. 4. Dependences signal's amplitude *A(h)* at pulsed excitation of the transducer

On the Fig. 6 it is shown the results of the signal decrement at pulsed excitation for tow samples and on different frequencies. Fig. 6a and Fig.6c correspond to the S1 sample and Fig. 6b and Fig.6d – to the S2 one. The plots demonstrate increasing sensitivity to the crack depth under increasing of the natural oscillations frequency. As an example, sensitivities for S1 are S_α(f=667 kHz)=34·10^3 $s^{-1}mm^{-1}$ and S_α(f=434 kHz)=7·10^3 $s^{-1}mm^{-1}$. Moreover, comparable analysis of these curves shows that different materials provoke to different signal decrement dependences on the crack depth. This fact can be used for evaluation of the physico-mechanical characteristics of the TO's material.

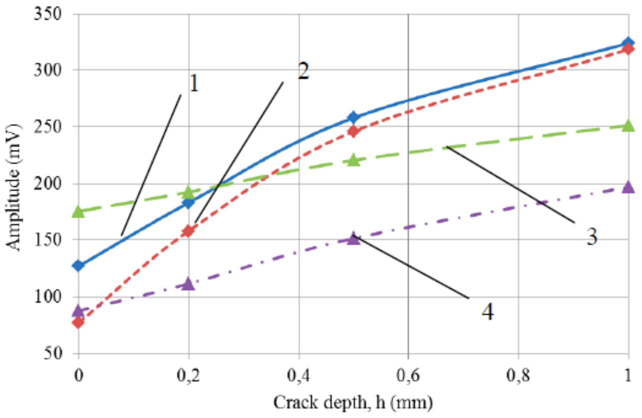

Fig. 5. Dependences signal's amplitude *A(h)* at continuous excitation of the transducer

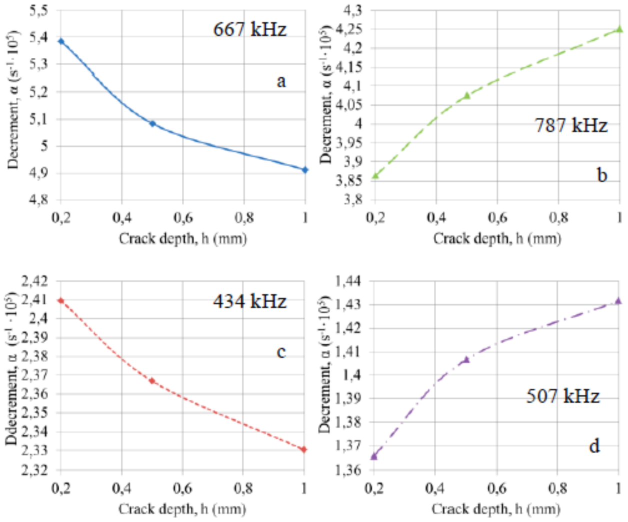

Fig. 6. Dependences signal's decrement *α(h)* at pulsed excitation of the transducer

The Fig. 7 shows results of the definition of natural oscillations frequency change as a function of the crack depth in a TO. The curves (a) and (c) on this figure belong to the S1 sample and display dependences f(h) for case when initial frequency of the signal's natural oscillations equal to 667 kHz and 434 kHz accordingly. The curves (b) and (d) belong to the S2 sample and they were obtained for frequencies 787 kHz and 507 kHz. After analyzing of these plots, it is clear that dependence f(h) approaches to the linear function and have a tendency to be decrease at increasing of the crack depth h. In this case sensitivity of the method to the crack depth h is improved at a signal frequency increasing. So, sensitivities for the sample S2 are S_f(f=787кГц)=83.6 Hz/mm and S_f(f=507кГц)=28.8 Hz/mm.

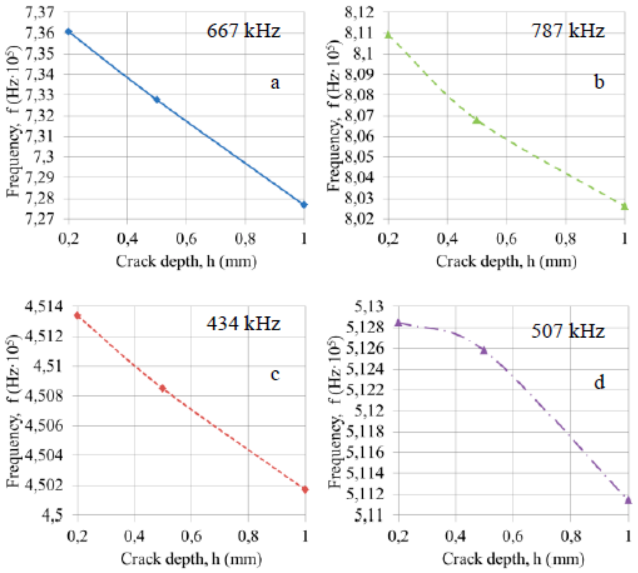

Fig. 7. Dependences signal's frequency *f(h)* at pulsed excitation of the transducer

V. CONCLUSIONS

Comparison of the signal's amplitudes change at the crack depth change for pulsed and harmonious modes of excitation is shown that sensitivity at continuous excitation of the transducer is better. However, use signal's amplitudes dependence on the crack depth in a TO allows to expand functional capabilities of the crack detection in some cases. Moreover, we can see increasing sensitivity of the transducer's informative parameters to a crack depth at increasing of the signal's initial frequency. Among those parameters are signal decrement and frequency of the natural oscillations.

Evaluation of the physico-mechanical characteristics of the TO's material can be realized by using dependence signal decrement and its frequency of the natural oscillations on a material and crack depth at pulsed mode excitation.

Thus, eddy current non-destructive testing at pulsed mode excitation in combination with digital signal processing can supplement well-known methods considerably by using analysis of such parameters as frequency of the natural oscillations, peak amount of the amplitude and signal decrement.

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