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ANALYSIS AND SYNTHESIS OF SIGNALS AND IMAGES

Using Signals of Special Form in Multi-Frequency Eddy Current Testing

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Abstract—An eddy current testing method based on the use of an exciting signal of special shape is proposed. Subsequent digital processing of the detected output signal makes it possible to calculate the measuring sensor parameters at different frequencies and to construct an experimental hodograph of the sensor–test object system. Experiments performed for materials with different physical and geometrical characteristics of constructing hodographs have shown that the proposed method provides a reliable separation of the main factors affecting the results of multi-frequency eddy current measurement. The results can be used in automated systems for inspection and non-destructive testing of materials and products.

Keywords: automation of measurements, eddy current method, inspection of materials, digital signal processing.

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INTRODUCTION

Eddy current testing is one of the most common methods for automated inspection of materials and structures [1]. It is used to evaluate the physical parameters [2] characterizing the state of the internal structure of metallic materials, detect surface subsurface defects [3], detect cracks arising during operation, and determine their size and location [4, 5]. The results of eddy current measurements are dependent on the joint action of a large number of factors. These include the physical properties of materials (electrical conductivity and magnetic permeability), the shape and geometrical dimensions of the test object, and the measurement conditions [6, 7]. In addition, the results depend on the design features of the sensors used [8, 9].

When using eddy current testing based on measurements at a single frequency, it is difficult to distinguish the controlled parameter and suppress the influence of all other factors. The eddy current method is best informative in multi-frequency measurements involving the construction and analysis of hodographs of the sensor–sample system [10]. Such hodographs reflect the joint influence of virtually all the factors essential for material inspection. The main problem in multi-frequency measurements is the accuracy of determining the sensor parameters in a wide frequency range. Experimental hodographs allow separation of the influence of different factors provided that sufficient accuracy is achieved [11, 12]. At the same time, in multifrequency eddy current measurements, it is common to use sequential frequency search. As a result, improving the accuracy of hodographs requires increasing the number of individual measurements and is rather time-consuming. Furthermore, during measurements, disturbing factors can change randomly, introducing additional distortions.

This paper presents a method of constructing experimental hodographs in which the above-mentioned drawbacks are eliminated. This method is based on exciting the sensor by a signal of special shape.

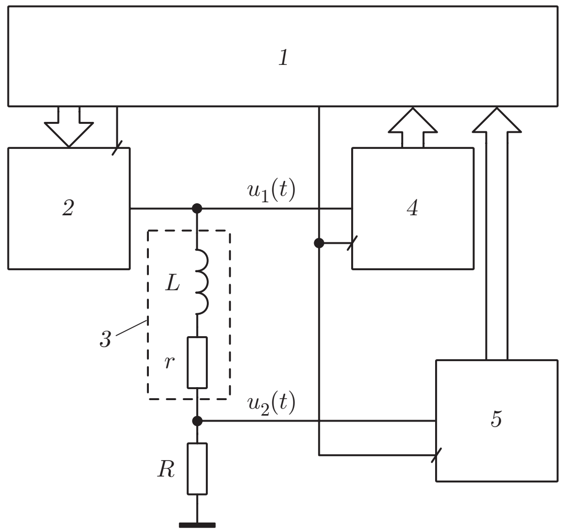

Fig. 1. Structural diagram of the measurements.

1. MEASURING DEVICE

The employed measurement technique allows automation of experiment and involves simultaneous determination of the sensor parameters at different frequencies. A block diagram of the measuring-computing device is shown in Fig. 1. The control device *1* generated a data array containing instantaneous values of the signal exciting eddy currents. This array was fed to the input of the signal shaper *2*, which included a clocked digital to analog converter with a low-pass filter at the output. The thus synthesized analog signal $u_1(t)$ was sent to the input of the measuring circuit, which consisted of a series-connected parametric transducer *3* (L is the inductance, r is the active resistance) and a reference resistance R. The time scans of the input $u_1(t)$ and output $u_2(t)$ signals were recorded synchronously using analog-to-digital converters *4* and *5*, respectively. As a result, data arrays for the input $\{u_n^{(1)}\}$ and output $\{u_n^{(2)}\}$ signals were obtained, which were sent to the control unit for further processing.

In the measurement diagram considered, the relationship between the input $u_1(t)$ and output $u_2(t)$ signals was described by the differential equation

$$\frac{du_2}{dt} + \frac{R+r}{L}\,u_2 = \frac{R}{L}\,u_1. \tag{1}$$

To analyze the frequency spectrum of recorded signals, formula (1) was subjected to a Fourier transform, resulting in the expression

$$\hat{U}_2 = \frac{R}{R+r+j\omega L}\,\hat{U}_1 = \dot{K}(j\omega)\hat{U}_1, \tag{2}$$

where $\hat{U}_1$ and $\hat{U}_2$ are the Fourier transforms of the functions $u_1(t)$ and $u_2(t)$, respectively; $\dot{K}(j\omega)$ is the complex transfer coefficient at frequency ω for the measuring circuit ($j = \sqrt{-1}$).

2. MODIFIED METHOD OF MULTIFREQUENCY MEASUREMENTS

In accordance with the basic idea of the proposed approach, for simultaneous measurement of the sensor parameters, the signal $u_1(t)$ applied to the input of the measuring circuit was obtained by superposition of M harmonic signals [13] with fixed frequencies $\omega_1, \ldots, \omega_M$:

$$u_1(t) = u_0 \sum_{m=1}^{M} \sin(\omega_m t), \tag{3}$$