Measurement System for Studying Thickness by Means of Subminiature Eddy-Current Transducers

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Abstract

A new gage system was made based on the eddy-current transducer. The system makes it possible to evaluate the possibility of using the eddy current method to measure the thickness of conductive and dielectric coatings applied on a conductive base material. In this article, in particular, the measurement features are described in detail. Also it represents data, showing the dependence of signal amplitude on objects of different thicknesses.

1 Introduction

To control the thickness of electrically conductive sheets, films, plates, coatings on them, the walls of pipes, cylindrical and spherical chambers and to determine the air gap between plates of the same material thickness gages based on the eddy current method are used. Eddy-current thickness gauging of the object, which is inherently a dielectric or conductive layer (so-termed, a coating) applied on a conductive base material requires the control, based on the phase measurement of the eddy-current transducer (ECT) signal [1]. This method makes it possible to determine the thickness of the coating d.

For the estimation of coating thickness with known conductivity, Urayama et al. [2] discussed the feasibility of thickness evaluation of Ni-based alloy coating sprayed on 304 austenitic stainless steels using swept frequency EC (SFEC) testing. The coating thicknesses were estimated within a maximum error of 22 fim through inverse modeling methods. Barbosa [3] presented a formula to obtain the coating thickness of galvanized steel wires from the impedance of a solenoid containing a sample of wires with the assumption that the skin depth of the ECs in the coating is much larger than the coating thickness. Tai et al. [4] and Yang [5] used pulsed EC and SFEC techniques to determine the thickness and conductivity of metallic coating on a metal substrate for the case when either the coating or the substrate is magnetic.

Sakran et al. [6] demonstrated a reflection mode EC technique to measure the thickness of conducting layers in a range from 0.1 to 1 im with the spatial resolution of 1-2 mm at the microwave frequency. Lefebvre [7] studied the behavior of the lift-off point of intersection (LOI) under various testing conditions, and LOI is presented to measure the thickness of conductive layers over the ferromagnetic substrates. Zhao et al. [8] experimentally demonstrated the feasibility of the nanometallic film thickness measurement by using the EC method.

Typically, surface ECT is used for these measurements. Such a transducer may have up to three windings: energizing winding (creating an excitation field), measuring winding (designed directly for measurements) and compensation winding designed to reduce the influence of the energizing winding on the final signal. In this case, it becomes possible to use electromotive force in transducer compensation winding as a reference signal, and the phase is measured based on the sinusoidal signal on the energizing winding. This approach is used to improve the measurement accuracy. The electromotive force introduced into the measuring winding has a phase depending on the geometric parameters of the ECT, using the frequency of the current f on the energizing winding. Important parameters influencing the phase are also the gap between the transducer and the coating, the electrical conductivity of the coating σ1 and the base σ2, as well as the magnetic permittivity of the base.

Among the problems of this approach is the variation in the electrical conductivity σ1 at different points of the coating surface of thickness d, and when controlling various objects with similar coatings [9]. This causes the oscillations of phase of the electromotive force, which leads to increase in errors when measuring the thickness of the coating. Various types of an offset (amplitude, phase, amplitude-phase) resulting from the influence of electrical conductivity σ1 in this case practically have no effect. Under frequency f of excitation of current on the energizing winding makes it possible to reduce the effect of electrical conductivity. However, in this case, the substrate thickness and the magnetic permittivity of the substrate become an important influence factor.

Taking in consideration the abovementioned factors, it is necessary to choose such a frequency of an instrument to offset from oscillations of electrical conductivity, while not permitting the influence of the magnetic permittivity of the substrate. Optimal in this case is to measure not the phase φ, but the amplitude A of the signal, on which the substrate parameters have lower effect, rather than on the phase.

Therein when measuring the amplitude of ECT signal for the purpose of measuring the coating thickness, a certain value of electrical conductivity is recognized.

The purpose of this work was to estimate the application possibility of the amplitude eddy-current method alone in order to determine the thickness of the conductive or dielectric coating, placed on the conductive base, as well as to estimate such measurements inaccuracy. The conducted research showed the possibility of the amplitude eddy-current method application to detect the local thick-ness of the conductive objects, represented by several alternating conductive and non-conductive layers and solid conductive objects.

2 Material choices and design

Subminiature ECT [10-12] is designed for experimentally local studies of the thickness of various coatings and to determine the effect of various coatings on the output signal value. The developed subminiature ECT represents a core wrapped with the following windings: energizing, measuring and compensation. ECT consists of a core wrapped with the energizing, measuring and compensation windings. Both the windings and the core are impregnated with a compound. They are enclosed in a washer of corundum. This equates to increase the mechanical stability of the transducer.

To test different conductive materials, a developed transducer is used, which is connected to a personal computer via a sound card that is used as a generator and as a signal transducer. The signal thus is sent directly to the energizing winding. The software is able to control the quantity of a signal applied to the energizing winding and also allows to read the voltage values from the measuring winding, which, taking into account the calibration, are converted into conductivity values. The developed software allows measuring the thickness of conductive and dielectric non-ferromagnetic coatings and conductive materials

ECT winding coils consist of a copper wire with the thickness of 5 μm. The core is made of ferrite 2000NM3 with an initial magnetic permittivity value of 2000 and has a pyramidic shape. Characteristics of the developed transducer make it possible to achieve high localization of the control, namely, to localize the field within 2500 μm2. The developed system provides a significant depth of penetration of the field into the prototype system up to values of ~ 5 mm (at frequencies of 500 Hz.)

The eddy-current transducer (Figure 1) is a transformer with measuring (1), exciting (2), and compensation (3) windings and a magnetic circuit 4, which is located inside the cylindrical platform 5 with tracks that are cut on the external side for windings. The platform is impregnated with a compound 6 at a temperature of 200°C to prevent the disintegration of the windings when the ferrite screen 7, which is intended for the localization of the electromagnetic field on the tested object, is put in place. From the outside the transducer is contained in a corundum washer 8, which protects the core 4 from contacting the tested object.

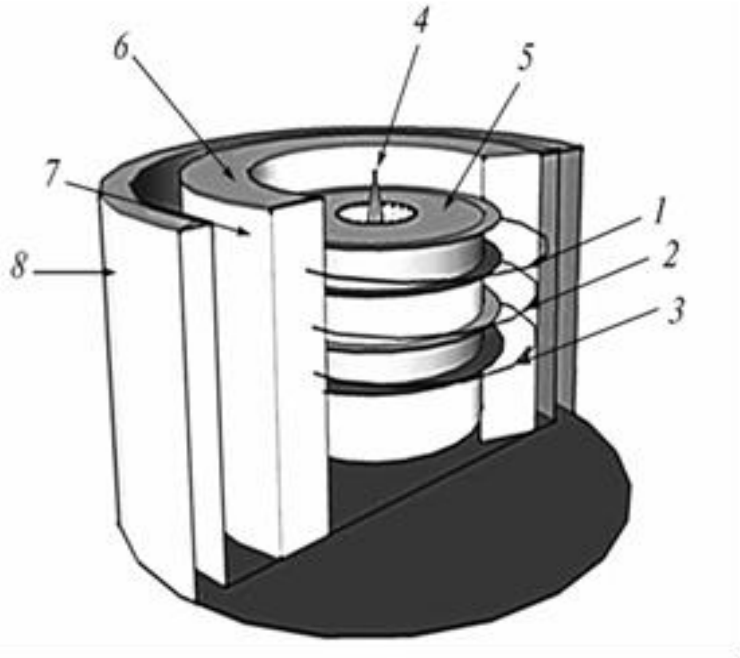

Figure 1: Scheme of eddy current transducer

The software coded in C++ for Windows allows controlling the signal on the energizing winding and receiving the signal from the measuring winding. With the help of the software it is possible to effectively control the signal, which is applied directly to the energizing winding. Also with this software it is possible to receive a signal directly from the measuring winding. The impressed voltage can be controlled using a special mixer built into the Windows. With the help of this mixer, the frequency and amplitude parameters of the generator sinusoidal signal are set. In turn, the sound card makes it possible to extend the signal bandwidth, which is applied directly to the energizing winding.
Use a third level heading for the acknowledgements. All acknowledgements go at the end of the paper.

3 Experimental results

To test the new gage system the scanning of an aluminium coating applied on a copper base material was performed. Measurements were made at a frequency of 700 Hz. The coating had different thickness, and the thickness of the copper base was 3 millimetres.

Figure 2 shows the dependence of the signal value on the thickness of the aluminium coating on a non-ferromagnetic base material. In case of an increase in the thickness of the coating to the value of 1200 μm, the signal decreases from 28 to 22 mV, therein at values from 750 up to 1500 μm, the signal is smaller than the monolith signal, this, in turn, demonstrates that the thickness of the coating is not large enough. Whereas, with a dielectric thickness of 1500 and up to 2500 μm, the signal value is constant and completely corresponds to the readings of the field value from the monolith.

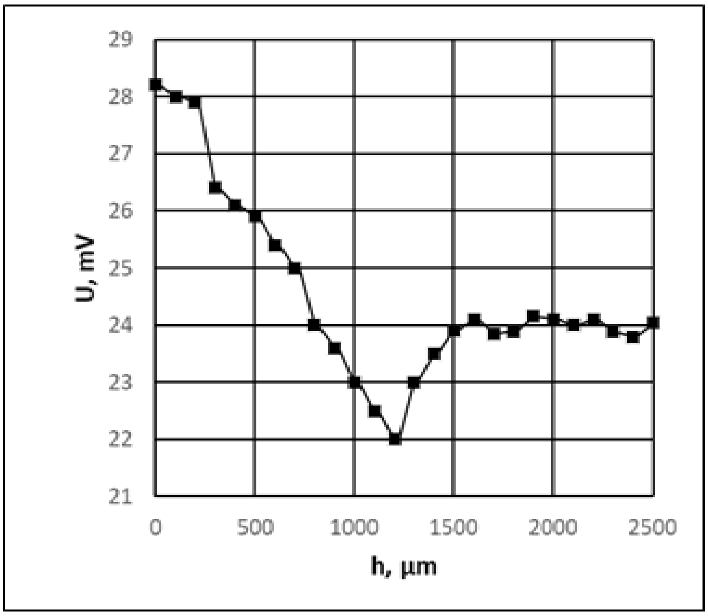

Figure 2. Dependence of the signal value on the thickness of an aluminium coating applied on a copper base

The experiment to determine the dependence of the thickness of a laminated coating, in which the layers of polyethylene alternate with the layers of the foil, was also conducted. The object of the study was the alternation of layers of aluminium foil of 20 µm and polyethylene of 20 µm. Measurements were made at a frequency of 1500 Hz.

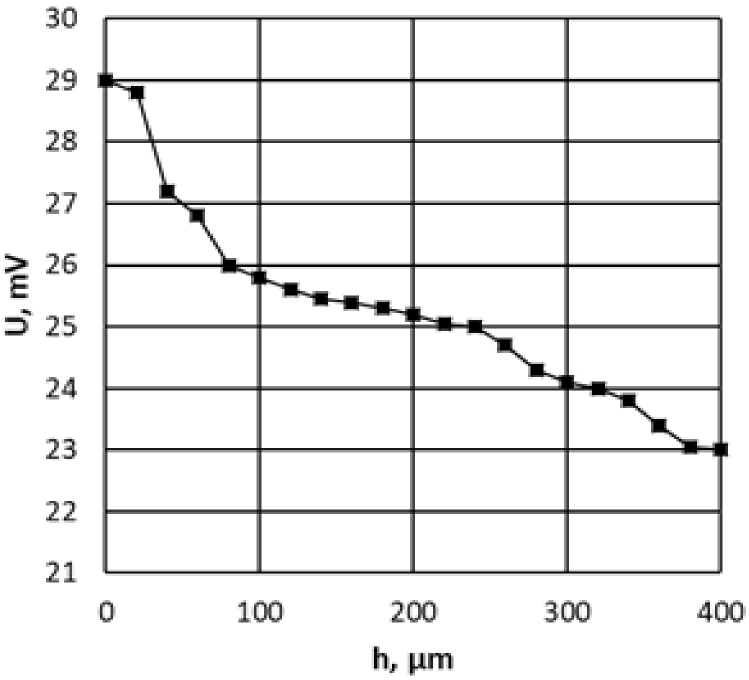

Fig. 3. Dependence of the signal intensity when scanning the laminated structure

Figure 3 shows the dependence of the signal intensity on the thickness of the laminated coating with the alternation of layers of foil and polyethylene applied on a copper base. When changing the thickness of the laminated coating from 0 to 100 µm, the value of the signal coming from the base varies from 29 to 24 mV In that case, if the thickness of the laminated coating consisting of polyethylene and foil varies from 100 to 250 µm, then the input signal shows more smooth values. In the range from 250 µm to 400 µm, the signal changes from 26 to 23 mV, that is caused by the contribution of the signal from the laminated coating and the decrease in the contribution of the signal from the copper base.

During the third test experiment a sample of a solid object of aluminium of different thicknesses was scanned. Measurements were made at a frequency of 500 Hz. Fig. 4 shows the dependence of the signal value on the thickness of a sample of aluminium. The contribution to the signal amplitude of the deeper layers of the sample increases with increasing of sample thickness. When changing the thickness from 100 to 1200 µm, the signal quantity increases from 7 to 25 mV When changing the thickness from 1200 to 2200 µm, the signal value is constant and corresponds to the value of the amplitude from the monolith (25.5 mV).

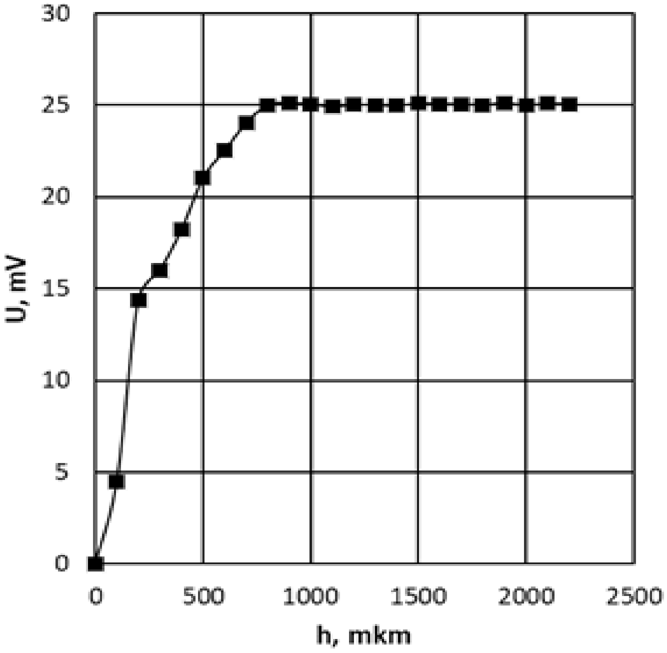

Figure 4. Dependence of the signal on the thickness of the sample of aluminium

In the final study, the experiment was also carried out with copper samples and paint coating. A layer of paint was applied to the pre-cut samples of copper. Measurements were made at a frequency of 400 Hz.

As it can be seen from the dependence of the signal amplitude on the thickness of the dielectric coating (Fig. 5), an output signal quantity decreases rapidly with increasing of coating thickness. This dependence can be approximated by an exponential function:

This dependence are graphically shown in Fig. 5. As can be seen from the figure, the received signal decreases exponentially with increasing of thickness of the dielectric coating.

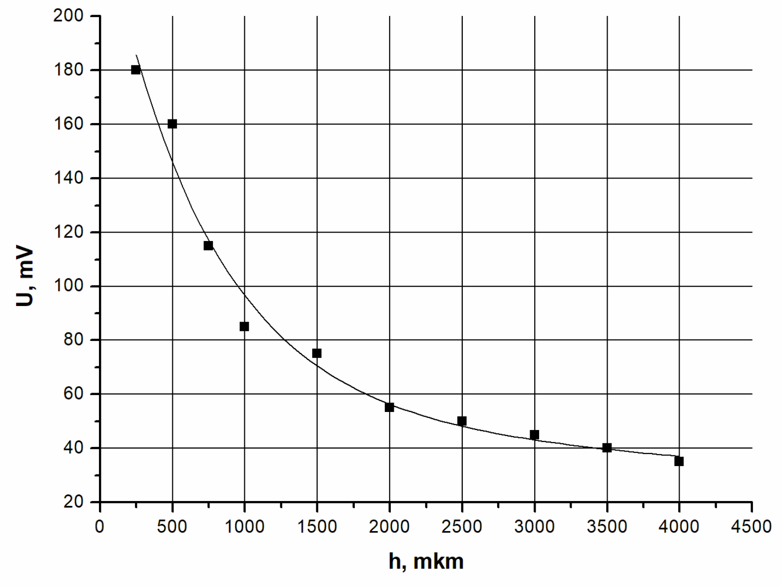

Fig. 5. Dependence of the eddy-current transducer response on the thickness of the dielectric coating (fit as an exponential function).

4 Conclusions

The presented gage system was used for the study of objects representing conductive and non-conductive coatings placed on a conductive basis, as well as for measuring the thickness of monolithic conductive objects. We assessed the possibility of local determination of the thickness of conductive and dielectric coatings using the amplitude of the signals of ECT.

It is found that the thickness of the coating affects the signal of the eddy-current transducer. This hereafter allows the use of the amplitude method to control objects of a similar class for local measurements of the thickness of conductive and non-conductive coatings, as well as other objects

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