

Research of aluminum alloys with using eddy-current transducers on the basis of cores of various form

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Abstract. The research aims to develop a microminiature eddy current transducer for aluminum alloys. The research topic is considered relevant due to the need for evaluation and forecasting of safe operating life of aluminum. A microminiature transformer-type transducer was designed, which enables to perform local investigations of unferromagnetic materials using eddy-current method based on local studies conductivity. Having the designed transducer as a basis, a hardware-software complex was built to perform experimental studies of aluminium. Cores with different shapes were used in this work. Test results are reported for a flaws in the form of hidden slits and apertures inside the slabs is derived for excitation coil frequencies of 300–700 Hz.

1. Introduction

Monitoring the quality of conducting materials occupies an important place in modern applied physics and industrial production. In the industrially developed countries, the total expenditure on monitoring the quality of work pieces is up to 3% of the production output. In areas of industry with elevated safety and reliability requirements (military, nuclear, aerospace), the cost of quality control can reach 20% [1].

One of the most widespread methods of control of conductive materials is non-destructive eddy current testing. One of the important advantages of the eddy current testing is a possibility to carry out researches without the direct contact between sensor and object that allows achieving of reliable results under high speed of scanning. However, at the same time, removal of noises affects, influencing significantly the value of desired signal is an important task. Limitation of eddy current testing can include small depth of scanning and also difficulties in determining of the burial depth of defect. Another small parameter restricting the method seriously is the area of the control zone. Maximum burial depth of defects and also minimal size of control zone are significantly limited by the constructive features of the transformers and insufficient hardware and program processing of the signal of eddy-current transformer. It's often difficult to access the geometrical parameters of separate defect in the depth of metal. In this connection, the topical task becomes the development of microminiature eddy current measurement systems for the local measurements of electroconductivity in nonuniform materials, search of defects in the alloys.

Construction produced of the aluminum-based alloys became widespread in modern machinery. Use of these alloys in such spheres as aircraft construction, automobile construction, space engineering, imposes high requirements on the structure and mechanical properties.



This task is the subject of a number of papers [2–6]. Flaw detection in cracks between two aluminum plates with a model defect in the center is discussed in [2]. The diameter of the measurement coil in this design for an eddy-current transducer was 7 mm. Scans were made at frequencies of 1 and 5 kHz, and the characteristic penetration depth of the eddy currents into the test plates at these frequencies were 3.82 and 1.71 mm. Experimental methods based on two eddy-current transducers operating in a differential mode are discussed in [3]. These kinds of circuits can greatly reduce the level of parasitic noise produced during continuous scanning in real time.

The tendency is to miniaturize the eddy-current transducer because of the need for local measurements. Recently eddy-current transducers have been developed with dimensions of 5×5 mm and a wire diameter of 0.15 mm in the working region [4]. These devices, however, do not ensure the required penetration depth and localization of the magnetic field required for local measurements in inhomogeneous media. This problem is solved using magnetic field concentrators made of ferrite with a high magnetic permeability. Ferrite concentrators significantly reduce the dispersion of the eddy currents [5, 6].

The localization of the mentoring by eddy-current transducers is improved when conical cores are used [7]. This shape makes it possible to reduce the measurement error and to detect flaws with small linear dimensions.

The worked out conception of the virtualized measuring device (transformer) enables a researcher to make a great number of measurements in different spheres with the help of one sensor only. To these spheres belong fault detection of conducting materials and stratified compos, thickness measuring, profilometry, tension measuring of permanent and variable magnetic fields and conductivity measuring of unferromagnetic materials and some others.

Producing such devices demands making a special technological line, due to that the final price of the device will increase significantly. To make the price lower we came to the conclusion that we should replace the expensive hardware blocks with the software for personal computers (PC). As a result, our device consists of eddy-current transducer (ECT) only, which is connected to the sound card of the PC, managed with the special software.

Software allows carrying out signal injection to the exciting winding of the transformer and also provide registration of the voltage on the measuring winding. Values of this voltage are later converted into values of electroconductivity.

2. Materials and methods

Microminiature eddy current transducer is developed for the control of parameters of items of aluminium alloys on small sites [8, 9]. Definable parameter is electroconductivity of the material and its distribution on the surface and depth of the control object. ECT is connected to the sound board of a personal computer with a special C++ program in the Windows system. The program controls the voltage delivered to the exciter winding of the eddy-current transducer and reads the voltage (in arbitrary units) from the measurement winding. It then uses a prior calibration to convert the received data into values of the electrical conductivity.

In general the scheme of the sensor is represented in Figure 1. In this scheme there are actuating (E) and measuring (M) windings, placed in the ECT.

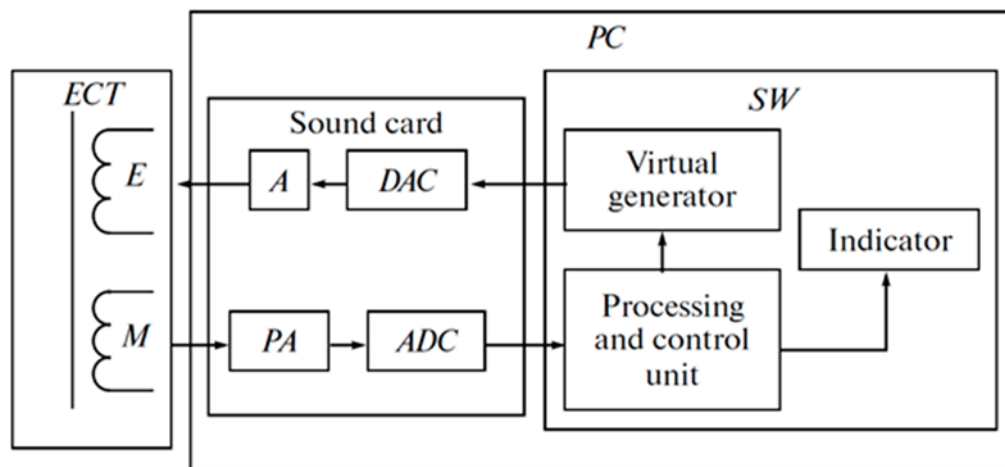


Figure 1. Scheme of the measuring device.

Specially formed signal of the virtual generator is transformed to the digital-to-analog converter. Digital-to-analog converter transforms the signal from digital to analog and transfers it through special intensifier to the exciting winding of eddy current transducer. This signal induces electromagnetic field interacting with control object. Arising field of eddy currents creates the electromotive force in the measuring winding of eddy current test. Electromotive force from the measuring winding of eddy current test allows receiving of data about the structural inhomogeneities of the control object in the active zone of eddy current transducer. This electromotive force appears and is intensified in special microphone amplifier. After filtration and selective amplification, signal is transferred into analog-digital converter, and moves to the input of sound card. The signal transforms into digital and is transferred into the unit of software processing and management. This unit allows processing of the signal and its displaying on the screen of personal computer.

Cores with different shapes were used in this work. Figure 2 shows a trapezoidal core VTP-1 (Figure 2a) and a core in the form of a sharpened cone, VTP-2 (Figure 2b).

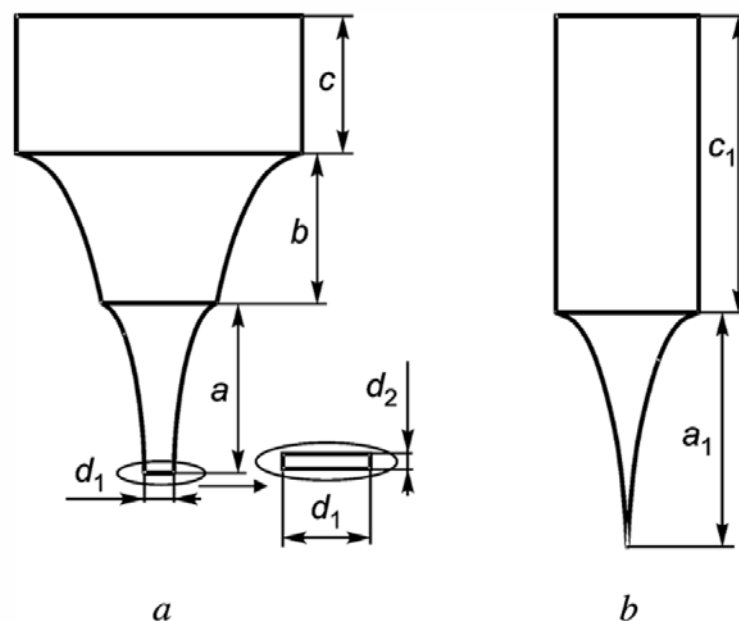


Figure 2. Scheme of the measuring device.

The dimensions of the cores are: $a = 2.2$ mm, $b = 1.8$ mm, $c = 1.6$ mm, $d_1 = 0.15$ mm, $d_2 = 0.03$ mm, $a_1 = 3.3$ mm, and $c_1 = 3.6$ mm. The cores were made of NMZ 2000 ferrite with a magnetic permeability of 500. They were used to construct eddy-current transducers with exciter, measurement, and compensation windings. The compensation winding attached to a measurement winding is used for subtracting the signal of the exciter winding from the resulting signal. The exciter and measurement windings have 200 turns, and the compensation winding, 160–180 turns. 5- μ m-thick copper wire is used for the windings. The diameters of the measurement and exciter coils of VTP-1 are 0.15 and 0.3 mm, respectively, and the core has a trapezoidal shape. The corresponding dimensions of the measurement coil for VTP-2 are 0.03–0.15 mm; the diameter of the exciter winding is 0.3 mm, and the core is in the shape of a sharpened cone.

Developed eddy current transducer (Figure 3) contains measuring (1), exciting (2) and compensating (3) windings. The windings are wound on the core (4), placed inside the special platform (5). To protect the windings, platform is impregnated with compound (6). For localization of magnetic field, ferrite screen is imposed on the construction (7). For the protection of the converter from physical impact, it's placed into the corundum washer (8).

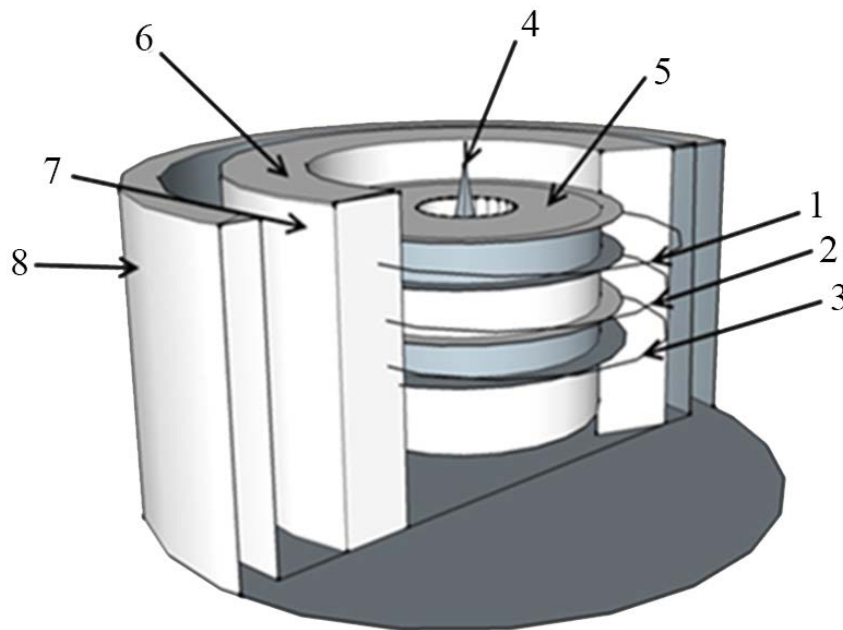


Figure 3. Scheme of the eddy current transducers.

Characteristics of the developed eddy current tests provide localization of magnetic field on the sites of about $2500 \mu\text{m}^2$ and provide significant depth of its penetration into the studied object during the work on rather low frequencies.

3. Experimental results

This measurement system was tested using samples with freely accessible model defects. Each sample was scanned by several of the eddy-current transducers with different core designs. The depth of the flaws was estimated indirectly.

Plates of aluminum-magnesium alloy (94% Al, 3% Mg) with thicknesses of 5.5 mm were used as samples. The first plate contained six faults in the form of 0.25-mm-thick slits at depths of 1.0, 2.0, 3.0, 4.0, 5.0, and 5.3 mm. The results of the scans are shown in Figure 4, where U is the voltage induced in the measurement winding of the sensor, and l is the position of the sensor relative to the tip of the object.

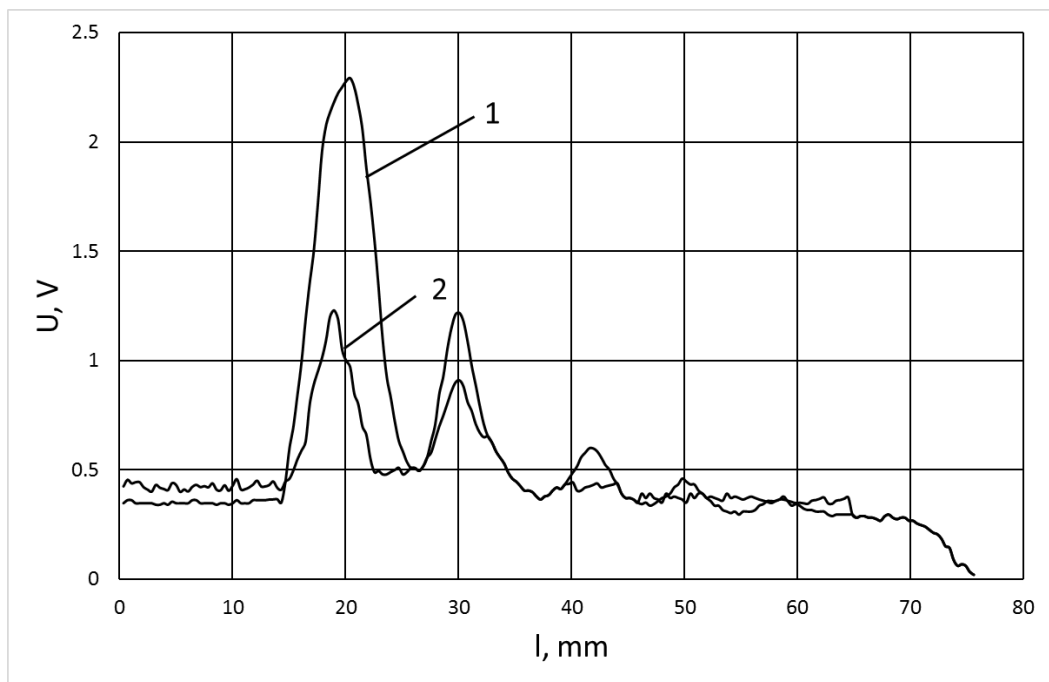


Figure 4. Results of scanning plates No. 1: 1) VTP-1; 2) VTP-2.

Flaw detection with the transducer VTP-1 revealed five of the six flaws. Scans with VTP-2 revealed only two of the flaws.

The second sample was in the form of a plate with six flaws at the same depth. The results of the scans are shown in Figure 5.

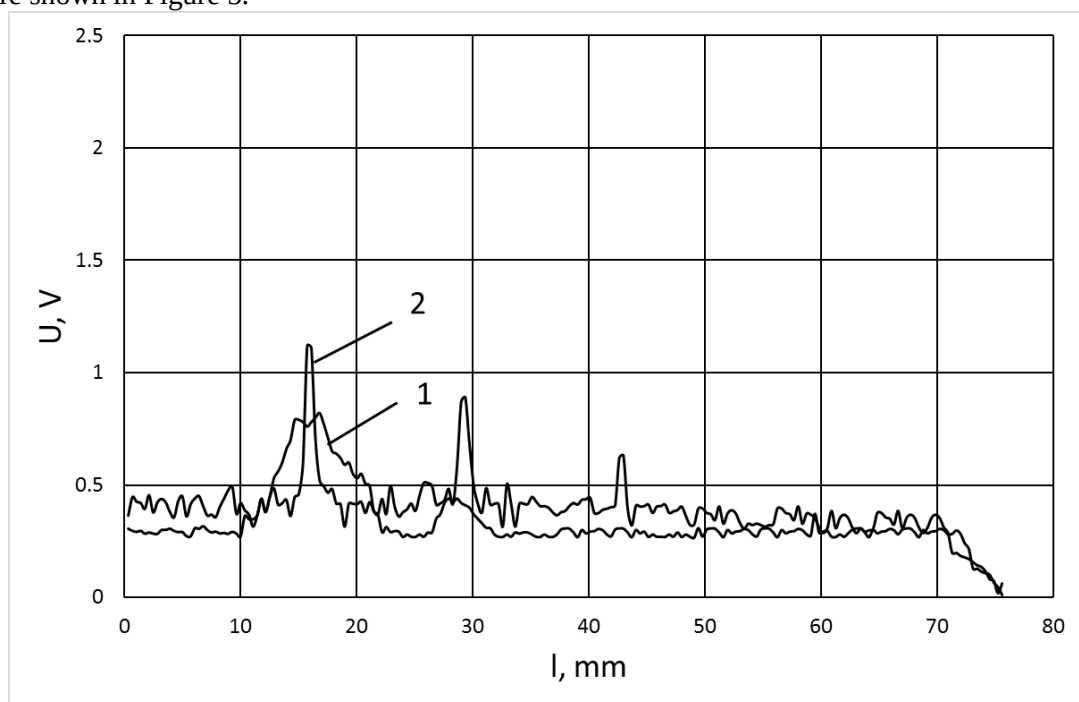


Figure 5. Results of scanning plates No. 2: 1) VTP-1; 2) VTP-2.

Flaw detection at a frequency of 500 Hz with the transducer VTP-2 revealed three of the flaws. Scanning with VTP-1 identified 2 flaws, but it was difficult to localize the position of the flaws with these transducer cores.

4. Conclusion

A measurement system has been developed for studying flaws in plates of aluminum-magnesium alloys with the aid of subminiature eddy-current transducers. The present study demonstrates the capabilities of the eddy-current monitoring technique in searching for small, deep-lying defects in aluminum alloy plates. Subminiature eddy-current transducers based on cores with a trapezoidal shape can efficiently detect long subsurface cracks with widths of 250 μm . For finding flaws in the form of hollows, it is better to use eddy-current transducers with cores in the shape of sharpened cones.

Use of microminiature eddy current transducer with ferrite cores of special shape and modified filters allowed achieving of significantly bigger localization of magnetic field and increasing of the depth of its penetration into the control object.

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