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MEASUREMENT SYSTEM FOR STUDYING FLAWS IN ALLOY SLABS BY MEANS OF SUBMINIATURE EDDY-CURRENT TRANSDUCERS

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A measurement system based on subminiature eddy-current transducers is developed for local study of defects in aluminum-magnesium alloy plates. A modified Delianna filter is made which can greatly enhance the signal-to-noise ratio. A dependence of the response of the eddy-current transducer on flaws in the form of hidden slits and apertures inside the slabs is derived for excitation coil frequencies of 300–700 Hz.
Keywords: *subminiature eddy-current transducer, aluminum alloys, flaw detection.*

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]. In this regard, the most important task is to develop subminiature eddy-current measurement systems for local measurement of the electrical conductivity in inhomogeneous materials to search for flaws in the alloys. 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 a 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].

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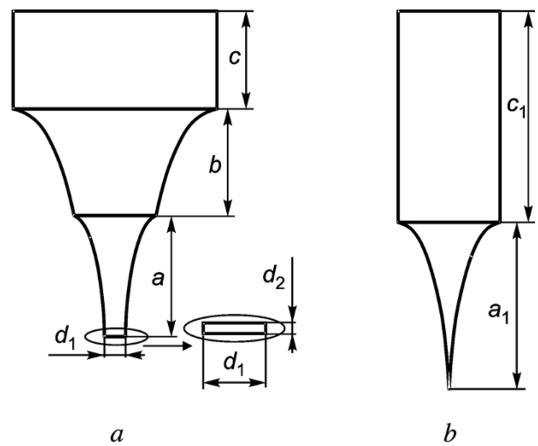

Fig. 1. The cores of the eddy-current transducers VTP-1 (*a*) and VTP-2 (*b*).

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.

Given the above, there is interest in developing subminiature eddy-current transducers capable of detecting flaws with linear sizes of about 100 μm at depths up to 5 mm. It is also important to determine the optimum core shape for finding flaws of different types and to develop filtration systems for reducing the noise in the measurement signal during scanning.

Transducer design. A subminiature eddy-current transducer has been developed for local monitoring of the physical parameters of plates made of aluminum alloys [8–11]. The parameter to be determined is the electrical conductivity of the material and its distribution over the surface and depth of the observed object. The eddy-current method is based on the dependence of the intensity and distribution of these currents in the monitored object on its geometrical and electromagnetic (and related) parameters, as well on the mutual position of the measurement transducer and the monitored object.

The eddy-current transducer 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.

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

The eddy-current transducer is a transformer with measurement, exciter, and compensation windings and a magnetic circuit enclosed in a cylindrical platform. Tracks for the windings are cut into the outside of the platform; they are impregnated with a compound at a temperature of 200°C to prevent damage when the ferrite screen is attached. The screen serves to localize the electromagnetic field on the monitored object. On the outside, the eddy-current transducer is attached to a corundum washer which protects the core from contact with the monitored object.

This eddy-current transducer can effectively localize the magnetic field to within an area of 2500 μm^2 and ensure that it penetrates to a significant depth in the test object during operation at fairly low frequencies [11].

This measurement system operates in the following way. The personal computer controls a rectangular voltage pulse generator with a pulse repetition rate f_1 and amplitude U. The repetition rate and amplitude of the pulses are set in accordance

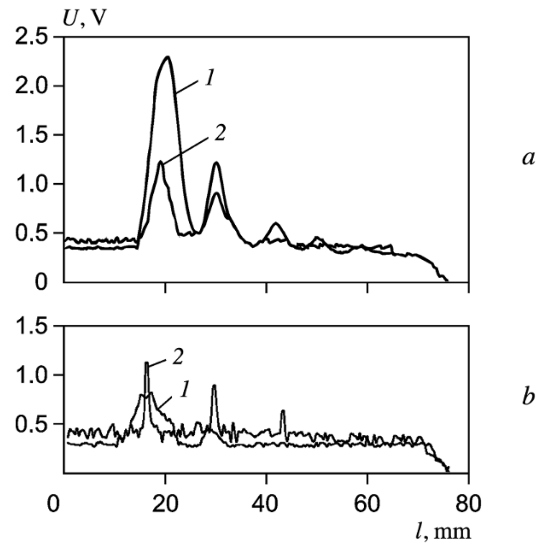

Fig. 2. Results of scanning plates No. 1 (*a*) and 2 (*b*): *1*) VTP-1; *2*) VTP-2.

with the measurement task. To convert the signal into a sinusoidal shape, the generated voltage pulses enter two integrators connected in series. After conversion, the signal power is increased in a power amplifier circuit (the gain is 20 ± 2). Then the signal enters the exciter windings of the eddy-current transducer inductor. The sinusoidal current applied to the transducer windings creates an electromagnetic field which excites eddy currents in an electrically conducting object. The electromagnetic field of the eddy currents acts on the measurement windings of the eddy-current transducer, inducing an emf in them [12–14] that carries information on the structural inhomogeneities of the monitored object in the zone where the transducer acts. The emf is amplified in a special selective amplifier based on a two-cascade modified Delianna filter with multiloop feedback. The classical filter configuration has been supplemented with a second cascade of selective amplification for increasing the amplitude of the signal at a specified frequency. With the second cascade, the filter system is highly stable and has low sensitivity to a small spread in the parameters of the component of the circuit.

The components of the filter are designed for operation at a frequency of 300–700 Hz. After filtering, the signal is fed to an amplitude detector and then through an analog-to-digital converter to the personal computer. Because of simultaneous control of the frequency of the generated signal on the exciter winding and the frequency cutoff of the filtration system, the useful signal that carries information on the distribution of the electrical conductivity inside the object (especially on possible flaws in the object) is separated. The computer program can be used to vary the working frequency of the measurement system.

Experimental results and discussion. 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 Fig. 2, 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.

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. 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.

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.

In the past, the eddy-current monitoring method has been used primarily to check for surface defects (cracks, slits, failure of surface continuity of a metal layer). Subminiature eddy-current transducers with specially shaped ferrite cores and modified filters can be used to localize a magnetic field on a small segment of an test object and to make the field produced by the exciter winding penetrate more deeply into the test object at a suitable frequency. The measurement system developed here has been used to study materials in the quality control laboratory for materials and structures at the Institute of Strength Physics and Materials Science (ISPMS SB RAS).

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