Based on a transformer eddy current transducer (ECT), a probe has been designed to study metal–dielectric–metal structures. The structural diagram of the probe is given and the basic technical data are stated (the number of windings is 10–130 turns, and the value of the initial permeability of the core $\mu_{\text{max}} = 500$). The scheme that uses the computer as a generator and receiver of signals from windings is considered. The measurement procedure allowing one to detect defects in laminate composites with a high accuracy is described. The transducer was tested on the layered structure consisting of paper and aluminum layers with a thickness of 100 $\mu$m each in which the model defect was placed. The dependences of the ECT signal on the defect in this structure are given.

**Abstract**—Based on a transformer eddy current transducer (ECT), a probe has been designed to study metal–dielectric–metal structures. The structural diagram of the probe is given and the basic technical data are stated (the number of windings is 10–130 turns, and the value of the initial permeability of the core $\mu_{\text{max}} = 500$). The scheme that uses the computer as a generator and receiver of signals from windings is considered. The measurement procedure allowing one to detect defects in laminate composites with a high accuracy is described. The transducer was tested on the layered structure consisting of paper and aluminum layers with a thickness of 100 $\mu$m each in which the model defect was placed. The dependences of the ECT signal on the defect in this structure are given.

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A subminiature eddy current transducer [1] has been designed to monitor physical parameters when studying the properties of metal–dielectric junctions. The monitored parameter is the conductance value of the material and its distribution over the surface and in the thickness of the studied object. The eddy current transducer (ECT) is connected to the sound card of the personal computer operating under control of the special software. The software controls the voltage applied to the generator winding of the transducer and reads voltage values from the measuring winding in terms of arbitrary units, which are thereafter, with allowance for the preliminary calibration, transformed into conductance values.

The exciting winding of the subminiature transducer consists of 10 turns, and its diameter is 0.13–0.12 mm. The measuring winding consists of 130 turns and has a diameter of 0.05–0.08 mm. To minimize the influence of the exciting winding on the received signal, the scheme contains the compensation winding, connected to the measuring winding so that the voltage of the exciting winding is subtracted. It consists of 20 turns. The copper wire with a diameter of 5 $\mu$m is used for winding turns. The windings are wound around a pyramid-shaped core. The core is made of a 2000 HM3 ferrite having an initial permeability of 500. The scheme of the subminiature ECT is shown in Fig. 1. The characteristics of the designed transducers allow one to efficiently localize the magnetic field within 2500 $\mu$m² and ensure a significant depth of its penetration into the studied object [2].

The ECT is connected to the sound card of the personal computer PC, operated under control of the special software (SW) (Fig. 2). The SW was developed in the C++ language for Windows operational systems. Using the mixer subsystem of Windows, the SW applies the voltage to the exciting winding of the transducer, specifying the level and frequency of the sinusoidal digital signal of the virtual generator.

The digital signal from the virtual generator arrives at the input of the digital-to-analog converter DAC of the sound card, from the output of which the analog signal is applied through the power amplifier $A$ to the exciting winding ($E$) of the converter. Being transmitted through the exiting winding of the ECT, the sinusoidal signal creates the electromagnetic field, which induces the emf in the measuring winding ($M$) of the ECT. This voltage arrives at the microphone input of the sound card and next through the preamplifier $PA$ at the input of the analog-to-digital converter (ADC) of the sound card. The analog signal is converted into the digital one and transmitted to the processing and control unit of the SW. The processing and control unit records the digital signal level in arbitrary units corresponding to voltage values at the measuring winding.

This level is assumed to be the zero level corresponding to the voltage level at the measuring winding without the monitored object; i.e., in the absence of the monitored object, the indicator shows zero corresponding to the zero conductance value.

The use of the computer sound card enables one, while scanning, to vary the frequency of the electromagnetic field, created by the exciting winding of the converter, from 20 Hz to 2 kHz.

The designed ECT allows one to efficiently study metal–dielectric junctions in miniature laminate metal–polymeric composite objects. Similar composites can contain several metallic layers separated by thin polymer dielectric interlayers [2]. Typical defects
of such materials include, e.g., discontinuities of layers and bridging between layers. The earlier designed ИЭНМ-5ФА device [3] (conductance meter for non-ferromagnetic materials) was used to study metal—dielectric—metal layer structures, and a specially modified Fourier analyzer was used to measure amplitude—frequency characteristics.

The structure composed of the alternating 100-μm-thick aluminum foil and the paper also having the 100-μm thickness was used to demonstrate the applicability of the proposed method. As a model defect, a hollow parallelepiped with 300-μm-thick walls was placed between layers.

Figure 3 shows the picture observed when the probe moves above the layered medium inside which a defect is located. The signal level from the measuring winding characterizes conductance values on the studied area. For the 1000-Hz basic operating frequency, the voltage introduced into the measuring winding was 130 ± 2 mV. Domains 1 and 2 in the graph, in which the voltage level drops to 115 mV, correspond to the parallelepiped walls. This change in the signal amplitude is 11% from the signal level corresponding to the defect-free area of the sample. In this case, oscillations of the signal amplitude on the defect-free area do not exceed 4 mV, being 3% of the signal level corresponding to the defect-free area of the sample.

The amplitude changes during the tests of the transducer at other frequencies are well noticeable on the graphs shown in Fig. 4. As the frequency increases, these changes are caused by a smaller depth of penetration of eddy currents into the layered structure and increased influence of various small cracks on the surface of the layered structure. As the frequency decreases, the field of eddy currents more deeply penetrates into the studied object. In this case, the influence of the model defect is not observed.
Fig. 3. Picture observed when the probe moves along the layered medium with a defect. The frequency of the transducer is 1000 Hz: (1, 2) walls of the parallelepiped, (3) defect-free part of the sample.

Fig. 4. Picture observed when the transducer moves along the layered medium with a defect. The frequency of the transducer is (a) 6000 and (b) 500 Hz.
Fig. 5. Picture observed when the probe moves along the layered medium with a defect. The frequency of the transducer is 7000 Hz.

When the measurement frequency is equal to 6000 Hz (Fig. 4a), the model defect is still well noticeable. However, the amplitude oscillations on the defect-free area of the sample already exceed 7% of the signal level corresponding to the defect-free part of the sample. When the monitored object with unknown defects is studied, similar changes in the amplitude can erroneously be interpreted as defects. At the probing frequency of 500 Hz (Fig. 4b), the oscillations of the amplitude on the defect-free area are insignificant. However, the change in the amplitude on the area of the defect itself does not exceed 3% of the signal level corresponding to the defect-free part of the sample. In laboratory and production measurements, a similar amplitude oscillation can be caused by external actions, which are not associated with the presence of defects.

The defect was located at a distance of 600 µm from the probe in the heart of the layered structure. Up to the defect occurrence depth equal to 1400 µm, the explicit dependence of the transducer response on the position of the transducer above the defect was observed. By fixing the change in the transducer response amplitude caused by the defect, it is possible to change the frequency of the current in the exciting winding so that the eddy currents are concentrated in composite layers located above the defect. The solution to the inverse problem allows one to determine the defect occurrence depth. Upon the calibration of the Fourier analyzer against typical defects, it is possible to use the ИЭНМ-5ФА device for diagnosing composite multilayer materials with a thickness of 1–1400 µm.

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