

Non-destructive testing of Al-Mg alloys by using the eddy-current method

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Abstract. The measuring system based on subminiature eddy-current transducers has been developed to carry out local investigations of aluminum-magnesium alloy plates for flaws. The Deliana filter has been modified to allow the significant increase of signal-to-noise ratio. A scheme that uses a computer as a generator and receiver of signals from windings is proposed. It is capable of automatically changing the filtering cutoff frequency and operating frequency of the device. The transducer has been tested on a number of aluminum-magnesium alloy plates with flaws. The article presents data on the relationship of eddy-current transducer response to the presence of flaws in alloys as hidden holes at signal frequencies comprised between 300÷700 Hz on an exciting winding.

1 Introduction

Nondestructive testing is relevant in terms of degradation of the material during the operation with long service life without the possibility of replacement or major repairs of the product. Questions defectoscopy of conducting materials occupy an important place in modern applied physics and industry. Al-Mg alloys are used as structural materials in aircraft and astronautics thanks to good combination of strength and lightness, as well as in the electrical, chemical and food industries.

Defects may appear in such alloys in casting and in subsequent manufacturing operations—for example, in poor-quality welding. The quality control of these alloys and their products is an urgent problem; investigations are making progress in this direction.

The traditional industries of industrialized countries, the cost of quality control products are 1 - 3% of the cost of production, and in industries such as defense, nuclear, aerospace, the cost of quality control of products increased to 12 ÷ 20%.

Despite a significant number of modern means and methods of defectoscopy of, the majority of the presented methods do not allow to scan quickly. Most of flaw detection methods may be used only in the laboratory, using complex technical instruments. Portable diagnostic methods materials relative little functional. Despite the possibility of finding defects, they are not designed to evaluate the degradation of the material and do not allow to conclude the possible timing of its further use and the risk breakdowns.

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This is due to the inability to simultaneously scan at different depths, search and analysis ultrasmall defect and scanning in real time. In this context, an urgent task is to develop eddy-current measurement systems based on miniature and subminiature eddy-current transducers designed for local measurements of electrical conductivity in inhomogeneous materials, finding defects in alloys and predict the reliability of technical systems.

L. Barbate et al. [2] scanned two aluminum plates with a model flaw in the center and tested cracks between the plates. The diameter of the measuring winding was 7 mm. The scanning was performed at 1 and 5 kHz. In this case, the penetration depth of eddy currents into the studied plates at the above mentioned frequencies was 3.82 and 1.71 mm.

The analysis of a recent investigations points to the miniaturization tendency for eddy-current transducers. Transducers with a size of 5×5 mm and a 0.15 mm diameter of the wire have been designed [3]. However, they do not provide the required penetration depth and localization of the magnetic field that are necessary for local measurements in different nonuniform media. Ferrite magnetic field concentrators are often used to increase the area of the magnetic field. A similar design provides an advantage that is related to the absence of the scatter of eddy currents [4]. In addition, a 2.5 mm penetration depth is attained. In this connection, the challenge is to design subminiature eddy-current transducers that provide a penetration depth of up to 5 mm and an area of $2500 \mu\text{m}^2$. Since the eddy-current inspection method is insensitive to non-conducting paint layers, it can also be used for diagnosing parts with paint coats [5].

2 Experimental section

One of the well-known drawbacks of eddy-current flaw detection is the ability to control the quality of a relatively thin surface layer of a conductive material. Upgraded design of the measuring system includes two differentially included subminiature transducers. Such a construction allows to detect defects at the a depth up to 5 mm due to its small size and the special shape of the cores.

We have developed a subminiature eddy-current transformer for local monitoring of the physical parameters in aluminum-alloy plates and weld seams. In contrast to existing sensors, it permits local measurements with sections measuring a few microns, to depths of the order of 5 mm. The electrical conductivity of the alloy is directly measurable, and its distribution over the sample surface and thickness may be readily established.

The exciting winding of the transducer consists of ten turns; its diameter is 0.12–0.13 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 recording signal, the circuit contains a compensation winding that is connected to the measuring winding in accordance with the well-known differential circuit. This consists of 20 turns. A copper wire with a $5 \mu\text{m}$ thickness is used for winding turns. The turns are wound around a pyramidal core. The proposed shape of the core is favorable for the area of the magnetic field. The core is made of ferrite with an initial magnetic permeability of 500.

Different transducers that are based on cores that have the same ratio of the base diagonal ($400 \mu\text{m}$) and edge length (1 mm) were calibrated using samples with a well-known electric conductivity. The characteristics of the designed transducers allow one to efficiently localize the magnetic field within $2500 \mu\text{m}^2$ and provide penetration of the magnetic field into the studied object at a depth of up to 5 mm [6–7].

The eddy-current transducer (Fig. 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.

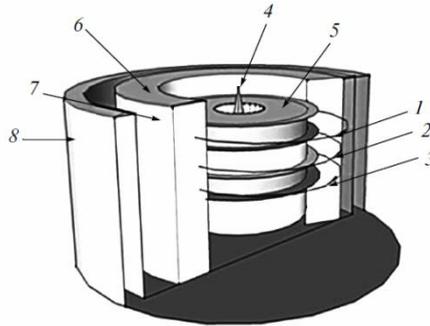


Fig.1. A block diagram of the eddy-current transducer.

The measuring system, which is based on a miniature eddy-current transducer, operates as follows. The software of the personal computer controls the operation of the generator, which produces a train of rectangular voltage pulses with the repetition rate f_1 that is necessary for the operation of the eddy-current transducers. The voltage pulses are transmitted from the generator output to two series integrators. They are then directed to the input of the power amplifier. From the amplifier output the voltage pulses arrive at the exciting inductance coils of the eddy-current transducers. The difference of the output voltages of the measuring coils of the transducers contains information on the structural heterogeneities of the tested object that is located in the effective area of the eddy-current transducers. It is detected and amplified in a special microphone amplifier. The signal arrives at the amplitude detector after the transmission through two series high-quality low frequency filters and two series selective amplifiers. The signal is then transmitted through an analog-to-digital converter to a personal computer. Due to the simultaneous control of the generated signal frequency at the exciting coil and the cutoff frequency of the filtering system and the selective amplification, the useful signal, which contains information on the electric conductivity distribution inside the object, in particular, on possible flaws of the object, is detected. The control program allows one to change the operating frequency of the measuring system so that the signal that is received from the measuring winding is reliably recorded.

3 Results section and Discussion

Experiments are conducted on Al-Mg plates 1 and 2. Plate 1 (thickness 5.5 mm) has three defects: notches (width 1 mm) that end at distances of 1, 3, and 4 mm, respectively from the opposite surface (Fig. 2a).

Plate 2 (thickness 5.5 mm) has six defects: notches (width 0.25 mm) that end at distances of 1, 2, 3, 4, 5, and 5.3 mm, respectively from the opposite surface (Fig. 2b).

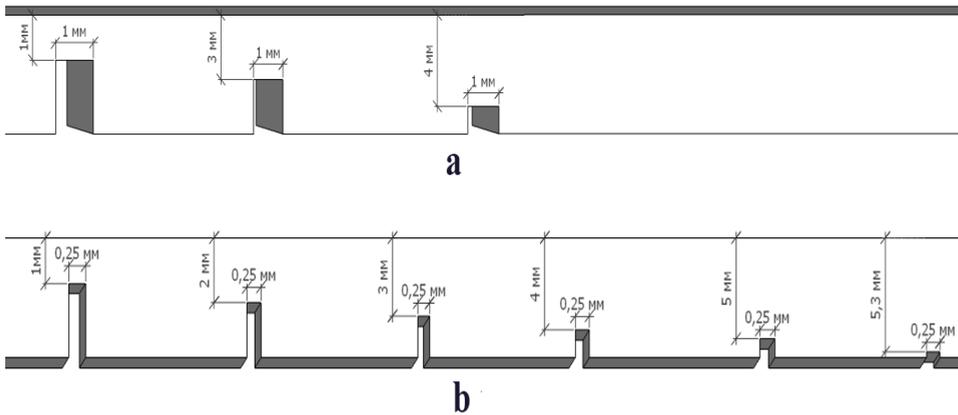


Fig. 2. Plates 1 (a) and 2 (b) in side view.

In the experiments with plate 1, the voltage applied to the exciting winding of the eddy-current transformer is $U_e = 2 \text{ V}$.

To determine the sensitivity of the sensor to defects of the metal, the plate is scanned on the side with no visible defects. The results are shown in Fig. 3a.

The results for plate 1 at a frequency $\omega = 500 \text{ Hz}$ permit the detection of all three slots on the basis of the reduced amplitude of the output signal U_m : the decrease in U_m is 0.75 V for the first defect, 0.2 V for the second, and 0.1 V for the third.

The experiments confirm the effectiveness of the proposed system in finding defects of width as small as 1 mm that end at a distance of 4 mm from the scanned (defect-free) surface.

To establish the limit of localization of the magnetic field, the eddy-current measuring system is tested with plate 2, in which defects (width 0.25 mm) end at depths as great as 5.3 mm from the scanned surface.

With an analogous voltage at the exciting winding, the first defect is detected at a depth of 1 mm from the scanned surface, with decrease in U_m by about 0.1 V (Fig. 3b).

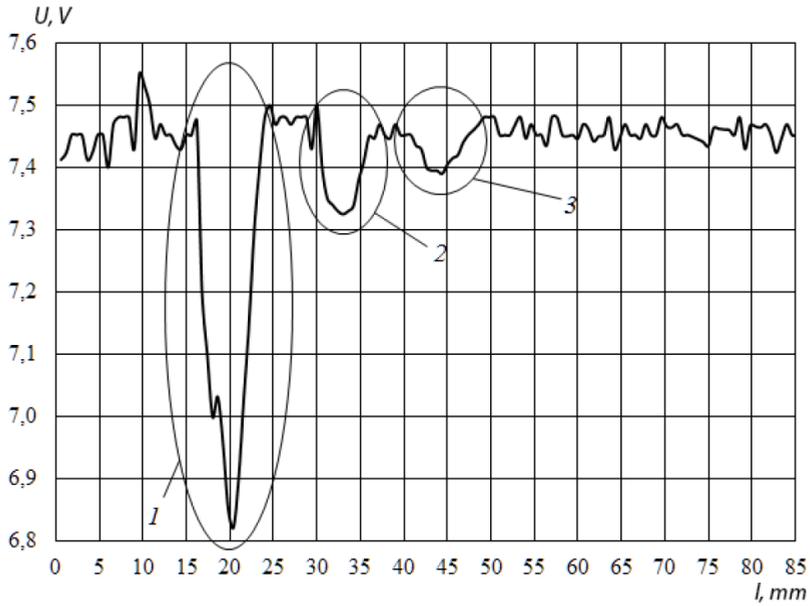


Fig.3.a. Results of scanning plates 1 by means of a measuring system with a single eddy-current transformer

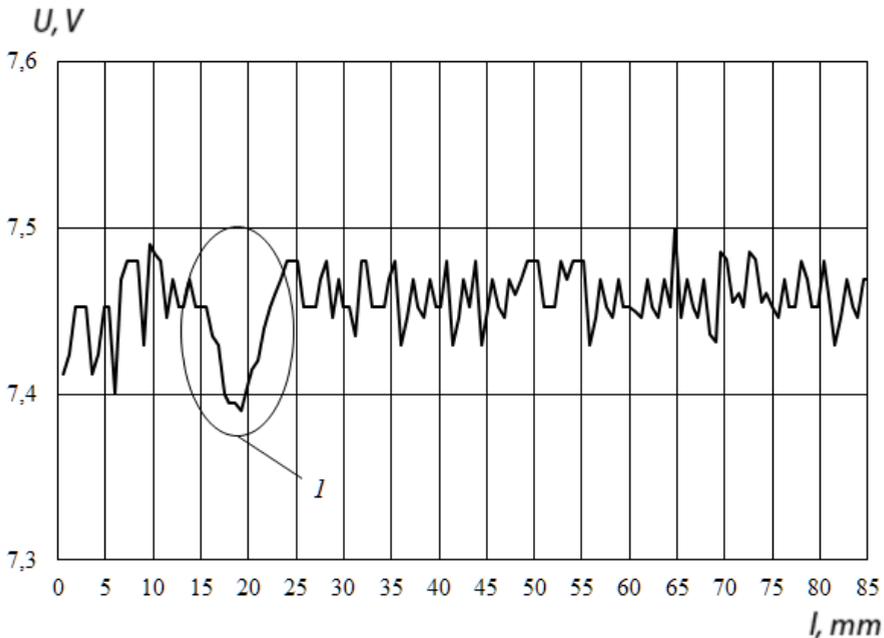


Fig.3.b. Results of scanning plates 2 by means of a measuring system with a single eddy-current transformer

With increase in amplitude of the signal at the exciting winding, the output signal from the measuring system will be exceeded and the results will be significantly distorted. To improve the localization of the magnetic field, the measuring system must be significantly

modernized. To increase the power of the electromagnetic field by increasing the voltage U_e at the exciting winding from 2 to 3.5 V, a second eddy-current transformer is introduced in the system. The first (fixed) eddy-current transformer is used to obtain the responses from the defect-free part of the sample, while the second eddy-current transformer is used directly for scanning. In the course of scanning, the signal from the second eddy-current transformer is subtracted from the signal produced by the first eddy-current transformer. In other words, the output signal of the measuring system is the difference between the responses of the two transformers.

The results for plate 2 at a frequency $\omega = 500$ Hz permit the detection of five defects at depths of 1, 2, 3, 4, and 5 mm from the scanned surface (Fig. 4). The corresponding decrease in U_m is 2.5 V for the first defect, 1 V for the second, 0.4 V for the third, 0.2 V for the fourth, and 0.1 V for the fifth. No change in U_m is noted on passing over the sixth defect.

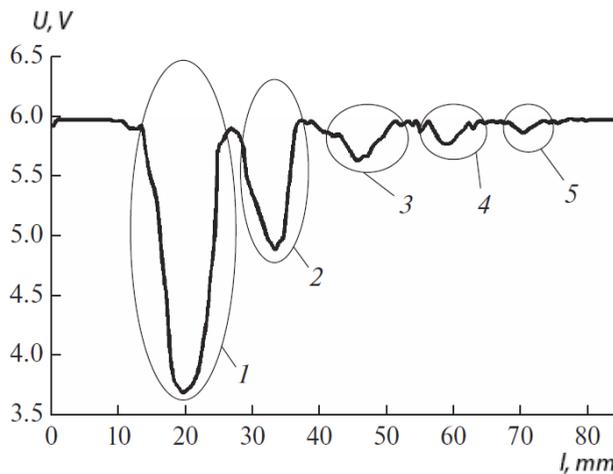


Fig.4. Results of scanning plates 2 by means of a measuring system with a two eddy-current transformers

4 Conclusions

Summing it up, the experiment results demonstrate great capabilities of the eddy current method when the defects, hidden in the metal depth, need to be studied. Earlier the eddy current control method could be used to investigate only surface defects (such as cracks, cuts and other examples of metal surface discontinuity), now, due to using subminiature ECTs and special software, it is getting possible to localize the magnetic field in a small zone of the controlled object and to achieve a high degree of the (magnetic) field penetration depth into the investigated object. The only condition is to choose a proper field frequency, created by the actuating winding.

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