IOP Conf. Series: Materials Science and Engineering **189** (2017) 012001 doi:10.1088/1757-899X/189/1/012001

Research of Conductive Materials by Multifrequency Measuring System on the Basis of Eddy Current Transducers

S Dmitriev[1], A Ishkov[2], A Katasonov[3], V Malikov[4], A Sagalakov[2], L Shevtsova[5], and K Ekkerdt[3]

[1]Assistant Professor, Altay State University, Barnaul, Russia
[2]Professor, Altay State Agrarian University, Barnaul, Russia
[3]Student, Altay State University, Barnaul, Russia
[4]Graduate student, Teacher, Altay State University, Barnaul, Russia
[5]Assistent, Novosibirsk State Technical University, Novosibirsk, Russia

E-mail: osys11@gmail.com

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 Delianna filter has been modified to allow the significant increase of signal-to-noise ratio. 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 slots at signal frequencies comprised between 300÷700 Hz on an exciting winding

1. Introduction

Nondestructive eddy-current monitoring may be used to find defects in any electrically conducting material. Where necessary, such measurements permit the investigation of each part produced at a plant. Duralumin and aluminum–agnesium alloys are widely used in manufacturing, especially in the aerospace industry and elsewhere. Thanks to their combination of strength and lightness, they are also suitable for high-speed trains, such as the Shinkansen trains (Japan).

Duralumin is also used in electrical engineering, in the chemical industry, in food processing, in ventilation systems, in radioengineering, and in construction. For example, D16AM alloy is used at extremely low temperatures, while D16T duralumin is used in shipbuilding, on account of its plasticity.

The quality control of these alloys and their products is an urgent problem; investigations are making progress in this direction.

2. Problem Statement

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 [1]. 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 [2]. In addition, a

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

2.5 mm penetration depth is attained. L. Barbato et al. [3] 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.

3. Research Questions

There are different well-known constructions of superimposed vortex-current transducers (VCT), whose working surface has either a plane or hemispherical form. Such kind of a surface provides a satisfactory contact of the VCT with the surface under control, but the tension quantity, sent to the VCT, greatly depends on the curvature of the controlled surface. The edge effect influences the work of the VCT considerably. This effect makes it impossible to control the details of complicated configuration and of small sizes. To solve these problems the VCT is often provided with an extra magnetic conductor. One of its terminals has a shape of a truncated cone. This solution of the problem has only one disadvantage. Despite the increased localization of the magnetic flux, the construction of the magnetic conductor has become considerably more complicated. It makes the measuring accuracy worse, because the output signal of the VCT depends to a great extent on the interaction of two magnetic conductors, which can influence the intensification of the vortex-current field in a rather unpredictable way. These currents contain the information about the controlled object.

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).

4. Purpose of the Study

The goal of this project is to provide a new type of eddy-current measurement system, capable of producing destructive testing of conductive materials at different depths to determine the depth and size of defects in real time.

5. Research Methods

We have developed a subminiature eddy-current transducer for local monitoring of the physical parameters in aluminum-alloy plates and weld seams [3]. 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.

We need to develop an adequate model of the response of eddy-current transducer s of plate type, which are sensitive to many variables and permit reproduction of the voltage hodograph at small values of $\beta 0$. We have plotted hodographs illustrating the influence of various parameters on the induced voltage on the basis of the proposed model [5–7].

The exciting winding (diameter D_1 = 0.12–0.13 mm) of the subminiature eddy-current transducer consists of ten turns of copper wire (cross-sectional area 5 μm^2). The measuring winding (diameter 0.05–0.08 mm) consists of 130 turns of copper wire (cross-sectional area 20 μm^2).

To minimize the influence of the exciting winding on the final signal, the circuit includes a compensation winding [8–10] that consists of 20 turns of copper wire (cross-sectional area 5 μm^2), connected to the measuring winding in such a way that the voltage of the exciting winding is subtracted from the result. The windings are wrapped around a core of 2000NMZ ferrite (relative magnetic permeability μ_{max} = 500 or else of 81NMA alloy annealed by a special method (if greater localization of the magnetic field is required). The core consists of a tetrahedral pyramid (height 1 mm), with a square base (sides of 0.2 mm). The measuring winding rests on the points of the pyramid, which improves the localization of the magnetic field. Such transducer s permit effective localization of the magnetic field, so that defects as small as 250 μm may be detected. In addition, the magnetic field penetrates into the sample to a considerable depth when working at relatively low frequencies.

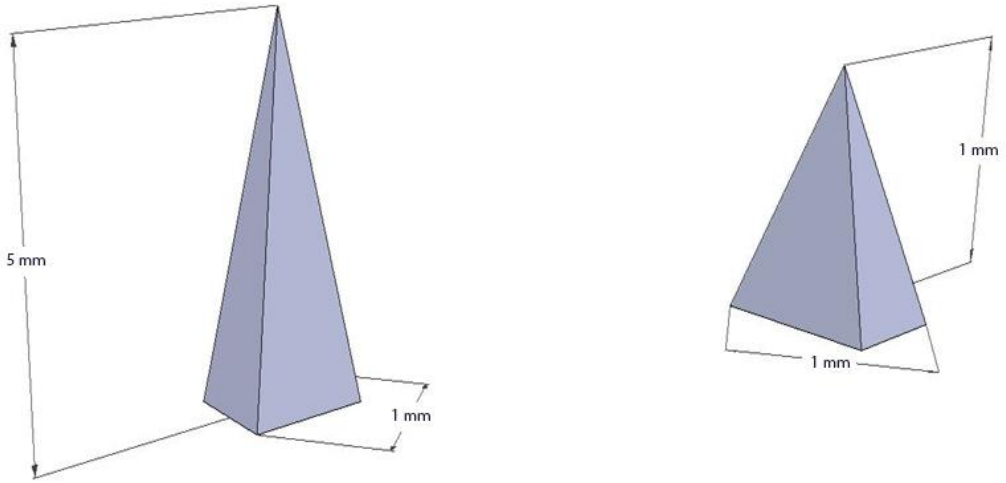

Figure 1. The cores of different sizes.

The laid on VCT consists of a pyramid shaped core. Such kind of a shape was achieved mainly in two ways. The first one is as follows: thin triangles (0.1 mm) were turned out of the alloy 81NMA. After that the plates were put together and their upper parts were ground off. Such kind of an approach has its disadvantages. For example, the tops were ground off unevenly; as a result the magnetic field was rather weak.

The second way to make a pyramid shaped core was grinding off the thin triangles and their matching into a pyramid.

Wire coils were placed on the pyramid shaped cores. The coils were impregnated with compound. The temperature of impregnation was 200 degrees Celsius, the diameter of the wire was 1.5×10^{-6} meters. The measuring winding was placed at the end of the top of the pyramid, the diameter of the winding was 0.05 mm, the number of winds varied from 100 up to 200. In the middle of the pyramid there was an actuating winding that consisted of one wind. The compensating winding was situated on the mobile frame and included 100 wires. The mobile frame enables it to move freely along the oxide core from the bottom up to the actuating winding.

We have made 10 VCTs. To subtract the directed current from the actuating winding into the measuring one we have retrofitted all the devices. We made different VCTs because we wanted to get the magnetic field of different tension. That was why the cores differed from each other in size. The correlation between the diagonal of the bottom and the edge of the pyramid varied from 1:1 to 1:10 (Figure 1).

The VTCs constructed on the basis of the cores, having similar correlation between the diagonal of the base (400 mkm) and the length of the rib (4 mm), have been calibrated on semi-conductors with the certain conductivity. Thus, the VCTs have identical geometric parameters of the cores and the same number of the winds of the actuating (1 wind), measuring (200 winds) and compensation (200±40) windings.

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 f1 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 cut off 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.

6. Findings

Samples with model defects were prepared in order to assess the maximum depth and the linear dimensions of the defects, for the detection of them it is advisable to use the eddy-current inspection method.

The samples were plates of Al–Mg alloy. The thickness of the first plate (sample №1) was 5.5 mm. The plate contained three defects in the form of slits 1 mm thick at the depths of 1, 3 and 4 mm (Figure 2).

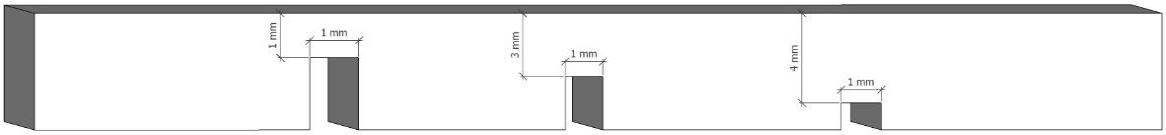

Figure 2. The appearance of the sample № 1.

The thickness of the second plate (sample №2) was 5.5 mm. The plate contained six defects in the form of slits 0.25 mm thick at the depths of 1, 2, 3, 4, 5 and 5.3 mm (Figure 3).

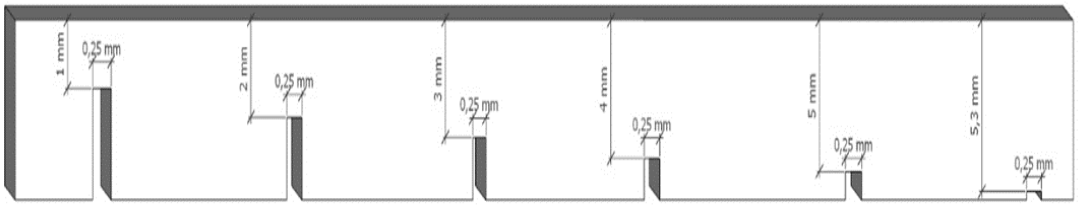

Figure 3. The appearance of the sample № 2.

In order to determine the sensitivity of the sensor to the defects at the depth of the metal, scanning of defect-free side of the sample was performed. During the experiments with the first plate the magnitude of the inserted voltage to the exciting winding of the transducer was 2 V.

The results of the defectoscopy of the first plate, thick at the frequency of 500 Hz and 2 V signal amplitude allowed to detect all three slits by means of signal amplitude drop (Figure 4). Signal amplitude drop in the first defect was 0.75 V, in the second one - 0.2 V, in the third one - 0.1 V.

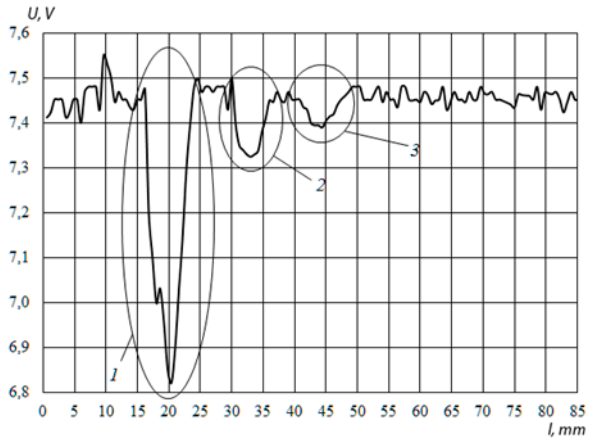

Figure 4. Results of scanning sample №1.

The results of defectoscopy of the second plate at the frequency of 500 Hz and 3 V signal amplitude allowed to reveal five defects (Figure 5). The signal amplitude drop at the first defect was 2.5 V, at the second defect – 1 V, at the third one – 0.4 V, at the fourth one - 0.2 V, at the fifth defect - 0.1 V. The changes in the response signal when passing over the sixth defect were not fixed. The experimental results show the effectiveness of the developed measuring system to find defects of the thickness from 0.25 mm at the depth of 5 mm.

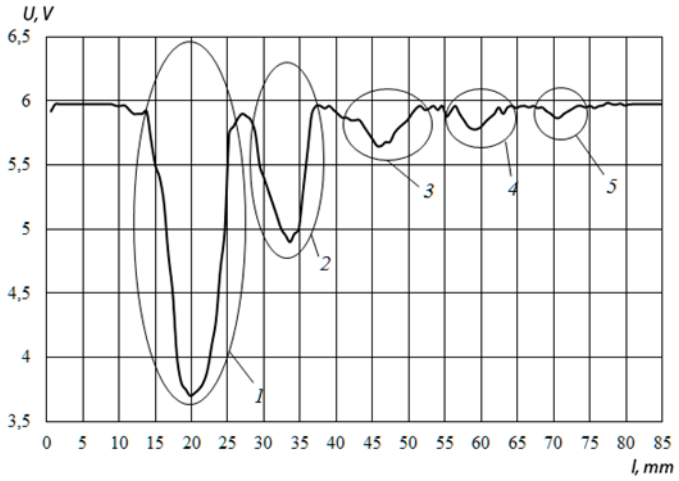

Figure 5. Results of scanning sample №2.

7. Conclusion

The developed measurement system based on eddy-current subminiature transducers, allows greater localization of electromagnetic field in comparison with previously known similar systems. The pyramidal shape of the core, the system of band pass filters and selective amplification allow to reduce interference and achieve significant penetration depth of eddy currents in the object under study. Defects scanning in aluminum alloys can detect defects with linear dimensions of the order of 100 microns at the depth of 5 mm. The developed software allows to automate measurements and make rapid changes in the operating frequency of the device

References

[1] Prance R J *et al* 2000 *Sens. Actuators, A* **85(1–3)** 361–364 DOI: 10.1016/S0924-4247(00)00375-7
[2] Prance R J *et al* 2003 *Rev. Sci. Instrum.* **74 (8)** 3735–3739 DOI: 10.1063/1.1590745
[3] Semenov V S *et al* 2003 *Bull. of the Tomsk State University* **278** 1–7 (in Russian)
[4] Barbato L *et al* 2015 *IEEE Trans. Magn*. **51(7:1–1)** DOI: 10.1109/TMAG.2015.2406765
[5] Rocha T J *et al* 2015 *Sensors and Actuators*, A **228** 55–61 DOI: 10.1016/j.sna.2015.02.004
[6] Litvinenko A A 2004 RF Patent 2231287 *Byull. Izobret*. **14** (in Russian)
[7] Lee K H *et al* 2012 *IEEE Transactions on Magnetics* **48(11)** 3965–3968 DOI: 10.1109/TMAG.2012.2202643
[8] Klyuev V V 2003 *Non-Destructive Testing* (Moscow: Mashinostroeniye) **2(1–2)** (in Russian)
[9] Malikov VN *et al* 2016 *Proc. of MEACS'15* 15805223 DOI: 10.1109/MEACS.2015.7414951
[10] Dmitriev S F *et al* 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **116(1)** 012013 DOI: 10.1088/1757-899X/116/1/012013