Eddy Current Defectoscope for Monitoring the Duralumin and Aluminum-Magnesium Alloys

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Abstract. The system developed is based on an eddy-current transducer of the transformer type, and is capable of inspecting plates made of duralumin and aluminum-magnesium alloys for defects. The measurement system supports absolute and differential control modes. The system was tested on a number of duralumin and aluminum-magnesium plates with internal flaws located as deep as 5 mm under the surface. The article provides data that demonstrates a link between the response time and the presence of defects in similar structures at a signal frequency of 1000 Hz.

1. Introduction
Existence of defects in the product structure or the object critical parts may substantially affect their service life. In the course of many years, great attention has been paid to the development and application of non-destructive methods, which would be able to predict the service life or the risks connected with further exploitation of the object in question [1].

Eddy current testing, which forms part of the electromagnetic testing methods, is a non-destructive testing (NDT) method that relies on electromagnetic induction to detect discontinuities in conductive material. Discontinuities such as geometrical changes, variations in material properties relating to conductivity and permeability and the presence of defects, both surface-breaking and subsurface, can be detected.

When a conductive material is placed close to an alternating magnetic field, there will be an oscillating electrical current induced in the conductive material due to Faraday’s law of induction. These induced eddy currents will produce a secondary alternating magnetic field which is in the opposite direction to the original alternating magnetic field. The presence of any discontinuity or defect in the material will disturb the eddy current flow; hence, the secondary magnetic field will be disturbed.

The application of methods and means of nondestructive eddy current testing is possible to search for defects in products made of any electroconductive materials. This measurement method allows to investigate each instance in the series of products in the factory, if it is necessary.

The most informative parameter in this method is the stress introduced into the measuring coil of the primary sensor, the eddy-current transducer.

This quantity depends on the composition and structure of the material, the type and parameters of flaws, their structure, the frequency of an alternating magnetic field which induces eddy currents, and on technology factors such as the construction and parameters of the transducer, clearance between the transducer and material surface, and other [2].
An important place in modern civil and military industries occupy duralumin and aluminum-magnesium alloys. Such alloys are the main structural material in aircraft and space exploration thanks to a good combination of strength and lightness. These alloys are widely used in the high-speed trains production (e.g., trains, Shinkansen (Japan) and in many other industries. Duraluminium is also used in many other branches of modern industry: in the electrical industry, in the chemical and food industry, as this alloy is resistant to most chemicals and products. Also, duralumin is used in the ventilation systems production, in radio engineering and building. For example, the alloy of D16AM grade is used in extreme low temperature conditions. Duralumin D16T is flexible and therefore it is used in shipbuilding and furniture manufacture.

Defects in these alloys can occur both at the stage of casting and other parts production, for example, as a result of defective welding. It is well known, in recent years the usage of aluminum-magnesium alloys in welded structures has increased.

2. Specifications, material choices and design
Despite our great experience in using eddy-current transducers (ECT) in the sphere of nondestructive control, several important aspects still need to be studied nowadays. In particular, the most vital problems are: carrying out local contactless measurements combined with controlled object scanning; price reduction in sensor engineering; making the control locality more accurate and the quick allocation of the frequency range, the most proper to scan the control object.

Along with the considerable price reduction of the device, the virtualization of the generator and signal receiver makes it possible to mark out the frequency range, at which the process of scanning of the control object gets very effective. The effectiveness is reached due to the quick varying of the current frequency, given by the virtual generator to the ECT. Thus, researchers can define the frequency, at which changing the amplitude of the signal on the measuring winding (when it is passing through the imperfect area) is at a maximum. Besides, frequency varying enables us to find the depth of the defect hiding, because the depth of the electromagnetic field distribution of the ECT directly depends on the frequency of the field sent to the actuating winding.

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 composites, 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 a vortex-current transformer (ECT) only, which is connected to the sound card of the PC, managed with the special software [3].

The software manages the voltage giving to the generative transformer winding, it also reads out values of the voltage from the measuring winding in conventional units. Later these units are transferred into the values of conductivity taking into account the preliminary calibration.

In general the scheme of the sensor is represented in Figure 1.
The digital signal from the virtual generator is input to an analog-to-digital converter (DAC), a sound card, after which the analog signal through the power amplifier (A) is fed to the exciting winding transducers. Passing through the excitation winding (E), sine wave creates an electromagnetic field which induces a voltage in the measuring winding (M) in eddy-current converter, which depend on the parameters of the object of control. This signal is fed to the microphone input of the sound card and then through the preamplifier (PA) to the input of an analog-to-digital converter (ADC) sound card. The analog signal is converted to digital one and transferred to the processing and control unit of the software (SW). The processing and control unit fixes the level of the digital signal in conventional units corresponding to the difference between the voltages on the measuring windings.

The principle of operation of the ECT is based on the alternating magnetic field, localized in the controlled object with the help of the oxide pyramid shaped core. The shape of the core is conditioned with the necessity to localize the magnetic flux from the actuating (generator) coil.

Exciting subminiature transmitter winding consists of 10 turns, and its diameter is 0.13-0.12 mm. Measuring winding consists of 130 turns and its diameter is 0.05-0.08 mm.

In order to minimize the influence of the exciting windings on the received signal, compensating winding is included into the circuit. The compensating winding is connected to the measuring winding so that the voltage of the exciting windings can be subtracted. The compensating winding consists of 20 turns. Copper wire 5 µm thick is used to wind the turns. The windings are wound on pyramidal shape core. The core is made of HM3 2000 ferrite with initial magnetic permeability of the value of $\mu_{\text{max}}=500$.

A copper wire, that is 0.005 mm thick, is used to reel the turns. The windings are wound round the pyramid shaped core. The scheme of the subminiature ECT is represented on the Figure 2.
The ECT has 1) an actuating winding 2) a compensation winding 3) and a magnetic conductor 4) which is placed inside the cylindrical platform 5) with the tracks for the windings, cut on the outer side 6) which is impregnated with a compound at 200 degrees centigrade in order to prevent the windings from destruction while the ferrite screen is being put on 7) which is meant for the magnetic field localization on the controlled object. From the outside the sensor is covered with a corundum washer 8 that protects the core 4 from contacting with the controlled object.

3. Experimental results
The worked out ECT enables the researchers to investigate the defects rather effectively. These defects may be found in the duralumin and aluminum-magnesium alloys. To demonstrate the operational capability of the suggested method we used plate of the duralumin. Plate thickness was 5.3 mm. As a model defects used slits having a thickness of 0.25 mm. The defect was located at a distance of 1-5.3 mm from the probe in the plate of the duralumin. Figures 3, 4 shows the picture observed when the probe moves above medium inside which a defect is located. The signal level from the measuring winding characterizes conductance values on the studied area.

Two major inspection modes are normally used viz. absolute and differential, with the older type reflection or bridge probes used for more specialised applications.

The absolute inspection mode utilise a single inspection coil with an internal instrument balance. Absolute mode is sensitive to variations in temperature and lift-off and is generally used to find large volume indications in tube inspection applications or generalised wall loss areas on thin conductive samples. Surface crack detection is also performed with the signal amplitude used to quantify the indication depth. The results of the experiment when scanning in absolute inspection mode presented in Figure 3.

The differential inspection mode utilise two probes in close proximity to one another and comparing one surface area with another. It is very sensitive for finding small indications and the effect of probe wobble and lift-off is also reduced since both coils are subjected to the same movement or distance influence. The results of the experiment when scanning in differential inspection mode presented in Figure 4.
For the 1000 Hz basic operating frequency, the voltage introduced into the measuring winding was 7450 ± 30 mV. Domain 1 in the graph, in which the voltage level drops to 6850 mV, correspond to the defects. This change in the signal amplitude is 8% from the signal level corresponding to the defect free area of the sample. Domain 2 and 3 in the graph, correspond to the deep-lying defects.
Figure 4. Results of scanning plate. Differential inspection mode.

For the 1000 Hz basic operating frequency, the voltage introduced into the measuring winding was 6000 ± 30 mV. Domain 1 in the graph, in which the voltage level drops to 3750 mV, correspond to the defects. This change in the signal amplitude is 37.5% from the signal level corresponding to the defect free area of the sample. Domain 2 in the graph, in which the voltage level drops to 4950 mV. This change in the signal amplitude is 17.5% from the signal level corresponding to the defect free area of the sample. Domain 3, 4 and 5 in the graph, correspond to the deep-lying defects.

4. Conclusion
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.

5. References
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