Multiparameter eddy-current NDT method for quality control of thin-sheet, multilayer products and coatings

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Abstract

For quality control of multilayer, thin-sheet metal products with dielectric layers and their defects evaluation it is proposed to implement multimeter eddy-current method of electrophysical and thermal-physical products' parameters measuring that provides sheet thickness measurement as well. The radio pulses generator via exciting winding of the eddy-current & thermal transducer (ECTT) induces whirling currents and generates thermal field in the examined product; informative parameters of eddy currents and thermal field are measured by relevant transducers, i.e. eddy-current and thermal. Based on revealed patterns of those parameters changes developed are methods of selective measurements of: conductivity, thermal diffusivity, metal sheet thickness and delaminations between product' metal and dielectric parts. The thermal diffusivity evaluation is based on measurement of velocity of temperature change in time and along the product surface; the temperatures measured at the moment of rectangular pulse impact end and one measured at the steady state mode are used for estimation of ratio of thermal diffusivity to sheet thickness; based on induced parameters of ECTT' windings measured are conductivity, dielectric coating' thickness and metal sheets integrity i.e. defects presence. In the paper presented are block diagrams and algorithms of the proposed eddy-current & thermal testing method as well as scheme of device for selective NDT of thickness, thermal diffusivity and conductivity of thin-sheet metal products (coatings) and composite materials. Also shown are functional layout and structural diagrams of instruments: -) for examination of delaminations and adhesion quality in multilayer thin-sheet metal products with dielectric layers; -) for detection of flaws relevant to integrity evaluation, metal plates thickening, internal corrosion, erosion and other types of defects.

Keywords: eddy-current and thermal NDT testing, conductivity, thermal diffusivity, metal integrity; thin-sheet metal products with dielectric layers, delaminations, thickness measurements, quality control

There exists a multiparameter eddy-current NDT method (ECT) for a defectoscopy of a large variety of metal and composite materials and its joinings and there are corresponding devices with improved metrological characteristics [1.2].

In this ECT NDT method an electromagnetic field of ECT impactly generates the thermal process in the object of control (OC), near-surface thermal transducer receives thermal response during and after thermal exposure and pulse-time information is being extracted to solve different diagnostics tasks – the determination of corrosion, thickness, joint quality, exfoliation of products, physic-mechanical qualities of materials.

The thermal process when there is an impact heating by eddy-current is being

determined by a totality of both thermal and electrophysical parameters of OC and enables to receive the whole information which is inherent in both thermal and ECT because of using double effect of eddy current – thermal and electromagnetic.

It is known that the use of thermal NDT method is limited by the needs of defectoscopy when the inspection of geometric dimensions is not used. The reasons of this are the low metrological characteristics of the thermal methods and devices used which are caused by a great influence of nonuniform surface of OC, its geometry.

Basic directions of development of ECT and NDT devices are connected with the use and measuring of processes of time-dependent thermal conductivity, with the investigation of peculiarities of temperature fields, which are being caused by different types of impulses of the thermal field, taking into account physic-mechanical and thermal characteristics of products, geometry, faulty state and peculiarities of conditions of ECT method of NDT.

ECM method of NDT is highly perspective for designing portable and multi-purpose NDT devices with a large number of functions for defectoscopy, structuroscopy and evaluation of thin-sheet and multilayer products from non-magnetic and ferromagnetic materials.

To create new effective ECT methods and devices of NDT it is necessary to investigate the possibilities of the use of time-dependent thermal conductivity processes and peculiarities of thermal fields, caused by different types of impulses of electromagnetic field.

The evaluation of the technical condition of objects using eddy current testing is based on the connection of local and integral thermal characteristics with parameters of defects in OC.

The presence of defects causes local or integral distortion of thermal field, which is typical for such product. Temperature difference appears after that. Spatial-temporal function of this temperature difference is being determined with the help of the temperature of the body, its heat exchange with environment, geometry and thermal-physic characteristics of an object of control and defects and with the help of time in time-dependent conditions.

One of the most perspective directions of eddy current testing of metals is the use of eddy currents in metal as a source of heat.

Quantitative analysis of ECT tasks is connected with solving time-dependent differential equation of heat conductivity, which describes heat transmission in solid. In such tasks usually superficial thermal fields of objects are investigated. Usually it is difficult to determine inner temperatures because of opacity of objects for thermal radiation.

We should admit that the use of eddy currents for causing impact thermal process causes a new group of parameters – electrophysical, because the evolution of thermal process in this case is being determined by its correlation with thermal-physic parameters of material of OC.

Besides, the above mentioned way of heating enables to extend the possibilities of testing using the double effect of eddy currents – thermal and electromagnetic and to get the whole information which is inherent in thermal and eddy current NDT testing.

It enables to consider that the thermal testing method, which uses eddy currents to cause impact thermal process in the object of control, is a multiparameter eddy current and thermal (ECTT) method.

Eddy current and thermal method means that eddy current and thermal signals of change in control objects characteristics are used together which is inherent in a certain physical connection between electrical and thermo physical parameters of metals. Information comes from the eddy current converter (ECC) and thermal transducer (TT), which registers parameters of time-dependent heat wave, which appears in OC because of eddy currents.

Time-dependent heat wave is being caused by a fast local warming of a ring domain which is b wide on the surface of OC when a high-power pulse of current 1_B and duration of τ_H passes exciting coil. The measuring coil of the converter covers with voltage U_{Bh}, which

depends only on parameters of OC (thickness d, conductivity of σ material) and parameters of control (frequency ω and gap h).

Because of the thinness of plate and high frequency of exciting current we may consider, that eddy currents are uniformly distributed among the thickness of plate. $J(r, z) \cong J(r, 0)$.

At a certain distance $r = R_M$ (Fig. 1) from the axle of exciting coil the density of eddy currents becomes maximum $J(R_M) - |J_M|$. Such distribution of eddy currents on r enables us to take as a width of heating area $b = b_1 + b_2$ (Fig. 1) circle sphere with bounds R_1 и R_2 on which the density of current is:

$$J(R_1) = J(R_2) = J_M / \sqrt[4]{2} \cong 0{,}84 J_M$$

The duration of the impulse of heating is τ_H ($\tau_H = 0{,}1\text{-}0{,}5$ seconds) when $\tau_H << \tau_0$, where τ_0 - the time of thermal process, $\tau_0 = R^2_B/\alpha$, R_B - is the radius of exciting coil, α - material's surface coefficient of heat conduction.

In non-destructive testing for quality control of thin-sheet metal products and with dielectric layers it is very important to detect flaws between layers – exfoliations, interstice, internal corrosion or wedging out, adhesion and other defects. It is very perspective to use ECT method for such tasks.

The basic element of this method is ECTT.

Based on ECT method of non-destructive testing and principle of working of eddy current and thermal transducer (ECTT), there was designed the construction of ECTT where ECT and thermal transducer are combined. Thermal pyroelectric transducer is located on the ECT axle and consists of two ceramic plates "TsTS-23" 1.0mm thick. Electrodes TT are located parallel to the ECT axle to decrease foils from the electromagnetic field, external electrodes TT are grounded and internal electrodes which are facing each other are isolated and with the help of axled channel lead to the preamplifier's repeater, which is located in the upper part of the body of ECTT.

Preamplifier and the body of ECTT are located inside cupreous cylindrical screen. There is a coil to provide dense connection between ECTT and OC. Transducer consists of two parts – internal dielectric frame and body to which with the help of soldering the frame is attached. In the frame, there are slots for ECT coils. In the given structure, there is used a superimposed transformer ECT, which has a powerful 10 coil (average diameter 12 mm) exciting coil made of 1.0mm "PEVO" wire.

Evaluating coil with average diameter 6.5mm has 240 turns of 0.2mm "PEVO" wire. Compensating coils have similar parameters.

Principle of operation of the quality control of joints and adhesion device is based on determination of changes in heat exchange between metal sheet and the basis on thermal-physic and electrical characteristics because a bad adhesion causes bad heat exchange.

On the basis of investigations there was designed a flaw detector with impulse eddy current heating of OC and registration of impulse thermal response of OC with a help of surface thermal transducer on the basis of pyro-receivers. It enabled to keep NDT contactless and insensible to pollution and color of the surface of OC.

The task was to design a device to provide all NDT directions of defectoscopy – exfoliation inspection, defect definition, inspection of corrosion and wedging out metal plates and surfaces judging by the changes of their thickness, definition of OC physic-mechanical parameters and other defects. Different types of thermal exposures were used for it – short-term $\delta(t)$ – functions, long from the unit function h(t) or finite duration impulse. Verification mode and thermal response were being defined by intervals of change of generalized time i.e. "F_0" parameter. When the exciting coil ECTT is powered by short and long eddy current impulses for value of generalized parameter: $F_0 \leq F_{0I} = 0{,}2$ and $F_0 < F_{03} = 0{,}33$ given intervals of generalized time are optimal for defying PMP material of the plate by thermal diffusivity

"α" because the information about the thickness of plate is minimized in thermal response.

We should choose $F_0 \geq F_{05} = 0,5$ parameter point when testing such defects as exfoliation and corrosion (wedging out) by the change of thickness by conservative value of temperature. Structure flowchart of the portable eddy current impulse defectoscope is shown in the Fig. 3. It contains 6 basic units – ECTT, which includes ECT transformer type and TT (pyro-receiver), generator unit, correction unit, pyro-receiver channel, TT signal processing and digital indication device, generator, verification mode, TT signal processing and digital indication device control unit.

On the above mentioned we designed two modifications of eddy-current thermal flaw detectors.

Fig. 1. Configuration of the ECTT

Fig. 1 demonstrates design of eddy-current thermal transducer (ECTT). The flaw detector (block diagram is presented in Fig. 2) uses ECTT.

Fig. 2. Block diagram of the ECT flaw detector

The operating principle is clear from the block diagram. Another modification of the pulse eddy-current thermal flaw detector is presented in the block diagram, Fig. 3.

Fig. 3. Block diagram of the pulse eddy-current thermal flaw detector

The major element of the block diagram is an eddy-current thermal transducer, which design is presented in Fig. 4.

Fig. 4. Configuration of the ECT transducer

Conclusions

(1)   There is given a universal structure chart and ECT method of selective NDT of thickness (corrosion), thermal conductivity and thermal conductivity of thin-sheet metal surfaces.
(2)   There are designed optimal ECTT constructions and computer-based plants for defectoscopy and NDT quality control of thin-sheet metal products and surfaces on dielectric basis.
(3)   There is an impulse flaw-detector designed which enables to display flaw discontinuities, exfoliations between metal and dielectric, internal corrosion and wedging out of surfaces.

References

[1] Шатерников В.Е., Клюеув С.В., Вихретокотепловой метод неразрушающего контроля тонколистовых металлических изделий, Москва, Машиностроение, 2007, 175 стр. (Shaternikov V.E., Klyuev S.V., Eddy-current thermal method of non-destructive testing of thin sheet metal items, Moscow, Mashinostroenie, 2007, 175pp.).

[2] Шатерников В.Е., Исаев А.А., Способы контроля толщины листа и коэффициента температуропроводности при импульсных тепловых воздействиях, 5-я международная выставка конференция «НК и техническая диагностика в промышленности», Москва, 2006, стр. 18-19 (Shaternikov V.E., Isaev A.A., Methods of

examination of sheets and thermal diffusivity in case of pulse thermal impacts, 5th International Exhibition-conference in Moscow, RSNTTD, 2006, pp. 18-19.
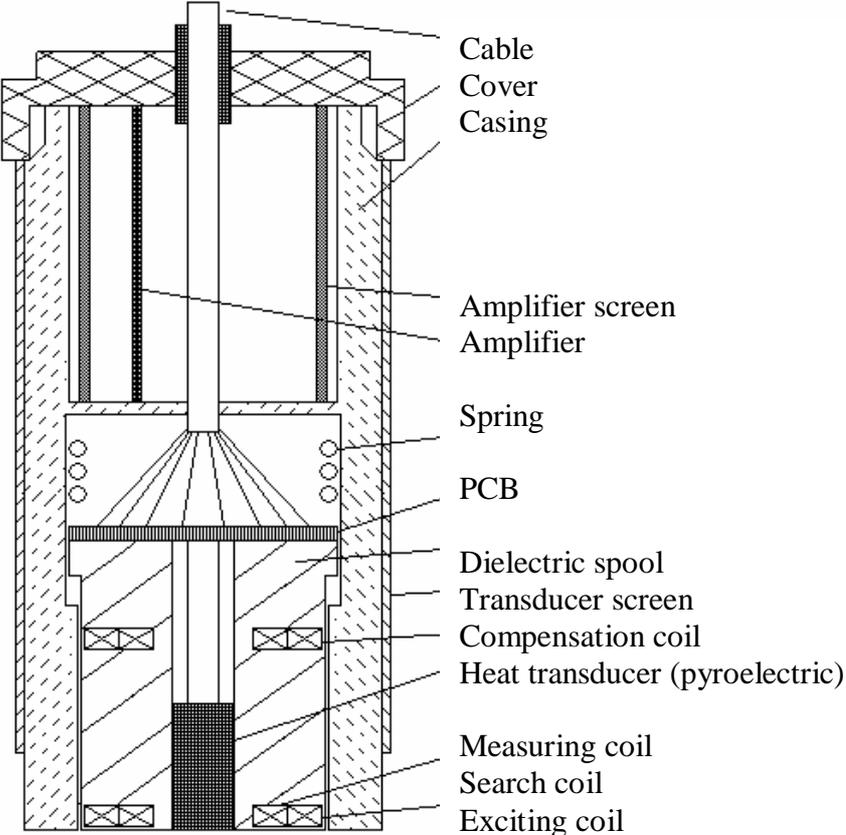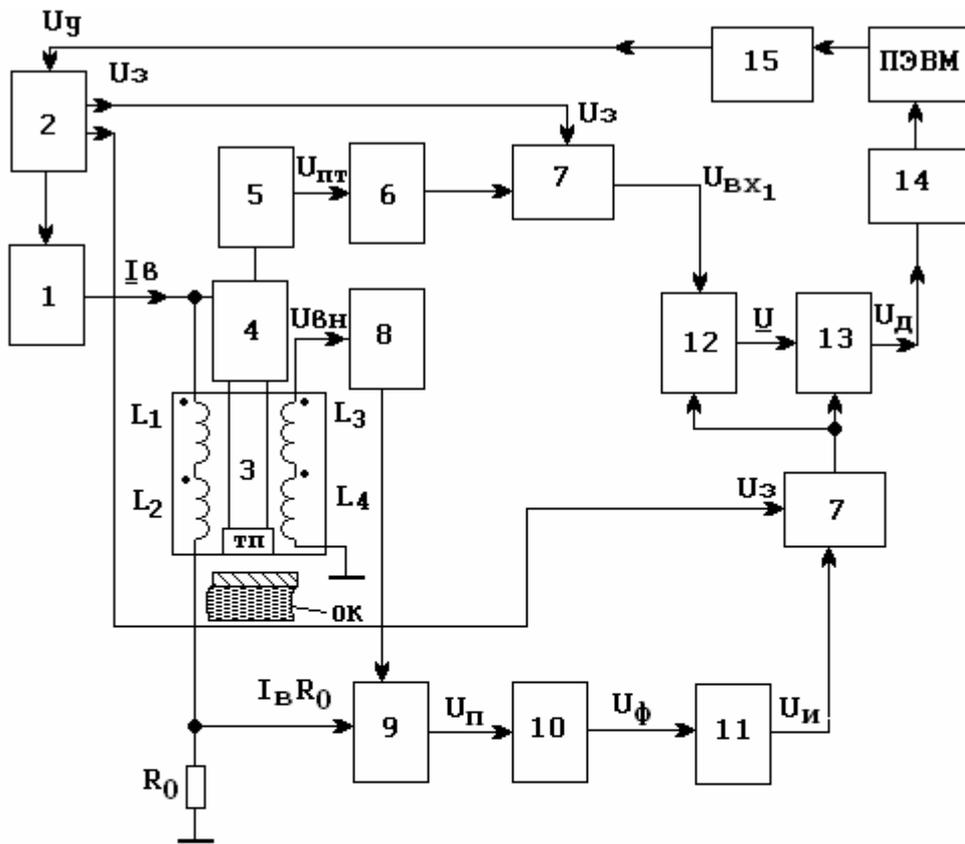

Fig. 1. Configuration of the ECTT

1. Generator
2. Control unit
3. ECTT
4. Preamplifier
5. Peak detector
6. Heat signal processing block
7. Access and storage block
8. Amplifier

9. Multiplier
10. LF
11. Integrator
12. Subtractor
13. Divider
14. ADC
15. DAC

Fig. 2. Block diagram of the ECT flaw detector

Fig. 3. Block diagram of the pulse eddy-current thermal flaw detector

1 - generator
2 - electronic switch
3 - power amplifier
4 - ECTT
5 - Correction unit
6 - automatic gain control unit
7 - primary amplifier
8 - band amplifier
9 - access and storage unit with differentiating amplifier at the input
10 - signal processing unit
11 - digital indication unit
12 - control unit
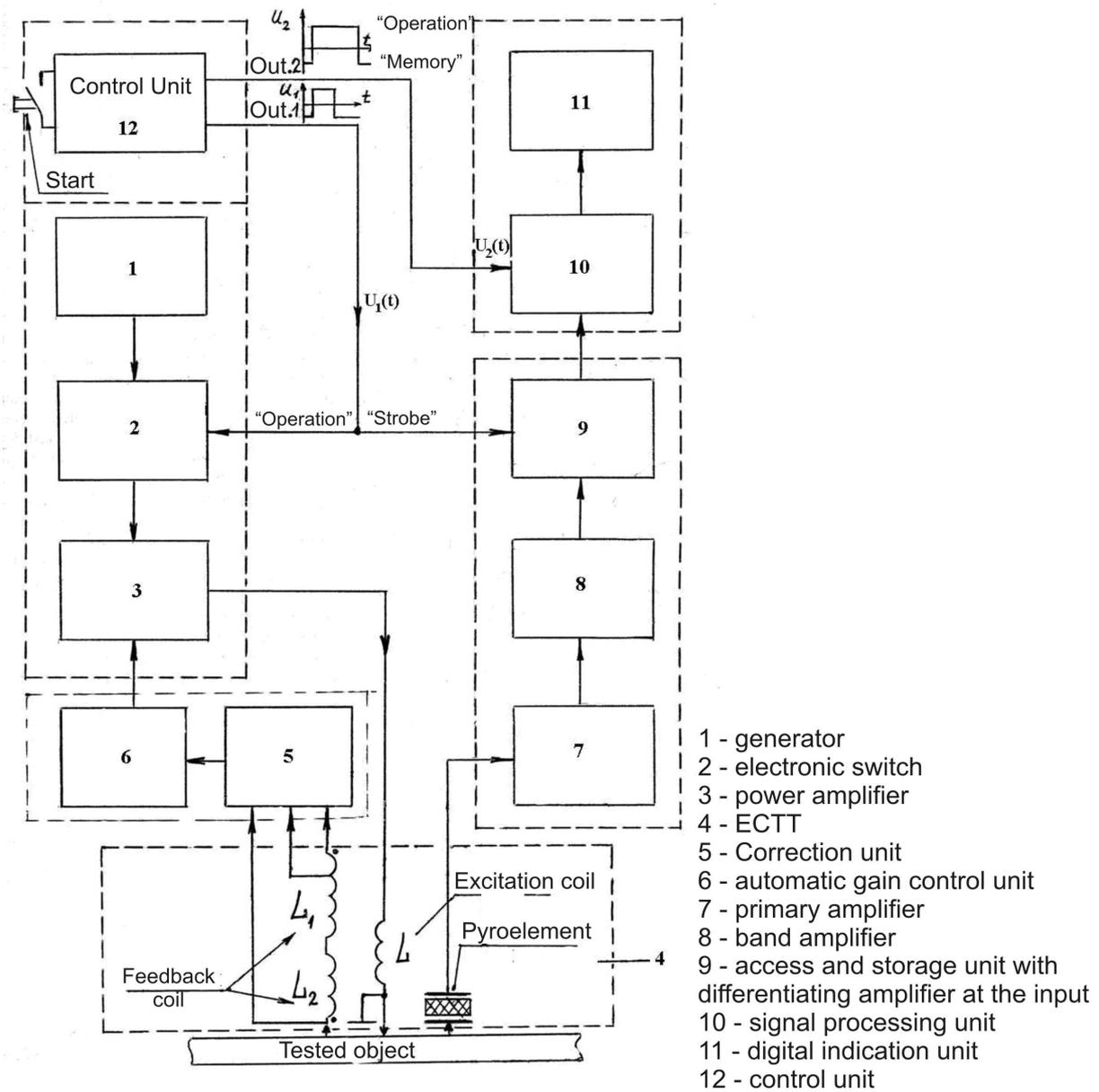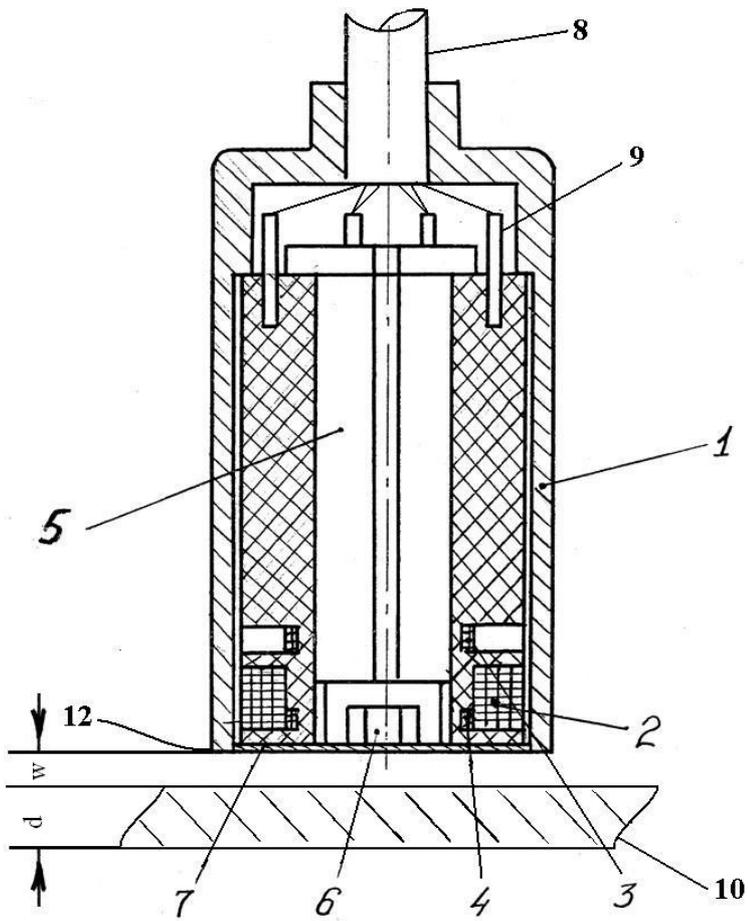
1. Body
2. Exciting coil WB
3. Correction coil W1
4. Correction coil W1
5. Pyroreceiver spool
6. TT receiver plates
7. Protecting plate
8. HF cable
9. ECT coil leads
10. Tested object
11. Screen
12. Plate

Fig. 4. Configuration of the ECT transducer