# Measuring of Wall Thickness of Metal Articles under Protective Coatings

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**Abstract.** The work considers build-up principles and algorithms of operation of measuring converters used for control of residual thickness of metal product walls under protective coating without removal of the latter.
The work describes build-up principles, scheme, construction and operation algorithm of measuring converters that include miniature electromagnetic converter and primary ultrasonic dual element transducer combined in unified block and connected by a cable with electronic processing and data presentation block.
Main technical parameters of thickness gages with developed converters are given.

Existing normative documentation prescribes periodic control of products' wall thickness in the process of their operation (pipes, reservoirs, bridge structures, hulls of ships and aircrafts, etc.). In most of the cases, especially for thin-walled products, stripping of the surface (removal of coating) at control points is executed. Besides the fact that stripping operations are rather labor-consuming, the possibility of missing local corrosion defects is rather high.

There are well known and extensively used electromagnetic methods of control of thickness of dielectric coatings at metal bases that have low measurement inaccuracy and wide measurement range. Besides that there is a well known range of ultrasonic converters for measurement of wave travel time in products of various purposes and measurement of their thickness. On the basis of accomplished search a goal was set to develop combined converter that permits to execute in control point the simultaneous measuring of protective coating thickness, summary time of ultrasonic wave travel in coating and metal, and to calculate the thickness of metal using measurement results.

To measure residual thickness of walls of metal products made of ferromagnetic and non-ferromagnetic metals under dielectric coating with high locality two types of measuring converters were developed.

Structural scheme of combined converter for measuring residual thickness of ferrous walls is shown in Figure 1. For measuring of protective coating thickness a built-in induction converter is used with armored magnetic conductor; outer casing of the conductor is made of steel, and central core is made of ferrite with increased magnetic inductivity to improve its sensitivity. Central core is passing coaxially through acoustic screen of dual element ultrasonic transducer. Primary $W_1$ and secondary $W_2$ windings are winded on the central core. Ultrasonic dual element transducer is built-in into outer casing of induction converter.

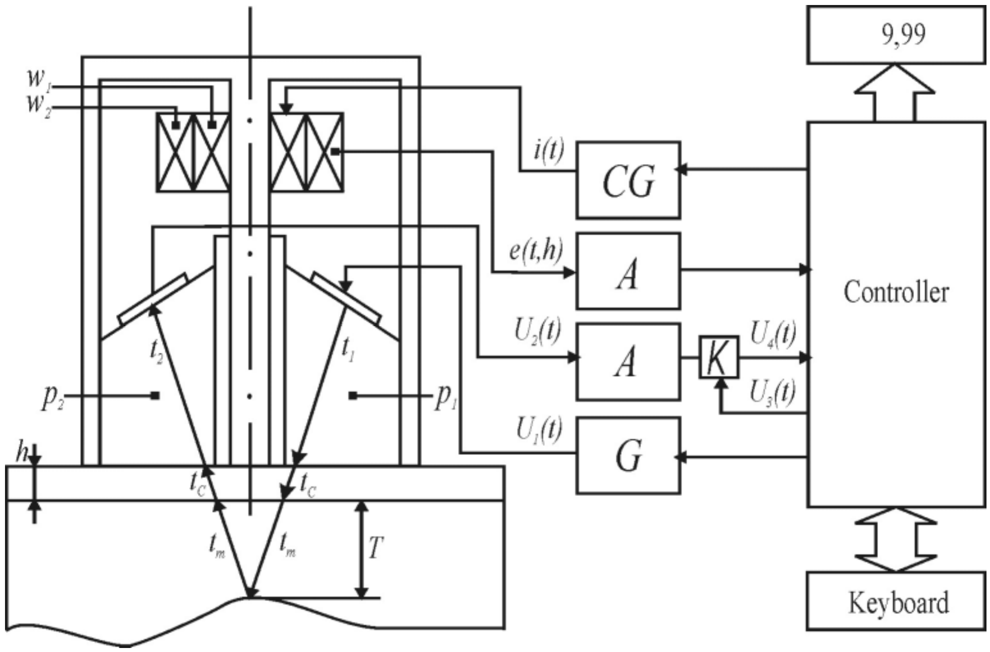


Figure 1. Structural scheme of measuring converter for ferromagnetic metals.
A- amplifier, G- generator, CG- current generator, P- prism,
$W_1$, $W_2$ – windings, K- switchboard

Principles of protective coating measuring is illustrated with time charts in Figure 2. At the moment when the measuring begins, the controller sends a control signal to generator CG, powering primary winding $W_1$ with current *i(t)*. On the secondary winding $W_2$ voltage *e(t,h)* is inducted with area *N(h)* during 20 ms is inversely proposal to coating thickness *h*. Impulse area is calculated with controller with use of built-in analog-digital converter, after that coating thickness h is calculated by calibration index, loaded into the memory.

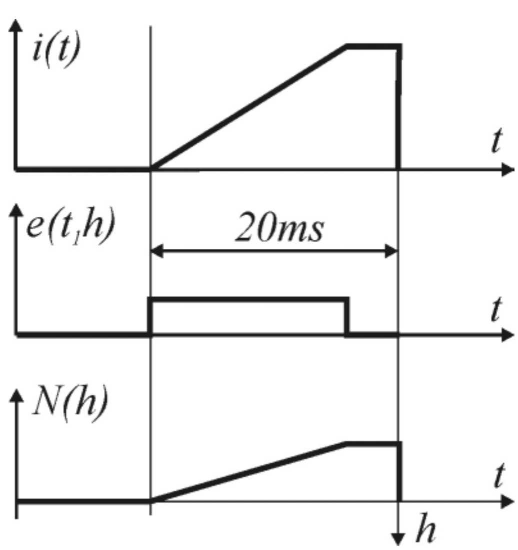


Figure 2 Scheme of operation of induction converter during measuring
of coating thickness h

This converting algorithm allows to reduce time, required for calculation of coating thickness, to about 0.08 s, thus avoiding effect from network and high-frequency induction and providing required measuring accuracy. In measurement point controller calculates *N(h)* and by calibration characteristics stored in memory calculates thickness of coating *h.*

Excitation of ultrasonic wave is executed by emitting piezo-converter glued to prism P1 that is fed from excitatory generator G. Reception of the wave that has gone through coating and metal is provided by piezo-converter glued to prism P2, after that the signal is delivered via amplifier A to input of controller that determines summary time of ultrasonic wave travel $t$ that is equal to

$$t = t_1 + t_2 + 2t_c + 2t_m \quad (1)$$

where $t_1$, $t_2$, $2t_c$, $2t_m$ – times of ultrasonic wave travel in prisms (1, 2), coating and metal correspondingly.

Time ultrasound travel in coating is equal to

$$t_c = h/V_c \quad (2)$$

where $h$ - thickness of coating, $V_c$ – speed of ultrasound in coating.

To determine the range of speeds $V_c$ in coatings research was accomplished at specialized installation; it showed that for varnishes, paints, enamels, primers, putties (that generally constitute suspension of pigments and fillers in organic reducers or water and form homogenous hard film after drying) and powder paints ultrasound speed $V_c$ lies in the range from 2190 to 2270 m/s, so the mean value is approximately 2230 m/s.

Time of travel in prisms made of quartz or temperature-controlled polyimide

$$(t_1 + t_2) = const \quad (3)$$

Time of travel in metal

$$t_m = T_m/V_m \quad (4)$$

where $T_m$ – thickness of metal in control point,

$V_m$ – ultrasound speed in metal.

Thus (1) with taking into account (2) - (4) can be transformed to the following form

$$t = (const + 2h/V_c + 2T_m/V_m) \quad (5)$$

From this it follows:

$$T_m = 0,5\ (t - const - 2h/V_c)\ V_m \quad (6)$$

i.e. these converter with controller that operate in accordance with above described algorithm permit to compensate influence of coating thickness $T_c$ upon accuracy of measurement of metal thickness $T_m$.

If during calculation of $T_m$ ultrasound speed value in coating is set equal to $V_c = 2230$ m/s, it follows from (6) that error due to inadequacy of value $V_c$ to the actual ($V_c+\Delta V_c$) will not exceed

$$\Delta T_m \leq h\ V_m/V_c * \Delta V_c/(V_c+\Delta V_c) \qquad (7)$$

For above mentioned coatings $/\Delta V_c/ \leq 40$ m/s, so for low-alloy steels ($V_m \approx 6000$ m/s)

$$\Delta T_m \leq 0{,}047h \qquad (8)$$

In the range of $h$ up to 500 µm $\Delta T_m$ will not exceed the value of 0.025 mm.

If control is executed by traditional thickness gages error due to coating existence amounts to

$$\Delta T_{m\,1} \leq h\ \mathrm{V_m}/V_c = 2{,}69h \qquad (9)$$

From (9) it follows that at $h$=500 µm $\Delta T_{m1} \approx 1{,}34$ mm. Thus, use of this converter and algorithm of measurements data processing permits to decrease approximately for 50 times the influence of coating thickness upon error in measurement of residual thickness of metal.

The basic feature of this method for measuring of residual metal thickness is that the more coating thickness is, the more is amplitude of ultrasonic signal, reflected from the border between metal and coating. At the same time, then thickness of the article decreases, amplitude of signal, reflected from its bottom, decreases accordingly. Under certain conditions, e.g. when checking highly corroded articles with thick coating layer, false response of converter measuring circuit from signal “coating-metal” is possible. To avoid this effect, the following structural and algorithmic features were implemented. As piezo-converters, piezo plates from Lead metaniobate were applied, which allowed to considerably reduce their reverberation noise. A switchboard K was included to the circuit, which after command from the controlled cancels receipt o signals from receiving piezo-converter to measuring circuit (MC), measuring time of impulse passing though coating and article. Operation algorithm of the circuit is as follows. First, induction converter measures time of ultrasonic signal transmission in the coating (2). Then after sending of ultrasonic signal $U_1(t)$ by emitting piezo plate, microcontroller gives command $U_3(t)$, thus inhibiting passing of impulses $U_4(t)$ from output of controlled amplifier to input of MC for the time, exceeding time of propagation of ultrasonic wave through prism and coating $2t_c+t_1+t_2$, i.e. signals from border between metal and coating will not come to the MC. This allows to change amplifying coefficient within wide frames, and thus to measure residual walls thickness in articles with small equivalent area of defects. Time chart, illustrating measuring process, is presented in Figure 3.

Structural scheme of measuring converter for non-ferromagnetic metals is represented in Figure 4. Design, scheme and algorithm of ultrasound dual-element transducer operation are similar to the ones presented in Figure 1. For measurement of coating thickness a built-in eddy-current converter is used. Eddy-current converter is included in circuit of active oscillator AO that is governed by controller. Oscillation frequency $f$ at output of the active oscillator is reciprocally proportional to thickness of coating $h$. In measurement point controller calculates $f$ and by calibration characteristics stored in memory calculates thickness of coating *h*. Then operation goes on similarly to operation of converter that is presented in Figure 1.

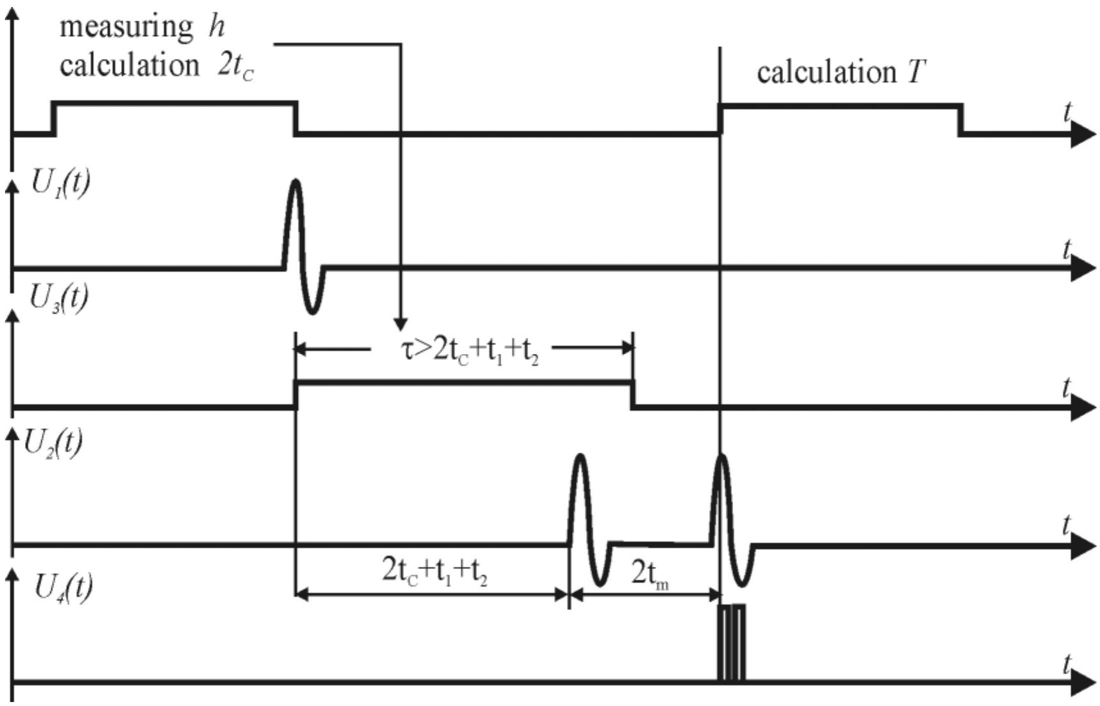


Figure 3 Chart, illustrating operation of combined converter during measuring of residual metal thickness T

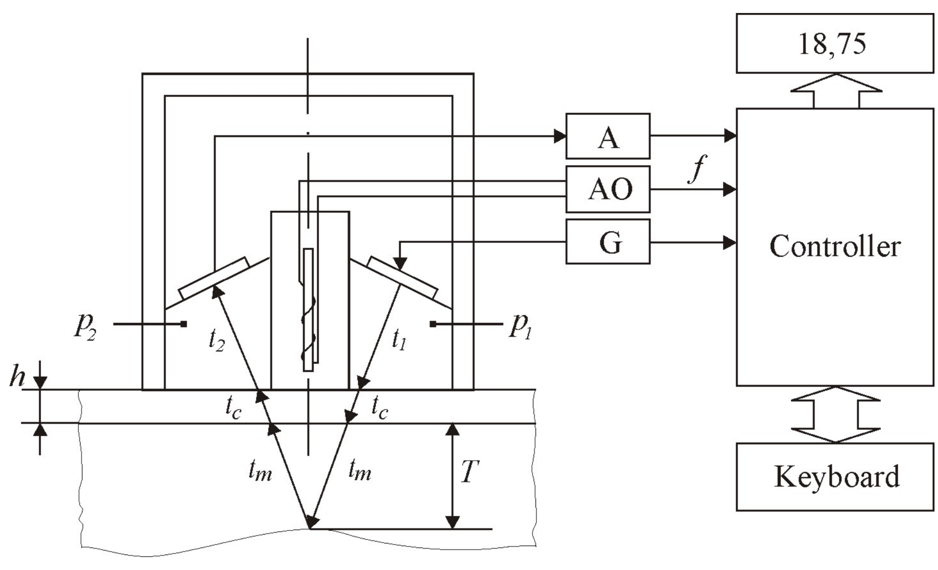


Figure 4. Structure of measuring converter for nonferromagnetic metals.
A – amplifier, AO - active oscillator, G – generator, P – prism.

Inaccurate position of combined converter axes on cylindrical surfaces (especially on pipes with small diameter) leaded to *h* measuring errors, reduction of ultrasonic signals amplitude and subsequently to additional measuring errors. To avoid such errors, a design was developed for combined converters, where the converter itself is installed in cylindrical casing with triangle-shaped hole in its lower part, providing precise positioning of the device relative to pipe axis. The converter inside the casing is pressed with a spring, thus ensuring guaranteed acoustic contact with the surface. Also, the design excludes turning of the converter inside the casing (during acoustic measurements the screen is located crosswise to pipe axis, thus reducing additional errors).

Use of measuring algorithm, described above, allowed to improve sensitivity of converters and design converters with contact area of 5.5 mm in diameter.

For operation with converters, device Bulat 2 was designed, with smaller dimensions, simplified measuring method and lower power consumption.

Certification tests demonstrated, that the device was capable to measure residual thickness of pipe walls from 0.4 mm with equivalent reflection diameter 1 mm and coating thickness up to 0.6 mm. A range of converters was designed for the device, intended for measuring of residual thickness of articles from 0.4 to 60 mm with allowable coating thickness from 0.6 to 4 mm accordingly. The device is recommended for use at aircraft construction, ship-repair and other enterprises. All required certificates are available.