PORTABLE ELECTROMAGNETIC-ACOUSTIC THICKNESS GAUGES (EMATG)

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Abstract: Two types of contactless electro-magnetic-acoustic handheld thickness gauges designed on the base of up-to-date digital technologies are described. The devices have self-contained power supply and effective design of magnetic concentrator of magnetic field with the use of new magnetic materials, which meets the requirements of state-of-the-art technology.

Thickness gauge KRM-C-Delta can work in different modes, e.g. it is possible to choose the informative impulses that are of users’ interest. LCD allows to watch a detailed echogram of reflected impulses and carry out analysis of received information that let us use this device as a flaw detector. PC helps perform the analysis and improve the methods of inspection in laboratory environment.

Thickness gauge EMATG-100 is a portable device with a build-in microprocessor, has small dimensions and weight that let us perform the inspection in field conditions. The device is efficient, simple in operation and can work in both static and dynamic modes. The distinguishing feature of this device is that it is able to work with greatly corroded objects. It is provided with two types of gauges, one having the rollers to travel.

Both devices feature inspection of isolated surface (up to 1.5 mm); no couplant is needed; no requirements for roughness of surface. EMAT-100 has passed pre-tests at Locomotive Shop, at Gascompressor plant and proved to be decisive at the inspection of gas-mains. It was used for the inspection of the wall thickness of the gas main (1220 mm in diameter), where the speed of inspection was high due to the above features.

Introduction: Ultrasound thickness gauges have proliferated much both in Russia and abroad. The contactless thickness gauges are special among them. Their advantages are obvious, namely there is no need to prepare the surface and use couplant, it is possible to work on a corroded and rough surface, to work with lift-off (up to several millimeters). Among other contactless techniques, the electro-magnetic-acoustic (EMA) technique has won the recognition. The technique does not require expensive equipment and much power.

To present day the EMA instruments, however, have not been widely adopted. The main reason for this is that the probes are low effective. And the effectiveness of contactless probes is usually much lower than the one of contact probes. This results in worse signal at the input of the receiver and low signal-noise ratio. New scientific and technical achievements have appeared for the last decades which allow us to see the problem from another side.

Discussion: The first achievement is regarded to digital techniques. Portable microprocessor systems allow to produce compact devices which have lots of possibilities of processing in digital format. Another achievement is new magnetic materials, e.g. ferrum-niodim-boron, which create strong local magnetic field. Permanent magnet system of special design can create magnetic field up to 1 tesla on the area of several square centimeters. Besides, long experimental and theoretical researches the optimal design of excitation and receiving coils and their positional relationship.

On the above achievements we designed two devices to solve different tasks of NDT which were problematic not so long ago. They were the possibility to work on rough (now possible roughness Rz 320), corrode and curved surfaces (now possible radius of curvature 20 mm). Another advantage of these devices is the possibility to work with the lift-off up to 2 mm. This allows us to measure the thickness of pipe wall without removing the isolation.

One of the devices – KRM-C-Delta is provided with a powerful microprocessor system of data processing. The device works in different modes, has an LCD to display the thickness and echo pulses that let it be applied for solving NDT tasks. The appearance of the device and its probe is shown in fig. 1. On the front panel you may see the display, sockets to connect the probe and control buttons. It is possible to set different modes of operation, to perform calibration and transfer the data to PC.

Fig. 1. Electromagnetic-acoustic thickness gauge KRM-C-Delta
1 – Electronic unit; 2 – EMA-probe; 3 – Cable; 4 – Object

Specification of KRM-C-Delta:

Thickness range (for any conducting materials), mm 2.5…120.0

Limits of allowable basic absolute error δ_{bas} in case of measurement by two echo pulses (see Tab. 1).

Table 1

Measurement range	$\pm\ \delta_{bas}$, mm
2.5…20	0.06
20…120	(0.001T+0.06)

T – readings from the device, mm.

Minimum curvature radius of surface, mm 20
Memory, number of measurements 100
RS-232 interface

Dimensions, mm, not more than
Electronic unit (length x width x height) 200 x 80 x 213
Probe (length x width x height) 75 x 35 x 35
Weight, kg, not more than
Electronic unit 2.5
Probe 0.5

The source of ultrasound oscillation is EMA single probe 1. The generator of outgoing pulses 2, controlled by microprocessor unit 5, generates high voltage pulses which feed the coil of EMA-probe 1. The reflected pulse form the other side of the object tested is received by the coil of the probe and goes to the input of the measuring amplifier 3. A digital signal from AD unit 4 stores into the memory unit 6. The microprocessor unit 5 process the data according to the mode, transfers the data to the display 7, into the memory unit 6 and PC by RS232 interface. The keyboard 8 is used to choose a mode.

The device features high efficiency of data processing of received signal. This, first of all, allows us to set the gain factor optimally that in its turn is an important condition of getting rid of an error caused by a shape of the signal. The shape of the reflected ultra-sound pulse is shown in fig. 3, where *T* is time and it depends on the frequency of ranging signal and usually ranges 0.2…0.5 μs. At the same time, when measuring short thicknesses, the time gap between reflected pulses can be of several μs. For example, for thickness 3 mm it is 2 μs. To design accurate metering instruments, however, it is necessary to provide accurate and reliable operation of the threshold unit. If the required accuracy is 0.1 mm, the error of measurement of time gap should not be less than 60 ns. The extension of the leading edge zone of the first pulse where we consider the time gap to be finished can be 10…30 ns. However the requirements for thickness gauges are high nowadays that results in requirements to measure the time gap more accurately (up to 1nS). In these cases it is obvious that the threshold unit should operate at the same relative level with respect to the amplitude of the pulse. The computing unit, which is a part of the measurement unit, solves this task. The gain factor of the amplifying unit which is used to amplify reflected pulses ranges widely in accordance with the level of input signal. The range of changing of input signal is also wide and depends on the material of an object, quality of the surface and the size of the lift-off. The changing may range up to 60 dB. In compliance with it the gain factor changes, which is controlled by the microprocessor. Earlier this task was solved by analog methods. The pinch-off voltage was set regarding the level of receiving signal. Digital processing, however, allows to solve this task more qualitatively and accurately.

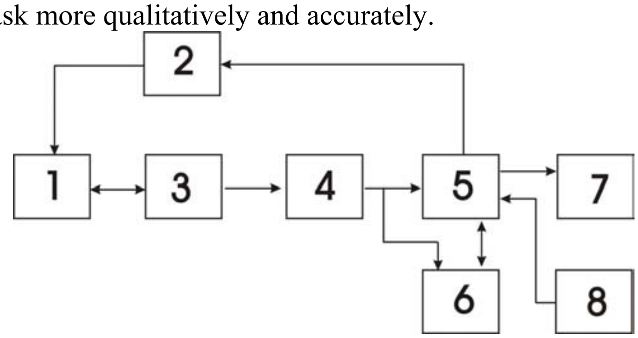

Fig. 2. Block diagram of electromagnetic-acoustic thickness gauge KRM-C-Delta
1 – EMA-probe; 2 – Generator of probing pulses; 3 – Measuring automatic amplifier; 4 – AD converter;
5 – Microprocessor; 6 – Memory; 7 – LCD; 8 – Film keyboard.

The possibility to fix the relative threshold level allows to solve some other tasks. As shown in fig. 3, there is an additional pulse before the main one, and it can cause a response of the unit if the pulse is high enough. The fixation of the relative level let us exclude this. Moreover, during the EMA excitation and reflection of transverse waves, some other waves appear and they cause an electrical signal at the input of the receiving unit. The above technique of data processing excludes false responses.

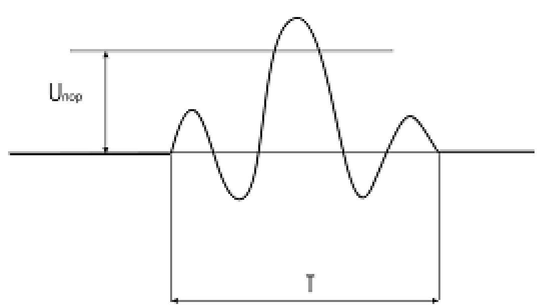

Fig. 3. The form of reflected ultra-sound pulse

The second feature of the device is the mode of storing of signal. If the level of signal is not high enough to be taken by the threshold unit, the probing and iteration cycles will go on until the level of signal is of the required level. This allows to single out the useful signal and work with isolated surface (coating up to 2 mm).

The “CURSOR” mode calibrates the device for the expected thickness and only these values of thickness with little deviation will be registered. It is very useful in mass testing of the same type objects. The “OKNO” mode let us set the response level manually and control the accumulation mode.

There is a build-in memory in the device for 100 measurements. The data stored can be either displayed or transferred to PC via RS-232. The batteries allow the operation of the device in field conditions.

Another EMA-thickness gauge designed at JSC “Spectrum-RII” is portable EMAT-100 which is intended to perform on-line testing (see fig. 4). The device can work at both field and workshop conditions and has self-contained power supply. The dimensions and weight make it easy to operate with.

Fig. 4. Ultra-sound thickness gauge EMAT-100

The device is provided with two exchangeable probes. One of them is to test in dynamic mode and the other one in static. The static mode is measurement of thickness in a point, and the probe for dynamic mode has some rollers and it can be used for continuous test. There are an LCDto display the thickness and the mode and a film keyboard to switch on/off the device, to calibrate it and control the modes.

Specifications:

Thickness range (steel), mm	3.0…100.0
Limits of allowable basic absolute error δ_{bas} , mm	δ_{bas}=±(0.1+0.001T)
Minimum curvature radius of surface, mm	10
Memory, number of measurements	100
Duration of continuous operation, hour, not less than	8
Dimensions, mm, not more than	
Electronic unit (length x width x height)	195 x 100 x 45
Static probe (length x width x height)	75 x 37 x 37
Dynamic probe (length x width x height)	60 x 80 x 55
Length of cable	1000±50
Weight, kg, not more than	
Electronic unit	0.6
Static probe	0.4
Dynamic probe	0.8

The block diagram is shown in fig. 5. The principal of operation is based on echo-technique which uses the property of ultra-sound waves to reflect from boundary surface between two mediums with different acoustic impedances. The excitation of ultra-sound waves happens due to the interaction of eddy-currents which are induced by the EMS-coil with the current of ultra-sound frequency and magnetic field of this probe.

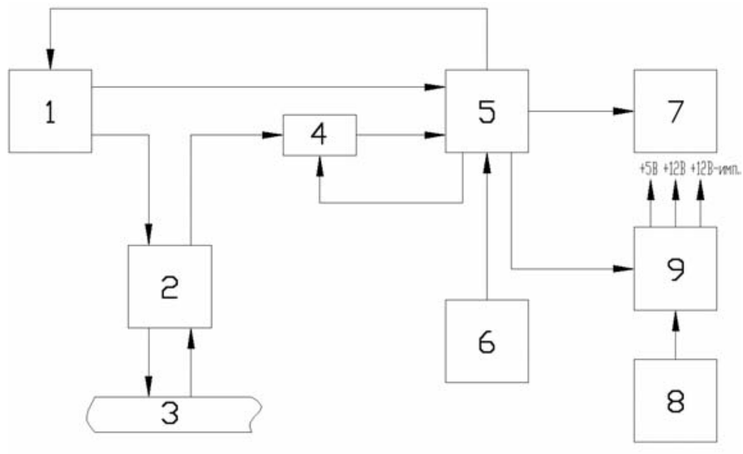

Fig. 5. Block diagram of EMAT-100
1 – Generator of probing pulses; 2 – EMA-probe; 3 – Object; 4 – Amplifier and analog processing unit; 5 – Microprocessor; 6 – Keyboard; 7 – LCD;
8 – Battery; 9 – Voltage stabilizer.

The EMA pulse spreads normally to the surface of object, reaches the side opposite, reflects from it and goes partially back to the probe. This process happens repeatedly. The secondary eddy-currents appear in the material due to ultra-sound oscillations and magnetic field. This secondary current induces a series of pulses onto the EMA-coil. The pulses repeat with the interval:

$$t = \frac{2 \cdot d}{V},$$

where t – time of travelling of ultra-sound oscillations from one surface to another and back;
d- thickness of object under test;
V – speed of travelling of ultra-sound oscillations in material.

The device operates in the following way. The generator of probing signals (1) starts its work under the microprocessor control (5). The microprocessor performs digital processing and controls the operation of the device on the whole. High-power probing pulse goes to excitation coil of the EMA probe (2), interacts with permanent magnetic field and it causes acoustic oscillations in the object tested. The reflected acoustic signals transform into electrical ones. They are amplified by the amplifying and analog processing units (4). The amplifying modes are switched over by microprocessor circuit (5). The microprocessor (5) gets the signals of the beginning of measurements from the generator (1) and the reflected pulses from the unit of analog processing (4). The microprocessor processes the data and shows the value of thickness on the display (7). The modes of the device operation are set by the film keyboard (6). The stabilizer (9) is also controlled by the microprocessor to follow the requirements of economy.

The device has some more features that broaden its application. For example, at mass or continuous testing in dynamic mode it is not sufficient to know the value of thickness only, but if this value is in the expected range. For this it is possible to program the device and an operator controls the signs on the display which tells him if the value of thickness is within some limits.

The device is intended to test objects made of different materials. Mainly the materials are magnetic steels and aluminum alloys. But the potentials of the device are not limited by that and if surface is smoothed out enough the device can work with stainless steels. Since the speed of ultra-sound oscillations differs for various materials, the device can be easily calibrated for the sample of the material to be tested.

The device itself was tested at the enterprises of Rail Carrier and proved to be decisive while testing oil-gas pipelines. In most cases the tests were performed without removing isolation, special working of surface, couplant that let us increase the speed of test.

Conclusion: Thus, on the base of all up-to-date technologies and development of new magnetic materials two types of portable EMA thickness gauges were designed to test rough surfaces with lift-off, to test curved surfaces with small curvature.
The KRM-C-Delta has different modes, LCD that allows a detailed analysis of the object under test and can be used as a defectoscope.
Another variant of the thickness gauge – EMAT-100 has small dimensions, low weight, efficient, simple in use, allows testing rough surfaces in field conditions. Both devices have self-contained power supply.