EMA TRANSFORMATION IN PULSED MAGNETIC FIELD AND ITS USE IN PORTABLE INSTRUMENTS FOR ACOUSTIC MEASUREMENTS

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Abstract: The article represents the results of researches of EMA transduction in pulse magnetic field. Alongwith were developed the means and equipment for EMAT excitation by pulse sequence, corresponding to Barker code. Given the features of structure and parameters of EMAT, technical characteristics and examples of application for the developed A1271 device for thickness measurements of tube walls with corrosion and erosion defects.

Introduction: The time measurement of ultrasonic oscillation propagation is the constituent part of ultrasonic non-destructive testing. The known meaning of ultrasonic propagation velocity and the measured time make it possible to recalculate the thickness of rolled products, tube walls, vessels, structures and objects, working under pressure, at high temperatures and in aggressive affection both during their production and exploitation. If the thickness of testing object is known, the measured time of propagation allows calculating the ultrasound velocity.

The testing in production conditions is connected with the influence of industrial noises, high temperatures and texture anisotropy. At testing the exploitable objects and structures they are affected by corrosion damages of external and internal surfaces and by the environmental temperature. Finally these factors influence the signal/noise relation up to the level that does not allow making measurement with the traditional methods and devices.

Because of that the greater attention is paid on the development of the portable ultrasonic devices based on the electro-magnetic acoustic transduction.

In the works [1 - 3] in references are given the results of researches and development of small-sized EMA transducers with the constant magnets on the base of rare metals for sending and receiving of SH waves with radial and linear polarization. This has allowed making the portable device A1270, provided the thickness and anisotropy measurements of rolling from aluminium and some other metals. To increase the signal/noise relation in the device the coherent accumulation was used. In different rolled samples the ultrasonic shear waves velocities with different polarization in relation to rolling direction was measured with this device and the influence of anisotropy on the measurement error and rolling thickness was estimate. The device is used for industrial testing of crucial products [3].

The analysis of the EMA sending and reception with the help of existing transducers on the base of constant magnets has shown, that their main disadvantage is the low transduction coefficient at work with the objects from ferromagnetic materials with corrosion embedded surfaces. It appears the necessity in increase of pulsing energy and magnetic field induction. This leads to the growing of power consumption, sizes and weight of EMAT and to significant limitation at work on steel objects, because of the damage danger, coursed by the its strong gravity to the testing object.

There are known the EMAT, which work as a part of stationary plants and provide the high sensitive at welds testing with Lamb waves, using the pulse magnetic biasing [4, 5]. But this kind of EMAT was not used in the devices with off-line power supply, because of its big sizes and large power consumption.

To develop a portable device with off-line power supply the authors have researched the EMA transduction in pulse magnetic field, which resulted with determination of parameters and modes of magnetic field, choice of biasing system type, determination of requirements for the power supply of electronic unit.

Results: The choice of parameters for EMAT pulse magnetic biasing system, used in the portable device, is the search of compromises between the transduction effectiveness and power consumption of the system. To create the necessary induction of magnetic field $\overline{B}$ in the EMAT the special biasing coil 1 is used, enclosing the sending-receiving coil 2 (figure 1).

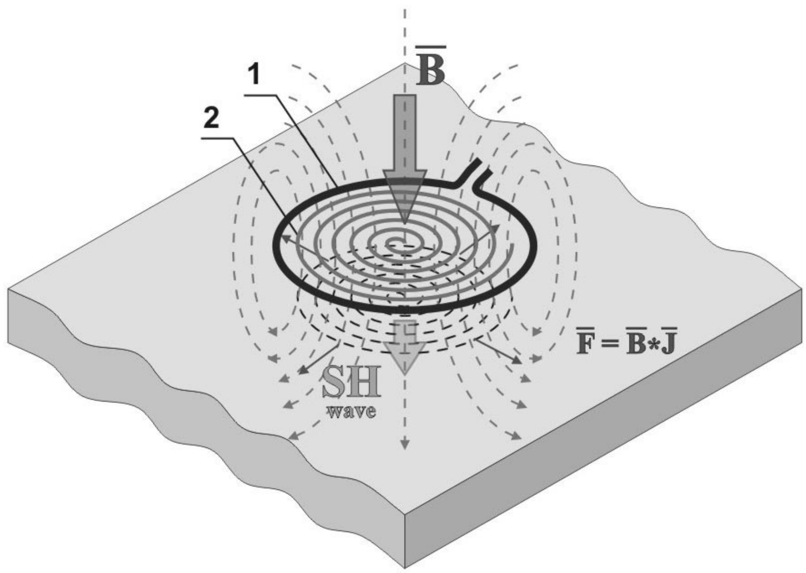

Figure 1. The scheme of EMA sending-reception of SH-waves with radial polarization with pulse magnetic biasing

The magnetic field in this case is created by pulse current source, providing the current of 300 - 400A in the coil. This source is an accumulating condenser with high-voltage key.

To low the power consumption in the new device the measuring range is limited by the thicknesses of 0.5 - 50 mm that corresponds to the signal reception operation area of 40 μs.

The results of measurement of the dependence of magnetic field induction on the time were made with the digital magnetometer MF-23IM and represented on the figure 2. It shows, that the biasing interval can be divided in 3 areas. The first area: from the moment of switching on the power supply source to the growing of induction up to the maximal meaning. The second area: operation area – the maximal induction meaning. The third area: from the moment of switching the biasing current off to the end of transition process.

The work with ferromagnetic materials in the first and the second areas is accompanied with the magnetic reversal noises. That's why, the measuring interval is chosen on the interval of slow induction changing in magnetic field.

The pulse magnetic field induction at work on ferromagnetic and non-ferromagnetic metals and alloys achieves 1 - 2 T. The energy, spent on one biasing cycle, is 2 - 5 Joule.

To increase the signal/noise relation the possibility of using phase-manipulated pulses and corresponding to them methods of received signals proceeding were researched. The figure 3 shows the type of

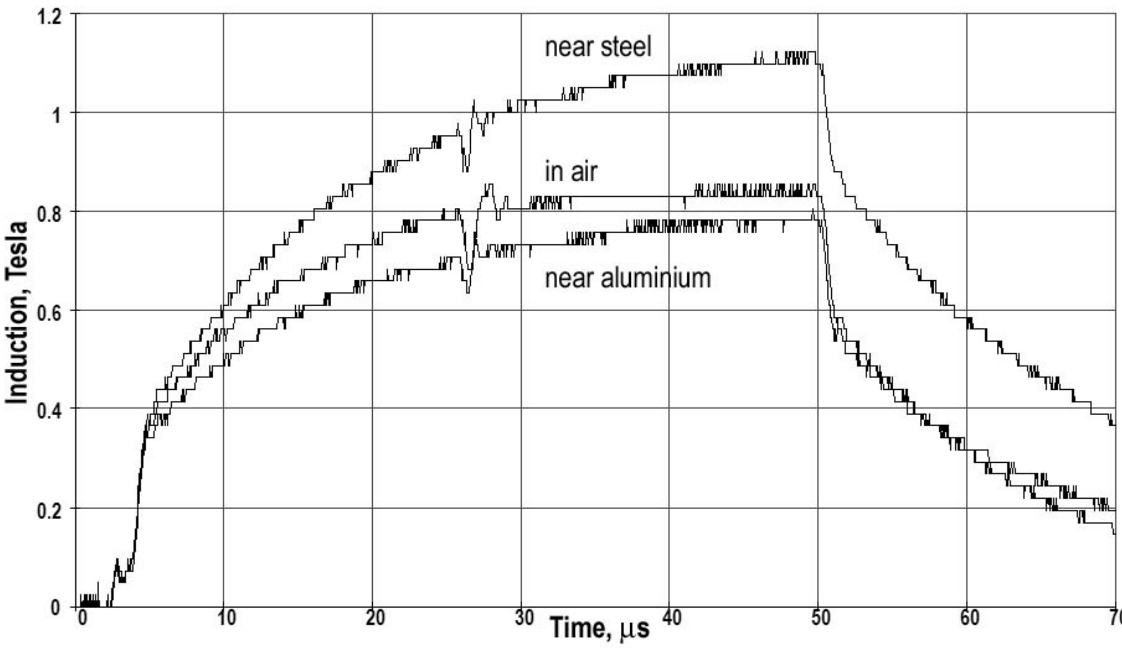

Figure 2. Dependence of magnetic field induction on time near the operation surface of EMAT

used signal for EMAT excitation: single radio-pulse and 13-elements Barker signal. To estimate the affectivity

of using phase-manipulated signals the thickness measurement of samples from aluminium, brass, titan, carbon and stainless steel with different surface state were made. The figures 4 - 5 show the typical realizations of multiple echo-signals and their autocorrelation functions (ACF). The time interval between the beginning of scale and the first maximum of ACF, which is equal to the double ultrasound propagation time in the material, was used for the calculation of layer thickness. The use of correlation proceeding allows widening the measurement range in the zone of small thicknesses, where it is impossible to be done with the threshold proceeding, because of the dead zone and not time allowed reflected pulses.

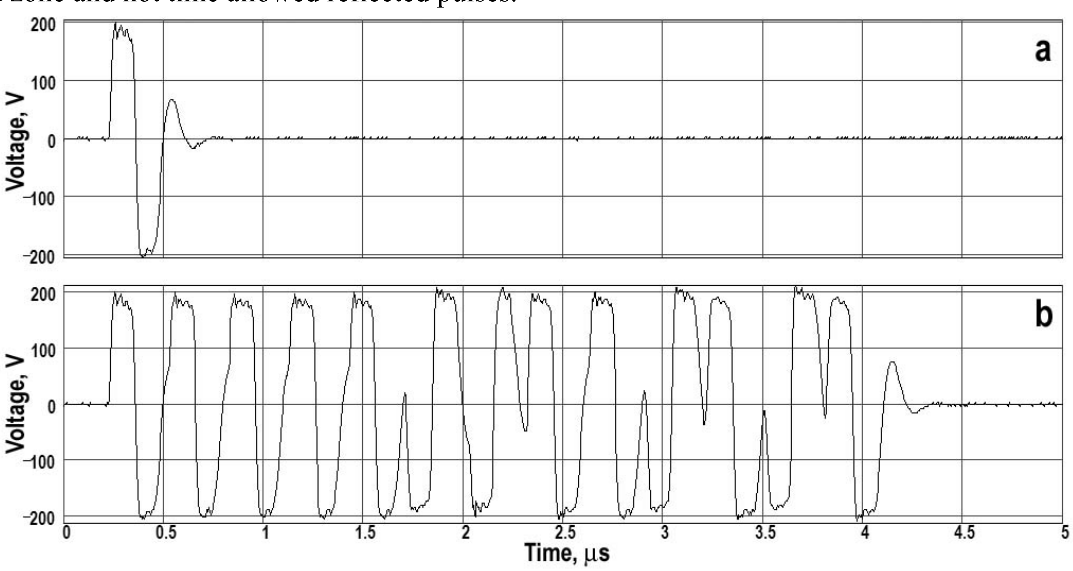

Figure 3. Form of EMAT excitation signal:

a) single radio-pulse
b) 13-element Barker signal

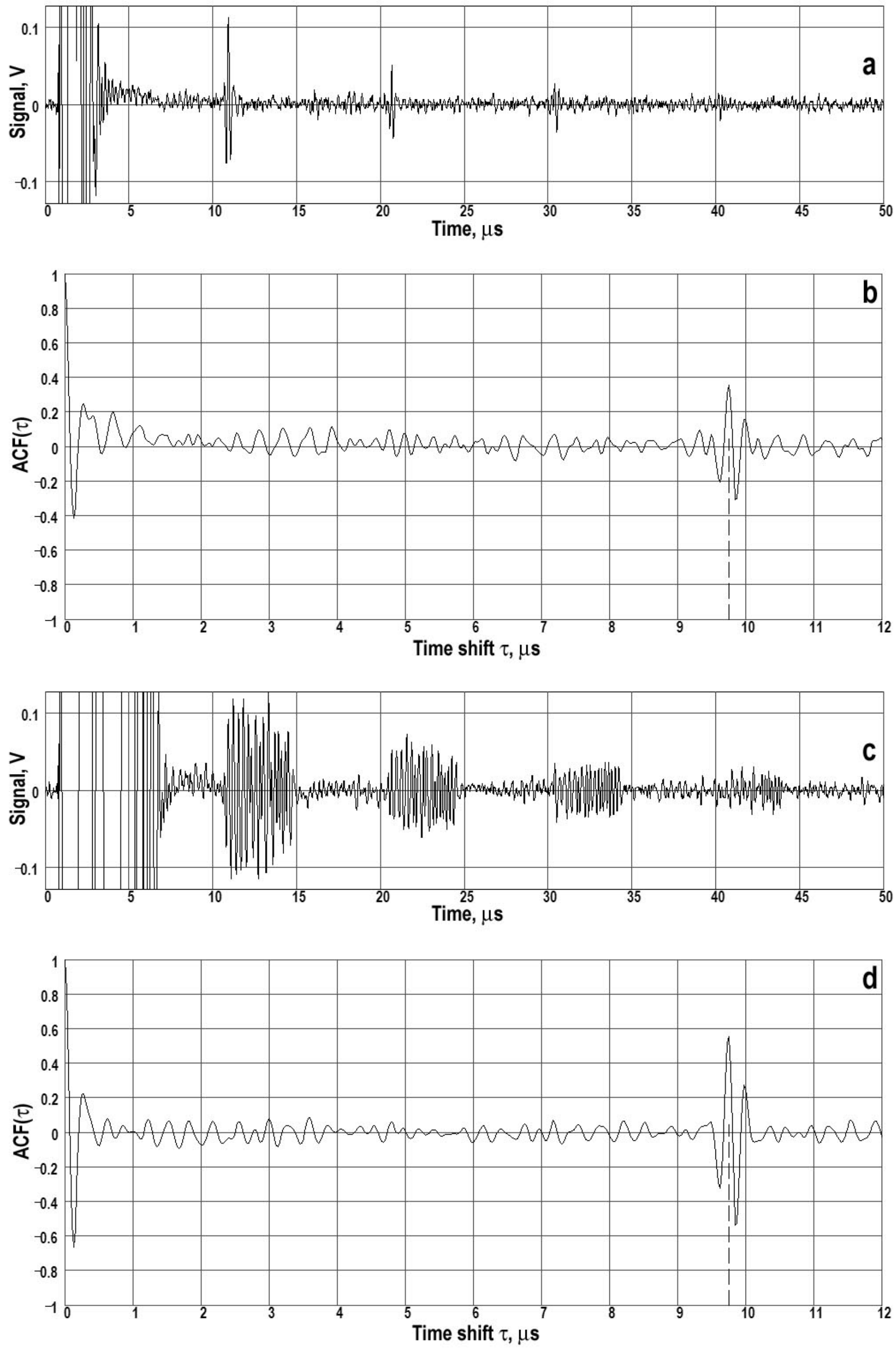

Figure 4. Realizations of received signals and ACF for EMAT excitation of SH-wave in the plate from aluminium alloy with:
a, b) single radio-pulse
c, d) 13-element Barker signal

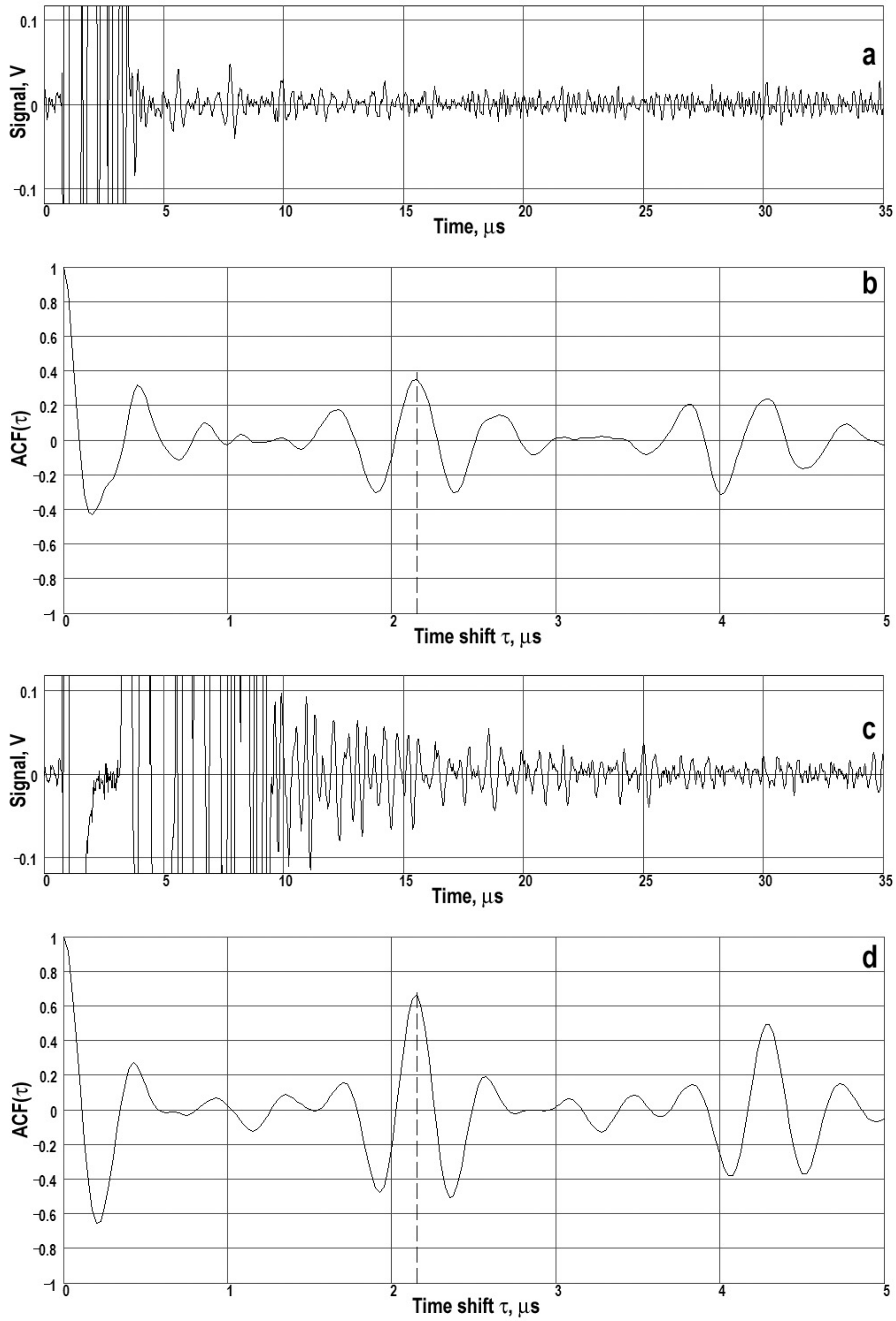

Figure 5. Realizations of received signals and ACF for EMAT excitation of SH-wave in a steel tube with corroded surface with:

a, b) single radio-pulse

c, d) 13-element Barker signal

The research results were used when developing the portable EMA thickness gauge with the correlation signal proceeding. It is a monoblock digital device with the off-line power supply. The information is displayed on the digital indicator. The EMA transducer of the device is made in two variants. In the first variant besides the sending and receiving elements and biasing coil there are the excitation pulses generator and the key with the accumulation capacity in it. The second variant differs from the first one with the generator, preamplifier and accumulation capacity, placed in the intermediate case that allows reducing the sizes and weight of EMAT and improving the testing conditions in hardly accessible places. The optimal relations between the biasing interval and moment of pulse sending provided the 8 hours operation of the device from the accumulator at the pulse sending frequency of 1 Hz.

Due to the EMA transducers for sending and reception of SH-waves with radial and linear polarization, which are in the basic delivery set, the EMA thickness gauge can be also used for estimation of anisotropy and strain-stress statement of crucial structure's units and details in workshops and in situ.

The main characteristics of EMA thickness gauge A1271

Measurement range	0.5 ÷ 50 mm (on steel)
Main error	± 0.05 mm
Minimal curvature radius	10 mm
Surface roughness, R_z	up to 320 um
EMAT* sizes	ø15 x 17 mm
EMAT* weight	50 g
Testing object's temperature range	-50 ÷ +100°C
Sizes of electronic unit	80 x 80 x 30 mm
Weight of electronic unit	600 g
Operating temperature range	-20 ÷ +50°C
Continuous operation time	8 hours

*For the second variant of EMAT

Discussion: The induction of pulse magnetic field in EMAT significantly exceeds the induction of constant magnets' field. This provides the effective use of EMAT at carbon steel testing.

Figure 6. The process of corroded steel rolling samples testing by EMAT with pulse biasing

The multiple echo-signal realizations of SH wave with radial polarization in the 15 mm thick aluminium alloy plates (figure 4 a, c) and corresponding ACFs (figure 4 b, d) are characterized with the clear echo-signals from both single radio-pulse excitation and 13-elements Barker signal. At the same time the exactness of measurements at noises existence for EMAT excitation with Barker signal is much better then with single radio-pulse.

The level of multiple echo-signals realizations of SH-waves with radial polarization in steel tube of 60 mm in diameter and with wall thickness of 3.8 mm thick (figure 5 a, c) is comparable to the noise level for both types of excitations. However the corresponding to them ACFs (figure 5 b, d) are different. For EMAT excitation with single radio-pulse the first petal of ACF is equal to 0.35, which can course a big error of measurements. For Barker signal the petal is equal to 0.66.

The advantages of using Barker signal is especially seen at measurements on steel sample with the rust and corrosion damages (figure 6).

Conclusions: 1. Proposed and researched the pulse magnetic biasing, which provides the creation of high-effective small-sized EMAT for sending and reception of shear waves with radial and linear polarization.

2. Developed the method and equipment for coherent proceeding of signals at acoustic measurements of objects with different level of corrosion surface damages.

3. Made the acoustic thickness measurements of rolled carbon steel samples after a long exploitation period without the preliminary surface cleanup.

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