ADVANCED INFORMATIVE AUTOMATED SYSTEMS OF ACOUSTIC CONTROL OF WELDING

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Advanced domestic and foreign high-information types of equipment for acoustic testing of pipeline welded joints are considered. Their performance capabilities and disadvantages are noted. The advantages of complex scanner, realizing ultrasonic, eddy-current and visual methods of testing and developed by ETC «Welding and Testing» together with «Molniya» enterprise, were described. Given are the examples of application of AVGUR system as well as ASBAT portable device, which passed interdepartmental testing and were implemented at OJSC Gazprom for testing of welded joints in nuclear-power engineering. 1 Table, 11 Figures.

Keywords: *acoustic testing, pipeline welded joints, scanner-flaw-detector, characteristics of testing system, portable device, head wave*

Significance of non-destructive methods of testing is sufficiently high due to large depreciation (more than 65 %) of processing equipment and necessity of reliable diagnostics of objects being constructed.

Cost of testing operations in manufacture of separate products of military-industrial complex in USA achieves 25–35 % from the total product cost. These costs make 10–12 % in building industry. The costs of testing and diagnostics in Russia are 15–20 time lower due to what number of accidents on different designation objects is an order higher than in the West.

Necessity in a safe high-information equipment is in particular relevant for a fuel-energy complex where the accidents are connected with large economic losses as well as disastrous effects.

Acoustic methods have found the largest application among all the variety of diagnostic methods during manufacture, building and operation of structures. Avtokon-AR-MGTU automated ultrasonic scanner-flaw-detectors are the most efficient means for weld quality testing in evaluation of technical state of main pipelines, gasholders and tanks.

The self-sufficient robotic system represents itself a displacement mechanism carrying a 32-channel ultrasonic flaw-detector with controlling processor and acoustic system, consisting of two 16-element combined probes (IP). The latter realizes a testing technology using phased arrays with beam swinging aperture in 40° range at 8 MHz frequency (Figure 1).

Two other 16-element probes, operating in separate mode, provide a testing technology applying Time-of-Flight Diffraction (TOFD) method (Figure 2, *a*).

The signals scattered on defect edges are registered and recorded during TOFD and B-scan is displayed on the screen (Figure 2, *b*).

The system is installed on the object of testing and moved along the welded joint automatically tracking it without any additional devices. A scanning mechanism is held on the pipe surface by constant magnets embedded in the wheels. The unit is small-size, easy in operation and serviced by two operators.

Comparison characteristics of robotic systems are given in a Table.

Domestic device, together with indicated above advantages (Table), allows testing the products of any shape (flat sheets, tanks, gasholders, etc.). Figure 3 shows an example of flaw detection of the circumferential pipe butt joints.

It should be noted that the best available foreign analog Pipe WIZARD-PA (RTD company) can only test circumferential butt joints (Figure 4) on the main pipelines.

Existing ultrasonic scanners Avtokon-AR-MGTU, «Sonet», USD-60, etc. do not allow de-

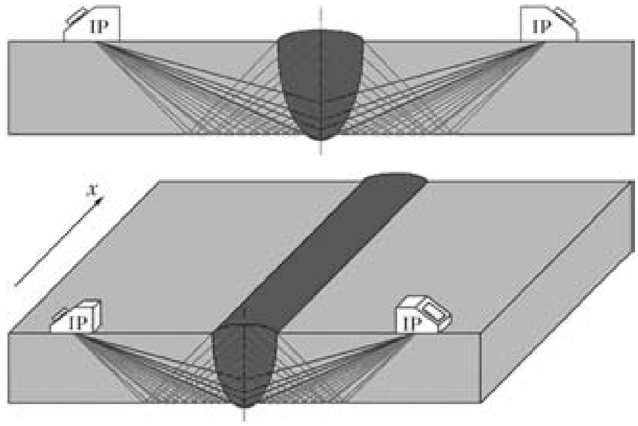


Figure 1. Acoustic system of scanner-flaw-detector Avtokon-AR-MGTU with phased arrays

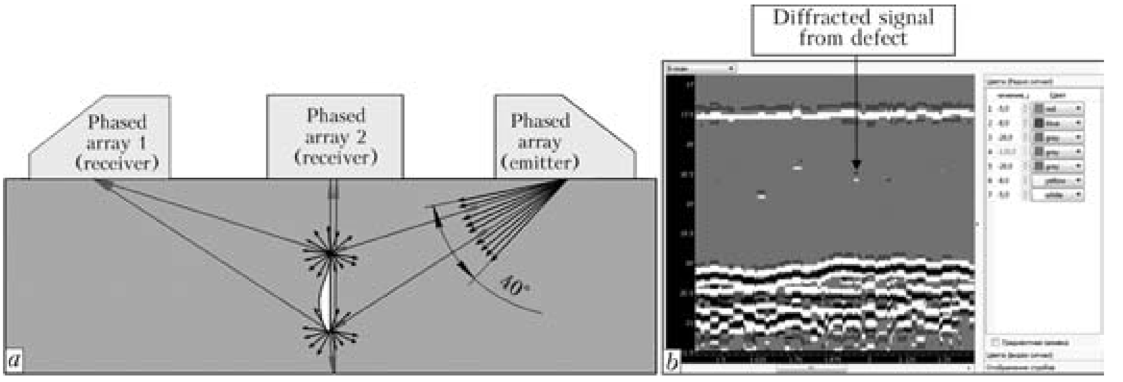


Figure 2. Acoustic system of scanner-flaw-detector Avtokon-AR-MGTU with phased array of «duet» type (*a*) and diffracted signals (*b*)

tecting the stress-corrosion damages in the main pipelines with high probability level. Thus, ETC «Welding and Testing» at the N.E. Bauman MSTU together with SPC «Molniya» developed a complex scanner realizing ultrasonic, eddy-current and visual methods of testing (Figure 5, *a*) for elimination of indicated disadvantage and increase of surface and internal defect detectability. It is designed for testing of 720–1420 mm diameter pipelines with wall thickness up to 35 mm at –40 to +40 °C temperature. Speed is up to 3 m/min and width of scanning zone makes 280 mm per one revolution at movement on helical line. The results of diagnostics are represented in a form of scanogram (Figure 5, *b*)

AVGUR 5.2 systems (Figure 6), developed at SPO «Ekho+», are the most efficient during testing of quality of butt welded joints in pipelines of primary coolant circuit of WWR- 1000 reactor. Large thickness (72 mm) and presence of a fillet from which cracks mostly initiate in service, are typical for these joints. AVGUR 5.2 system finds occurring defects with high reliability and allows identifying their sizes and configuration (Figure 7).

AVGUR 5.2 system after insignificant rekitting is successfully used for testing of bends of pipelines of WWR-1000 primary coolant circuit (Figure 8).

Information about form, size and coordinates of the defects is not always enough for evaluation of object serviceability. Presence of residual stresses in different elements of structures, in particular in defect zone, makes a significant effect on a stress-strain state level.

There is a great number of devices for evaluation of residual stresses, effect of which is based

Comparison characteristics of robotic testing systems Pipe WIZARD-PA (RD TECH™) and Avtokon-AR MGTU

Parameter or characteristic	Pipe WIZARD-PA	Avtokon-AR MGTU	Note
Self-sufficiency	Within the length of communication cable of mobile block and hose for couplant feeding	Complete	At pipeline testing the main block of Pipe WIZARD-PA should be mounted on a car and length of the cable and hose ≥20 m
Scanning method	Automatic, along a guide, mounted on the weld	Automatic, without additional devices	AVTOKON-AR-MGTU is equipped with a sensor for tracking weld reinforcment bead or flexible strip
Weight, kg	More than 50 kg without the weight of external computer, couplant tank, hoses and cables	≤18	Pipe WIZARD-PA is not portable
Range of controlled thicknesses of pipeline base metal, mm	7–32	6–35 (at acoustic block replacement)	Mainly, pipeline base metal thickness ≥8–30 mm
Range of working temperatures, °C	–15–+30	–40–+ 50	Testing mostly is carried out at negative temperatures
Main testing results	Defect detection, determination of their location and measurement of conditional dimensions	Defect detection, determination of their location and measurement of conditional dimensions	–
Function of acoustic coupling monitoring	Yes (separate transducer by reflection from pipe inner surface)	Yes (at each starting of any channel without application of additional equipment)	–
Testing scope	Circumferential welds	Circumferential and longitudinal welds, pipe body	–

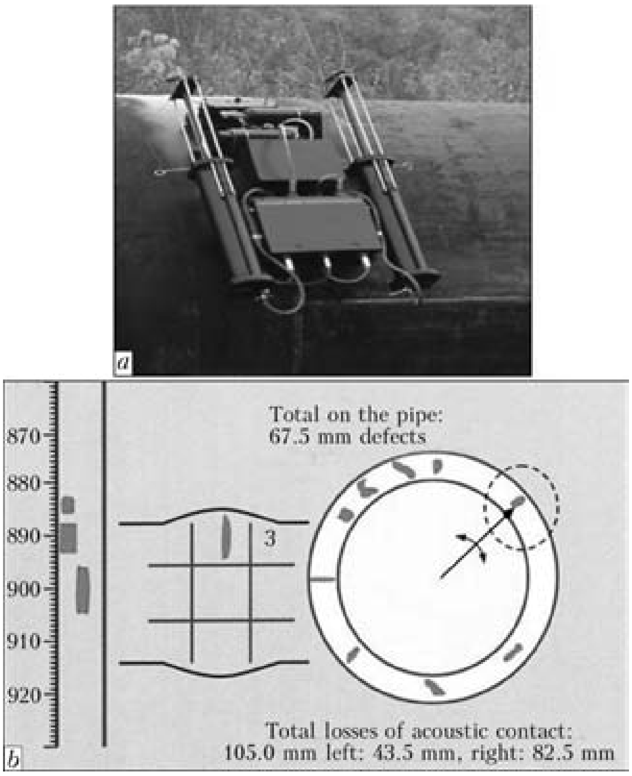


Figure 3. Scanner-flaw-detector Avtokon-AR-MGTU (*a*) and representation of testing results on monitor screen (*b*)

on measurement of different characteristics of magnetic, electromagnetic or ultrasonic fields. Low measurement accuracy (20–25 %) is their common disadvantage. LZM-USJzfp unit (German Institute for Non-Destructive Testing) is the most perfect among the well-known systems for measurement of internal stresses. Its principle of operation is based on measurement of transverse

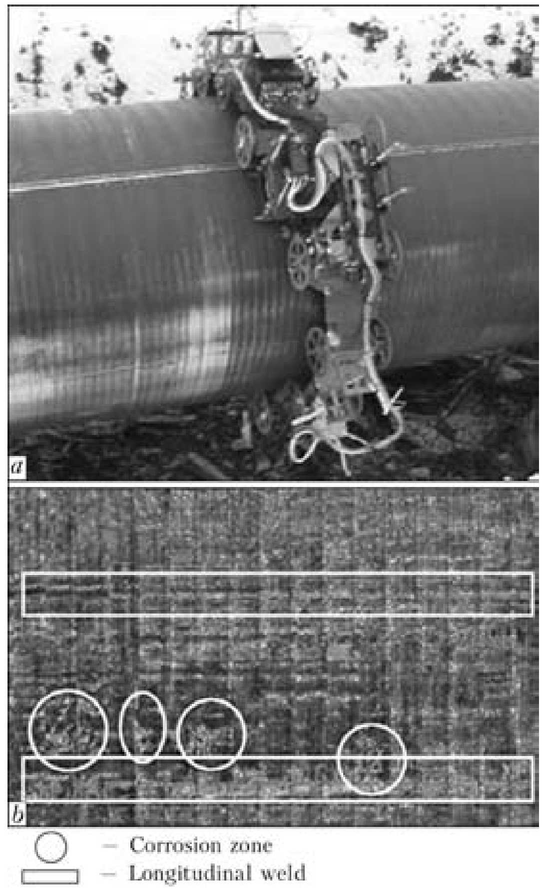


Figure 5. Automated complex system for testing of main pipelines (*a*) and scanogram of defects (*b*)

velocities of US-waves in mutually perpendicular direction. At that excitation of SH-waves is performed by EMA-transducers. This system allows measuring only uniaxially-stressed state with

Figure 4. Pipe WIZARD-PA scanner

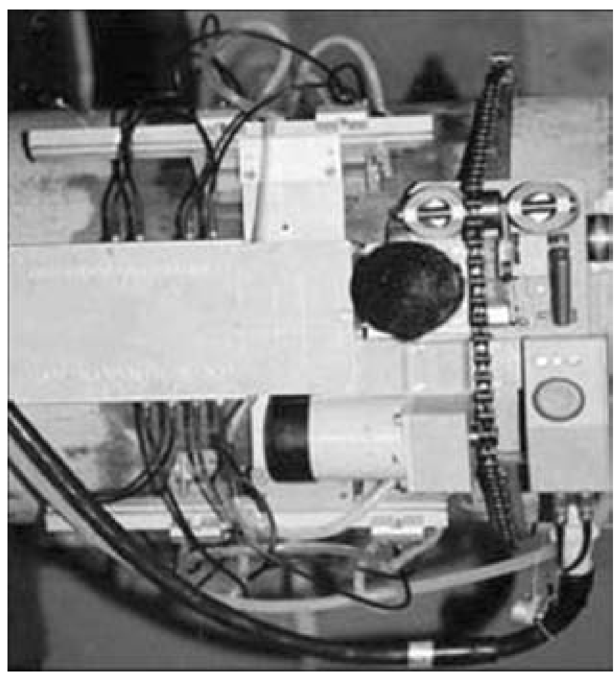


Figure 6. System AVGUR 5.2 for automated ultrasonic testing of circumferential butt welded joints of pipelines of WWR-1000 reactor primary coolant circuit

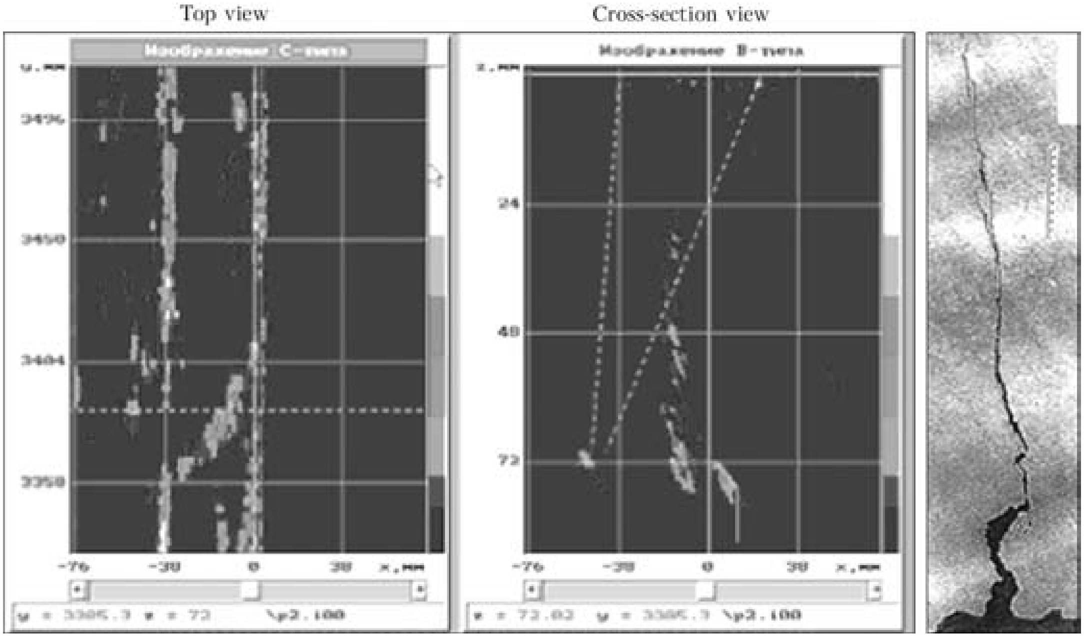


Figure 7. Image of a defect in welded joint with PET angle of incidence 40°

Figure 8. AVGUR system for automated ultrasonic testing of bends of pipelines of WWR-1000 reactor primary coolant circuit

5 m/s accuracy that is not always met customer requirements.

ETC «Welding and Testing» at the N.E. Bauman MSTU developed a portable device ASBAT (Figure 9, *a*) for examination of values of mechanical stresses in uniaxial and biaxial stress-strain state in object thickness by measurement of velocities of all three types of waves, namely two transverse waves with mutually perpendicular polarization and one longitudinal. Direction of these waves' propagation is normal to plane of stress action (Figure 10).

The method is based on birefringent effect, i.e. phenomenon of decomposition of acoustic wave into two constituents in anisotropic media,

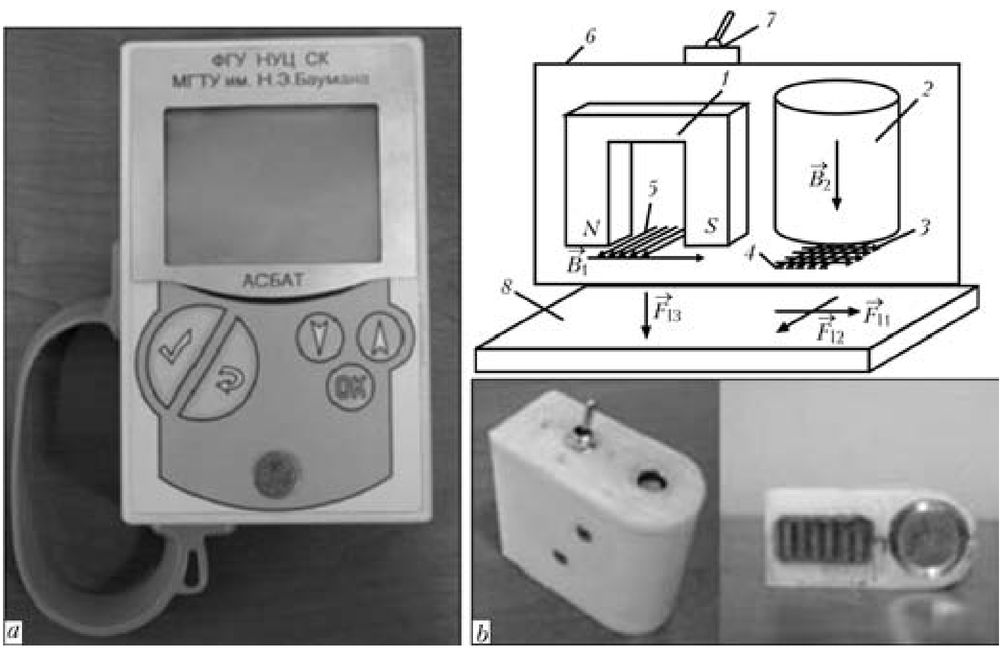
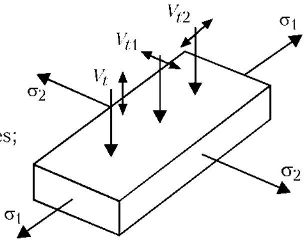


Figure 9. Hardware for contact-free acoustic tensometry (ASBAT) (*a*) and complex sensor (*b*) (*1–7* — see in the text)

$$\begin{cases} V_1 = V_{01}(1 + k_1\sigma_1 + k_2\sigma_2), \\ V_2 = V_{02}(1 + k_3\sigma_1 + k_4\sigma_2), \\ V_3 = V_{03}(1 + k_5\sigma_1 + k_6\sigma_2), \end{cases}$$

where σ_1, σ_1, V_2, V_2 are the stresses and corresponding to them wave velocities; k_1, k_2, k_3, k_4, k_5, k_6 are the coefficients of elastic-acoustic coupling.



For uniaxial stressed state:

$$\sigma_u = K_s(A_s - A_{s0}),$$

where

$$A_s = \frac{t_2}{t_1} - 1 \quad A_{s0} = \frac{t_2^0}{t_1^0} - 1;$$

For biaxial stressed state:

$$\sigma_{u1} = K_1\Delta_1 - K_2\Delta_2, \qquad \Delta_1 = \left(\frac{t_{01}}{t_{03}}\frac{t_3}{t_1} - 1\right),$$

where

$$\sigma_{u2} = K_3\Delta_2 - K_4\Delta_1, \qquad \Delta_2 = \left(\frac{t_{02}}{t_{03}}\frac{t_3}{t_2} - 1\right),$$

where A is a value of acoustic anisotropy; t_1, t_2 are the delays of transverse wave pulses V_{t1} and V_{t2}, respectively.

Figure 10. Procedure for determination of integral by thickness value of mechanical stresses

where particle oscillations in these two waves are mutually perpendicular (Figure 10). Complex EMA-transducer (Figure 9, *b*) was developed for realization of this effect.

Two magnetic systems *2* and *1* are located in single body *6*. Magnetic system *2* (with alternating current coil *3*) is designed for excitation of transverse wave in testing object *8* under effect of Lorentz force F_{12}. Magnetic system *2* (with alternating current coil *4*) is designed for excitation of transverse wave in testing object *8* under effect of Lorentz force F_{11}. Coils *3* and *4* are located one under another and have mutually perpendicular orientation for excitation of the transverse waves with mutual perpendicular polarization. Magnetic system *1* (with alternating current coil *5*) is designed for excitation of a longitudinal wave in testing object *8* under effect of Lorentz force F_{13}, which is directed normal to the testing object. Switch *7* is intended for mode selection.

Realization of multiple echo-signals of shear waves with radial polarization in the anisotropic plates and shear waves with linear polarization at 45° displacement in rolling direction is typical by division of pulses which is clearly observed already for second-third echo-signal depending on level of material anisotropy. This can be explained by the fact that the shear waves in process of their propagation are splitted into two waves with oscillatory displacements along and across the rolling direction, propagating with different velocities.

Increase of the material anisotropy rises the mutual time displacement of pulses of both components of the shear waves at constant path of

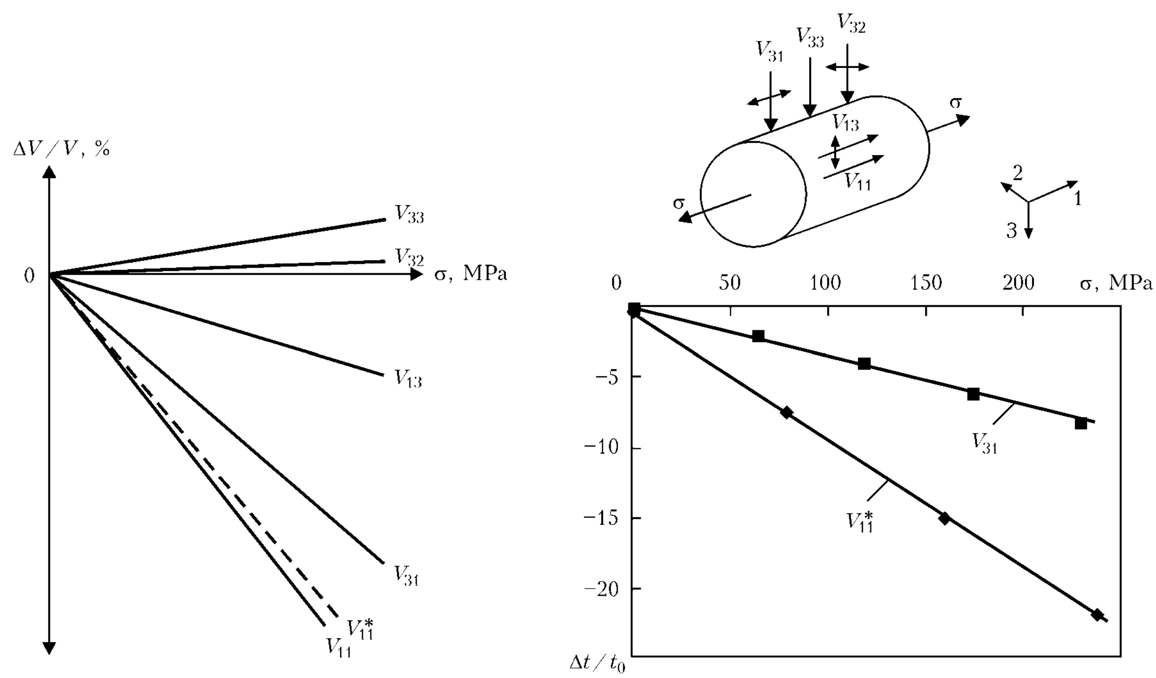


Figure 11. Dependence of head wave sensitivity on mechanical stress: V_{11} — longitudinal; V_{11}^* — head; V_{13} — Rayleigh; V_{31}–V_{33} — transverse waves

their propagation in the material (constant thickness). Relative time of displacement of wave pulses with different polarization achieves the value of interval of double propagation of each wave in layer thickness and exceeds it at sufficiently large path of signal propagation.

Level of anisotropy rises at application of load to testing object along one of the anisotropy axes, thus the mutual time displacement of pulses of two waves with mutually perpendicular polarization increases. Change of relative difference of wave velocities in initial (unloaded) and final (loaded) state is proportional to effective stress.

The authors proposed applying a head wave in contact variant for providing higher sensitivity to the mechanical stresses. Experiments and calculations showed that it sensitivity is 2.7 time higher (Figure 11) in comparison with transverse wave for steel 30.

ASBAT passed interdepartmental tests and after corresponding certification was implemented at OJSC «Gazprom» objects.

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