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Development of a method for removing residual mechanical stresses in welded joints of NPP pipelines after their execution by ultrasonic hardening

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Abstract

This article describes the description and the results of experimental work to confirm the efficiency of the method for removing residual mechanical stresses in welded joints of NPP pipelines after they have been performed by ultrasonic hardening. Also, based on the results of the experiment, it is proposed to develop an automated device, the work of which is based on the proposed method.

Keywords: NPPs, residual mechanical stresses, pipelines, welded joints, magnetostrictive transducer.

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1. Introduction

A large number of pipelines are required to connect all the devices and units of the nuclear power plant. The total length of all the NPP pipelines is about a hundred kilometers. The cost of pipelines can reach 10% of the cost of the entire station. In addition, reliability and safe operation of the nuclear power plant directly depend on the state of the critical circulation pipelines of the first circuit [1].

Pipelines at nuclear power plants are subject to various destructive factors (high pressure inside pipelines, vibrations, contact with corrosive media, ionization radiation, etc.). When the critical pipelines are destroyed, the safe operation of the nuclear power plant is threatened. To carry out costly repairs, a complete shutdown of the nuclear reactor is necessary, which, in turn, entails great financial costs.

All of the above listed factors indicate that it is necessary to carry out a whole range of procedures aimed at ensuring the reliability of the pipelines of nuclear power plants, and specifically their welded joints, because they, in view of the features of the technological process, are subject to the greatest destruction due to the formation of residual stress and residual deformation during welding. In addition, during operation,

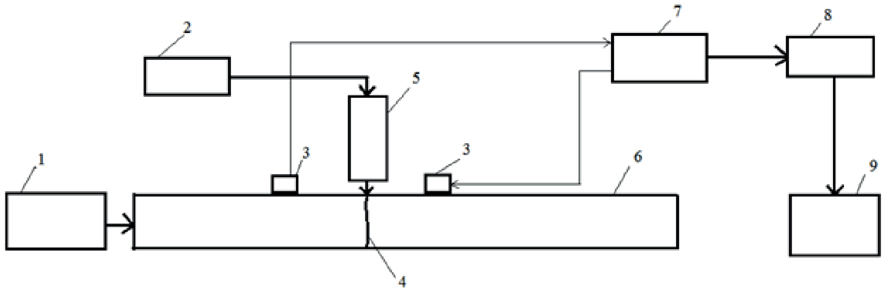

Figure 1: Functional diagram of the experimental setup: 1 - hydraulic pump; 2 - ultrasonic generator (UZG); 3 - piezoelectric transducer (PEP); 4 - welded seam; 5 - magnetostrictive transducer (ICP); 6 - pipeline; 7 - flaw detector; 8 - analog-to-digital converter (ADC); 9 - electronic computer (computer).

additional mechanical stresses may occur in welded joints under the influence of the above loads and factors. There are a number of different procedures specially designed to remove residual stresses, but due to the technological peculiarities of operating NPP pipelines (ionization radiation, limited space between pipelines, etc.), many of them can not be used. Therefore, the removal of residual stresses in welded joints of NPP pipelines remains an urgent task.

In this paper, the experimental justification of the method for removing residual mechanical stresses in welded joints of NPP pipelines is presented after their execution by ultrasonic hardening. The essence of the method is that, due to ultrasonic vibrations at the end of the acoustic ultrasonic waveguide, the crystal structure of the metal changes during its plastic deformation. In a welded joint this allows to remove residual stresses due to the fact that dislocations transmit the energy necessary for them to return to their initial state after deformation [3].

2. Experiment

The purpose of the experiment is to confirm the operability of the method of removing residual stresses in welded joints of NPP pipelines after their execution by ultrasonic hardening. In order to confirm that the theory of ultrasonic work hardening works, stresses were created in the weld joint and their measurement was made. Then, residual stresses were taken with the help of the USN and their measurement again took place. To carry out experimental work at the IAE in the laboratory of the Department of AKiD, an experimental setup was assembled, the functional diagram of which is shown in Fig. 1.

Hydraulic pump 1 has a manometer. With the help of high-pressure hoses, it is connected to a fragment of pipeline 6, welded from both ends, the pipeline material - structural steel (22 K). The pipeline fragment is welded from two parts and has a weld seam 4. The inclined joint profiled PEP 3 (P121-1,8-40) are rigidly fixed on the pipeline on opposite sides of the weld at a distance of about 10 cm from each other. One of them is used As an emitter of an ultrasonic wave, the other as a receiver. The angle of input of the PET lies in the interval between the first and second critical angles of entry, so after refraction of the longitudinal wave at the interface of the plexiglas-steel, only the transverse wave propagates in the wall of the pipeline, the longitudinal component passes into the surface wave. As the contact layer, ciatim-201 was used. The PETs are connected to an ultrasonic flaw detector (UD2-12) 7, which is used as blocks of electric pulse generators and amplifier blocks. The digital storage USB oscilloscope AKIP-4111 (8), which performs the functions of ADC, is connected to the flaw detector. The signal from the oscilloscope is fed to the computer 9, on the screen of which the digitized signal from the flaw detector is reproduced using the program PicoScope 6.

A magnetostrictive transducer (PMS-1.5 / 22) 5 was used to perform the ultrasonic work hardening, which was fed from an ultrasonic generator (UZG-1.5) 2.

The change in the speed of ultrasound, according to the theory of acoustoelasticity, indicates a change in the mechanical stresses. Since the PES are rigidly fixed on the pipeline and the distance between them does not change, the change in the time during which the transverse RAS passes the path from the radiator to the receiver will indicate a change in its propagation velocity and, accordingly, a change in the mechanical stresses in the welded joint. The propagation time of the RAS was determined as the difference between the time of arrival of the signal to the receiver and the time of signal delivery to the radiator.

At the beginning of the experiment, the time of propagation of the transverse ultrasound in the near suture zone and the weld seam was determined with the help of a PET, flaw detector, digital oscilloscope and computer. The pressure in the pipeline was not created. This time is considered "standard", because corresponds to the minimum value of mechanical stress in the welded joint. Measurement of the arrival time of the signal was carried out on the leading edge of the pulse. Figure 2 shows an oscillogram for determining the propagation time of a transverse ultrasonic wave from the emitter to the receiver. The figure shows that the time t is 152.8 μs.

Then, using a hydraulic pump, the pressure in the pipeline was p = 2.5 kgf / cm2 and, at the pressure created, the transit time of the transverse ultrasound was determined from the oscillogram.

Then the pressure was reset and the time of the passage of the ultrasonic wave was again determined, a change in this time indicates a change in the residual stresses that

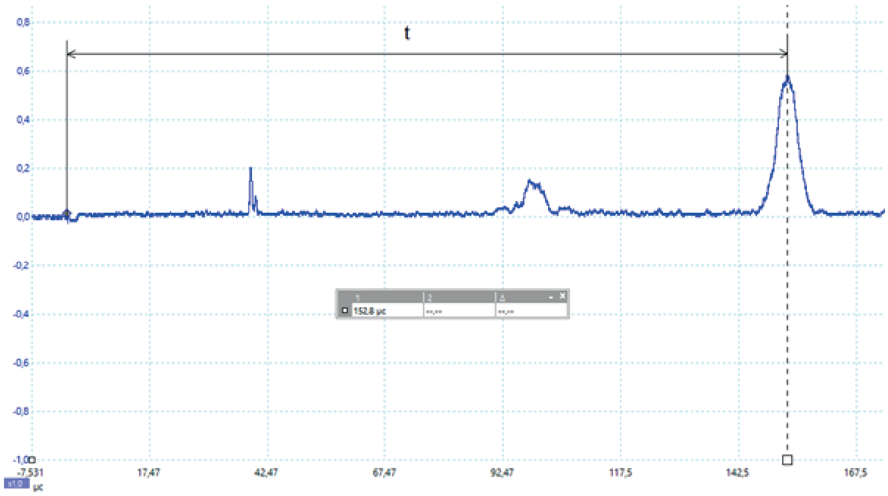

Figure 2: Oscillogram of determining the time t, during which the transverse USV will pass the path from the radiator to the receiver without the created internal pressure.

arose after the creation of an elevated pressure. After measuring the time, an ultrasonic hardening was performed, after which the time of propagation of the transverse ultrasonic wave was also measured.

The procedure described above was repeated for pressures p = 5; 7.5; 10; 12.5 kgf / cm^2.

UZN was carried out from two sides of the welded seam for 10-15 seconds from each side. The amplitude of the displacement of the working surface of the waveguide is 15 μm at a frequency of 22 kHz. The SME was powered by an ultrasonic generator with a power of 1.5 kW. The frequency of the generator was previously tuned to the resonance frequency of the SMP waveguide. To increase the accuracy of the experiment, measurements of the RAS propagation time were carried out 10 times in each experiment. Since the pressure created in the pipeline was measured in kgf / cm2, the pressure was transferred to MPa to simplify further calculations.

Table 1 shows the average values of the measured time at the created pressure (td), after its discharge (tcb) and after ultrasonic hardening (tn) for all pressures created, and also the corresponding errors (Δt).

Calculation of equivalent mechanical stresses in the pipeline wall was carried out according to the method described in [4].

3. Results of the experiment

To process the results of measurements, the Microsoft Excel 2010 program was used. With its help, graphs were obtained of the average time of propagation of a transverse

Table 1: Results of the experiment.

	0,25 МПа	0,5 МПа	0,74 МПа	0,98 МПа	1,23 МПа
t, мкс	151,21	151.00	150,53	150,21	149,82
Δt, мкс	0,19	0,19	0.14	0.13	0.26
t, мкс	152,09	152,11	152,21	152,34	152,36
Δt, мкс	0.21	0.20	0.27	0.24	0.25
t, мкс	152,06	152,33	152,45	152,50	152,44
Δt, мкс	0.25	0.29	0.30	0.31	0.20

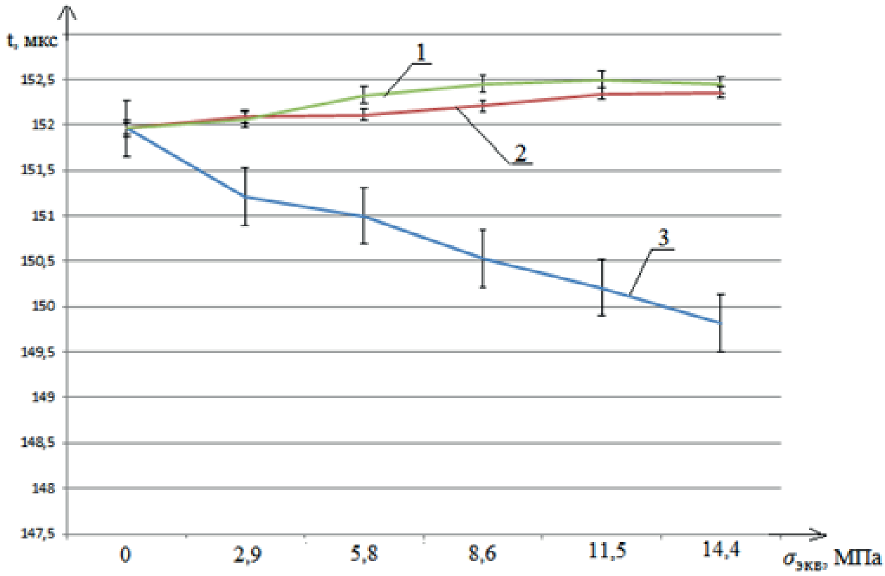

Figure 3: Graph of the dependence of the propagation time of RAS from the equivalent voltage: 1 - after ultrasonic hardening, 2 - after pressure relief, 3 - at the created pressure in the pipeline.

ultrasound in the weld seam and near the seam zone from the created equivalent stress in the pipeline wall (σ_eq) at the created pressure, after its discharge and after UZN. The graph is shown in Figure 3:

According to the theory of acoustoelasticity, when the mechanical stresses change in the material, the propagation velocity of the RAS should change, and accordingly the time for which the USV will pass the path from the radiator to the receiver must change. Confirmation of this statement is clearly seen in the graph of Figure 3, where when the equivalent stresses in the pipeline increase, the propagation time of the RAS decreases.

The graph of the dependence of the propagation velocity of the RAS from the created voltage after the USP (1) is above the graph of the same dependence after the pressure drop (2), which indicates the removal of the residual stresses. The fact that the propagation time of the RAS after the hardening is greater than before the work hardening can be explained by the fact that in the welded joint, the stresses generated during welding could remain.

Based on the results of the experiment, it can be concluded that ultrasonic hardening really reduces residual stresses and levels them. In addition, according to [5], after USN, the surface layer of the article hardens at the hardening point, the probability of fatigue cracks formation increases, its corrosion properties improve, which undoubtedly is a positive effect of this method. Proceeding from the above, we can conclude that the goals of the experiment are achieved.

4. Conclusion

In this article, the results of experimental studies on the justification of the proposed method for removing residual mechanical stresses in welded joints of pipelines after their execution by ultrasonic hardening were presented. At present, the automated device for removing residual mechanical stresses in welded joints of the NPP pipelines is being developed after they have been performed by ultrasonic hardening. It should consist of the following elements:

- Magnetostrictive transducer, by means of which ultrasonic hardening is performed;
- Ultrasonic generator, for supplying a magnetostrictive converter;
- Autonomous cooling system, for cooling the magnetostrictive converter;
- Movement mechanism and stepping motor, for moving the movable part of the device along the welded joint;
- Programmable logic controller, for device control;
- Ultrasonic piezo transducer with a transmission frequency of 20 kHz, for monitoring the performance of ultrasonic work hardening;
- Guide, for fixing the device to the pipeline.

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