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Prykhodko[1], V.I., Vysokolyan[1], M.V., Volochai[1], V.V., Prokopenko[2], G.I., Mordyuk[2], B.N., Cherepin[3], V.T., Krasovskiy[3], T.A., and Popova[4], T.V.

[1] PJSC Kriukov Railcar-Building Works, Kremenchuk
[2] The Kurdiumov Institute of Metal Physics of NASU, Kyiv
[3] Physical and Technical Research and Training Center of NASU, Kyiv
[4] Ukrainian Research Institute of Railcar Building Subsidiary, Kremenchuk

CREATION OF ULTRASONIC EQUIPMENT FOR STRENGTHENING AND RELAXATION TREATMENT OF WELDED STRUCTURES IN RAILCAR BUILDING

A new modification of portable ultrasonic equipment (0.8 kW power, digitally controlled) has been developed for strengthening and relaxation treatment of metallic product surface. A batch of such devices has been produced; the design documents on the ultrasonic generator and impact instrument with a piezoceramic transducer have been prepared. Preparation of ultrasonic impact treatment technique for welded structures has been accomplished. The comparative tests related to the effects of different types of treatment and applied materials of welded structures on fatigue life have showed the expediency of ultrasonic impact treatment for the prolongation of operation life of products.

Key words: ultrasonic impact treatment, welded structures, fatigue life, residual stresses, stress concentrators.

It is a well-known fact that the welded joint strength is low, as a result of the deterioration of the structure during metal melting, as well as of the appearance of stress concentrators and tensile stresses in the weld area. If they are superimposed on the external cyclic stresses the premature fatigue fracture occurs in the weld area, which sometimes leads to disastrous consequences. The tensile stress can be reduced by heating the elements, but it is difficult to do for large structures, therefore the methods of local treatment of welded joints should be used in this case. The research conducted at the E.O. Paton Electric Welding Institute has showed that the ultrasonic impact treatment (UIT) leads to the most significant increase in fatigue strength of specimens and structural elements as compared with other methods of treatment [1—3].

Today, there are many ways to strengthen the surfaces of parts and structural components: from the application of special coatings and surface alloying to the severe surface deformation. The latter has been classified as *superficial plastic deformation* (SPD) [4, 5]. The SPD methods are very diverse, but more often they are based on the energy of ultrasonic vibrations [1]. The high-power ultrasound is referred to the SPD intensive methods and results in significant changes in the structural and phase composition of metals and alloys. Welding of sheet structures often changes their geometry as a result of residual stresses. The ultrasonic treatment reduces these stresses due to relaxation or redistribution by creating the compression stresses in surface layers. This is one of the examples of application of this technique to eliminate the deviations from the specified sizes in the thin-sheet welded structures.

The Ukrainian researchers have developed the UIT for welded joints of critical structures operating under alternating load conditions, which greatly increases the fatigue strength and life of the products [6, 7].

Sometimes, the term «high-frequency mechanical peening (HFMP)» is used instead of UIT, but in the world practice it is known as the Ultrasonic Impact Treatment (UIT). This technique is used in such industries as shipbuilding and bridge construction, mining and oil industry and in other industrial sectors. In Ukraine, application of UIT technology is very limited. There have been reported some examples of UIT application when repairing the welds of 10 000-ton pressing machine at the pipe plant in Dnipropetrovsk, in 2001, and some bridges in Kyiv and Poltava. This is due to the fact that in Ukraine there is no high-quality ultrasonic equipment for UIT of metal structures and products. Insofar as the quality and service life of critical structures are always of great importance, the development of new equipment and the implementation of ultrasonic technique is an urgent task of the innovation industry development in Ukraine in terms of resource saving.

Recently, all over the world, the researchers have been increasingly focusing their efforts on high-frequency impact methods of surface treatment of metallic materials inasmuch as under such stresses the nano-crystalline structures appear in thin surface layers. It has unique physical and mechanical properties and opens the future prospects for ultrasonic technique with respect to surface modification and engineering.

In Ukraine, a method for UIT of metals and alloys has been developed to improve their mechanical properties, which lays foundation for developing a technique for strengthening of welded joints and redistribution of residual stresses [8]. The prototypes of appropriate equipment were manufactured [7]. The current tasks are the development and manufacture of advanced ultrasonic equipment, its certification, introduction of this method to the regulations and standards, and implementation in the industrial field of Ukraine.

The purpose of this study was to develop new ultrasonic equipment with the cutting-edge innovations in electronics and digital technologies taken into consideration. As a result of the innovative project a batch of new ultrasonic equipment operating at frequency of 22.5 kHz has been manufactured and the design documentation has been prepared for the ultrasonic generator and impact tools.

Within the framework of agreements on scientific and technical cooperation between the Kurdiumov Institute for Physics of Metals of the National Academy of Sciences of Ukraine (NASU), PJSC Kriukov Railcar-Building Works, and Instrumental Works LTD (Kremenchuk) these companies conducted the comprehensive fatigue tests of specimens of structural elements treated by the traditional (annealing to relieve the residual stresses after welding) and the ultrasonic techniques.

The tests showed the feasibility of using the latter for the welded structures of railway rolling stock. The ultrasonic technique was recommended for implementation in the industry.

The long experience in operating the welded structures of railcars under conditions of dynamic loads has showed that the zone of welded joints is the weakest point of such structures. The International Institute of Welding has generalized many studies dealing with resistance to fatigue fracture of different welded joints. Unfortunately, the IIW recommendations have not been included in the applicable standards for the design and manufacture of railcar-building products, which often leads to the project failure. The draft standard for designing and manufacturing steel structures of railcars designed in the Research Institute of Railway Transport (Moscow, Russia), which has to replace OST 24.050.34-84, reflects the IIW recommendations in the best way. Therefore, the most important factor in the design of welded structures is to use these guidelines to create the railcar-building products with high level of resistance to static and fatigue fractures, as well as with significant safety factor.

In Ukraine, there are all the prerequisites and possibilities to expand application of UIT technique in machine-building and construction of the critical structures. The methods and tools are protected by USSR author's certificates, Ukrainian patents, the PCT (Patent Cooperation Treaty) applications, and by the U.S. patent [9—13]. For many years, the Kurdiumov Institute for Physics of Metals and the E.O. Paton Electric Welding Institute (NASU) have carried out many basic and applied studies of structural-phase transformations under the action of high-power ultrasound and UIT on physical and mechanical properties of metals and alloys [14—16]. The factors affecting the fatigue properties of structural materials, including the welded joints, have been studied in detail [17—19]. Therefore, it can be stated that the Ukrainian researchers have elaborated the scientific fundamentals of this technique which has to take an appropriate place in the domestic industry and be competitive in the world market.

DEVELOPMENT OF TOOLS FOR UIT OF METAL PRODUCTS

The long-time experience of ultrasonic treatment of metals for their surface strengthening allows us to formulate the basic requirements for the ultrasonic transducer and the impact tool as a whole. One of the most effective ways of energy impact on the properties of metals, alloys, and welded joints is shock-vibrating treatment of surfaces. The frequency of impacts can vary from a few hertz to tens of kilohertz. The equipment differs by physical effects on which the action of impact loading of definite frequency is based and can be classified into machines with the pneumatic, the electromagnetic, and the acoustic tools.

One of the most promising types of drivers for shock-vibrating treatment are those based on ultrasonic electromechanical transducers, i.e. those with high-impact loads which are preferable inasmuch as they substantially improve quality and efficiency of treatment. At the heart of these benefits there are the physical effects which for many years have been studied in the Solids Acoustics Department of the Institute for Physics of Metals. Today, there are the well-known examples of tools with the use of magnetostrictive ultrasonic transducers. For the first time, they were used by Ye. Sh. Statnikov, one of the first inventors of this method [20] and the founder of *Applied Ultrasonic Inc.* (USA). However, the recent achievements in the field of modern highly effective ceramic materials [21] have made it possible to partially refuse from cumbersome and inefficient magnetostrictive sources of ultrasonic vibrations, which gave impetus to further improvement and creation of new high-power converters based on piezoceramics. These converters were the first ever used in Ukraine for UIT [7, 9, and 10], and later in other countries (France, China, and Canada). Thus, the implementation of modern piezoceramic transducers that have a twice greater efficiency because of higher quality factor allowed us to refuse from the system of liquid cooling and to reduce several times the size and weight of equipment as a whole. This is especially important for the portable devices operating in the field, sometimes, in very complicated conditions. For example, while treating the welded joints in large structures (bridges, ships, etc.) the operator has to keep the tool for a long time. Therefore, any tool heavier than three pounds is very uncomfortable for long-term use in manual mode.

The first task was to create the transducers and ultrasonic generators with a frequency of 22.5 kHz and maximum amplitude of oscillations of waveguide end (ultrasonic enhancer) at the level of 20—30 microns. This new tool should be tested under the real working conditions, because the laboratory tests make it impossible to adequately reproduce operation of equipment in complex operating environment. One of the main advantages of the ultrasonic instrument in comparison with the pneumodynamic one is, for example, reduction of noises and vibrations harmful for the human body. According to the Japanese researchers these noises do not exceed the industrial standard of acceptable level of 80 dB.

As one can see in Table 1, the noises and acceleration on the handle of the ultrasonic tool, i.e. its harmful vibrations, are significantly lower as compared with the pneumodynamic tool.

Based on the experience of industrial application of UIT, the workers of foreign companies prefer the ultrasonic tools. This is an important indicator inasmuch as safety in this case plays a decisive role. In this connection, a quite high cost of ultrasonic equipment is not an obstacle to its use. However, it should be noted that the foreign companies dealing with production and sale of UIT equipment (*Applied Ultrasonics Inc.* (USA), *SIN TEK Inc.* (Canada), and *SONATS Inc.* (France)) establish its price at the level of 40 thousand U.S. dollars, which certainly narrows down the market for equipment sales and hampers wide use of this equipment in Ukraine. Therefore, our task is to create equipment competitive in the world market, especially, in view of the fact that Ukraine possesses the qualified personnel having experience in the development of UIT technique and equipment.

The core PCT usually contains several pair of ceramic plates located between the rear and the front metallic cover plates. The enhancer is usually attached to the front to increase several times the amplitude of ultrasonic vibrations. This vibrator has the length of half-wavelength at a certain frequency. Typically, the oscillation frequency of technological installations is 18—40 kHz, depending on the purpose. It should be noted that the amplitude of oscillations is inversely proportional to the square of frequency, so the vast majority of installations are running at low ultrasonic frequencies of 18—27 kHz.

Table 1

Comparative test results for the ultrasonic and the pneumodynamic tools with respect to noise and vibrations of tool body harmful for operator's body (N. Tominaga, et al. / IIW Document XIII—2170—07)

Tool	Acceleration, m/s^2	Maximum acceleration, m/s^2	Noise, dB
UIT	16—18	90	69—74
Pneumodynamic	562—631	1200	83—87

If velocity of ultrasonic oscillations C is known, then wavelength is calculated by a simple formula: $\lambda = C / F$, where F is frequency of oscillations. However, the calculations for real transducers in general case are not so simple [22]. The nowadays methods of calculation and the relevant computer programs have been used in this research. Fig. 1 (*a*) features the drawings of PCT with a frequency of 22.5 kHz. This is the simplest ultrasonic transducer known as *the Langevin vibrator*. Its calculation is the simplest because its length is equal to $\lambda/2$. However, it is necessary to consider the speed of vibrations in materials from which the front and the back cover plates are made, as well as their density and mass. Piezoceramics also has specific acoustic properties which should be taken into consideration when making the calculations.

Design of the ultrasonic impact tool in 3D format (AutoCAD) (Fig. 1*b*) has significantly improved and speeded up the simulation and optimization of arrangement of transducer's parts in the tool's casing to improve its ergonomics and appearance. We have developed a new design of the tool characterized by compact size, light weight, and exclusive system for continuous cooling of the unit of impact loading by cold air (7—10 °C), which reduce significantly the air compressor capacity. This impact tool is intended for the most complex cases and is suitable for long-time operation both in the manual mode and in the industrial conditions.

After the manufacture of PCT the length of cover plates was corrected so as to ensure the required resonant frequency. The length of the front cover was reduced to 37 mm, and that of the rear downs to 27 mm. In this case, the resonant frequency was equal to 22.58 kHz. To increase the amplitude a transformer of vibrational speed or an enhancer should be connected to the output end of the ultrasonic transducer.

The enhancer was selected on the basis of sufficiently high amplifying factor under the stable operation at the resonant mode [23]. The stepwise enhancer corresponds to these requirements. The matter is that the shock vibrating mode of ultrasonic transducer operation adversely affects the performance of piezoceramics and, therefore, of the entire transducer as whole. The ultrasonic transducer is placed inside the body for the purpose of maximum isolation of ultrasonic vibrations from the tool and from the operator's hands. In the course of laboratory testing the tool its design was considerably improved, especially, in relation to reduction of harmful vibrations. This has been realized due to increasing the transducer mobile element weight and adding the shock absorbing pads, as well as due to making other design improvements upon the results of the previous inspection at the Kriukov Railcar-Building Works.

During the working cycle the tool is forced against the surface to be treated by a small force of 30—50 N. The hammers are vibrating forcedly between the surface of the product and the end face of the enhancer oscillating at ultrasonic frequency of about 22.6 kHz and amplitude of 30 microns. The frequency of shock vibrations is of stochastic character, it is lower than the ultrasonic one and ranges within 1—3 kHz according to various estimates and measurements. However, it is quite high as compared with other shock methods; therefore it is often called *high-frequency mechanical peening*. Vibrations of hammering part are transmitted to the transducer's body, but they are damped by spring and rubber pads, so both the high- and the low-frequency vibrations of the tool's body are negligible, which promotes the safe operation. It should be noted that the tool is designed in such a way as to ensure simplicity, easiness, and suitability for repair. Depending on the operating conditions (especially in hot climate) the tool is equipped with devices for forced air cooling.

DESIGN AND MANUFACTURE OF ULTRASONIC GENERATOR WITH DIGITAL CONTROL

Upon the results of laboratory and industrial tests of ultrasonic generator (USG) as a power source for the ultrasonic impact tools the following serious drawbacks were identified:

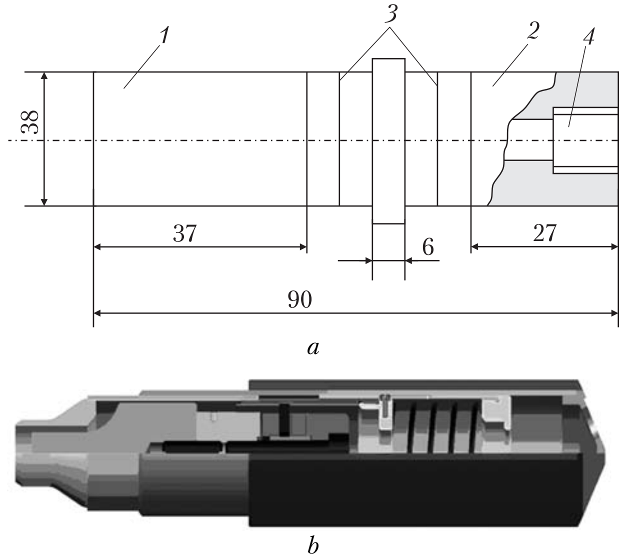

Fig. 1. Design of ultrasonic transducer (*a*): *1* — front cover plate; *2* — rear cover plate; *3* — piezoceramic rings; *4* — load-bearing screw bolt. General view of ultrasonic transducer in 3D format (*b*)

- Unstable keeping of resonant vibrations of the ultrasonic transducer during transition processes in a wide range of varying destabilization factors (as a result of significant fluctuations of mechanical load and temperature);
- Difficulties related to replacement of working ultrasonic tool and its adjustment to the USG in manufacturing environment;
- Poor protection of USG electronic circuit elements from industrial dust containing metal particles.

Due to these shortcomings the task of innovation project was to develop a digitally controlled USG with principally new design of its body in which the electronic items could be protected from dust.

To create such a device it was necessary:

1) To upgrade the digital control circuit design;

2) To improve the design of existing ultrasonic generator in combination with ultrasonic impact vibrating tool; and

3) To manufacture the device prototypes for pilot testing in manufacturing environment.

In the course of the project, the following tasks have been accomplished:

1) The USG diagram with digital phase locked loop made by direct digital synthesis with enhanced range of keeping the resonant mode under the action of various destabilizing factors on the piezoceramic transducer have been upgraded; this improvement provides a high level of accuracy and repeatability of results;

2) A complete set of design documents in electronic format for the circuit diagrams and printed circuit boards, as well as the drawings of all the USG design elements have been developed;

3) A hardware and software complex and the methods for adjustment of USG with PCT have been designed and manufactured;

4) A new body for the mobile and the stationary USG has been designed and manufactured to ensure longtime operation in the open air and under the conditions of industrial dust pollution.

As a result, a new generator of ultrasonic vibrations with the following technical specifications has been made:

- Voltage: 170—240 V;
- Output power: 800 W;
- Stabilization of ultrasonic vibrations of acoustic system within the range of input voltage from 170 to 240 V without changing the operating frequency and output power;
- Automatic frequency control of USG within the frequency range from +1 to –1 kHz;
- Digital control, control of frequency and amplitude of the tool vibration, possible adjustment of the amplitude within the range from 10 to about 100%;
- Soft start without a mechanical switch when turning on USG;
- Protection from mechanical and electrical overload and overheating;
- An interference filter and a power factor adjuster;
- Digital service for peripheral equipment (tool) in case of deviation of its parameters from the initial characteristics.

The general view of ultrasonic generator and tool is given in Fig. 2. The equipment differs from the analogues designed in Russia, USA, France, and China by small size and relatively low weight. The weight of USG is 4.1 kg and that of the impact tool is 2.2 kg. Their design is based on new technical solutions raising the effectiveness. The applications for the patent of Ukraine have been made with respect to the generator operating principle and the tool design.

The tool is equipped with replaceable impact heads (quantity of impact elements (strikers) is 1, 3, 4, and 7) used depending on the type and material of welded joints. The duration and sequence of treatment of given part of the welded joint and weld area around it are preset by the previous laboratory studies underlying a new method of treatment of welded joints.

INFLUENCE OF DIFFERENT TYPES OF TREATMENT AND MATERIALS OF WELDED STRUCTURES OF PASSENGER RAILCAR BOGIE FRAMES ON FATIGUE LIFE

In the initial state the welded joints are characterized by a significantly lower fatigue resistance than the parent metal. Therefore, the additional treatments are required. The technological methods for improving fatigue of joints can be divided into 2 groups [5]:

1) The techniques for reducing the concentration of residual tensile stresses due to heat treatment (high tempering method);

2) The methods based on the creation of compression stresses in hazardous areas.

This research presents the comparative results of fatigue tests of the longitudinal beams of passenger railcar bogie frames and the recommendations for effective use of various methods to increase the fatigue strength of the structure. To relieve the internal stresses after welding PJSC Krukov Railcar-Building Works applies high tempering: heating and keeping at a temperature of t_1 = 750 °C with cooling in the furnace to a temperature of t_2 = 100 °C. The treatment cycle lasts about 24 hours. The power consumption is about 1000 kW/h.

The high tempering technique is a traditional method to remove internal stress that may lead to

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both the positive and the negative effects on fatigue resistance of welded joints [2]. The most effective methods of increasing the fatigue strength are the local methods ensuring the residual local compressions in the area of concentration of stresses from welding. Such methods may include:

- Local heating;
- Surface cold hardening by different methods;
- Pneumodynamic treatment; and
- Ultrasonic impact treatment

Proceeding from the results of study of UIT effect on increasing the fatigue strength of welded structures (the E.O. Paton Electric Welding Institute) and research of the Kurdiumov Institute for Physics of Metals in the field of developing the ultrasonic systems, the specialists of PJSC Kriukov Railcar-Building Works have made the analysis of tests of passenger railcar bogie frames, model 68-7041 (Fig. 3), and identified the stress concentration locations, as well as the areas of structural damages during fatigue tests. On the basis of calculations one can conclude that the maximum equivalent stress occurring in the structure under the action of load does not exceed the allowable stresses, with the bogie frame strength being sufficient for all the modes calculated. In the course of fatigue tests the bogie frame fracture occurred along the longitudinal beam in the place of welding on lever bracket having an equivalent stress of 127 MPa while the admissible value was 216 MPa.

The nature of fatigue fractures is explained by the fact that the lever bracket is welded to the bottom sheet of longitudinal beam; so, it is a stress concentrator. In the initial state, after welding the fatigue cracks always appear at the boundary of weld fusion zone, between the bracket and the bottom sheet.

The main objective of research was to determine the effect of different methods of relieving the internal stresses on fatigue strength of passenger railcar bogie frames, as well as the influence of different grades of steel on fatigue strength and the effect of UIT on cyclic life of structure having passed 50% of its service life.

Fig. 2. Digital ultrasonic generator with vibro-impact tool

Fig. 3. Place of welding on lever bracket to bottom sheet

The geometrical parameters of samples used for the fatigue tests correspond to those of the longitudinal beams of bogie frame (model 68-7041, produced serially). To manufacture the model samples two materials most widely used in the manufacture of railcars, including the bogie frames, were used:

1) *Steel St 20*: This structural high-quality steel has a low strength, but high indices of ductility according to GOST 19903-74 and GOST 1577-93 (its chemical composition and mechanical properties are showed in Table 2).

2) *Steel S355 j2*. This is high-strength welding structural steel. It is well-deoxidized and has very low carbon content (less than 0.2%). High strength of this steel is ensured by the alloying elements, mainly, by manganese. The chemical composition and mechanical properties of this steel are shown in Table 3.

The fatigue tests conducted at the PTsA-100 facility are shown in Fig. 4. The test results are shown in Table 4. Treatment was made at the USTREAT-2.0 facility by rod-shaped heads having 4.0 mm in diameter with 3 units located in a row, with the following parameters:

- USG power P = 475 W, the amplitude of ultrasonic oscillations is A = 18 μm;
- Treatment speed is 3.5—4.0 mm/s;
- Control method: visual, the presence of hollows (grooves) in the fusion zone.

The design of the weld does not allow the worker to weld the bracket arm in the flat position. Therefore, the beginning and the end of the weld runs out to the beam axis. The multiple-pass welding is made in a horizontal position.

Welding works, quality of welded joints, methods for removal and monitoring of defects have been carried out in accordance with OST 24.050.34-84. Welding of structure was made manually in a gaseous medium (82% Ar + 18% CO_2). After making each layer the weld was cleaned from spatters and other minor defects. Welding was made is such a way as to ensure a smooth transition from the weld to the parent metal. Quality control of welded joints was carried out by ultrasonic flaw detector according to GOST 14782-76.

As one can see from Table 4, the average number of cycles before fracture of bogie frames after welding is 1.13 and 1.83 million cycles for steels S355j2 and St 20, respectively. In all the cases the cracks with subsequent fracture of the full-scale specimen were observed in the fusion zone of weld with the parent metal along the bottom portion of the bracket. Higher life values of bogie frames made of steel St 20 can be explained by its higher ductility as compared with steel S355j2 (batch of samples 201—203 and 501—503, respectively). Therefore, the further tests were conducted on the samples of steel St 20.

After welding the frame samples were divided into three batches, each of them being tested on fatigue life after certain treatments. The first batch of samples (101—103) was annealed at a temperature of 750 °C during 12 hours and cooled in the furnace down to a temperature of 100 °C. After this treatment the average life increased up to 2.62 million cycles.

The second batch of samples (301—303) was treated only by UIT; the total time of processing of one sample was about 0.5 hours; power consumption by ultrasonic equipment was 0.4kW/h. Under these conditions, the average life of samples 301—303 increased up to 4.67 million cycles, i.e.

Table 2

Chemical composition and mechanical properties of Steel St20

Chemical composition, wt. %						
C	Mn	Si	S	P	Cr	Ni
0.2	0.47	0.19	0.009	0.015	0.043	0.01
The yield point σ_T (+20 °C) = 282 MPa; the tensile stress σ_t (+20 °C) = 434 MPa; elongation δ = 29%						

Table 3

Chemical composition and mechanical properties of Steel S355j2

Chemical composition, wt. %												
C	Mn	Si	S	P	Cr	Ni	Cu	Al	N	Mo	Ti	V
0.18	1.44	0.44	0.0011	0.001	0.035	0.016	0.018	0.039	0.0044	0.0027	0.0023	0.023
The stress point σ_T (+20 °C) = 415 MPa; the tensile stress σ_t (+20 °C) = 577 MPa; elongation δ = 25%												

by 255% as compared with the initial state (Table 5). After UIT, in the zone of fusion, the separate lacks of penetration were revealed on 2 beams. These defects were revealed under this treatment, but not always can be detected by non-destructive ultrasonic control or by visual examination.

The cases when the structure has operated for about 50% of the design life and its treatment was performed with the use of UIT are of a special interest. One of the sample batches (401—403) has been initially loaded to 1 million cycles. The parameters of dynamic loading in hydropulsator unit PTsA-1000 are as follows: frequency of pulsations is 11 Hz, the maximum cycle load is P_{max} = 147 kN, the minimum one is P_{min} = 122.5 kN. Thereafter, the welds of the batch samples were treated by UIT. After the treatment the life increased by 192%. This result is lower than that for the samples 301—303 treated immediately after welding. It should be noted that one of the samples (301) was fractured on the parent metal, but not in the transition fusion zone.

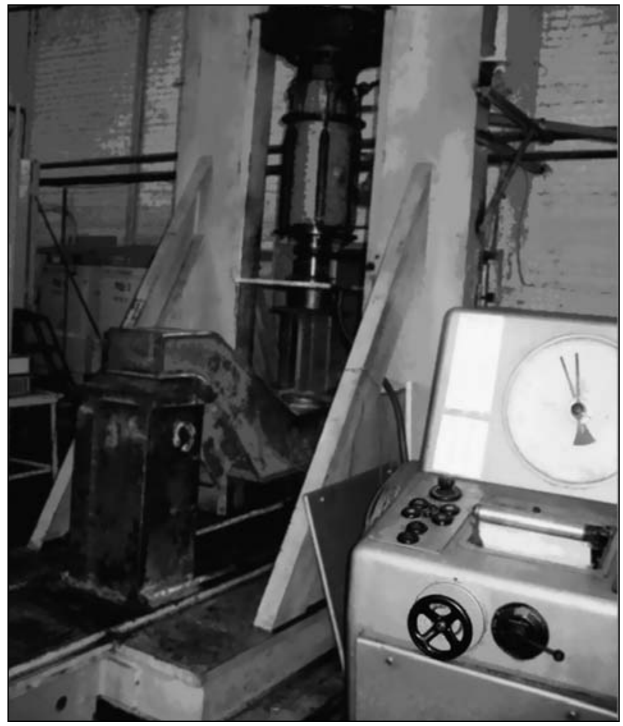

Fig. 4. General view of PTsA-100 facility

Table 4

Sample materials, mode of treatment, and number of cycles before fracture

Material and pretreatment of prototype	Marking	Number of cycles before fracture, million cycles	Average number of cycles before fracture, million cycles
St 20 annealed 750 °C	101	2.52	2.62
	102	2.65	
	103	2.7	
S355j2, not annealed	501	1.1	1.13
	502	1.25	
	503	1.05	
St 20, not annealed	201	2.14	1.83
	202	1.8	
	203	1.54	
St 20 treated by			
1) Preload: 1 million cycles;	401	3.31	3.52
2) UIT of welds	402	3.15	
3) Testing until fracture	403	4.11	
St 20,	301	4.65	4.67
not annealed	302	3.85	
UIT of weld joints	303	5.5	

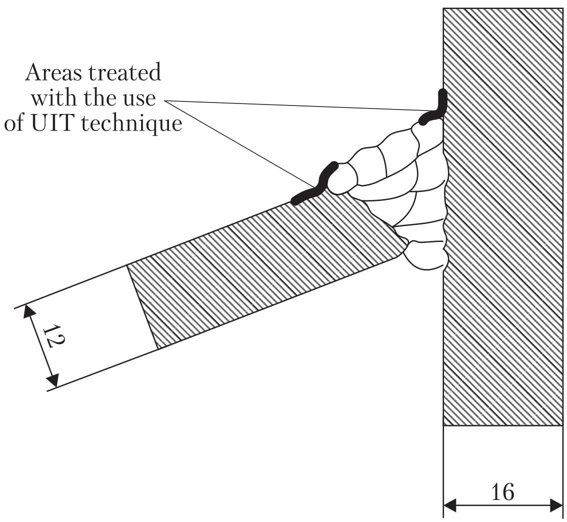

Fig. 5. Places of treatment of welds using UIT technique Areas treated with the use of UIT technique

Thus, the fatigue tests of specimens (the passenger railcar bogie frames) made within the period from 06.12.2012 till 05.10.2013 have showed the feasibility of using the UIT technique to strengthen some welded structures in railcar-building [24]. However, it is necessary to conduct further comprehensive tests with respect to the reliability of ultrasonic equipment and its safety for the attending personnel, as well as to certify the products and techniques and to include the UIT into the applicable regulations and industrial standards and Government Standards of Ukraine.

Table 5

Effect of different methods of treatment and materials on service life of prototypes

Material and pretreatment of prototype	Change in durability of prototypes (before fracture) at fixed loads, %
St 20, not annealed	100
S355j2, not annealed	62
St 20 annealed 750 °C	143
St 20, not annealed, treated by 1) Preload: 1 million cycles; 2) UIT of welds 3) Testing until fracture	192
St 20, not annealed, UIT of weld joints	255

CONCLUSIONS

1. The method for calculating the parameters of ultrasonic transducers of different designs has been proposed.

2. A device for assembling the transducers under the same conditions with compression in the press unit of 10.0 tons and tightening the reinforcing bolt by torque wrench has been manufactured.

3. The designing documents for ultrasonic transducer and impact tool have been worked out from the results of the current tests of working model of UIT equipment for the welded joints in the laboratory and in the manufacturing environment.

4. A new design of universal ultrasonic generator with digital control on microprocessor has been developed on the basis of the detailed studies of cutting-edge microprocessor techniques.

5. The elementary schemes of USG with digital control of electric parameters and operation have been elaborated; the design documents for USG have been specified. An USG prototype has been manufactured and tested in accordance with the technical requirements.

6. Two units for ultrasonic impact treatment of welded structures have been manufactured.

7. Within the framework of the agreement on scientific and technical cooperation with the Kriukov Railcar-Building Works (Kremenchuk) the fatigue tests of specimens of welded structures similar to the passenger railcar bogie frames have been carried out.

8. The main test result is: having been annealed with the use of traditional technique at a temperature of 750 °C, after welding, the samples increase their life by 143% as compared with the initial state and having been treated by UIT they increase their life by 255%.

9. Based on the test results it has been decided on feasibility and scope of implementing the ultrasonic technique in the manufacture of individual parts and structures for railcar-building.

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В.І. Приходько, М.В. Височолян, В.В. Волочай, Г.І. Прокопенко, Б.М. Мордюк, В.Т. Черепін, Т.А. Красовський, Т.В. Попова

СТВОРЕННЯ УЛЬТРАЗВУКОВОГО ОБЛАДНАННЯ ДЛЯ ЗМІЦНЕННЯ ТА РЕЛАКСАЦІЙНОЇ ОБРОБКИ ЗВАРНИХ КОНСТРУКЦІЙ У ВАГОНОБУДУВАННІ

Розроблена нова модифікація портативного ультразвукового обладнання потужністю 0,8 кВт з цифровим керуванням для зміцнення та релаксаційної обробки поверхні металевих виробів. Виготовлена партія таких приладів, підготовлена конструкторська документація на ультразвуковий генератор та ударний інструмент з п'єзокерамічним перетворювачем. Здійснена підготовка технології ультразвукової ударної обробки зварних конструкцій, проведені порівняльні випробування впливу різних типів обробки і застосованих матеріалів на втомну

довговічність. Випробування показали доцільність використання ультразвукової ударної обробки для подовження строку експлуатації виробів.

Ключові слова: ультразвукова ударна обробка, зварні конструкції, втомна довговічність, залишкові напруження, концентратори напружень.

В.И. Приходько, М.В. Высоколян, В.В. Волочай, Г.И. Прокопенко, Б.Н. Мордюк, В.Т. Черепин, Т.А. Красовский, Т.В. Попова

СОЗДАНИЕ УЛЬТРАЗВУКОВОГО ОБОРУДОВАНИЯ ДЛЯ УПРОЧНЕНИЯ И РЕЛАКСАЦИОННОЙ ОБРАБОТКИ СВАРНЫХ КОНСТРУКЦИЙ В ВАГОНОСТРОЕНИИ

Разработана новая модификация портативного ультразвукового оборудования мощностью 0,8 кВт с цифровым управлением для упрочнения и релаксационной обработки поверхности металлических изделий. Изготовлена партия таких приборов, подготовлена конструкторская документация на ультразвуковой генератор и ударный инструмент с пьезокерамическим преобразователем.

Осуществлена подготовка технологии ультразвуковой ударной обработки сварных конструкций. Проведены сравнительные испытания влияния разных типов обработки и примененных материалов на усталостную долговечность. Испытания показали целесообразность использования ультразвуковой ударной обработки для увеличения срока эксплуатации изделий.

Ключевые слова: ультразвуковая ударная обработка, сварные конструкции, усталостная долговечность, остаточные напряжения, концентраторы напряжений.

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