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DEVELOPMENT OF TECHNOLOGY AND EQUIPMENT FOR REDUCTION OF RESIDUAL STRESSES AND STRAIGHTENING IN WELDED STRUCTURES APPLYING ELECTRODYNAMIC TREATMENT

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A new technological process of postweld treatment of welded joints is presented, namely the electrodynamic treatment by pulses of high-density electric current. The carried out complex of experimental investigations on specimens of aluminium alloy AMg6 at different parameters of electric current pulses and inductance of power source showed that electrodynamic treatment influences the structure of treated metal and allows a significant reduction in residual stresses in welded joints, increasing their resistance to fatigue and brittle fracture, and also eliminating buckling deformations of thin-walled structural elements. The developed technologies and equipment provided the possibility of performing electrodynamic treatment of welded joints of ship-building structures and repair welds of intermediate casing of aircraft engine, which facilitated their increased operational reliability and service life. 8 Ref., 18 Figures.

Keywords: *electrodynamic treatment, aluminium alloy, welded joint, residual stresses, current pulse, mathematical modeling, current density, plastic deformation*

The high requirements specified to welded structures of advanced engineering cause the necessity in the development of technologies for their postweld treatment. Prospective are the processes based on the effect of electrodynamic forces on conductive materials during passing of electric current pulses (ECP), realized in a new technological process: electrodynamic treatment (EDT). Using the energy of ECP and the electrodynamic forces initiated by it, which affect the treated elements of metal structures at EDT, it is possible to influence the stressed state of metal materials. The effectiveness of EDT is determined by interaction of two components: the electric pulse one, realized during passing of ECP of density j over the workpiece treated and the dynamic one preset by the amplitude-frequency characteristic of waves of dynamic stresses. The increase in the service characteristics of welded joints as a result of EDT is predetermined by the complex influence of the following factors. Thus, in the treatment zone under the action of electrodynamic forces, the stress waves are formed in the weld metal, which, interacting with residual welding stresses, initiate a reduction in the latter. As a result of EDT, zones with refined grains are formed in the metal, the evolution of their structure being determined by plastic deformation under conditions of the realization of the electroplastic effect (EPE) based on the electron-dislocation interaction [1], initiated by passing of ECP at $j \geq 1$ kA/mm^2.

Taking into account the specifics of EDT of welded structures, which is distinguished by a large length of welded joints and their different spatial positions, the possibility of mobile positioning of equipment is provided to realize electrodynamic effects. The features of welded joints determine the requirements for equipment designed to perform EDT, which include:

- equipment for EDT should consist of separate components, such as ECP source (ECPS), an executive electrode device (ED) designed to realize the electrodynamic effects on the welded joint treated, as well as communication means between ECPS and ED;
- ergonomic characteristics of ED and the means of its communication with ECPS should provide convenience in realizing electrodynamic effects with a preset duration, amplitude and periodicity in manual mode and as a part of automated welding complexes.

Based on the analysis of pulse current generating devices, it was found that the most suitable for the formation of ECP in the composition of ECPS is the use of capacitor systems which have a number of advantages over other devices, such as the possibility of accumulating a controllable level of electric charge energy, creation of different shapes and duration of ECP, as well as simplicity in recovery of electrical parameters of the discharge mode. The most effective way to regulate the ECP discharge parameters is the control of voltage of the capacitive energy storage (CES) before passing a discharge pulse. Another regulating parameter of the device is the pulse duration. For this, it is necessary to provide the possibility of changing the electrical parameters of the discharge circuit of the capacitor. The control device, by means of which the pulse duration is regulated, is the inductance coil (IC) included into the ED. Moreover, the coil inductance can vary within a wide range. Coming from the requirements specified to ED, it is recommended to use IC in the form of a plane inductor. Thus, the control parameters of the ECPS are the charge voltage of CES, which can be varied over a wide range by means of a control system, and also the inductance of the discharge circuit L. At present, single- and double-circuit ECPS are designed, the appearance of which is shown in Figure 1.

A feature of the single-circuit ECPS (Figure 1, *a*) is the direct passing of ECP of the main circuit through the material treated, and that of the double-circuit is the separate passing of current through the circuits, providing the electric pulsed and dynamic components of the electrodynamic effect. The advantages of a single-circuit ECPS is the simplicity of its design, relatively small weight (up to 20 kg) and dimensions (450×450×250 mm), positioning mobility and simplicity in operation. Its drawbacks include lack of possibility in regulating the frequency characteristics of the electric pulsed and dynamic components of the electrodynamic effect. The advantage of the double-circuit ECPS (Figure 1, *b*) is the equipment regulation of frequency characteristics of the components of the electrodynamic effect, and the drawbacks are a relatively large weight (up to 120 kg) and dimensions (1500×450×450 mm).

For realization of EDT using a single-circuit ECPS, a specialized ED was developed, the design of which provides passing of ECP through a one-channel circuit.

Figure 1. Appearance of single-circuit (*a*) and double-circuit (*b*) sources of pulsed electric current for EDT

The schematic diagram and appearance of one-channel ED are shown in Figure 2. The ED provides electric contact between the discharge circuit and the metal treated through one channel, through which the ECP is passed into the latter. ED provides the realization of a dynamic and electric pulse effect

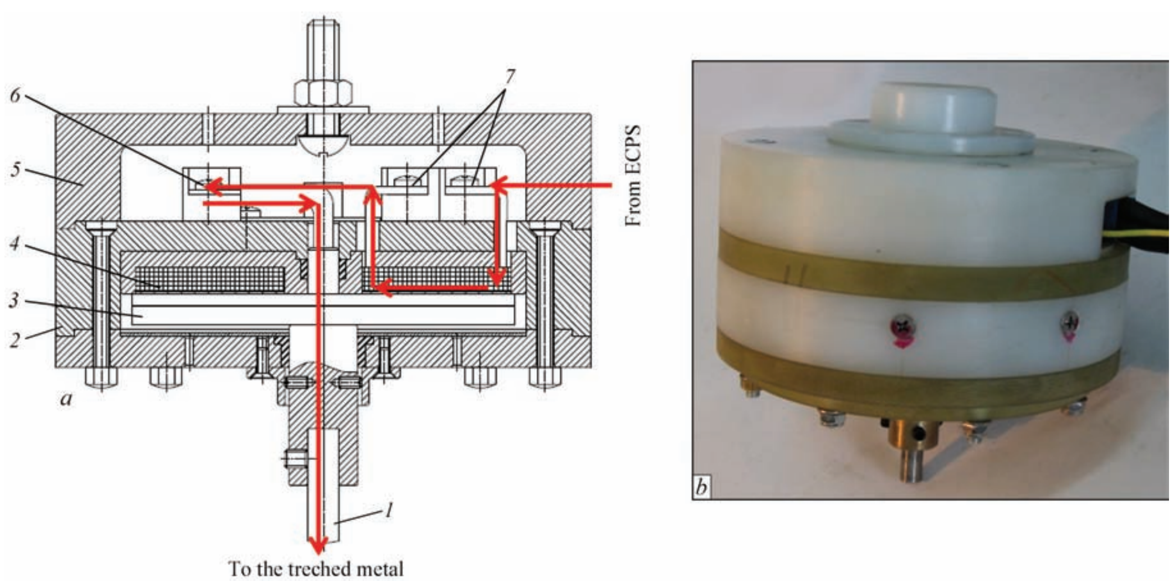

Figure 2. Electrode device for EDT: *a* — schematic diagram (*1* — electrode; *2* — body; *3* — disc; *4* — inductance coil; *5* — cover; *6*, *7* — terminals); *b* — appearance

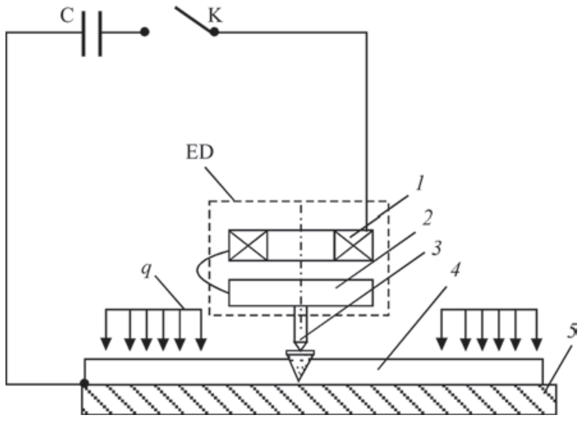

Figure 3. Circuit of EDT of welded joints (C — energy storage capacitor; K — power key; *q* — fixing load); *1* — inductor; *2* — disc; *3* — electrode; *4* — specimen; *5* — assembly plate

on the metal. The direction of ECP passing through the ED circuits from the ECPS to the metal treated is shown by the arrows in Figure 2, *a*. The operating element of ED is the electrode *1*, fixed in the body *2*. The working surface of the electrode contacts the metal treated. The body *2*, rigidly connected to the disc *3*, together with the electrode *1* is included into an impact mechanism (IM), which has the ability to move in a vertical direction. The disc *3* is coupled with the inductance coil *4*. At the top the connection terminals are closed by cover *5*, designed also for positioning the ED in the process of treatment. To connect the ED to the ECPS, the terminals *6* and *7* are located on the top of body *2*. The terminal *6* provides passing of the ECP through the electrode, and *7* — through the inductance coil.

For a double-circuit ECPS, a two-channel ED circuit was developed. The design of the two-channel ED is similar to that shown in Figure 2, but the ECP passing through the electrode *1* and the inductance coil *4* occurs separately.

During operation the ED rests against the metal by the electrode end face and is set perpendicularly to surface treated. Passing of the ECP through the inductance coil in a disc excites a magnetic field, initiating eddy currents in the disc. The interaction of induced currents *I* with the exciting magnetic field leads to the appearance of an electrodynamic force *P*. The scheme of EDT of welded joints by one-channel circuit is shown in Figure 3.

The oscillograms of the dynamic pressure *P* and the pulsed current *I*, passing through the plate of the aluminium AMg6 alloy of thickness δ = 4.0 mm with a charge voltage U_{ch} = 500 V and an CES capacitance C = 6600 μF by one-channel circuit are shown in Figure 4. As to its duration the effect of ECP-I on the treatment zone at one-channel circuit exceeds the period of action of force *P* (Figure 4), which is preset by the configuration of the discharge circuit. The features of the two-channel circuit guarantee an independent change in the duration of ECP-I and *P* in the range from 0 to 0.68 s, determined by the parameters of the electric circuit of the separate discharge circuits. This allows presetting different ratios of the amplitude-frequency characteristics of the current and dynamic effects on the metal treated.

To position the ED relative to the surface being treated and to provide a reliable electric contact of the working part of elelectrode in the EDT zone, a specialized manual tool was designed (Figure 5). The design elements of the tool are the base *2*, on which the fixed handle *1* and the fixing plate of ED *3* are located. The

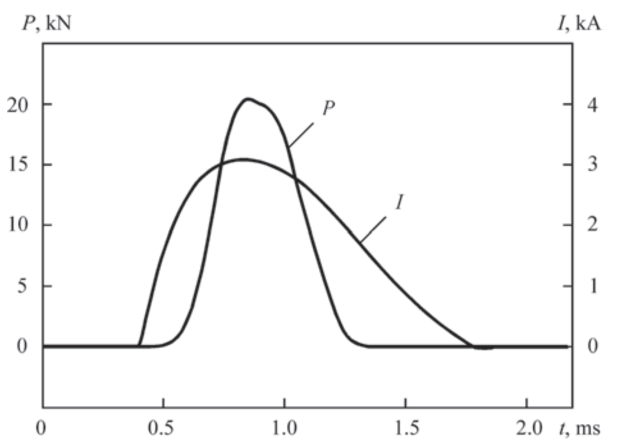

Figure 4. Oscillograms of dynamic pressure *P* and pulsed current *I* passing through the metal treated at a charge voltage U_{ch} = 500 V, CES C = 5140 μF, and the inductance *L* = 5.0 μH in the one-channel circuit of discharge circuit

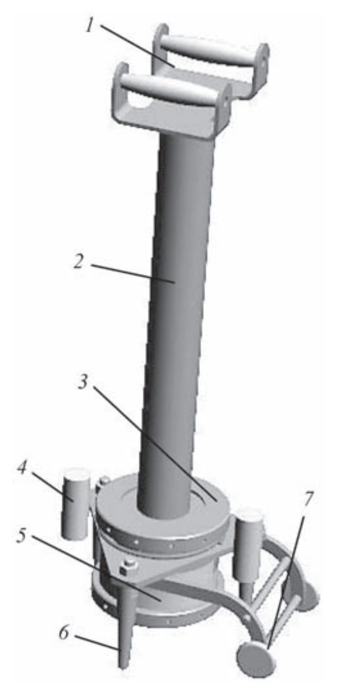

Figure 5. Appearance of manual tool for EDT (*1* — fixed handle; *2* — base; *3* — mechanism for ED fastening; *4* — backlight; *5* — ED; *6* — support; *7* — transport trolley

handle is designed for moving the tool by the operator, and on the plate the backlight of EDT zone — *4*, ED — *5* and two supports *6* are fixed, which together with the electrode of ED provide a three-point resting of the tool against the metal surface treated.

The tool is equipped with a transport trolley *7*, designed for working and sliding movements of ED along the welded joint.

It should be noted that the experimental evaluation of the effectiveness of EDT for the purpose of determining the optimal mode of treatment of welded joints is a rather laborious task, which is associated with the consideration of a large number of parameters of EDT mode, the types of welded joints and mechanical characteristics of metals and alloys subjected to treatment.

In order to optimize the process of selecting the EDT mode, a mathematical model of non-stationary electrophysical [2] and dynamic [3] processes was developed, which determine the mechanism for EDT of welded joints. On the basis of the model, a selection of the mode characteristics is performed to provide the ECP parameters sufficient for effective control of residual stressed state of metal structures.

The adequacy and reliability of mathematical modeling of non-stationary processes in the metal treated is confirmed by experimental investigations carried out on the developed ECPS (Figure 1, *a*) [2].

The description of electrophysical processes at EDT was carried out on the basis of reduction of Maxwell equations to the system of integral equations for current density and electrodynamic forces in the contact zone of the electrode *3* and the specimen *4* (Figure 3).

Figure 6 shows the distribution of lines of equal value of density of ECP j across the thickness *z* of the plate of AMg6 alloy at $L = 5$ μH, C = 5140 μF, $U_{ch} = 500$ V at the moment of time $t = 0.71$ ms (Figure 4), which corresponds to the maximum value of ECP in the discharge circuit. It can be seen that the presented mode provides the values of current density $j \geq 1$ kA/mm^2, which can initiate EPE in the AMg6 alloy treated.

The realization of EPE is confirmed by the data in Figure 7, which shows the distribution of lines of equal value of radial plastic deformations ε_r of tension across the thickness z of the plate of AMg6 alloy at EDT mode, similar to that used in Figure 6. The presented distribution ε_r is caused by the action of electrodynamic forces arising when ECP passes in the zone of electrode contact with the metal treated. It can be seen that electrodynamic forces provide electroplastic deformation of the AMg6 alloy in the treatment zone. It should be noted that the interaction of deformations initiated by EDT with residual welding

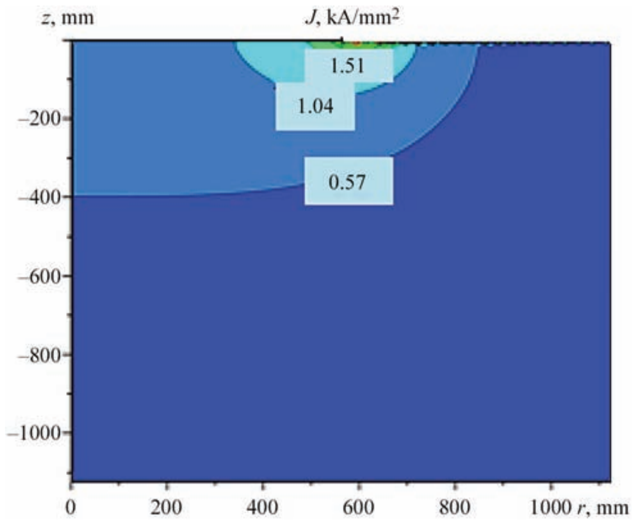

Figure 6. Distribution of lines of equal value of ECP density *j* on width r and thickness *z* of plate of AMg6 alloy (explanations see in the text)

plastic compression deformations affects the reduction of stress-strain state of welded structures.

The influence of dynamic component of the electrodynamic effect was determined on the basis of the theory of plastic flow based on the Prandtl–Reiss relations. Figure 8 shows the residual distribution of effective plastic deformations ε^p_{eff} in the cross-section of unstressed plate of the AMg6 alloy of thickness $\delta =$ $= 4$ mm after a single ECP at EDT mode at $L = 5$ μH, C = 5140 μF and $U_{ch} = 200...800$ V. It can be seen that at $U_{ch} = 200$ V, the zone of plastic deformation with a range of values $\varepsilon^p_{eff} = 0.04...0.07$ is localized near the surface of the plate (Figure 8, *a*). When U_{ch} is increased to 500 V, the zone of plastic deformation with a range of values $\varepsilon^p_{eff} = 0.03–0.17$ is propagated almost to the central zone of the plate section (Figure 8, *b*). The increase in the value of U_{ch} to 800 V (Figure 8, *c*) initiates the propagation of the zone of

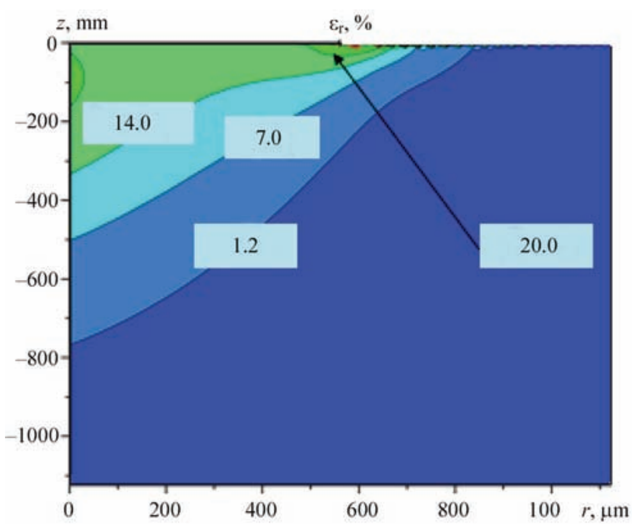

Figure 7. Distribution of lines of equal value of radial plastic deformations ε_r along width *r* and thickness *z* of the plate made of AMg6 alloy (explanations see in the text)

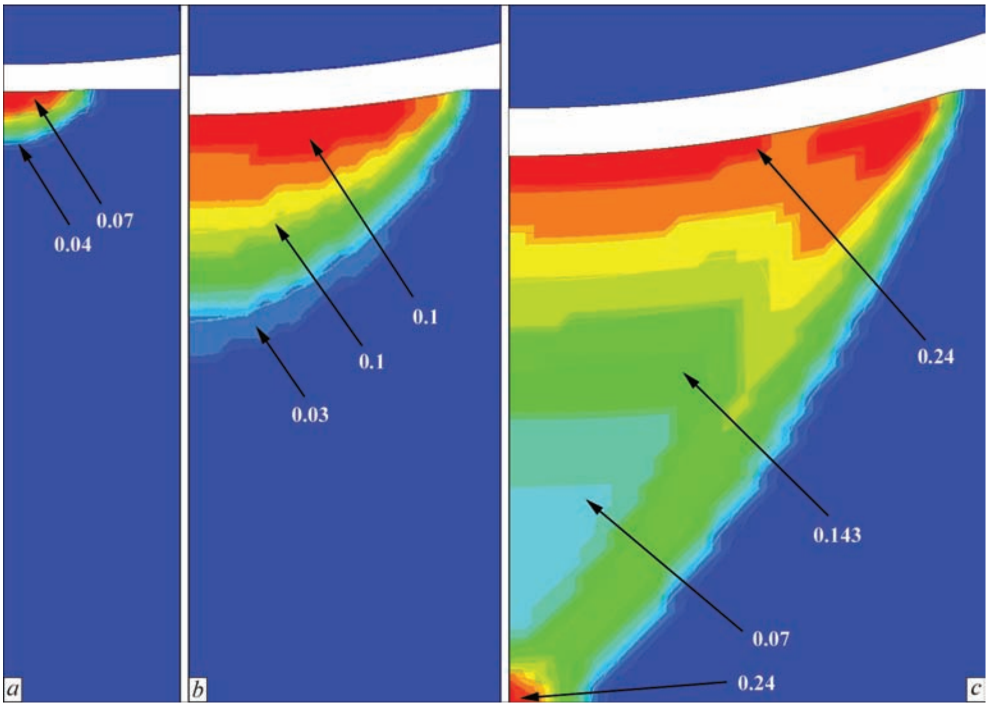

Figure 8. Residual distribution of effective plastic deformations ε^p_{eff} in the cross-section of the plate of AMg6 alloy of thickness δ = 4 mm at *L* = 5 μH, C = 5140 μF: *a* — U_{ch} = 200; *b* — 500; *c* — 800 V

plastic deformation in the range ε^p_{eff} = 0.07–0.24 over the entire section of the plate.

Moreover, in contrast to the data in Figure 8, *a*, *b*, the reflection of the deformation wave from the back surface of the plate is observed, confirmed by the equality of values ε^p_{eff} = 0.24 on both sides of the specimen, and also by their decrease in its center.

The data in Figure 8, *b* confirm the distribution of radial component of the residual stresses σ_r after a single ECP at U_{ch} = 500 V, shown in Figure 9. It can be seen that the propagation of ε^p_{eff}, determined by the dynamic effect, initiates the fields of residual compressive stresses, respectively, σ_r = 73.8 and –40.5 MPa in the treatment zone and at moving off from it. The superposition σ_r of compression with residual welding tensile stresses can substantially reduce the peak values of stresses in the welded joint.

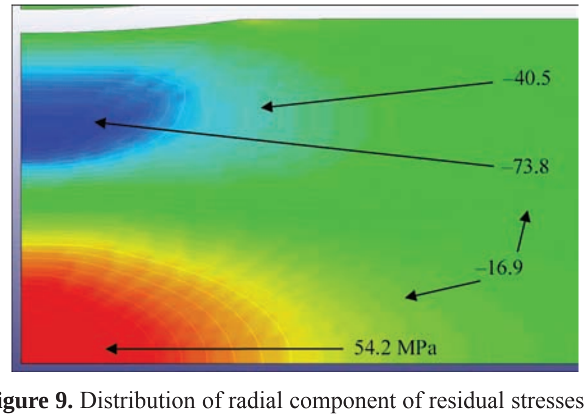

Figure 9. Distribution of radial component of residual stresses σ_r after single ECP at U_{ch} = 500 V

In general, analyzing the data in Figures 6–9, it can be concluded that electrodynamic and dynamic effects, considered separately within the frames of mathematical modeling of EDT process, have a significant effect on the stress-strain state of the AMg6 alloy, which is confirmed by experimental investigations, the results of which are presented below.

The investigations of evolution of structure of the structural materials caused as a result of EDT allowed determining the features of electrodynamic effect on the mechanism of plastic deformation of metals and alloys as a result of treatment. The features of the structure and relief of fractograms were investigated using the scanning electron microscopy.

The effect of EDT on the features of fracture of plane specimens of the AMg6 aluminium alloy treated applying EDT according to one-channel circuit was investigated. The treatment was carried out applying single ECP of the base metal and welded joints with the dimensions of working part being 150×30×4 mm at EDT mode at the charge voltage U_{ch} of 500 V and at CES of 6600 μF.

To determine the electrodynamic effect on change in the structure of the material, the topography of macrorelief of the fracture of specimens of the AMg6 alloy at the abovementioned mode was compared in the initial state (Figure 10, *a*) and after EDT (Figure 10, *b*) , from which it is seen that the fractures have an advantageous fibrous structure with tearing crusts formed on the mechanism of mixed fracture [4].

To study the relief of fractures after the electrodynamic effect, the specimens with a one-sided treatment of the material were used. In Figure 10, *b* (zone A), it can be seen that the fracture on the treated side has a more developed fibrous structure as compared with the initial state (Figure 10, *a*). The depth of distribution of the fibers reaches 3.0 mm across the thickness of the specimen, which is confirmed by the data in Figure 8, *b* and characterizes the electrodynamic effects as a volumetric one. At the profound study of the fracture relief after EDT (zone B in Figure 10, *b*), the developed groups of plane sliding lines were observed, the orientation of which coincided with the treated surface of the specimen. Moreover, the sliding has the signs of a rotational mechanism [5], which indicates an intensive running of the process of volumetric plastic flow of the material under the conditions of electrodynamic effects.

The increment of density of the treated areas of the polycrystalline structure leads to deformation hardening, which was confirmed by the results of measurements of hardness HV, which were carried out in the device M-400 of the company LECO at the load value of 0.1 N. The values of *HV* for non-treated material (Figure 10, *a*, zone B) were 824 MPa. The maximum values of *HV* 1290–1310 MPa were observed near the surface treated (Figure 10, *b*, zone A), where there was a rotational sliding along with the plane one. Thus, the hardness of the AMg6 alloy after EDT is by 35–40 % increased as compared to an untreated one.

The metallographic examinations of the AMg6 alloy in the initial state and after EDT at the mode described above, showed that the structure of the metal being not treated by the current, consists of dispersed precipitations of the β-phase of Al_3Mg_2 in the enclosure of magnesium silicide MgSi, where the β-phase has a large area and a lighter shade surrounded by dark lines and spot inclusions of magnesium silicide. At the same time, the treated structure is characterized by a refined grain, which increases the resistance of metal to delayed fracture.

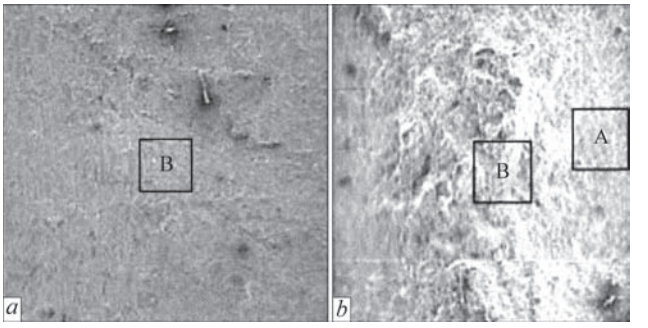

Figure 10. Fractograms (×33) of fractures of the AMg6 alloy, obtained during fracture of specimens without EDT (*a*) and after EDT (*b*) (zone A is the treated area near the metal surface, B is the middle fracture area)

Using the method of «thin foils» [6], the fine initial structure of the AMg6 alloy, as well as its evolution as a result of dynamic and electrodynamic effects according to the one-channel circuit of EDT were investigated. The dynamic effect was realized by eliminating the passing of ECP through the metal treated. The treatment was carried out applying single ECP of specimens of 150×30×4 mm at EDT mode at the charge voltage of U_{ch} = 350 V and CES of C = 6600 μF.

As was shown by the results of investigations (Figure 11), the grains of the untreated metal are characterized by a substructure (Figure 11, *a*) with the dimensions d_s within the ranges of ~1.8–5.0 μm, as well as a uniform distribution of density of dislocation structure between the volume ρ_v and the grain boundary ρ_b. The value of ρ_v reaches $6\cdot10^9$ cm^{-2}, and ρ_b — $8\cdot10^9$ cm^{-2}, which leads to the absence of density gradient of dislocations $\Delta\rho_v$ in the grain volume.

In the metal, after the dynamic effect (Figure 11, *b*), both the dispersed d_s ~ 1.1 μm as well as large-sized substructure of d_s ~ 3.2 μm is observed without formation of distinct subboundaries. An increase in the density level of dislocations at the grain boundaries ρ_b

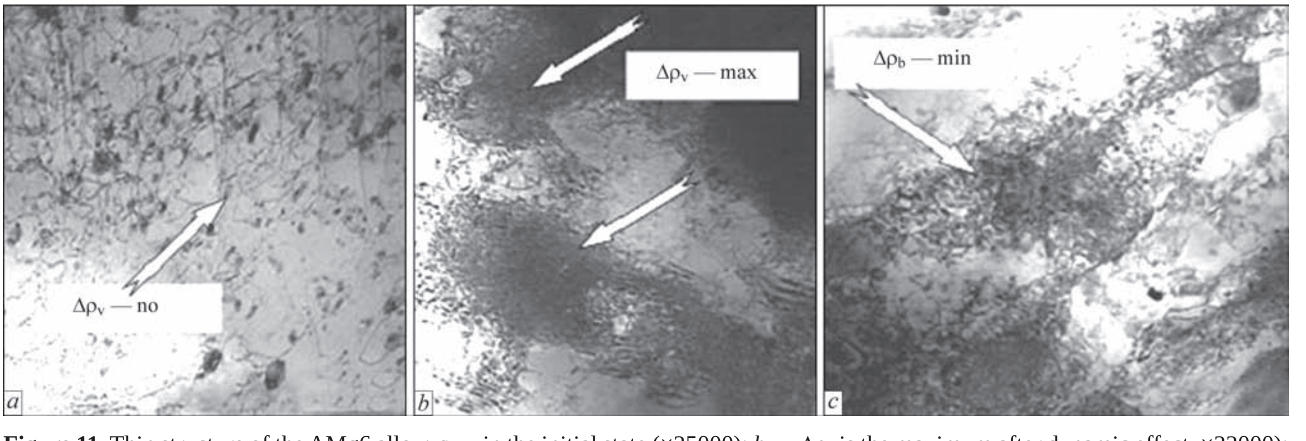

Figure 11. Thin structure of the AMg6 alloy: *a* — in the initial state (×25000); *b* — $\Delta\rho_v$ is the maximum after dynamic effect, ×22000); *c* — $\Delta\rho_b$ is the minimal after electrodynamic effect ($\Delta\rho_b$, $\Delta\rho_v$ are the gradients of the density of dislocations at the boundaries and in the volume of grains)

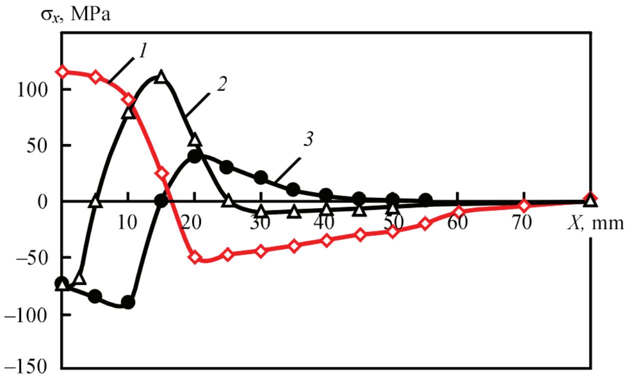

Figure 12. Distribution of longitudinal residual stresses σ_x in the cross-section of welded plate of the AMg6 alloy (curve *1* — initial σ_x; *2* — σ_x after EDT along the weld axis; *3* — σ_x after EDT of the weld axis and base metal at the distance of 10 mm from the weld axis)

was registered, as well as the gradient $\Delta\rho_v$ between the inner volume of grains ρ_v ~$6\cdot10^8$–$4\cdot10^9$ cm^{-2} and ρ_b ~ $2\cdot10^{11}$ cm^{-2}.

After electrodynamic effect, the metal is characterized by the formation of substructures (Figure 11, *c*) with distinct boundaries d_s = 0.8–2.5 μm. Moreover, the density of dislocations ρ_b decreases as compared to the metal after the dynamic effect, as well as their uniform distribution over the entire volume of the metal (without sharp gradients along the grain boundaries $\Delta\rho_b$) between the internal volume of grains ρ_v ~ 2–$3\cdot10^{10}$ cm^{-2} and near grain boundaries ρ_b ~ 6–$8\cdot10^{10}$ cm^{-2}.

The formation of this structure confirms the proposed concept based on the theory of electron-dislocation interaction [1] about the contribution of ECP to relaxation of residual stresses.

To evaluate the electrodynamic effect on residual stresses, the treatment of the specimens of butt welded joints of the AMg6 alloy with dimensions of 400×300×4 mm with the central weld was performed. The weld was produced by automatic butt TIG welding at the mode with arc voltage U_a = 18 V, welding current I_a = 250 A and speed v_w = 3.1 mm/s. Two-sided treatment of welded plates was carried out by ECP at EDT mode at the voltage U_{ch} = 550 V and the capacitance CES C = 6600 μF. The distance between the zones of electrodynamic effects did not exceed 5 mm.

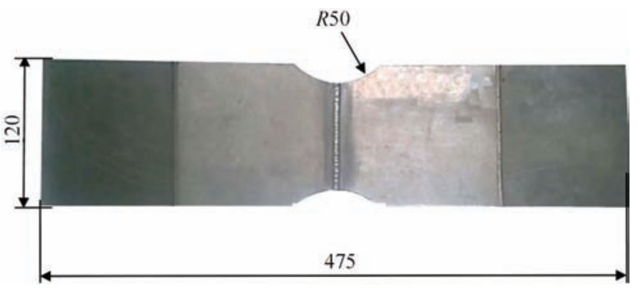

Figure 13. Specimen of welded joint of AMg6 alloy for fatigue tests

The measurements of residual stresses were carried out using the method of electron speckle-interferometry [7].

The distribution of longitudinal (along the weld line) residual stresses σ_x before and after EDT is shown in Figure 12. It can be seen that the initial maximum of σ_x did not exceed 120 MPa (curve *1*). After EDT of the welded joint along the weld axis, the initial values of σ_x in the weld changed from 120 to –75 MPa, and the maximum residual tensile stresses up to 115 MPa were formed on the untreated part of the plate (curve *2*). After EDT of the weld and base metal at a distance of 10 mm from the weld axis (curve *3*), the values of σ_x are changed from 90 to –100 MPa, which is comparable with EDT of the weld center. By analyzing the data in Figure 12, it can be seen that the maximum efficiency of the electrodynamic effect is achieved at EDT along the weld axis and the base metal near the fusion line (curve *3*).

The influence of EDT on the fatigue resistance of welded joint specimens of the AMg6 alloy with the thickness δ = 2 mm (Figure 13) made by automatic TIG welding (Ar) at the values of arc voltage, welding current and speed of the process, respectively U_w = 20 V, I_w = 170 A, v_w = 5.5 mm/s. Two-sided treatment of specimens along the weld line of 90 mm length was carried out by the series of ECP at the mode of two-channel EDT with the charge voltage U_{ch} = 430 V and the capacitance CES of C = 5580 μF. The distance between the zones of applying electrodynamic effects was 5 mm, the width of the working part of specimen was 265 mm.

The fatigue tests on the cantilever bending of specimens of welded joints were carried out in the machine UPM-02 at the symmetrical cycle at the amplitude of cycle stresses in the range of $2\sigma_a$ = 80–160 MPa.

From Figure 14, which presents the results of fatigue tests in the coordinates $2\sigma_a$ – *N* of specimens in the initial state and after EDT, it can be seen, that the cyclic life N of specimens of welded joints in the in-

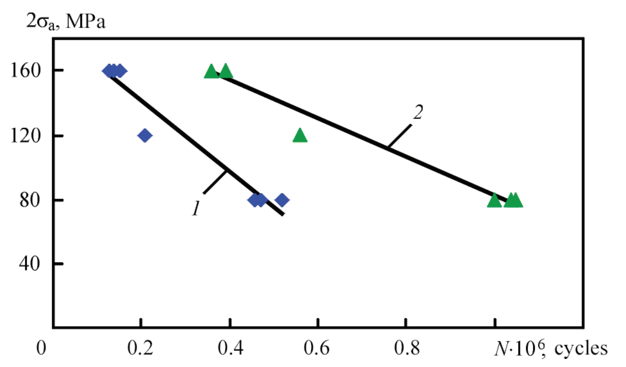

Figure 14. Results of fatigue tests for specimens of welded joints of AMg6 alloy (see Figure 9) in the coordinates $2\sigma_a$ *N* (curve *1* — initial state; *2* — after EDT)

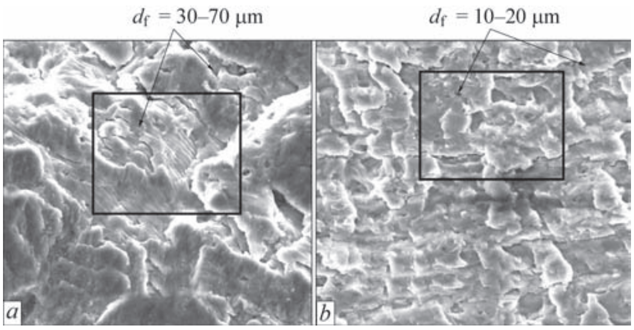

Figure 15. Fracture surfaces of specimens of AMg6 alloy after a low-cycle loading (×810): *a* — initial specimen; *b* — after EDT

vestigated range of $2\sigma_a$ up to three times increases as a result of treatment. At the same time, the fracture of both the initial specimens as well as the treated ones occurs along the fusion line.

On the basis of the results presented above, it can be concluded that EDT has a positive effect on increasing service life of welded joints of the AMg6 alloy, which is to a significant extent determined by decrease in the level of residual welding stresses.

The fractographic analysis of the microrelief of the surface of the initial and treated specimens fractured as a result of cyclic loading at $2\sigma_a$ = 160 MPa (Figure 15) showed that the treated metal is characterized by dispersion of structural elements, such as 3 times refinement of the size of d_f facets (Figure 15, *b*) as compared to the initial state before EDT (Figure 15, *a*). This confirms the positive influence of electrodynamic effects on the evolution of the structure of treated metal for improvement of its resistance to fatigue fracture.

The level of residual stresses determines the parameters of buckling of welded structures [8]. The EDT effects on the local deformation of the «bulge» type, arising during welding of a load-carrying system in the sheet hull structures, was investigated. The specimens of the AMg6 alloy of 4 mm thick were used (Figure 16). Figure 16, *a* shows the dimensions of the specimen, representing a plate, to which the stiffeners are rigidly welded-on applying argon arc welding by fillet welds. The welding mode corresponded to U_w = = 20 V, I_w = 180 A, v_w = 1.4 mm/s. After manufacture of specimens, the values of the deflection *f* were

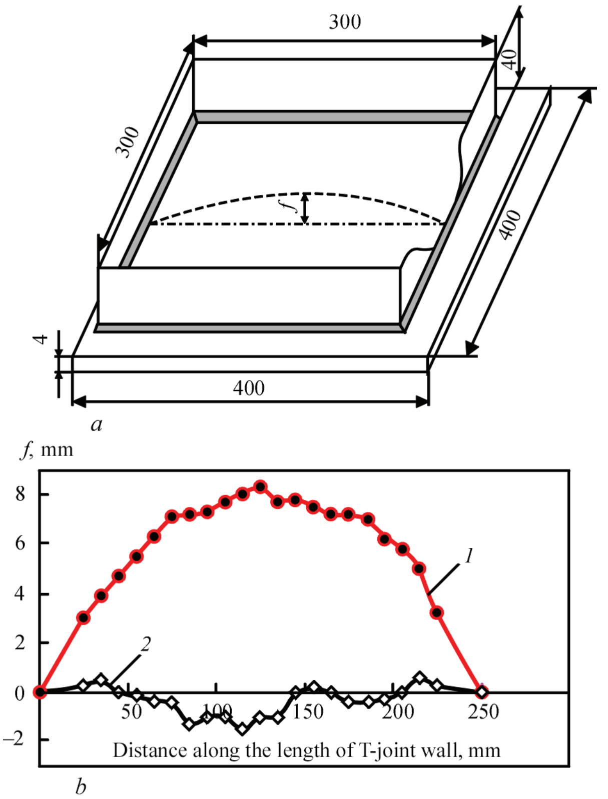

Figure 16. Specimen of welded joint of AMg6 alloy with a bulge: *a* — scheme of specimen (*f* — deflection); *b* — varying shape of specimen (curve *1* — initial deflections *f* in the center of the specimen; *2* — *f* after EDT)

registered at the center of the specimen (Figure 16, *a*). Then, the treatment of the convex surface of the specimen applying the series of pulses with a pitch of 10 mm at the mode at U_{ch} = 500 V and the capacitance of CES C = 6600 μF was carried out. Figure 16, *b* shows the residual shape changes of the plate before and after EDT-straightening. It is seen that as a result of electrodynamic effects, the residual deflections *f* decrease to 1 mm, which is acceptable for the most welded products.

EDT is applicable for increasing the life and reducing the residual stress-strain state of different types of welded structures.

Thus, the use of EDT in the manufacture and repair of small ships of the AMg6 alloy (Figure 17, *a*) allowed increasing the service characteristics of the products. EDT-straightening of structural elements

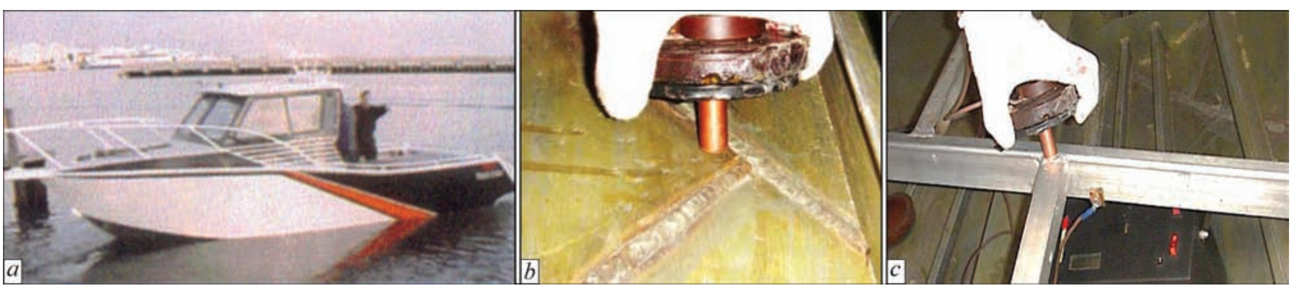

Figure 17. Using of EDT in the manufacture of ship hull of the AMg6 alloy: *a* — outer appearance of hull; *b* — EDT-straightening of welded joints of lining; *c* — EDT-straightening of the bottom beam structures

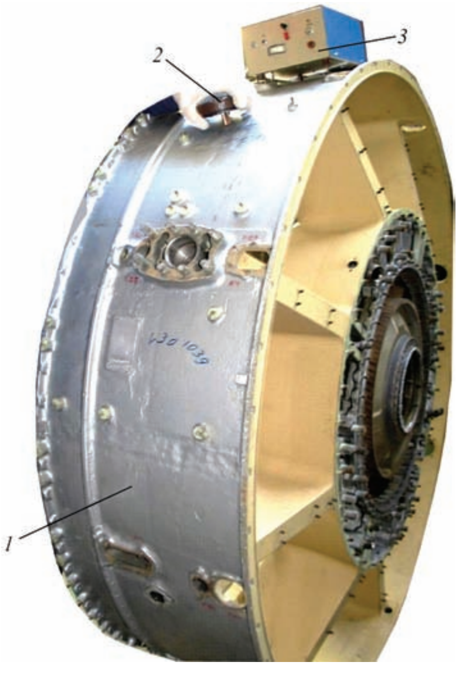

Figure 18. Treatment of repair weld on the outer surface of the outer shell of IBAE of the ML10 alloy applying EDT method: *1* — IBAE; *2* — electrode device; *3* — power source for EDT

allowed a significant improvement of hydrodynamic characteristics and habitability of hulls. Thus, the straightening of bulges in the lining (Figure 17, *b*) reduced the local deflections in the welded joint area from 10 to 1.5 mm, and the elimination of the curvature of transverse beams of bottom reinforcement (Figure 17, *c*) from 8 to 0.5 mm provided the guaranteed adjacency of bottom ceilings. At the same time the EDT of repair welded joints of lining and the load-carrying system provided a reduction in residual stresses from 150 to 40 MPa, which allowed 2–6 times extending the service life of the hulls.

The structural element of the aircraft AN-74 is the intermediate casing of the aircraft engine (IBAE), the purpose of which is mounting the engine D-36 to the wing. IBAE is a large-sized hollow cast structure of the heat-resistant magnesium alloy ML10 (Figure 18), which consists of the outer and inner cylindrical shells coupled between each other by stiffeners-struts, in the internal cavities of which the cooling fluid is circulating. The typical damages of IBAE, which are eliminated by repair welding, are fatigue cracks violating the integrity of the outer and inner shells, and also fracture on the front surface of the outer shell in the reinforcement zone under the flange of the cooling pipeline. Here, the maximum values of tensile stresses in repair welds without heat treatment reach 120 MPa, which corresponds to the yield strength of ML10 alloy. Reduction of stresses with the use of heat treatment is a rather expensive operation, which in some cases is by an order higher than the cost of repair welding. The application of EDT allows changing the distribution of residual welding stresses in repair welds from tensile to compressive ones, the value of which reaches –40 MPa, which is more effective than heat treatment, and much lower in cost.

The experience of practical using of EDT showed that one-channel ED, in view of their simplicity and a longer cycle of charge (as compared to two-channel ones) is advisable to apply for straightening the thin-sheet welded structures. At the same time, two-channel ones, due to the peculiarities of input of the pulsed current into the material treated, are most preferable for lowering the level of residual welding stresses. At the same time, a short charging time, typical for two-channel ED, allows using this type of EDT together with the welding cycle, which is promising for carrying out deformation-free welding of critical structures.

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