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TECHNOLOGIES OF REPAIRING CATHODE UNIT OF ELECTRON BEAM GUN WITH THE USE OF ELECTRON BEAM WELDING

V.I. Zagornikov, V.M. Nesterenkov, Yu.V Orsa, A.M. Ignatenko

E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

ABSTRACT

The elements of repair technology of electron beam welding in the manufacture of a metal-ceramic cathode unit of a powerful welding electron beam gun are considered. A low degree of heat generation at the place of weld overlapping inherent in electron beam welding reduces the risk of buckling parts being joined and provides the maximum compliance with the required sizes of the unit. The need in repair of the cathode unit was determined by the cases of supplying imported insulators with defects in the form of deviations of a thickness from 0.5 to 1.0 mm in the wall of the metal flange ("collar") in the brazed joint with the insulator. It was necessary to eliminate the consequences of a violation of the mechanical treatment of the insulator collar after brazing. The possible ways and schemes of repair technologies of such units are shown that allow avoiding the rejection of valuable parts and transferring them to the category of those subjected to restoration. The presented repair technologies involve the use of circumferential inserts-bandages of different configuration for two variants to eliminate welding defects associated both with local repair of the edge as well as with repair of its quite elongated areas. Due to a correct choice of the shape of repair inserts, the use of some technological methods and observance of the accuracy of assembly and the sequence of repair welding, it became possible to preserve geometric dimensions and to ensure the functionality of the welded assembly as a whole.

KEYWORDS: electron beam welding, pulsed mode, nickel alloy, cathode unit, repair circumferential shaped insert, schemes of joints of different welding stages

INTRODUCTION

In electronic devices the types of joints are used inherent in general engineering (butt, overlapped and fillet), but the shape of prepared edges in some cases is significantly different from the conventional one. These are joints with edges flanging instead of overlapped or butt joints. Such joints allow reducing the total heating of welded parts, reducing the total deformation of the assembly and restoring joints after cut out for repair [1, 2]. For joints the tolerances on assembly sizes over edges flanging are less rigid, which makes them more challenging in manufacture and repair of thin-walled joints [3].

In repair works, where it is necessary to provide a minimal heat impact on a product (in our case, cathode unit (CU) of the electron beam gun (EBG), the use of electron beam welding (EBW)) is challenging [4].

Since fusion welding of electronic devices is performed without filler material and the weld is formed from the metal of melting edges of welded products, the accuracy of grooving welded edges (thickness of machined edges around the perimeter of the circumferential joint) becomes essential.

The need to consider the variants of restorative repair of this expensive unit was determined by the cases of import delivery of sets of insulators with different thickness of the flange — "collar" brazed-in to the wall for welding EBG. Taken into account a high cost of EBW equipment, the possibility to avoid rejection of individual EBG units and transfer them to the category of those subjected to restoration by repair, is very relevant.

For repair it is necessary to form a defect-free welded joint without damage to adjacent brazed areas. The repair of such joints was not previously carried out, so the development of elements of repair technologies on the example of assembling the joint of the "leg" (CU) into the brazed "collar" of the ceramic insulator of EBG becomes relevant. Welding on the edges flanging did not cause difficulties until there was a need to produce a vacuum-tight weld on flanging in the presence of different thickness of the wall of the "collar" of the insulator along the perimeter as a result of its machining after brazing with the violation of technological mode. In the process of welding in the places of thinning of the wall of the joint, there was a local burnout with the violation of vacuum tightness of the weld, there were undercuts, loss of weld shape (Figure 1, *a*, *b*). This variant is possible and almost inevitable as a result of a violation of the mode of mechanical treatment of the "collar" of the insulator after brazing and before welding. Repeated, "cosmetic" pass in this case appeared to be ineffective, which required the development of other methods of repair technologies.

The following technological repair methods and rules found a real embodiment in our work:

- prevention of burnout and flashing of thin edges in the weld zone by increasing the intersection of parts by inserts to remove the edge from the welding zone;

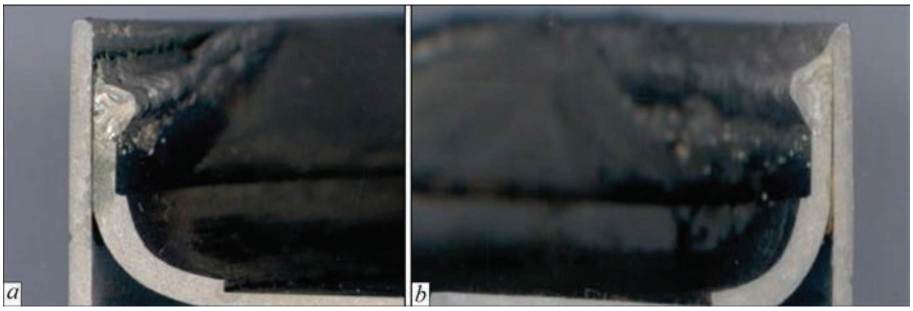

Figure 1. Defects of welded joint formation caused by violation of the technological mode of assembly and welding: *a* — leaking of weld metal down the inner side wall; *b* — loss of weld shape, undercut of the inner edge

- removal of defects by repeated passes with mounting gaskets — circumferential inserts of different configuration;
- pulsed mode that provides minimal specific heat input to the welding zone and accurate power adjustment, minimizes the risk of burn-through and buckling of thin-walled joints (less than 1–2 mm);
- obtaining the required weld shape to eliminate root defects. It is mainly realized by the choice of level of beam focusing and electron beam scanning;
- providing local rigidity of the joint fixation by mounting numerous tacks, i.e. by preliminary welding of edges at several points along the length of the joint.

Development of the tooling with an accurate fixing of parts by the clamp with efforts that do not exclude the possibility of free shrinkage and prevents the development of hot cracks during welds shrinking. I.e., it provides a decrease in rigidity of fixing welded workpieces.

The aim of the work is the development of repair technology of assembly and welding of CU, which is a part of welding EBG, taking into account the need to eliminate the consequences of violation of the mode of mechanical treatment of the "collar" of the insulator after brazing.

The task was to develop a repair technology, which due to the rational designing of welded repair elements, the use of technological EBW methods and the use of modern welding equipment will significantly reduce the cost of manufacture and repair of electronic equipment units.

MATERIALS AND RESEARCH PROCEDURE

The studies were performed in the laboratory installation of UL-112 type for EBW designed by the PWI of the NASU, which has a working chamber with inner sizes of 600×600×600 mm. The installation has a relatively simple design with a stationarily fixed outer welding gun, equipped with a manipulator that provides a linear movement of the table along the coordinates *X*, *Y*. As a structural material for the manufacture of CU, kovar 29NK alloy was used. To work out the technique of welding-in CU in a thin-walled flange ("collar") of the insulator, the rotator of the installation was provided with a high-precision CNC-controlled electric drive (computer numerical control). A high-voltage power source with a power of 15 kW was used at an accelerating voltage of 60 kV. The emission system of the welding gun provided an electron beam current of up to 250 mA. To combine an electron beam with a welded joint, a coaxial television monitoring system was used. The use of a coaxial television system allows realizing accurate positioning of an electron beam axis with a welded joint [3].

EXPERIMENTAL PART AND DISCUSSION

The influence of preparing welded edges on the quality of welded joints was revealed. To provide the high quality of the weld, the joined surfaces should be obligatory subjected to cleaning from conservation means, contaminants, rust and oxide films. Immediately before welding, the outer surface of welded parts in the joint area can be cleaned with a low-power scanning electron beam, preventing flashing edges to enable the software adjustment of the electron beam position relative to the joint during welding.

When developing the welding technology, simulator specimens for practicing welding modes did not fully reflect the stress-strain state of the real welded joint [5]. However, previous experience in welding parts of such type allowed minimizing the number of adjustable parameters to produce a quality weld. They include the range of admissible specific heat input from the so-called elimination of overheating and violation of vacuum tightness of the weld (welding in the pulsed mode), the minimum value of the gap in the joint, angle and place of guiding of the electron beam into the welded joint. The maximum penetration depth without splashing of metal can be achieved at an optimal combination of increased pulse duration and reduced power density. The coefficient of overlapping of adjacent spots is an important criterion that affects the quality of welds. To produce dense welds, its recommended values are from 50 to 80 % [2, 6]. The choice of welding speed was performed empirically on simulator specimens. For the analyzed thicknesses, the choice of welding speed in the region of 10 mm/s increased the possibility of producing quali-

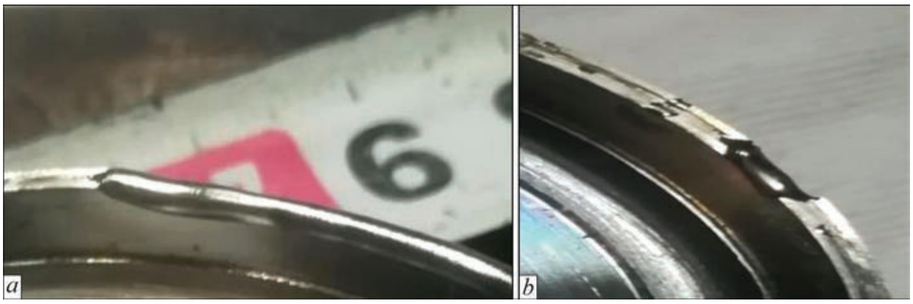

Figure 2. Initial fragment of the weld (*a*) and the tack (*b*)

ty weld formation. On the basis of the carried out calculations and experiments, the following parameters of the pulsed mode of EBW were determined:

Accelerating voltage U_{acc}, kV	60
Beam current, mA	13.5–15.0
Working distance, mm	70–300
Frequency of passed pulses f, Hz	30
Pulse duration τ_{pulse}, ms	16.5
Pause duration τ_{pause}, ms	16.5

For successful welding with full penetration and lack of fusion of the edges, it is necessary to defocus the electron beam so that on the welded surface of edges the focal spot was not less than 0.8 mm and not more than 1.0 mm. The size of the focal spot was set experimentally. The focus of the beam was pulled on 1–2 mm relative to the surface of the welded edge (sharp focusing I_{fo} plus 15–25 mA). Adjusting these values can significantly increase the stability of the welding pool and eliminating metal splashes. The lack of splashing of the welding pool metal significantly improves the aesthetic appearance of the product, and also reduces the probability of surface corrosion appearance.

It is also necessary to consider the fact (related to the features of the EBW method itself), that with an increase in gaps over a certain limit, it is almost impossible to produce satisfactory formation of welds without undercuts and burnouts. The sizes of the gaps are very critical because the thickness itself of the wall of the brazed flange–collar is only 0.5 mm in some places. The developed designs of assembly and welding equipment provided the addition of a butt joint with minimal (not more than 0.08 mm) gaps on the end surfaces and guaranteed tension over cylindrical ones [1, 5]. The negative impact of gaps on the shape of the weld was eliminated. Checking the accuracy of assembly was carried out with templates and probes. In order to provide that in the welding process the set gaps and position of thin-walled parts are not changed, preliminary tacking of the parts is made before welding. The tacks are designed to position the joined elements maintaining their shape and dimensions before the final EBW [4, 5]. In order to avoid overheating of the product and violation of the tightness of the welds, it is necessary to reduce the feeding and removal of the current while producing tacks. The length of each of two linear tacks should be at least 2–5 of the thicknesses of the base metal. The dimensions of the tacks section should be such that they are melted completely during overlay of the main welds (Figure 2).

Table 1. Parameters of the mode of producing welding spot tacks (without modulation)

Beam current I_b, mA	Current of focusing lens on the surface I_{fo}, mA	Operating current of focusing lens I_f, mA	Working distance, mm
4	600	625	200

Table 2. Parameters of the mode of producing welding spot tacks (with modulation)

Beam current I_b, mA*	Current of focusing lens on the surface I_{fo}, mA	Operating current of focusing lens I_f, mA	Working distance, mm	Welding speed v_w, mm/s
8	600	625	200	10
*Welding in a pulsed mode.				

As the distance between the tacks decreases, the maximum displacement of the joint decreases during the main welding pass with the electron beam [4]. The priority of spot tacks over linear in terms of minimizing heat input into the weld and reducing deformations is emphasized. Therefore, most often at a considerable difference in the thickness of the walls of the parts instead of linear tacks to be welded, numerous spots were used. It is recommended to reduce the heat input of spot tacks, which are placed diametrically opposite (criss-cross) in the amount of 8–16 pcs. The current of the focusing lens corresponded to the sharp focusing at a set working distance — 200 mm (I_{fo} = 600 mA plus 25 mA).

The mode of producing welding tacks is given in Tables 1 and 2.

The formation of the weld of the required shape with a smooth (without undercuts) transition from the weld surface to the base metal was carried out due to the correct distribution of the electron beam concentration. In all cases, the joint is performed by EBW with a requirement (justification) of minimum admis-

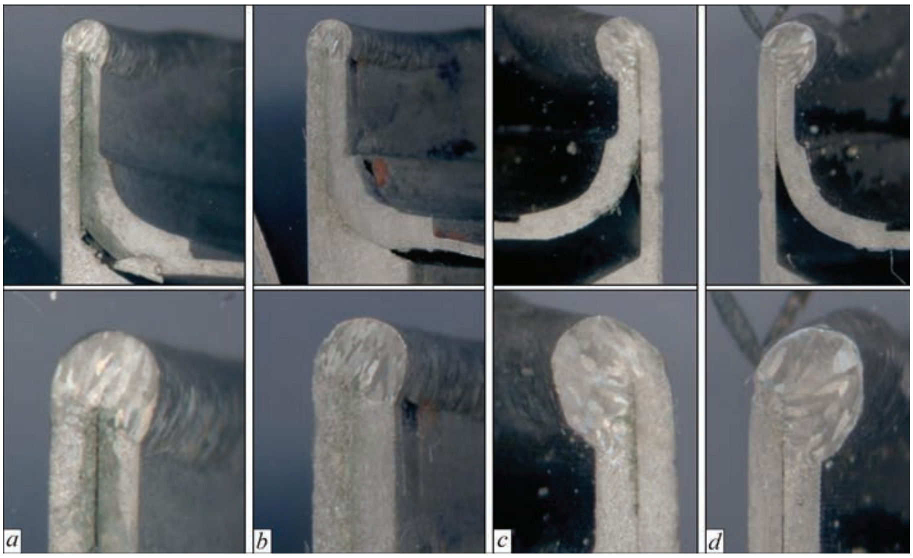

Figure 3. Transverse macrosections on specimens-simulators of different modes of electron beam weld with two-sided edge flanging with one and multiple repair passes: EBW in a standard mode (*a*), pulsed EBW (*b*), double remelting in a pulsed mode (*c*), triple remelting in a pulsed mode (*d*)

sible sizes of welds and limitation of the number of repeated passes (Figure 3). To reduce the probability of pores and cracks formation, edges flashing with the loss of their shape, the number of repeated repair passes should not exceed two.

ASSEMBLY FOR WELDING, APPROPRIATE TECHNOLOGICAL EQUIPMENT, CHOICE OF WELDING MODES BY TWO VARIANTS

Fundamental features of methods of fixing CU elements during its assembly for welding and the main provisions of technology of EBW of CU were developed previously in [3].

For two variants of eliminating welding defects, repair technologies at the final stage of the operation of producing joints of “CU as an assembly” involve the use of circumferential inserts of different configuration and use of them as a bandage to provide the calculated strength and accuracy of the sizes of the assembly.

The similar designs of inserts are simple and advantageous in the fact that they provide sufficient volume of additional metal, fixation and dense contact of the joined parts. A scheme of welded repair joints, fundamentally independent of this was developed irresective of a local or elongated defect.

Before welding CU, it should be mounted into the mandrel and each time the radial beating should be checked, which should not exceed ± 0.05 mm.

Let us consider two repair variants in more detail.

VARIANT No. 1

Welding-in of CU into the brazed flange of the ceramic insulator of EBG in the presence of flange vertical wall thickness different along the perimeter (0.5–1.0 mm) in two stages. Here, it is possible to produce a vacuum-tight weld after a proper preparation of the welding place, butt mounting of a remained shaped circumferential insert with the edges flanging, followed by EBW on both sides in a pulsed mode.

The assembly and welding device represents a support mounted and fixed on the rotator. The insulator for EBW assemblled on it with a shaped circumferential insert is fixed by a flange and studs. Protection of the ceramic surface of the insulator from spraying with metal vapors in EBW at the working power was carried out by aluminium foil outside and by inserts of nonmagnetic material directly in the joint area.

The circumferential insert in the first variant was applied based on the need to give the edges approximately the same cross-sectional size (Figure 4).

Such an insert is intended to reduce the criticality of the failure to keep with the same (1.0 mm) thickness around the perimeter of the wall of the thin-walled “collar” brazed-in to the insulator. The use of this shape of technological insert provides an accurate fixation of welded edges with the minimum gap and provide their parallelism. In the process of welding, the heat source (electron beam) affects mainly on the flange of the shaped substrate, which significantly reduces the overheating of welded parts and makes it possible to avoid the appearance of burnouts in the joint. During welding-in of the “leg” to the repaired insulator, the protection of the ceramic surface of the insulator in the form of a shielding device of nonmagnetic material was used. Atop over the studs, the elastic “rocker” serves as a fixer of the whole structure in the conductor and through it grounding of all elements of CU is performed. The choice of rational (in terms of reduction of residual welding deformations) sequence of overlaying repair welds during welding on the facial and back side of the joint “CU-insulator”. Initially, the operation of fixing the

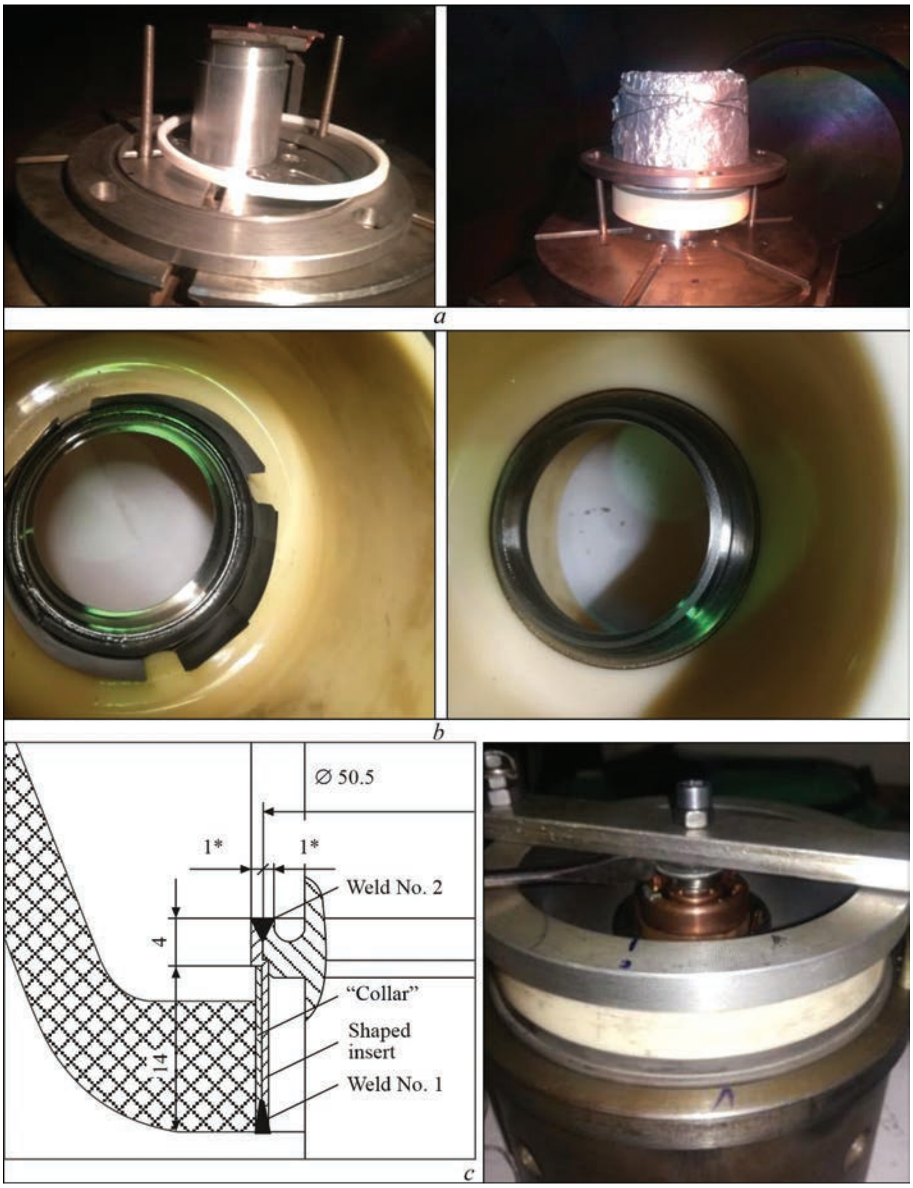

Figure 4. Stages of repair works according to the variant No. 1: *a* — assembly and welding device with a subassembly of insulator with a shaped circumferential insert for EBW according to the variant No. 1; *b* — appearance of the weld with a shaped circumferential insert according to the variant No. 1 after EBW and after machining the weld in size; *c* — fragment of circumferential joint of the "collar" with a shaped insert according to the variant No. 1 and final assembly

shaped circumferential insert to the defective "collar" of the insulator (weld No. 1) was performed. Then, after removing tolerance on mechanical treatment, the operation of final assembly and welding-in was performed using EBW of the "leg" to the insulator (weld No. 2).

The mode of producing the first welding pass (weld No. 1) is presented in Table 3.

The mode of the second welding pass (weld No. 2) is presented in Table 4.

VARIANT No. 2

Restoration of the "leg" after its cutting from the assembly weld with the elongated linear defect. In this case, the restoration was subjected to the "leg", not the "collar" of the insulator. To carry out this repair

Table 3. Parameters of mode of producing welding pass with modulation (weld No. 1)

Beam current I_b, mA*	Current of focusing lens on the surface I_{fo}, mA	Operating current of focusing lens I_f, mA	Working distance, mm	Welding speed v_w, mm/s	Angle of product inclination α°
13.5	600	615	260	10	5

Notes. *Welding in a pulsed mode. I_{fo} = 600 mA corresponds to the sharp focusing of the electron beam on the welded surface. The size of the working distance is 260 mm.

Table 4. Parameters of mode of producing welding pass with modulation (weld 2)

Beam current I_b, mA*	Current of focusing lens on the surface I_{fo}, mA	Operating current of focusing lens I_f, mA	Working distance, mm	Welding speed v_w, mm/s	Angle of product inclination α°
15	700	715	70	10	10

Note. I_{fo} = 700 mA corresponds to the sharp focusing of the electron beam on the welded surface. The size of the working distance is 70 mm.

Table 5. Parameters of mode of producing welding pass without modulation

Beam current I_b, mA*	Current of focusing lens on the surface I_{fo}, mA	Operating current of focusing lens I_f, mA	Working distance, mm	Welding speed v_w, mm/s	Angle of product inclination α°
12	635	650	130	10	5–10

Note. I_{fo} = 635 mA corresponds to the sharp focusing of the electron beam on the welded surface. The size of the working distance is 130 mm.

operation, it is necessary to cut out the "legs" of the insulator and, after welding-in of insert-bandage, repeated assembly-welding should be performed.

The shape of the bandage was different from the variant No. 1 by the absence of a horizontal flange and the presence of rest to the wall of the "leg" for better fixation, preservation of rigidity of the assembly. The center of the heating spot is shifted toward a bandage-insert that has a larger thickness (Figure 5, *a*).

The parameters of the mode of this variant of welding were set on the basis of the conditions of producing a vacuum-tight weld with a good outer formation without undercuts, penetration depth of at least 2.0 mm and the absence of root defects. Choosing the optimal bandage-insert for EBW according to the variant No. 2 and the corresponding parameters of welding mode allowed solving the problem of restoration of geometric dimensions of the "leg" cut out from the insulator.

In welding-in the insert according to the variant No. 2, the angle of inclination of the product from the vertical should be different from zero. The need in inclination is explained by the proximity of the upper vertical wall of the assembly to the welding zone, as a result of which the probability of shielding a part of the electron beam by the wall increases. The weld was located on the end surface of the two-sided flanging with a slight deviation from the vertical. It was experimentally established that the value of the external elimination of the electron beam axis from the inner edge of the end of the bandage in the case of the angle of inclination of the product α within 5–10° from the vertical, should be 0.3 mm. These conditions provide a guaranteed penetration of the required shape. Such negligible values of removing an electron beam are convenient to control with the use of coaxial television monitoring system (Figure 5).

Table 6. Parameters of the mode of welding-in "leg" (CU) to the brazed "collar" of ceramic insulator of EBG

Beam current I_b, mA*	Current of focusing lens I_{fo}, mA	Welding speed v_w, mm/s
12	I_{fo} + 20	10

Notes. *Welding in a pulsed mode. I_{fo} = 600 mA corresponds to the sharp focusing of the electron beam on the welded surface. The size of the working distance is 220 mm.

The mode of the "leg" restoration by welding-in a bandage on it without modulation on a normal, not pulsed mode, is shown in Table 5.

FINAL ASSEMBLY OF CU

In the final stage (after welding-in repair inserts and their machining in size), welding was carried out with two-side edges flanging, which eliminates the need in inclination of the product, maintaining all the benefits of this scheme (Figure 6).

The final operation mode of welding-in "leg" (CU) to the brazed "collar" of the ceramic insulator of EBG is shown in Table 6.

The availability of modern welding equipment in combination with a preliminary thought out and veri-

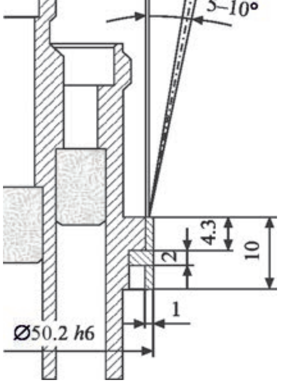

Figure 5. Scheme of welding-in insert according to the variant No. 2 (*a*) and "leg" of CU after EBW and finishing machining of welded-in insert (*b*)

Figure 6. General outside (*a*) and inside (*b*) appearance of repaired CU of EBG

fied design of the welded assembly, a properly selected type of a weld, allowed eliminating deformation of the part and minimizing the percentage of rejection. The geometrical tolerances of CU after completion of all stages of welding were observed. The shapes of the product are preserved.

The technology was checked during the work of standard products in real production conditions. The use of developed EBW technology after repair was proved by a continuous operation of CU for 40 h.

Production and delivery of such assemblies can be carried out by the designing companies, manufacturers of power units and installations for EBW and small business enterprises.

CONCLUSIONS

1. In the work, the method of technological inserts is substantiated, which allows eliminating not only defects of welding the cathode unit, but also producing high-quality vacuum-tight joint on an expensive part, made with violation of geometric dimensions during its mechanical treatment (deviation in the sizes of the vertical wall thickness along the perimeter of the insulator flange).

2. The technology of repair of two types of defects was mastered in the presence of different thickness of the vertical wall of the flange along the perimeter and after its cut out from an assembly weld behind an elongated linear defect. The repair of both types of defects is carried out by means of inserts–rings of a different configuration.

3. The adopted welding technology was successfully applied during repair of CU. Such properties as quality, fatigue life, reliability were confirmed during operation of repaired real products and became the criterion of correctness of the developed technology.

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ORCID

V.I. Zagornikov: 0000-0003-0456-173X,
V.M. Nesterenkov: 0000-0002-7973-1986,
Yu.V Orsa: 0000-0002-1208-4171

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

V.M. Nesterenkov
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: nesterenkov@technobeam.com.ua

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