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FEATURES OF APPLYING ELECTRON BEAM WELDING IN MANUFACTURE OF THE CATHODE ASSEMBLY OF THE ELECTRON GUN

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The efficiency of using electron beam welding in producing permanent joints of structural materials of all thicknesses and shapes is well-known. The work for the first time considers the possibility of using electron beam welding for the production of high-precision parts of optical system in cathode unit, providing the necessary parameters and their joining with electron beam gun insulator in future. The use of electron beam welding at the final stage of manufacturing cathode unit opens the opportunity of minimizing the number of further technological operations. It is noted that to create the welding technology, in which the operation of welding would become a final assembly operation, the development of new designs of welded joints and schemes for assembly of cathode unit are required. Due to a correct design of welding units and compliance with the accuracy of assembling for welding, it became possible to preserve geometric dimensions after electron beam welding and to provide the operational reliability of the design as a whole. 5 Ref., 6 Figures.

Keywords: electron beam welding, pulsed mode, nickel alloy, cathode unit, welding equipment

In the industry new tasks are emerging that are successfully solved by using electron beam welding (EBW). In this process welding guns of different power are used to provide the formation of welded joints with a thickness from 0.5 to 150 mm or more.

Cathode units (CU) of optical systems are the base of electron beam guns and are subjected to increased requirements during manufacturing. Taking into account the capabilities of EBW, it is very promising to use it in the manufacture of CU, which represent a complex metal-ceramic product. Considering a high cost of equipment for electron beam welding, the task of manufacturing and at the same time extending the service life of CU is very important. In order to increase the long-term and stable formation of electron beam welds, high-precision parts of a cathode part of the electron beam gun (EBG) were designed and manufactured using EBW.

In the manufacture of such units it is necessary to solve a number of problems related to the presence of residual inherent stresses caused by the difference of thermal coefficients of linear expansion of metal and ceramics [1].

As is known, cathodes for electron welding guns are made of tungsten and lanthanum hexaboride LaB_6. Tungsten is much more resistant to vapors of welding metals and residual gases, while the cathodes of lanthanum hexaboride are rapidly contaminated by vapors of welded metals and lose their emission capacity [2]. However, the power of heating required for the normal operation of the tungsten cathode is 3−4 times higher than the heating power of the cathode of LaB_6. Due to the influence of high operating temperatures, the cathode can be shifted relative to the optical axis and the focusing of the electron beam can be violated.

As a consequence, the operating temperature of the tungsten cathode holder and the elements connected with it prevent the use of brazed joints in the cathode assembly design. The paper for the first time considers the possibility of using EBW to join high-precision parts of the optical system (CU) with the necessary parameters.

The problem solved in this work consisted in developing a technology that allows the EBW operation to be a finishing operation of the CU electrode connection while maintaining its full operational properties.

The experimental works were carried out in the SV112 installation of the design of the E.O. Paton Electric Welding Institute (PWI) with the computer control of EBW parameters. Carrying out EBW in a small-sized SV112 installation in difficult-to-weld places (interelectrode spaces), where the use of a standard monitoring system in the secondary electrons was problematic, became possible due to the presence of a coaxial monitoring system on the base of digital videocamera.

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To produce welded joints from the parts of kovar used during the manufacture of CU it is necessary to minimize residual stresses by minimizing penetration depth and overheating of the base metal [3]. This is achieved by optimizing the welding parameters: welding speed V_w, beam current I_w, focusing lens current I_f and working distance, which provide the formation of welds with penetration to a partial thickness with a minimum recrystallization zone. The weld formation is significantly influenced by the position of the electron beam focus relative to the surface of the product. The best results are achieved by placing the focus below its surface. The welding modes are selected such that to provide that the value of the weld shape factor was close to H_p/B = 1.8−2.0 mm. Such shape is predetermined by the need in a minimal heat input to reduce the probability of arising burns out, cuts, increased spattering and periodic hump shape of the weld.

For the same purpose EBW pulsed mode is successfully used. Pulsed EBW due to a low heat input has become irreplaceable during welding in the direct vicinity from the place of soldered joints of metal with ceramics. The heat input during welding is minimized and the welding speed is maximized to reduce the size of the weld pool and crystallization period.

The EBW pulsed mode parameters are the following:

- rigidity of the *G* mode (ratio of pulse duration to pause duration between them);
- frequency of transmission of current pulses of electron beam *F*.

A significant influence on the value of input energy and quality of welded joint during welding in a pulsed mode is also provided by the welding speed V_w, the choice of which in each specific case depends on duration of an individual pulse and length of the path traveled by the beam during a pause between the pulses, which determines the factor of the overlap.

To keep with the conditions of formation of a sealed (vacuum-tight) welded joint, the overlap factor of welding points is set not less than 0.6−0.7. Based on the carried out calculations and experiments, the pulsed mode parameters of EBW were determined.

EBW pulsed mode parameters

U_p, kV	60
Beam current, mA	10−12
Working distance, mm	150−300
Pulse frequency *F*, Hz	30
Pulse duration τ_{pulse}, ms	16.5
Pause duration τ_{pause}, ms	16.5

The welding speed on different types of welded joints of CU varied from 3 to 10 mm/s. The further increase in speed resulted in the Humping effect.

The reduced welding speed threatens with overheating of the product right up to distortion of its shape.

In addition, the EBW pulsed mode allows reducing the requirements to the accuracy of aligning thin-walled structural elements and, first of all, the value of gap between these elements. Our previous investigations have shown that the gap in the joints of CU should not exceed 0.06−0.08 mm. In this case the error of 0.09 mm is admitted. The excess of edges should be not more than 0.5 mm or 20−25 % of the thickness. Welding on the edge flange while maintaining the assembly gap within 0.06−0.08 mm also did not cause any difficulties.

All the welds in the considered welded design of CU were circumferential. It is known that the products, the parts of which substantially differ in thickness, are welded with a preliminary treatment of the edge to equalize the temperature field, which provides a symmetrical shape of penetration. In order to minimize the heat removal into the product during welding of circumferential welds of CU, the designing samplings were used (Figure 1).

The welding process is also critical as to the accuracy of the heating spot location with respect to the butt. In case of its deviation from the trajectory of the butt, lacks of penetration, burns out and undercuts are possible. Lacks of penetration and burns out do not provide the vacuum density of welds and are the main rejection criteria as the most dangerous defects. Such defects are difficult to eliminate during remelting. Repeated passes lead to the formation in weld of a coarse-grained columnar structure and hot cracks to which nickel alloys are prone. Therefore, the number of passes should not be more than two.

Based on the results of previous investigations of EBW, a small chart of technological production of CU was created, consisting of six parts: Wehnelt electrode bushing, cathode bushing, heater bushing, lid and pin of cathode heater (Figure 2).

In Figure 3 the chart is supplemented with a photo of macrosection of typical types of welded joints.

The parts of CU (cathode bushing with a high-voltage input and bushing of the heating device with a high-voltage input) were manufactured and joined (weld No.2 and weld No.3) in two design variants: *a* — butt joint of CU electrodes; *b* — butt joint of CU electrodes with the use on flanging.

The use of the design as to the variant (*b*) made it possible to reduce the criticality of a butt gap value. The welded joint with edge flanging was also produced when the pin of the heating device was installed to the CU lid (weld No.5).

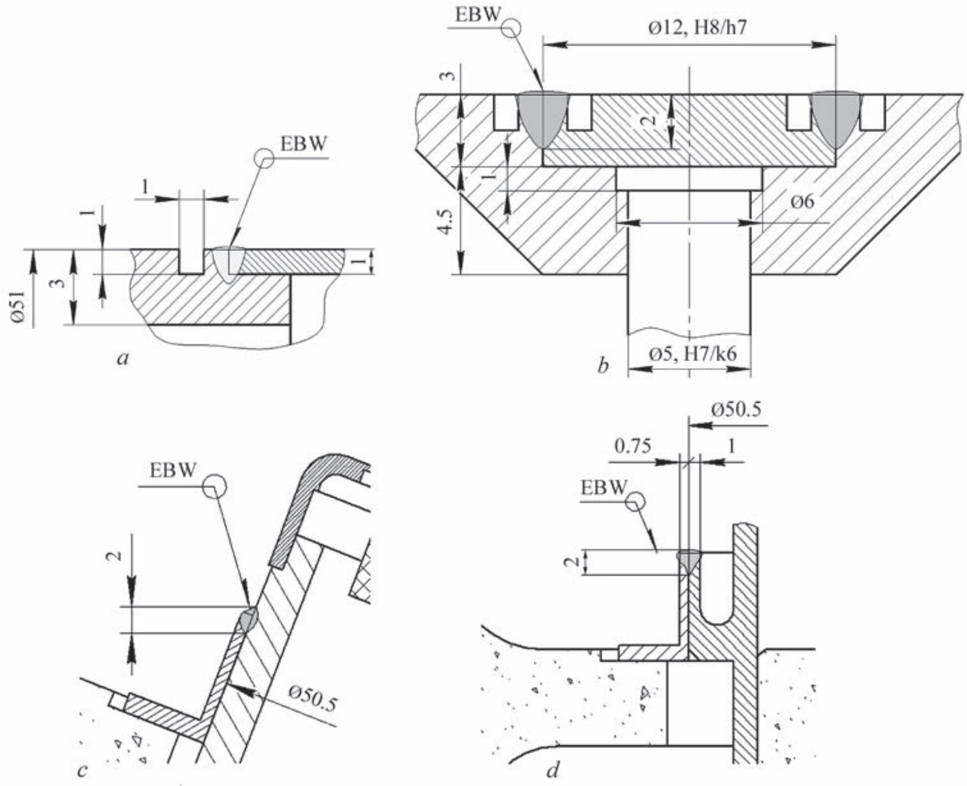

Figure 1. Examples of design of welded joints of CU (*c*, *b*): *a* — butt joint with one-sided edge flanging; *b* — with double-sided edge flanging. Two types of electron beam joints of cathode unit with EBG insulator (*c*, *d*): *c* — overlapped; *d* — with double-sided edge flanging

As a result, in the cathode unit high quality welds were produced, the fragments of which together with the general appearance of CU are presented in Figure 4.

The final and the most responsible stage of welding-in CU into a thin-walled (0.5–0.8 mm) flange of the EBG ceramic insulator is carried out in the conductor specially made in the form of seating positions of the insulator. The conductor is fixed in the rotator at an angle with a deviation from the vertical to 10°. This requirement is mandatory to provide the possibility of welding-in difficult-to-reach areas of welded CU with coaxial welds at different heights.

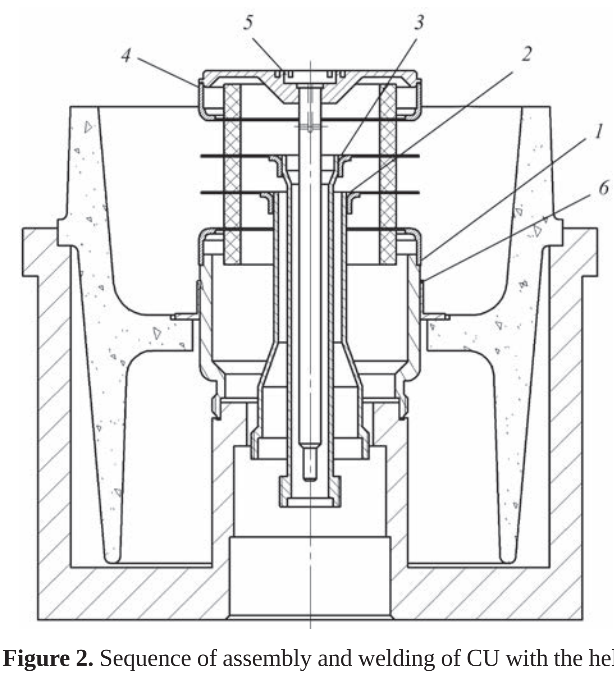

Figure 2. Sequence of assembly and welding of CU with the help of EBW: weld No.1 (Wehnelt electrode bushing with a high-voltage input); No.2 (cathode bushing with high-voltage input); No.3 (heating device bushing with high-voltage input); No.4 (lid with high-voltage input); No.5 (mounting of pin of heating device into the lid); No.6 (joining of CU with insulator)

In order to increase the manufacturability of the assembly and welding process, the design of CU was modernized. In particular, the type and shape of welded joint during welding-in CU into the insulator were changed.

Replacement of one type of welded joint – overlapped welded at a sharp angle into the end (Figure 1, *c*), i.e., a welded joint in which welded elements are arranged in parallel and partially overlap each other on a bilateral flanging (Figure 1, *d*) made it possible to

Figure 3. Macrosections of characteristic types of welded joints of cathode unit (CU): *a*–*c* — respectively welds No.1, No.5, No.6

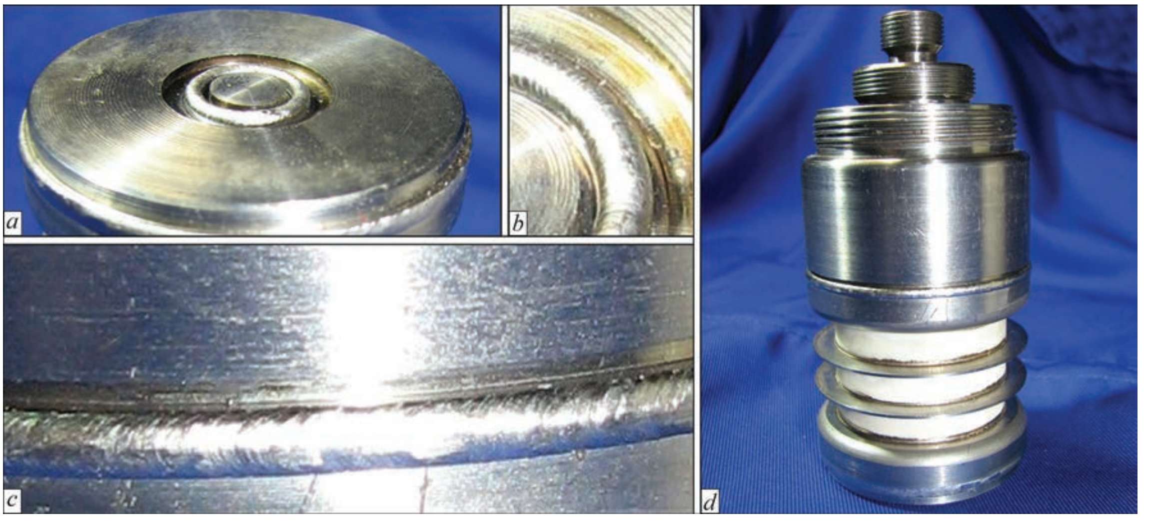

Figure 4. Fragments of welds of different parts of CU (*a*–*c*) and its general appearance as-assembled (*d*): *a* — top view on the lid of CU with welds No.4 and 5; *b* — fragment of weld No.5; *c* — fragment of weld No.1

simplify the welding scheme at the final stage. Such a scheme allowed reducing the risk of both lack of penetration as well as burn out of a thin side wall of CU. On the other hand, the probability of overheating the area near the brazed joint (flange with insulator) and, as a consequence, a violation of its vacuum density were eliminated. After completion of all welding stages, the geometric dimensions of CU were within tolerance. At the same time the time of preparatory works before welding was significantly shortened without reducing the accuracy of assembly of such products. Figure 5 shows CU as-assembled with a high-voltage insulator.

The technique of assembling thin-walled high-precision welded structures, the corresponding welding devices and the ways of their improvement are described in the literature [4, 5].

We developed a set of welding equipment for the assembly-welding of electrodes in CU and a subsequent welding into the EBG insulator.

The welding equipment represents a set of cylindrical frames, which are fixed on the rotating device, depending on the stage of welding process, (Figure 6, *a*).

Figure 5. Appearance of CU as-assembled with insulator: *1* — insulator; *2* — CU; *3* — weld

EBW of the cathode unit is a precision process and requires a minimal axial and radial beating of rotating device. With this aim, the welding equipment was manufactured in such a way that its attachment together with a welded products occurs directly on the shaft of the rotating device.

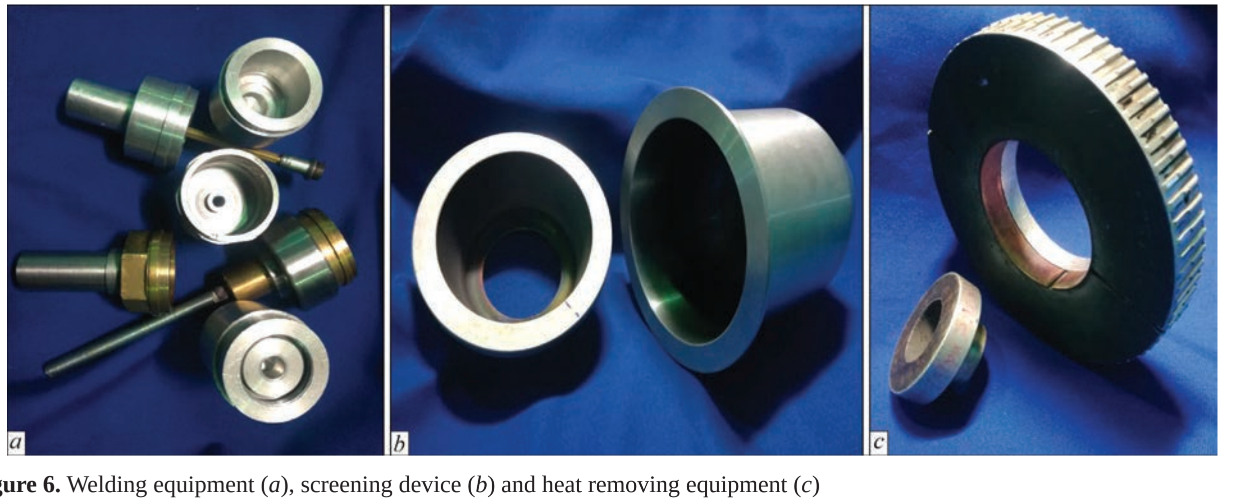

Figure 6. Welding equipment (*a*), screening device (*b*) and heat removing equipment (*c*)

Such a solution allowed minimizing the need in a software adjustment of the electron beam position relative to the butt joint during welding.

During assembly of parts for welding, the absence of a gap on the end surfaces and a guaranteed tension on the cylindrical ones were provided.

To protect the interelectrode space of CU of the electron optics from contamination with metal vapors during EBW at an operating power and avoiding short circuits of electrodes as a result of that, insulating spacers, caps and shields of nonmagnetic material were used (Figure 6, *b*, *c*). In case of welding-on bushing of the Wehnelt electrode the heat-removal equipment with a non-magnetic material of ring type with a copper insert was additionally applied (Figure 6, *c*).

Finally it can be noted that due to changes introduced to the design of CU, development of EBW technology, including on the pulsed mode, the experimental industrial batch of CU for domestic EBGs with accelerated voltage of 60 and 120 kV was manufactured.

Conclusions

1. The optimal design of the cathode unit (CU) and assembly-welding device were developed.

2. The order of assembly and welding of the cathode unit was proposed, which allowed eliminating the losses of a shape of a product, burn outs and contamination of CU electrodes with metal vapors.

3. The possibility of using EBW as a final operation during manufacture of CU was grounded providing operation reliability of the whole unit, including its connection to insulator.

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