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Pulse diffusion welding of female joints

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Abstract: Special feature of operation of electrovacuum tubes, in particular the cathode assembly, is constant heating due to bombardment of its surface with electrons. Stable characteristics and durability of the cathode assembly depend on high-quality connection (welding) of the core surfaces with the emitter over the entire area of the overlapped conjugation. The use of diffusion welding for joining a cathode assembly made of dissimilar materials is not possible due to the occurrence of poor welding fusion due to the presence of gaps in the ring sectors of the equipment, and, consequently, a decrease in the service life of the cathode assembly. The authors proposed to implement the process by combining magnetic pulse welding with diffusion welding. The originality of the work is the possibility of remote action on the joint through a dielectric quartz cup, which is a part of the technological vacuum chamber. The inductor system is outside the quartz cup, which allows heating the assembled unit without heating the tool – an inductor made of dissimilar materials – to a temperature of 700 °C and higher. The authors determined the main parameters of the process of pulse diffusion welding in vacuum: pressure in the working chamber is B=0.66·10^{-2} Pa (5·10^{-5} mm Hg); preheating temperature is T=700–1250 °C; magnetic field pulse energy is W=5÷17 kJ; operating frequency of current pulse discharge is f_d=5–15 kHz; magnetic pressure is P_m>·10^7 N/m^2. In this way, cathode assemblies of a wide range of metal pair combinations with a base diameter of d=20 mm and a sample length of L=40 mm were produced. The proposed technology has been successfully implemented and introduced at Tantal (Open Joint Stock company). The economic effect consists in reducing labor intensity and obtaining joints of stable quality.

Keywords: pulse diffusion welding; welding of female joints; magnetic pulse welding; inductor; magnetic pressure; input energy; dissimilar alloys.

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INTRODUCTION

In the production of electrovacuum tubes (EVT), emitter materials based on platinum-barium, palladium-barium, iridium-lanthanum, etc. alloys are widely used. The connection of the emitter with the cathode core is a typical female design. The emitter should be welded to the core surface in the solid phase without mixing the materials. Fig. 1 shows typical representatives of cathode assemblies. A specific performance feature of the cathode assembly is its constant heating due to the bombardment of its surface with electrons. To ensure stable operational properties and durability of devices, it is necessary to ensure high quality of welding of the core surfaces with the emitter over the entire area of the overlapped conjugation.

Classical diffusion welding in a protective environment with a static load ensures the production of high-quality connections, which guarantees the required service life of the units. Examples and parameters of diffusion welding modes for metals in homogeneous and heterogeneous combinations are shown in more detail in [1]. Moreover, replacing the factory laser welding technology with diffusion welding allows increasing the productivity of the welding technology up to 75 % [1].

Despite the significant advantages of diffusion welding, if its technology is violated or there is no long-term testing of the resulting joints under various loading conditions (thermal, thermomechanical), defects such as poor welding fusion occur during the production process, and cracks occur during operation, which is unacceptable in EVT. The relationship between defects and the causes of their occurrence, which must be taken into account when developing the technology, as applied to the design of the welded parts is described in [2].

To expand the capabilities of diffusion welding and produce defect-free welded joints, it is possible to use intermediate layers that have sufficient affinity for a pair of metals that are difficult to weld together. It has been proven that the use of intermediate layers allows reducing the temperature of the diffusion welding process to 350–750 °C when welding ARMCO iron with a high-purity nickel alloy [3].

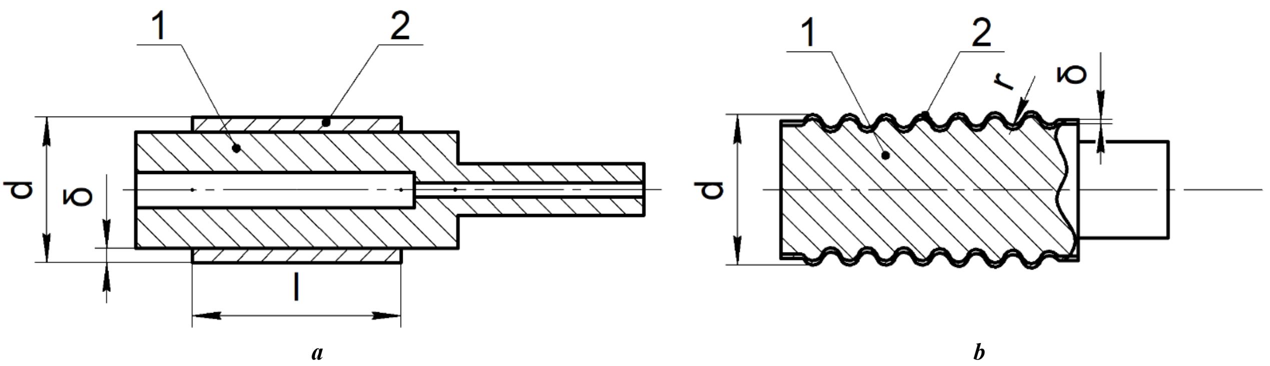

Fig. 1. *Design of cathode assemblies:*
a *– welding on a cylindrical surface;* ***b*** *– welding on a developed surface.*
1 – core; 2 – emitter; d – assembly diameter; δ, l – emitter thickness and width; r – surface curvature
Рис. 1. *Конструкция катодных узлов:*
a *– сварка по цилиндрической поверхности;* ***b*** *– сварка по развитой поверхности.*
1 – керн; 2 – эмиттер; d – диаметр узла; δ, l – толщина и ширина эмиттера; r – кривизна поверхности

The authors of [4] used an intermediate Ni layer to reduce the likelihood of intermetallic compound formation and to obtain Mo–Ni and Cu–Ni solid solutions during diffusion welding of Mo–Cu. The paper [5] showed that the use of an intermediate Zn layer facilitates the formation of a strong bond between Al and Cu during a short period of time and at a low temperature of the process between Zn, Cu and Al. When using Ag as an intermediate component [6] and increasing the process temperature to 700 °C, the formation of Ag–Ti intermetallic compounds and an Ag solid solution instead of Cu–Ti intermetallic compounds was identified in the welded joint. The use of CoCrFeMnNi alloy as an intermediate layer during diffusion welding of Cu–Ti or 0Cr18Ni9 allows reducing the brittleness of Cu/Ti joints due to the formation of solid solutions at a process temperature of 800 °C [7; 8]

In the absence of intermediate materials, diffusion welding of Cu and Ti was carried out at temperatures of 800–900 °C. The shear strength of the joints was about 28 MPa. A number of brittle intermetallic compounds, such as β-Cu_4Ti, Cu_2Ti and Cu_3Ti formed at the joint boundary, were found [9].

When implementing the process of diffusion welding at high temperatures, significant thermal stresses were detected in the joint, the grain size of the weld, the near-weld zone and the base metal increased [10]. The authors [10] note that with increasing temperature, the diffusion component of the process increases. Thus, diffusion processes were identified when studying the phase-structural components at a temperature of 830 °C, a pressure of 15 MPa, and even at 550~580 °C and a pressure of 30~40 MPa.

As a result of studies of diffusion welding of dissimilar metals, it was found that it must be carried out at the lowest possible melting temperatures and a short process duration. The intermediate metal must have the lowest melting temperature in relation to the welded parts and have the greatest affinity in crystalline structure [11].

The author of the work [12] presented the results of studies of the possibility of producing bimetallic joints of the AlMn alloy with kovar (29NK alloy) and nickel (NP2 alloy) by the method of diffusion welding in a vacuum with subsequent fabrication of parts from them. The products were hollow cylindrical blanks of the AlMn alloy, into which the 29NK or NP2 alloy in the form of a cylindrical blank of solid cross-section was pressed with a force of 7000 N at a temperature of 610 °C. Analysis of the resulting joints under these welding conditions showed uniform distribution of elements across the thickness of the transition layer (up to 30 μm wide) and mutual diffusion achieved at a given temperature and welding force. Intermetallic compounds were not detected.

Analysis of literary sources showed that all welded joints were produced with an initial parallel arrangement of the welded surfaces relative to each other. The arrangement of the welded surfaces at an angle during diffusion welding was not carried out [13]. Despite the wide range of permanent joints obtained by researchers using diffusion welding, the literature does not contain any information on producing joints from copper-nickel alloy with platinum, TP 439 alloy, MPVF molybdenum (pure molybdenum manufactured by vacuum fusion) or nickel-vanadium alloy with PtBa alloy.

At the Don State Technical University, together with the Microengineering Research Institute, a number of magnetic pulse welding (MPW) processes have been developed that make it possible to abandon glancing collision and clean the surfaces to be joined by electrical erosion or vacuum heat treatment. The authors of the paper propose to carry out diffusion welding by means of pulsed magnetic fields, which provide radial pressure on the welded unit according to the “crimping” scheme [13].

As with classical diffusion welding, in this work it is proposed to heat the unit assembled for welding in a vacuum, which leads to a decrease in the resistance of materials, deformation and acceleration of stress relaxation in the joint zone, and helps to clean the surfaces being joined from adsorbed inclusions and other contaminants.

The development of the equipment was based on similar units from dissimilar connections during magnetic-pulse assembly, diffusion welding [14–16]. Fig. 2 shows the equipment for welding facing emission coatings on cylindrical surfaces of cores. The design allows pressing the welded elements during welding due to the difference in the thermal coefficients of linear expansion (TCLE) of its parts. The casing element is usually made of molybdenum, kovar or materials with low TCLE, and the ring sectors of the equipment are made of TP 439 steel with high TCLE.

Due to the presence of gaps in the ring sectors of the equipment, such defects as poor welding fusion occur during diffusion welding of the emitter with the core. With prolonged isothermal action on the processed unit, intermetallic phases often occur in the zone of conjugation of the welded surfaces.

To produce joints of dissimilar materials while maintaining an organized structure, pulse welding methods are widely used. The mechanism for cleaning the welded surfaces is realized due to the glancing collision of the thrown elements, the conjugated surfaces are cleaned with a cumulative jet and the subsequent joint deformation of the materials and, as a result, a connection in the solid phase occurs by analogy with explosion welding. The principle of glancing collision is also used in classical MPW. The energy carrier changes: instead of the action of an explosive substance, the ponderomotive force is used – magnetic pressure, which allows using the MPW technology to weld small-sized units in workshop conditions with increased requirements for process hygiene [17; 18].

For MPW, depending on the design of the assembled parts for welding, various types of inductor systems have been developed and studied, which are characterized by inductive resistance, magnetic induction in the working area, and durability during operation [13–15; 19–21].

The purpose of this work is to study the process of pulse welding in a controlled environment, which allows reducing the duration of producing a joint in the solid phase from dissimilar materials.

METHODS

In electrovacuum tubes, cathode assemblies with a diameter of d=(5–100)·10^{-3} m are used. To implement pulse diffusion welding (PDW) in a vacuum, the process is carried out using copper shells – satellites [22]. The wall thickness of the copper bushings was selected so that the penetration depth of the magnetic field H through the satellite material – the deformable bushing – did not exceed the thickness of its wall. To produce joints from refractory materials, the satellite material was replaced by nickel or molybdenum with a wall thickness of t_{sat}=0.2·10^{-3} m. When welding on developed surfaces, the heated satellite behaves like an elastic punch.

Fig. 3 shows the proposed scheme for implementing PDW. The process is carried out as follows. The core (1) with the lining (2), heating element (3) and satellite (4) are installed in the vacuum chamber and placed in the working area of the magnetic-pulse tool – inductor (6). The air in the vacuum chamber is rarefied to a pressure of 0.66·10^{-2} Pa. The heating element increases the temperature of the assembly to 700–1250 °C. The pulse current generator (5) is discharged onto the inductor (6) causing the discharge current I_d (7) to flow through the inductor. In this case, the magnetic flow H (8) induces induced currents in the satellite I_i (9). The magnetic interaction force P_m (10) arises. The satellite (4) is deformed (compressed), and the lining (2) and the core (1) are welded in the solid phase. The duration of the process with isothermal holding does not exceed 100–200 μs. When calculating the process characteristics, the following parameters were taken as

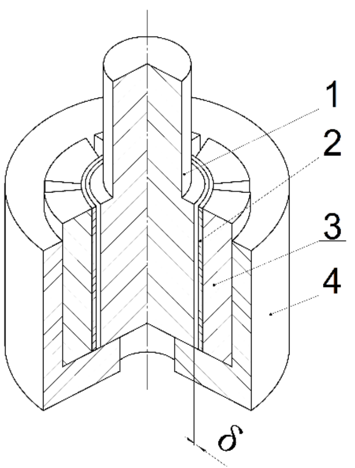

Fig. 2. *Equipment for diffusion welding of a cathode assembly:*
1 – core; 2 – emitter; 3 – ring sectors of the equipment; 4 – casing element; δ – preliminary gap
Рис. 2. *Оснастка для диффузионной сварки катодного узла в сборе:*
1 – керн; 2 – эмиттер; 3 – кольцевые секторы оснастки; 4 – корпусной элемент; δ – предварительный зазор

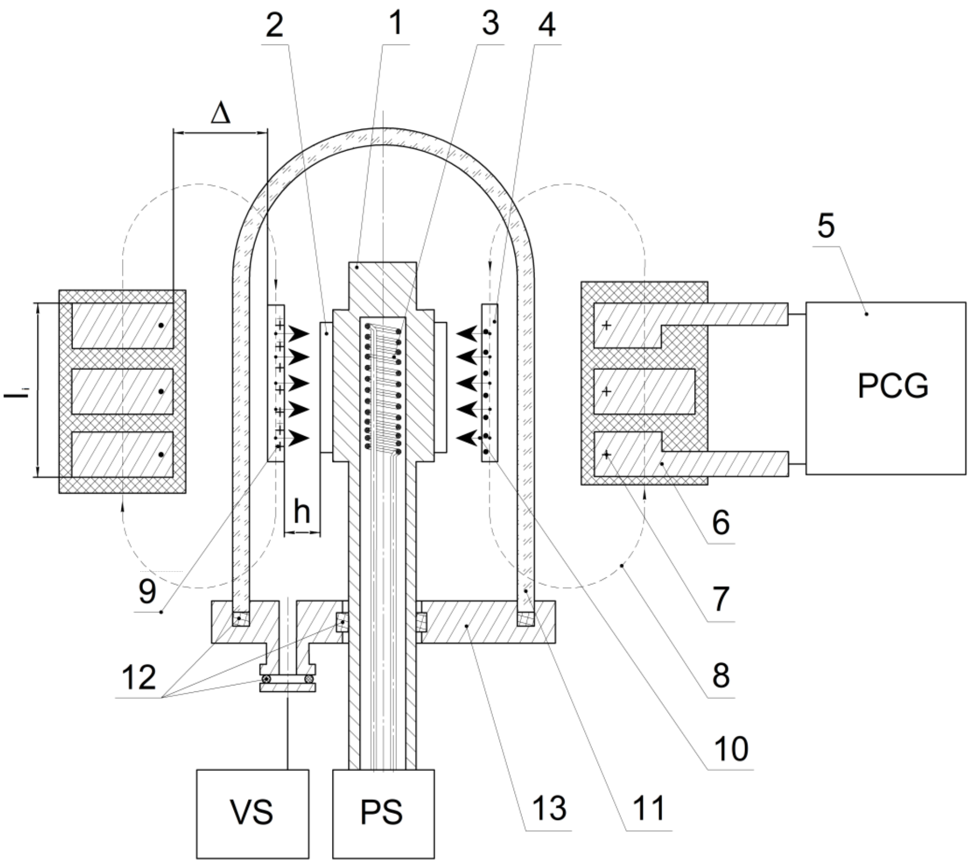

Fig. 3. *Structure diagram of a device for pulse diffusion welding in a vacuum:*
1 – base (core); 2 – lining (emitter); 3 – heating element;
4 – satellite; 5 – pulse current generator PCG; 6 – inductor; 7 – discharge current (I_d); 8 – magnetic flow (H);
9 – induced current (I_i); 10 – magnetic interaction force (P_M); 11 – dielectric cup;
12 – vacuum seal; 13 – vacuum chamber base;
PS – power source; VS – vacuum system; h – gap between the emitter and the satellite;
Δ – gap between the inductor and the satellite; l_i – length of the inductor working zone
Рис. 3. *Схема устройства импульсной диффузионной сварки в вакууме:*
1 – основание (керн); 2 – облицовка (эмиттер); 3 – нагревательный элемент;
4 – спутник; 5 – генератор импульсных токов PCG; 6 – индуктор; 7 – ток разряда (I_d); 8 – магнитный поток (H);
9 – индуцированный ток (I_i); 10 – сила магнитного взаимодействия (P_M); 11 – диэлектрический стакан;
12 – вакуумный уплотнитель; 13 – основание вакуумной камеры;
PS – источник питания; VS – вакуумная система; h – зазор между эмиттером и спутником;
Δ – зазор между индуктором и спутником; l_i – длина рабочей зоны индуктора

constants: the number of inductor turns n=6, the inductor diameter $D_i=30\cdot10^{-3}$ m, the length of the inductor working zone $l_i=45\cdot10^{-3}$ m, the capacity of the installlation storage tank $C=1500\cdot10^{-6}$ F, and the voltage on the storage tank $U_s=5\cdot10^3$ V.

The optimal parameters of the PDW process were determined in accordance with the conditions for producing high-quality welded joints given in the literature [23]. The first and second conditions are the time parameters of the process: the MPW implementation should be completed in ½ of the current discharge period, including the time of contact melting, electroexplosive cleaning, shaping and welding. The third condition states that the values of the induced current density for welding each material must be provided in the range I_{min}–I_{max}. The fourth condition describes the time relationships of solid-phase interaction: the duration of contact stresses in the joint zone should be longer than the time of deformation activation of the contact surface and the relaxation time (relaxation characteristics of the blank and temperature in the interaction zone). The fifth condition consists in determining the specific impulse of the first half-wave of magnetic pressure, taking into account the tool parameters – the inductor, the operating voltage and inductance of the pulse current generator (PCG), the value of which will allow determining the magnitude of the relative deformation ε to level the initial gap between the inductor and the satellite wall. The presented limitations for the operating frequency of the process allow determining the frequency characteristics of the magnetic-pulse equipment, taking into account the low penetration of the magnetic flow into the gap between the inductor and the satellite to ensure cleaning of the welded surfaces – this is the sixth condition of high-quality processing.

Diffusion welding modes were tested in controlled environments on the Impulse–BM magnetic-pulse processing unit manufactured at Microengineering Research Institute (Rostov-on-Don, Russia) [24]. The same equipment is used to implement the technology of pressing, sintering and welding of facing coatings from powder compositions.

The quality of the welded joints produced by pulse diffusion welding was determined based on the test results: leak testing with a TI1-50 helium leakage detector (Russia), GOST 3242-79, mechanical shear testing on a UMM-10 machine (Russia), GOST 6996-66, metallographic analysis of the produced joints using a PMT-3 microhardness tester (Russia), GOST 9450-76, multiple cyclic heating in a vacuum by electron bombardment and tenfold heating to a temperature of 1000 °C with holding for 1 h and gradual cooling. The heating and cooling time did not exceed 1 h, which should ensure a vacuum level of at least $0.66 \cdot 10^{-2}$ Pa during testing.

RESULTS

From the dependences of the welded joint shear strength τ on the process temperature *T* for two values of the input energy of 10 and 12 kJ, it is evident that with an increase in the input energy, the shear strength increases (Fig. 4). At the same time, with an increase in the process temperature, the strength indicators also increase. The highest strength indicators of the samples were found in the temperature range of 500–1000 °C.

Table 1 presents the results of tests for the tightness and mechanical strength of joints of M0b copper with Pt obtained at different degrees of vacuum (pressure). From the obtained data, it follows that with an increase in the degree of vacuum from $1 \cdot 10^{-3}$ to $5 \cdot 10^{-4}$ Pa, the quality of the welded joints improves due to the cleaning of the joint zone from contaminants, solid-phase interaction occurs over the entire area of impact of the welded surfaces with a clear boundary of the joint zone.

Fig. 5 illustrates the reduced calculated dependences of the inductance $L_{i\text{–}b}$ and active resistance $R_{i\text{–}b}$ of the inductor-blank system, the operating frequency f_o, the magnetic interaction force P_m, the specific impulse of the first half-wave of the magnetic pressure J_M, the mean time between failures of the inductor N_i on the gap between the inductor and the copper satellite Δ. The gap value Δ depends on the manufacturing accuracy of the satellite itself. The air gap is necessary for feasibility cleaning from contaminants, oxide films under the radial action of ponderomotive forces arising from the interaction of the inductor magnetic flow with induced currents in the satellite wall. The obtained dependences of the quality of the welded joint are conventionally divided into 4 zones: 1) a gap of $(0\text{–}2.1) \cdot 10^3$ m – it is impossible in terms of design to assemble the unit in the inductor; 2) a gap of $(2.2\text{–}3.5) \cdot 10^3$ m is characterized by low performance characteristics and service life of the cathode assembly; 3) an initial gap of $(3.6\text{–}6.1) \cdot 10^3$ m allows producing high-quality welded joints characterized by long service life; 4) a gap of more than $6.1 \cdot 10^3$ m – the efficiency of magnetic pulse action decreases, such defects as poor welding fusion are possible in welded joints.

If the conditions for high-quality material processing are met [23], PDW made it possible to produce permanent joints from the following metals and alloys used when manufacturing electronic products. Base material: M0b alloy, Ni, TP 439 steel, copper-nickel alloy, 29NK alloy, MPVF molybdenum (pure molybdenum manufactured by vacuum fusion), nickel-vanadium alloy. Lining material: Al–Ba, Ni, Pt, Pt–Ba, Ir–La.

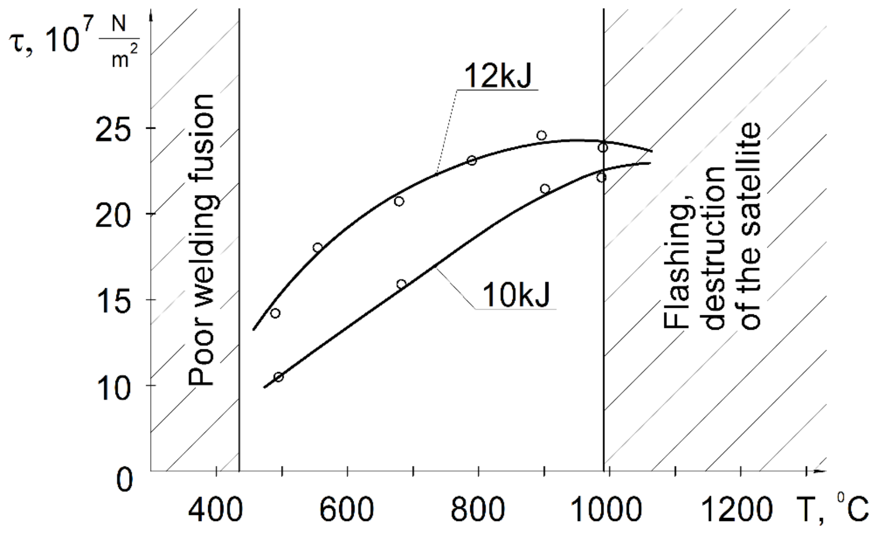

Fig. 4. *Dependence of shear strength τ of the Pt + MPVF joint on the preheating temperature T and pulse energy W*
Рис. 4. *Зависимость прочности соединения на срез τ соединения Pt + МЧВП (молибден) от температуры предварительного разогрева T и энергии импульса W*

Table 1. *Results of tests for tightness, mechanical strength of joints of M0b copper with Pt obtained at different degrees of vacuum (pressure) in the process chamber*
Таблица 1. *Результаты испытаний на герметичность, механическую прочность соединений меди М0б с Pt, полученных при различной степени разрежения (давлении) в технологической камере*

No.	Pressure, Pa	Results of metallographic analysis after thermal testing	Shear strength, τ $N/m^2 \cdot 10^7$	Leakage, $m^3 \cdot Pa/s$
1	1·10	Buckle	5.0	$1\cdot10^{-4}$
2	$5\cdot10^{-1}$	Buckle	7.5	$1\cdot10^{-4}$
3	$5\cdot10^{-2}$	Pockets and laminations	11.5	$4\cdot10^{-6}$
4	$1\cdot10^{-2}$	Discontinuous poor welding fusion	13.5	$1\cdot10^{-7}$
5	$5\cdot10^{-3}$	No pockets and laminations	14.5	$5\cdot10^{-13}$
6	$1\cdot10^{-3}$	No pockets and laminations, clear joint boundary	15.0	$5\cdot10^{-14}$
7	$5\cdot10^{-4}$	No pockets and laminations, clear joint boundary	15.0	$1\cdot10^{-15}$

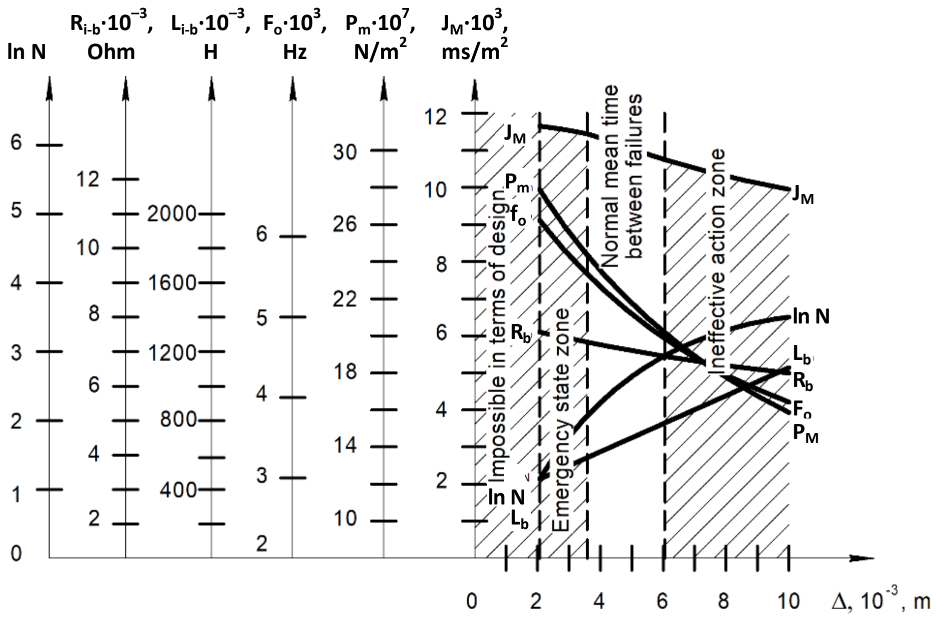

Fig. 5. *Calculated dependencies: Δ of the inductance $L_{i–b}$ and active resistance $R_{i–b}$ of the inductor-blank system, the operating frequency f_o, the magnetic interaction force P_m, the specific impulse of the first half-wave of magnetic pressure J_M and the mean time between failures of the inductor N_i on the gap between the inductor and the satellite Δ*
Рис. 5. *Расчетные зависимости: Δ индуктивности $L_{i–b}$ и активного сопротивления $R_{i–b}$ системы «индуктор – заготовка», рабочей частоты f_o, силы магнитного взаимодействия P_m, удельного импульса первой полуволны магнитного давления J_M и наработки на отказ индуктора N_i от зазора между индуктором и спутником Δ*

Geometric dimensions of the joints: base diameter d=20 mm, sample length L=40 mm. Fig. 6 shows the obtained PDW units consisting of a molybdenum core (pos. 1) with Pt–Ba emitters (pos. 2).

The optimal parameters of the PDW processes for the following cathodes of ultra-high-frequency electrovacuum tubes were determined and experimentally confirmed by calculation [23].

1. Base: core – copper-nickel alloy, diameter is 12 mm; lining: emitter – Pt, thickness is 0.1 mm, length is 20 mm. PDW mode: operating temperature is T=700 °C, input energy is W=6 kJ, magnetic pressure is P_m=10.2·10^7 N/m^2.

2. Base: core – TP 439 high-alloyed steel, diameter is 12 mm; lining: emitter – PtBa alloy, wall thickness is 0.2 mm, length is 20 mm. PDW mode: operating temperature is T=700 °C, input energy is W=8.67 kJ, magnetic pressure is P_m=12.0·10^7 N/m^2.

3. Base: core – MPVF molybdenum (pure molybdenum manufactured by vacuum fusion), diameter is 17 mm; lining: emitter – PtBa alloy, thickness is 0.1·10^{-3} mm,

Fig. 6. *Cathode assemblies produced by pulse diffusion welding: molybdenum core (1) with Pt–Ba emitter (2)*
Рис. 6. *Катодные узлы, полученные ИДС: молибденовый керн (1) с эмиттером Pt–Ba (2)*

length is 30 mm. PDW mode: operating temperature is T=900 °C, input energy is W=10.26 kJ, magnetic pressure is P_m=14.22·10^7 N/m^2.

4. Base: core – nickel-vanadium alloy, diameter is 18 mm; lining: emitter – PtBa alloy, thickness is 0.15 mm, length is 40 mm. PDW mode: operating temperature is T=1000 °C, input energy is W=13.23 kJ, magnetic pressure is P_m=18.33·10^7 N/m^2.

DISCUSSION

The analyzed results of using diffusion welding to join dissimilar metal pairs showed that their diversity is small: Al–Cu, Cu–Ti, AlMn–29NK. As a rule, to reduce the likelihood of intermetallic compounds, an intermediate metal is used that has good adhesion to the welded metals and a low melting point. The results of studies of joints made by diffusion welding of metal pairs – copper-nickel alloy + Pt, TP 439 steel + PtBa, MPVF molybdenum + + PtBa, nickel-vanadium alloy + PtBa – were not found in the literature.

Researchers have shown that at temperatures above 700 °C, intermetallic compounds are formed during diffusion welding. At temperatures of 350–700 °C, solid solutions of the welded metals with an intermediate one often appear [17–21]. The process scheme proposed by the authors is implemented in the temperature range of 700–1250 °C, which should initiate the formation of intermetallic phases, but due to the short duration of the magnetic-pulse action process of 100–200 µs, their presence in the structure was not detected.

Magnetic pulse welding is mainly used to produce dissimilar joints with high electrical and thermal conductivity, usually Al+Cu. Cleaning during MPW is implemented due to the cumulative jet, which occurs during glancing collision of metals. During magnetic pulse welding of female structures, the cumulative jet is obtained due to the conical shape of one of the welded parts. The developed designs of inductor systems allow concentrating ponderomotive forces in the magnetic-pulse action zone with a magnetic induction value of up to 100 T [13–15; 17–21]. However, the use of composite inductors has a significant drawback – the presence of an uneven magnetic field at the junction of the component elements of the inductor sector, which reduces the quality of the welded joint. The twisted inductors used by the authors of the paper have a shorter service life under normal atmospheric pressure compared to sectional inductors; however, this is justified by the fact that they have a uniform distribution of the magnetic field. Moreover, the durability of twisted inductors is compensated by heating the welded products before welding in a vacuum to temperatures of 700–1250 °C, which reduces the amount of input energy, as well as their location outside the heating zone (separated by a heat-resistant, vacuum-tight dielectric (quartz or ceramic) glass), which has not been used by researchers before. This design scheme allows welding of facing joints in a high vacuum with heating of the assembly to a temperature above 700 °C without destruction of the insulation of the tool – the inductor to produce permanent joints from dissimilar pairs of metals of a wider range.

At the same time, as the authors of works on PDW note, the presence of a gap between the inductor and the welded parts reduces the efficiency of magnetic-pulse action [19–21]. Thus, with magnetic-pulse action through a quartz glass on a unit placed in a vacuum (Fig. 5), the greatest efficiency of the Pt + MPVF joint is achieved at temperatures of 500–1000 °C, for other pairs of metals, the temperature can reach 1200 °C. At lower temperatures in the joint zone, poor welding fusion is observed, at a temperature above 1000 °C, melting and destruction of the copper satellite occurs.

The analysis of the calculated data allowed determining the non-conductive gap zone Δ equal to (4÷6)·10^{-3} m, which is feasible in terms of design and ensures reliable operation of the tool located in the atmosphere, and the corresponding parameters of the process, equipment and inductor tool: $L_{i–b}$, $R_{i–b}$, f_o, P_m, J_M, and N_i.

The analysis of welded joints produced in optimal modes showed the presence of a clear boundary of the materials being joined, the absence of common grains, increased microhardness in the joint zone, which is typical for various types of solid-phase welding [13] using the example of cathode pairs of pure molybdenum manufactured by vacuum fusion and nickel-vanadium alloy with PtBa alloy.

Visual inspection did not reveal any buckles of the emitter, i.e. no poor welding fusion was detected. In the absence of a high-quality solid-phase connection between the emitter and the core, the latter melts during operation at the site of poor welding fusion. The analysis of welded joints showed that the formation of the joint occurs in the solid phase, which reduces the probability of the presence of intermetallic inclusions in the joint zone, thereby increasing the service life of the products.

The technology of pulse diffraction welding of cathodes of electrovacuum tube devices was developed at the Micro-engineering Research Institute together with Don State Technical University and implemented at Tantal (Open Joint Stock company). As a result of developing the new process, it was possible to reduce the labor intensity of welding cathode assemblies by 10 times.

CONCLUSIONS

Analysis of the produced welded joints showed that the joint is formed in the solid phase, which reduces the probability of the presence of intermetallic phases in the joint zone, thereby increasing the service life of electronic equipment.

A design scheme of special technological equipment for pulse diffusion welding with an inductor in the atmosphere and a heated welded unit in a vacuum was developed and implemented, which made it possible to ensure the necessary operability of the equipment and reduce the labor intensity of producing secondary-emission cathode assemblies of ultra-high-frequency electrovacuum tubes.

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Импульсная диффузионная сварка охватывающих соединений

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Аннотация: Особенностью эксплуатации электровакуумных приборов, в частности катодного узла, является постоянный нагрев за счет бомбардировки его поверхности электронами. Стабильные характеристики и стойкость катодного узла зависят от качественного соединения (сварки) поверхностей керна с эмиттером по всей площади нахлесточного сопряжения. Использование диффузионной сварки для соединения катодного узла из разнородных материалов не представляется возможным по причине возникновения непроваров из-за наличия зазоров в кольцевых секторах оснастки, а следовательно, снижения срока службы катодного узла. Авторами предложено реализовать процесс путем совмещения магнитно-импульсной сварки с диффузионной. Оригинальность работы заключается в возможности дистанционного воздействия на соединение через диэлектрический кварцевый стакан, который входит в состав технологической вакуумной камеры. Индукторная система находится снаружи кварцевого стакана, что позволяет осуществлять нагрев собранного узла без нагрева инструмента – индуктора из разнородных материалов – до температуры 700 °С и выше. Определены основные параметры процесса импульсной диффузионной сварки в вакууме: давление в рабочей камере B=0,66·10^{-2} Па (5·10^{-5} мм рт. ст.); температура предварительного разогрева T=700–1250 °С; энергия импульса магнитного поля W=5÷17 кДж; рабочая частота разряда импульсов тока f_p=5–15 кГц; магнитное давление $P_м$>·10^7 Н/м^2. Таким образом были получены катодные узлы широкой номенклатуры сочетаний пар металлов с диаметром основания d=20 мм и длиной образца L=40 мм. Предложенная технология успешно реализована и внедрена на ОАО «Тантал». Экономический эффект заключается в снижении трудоемкости и получении соединений стабильного качества.

Ключевые слова: импульсная диффузионная сварка; сварка охватывающих соединений; магнитно-импульсная сварка; индуктор; магнитное давление; вводимая энергия; разнородные сплавы.

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