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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF THE GASDYNAMICS OF THE DISCHARGE CHAMBER ON THE POWER CHARACTERISTICS OF VORTEX PLASMATRONS WITH AN INTERELECTRODE INSERT

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The author investigated experimentally the effect of the gasdynamics of the discharge chamber on the power characteristics of vortex plasmatrons with a sectioned interelectrode insert and a gas curtain of the sections, with porous bushings of the sections that ensure radial and tangential injections of the working gas into the discharge channel of the chamber, and with a water-cooled solid interelectrode insert. Results of the investigations demonstrate a substantial effect of the gasdynamics of the discharge chamber on the power characteristics of vortex plasmatrons with interelectrode inserts.

A comparative analysis of electric-arc plasmatrons of various schemes demonstrates that plasmatrons with vortex stabilization of the arc discharge are the most promising in terms of efficiency, service life, and the power level. It is vortex plasmatrons with an interelectrode insert (IEI) that find the widest application.

Vortex plasmatrons with an IEI have been developed with end, core, thermal, and thermochemical cathodes, as well as with hollow copper ones [1]. The interelectrode inserts in these plasmatrons are made in the form of solid or sectioned diaphragms; a vortex gasdynamic IEI is also realized [2]. The use of IEIs makes it possible to improve the stability of the parameters of the generated plasma flow due to fixing of the arc's length and to increase the arc-discharge strength by contraction of the arc in the discharge channel and the efficiency of the plasmatron and the service life of the electrodes made of copper by increasing their inside diameter.

In plasmatrons with sectioned IEIs, for generation of high-enthalpy plasma flows, injection of the working gas distributed among the sections is usually executed through short vortex chambers ($h/R << 1$). As was shown by investigations of short vortex chambers [3], at low flow rates of the working gas at the periphery of the chamber special features of the flow emerge that do not allow optimization of the circular velocity at the inlet to the discharge channel, and therefore direct injection of the working gas into the discharge channel is more efficient. Figure 1 presents profiles of the circular velocity in the discharge channel of a plasmatron in diaphragmed and direct injections of the working gas into the discharge channel. The circular velocity is measured with a laser anemometer; the air flow rate is 2 g/sec and the discharge-channel diameter is d = 20 mm.

In diaphragmed injection through a short vortex chamber, the air entered through vortex generators with two tangential ∅3 mm holes; the injection radii were 18.5 and 43.5 mm. Direct injection into the discharge channel was also executed through two tangential ∅3 mm holes; the injection radius was 14.5 mm.

In direct injection of the gas into the discharge channel, the circular-velocity profile differs from the profile of diaphragmed injection and, in the axial zone, the circular velocity is higher (Fig. 1), which contributes to intensification of the heat exchange of the working gas with the arc discharge. Furthermore, direct injection also makes it possible to produce gas curtains for IEI sections by releasing part of the injected gas at the periphery of the gap between the IEI sections.

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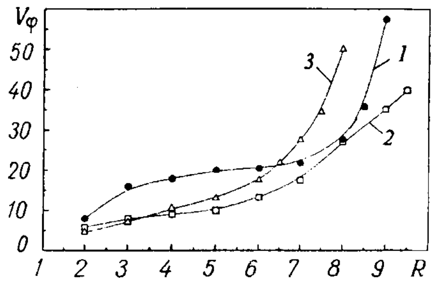


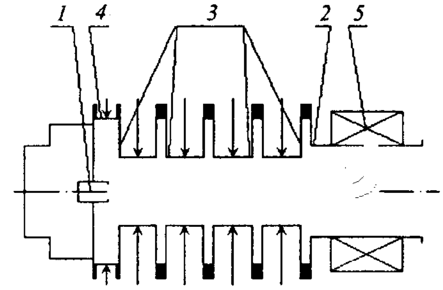
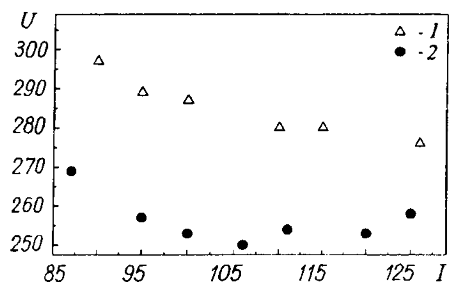


Fig. 1. Radial circular-velocity profiles in the cross section of a swirl in a discharge channel: 1) direct injection into the discharge channel (R = 14.5 mm); 2 and 3) diaphragmed injection through a short vortex chamber (R = 43.5 and 18.5 mm).

Fig. 2. Diagram of a plasmatron with a porous IEI: 1) cathode; 2) anode; 3) sections of the porous IEI; 4) vortex generator of a short vortex chamber; 5) solenoid.



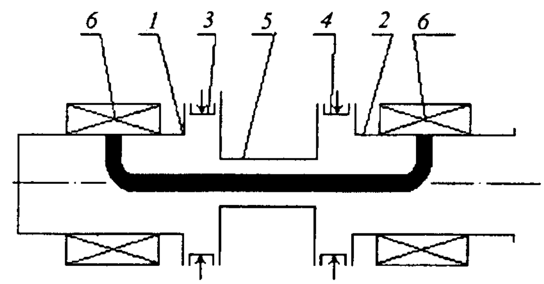


Fig. 3. Volt-ampere characteristics of plasmatrons with a porous IEI (a flow rate of nitrogen of 16.5 g/sec): 1) radial and 2) tangential injection of the working gas.

Fig. 4. Diagram of a plasmatron with a solid IEI: 1) cathode; 2) anode; 3 and 4) cathode and anode vortex chambers; 5) water-cooled solid IEI; 6) solenoids.

An experimental investigation of an electric-arc plasmatron with an IEI with supply and release of a stabilizing gas in operation with air confirmed the efficiency of this method. The thermal efficiency of the plasmatron at a pressure of 25 atm, a current of 950 A, and an arc voltage of 3.5 kV amounted to 90%. The enthalpy level on the axis of the plasma jet attained 45 MJ/kg with a bulk enthalpy of about 4 MJ/kg, which indicates the presence of a high-enthalpy core that is localized in the axial zone and has limited heat and mass exchange with the peripheral gas flow. The enthalpy on the jet axis was calculated by the Fay–Riddel equation [4] from heat fluxes measured in a calorimeter. The maximum density of the heat flux to the wall of the stabilizing discharge channel did not exceed 2 kW/cm^2.

Interelectrode inserts can also be made of porous materials, through which the working gas is injected radially; this leads to intensification of heat exchange and equalization of the temperature over the cross section of the discharge channel. Porous injection makes it possible to substantially increase the power put into the gas. Here, it becomes unnecessary to cool the IEIs, which contributes to improvement of the thermal efficiency of such plasmatrons [5].

Through porous IEIs, the working gas can also be injected tangentially using specially manufactured porous bushings. To investigate the effect of this injection of the working gas through a porous bushing, we manufactured a plasmatron whose diagram is presented in Fig. 2.

The plasmatron is made with an end cathode 1 with a zirconium insert and a water-cooled copper anode 2, with a replaceable sectioned IEI with tangential and radial injection of the working gas through sec-

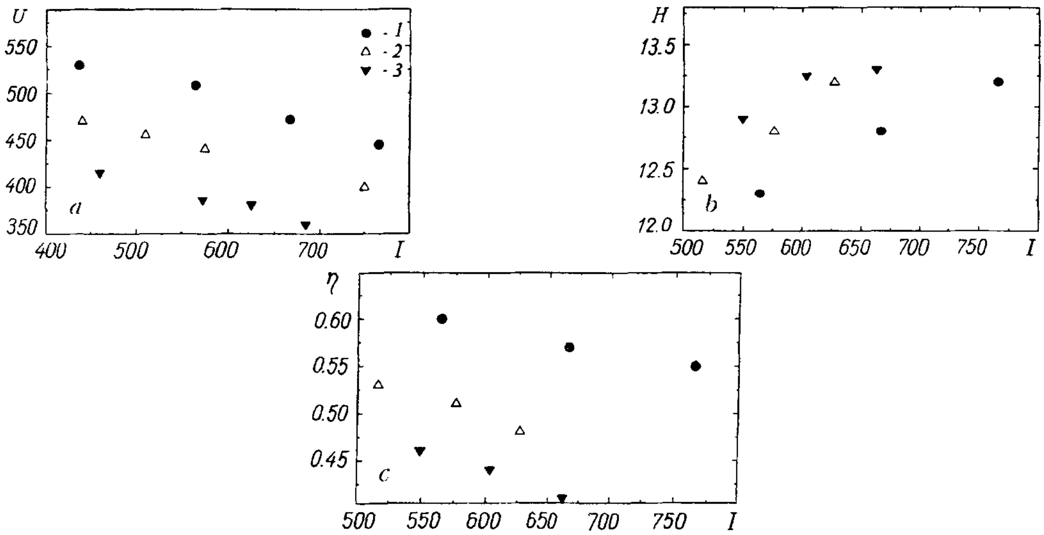


Fig. 5. Volt-ampere characteristics of a plasmatron with a solid IEI (a), bulk enthalpy of the generated plasma flow (b), and plasmatron efficiency (c) for an air flow rate of: 1) 14 g/sec; 2) 10; 3) 8.

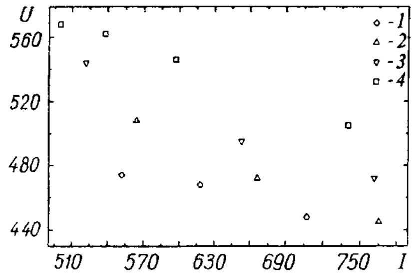
tions 3. The inside diameter of the IEI is 15 mm and the length of the replaceable IEI is 50 mm. To move the arc's reference spot over the surface of the anode, we installed on it a solenoid 5 connected in series with the anode in the supply system of the plasmatron. The total flow rate of the working gas was 16.5 g/sec. Figure 3 gives volt-ampere characteristics (VACs) of plasmatrons with radial and tangential injection of the working gas. The volt-ampere characteristics of the plasmatron with radial injection of the working gas are somewhat higher than those of the plasmatron with tangential injection; however the stability of the arc parameters in the plasmatron with tangential injection is better. In the IEI with radial injection, we observed electrical breakdowns in the gaps between the sections; no similar cases were noted in tangential injection.

In addition to determining the VAC parameters, we measured heat-flux densities on the axis of the generated plasma jets at a distance of 30 mm from the anode end. According to the data of the VACs (Fig. 3), at equal flow rates the arc-discharge power in the plasmatron with tangential injection is lower over the entire range of variation of the arc current than in the plasmatron with radial injection. However the heat-flux density in tangential injection was 15–20% higher.

The results of the experiments show that use of IEIs with tangential injection of the working gas fosters formation of a high-temperature core and improves the reliability of plasmatron operation due to an increase in the thickness of the cold gas interlayer at the periphery of the discharge channel.

We also investigated the effect of the gasdynamics of the discharge chamber of a plasmatron with a water-cooled solid IEI on its power characteristics. A diagram of the plasmatron is presented in Fig. 4.

Water-cooled cathode 1 and anode 2 are made of copper with equal inside diameter of 40 mm and length of 170 mm. The inside diameter of diaphragm 5 is 20 mm and length is 70 mm. To move the arc's reference spots, we installed, on the electrodes, solenoids 6, series-connected in the supply system of the plasmatron. The working gas was injected into the discharge chamber through cathodic 3 and anodic 4 short vortex chambers. The vortex generators in the two chambers are identical, with four tangential ∅3 mm holes. The experiments were conducted at an air flow rate of 8, 10, and 14 g/sec and equal flow rates of air through the cathode and anode vortex chambers. All the water-cooled elements of the discharge chamber of the plasmatron were measured calorimetrically by measuring the flow rate of the water and the temperature at the inlet and the outlet of the water-cooled element. The plasmatron VAC is presented in Fig. 5a, and the bulk enthalpy of the generated plasma flow is shown in Fig. 5b. Judging from the bulk enthalpy of the generated plasma flow, we can note that, as the air flow rate decreases, the bulk enthalpy of the generated plasma flow increases with the arc current but the plasmatron efficiency decreases (Fig. 5c).



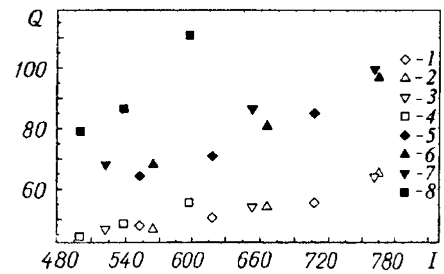


Fig. 6. Volt-ampere characteristic of a plasmatron with a solid IEI for an air flow rate of 14 g/sec with a change in the relation of the flow rates through the cathode and anode vortex chambers: 1) flow rate of 6 g/sec through the cathode chamber and 8 g/sec through the anode chamber; 2) 7 and 7; 3) 8 and 6; 4) 10 and 4.

Fig. 7. Heat losses in the cathode (1-4) and in the anode and the interelectrode insert (5-8) for a flow rate of air of 14 g/sec with a change in the relation of the flow rates through the cathode and anode vortex chambers: 1 and 5) flow rate of 6 g/sec through the cathode chamber and 8 g/sec through the anode chamber; 2 and 6) 7 and 7; 3 and 7) 8 and 6; 4 and 8) 10 and 4.

We also conducted experiments with a change in the flow rate of the air through the cathode and anode vortex chambers with a constant total flow rate of 14 g/sec; the VAC is presented in Fig. 6.

An increase in the air flow rate through the cathode vortex chamber (6, 7, and 8 g/sec) makes the drop in the arc voltage higher, and here the heat losses change insignificantly in the cathode but increase in the IEI and the anode (Fig. 7).

The experimental investigations of the effect of the gasdynamics of the discharge chamber of a vortex plasmatron on its power characteristics indicate its significant action. The parameter distribution of the working-gas flow in the plasmatron's discharge chamber is governed by its geometry, the method of swirl, and the parameters of the working-gas flow at the inlet to the cavity of the discharge chamber through the vortex generator. Any gasdynamic scheme of a vortex plasmatron can always be represented in the form of an arrangement of short ($h/R \ll 1$) and long ($h/R > 1$) vortex chambers. The short vortex chambers are employed for swirling the flow of the working gas, while in the long vortex chambers interaction of the arc discharge with the working gas is realized. In these chambers, there are typical features of the flow that should be employed purposefully in developing the scheme of a discharge chamber [6].

A study of the effect of the swirl rate of the working gas at the inlet to the discharge channel showed its significant action on the power characteristics of vortex plasmatrons [7]. Thus, when the structure of a vortex plasmatron is developed, it should be borne in mind that the selected scheme of the plasmatron and the specific geometry of the discharge chamber require optimization of the swirl parameters of the working gas injected into the discharge chamber. The performed experimental investigations of the effect of the gasdynamics of the discharge chamber of vortex plasmatrons on their power characteristics indicate that this is one of the main directions for optimization of the parameters of the generated plasma flow and the plasmatron efficiency and service life.

NOTATION

R and h, radius and height of the vortex chamber, mm; d, diameter of the discharge channel, mm; V_φ, circular velocity, m/sec; U, arc voltage, V; I, arc current, A; H, enthalpy of the generated plasma flow, MJ/kg; Q, heat losses to the water-cooled elements of the discharge chamber, kW; η, plasmatron efficiency.

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