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ELECTRICAL AND THERMAL STRUCTURE OF THE ARGON ARC OF A TWO-JET PLASMATRON

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The thermal structure and the distribution of the axial electric field strength of the arc of a two-jet plasmatron were investigated experimentally.

Characteristic features of two-jet plasmatrons (plasma generators) are the high thermal efficiency, up to 90% [1], and the presence of an exterior stabilized electric arc. Because of this plasmatrons of such type are of great promise for application in chemical technology, heat engineering, deposition techniques, spectroscopy, etc. [2-4]. The literature, however, contains no information about the results of investigations of two-jet plasmatrons with the heads opposite one another.

The aim of the present work was to determine the electrical and thermal structure of the arc burning in the open atmosphere between the opposite heads of a two-jet plasmatron and stabilized by argon streams at atmospheric pressure.

During the experiment the plasmatron, which was equipped with a rod-type thermionic tungsten cathode and an everlasting end-type copper anode [5], operated in the following conditions: arc current I = 100-200 A, voltage U = 100-300 V, flow rate of plasma-forming gas through each of the heads $G_a = G_c = (0.25\text{-}0.5)\cdot 10^{-3}$ kg/sec. The diameters of the head nozzles were $(5\text{-}7)\cdot 10^{-3}$ m, and the distance between the nozzle exits was varied in the range $L = (5\text{-}25)\cdot 10^{-2}$ m. These ranges of controlling parameters were optimal, and the alteration of even one of them in either direction led to destruction of the heads or to arrest of the arc.

The electric field strength along the arc axis was investigated with the aid of movable tungsten probes, which moved perpendicular to the arc axis at a speed W = 1 m/sec. The results of the measurements are presented in Fig. 1 (curves 1), which shows that the electric field was strongest near the nozzle exits and decreased with increasing distance from them: At a distance of about $4\cdot 10^{-2}$ m the field strength was $E = (6\text{-}7)\cdot 10^{2}$ V/m, which is a typical value for freely burning unstabilized argon arcs [6]. We can divide the arc lengthwise into five regions. The initial regions of the cathode and anode jets (in Fig. 1 from the nozzle exits to sections A and D, respectively) are characterized by an electric field strength that depends on the nozzle diameters and the argon flow rate. In these regions the arc is compressed and is stabilized by the rigid jets of plasma-forming gas issuing from the nozzles.

In the regions with fully developed flow (in Fig. 1 from section A to section B and from C to D) the field strength along the axis is constant and is practically independent of the arc burning conditions, which in view of the measured value $E = (6\text{-}7)\cdot 10^{2}$ V/m indicates laminar flow of the jets [7, 8]. In these regions the arc is spatially stable. The arc bends readily under the action of a transverse stream of gas, but when the stream is removed the arc resumes its former position. The length of these regions depends on the flow rate of the plasma-forming gas, the distance between the nozzle exits, and the lengths of the regions in which the jet flow is laminar.

The dimensions of the region where the anode and cathode plasma jets meet (between sections B and C in Fig. 1) depend on the distance L and the argon flow rate. Beginning at $L = 15\cdot 10^{-2}$ m or more, the gas discharge in this region is unstable, and the scale of the instability increases with increase in the size of this region. The appearance and development of instability cause an increase in the voltage fluctuations on the arc, which can reach 40%

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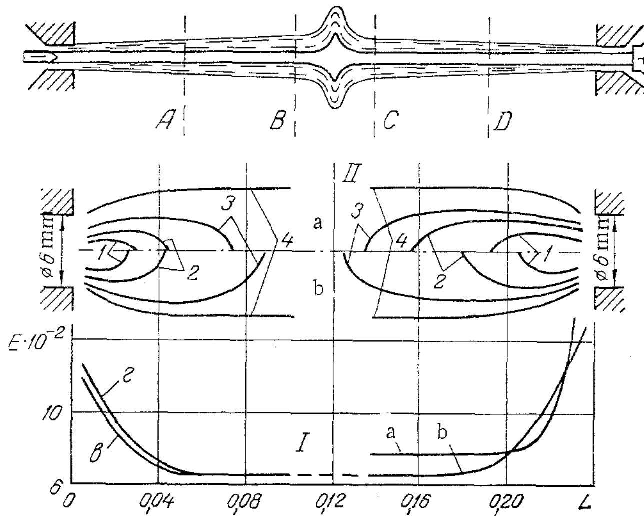

Fig. 1. Axial distribution of electric strength (curve I) and temperatures (curves II) in argon arc for I = 150 A: a) $G_c = G_a = 0.5 \cdot 10^{-3}$ kg/sec; b, c, d) $0.25 \cdot 10^{-3}$ kg/sec; c) $d_c = 6 \cdot 10^{-3}$ m; d) $d_c = 7 \cdot 10^{-3}$ m. 1) $T = 12 \cdot 10^3$; 2) $11 \cdot 10^{-3}$; 3) 10^4; 4) $9 \cdot 10^3$ K. L in m, E in W/m.

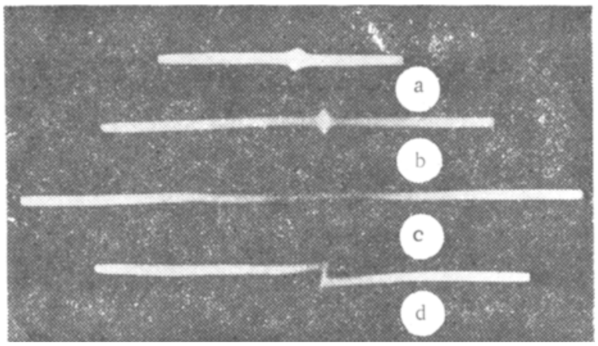

Fig. 2. Photographs of exterior arc of a two-jet plasmatron with different distances between the opposite heads: a) L = 0.125; b) 0.210; c) 0.295; d) 0.230 m.

of the nominal value when $L = 25 \cdot 10^{-2}$ m. Figure 2 shows photographs illustrating the behavior of the arc in the region where the plasma jets meet. The photographs clearly show the plasma disk (Fig. 2a, b), the conversion of the arc to a diffuse discharge (Fig. 2c), shunting and transverse oscillations of the arc (Fig. 2d). The screw instability reported in [8, 9] was not observed. This can probably be atrributed to the good stabilization of the arc by the streams of plasma-forming gas.

From an examination of the relation $E = f(L)$, shown in Fig. 1 (curve 1), surrounding atmosphere and the arc burns in pure argon, which was confirmed by the results of qualitative spectral analysis of the arc at different cross sections. The spectograms obtained with an ISP-28 quartz spectrograph at 3-cm intervals along the arc contained the ArI and ArII lines and a continuum. No nitrogen or oxygen emission lines, which are characteristic of atmospheric air, were detected. The probable reason for this is that the gas in the discharge moves mainly in the axial directions and radially from the center to the periphery. Thus, a protective laminar argon sheath with insignificant excess pressure is formed and prevents the penetration of air into the arc. Laminar outflow of the jets at flow rates $(0.25\text{-}0.5) \cdot 10^{-3}$ kg/sec was indicated by the low noise of the arc (up to 80 dB) and its spatial stability.

In the conditions of this experiment stable burning of the arc was obtained when the plasma jets emerging from the nozzles had the following flow parameters: Reynolds number Re = 200-400, Mach number M = 0.08-0.16, outflow speed V = 140-280 m/sec, which also indicates the laminar nature of the outflow.

The thermal structure of the arc burning between opposite heads of a two-jet plasmatron was investigated by the method involving the absolute intensities of the Ar I 4300 Å and Ar II 4806 Å lines. The absolute line intensities were found by comparison with the emission of the anode crater of a dc carbon arc in the prehissing state. The standard radiation source and the investigated arc were photographed in identical conditions. Figure 1 (curves II) shows the isotherms of the investigated arc, obtained from the mean values of five measurements. As was to be expected, the temperature was greatest at the nozzle exits (12,000°K), and decreased with increasing distance from them; at a distance of $8 \cdot 10^{-2}$ it was about 9000°K. The distance in temperatures of electrons and heavy particles in the plasma was determined from the formula [6]

$$\frac{T_e - T_g}{T_e} = \frac{m_g}{4m_e}\left(\frac{2\lambda_e eE}{3KT_e}\right)^2.$$

For the considered case $T_e - T_g \approx 50°K$. Hence, we can assume local thermal equilibrium (LTE) in the investigated arc, since for an argon plasma the condition $T_e - T_g \leqslant 2\%\ T_e$ is confirmation of the existence of LTE [10]. The same inference can be made from the results of investigations of other authors. According to the data of [11], the region of existence of LTE in an AR plasma at atmospheric pressure lies above $N_e \geqslant 5 \cdot 10^{15}$ cm^{-3}. The results of investigations given in [12] indicate that at $T_e = (9\text{-}12) \cdot 10^3$ °K the electron concentration in a plasma with such parameters is $N_e = (5.3\text{-}66.7) \cdot 10^{15}$ cm^{-3}, i.e., the condition for LTE in the considered case is amply fulfilled. The existence of LTE in the investigated arc was also indicated by calculations of the mean conductivity of argon, made from the formula $\sigma = I/ES$, which agreed with calculations of the conductivity from the mean plasma temperature to within 10%. The conductivity in different cross sections varied in the range 0.25-0.35 $\Omega^{-1} \cdot m^{-1}$.

It is apparent from the distribution of the isotherms that after the jets emerge from the nozzles their thermal diameter increases by 30-45% and then remains the same until they meet.

NOTATION

E, electric field strength; T_e and T_g, temperatures of electrons and heavy particles; m_g, mass of heavy particles; e and m_e, charge and mass of electron; λ_e, mean free path of electrons; K, Boltzmann constant; N_e, electron concentration.

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THE IMPEDANCE OF AN ELECTRODYNAMIC, COAXIAL PLASMA ACCELERATOR

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The properties of the impedance of an electrodynamic plasma accelerator are investigated. Drawing upon an analysis of the generalized Ohm's law, the factors resulting in a decrease in impedance, observed when the "extension currents" of the coaxial gun are blocked, are discussed.

The impedance z of the accelerator system plays an important role in the determination of the macroscopic properties of an electrodynamic plasma accelerator. The impedance consists of two components: ohmic (z_1) and electrodynamic (z_2) [1]. Depending on which of these components prevails, one can judge the character of the occurrence of the plasma-acceleration process [2, 3]. Therefore, it is important to know the laws of variation of these components over the time of operation of the accelerator.

The impedance of a coaxial gun operating in the fractional mode of plasma acceleration was investigated. For this a unipolar current pulse, obtained using an inductive energy accumulator [4, 5], was used for the accelerator supply.

From an examination of typical oscillograms (Fig. 1) of discharge current and voltage obtained, it follows that in the fractional mode of plasma acceleration the total accelerator impedance ($z = z_1 + z_2$) is always kept at a rather high level and its value reaches $z = (1\text{-}1.3)\cdot 10^{-2}\ \Omega$ for a mean discharge current I = 25-30 kA and a voltage U = 300-400 V. It must be assumed that most of the voltage is due to the presence of a back emf, generated as a result of plasma motion through the H_φ field, so that z_2 must be larger than z_1. To confirm this, we estimate the magnitudes of the components z_1 and z_2 on the basis of the energy balance of the accelerator system.

It is known that the energy efficiency of an accelerator depends on z_1 and z_2, which characterize the fractions of input energy expended on ohmic losses in the discharge and on electrodynamic plasma acceleration, respectively. Knowing the accelerator input energy W_{in} and the energy W_{pl} of the plasma jet, one can estimate the mean values of z, z_1, and z_2 from the equations $W_{in} = I^2zt$, $W_{pl} = I^2z_2t$, and $W_{ohm} = I^2z_1t$. On the basis of the experimental data obtained (W_{in} = 3.5 kJ, W_{pl} = 2.8 kJ, W_{ohm} = 700 J, I = 25 kA, $t = 5\cdot 10^{-4}$ sec) we determine the following: $z = 1.1\cdot 10^{-2}\ \Omega$, $z_2 = 0.9\cdot 10^{-2}\ \Omega$, $z_1 = 0.2\cdot 10^{-2}\ \Omega$. It follows from the estimates that z_2 is far larger than z_1. The good agreement between the value of z and the value determined earlier from the volt—ampere characteristic curve indicates the reliability of these estimates.

On the other hand, the total impedance z calculated from the current and voltage oscillograms retains an almost constant value (Fig. 2a) during the entire discharge pulse. During a twofold decrease in current, z does not vary. This means that, in contrast to ordinary high-current (arc) discharges, in the mode under consideration the current is a linear function of the applied voltage. Evidently, the reason for this is the constancy of the component z_2, connected with the plasma motion: $z_2 \sim bV$ (where b is the linear inductance of the accelerator; V is the plasma velocity). From a comparison of the discharge oscillograms (see Fig. 1) and streak-camera pictures (Fig. 3a, b) it follows that as the total current (discharge power) is varied, only the repetition frequency of the plasmoids varies, while their

*Deceased

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