Using Bernoulli's equation, we evaluate the magnitude of the pressure drop created by the vortex street when one end of the channel is closed:

$$\Delta P = (P_0 - P) = \frac{\rho V^2}{2}. \tag{8}$$

Setting for air $\rho = 1.29$ kg/m^3 we find that $\Delta P \approx 90$ N/m^2 for the symmetric order and $\Delta P \approx 14$ N/m^2 for the checkerboard order.

Experimental studies of the method with a more efficient symmetric arrangement of the streets with three vortices in one street gave pressure drops which were somewhat lower than the computed values. In the experiment the pressure drop under the same conditions chosen above equalled $\Delta P \approx 25$N/m^2 for the symmetric street. The lower value of ΔP obtained in the experiment can be explained by the approximate nature of the determination of the value of Γ in the theoretical calculations, and also by the effect of energy dissipation owing to viscous friction.

From the estimates obtained above it is evident that the method developed enables increasing not only the stability of the optical nonuniformities, created in the flow of the gas medium analyzed in the channel with open ends (velocity estimates), but it can also be used to organize a flow of a gaseous medium in a channel (pressure estimate).

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HIGH-EFFICIENCY AIR PLASMATRON

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The results of an investigation of a 1.2-MW plasmatron with air injected through the porous channel in an insert between the electrodes and an efficiency of 0.95 are presented.

The efficiency of energy conversion and the operating lifetime of electric-arc plasmatrons are being increased by increasing their voltage—current ratio U/I. The reduction of the current owing to an increase in the voltage with fixed power enables reducing erosion and the thermal losses in the electrodes. In linear plasmatrons, with the plasma-forming gas injected through a porous channel in an interelectrode inset (IEI) the thermal losses are recovered, and the interaction of the cold gas with the discharge is intensified [1]. This increases the electric-field intensity in the arc channel and enables creating highly efficient small plasmatrons, whose efficiency reaches 0.9-0.95 [2].

In this work, we studied an arc discharge in the flow-through channel of an air plasmatron (Fig. 1). The cathode 1 has a zirconium thermal-emission inset with a diameter of $5 \cdot 10^{-3}$ m. Nitrogen is injected between the cathode 1 and the cathode diaphragm 2 in order to screen the Zr insert ($G_c = 10 \cdot 10^{-3}$ kg/sec). Air was injected ($G/p = 0.1$-0.75 kg/sec) through the porous channel 3 of the IEI ($d_c = 28 \cdot 10^{-3}$ m, $\ell_c = 150 \cdot 10^{-3}$ m). The porous channel was fabricated from an electric insulation material (cordierite). It contains a viewing window

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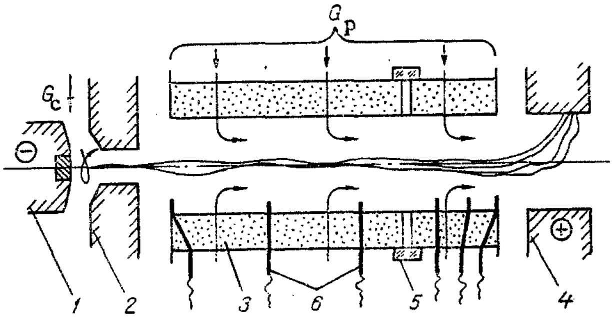

Fig. 1. Diagram of plasmatron.

5, and 6 probes consisting of tungsten wire $0.8 \cdot 10^{-3}$ m in diameter. The probes are inserted into the arc channel to a depth of $3 \cdot 10^{-3}$ m. The copper water-cooled anode 4 with a cylindrical part $7 \cdot 10^{-2}$ m long contains a solenoid in order to move the base of the arc.

The discharge was photographed through the viewing window 5 in the end section of the channel with the help of a VFU-1 high-speed camera. The latter was equipped with an additional shutter, which opened by one revolution of the mirror with the help of an electronic switching circuit. Motion-picture photography (Fig. 2) shows that for low specific volumes of air blown into the channel, the column of the air lies on the axis of the channel, and an increase in the current has a stabilizing effect (Fig. 2a). At some flow rate of the air the transverse dimensions of the arc column being to increase and the arc decomposes into separate current conducting filament (Fig. 2b). The latter form, move, and vanish, and in addition the characteristic reconstructuring time of the discharge equals 10^{-4}-10^{-6} sec. For large specific volumes of air blown into the channel, an increase in the current destabilizes the discharge. The vanishing of the current filaments and the subsequent recombination of the plasma formations could be one of the factors responsible for the appearance of nonuniformities in the parameters. The observed change in the structure of the discharge with increasing flow rate affects the distribution of the electric-field intensity in the arc channel.

The distribution of the potential in the arc channel was determined with the help of probes, the signal from which was fed through a voltage divider (~ 10 MΩ) to a loop ($N = 338$) and an electronic (S8-14) oscillograph. The current from the probe did not exceed 0.5 mA. The frequencies of the pulsations of the potential lie in the band 10 Hz-10 kHz, and there is a characteristic frequency, equal to 300 Hz (the rectification frequency of the current). Decreasing the discharge current and increasing the flow rate of the air shorten the leading edges of separate pulsations from 10^{-3} to 10^{-5} sec, and the amplitude of the pulsations increases, especially near the anode (Fig. 3). For large injected volumes of air, "discontinuities" of the beam with a duration of 10^{-6}-10^{-7} sec, indicating a sharp change in the voltage, are observed on the voltage oscillograms. Characteristically, inductions of the white noise type with a frequency of up to 10^7 Hz were recorded at distances of 1.5 m from the plasmatorn. The latter is comparable to the relaxation times of an air plasma with sharp interruption of the current.

In the presence of voltage pulsations, the potential difference between the two probes remains approximately constant in time (Fig. 3). The distribution of the voltage U and of the electric field intensity E, obtained by graphical differentiation of the voltage curves, are shown in Fig. 4. The intensity E grows monotonically along the channel (the air flow rate increases linearly along the porous channel). At the same time, E varies from 20-40 V/cm, characteristic for the starting section of the arc in a smooth channel [3], up to 250 V/cm in the last section. We note that in smooth channels with air injected between sections the values obtained for the electric field intensity do not exceed 50-80 V/cm [3, 4].

As the flow rate of air is increased from 0.1 to 0.75 kg/sec the voltage on the plasmatron increases from 1.0 to 2.5 kV, the pressure in the arc channel increases from 0.2 to 0.9 MPa, and the pressure in front of the porous wall of the channel increases from 0.5 to 3 MPa. In the range of currents studied $I = 200$-600 A the current—voltage characteristics decrease monotonically. Doubling the current reduces the voltage by 10%, and the mean-mass temperature increases linearly from 1500 to 2200 K with the efficiency decreasing from 0.97 to 0.93 in the range of flow rates and pressures studied. The volt equivalents of the thermal losses equal $Q_a/I \approx 100$ V and $Q_K/I \approx 16$ V at the cathode.

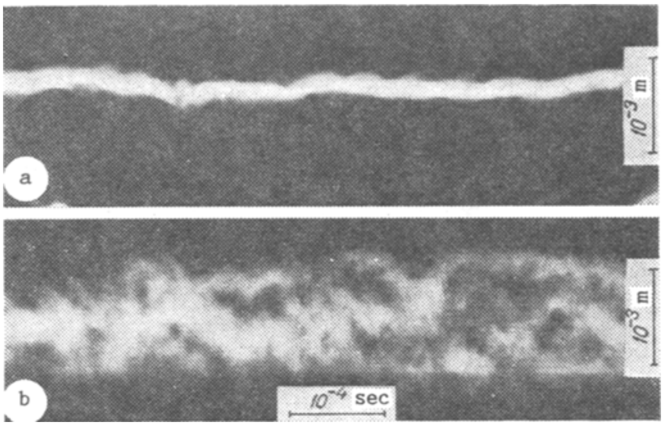

Fig. 2. Photographs of the discharge: a) G = 0.065 kg/sec, P = 0.2 MPa, I = 320 A; b) 0.25, 0.35, and 520.

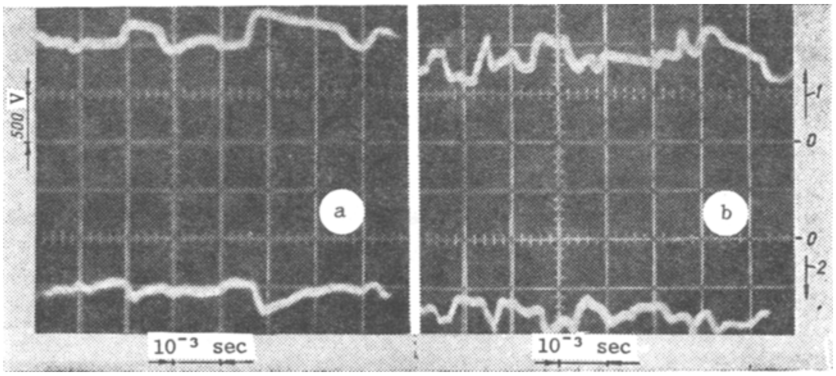

Fig. 3. Oscillograms of the voltages of two probes: a) G = 0.095 kg/sec, I = 330 A; b) 0.21 and 280; 1, 2) direction of deflection of the beam from the probes III and IV, respectively.

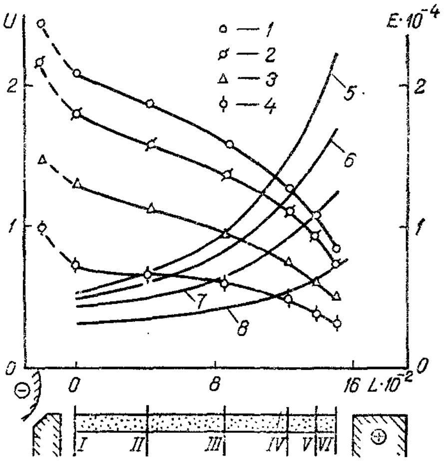

Fig. 4. Voltage distribution and electric field intensity distribution along the arc channel: 1-4) U; 5-8) E: 1, 5) G = 0.77, I = 400, P = 0.9; 2, 6) 0.52, 380 and 0.6; 3, 7) 0.21, 330 and 0.4; 4, 8) 0.1, 240 and 0.2. G, kg/sec; I, A; P, MPa; U, kV; E, V/m.

In connection with the high voltage-to-current ratio and the high flow rate of air, regenerative cooling of the anode, which is the main source of thermal losses, becomes possible. In the experiment, the entire air flow ($G = 0.75$ kg/sec) was used to cool the anode, after which it entered the IEI and the arc channel. The heating of the air in the anode did not exceed 100 K. This enabled raising the efficiency of the plasmatron up to 0.97-0.98. Regenerative air-cooling of the cathode is under study. Realization of the latter will make it possible to eliminate water cooling.

The content of nitrogen oxides at the outlet from the plasmatron was analyzed. At a mean-mass temperature of 1800 K the volume content of NO reached 3%, which is approximately 10 times higher than the computed equilibrium value at this temperature. It should be noted that the results were obtained without the use of a quenching setup. Quenching evidently occurs in the arc channel itself owing to the intensive interaction of the injected cold gas with current-conducting filaments. The thermochemical nonequilibrium under similar conditions with nitrogen injected into the arc channel is analyzed in [5].

The results presented show that high-efficiency plasmatrons with a high energy-liberation density can be built. An arc discharge of this type is promising for generating flows of a dense, nonequilibrium, molecular plasma.

NOTATION

U, voltage; I, arc current; G_p, flow rate of the gas through the porous channel; G_c, flow rate for the cathode screen; I_c, length of the porous channel; E, intensity of the electric field; P, gas pressure; Q_a, heat loss at the anode; and Q_c, heat loss at the cathode.

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