3. $V_c < \varphi$; then

$$Q = \frac{2\pi\sqrt{2m}}{h}\frac{(\varphi - V_c)^{5/4}V_c^{1/4}}{E_c}\int\limits_0^{\frac{V_c}{\varphi - V_c}}\frac{\sqrt{1+t}}{t^{1/4}}\,dt =$$

$$= \frac{2\pi\sqrt{2m}}{h}\frac{(\varphi - V_c)^{5/4}V_c^{1/4}}{E_c}\,{}_2F_1\left(-1/2;\,3/4;\,7/4;\,-\frac{V_c}{\varphi - V_c}\right).$$

As in case 1, knowing Q, we can determine the current density of the field emission into a plasma j_{F-P}.

Figure 3a shows how the current density j_{F-P} varies with E_c for $\varphi = 4.5$ V and $V_c = 4$, 3.5, 3, 2.5, and 2 V; Fig. 3b gives the results for $\varphi = 4$ V and $V_c = 3.5$, 3, 2.5, 2, and 1.5 V.

We note, in conclusion, that when $V_c \geqslant \varphi$, the current density of the field emission into a plasma j_{F-P} must be smaller than the current density into a vacuum, and it approaches its minimum value defined by (3) as V_c tends to φ. When $V_c < \varphi$, the current density j_{F-P} can be either smaller or greater than j_F.

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EXPERIMENTAL INVESTIGATION OF THE PLASMA IN A MULTICHANNEL CATHODE

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In electroplasma accelerators and plasma sources, hollow cathodes are finding applications [1, 2]. One of the possible variations of their application is the multichannel cathode [3, 4]. Although at the present time there are a considerable number of papers on the single-channel hollow cathode [3-6], the physical conditions in a multichannel cathode remain unstudied; this is due to the difficulties in determining the plasma parameters in channels of small cross section, the high temperature of the working surface, and the high density of the plasma. The problem concerning the magnitudes of the pressure, concentrations, and temperature, degree of ionization of the plasma, and the dependence of these parameters on the discharge current remains unexplained. While the existing experimental data on the single-channel cathode are attributed predominantly to a plasma of different gases, the alkali metals also offer practical interest as working substances.

In this paper the parameter of a plasma in the hollow multichannel cathode of a coaxial plasma source with a power of 7 kW, operating on lithium, are studied. An experimental investigation is carried out, based on the use of a special optical system of observation behind the plasma in the discharge section of the channel.

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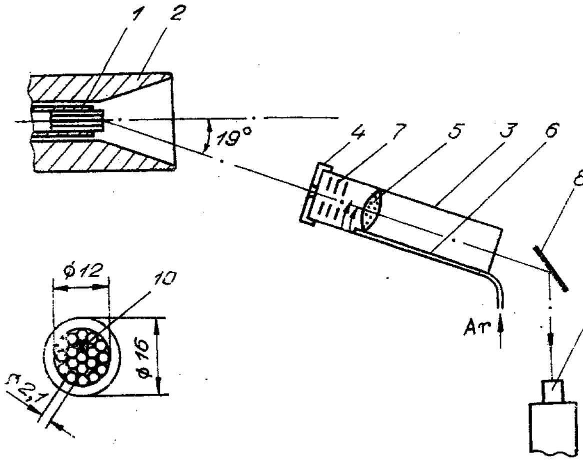

Fig. 1

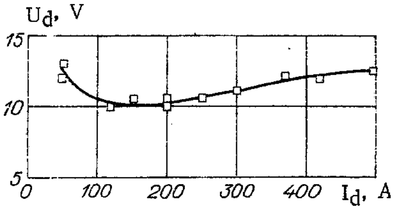

Fig. 2

The layout of the experimental equipment is shown in Fig. 1. The cathode 1 of the plasma source is a bundle of 19 tungsten tubes with an internal diameter of 12 mm and an external diameter of 16 mm. The tubes were made from tungsten foil with a width of 25 mm and thickness 0.05 mm by rolling without hermetic sealing of the longitudinal joints, and they protruded from the ring by 5 mm. The anode nozzle 2 is made of molybdenum and had an outlet diameter of 60 mm. The working substance (lithium) was fed into the source by means of an electromechanical feed system. On passing through the vaporizer, the lithium in vapor form reaches the cathode, where it is further heated up and where ionization takes place. The flow rate of the working substance in the main series of experiments was 0.01 g/sec.

At a distance of 110 mm from the cathode, at an angle of 19° to its axis, a tube 3 of stainless steel was placed, closed in front with a boron aluminonitride blend 4. A quartz lens 5 was installed in the tube; it had a focal length of f = 150 mm and was protected from heating and dustiness of the alkali metal by blowing in argon (through the tube 6) and also with the aid of metal screens 7. The optical system, consisting of a lens and mirror 8, formed an image of the channel selected for observation magnified 10-fold on the entrance slit of the spectrograph 9. The contribution of the emission of the interelectrode plasma column was taken into account by means of a monitoring tungsten rod 10, installed in one of the adjacent channels.

The working pressure in the vacuum chamber during the admission of argon (for the purpose of creating a protective screen in front of the lens) was $\sim 5 \cdot 10^{-1}$ mm Hg. The discharge current was varied from 50 to 500 A and the voltage, from 10 to 15 V.

An ISP-51 spectrograph with cameras of f = 1300 and 270 mm in a Fabry-Perot interferometer was used for the spectral measurements. The spectrograms were processed on an MF-4 microphotometer. The electron concentration in the cathode channels was measured by the Stark broadening of the LiI 413.2-nm line, using the recommendations of [7], and the concentration of neutrals was measured by the distance between the maxima of the self-reversal line of LiI 670.7 nm [8]. The electron temperature was determined by Ornstein's method by the LiI 497.2-nm and LiI 398.5-nm lines, and the temperature of the heavy component was determined by the Doppler broadening of the LiI 497.2-nm line. The errors in measuring the absolute magnitudes did not exceed 20% for n_e, 20% for T_α, 30% for T_e, and 40% for n_α. The cathode temperature was determined by an ÉOP-66 optical pyrometer. The precathode potential drop was monitored by means of a "floating sensor," located at a distance of $\sim$ 2 mm from the end of the cathode.

A typical volt—ampere characteristic curve of the discharge, increasing over the range 150-500 A, is shown in Fig. 2. When the current is reduced to 50 A, the discharge becomes unstable, its voltage is increased, and when $I_d \approx 40$ A, it is extinguished. The magnitude of the precathode potential drop in the experiments being described was $\sim$ 80% of the total discharge potential.

When observing the cathode channels at an angle of 19° to the axis of the source through the eyepiece of the ÉOP-66 optical pyrometer (or their images on the entrance slit of the spectrograph), around the edges of the channels luminous "crescents" can be seen clearly, having a brightness temperature for I_d = 400 A of approximately 2100°K; for the degree of blackness of the channel walls corresponding to the polished surface of the tungsten, this gives

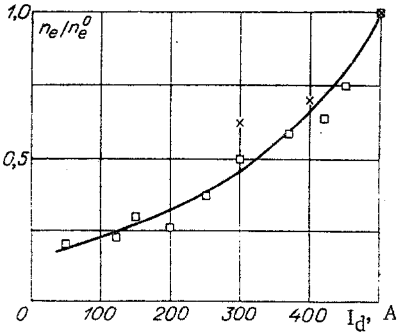

Fig. 3

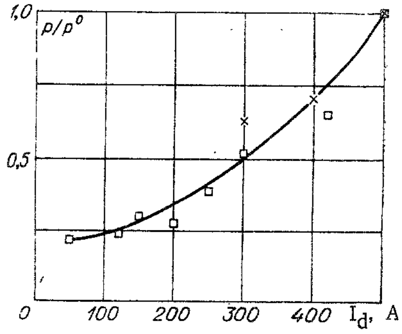

Fig. 4

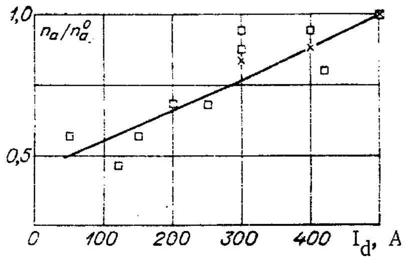

Fig. 5

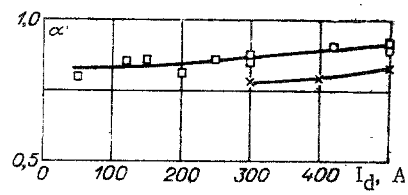

Fig. 6

a "true" temperature of ∿2300°K. The brightness temperature of the deeper part of the channel is ∿1800°K. The thickness of the "crescents" corresponds to a depth of 1 to 1.5 tube diameters and makes it possible to judge the dimensions of the active burning zone of the discharge in the channel of the hollow multichannel cathode. With currents of I_d = 300-500 A, a survey of all the channels of the cathode was carried out. Under these conditions, all the channels "gleamed," i.e., they were active.

During 1 h of operation, the cathodes being studied did not fail; however, embrittlement of the foil after the experiment made them difficult to use later. During disassembly of the cathodes after completion of the experiments, traces of burning of the discharge up to a depth of 1 to 1.5 tube diameters were observed on the inside surface of the tubes. The outside surfaces of the tubes remained shiny. Fusible indicators of molybdenum and steel wire located between the tubular elements of the cathode showed that their temperature with a current I_d = 500 A over the whole length exceeded 1800°K, and in the active zone it reached 2900°K (the molybdenum wire was fused to a depth of 5 mm).

The principle results of the spectroscopic investigations are shown in Figs. 3 to 6. The experimental values, denoted by crosses and squares, refer to different experiments and to different channels of the cathode, respectively. It follows from the graphs that the electron concentration n_e (Fig. 3), the concentration of neutrals n_α (Fig. 4), and the plasma pressure p (Fig. 5) in the active zone, referred to the corresponding values with a current of 500 A, are increasing functions of the discharge current. (The plasma pressure was calculated on the basis of the measured values of the concentrations and temperature by the relation $p = k[n_eT_e + n_iT_i + n_\alpha T_\alpha]$ on the assumption of quasineutrality of the plasma $n_e \approx n_i$ and equality of the temperatures of the ions T_i and the atoms T_α.) The absolute magnitudes of these parameters with I_d = 500 A are as follows: $n_e^0 \simeq 5 \cdot 10^{15}$ cm^{-3}, $n_\alpha^0 \simeq 5.7 \cdot 10^{14}$ cm^{-3}, and $p \simeq 4.5$ mm Hg. The noncoincidence of the points in Figs. 3 and 5 is explained by the effect on p of the neutral component. The change of degree of ionization of the plasma α with increase of I_d is shown in Fig. 6. Over the whole range of discharge currents, α exceeds the value of 0.75. No noticeable change of the electron temperature T_e and the temperature of the neutral atoms T_α with the discharge current was observed in the experiments. The average values of the temperatures were $T_e \simeq 5500$°K and $T_\alpha \simeq 3000$°K.

In order to explain the effect of the flow rate of the working substance on the plasma parameters, an experinent was carried out in the cathode channels with a current of I_d = 400 A, with different lithium flow rates. It was found that the electron concentration in the active zone depends weakly on the flow rate of the working substance. With a reduction of the lithium flow rate by a factor of 12 (from 0.018 to 0.0015 g/sec), the quantity n_e changed by a factor of 1.75 (from $1.75 \cdot 10^{15}$ to $1 \cdot 10^{15}$ cm^{-3}). Under these same conditions, the concentration of neutral atoms decreased approximately by a factor of 2.6, which corresponds to an increase of α from $\sim$88 to $\sim$92%.

There were no spectral lines of argon ions and atoms on the spectrograms obtained. This means that the argon, fed into the vacuum chamber in order to protect the optical system, made no contribution to the ion component of the plasma. This is confirmed by the fact that an increase of pressure in the vacuum chamber from $\sim 10^{-3}$ to $\sim 5 \cdot 10^{-1}$ mm Hg, due to a change of the argon flow rate, has no effect on the electrical parameters of the discharge. The experimental results obtained can be used for the development of a theoretical model of the operating process in a multichannel cathode.

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ELECTRODYNAMIC INTERACTION OF THE ARCS OF PLASMA SMELTING FURNACES

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INTRODUCTION

In plasma smelting furnaces with a ceramic crucible, it is necessary (in contrast from the usual arc furnaces) to deal with long arcs (1 m or more long). In this case, in order to achieve high powers (tens of megawatts or more), several arcs burning in parallel are used.

Under these conditions, it is found that there is a significant electromagnetic interaction of the arcs, leading to their constriction — distortion of the axes and convergence of the anode spots. The force of interaction depends on the distance between the plasmotrons, the length of the arc, and the current strength. Starting from some values of these parameters, the anode spots of the arcs merge into one. It is established by an experimental method that with further increase of constriction of the arcs their burning becomes unstable; pronounced spatial oscillations of the arcs and also voltage fluctuations in them originate, which have a detrimental effect on the operation of the furnace. This circumstance, in the first place, requires careful thought about the design of the current conductors

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