sion D_T, which was added to D_L and D_i in the calculations, leads to a growth in the anode potential fall and the thickness of the anode layer (Fig. 4, I = 100 mA/cm², d = 0.5 cm).

LITERATURE CITED

1. Yu. S. Akishev, F. I. Vysikailo, A. P. Napartovich, and V. V. Ponomarenko, Teplofiz. Vys. Temp., 18, No. 2 (1980).
2. Yu. S. Akishev, A. P. Napartovich, P. I. Peretyat'ko, and N. I. Trushkin, Teplofiz. Vys. Temp., 18, No. 4 (1980).
3. Yu. P. Raizer, Foundations of the Modern Physics of Gas Discharge Processes [in Russian], Nauka, Moscow (1980).
4. A. M. Dykhne, A. P. Napartovich, T. V. Taran, et al., A Numerical Study of a Two-Dimensional Electrical Discharge [in Russian], Preprint No. 164, Inst. of Applied Mathematics, Academy of Sciences of the USSR, Moscow (1981).
5. L. Huxley and R. Crompton, Diffusion and Drift of Electrons in Gases [Russian translation], Mir, Moscow (1977).
6. A. A. Samarskii and E. S. Nikolaev, Methods for Solving Equations on a Grid [in Russian], Nauka, Moscow (1978).
7. V. I. Blokhin, V. V. Breev, S. V. Dvurechenskii, and S. V. Pashkin, Teplofiz. Vys. Temp., 19, No. 5 (1981).
8. N. L. Aleksandrov, A. M. Konchakov, A. P. Napartovich, and A. N. Starostin, Plasma Chemistry [in Russian], Vol. 11, Moscow (1984).
9. F. I. Vysikailo, Fiz. Plazmy, 13, No. 2 (1987).
10. V. I. Blokhin and S. V. Pashkin, Teplofiz. Vys. Temp., 14, No. 2 (1976).

TWO FORMS OF DISCHARGE IN ARGON PLASMAS WITH AN EMISSION-ACTIVE POTASSIUM ADDITIVE

V. O. German and V. S. Uspenskii

UDC 533.9

There are currently a substantial number of papers devoted to research on the stability of distributed discharges in gases with different assumptions about the character of the flow in the interelectrode gap, the external electrical circuit, the electrode potential falls, etc. ([1-6], for example). The loss of stability by a discharge can lead a priori to a transformation of the solutions that describe the flow of current in the discharge to a new stationary state or to quenching of the discharge. It turns out that a nonuniqueness in this type of transformation can be observed in a number of cases. For a given total discharge current one can have both a distributed discharge regime with diffusive coupling to the anode and a contracted discharge with an anode spot.

In this paper we obtain experimentally the current—voltage characteristic of a discharge in a high-temperature argon plasmotron with distributed and contracted branches. The distinctive feature of the experimental apparatus lies in supplying a small amount of emission-active potassium additive to the cathode to ensure a high thermal-emission current [7] under atmospheric and higher pressure conditions, so that the discharge is coupled diffusively at the cathode independently of the behavior of the discharge in the plasma volume. In this way we exclude the cathode's having a significant effect on the discharge in the plasma volume, as happens in most other devices where a transition to field emission takes place at the cathode with the appearance of a cathode spot when the discharge contracts. We believe that ensuring diffusive coupling of the discharge to the cathode prevents the streamer formation in the plasma volume from the cathode side observed during the transition from thermionic emission to field emission as the mechanism for current flow at the cathode. Shifts into distributed and contracted stationary discharge regimes corresponding to a single val-

---

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 6-8, September-October, 1990. Original article submitted February 24, 1989; revision submitted April 20, 1989.

0021-8944/90/3105-0667$12.50

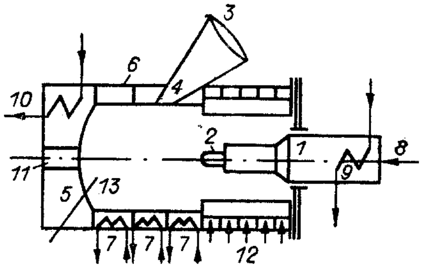

Fig. 1

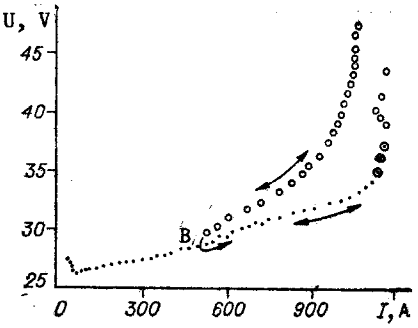

Fig. 2

ue of the total current between the electrodes are produced experimentally in the apparatus. The shift to a distributed discharge at high currents (I ≥ 600 A) is produced by means of a controlled supply of the easily ionized potassium additive to the volume followed by a reduction in the feed rate.

The experimental apparatus was constructed subject to the requirements for metal—film tungsten cathodes operating at atmospheric and higher pressures [7, 8]. Thermionic cathodes with emission-active additives operating in vacuum and at surface temperatures close to the melting point are well known. Unlike these cathodes, a tungsten cathode with emission-active potassium or cesium additives operates at atmospheric and higher pressures in the thermionic regime at substantially lower temperatures (T_s ~ 2200°C). The high adhesion coefficient of cesium and potassium to the tungsten cathode plays an important role in the choice of emission-active additives under atmospheric conditions. Figure 1 shows a conceptual diagram of the apparatus with the following components: (1) cathode assembly, (2) cathode, (3) optical apparatus, (4) diaphragm of the optical apparatus, (5) sectioned anode, (6) discharge vessel, (7) insulators, (8) inlet for emission-active substance, (9, 10) heat exchangers, (11) output nozzle of the plasmotron, (12) inlet for working gas, (13) probe.

The discharge was ignited by shorting the electrodes with a thin wire or using an rf oscillator. The interelectrode distance was varied from 4 to 70 mm. The argon plasma-forming gas was fed into the device at a rate of up to 6 g/sec. The range of operating currents extended to 1500 A during operation with a tungsten cathode with an emission-active substance. Three water-cooled ballast rheostats with resistances of 0.4 Ω each were used in the external circuit. The resistances could be inserted in the circuit during operation either in parallel or in series. The maximum parameters of the dc motor generator and circuit were: open circuit voltage 800 V and working current 1500 A.

The system for monitoring the operation of the apparatus included calorimetric measurements of the water-cooled sections of the plasmotron and measurements of the electrical characteristics of the discharge (voltage and total current between the electrodes). The discharge plasma was diagnosed from the probe current—voltage characteristic analyzed by a computer during the course of the experiment by the method of [9]. The temperature T_e of the free electrons and their density n_e were determined. The optical system was used as a television to monitor the state of the anode surface during the experiment.

Description and Results of the Experiments. Potassium—sodium eutectic (80% K + 20% Na) was fed into the cathode part of the plasmotron through a porous plug after the apparatus was turned on at small interelectrode gaps and low feed rates of the plasma-forming gas (Ar). The eutectic was vaporized in the cathode assembly and transported to near the tungsten rod electrode. The average feed rate of eutectic was ~0.1 g/sec in the initial operating phase during ignition. On passing to the operating regime after 3-5 min, the feed rate of the emission-active eutectic to the cathode fell to $0.5 \cdot 10^{-5}$ g/sec. The subsequent operating time of the device was at least 5 h.

Figure 2 shows the current—voltage characteristic of a discharge in argon obtained experimentally in the stationary discharge state. The pressure in the working vessel was p = 1 atm. The argon feed rate was G_{Ar} = 0.3 g/sec, the interelectrode gap was ℓ = 44 mm, and the ballast resistance in the external dc circuit was R = 0.8 Ω. The points denote states corresponding to a distributed discharge with diffusive coupling at the anode (Fig. 3), while the circles correspond to a contracted discharge with an anode spot (Fig. 4). The circles with dots correspond to a transition regime where arc spots appear against a back-

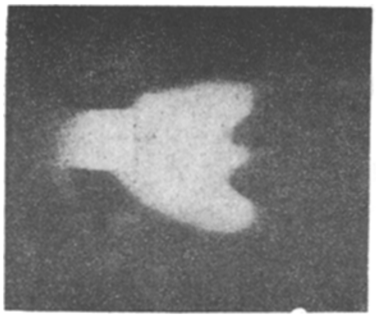

Fig. 3

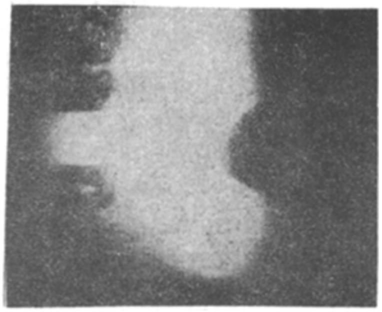

Fig. 4

ground of diffusive coupling to the anode. In Figs. 3 and 4 the anode is located to the right and has a conical shape. Similar operating regimes of this device have also been observed during operation with flow-through anodes. It may be noted that changes in the steady state to one or the other side (denoted in Fig. 2 by arrows) by controlling the emf of the source uniquely reproduces both the lower branch (the current–voltage characteristic of a distributed discharge) and the upper branch (that of a contracted discharge). The distinctive feature of the transition from the upper branch of the current–voltage characteristic to the lower (the point B, the bifurcation in the current–voltage characteristic of Fig. 2) lies in the fact that as the source emf is increased smoothly in the neighborhood of the state at point B, the transition occurs along the lower branch and corresponds to the distributed form of the discharge. When the voltage on the electrodes is increased suddenly by switching on part of the ballast resistors, a state with an anode spot that corresponds to the upper branch of the current–voltage charateristic is predominantly realized. The stationary solution is two-valued. Both solutions are stable. A transition from a contracted discharge to a distributed discharge at currents $I \gtrsim 600$ A without controlling the source emf is realized by first feeding a lightly ionized additive into the volume and then stopping (a minimum feed to the cathode $G_k \lesssim 0.5 \cdot 10^{-5}$ g/sec is continued in order to ensure that it operates in a thermionic emission regime with diffusive coupling). Here the main generator of free electrons in the volume portion of the distributed discharge outside the electrodes becomes the plasma-forming gas (Ar) itself. ($T_e > 9500$ K from an analysis of the probe characteristics.)

LITERATURE CITED

1. A. V. Nedospasov and V. D. Khait, Oscillations and Instabilities in Low-Temperature Plasmas [in Russian], Nauka, Moscow (1979).
2. I. M. Rutkevich and O. A. Sinkevich, "Waves and instabilities in low-temperature plasmas," Itogi Nauki Tekn., Ser. Mekh. Zhidkosti Gaza, VINITI, 14 (1981).
3. D. Bedeaux, P. Mazur, and R. A. Pasmanter, Physica, 86A, No. 2 (1977).
4. M. S. Benilov, Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 4 (1986).
5. S. Ya. Bronin and V. M. Kolobov, in: Proc. 8-th International Conf. on MHD Energy Conversion, Vol. 1, Moscow (1983).
6. A. P. Glinov, Teplofiz. Vys. Temp., 20, No. 5 (1982).
7. V. O. German, Yu. P. Kukota, and G. A. Lyubimov, "Stabilization of the diffuse form of discharge coupling on cooled electrodes with transpiration feed of activating additives," in: Generation of Fluxes of Electric Arc Plasma [in Russian], Nauka, Novosibirsk (1987).
8. G. A. Dyuzhev, N. K. Mitrofanov, E. A. Startsev, et al., "Physical studies of the operation of a hollow cathode arc," Leningrad (1978) (Preprint No. 583, A. F. Ioffe Leningrad Physicotechnical Institute).
9. F. G. Baksht, G. A. Dyuzhev, V. B. Kaplan, et al., "Probe diagnostics of low-temperature plasmas," Leningrad (1977) (Preprint No. 532, A. F. Ioffe Leningrad Physicotechnical Institute).