DYNAMIC CURRENT–VOLTAGE CHARACTERISTICS OF A LINEAR PLASMOTRON

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The results are given of an experimental investigation of the region of stable operation of a linear plasmotron according to the static current–voltage characteristics and data on the investigation of its dynamic current–voltage characteristics.

The linear plasmotron, with a longitudinal-vortex blowing of the arc column, is a widely spread type of plasmotron. Therefore, determination of the region of stable operating cycles of such a device (mutual coupling of the gas discharge with the current magnitude and potential drop in the arc), i.e., determination of the intervals of change of these characteristics, is essential. This is also important from the point of view of investigating the dynamic current–voltage characteristics at large amplitudes of current variation.

The recent widespread approximation methods for estimating the principal operating characteristics of the plasmotron are based on extensive experimental data [1-3]. However, these data do not permit the zone of stability of operation of the plasmotron to be determined. There are no projects specially devoted to the experimental determination of the region of stability of the linear plasmotron. Researchers, as a rule, are limited to plotting the individual static U–I characteristic curves. To date, the sole reliable method for determining the entire range of change of the parameters of plasmotron stable operation is by experiment.

This paper also is devoted to determination by an experimental method of the limits of the stable operating zone of a linear plasmotron and an investigation in this region of the dynamic U–I characteristics at large amplitudes of variation of perturbing effects.

The investigations were carried out on an experimental apparatus and by the measurement procedure described in [4].

Plasmotron Discharge Chamber. The plasmotron (Fig. 1) consists of two electrodes: the anode 5 and cathode 1. The cathode is a copper sleeve with inside diameter $d_c = 8$ mm, sealed at one end. The anode is made in the form of a copper cylindrical thimble with a diameter $d_a = 5$ mm. Both electrodes are located in brass housings through which the cooling water is supplied.

The gas in the chamber was fed into the interelectrode gap tangentially. In addition to the gas-dynamic effect on the radial sections of the arc, there was also the effect of the external magnetic field strength created by the magnetic coil 2. This made it possible to ensure the required operating resources of the plasmotron.

The polarity of the electrodes was maintained invariable: the sealed electrode was the cathode and the open electrode was the anode.

The gas blown into the electric arc 4, was heated and flowed from the anode in the form of a plasma jet 6.

Static Current–Voltage Characteristics. The static U–I characteristic curves of the linear plasmotron, using air as the plasma-forming gas, are shown in Fig. 1b.

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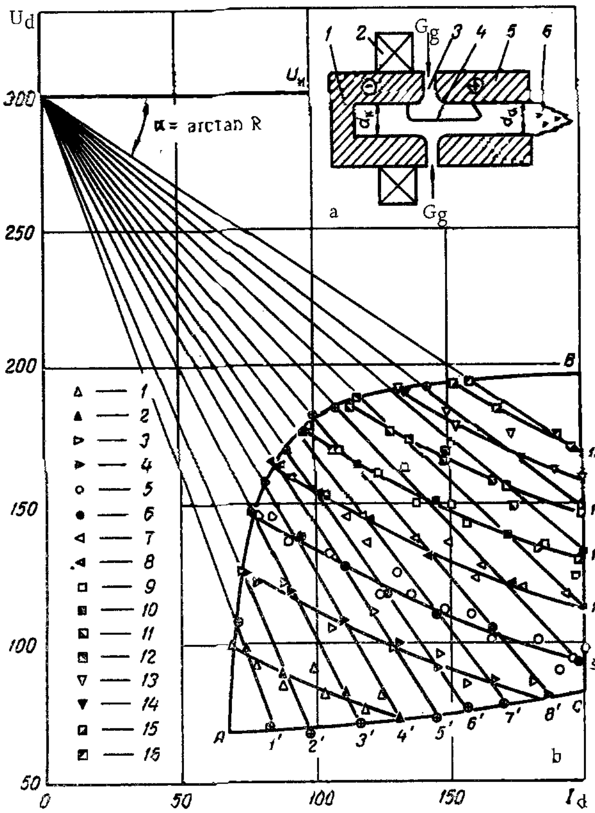

Fig. 1. Linear plasmotron: a) diagram of discharge chamber; b) static current – voltage characteristic curves (gas – air; d_c = 8 mm; d_a = 5 mm); ABC) region of stable operation. 1, 2) G_g = 0.25 g/sec; 3, 4) 0.35; 5, 6) 0.5; 7, 8) 0.6; 9, 10) 0.75; 11, 12) 0.85; 13, 14) 1.0; 15, 16) 1.1; 1') R = 2.75 Ω; 2') 2.4; 3') 2.0; 4') 1.75; 5') 1.6; 6') 1.45; 7') 1.3; 8') 1.2; 9') 1.05; 10') 0.95; 11') 0.8; 12') 0.75; 13') 0.65.

In consequence of the continuous shunting of the arc at the wall of the discharge chamber, its parameters are changing periodically [5]. The plasmotron characteristics, therefore, are designed round the average values of the current and voltage.

When G_g = const and R = var, the static U – I characteristic curves are steep curves which, with change of gas flow rate, are strongly stratified and with increase of the gas flow rate they are displaced in the direction of higher voltages. Thus, for example, with a change of gas flow rate from 0.5 g/sec to 1.0 g/sec for a current of I_d = 150 A, the magnitude of the voltage changes by 70 V. A similar change of the gas flow rate for a coaxial type of plasmotron leads to a voltage change of 15 V [4].

The region of stable operating conditions of the linear plasmotron (Fig. 1b) is bounded above by the curve AB, corresponding to the operating conditions of the plasmotron for which $U_{d\,max}$, $I_{d\,min}$, and G_g = const, i.e., the arc is quenched because of the increase of its length; below, the region is bounded by the curve AC corresponding to the operating conditions of the plasmotron for which $U_{d\,min}$, $I_{d\,max}$, and G_g = const, i.e., the arc burns in the interelectrode gap; on the right, the boundary is the straight line BC which corresponds to maximum current of the device I = 200 A.

Thus, the plasmotron operates stably within the following limits of change of parameters: 69 A $\le I_d \le$ 200 A; 68 V $\le U_d \le$ 195 V; 0.25 g/sec $\le G_g \le$ 1.1 g/sec and 0.65 Ω $\le$ R $\le$ 2.75 Ω.

It should be noted that the lower boundary AC of the region of stable operation does not have a falling but a rising trend, i.e., with increase of the gas flow rate the arc burns in the interelectrode gap at a higher voltage in the flow.

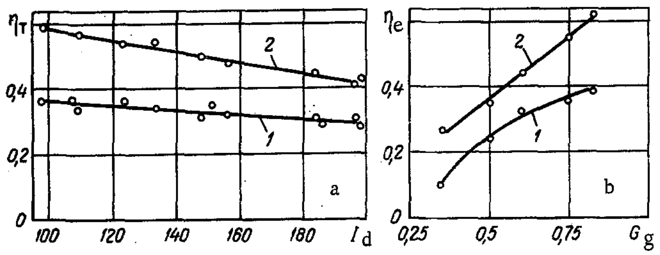

Fig. 2. Dependence of efficiency of linear plasmotron on current strength (G_g = 0.75 g/sec) (a) and on gas flow-rate (R = 1.17 Ω) (b); 1) thermal efficiency; 2) electrical efficiency. I_d, A; G_g, g/sec.

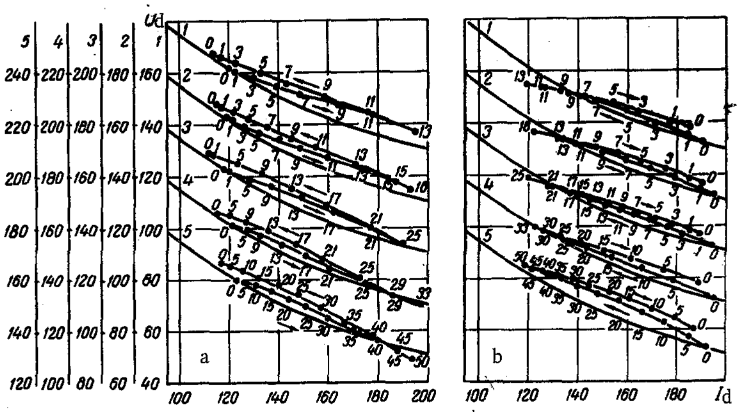

Fig. 3. Dynamic current — voltage characteristics of a linear plasmotron (gas–air; d_c = 8 mm, d_a = 5 mm; G_g = 0.75 g/sec). a) Current larger–smaller; b) current smaller–larger; 1) dI/dt = 5 A/sec; 2) 4; 3) 3; 4) 2; 5) 1.5 A/sec. U, V; I, A. Figures at points are the times, sec.

By comparing the coaxial [4] and linear plasmotron, it can be seen that the region of stability of the latter is considerably broader and the condition of the static characteristic curves in U, I-coordinates depend considerably more strongly on the gas flow rate.

This is because, in the plasmotron with a linear electrode arrangement the arc is blown intensely in the longitudinal direction and its average length is greater. In the coaxial plasmotron, the arc as a rule is shorter and is blown by the incoming gas stream in the transverse direction. With identical gas flow rates, the rate of blowing of the arc in the linear plasmotron is considerably higher than in the coaxial plasmotron [4], in view of the geometrical dimensions of the discharge chamber.

Because of this, the arc potential in the linear plasmotron increases with increase of the gas flow rate, not only on account of the increase in length of the arc but also on account of the increase of electric field strength.

Thermal and Electrical Characteristics. The dependence of the thermal and electrical efficiency of the plasmotron on the current strength and gas flow rate is shown in Fig. 2.

The thermal and electrical efficiencies vary respectively within the limits η_t = 0.29–0.36 and η_e = 0.43–0.59 for a current change from 98 to 168 A (G_g = 0.75 g/sec) and within the limits η_t = 0.1–0.39 and η_e = 0.27–0.61 for a change of gas flow rate from 0.35 to 0.82 g/sec (R = 1.17 Ω).

In this case, a change of current and gas flow rate are found to have an opposite and stronger effect on the nature of change of efficiency of the linear plasmotron than in the case of the coaxial plasmotron [4].

Dynamic Current–Voltage Characteristics. The dynamic U–I characteristics are obtained in the case of change of the arc current with time, caused by periodic changes of resistance of the rheostat connected in series with the plasmotron. With this, the rheostat resistance was varied from 0.05 to 0.4 Ω during t = 13, 16, 25, 33, and 50 sec, which corresponded to rates of change of current of 5, 4, 3, 2, and 1.5 A/sec.

Investigation of the dynamic U–I characteristics was made within the limits of change of parameters for which the statistical U–I characteristic curves were plotted. For this, in both cases the gas flow rate was constant and equal to 0.75 g/sec.

Figure 3a shows the dynamic U–I characteristics obtained for conditions when the current was increasing at first and then decreasing; Fig. 3b shows the same characteristics when the current was decreasing at first and then increasing. The static U–I characteristic curves are shown in this same figure for $G_g = 0.75$ g/sec and R = var, which permits comparison of these characteristics.

It can be concluded on the basis of the experiments carried out that, independently of whether the current increases at first or decreases at first, the dynamic U–I characteristics on the return path are higher than on the direct path. It should be noted that the plasmotron, after a periodic change of current, operates for a certain time at a higher (by ~5%) voltage and a low current. This confirms that the dynamic U–I characteristics of a linear plasmotron of constant current and with a self-adjusting arc length and vortex stabilization have a hysteresis, which is conditioned obviously by the different rate of adjustment of the average length and the effective conducting diameter of the arc channel and depends on the direction of the change of current.

It can be seen from Fig. 3 that the dynamic U–I characteristics, within the limits of the rate of change of current from 1.5 to 5 A/sec, are different from the static characteristics: the former curve upward and the latter downward. This behavior of the plasmotron characteristics in dynamic conditions probably is associated with the process of change of electric field strength of the positive column of the arc whilst its current is changing with time.

NOTATION

U_d is the voltage drop on arc, V;
I_d is the arc current, A;
R is the rheostat resistance, Ω;
G is the gas flow rate, g/sec;
η is the plasmotron efficiency;
dI/dt is the rate of change of current, A/sec.

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