CHARACTERISTICS OF A VORTEX-STABILIZED PLASMA GENERATOR AT REDUCED PRESSURE

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The operation of an argon plasma generator at discharge chamber pressures in the region $(3-100) \cdot 10^3$ N/m^2 has been experimentally investigated. Current-voltage characteristics in dimensional complexes have been obtained for stable operating regimes.

NOTATION

U – arc voltage, V; I – arc current, A; G – gas flow rate per second, g/sec; p – gas pressure, mm Hg; d – diameter, cm; subscripts: 1 – main chamber, 2 – end chamber.

There are no references in the literature to systematic studies of the operation of plasma generators with vortex gas stabilization at low pressures; the data are only fragmentary [1, 2] and do not make it possible to form even a qualitative idea of the nature of the electrothermophysical processes under these conditions.

In [1] the mechanism of establishment of the arc length was investigated. The pressure in the arc chamber was varied from 0.1 to 1 atm abs. Argon and nitrogen were used in the experiments.

The authors obtained a stable operating regime for argon. We note that as the flow rate decreases the arc burning regime becomes unstable: the arc voltage fluctuates with a frequency of 2-3 kHz.

We have conducted experiments on a plasma generator designed at the Institute of Theoretical and Applied Mechanics of the Siberian Division of the Academy of Sciences of the USSR (Fig. 1). The copper anode 2 and cathode 5 are water-cooled. The inside diameters of both electrodes are the same and equal to 10 mm. The working gas is supplied through two swirl chambers 4 (a main chamber between the electrodes and an end chamber). The inside diameters of the swirl rings of both chambers were equal to 50 mm. The power source was a 220-V dc generator 6. The current was regulated by means of a water-cooled sectional wire rheostat 7. The plasma jet flowed into a vacuum chamber 1, the minimum pressure in which reached $1 \cdot 10^{-2}$ mm Hg. The results of the experiments are presented in Table 1.

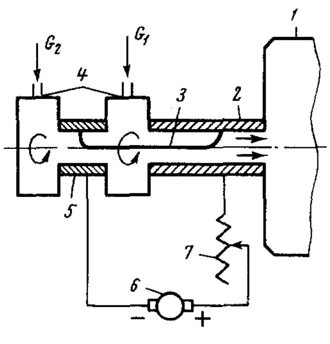

Fig. 1

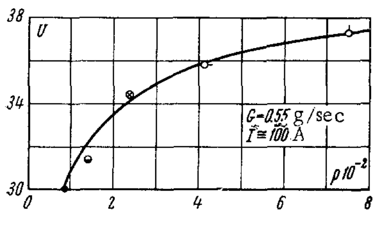

Fig. 2

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TABLE 1

Expt. no.	U, V	I, A	G_1, g/sec	G_2, g/sec	P, mm Hg	Fig. 3
1	33.4	25.7	0.448	0.077	66.0	
2	30.8	61.3	0.446	0.077	77.0	1
3	29.9	93.5	0.445	0.077	85.0	
4	29.4	170.0	0.445	0.075	101.0	
5	41.5	25.6	0.506	0.079	137.0	
6	35.4	59.7	0.501	0.077	138.0	2
7	31.4	98.0	0.508	0.076	139.0	
8	31.6	148.5	0.504	0.072	146.0	
9	38.6	58.1	0.482	0.072	237.0	
10	34.4	92.0	0.518	0.074	235.0	3
11	32.8	150.0	0.490	0.077	239.0	
12	43.5	25.2	0.512	0.073	227.0	
13	49.4	24.4	0.494	0.075	408.0	
14	40.4	49.0	0.494	0.076	410.0	4
15	35.8	98.5	0.490	0.076	411.0	
16	31.8	149.0	0.492	0.075	412.0	
17	51.7	24.4	0.460	0.074	750.0	
18	42.9	48.0	0.460	0.074	751.0	5
19	37.3	96.0	0.460	0.074	749.0	
20	21.4	18.7	0.143	0.000	15.0	
21	18.8	49.3	0.140	0.000	15.0	6
22	18.8	95.0	0.136	0.000	18.0	
23	18.4	139.5	0.135	0.000	14.5	
24	25.2	17.4	0.185	0.000	20.0	
25	23.6	52.5	0.185	0.000	23.5	7
26	20.4	99.0	0.185	0.000	27.0	
27	20.6	148.5	0.185	0.000	30.0	
28	61.0	14.7	1.235	0.236	212.9	
29	54.5	52.5	1.265	0.224	234.9	8
30	52.5	83.6	1.170	0.227	248.9	
31	50.0	150.0	1.165	0.224	274.9	
32	44.8	16.8	0.688	0.143	112.9	
33	37.2	49.6	0.648	0.140	128.9	9
34	35.6	91.7	0.645	0.141	131.9	
35	35.0	146.6	0.631	0.140	154.9	
36	90.0	12.3	2.350	0.625	401.9	
37	78.0	45.3	2.360	0.630	459.9	10
38	73.0	98.7	2.360	0.628	510.9	
39	70.0	134.1	2.360	0.628	532.9	
40	30.8	17.5	0.256	0.058	34.7	
41	25.2	52.7	0.256	0.058	40.7	11
42	22.8	98.0	0.256	0.058	45.7	
43	22.2	147.0	0.256	0.058	39.7	
44	20.4	37.0	0.151	0.000	20.6	
45	18.7	73.5	0.151	0.000	21.7	
46	18.4	99.5	0.151	0.000	22.7	12
47	19.4	149.5	0.151	0.000	24.7	
48	20.2	175.0	0.151	0.000	25.7	

TABLE 2

№	d	G	I	p	Reference	Remarks
1	1.0	0.15—3.00	12—175	15—751	This article	—
2	2.0	4—12	200—840	≈ 760	[5]	$G_2 = 0$
3	5.0	100—165	600—2600	≈ 760	[4]	—

As seen from the table, the current-voltage characteristics fall. However, at pressures in the discharge chamber of about 23 mm Hg the current-voltage characteristic has an ascending branch when the current exceeds 100 A. This is attributable to the fact that under the conditions in question stabilization is effected by the anode walls.

The minimum pressure in the chamber at which stable operation was still observed at currents not less than 20 A was 15-20 mm Hg. At lower pressures the arc was shunted in the minimal gap between the electrodes, and the arc was not stabilized on the axis.

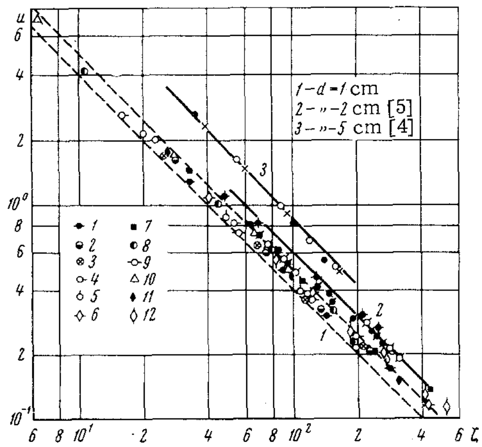

Fig. 3

The dependence of the arc voltage U on the pressure p in the discharge chamber at $I \approx 100$ A and $G = 0.55$ g/sec is illustrated in Fig. 2. As the pressure increases, the voltage increases as $p^{0.12}$.

The experimental data obtained were then analyzed in criterial form. Many authors [3, 4] have demonstrated the possibility of a generalized description of the processes in a plasma generator in the form

$$\frac{Ud}{I} = c\left(\frac{I^2}{Gd}\right)^{\alpha}\left(\frac{G}{d}\right)^{\beta}(pd)^{\gamma} \tag{1}$$

In certain cases [3] it is possible to manage just with the complex I^2/Gd. On the basis of our experiments it is possible to extend the boundaries of the criterial generalizations previously obtained. A criterial analysis of the experimental data in accordance with expression (1) is presented in Fig. 3 in the form $u = u(\zeta)$ (for the notation see Table 1):

$$u = \frac{Ud}{I}, \quad \zeta = \left(\frac{I^2}{Gd}\right)^{0.58}\left(\frac{G}{d}\right)^{0.25}(pd)^{-0.12}$$

The same figure includes curve 2 from [5] and curve 3 from [4]. Clearly, there is a distinct "stratification" with respect to diameter, which can be correlated by introducing the factor $d^{0.35}$. When our knowledge of the processes in a plasma generator and, in particular, of their linear scales is more complete, it may be possible to introduce the diameter into the criterial equation in the form of dimensionless simplexes. For engineering calculations it may be assumed that the dependence of arc voltage on the regime parameters takes the form:

$$U = 46 I^{-0.16} G^{0.33} p^{0.12} d^{0.30} \tag{2}$$

At a constant gas pressure close to atmospheric, relation (2) almost coincides with that presented in [4]. On the parameter interval investigated in the presence of gas stabilization this relation describes the experimental data with an error not exceeding ±15%. The ranges of variation of the basic parameters for these experiments and the experiments of [5, 4] are presented in Table 2.

In the experiments we also estimated the average contamination of the flow by electrode erosion products. It did not exceed 0.11% by weight.

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