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CURRENT-VOLTAGE CHARACTERISTICS OF A THREE-PHASE ONE-CHAMBER ALTERNATING CURRENT PLASMATRON

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A method for the determination of the current-voltage characteristics of a one-chamber three-phase industrial-frequency plasmatron is considered. The form of the characteristics is set proceeding from general laws governing a gas flow past an arc; a numerical value of the coefficients entering these characteristics is calculated with account of the data obtained in the experiment.

One of the main characteristics of an electric-arc plasmatron in general, and of a three-phase plasmatron in particular, is its current-voltage characteristics (CVChs). In this case a special feature of three-phase plasmatrons is the fact that direct measurement of CVChs of them is impossible, because one can measure neither current nor voltage on the arcs. Thus, in plasmatrons of the "star" type the value of the voltage on the arc is indeterminate due to the complexity of the determination of a common point of the closure of arcs that lies in the mixing chamber on which phase plasmatrons operate [1]. In a one-chamber plasmatron such an important characteristic as the current of the arc is indeterminate. Ignition, burning, and extinction of the arc occur here between three electrodes situated in one chamber [2]. By design, the chamber is a converging cylinder with the electrodes positioned on the larger end surface. Stabilization of the zone of burning of the arcs is provided by tangential supply of a plasma-forming gas which prevents by-pass of arcs to the walls of the chamber. As is shown by the experiments, not more than two arcs burn simultaneously in the volume; with normal operation each electrode succeeds in changing the polarity twice during the period and the duration of operation of the electrode as a cathode and an anode is approximately the same.

The system of energy supply of the three-phase plasmatron consists, as a rule, of a power transformer with the inductance as a ballast being introduced to the secondary winding, so that in combination with the plasmatron the system is a connection of the "start-triangle" type with a nonlinear nonuniform load [3].

In [4] CVChs were determined experimentally by switching one of the phases off, so that the value of the linear current corresponded to the current through the arc. However, on changing the plasmatron over to a one-phase mode the gas-dynamic parameters in the volume can change and the CVChs will not correspond to a three-phase mode of operation.

The value of the current in the arcs can be calculated with the value of linear currents and the data of high-speed shooting, which indicates between what pairs of the electrodes arcs burn. However, this method possesses a number of drawbacks: first, shooting of the electrodes is not always possible; second, a system of frame-by-frame synchronization with recording of linear currents is required; and third, the accuracy of the determination of the instant of extinguishing and ignition of the arc is low, especially under the conditions of diffuse burning without a clearly defined contour of the phase-lock and the diameter of the arc. These methods are inapplicable to systematic measurements and control over the operation of the plasmatron.

The form of the CVChs can be determined on the basis of general laws associated with a gas flow past an arc [5, 6]. So, in the absence of the outer magnetic field the generalized CVChs for the fixed composition of the gas and the geometry of the plasmatron can be presented in the form

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$$\frac{U_{i,j}L}{I_{i,j}} = A\left(\frac{GL}{I_{i,j}^{2}}\right)^{n} + C\frac{\dot{I}_{i,j}}{I_{i,j}} + B\frac{I_{i,k}}{I_{i,j}}, \quad i, j, k = 1, 2, 3; \quad i \neq j \neq k. \qquad (1)$$

A generalized resistance corresponding to each pair of the electrodes is in the left-hand side.

The first term in the right-hand side is an expression similar to the amount of convective heat transfer. The choice of the exponential function is associated with the fact that, on processing a large amount of experimental data obtained for arcs in convective heat transfer, this function has the best approximation compared to other two-parameter relations. The value of the exponent lies within the range 0–1. Here, if $0 < n < 0.5$, then in the current–voltage coordinates the CVChs are increasing, and within the range $0.5 < n < 1$ they are decreasing.

The second term is stipulated by instability of the combustion of the arc. Its effect reflects the fact of thermal inertia which in this case depends on the characteristic time of the residence of the plasma within the volume of the plasmatron. The coefficient C is proportional to the ratio of the time of the residence of the plasma within the volume of the plasmatron to the characteristic time of discharge $L^3\rho/Gt_{\text{disch}}$. It is restricted from above by either the time of relaxation of the arc plasma in its free decay or the loss of the emission of the cathode.

The third term allows for the effect of simultaneous burning of arcs within the same volume. The magnetic fields induced by the arcs cause electrodynamic forces, the direction of the action of which under the conditions of a turbulent flow has an unstable random character. One can judge the efficiency of this effect by the covariation coupling between the voltages. The largest coupling is likely to correspond to burning of the arcs with a common portion carrying a current. At large flow rates, i.e., at a small time of residence of the plasma within the volume, and with an insufficient effect of the burning arcs on each other, the CVChs correspond to a static characteristic.

To determine the coefficients in relation (1) numerically, we solve the nonlinear Kirchhoff equations written for a three-phase circuit. The value of the voltage on the arcs as a function of time is taken from the experiment. The calculation is made proceeding from the minimization of the function $|U_{i,j} - U_{i,j}^{\text{exp}}|^2$ for each arc burning between the pair of electrodes. In the solution we use the method of least squares with account only for the first term in the right-hand side of (1) and then the method of quickest descent with account for the remaining terms [7].

The solution of the equations of the three-phase circuit for the determination of the coefficients of (1) on transition of the current through zero does not cause difficulties. For plasmatrons with a semi-self-maintained discharge the conductivity of the interelectrode gap is known *a priori* or is selected as a result of the calculation because it is produced by the work of the preionizer. In this case the error in the determination of the conductivity on transition of the current through zero is not very substantial. The calculations show that a two-order change in the conductivity has an effect on the form and value of current and voltages at neither descending nor ascending CVChs. For plasmatrons with a self-maintained discharge in the presence of peaks of ignition of the arcs the conductivity of the interelectrode gap is determined from the condition of equality of voltages $U_{i,j} = U_{i,j}^{\text{exp}}$ preceding the ignition.

The above-described method was used to calculate currents and to obtain the CVChs on ÉDP plasmatrons [8], for which a transverse gas flow past the arcs is typical. In this case the design of the plasmatron is such that each arc has its own region of burning, which does not overlap the region of burning of the neighboring arc. The presence of a time shift between the burning arcs, in one of which the current increases and in the other of which it decreases, is essential. An analysis of a mutually covariational function of voltages showed that the covariational coupling is small. The normalized coefficient of mutual covariation does not exceed 0.1, so in first approximation the interaction of covariation can be neglected. Pulsations of voltage on the arcs are such that the spatial integral scale of these pulsations is not higher than the characteristic distance between the regions where the current is carried. In other words, burning of the arcs is separated in space and time. As a result of processing of the experimental data of CVChs of the ÉDP plasmatron with end electrodes, which operates on nitrogen at a pressure close to atmospheric and flow rates of from 30 to 60 g/sec, is satisfactorily described by one relation for the range of current of 300–800 A

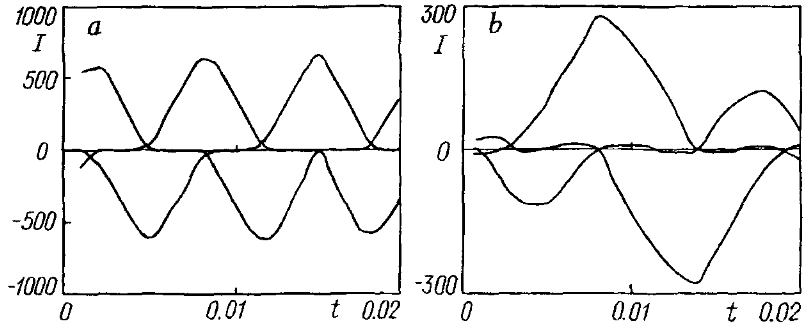

Fig. 1. Current in the arcs: a) normal mode; b) abnormal mode.

$$\frac{U_{i,j}L}{I_{i,j}} = 290.2\left(\frac{GL}{I^{2}_{i,j}}\right)^{0.485}$$

The distance between the electrodes is taken to be a characteristic size. The effect of a nonstationary term is not substantial here.

Figure 1a presents the form and value of the current in the arcs for one of the operating modes of the plasmatron. As is seen from the figure the arc discharge between the electrodes is replaced by nonarc transfer of the current and at each instant of time not more than two arcs burn, which is in correspondence with the data of high-speed shooting. The form of the current is close to triangular.

Since the characteristic time in the arcs is of the order of $10^{-6} - 10^{-4}$ sec, this makes it possible to calculate currents in the arcs in nonstationary, transient modes of operation of the supply system of the plasmatron. So, use of the power source with a low active resistance for a descending CVCh of the plasmatron can lead to the fact that the current between the two pairs of the electrodes will substantially surpass the current between the third pair. This abnormal mode of operation of the plasmatron is shown in Fig. 1b. In this case the nonuniformity of heat release generates additional transverse pulsations of the parameters in the plasmatron.

The technique suggested allows one to determine the value and form of the current in the arcs of three-phase one-chamber plasmatrons and, consequently, to correctly calculate mean and instantaneous power, and the obtained results of the calculation of CVChs can form a basis for systematization of the design of these plasmatrons.

NOTATION

U, voltage, V; I, current, A; $\dot{I}$, velocity of a change in the current, A/sec; L, characteristic size, m; ρ, characteristic density, kg/m^3; G, gas flow rate, kg/sec; t, time, sec; A, B, C, n, empirical constants. Super- and subscripts: i, j, k, refer to different electrodes; exp, experimental; disch, discharge.

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