ELECTRIC ARC OF A TWO-JET PLASMOTRON IN AN ALTERNATING MAGNETIC FIELD

S. P. Polyakov and N. V. Livitan

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The results of experiments and analytic expressions describing the behavior of an arc in a two-jet plasmotron in an alternating magnetic field are presented.

There are a large number of papers on the behavior of an electric arc in a magnetic field [1-5]. In [5], for example, an electric arc placed in a transverse magnetic field, used to move the cathodic and anodic spots along the electrode surfaces, was investigated. An electric arc, one of whose reference spots is fixed on the surface of the corresponding electrode and the second can move under the action of different physical factors along the surface of the other electrode, is also described. In addition, both the usual welding arc [1-3] and a unilaterally stabilized arc maintained with the help of a direct action plasmotron were also investigated [4]. In recent years, two-stream plasmotrons [6] have been increasingly widely used. Their use is especially promising in plasmochemistry, for welding and cutting nonconducting materials, and for depositing protective coatings. A distinguishing feature of the electric arc of a two-stream plasmotron is its bilateral gas-dynamic stabilization. The latter circumstance largely determines the form and behavior of the electric arc in a magnetic field.

This paper is concerned with studying the behavior of an electric arc in a two-stream plasmotron, whose anodic and cathodic sections are separately acted upon by a transverse alternating magnetic field.

In performing the investigations the anodic and cathodic units of the two-stream plasmotron were equipped with magnetic systems which permit deflecting both parts of the arc in a plane passing through the longitudinal axes of the plasma streams (Fig. 1).

Argon was used as the plasma-forming gas. The anodic unit of the plasmotron, made according to the direct action type plasmotron, was equipped with a copper electrode with a flat face and the cathodic unit was equipped with a tungsten core electrode. The magnetic deflection systems contained two coils each, placed on the magnetic cores, fixed on the housings of the plasmotron units. An alternating sinusoidal voltage at the commercial frequency was applied to the coils from a separate power supply. The current and the voltage in the arc and in the coils of the magnetic deflection system were recorded with the help of a N117 oscillograph. The magnitude of the induction of the external magnetic field was determined with the help of an induction-type transducer, consisting of a measuring coil connected to a S1-76 oscillograph [7].

In the course of the measurements, the behavior of the electric arc was fixed with the help of a high-speed SKS-1M motion-picture camera. In the first series of experiments the magnetic deflection system provided synchronous deflection of the anodic and cathodic sections of the electric arc in one direction. In the second series, over a complete period of variation of the magnetic field, between the pole pieces of the magnetic systems the anodic and cathodic sections of the electric arc were periodically deflected in opposite directions. Figure 2 shows curves of the changes in the parameters of the electric arc of the two-stream plasmotron being studied as a function of the magnitude of the magnetic induction of the external field. The pulsations of the current and the voltage in the arc constitute 4-9% of their average values in the first case (Fig. 2a) and 20-45% in the second case (Fig. 2b). This is related with the fact that with the deflection of the anodic and cathodic sections of the arc with the help of the magnetic system in one direction the total length of the arc changes insignificantly — the decrease of one section is compensated by an increase of another section. If, however, the sections of the arc are deflected in opposite directions, then

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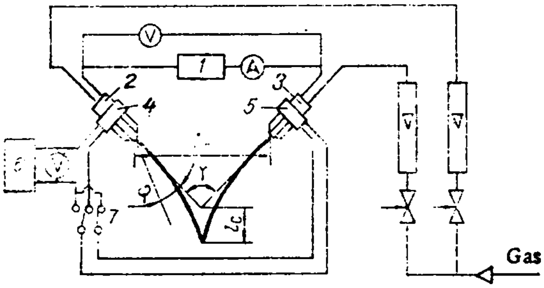

Fig. 1. Diagram of the experimental setup: 1) power supply source; 2, 3) anodic and cathodic units of the two-stream plasmotron; 4, 5) magnetic deflection systems; 6) power supply of the magnetic deflection systems; 7) commutating setup.

their length changes simultaneously, which involves considerable oscillations of the total length of the electric arc and causes pulsations of the current and voltage in it. The latter is confirmed by the motion pictures obtained.

Thus, under the action of an external magnetic field, the form of the electric arc and its position in space change considerably.

Analytic expressions can be obtained in order to determine the total length of the arc and the magnitude of its deviation from its initial position. Thus, for the first examined case of the action of a magnetic field on an electric arc — synchronous deflection of its sections in one direction — the total length of the arc L can be determined from the expression

$$L = \frac{l_0 \cos\varphi}{\sin\frac{\gamma}{2}} + 2l_c. \tag{1}$$

The first term in expression (1) corresponds to the length of the arc of a two-stream plasmotron neglecting the length of the region of mixing of its anodic and cathodic sections and is obtained from geometrical relations. The second term corresponds to the length of the arc in the region of mixing of its separate sections. The analysis of motion pictures showed that the length of the region of mixing is described well by the expression

$$l_c = K\frac{l_0}{2}\cos\frac{\gamma}{2}, \tag{2}$$

where K is an empirical coefficient which depends on the magnitude of the current and other characteristics of the electric arc and for angles γ = 30–120° assumes a value in the range 0.1–0.3.

Substituting (2) into (1), we obtain

$$L = l_0\left(\frac{\cos\varphi}{\sin\frac{\gamma}{2}} + K\cos\frac{\gamma}{2}\right). \tag{3}$$

It should be noted that the base of the region of coalescence of the sections of the arc in the case being examined moves over a circle whose radius is

$$R = \frac{l_0}{2}\left(\frac{1}{\sin\gamma} + K\cos\frac{\gamma}{2}\right). \tag{4}$$

For the second examined case — displacement of sections of the arc by an alternating magnetic field in opposite directions — the total length of the electric arc can be determined from the expression

$$L = \frac{l_0}{\sin\left(\frac{\gamma}{2} + \varphi\right)} + 2l_c. \tag{5}$$

As in Eq. (1), the first term in (5) was obtained from geometrical relations, and the second

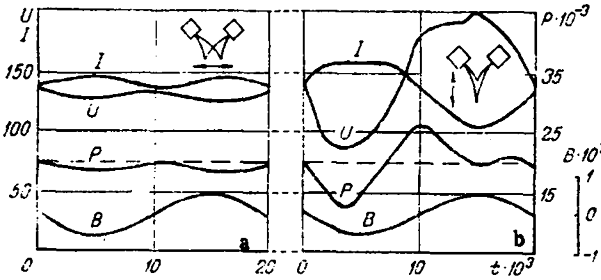

Fig. 2. Change in the current, voltage, and power liberated in the electric arc under the action of an alternating magnetic field with deflection of sections of the arc in one direction (a) and in opposite directions (b). U, V; I, A; P, W; B, T; t, sec.

was determined from an analysis of empirical data as

$$l_c = K\,\frac{l_0}{2}\cos\left(\frac{\gamma}{2} + \varphi\right). \tag{6}$$

Substituting (6) into (5), we obtain an expression for determining the arc length

$$L = l_0\left[\frac{1}{\sin\left(\frac{\gamma}{2} + \varphi\right)} + K\cos\left(\frac{\gamma}{2} + \varphi\right)\right]. \tag{7}$$

In the last case the base of the region of coalescence of the anodic and cathodic sections of the electric arc will move along a straight line, which serves as an axis of mirror symmetry for the units of the two-stream plasmotron.

Expressions (3) and (7) permit determining the length of the arc of a two-stream plasmotron for different variants of imposition on it of an alternating magnetic field depending on the initial orientation of the units of the plasmotron and the magnitude of the angle of deflection of sections of the arc from its starting, unperturbed position. It is interesting to obtain in an analytic form the dependence of the angle of deflection of the electric arc on the magnitudes of the induction of the magnetic field and of the current. As already noted, this problem has been studied in many papers, but the expressions presented in them describe the deflection of an arc for the case of an unstabilized or singly stabilized electric arc.

In addition, the expressions obtained describe the behavior of an arc, as a rule, in a uniform magnetic field, which is relatively rarely realized in specific technical setups.

In order to obtain the expressions sought, it is necessary to form the balance of forces acting on some section Δl of the electric arc. In the general case, it is necessary to include the entire complex of forces acting on the arc [1-4]. In the case under study, however, inertial forces and Ampere's force have a determining effect on the form and behavior of the electric arc in a magnetic field. In this approximation the expression describing the balance of forces will have the form

$$\rho\Delta lS\,\frac{v^2}{R} = IB\Delta l. \tag{8}$$

Using the well-known relation between the radius of curvature and the change in the angle of deflection of the section of arc being examined and expression (8), we can write

$$\frac{d\varphi}{dl} = \frac{IB}{\rho v^2 S}. \tag{9}$$

In describing the deflection of electric arc in an inhomogeneous magnetic field the value of the magnetic induction is approximated well by the expression

$$B = B_0\exp(-al^2), \tag{10}$$

where a is a parameter determined experimentally as a function of the form of the pole pieces of the magnetic deflection system [8].

After substituting expression (10) into (9), the latter can be rewritten in the form

$$\varphi = \int_0^l \frac{IB_0 \exp(-al^2)}{\rho v^2 S} dl. \tag{11}$$

Since the magnitude of the magnetic induction of the external field decreases with increasing distance quite rapidly, the integral (11) can be used to obtain the limiting value of the angle of deflection of the section of electric arc being examined

$$\varphi = \frac{1}{2} \frac{IB_0}{\rho v^2 S} \sqrt{\frac{\pi}{a}}. \tag{12}$$

Analysis of the motion pictures shows that the expressions obtained describe satisfactorily the change in the angle of deflection along the length of the electric arc under the action of a magnetic field and can be used in (3) and (7) to determine the arc length. It should be noted that the expressions obtained can be used for small frequencies of variation of the external magnetic field. A specific value of the admissible limiting frequency can be obtained, for example, as follows. The displacement time t of some volume of arc along its length must be comparable to the period of oscillations τ and must be some fraction of it. Let $t \leq 0.1\tau$. Then for a section of arc with a length of 0.1 m and with a flow velocity in it of v = 100 m/sec, we find that $\tau \geq 10^{-2}$ sec, i.e., expressions (11) and (12) can be applied to arc with the described aerodynamic parameters when a magnetic field with frequency $f \leq 100$ Hz is applied to it.

Thus the investigations performed showed that the imposition of an alternating magnetic field on the anodic and cathodic sections of an electric arc in a two-stream plasmotron permits effective control of the power liberated in the arc and control of the motion and position of the sections of the arc and the regions where they coalesce. For example, the power of the electric arc in the course of the experiments varied from 13 to 24 kW, and its was changed without using the complicated electronic regulators usually connected to the circuit supplying power to the plasmotron. The amplitude of the displacement of sections of the arc of the plasmotron investigated and the region of their coalescence reached 80-100 mm, which indicates the prospects for using two-stream plasmotrons with magnetic control of the electric arc in performing different technological processes.

NOTATION

I, U, current and voltage on the electric arc; P, electrical power liberated in the arc; B, magnetic induction of the external field; t, time; τ, period of oscillations; f, frequency of oscillations; γ, initial angle between the sections of the electric arc; φ, angle of deflection of the electric arc in the external magnetic field; l_0, base distance between the nozzles of the units of the two-stream plasmotron; l_m, length of the mixing region; ρ, density of the gas in the electric arc; v, velocity of the gas flow in the arc; and S, cross section of the column of the arc.

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