VIBRATIONS OF THE ELECTRIC FIELD STRENGTH OF ARCS AT THE AXIS OF A SUBMERGED JET

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It is shown experimentally that pulsed variation of the arc shape produces damped voltage and field strength vibrations.

The strength of the electric field of an arc in the plasmatron channel is affected considerably by the arc current, the type, discharge, and pressure of the stabilizing gas, and the dimensions of the electric arc chamber [1, 2]. In many papers, a survey of which can be found in [1-3], it was demonstrated that the electric field strength along the plasmatron channel diminishes with a reduction in the discharge of the plasma-forming gas and that it increases with this discharge. The strength drop in the range of small discharge values for the stabilizing gas is explained by transition from turbulent flow conditions to laminar flow.

An arrangement involving gas flow with arcing in the plasmatron channel whereby the flow gradually changes its character along the channel, from laminar to turbulent, is described in [1]. Depending on the plasma-forming gas discharge, the strength of the electric field of the arc changes substantially. Let us consider the qualitative model of the process. With a low discharge of the stabilizing gas, there may exist simultaneously several current channels with equal conductivities over the turbulent section, as a result of which the overall electric resistivity, the arcing voltage, and the electric field strength decrease within this section. An increase in the stabilizing gas discharge eliminates all the secondary current channels and results in strong arc pinching, which manifests itself in increased electric resistivity, voltage, and field strength of the arc. However, the pattern of changes in the arcing parameters during and after the action of the turbulence-producing factor is still unclear.

We are concerned here with an experimental investigation of the effect of pulsed perturbation of the arc on the arcing current and voltage. Since it is difficult to observe and investigate the arc in a channel, we used, for the sake of simplicity, the external argon arc of a two-jet plasmatron with arcing in the open.

Our investigations have shown that such an arc possesses three-dimensional stability for currents of 90-200 A, an argon discharge through the anode head of $0.12\text{-}0.5 \cdot 10^{-3}$ kg/sec, and an anode section length of up to 0.160 m [4], while its current and voltage remain unchanged during an experiment. A device for pulsed variation of the arc shape by air injection over periods of 0.003-0.007 sec at a frequency ν = 5-10 Hz was developed. The device consists of a cylindrical chamber with a diaphragm driven by an electromagnet and a flat nozzle for the outflow of gas. Such a device makes it possible to create jet perturbations at a point. During experiments, a K-117 loop oscillograph was used for recording the arcing current and voltage, while the probe method was used for recording the arc potential with respect to the anode; the arcing was filmed with an SKS-1M high-speed motion picture camera. The basic parameters of the plasmatron and the plasma jet were the following: I = 170 A, U = 160 V, $G_a = G_c = 0.29 \cdot 10^{-3}$ kg/sec, $d_a = d_c = 6.5 \cdot 10^{-3}$ m, and l = 0.13 m. The gas pulse acted on the jet at a distance of 30 mm from the nozzle cutoff in the anode head.

Measurements have shown [4, 5] that, regardless of the stabilizing gas discharge through the anode head, the field strength at a distance larger than $30\text{-}35 \cdot 10^{-3}$ m from the cutoff end of the nozzle remains constant. An increase in argon discharge causes the value of E to rise near the heads, where compressive gas action is still observed.

As a gas pulse acts on the arc in the direction perpendicular to its axis, the arc column is disturbed: The current first decreases, reaching a minimum value, and then smoothly increases up to its initial value, while the voltage varies according to the law of damped vibrations (Fig. 1):

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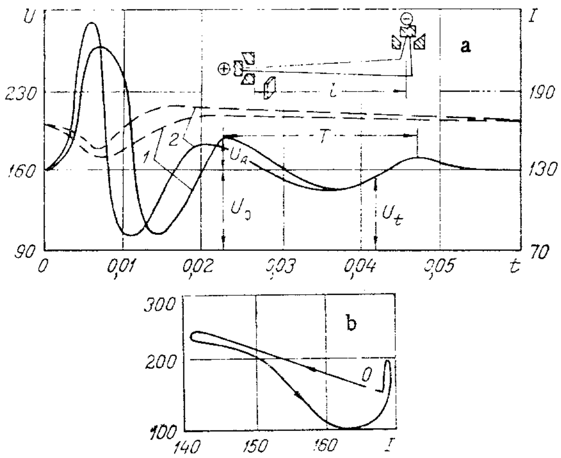

Fig. 1

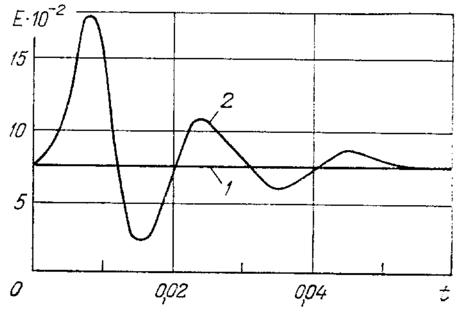

Fig. 2

Fig. 1. a) Time variation of the current and voltage with pulsed perturbation of the arc: 1) τ = 0.007 sec; 2) 0.006 sec; b) volt—ampere characteristic over a cycle of arc perturbation (the arrows indicate the direction of change in the volt—ampere characteristic); U is given in volts; I is given in amperes; t is given in sec.

Fig. 2. Electric field strength for an arc at the submerged jet axis as a function of time. 1) Without perturbations; 2) perturbations applied in the form of a gas pulse with the duration τ = 0.007 sec; E is given in volts per meter.

$$U_t = U_0 + U_{tA}, \quad (1)$$

$$U_{tA} = U_A \sin \frac{2\pi}{T} t \exp[-\varepsilon t]. \quad (2)$$

For an electric circuit consisting of the inductance L, the resistance R, and the capacitance C, the damping decrement is given by

$$\delta = \frac{\pi R}{L\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}}. \quad (3)$$

Calculations show that the damping decrement varies in the $\delta \approx 1.33\text{-}1.02$ range, decreasing with the damping of voltage vibrations, while the vibration period, on the contrary, increases: $T = 16\text{-}25 \cdot 10^{-3}$ sec.

The use of expressions (2) and (3) pertaining to damped vibrations in a linear system to describe arc voltage variation in the case of pulsed arc perturbations is formally possible with an error of 30%. The volt—ampere characteristic of arcing (Fig. 1b) has a rising branch which then passes into a descending branch within a vibration cycle, thus forming a loop. It should be noted that, within the limits of stable operation, the damping time of vibrations of the perturbed arc $\tau_d \approx 0.05$ sec does not depend on the amplitude and duration of the agitating gas pulse ($\tau_u \leq 0.007$ sec), but rather on the arc current and length and the type and discharge of the stabilizing gas. During the gas pulse action, the arc voltage increases by 65%, while the current decreases by 17%. Processing of motion picture stills has shown that the luminous extent of the arc increases by 20% in this case. After the gas pulse action is discontinued, the rise stops, and the voltage starts to drop, while the current still continues to decrease for some time ($\tau \approx 0.001$ sec). This is followed by a further reduction in the voltage and a rise in the current.

A characteristic feature of the voltage variation after removal of the gas pulse is that the voltage decreases by 37% after reaching its initial value. Since the spacing between the plasmatron heads has not changed, one must assume that the electric field strength in the perturbed region of the arc diminishes. Probe measurements along unperturbed arc sections near the electrodes have shown that perturbation of the central arc section does not affect the potential distribution in the unperturbed sections. Therefore, the assumption was made that the voltage changes only within the perturbed section. This allowed us to plot the time dependence of the mean electric field strength (Fig. 2) over the perturbed section. The maximum mean field strength occurs for arcs with transverse blowing [2]. The minimum mean field strength obtained experimentally ($E \approx 200$ V/m) was lower than that for arcing in a channel and arcing under similar conditions at the axis of a submerged jet [1]. In previously published papers, the electric field strength values were apparently averaged for an arc section where several continuously excited turbulent zones existed simultaneously.

The mean value of the field strength decreases for two reasons: the increase in the diameter of the electrically conducting column and the shunting between the neighboring curved sections of the arc. The existence of two current channels, a curved one and a newly formed channel, over a certain time ($\tau \approx 0.005$ sec) is observed on the motion picture stills. From Ohm's law in differential form ($E = j/\sigma$), it follows that the drop in E occurs with a reduction in the current density. Actually, processing of high-speed motion picture stills indicates that perturbation of the arc by a gas pulse reduces the luminous diameter, and the existence of two current channels is observed after the perturbing pulse is removed. It is interesting that, although application of pulsed perturbation to the arc produces vibrations of the energy liberated in the arc, the energy averaged over the time of current and voltage vibrations is equal to the energy released in an unperturbed arc during the same time.

Analyzing the results of our experiments, we reach the conclusion that the arcing parameters change with pulsed perturbation of the arc: The voltage and the strength of the electric field vary according to the law of damped vibrations. The vibration damping time (within the limits of stable arcing) does not depend on the initial amplitude of the voltage deviation, but is a function of the current and the length of the perturbed arc section and the type and discharge of the stabilizing gas.

On the basis of the investigation results, we can state the assumption that, as a result of external action, one can ensure arcing conditions with reduced or elevated values of the field strength.

NOTATION

ν, vibration frequency; I and U_0, arcing current and voltage, respectively; G_a and G_c, discharge of stabilizing argon through the anode and cathode plasmatron heads, respectively; d_a and d_c, diameters of the outlet nozzle openings in the anode and the cathode heads, respectively; l, distance indicated in Fig. 1; τ, time; j, current density; σ, conductivity of the arc plasma; U_t, arc voltage in the case of arc perturbation; U_{tA}, deviation of the arc voltage from τ; ε, damping factor; δ, damping decrement; L, C, and R, inductance, capacitance, and ohmic resistance of the arc — supply source circuit.

LITERATURE CITED

1. M. F. Zhukov, A. S. Koroteev, and B. A. Uryukov, Applied Thermal Plasma Dynamics [in Russian], Nauka, Novosibirsk (1975).
2. O. I. Yas'ko, Electric Arc in a Plasmatron [in Russian], Nauka i Tekhnika, Minsk (1977).
3. A. V. Donskoi and V. S. Klubnikin, Electric Plasma Processes and Devices in Machine Construction [in Russian], Mashinostroenie, Leningrad (1979).
4. S. P. Polyakov and V. I. Pechenkin, "Investigation of the electric and thermal structure of the argon arc of a two-jet plasmatron," Inzh.-Fiz. Zh., 43, No. 5, 833-837 (1982).
5. M. F. Zhukov, A. S. An'shakov, I. M. Zasypkin, et al., Electric Arc Generators with Interelectrode Inserts [in Russian], Nauka, Novosibirsk (1981).