EXPERIMENTAL INVESTIGATION OF VAPOR JETS IN HEAVY-CURRENT ARCS

V. I. Alferov and N. I. Krasovskaya

Inzhenerno-fizicheskii zhurnal, Vol. 8, No. 1, pp. 27-30, 1965

Results are given of an investigation of vapor jets in free arcs in the current range I = 500-1,000 a.

Experiments were carried out in an experimental set-up consisting of an arc struck between two graphite electrodes. The arc was supplied from a dynamo with a 400-v maximum output, a 0.34-ohm series ballast resistance was included to give steady conditions, and oscillograms of the discharge current and voltage were recorded.

The electrodes were made of electrode graphite, the cathode being a blunt cone-cylinder 35 mm in diameter, while the anode shape varied with the purpose of the experiment, being either a 50-mm $\phi$ cylinder, or a diaphragm with a cylindrical aperture of diameter $f$ = 10 mm. In a number of tests a nozzle of throat diameter $d_t$ = 15 mm was used.

First a method was developed to make the arc structure visible. High-speed photography (100 frames/sec) was used for direct observation of processes occurring within the arc—temperature zones and vapor jets. Various light filters were used to detect temperature zones in the arc, as well as the arc column. Colored glass filters, and interference filters with maximum transmission at wavelengths $\lambda_{max}$ of 5,900 and 4,100 A were used. Choice of filter wavelength interval was based on radiation spectra data for the plasma jets.

The photographs of Fig. 1 were taken by this method.

The clearest pictures of plasma jet flow were obtained with an OS-14 light filter and a yellow interference filter with $\lambda_{max}$ = 5,900 A. The central part of the jet then showed up sharply, while light from peripheral regions was cut off (Fig. 1). Several cathode and anode spots were also observed.

Great interest attaches to evaluating the momentum of the vapor jet, and to determining the pressure distribution inside the nozzle when the arc is struck. A nozzle-anode was therefore prepared from electrode graphite; this was used with a cylindrical cathode, d = 35 mm. Seven pressure taps were made in the nozzle, and these were connected via nipples and rubber tubing to U-tube alcohol manometers. The total pressure at the nozzle exit was measured with a total-pressure probe. The manometers were mounted on one panel, and their readings were recorded with a camera filming at 24 frames/sec.

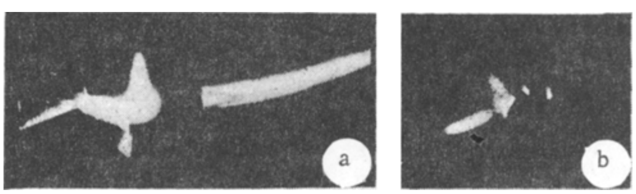


Fig. 1. Photographs of plasma jet flow

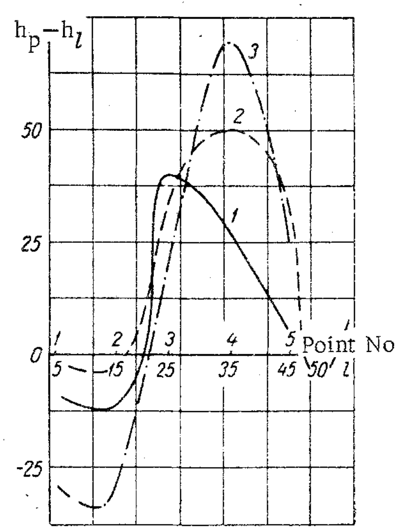


Fig. 2. Pressure distribution ($h_p - h_l$ = = 0.784 newton/m$^2$) along the length ($l$, mm) of the nozzle, for current intensities (a): 1—500; 2—600; 3—900

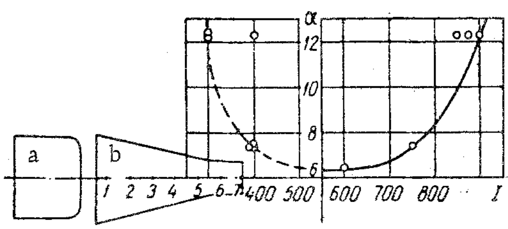


Fig. 3. Angle of inclination of arc as a function of arc current I (a): a—cathode; b—anode-nozzle

The results were used to draw graphs of the pressure difference as a function of burning time and nozzle pressure distribution for various current intensities and interelectrode distances (Fig. 2). The current was varied in the range 300-900 a. It turned out that the pressure distribution was similar in character for all conditions. At the nozzle inlet (points 1 and 2) a vacuum exists, the static pressure being less than atmospheric; at points 3, 4, and 5 the pressure difference is positive, and in the throat region there is again a vacuum. This indicates that a process of suction of the surrounding air layers exists in the nozzle, i.e., there is an induction effect. The effect increases sharply for currents I = = 500-600 a and interelectrode distances $l$ = 30 – 20 mm, when the jet is located almost along the nozzle axis, and the total-head probe indicates maximum pressure difference. When the interelectrode distance is reduced to 15 mm, the induction effect also diminishes; the jet closes at the nozzle entrance.

At larger currents (I = 900-700 a) the arc behaves erratically and is not accurately centered in the nozzle, closing in the region of the first points, whereupon the pressure at the inlet increases sharply, while that at the probe falls to atmospheric. Fig. 3 shows the angle of inclination of the arc as a function of the operating conditions. The explanation of this effect is evidently as follows.

At small currents (I = 400 a) the arc follows the shortest path. When one vapor jet appears (I = 500-600 a), the current is propagated along it, and closes at the nozzle throat. At larger currents (I = 600 a), several vapor jets develop [1]; since the conductivity in the jets is greater, the current for the most part flows along them. As a result of the interaction of these currents, the jets become twisted, and the arc closes at the beginning of the nozzle.

If the relationship between jet velocity and cathode distance given in [1] is used to construct a dimensionless velocity profile $v_m/v_0 = F(x)$ (Fig. 4), where $v_0$ is the initial jet velocity, $v_m$ is the velocity at the center of the jet at a given point, $\bar{x} = x/r_0$, where x is the distance from the cathode and $r_0$ is the initial radius of the single jet (in this case $r_0 = 0.016$), it turns out that the dimensionless jet velocities at different currents coincide completely.

From the fact that the dimensionless jet velocities in the center of the arc coincide closely at different currents, it may be asserted that the velocity profiles in the arc are similar. A certain deviation of the dimensionless profiles at large values of $\bar{x}$ can be attributed to the spreading of the vapor jet. Analogous relations for air and carbon plasmas calculated by the method of [2] are given for comparison.

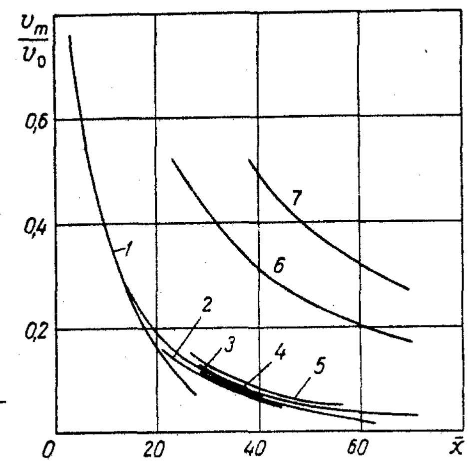


Fig. 4. Dimensionless velocity profiles: 1—I = 1200 a (6 jet); 2—1,000; 3—900; 4—800 (4 jet); 5—700 (curves 2, 3, 4, and 5 were obtained experimentally); 6—$a\lambda^2$ = 0.13, x—1.19; 7—$IA^2$ = 0.42, x = 1.67

In the calculations it was assumed that a supersonic jet with Mach number M depending on the current strength chosen is propagated in a flooded space homogeneous in structure and analogous in nature to the jet. The stagnation temperature was taken to be constant across the whole section of the arc, this being the temperature that the gas would acquire if brought to rest adiabatically. If allowance is made for the stagnation temperature of the jet being greater than that of the surrounding gas, the agreement will be even more complete, especially if it is assumed that the jet consists of a carbon plasma.

The similarity between the experimental and the calculated jet velocity attenuation permits the hypothesis that the velocity profiles across the jet are also similar.

Comparison of the velocity attenuation curves shows that agreement is best for a relative velocity $v_m/v_0$ close to unity; with decreasing relative velocity they diverge. This points to mixing of the colder (denser) layers of the arc with the flow of the vapor jet, intensifying the retardation.

At a certain distance from the cathode the whole arc is in motion.

Using the pressure distribution along the nozzle, a comparison can be made between the total pressure measured experimentally and that derived on the basis of the "universal" velocity profile. From the "universal" profile the jet velocity at any distance from the cathode can be determined.

The density of the carbon plasma was determined from the conditions $p_{st} = 9.8 \cdot 10^4$ n/m², $T_{st} = 7,000°$ K, the latter from spectroscopic measurements. For an arc current I = 800 a and a cathode distance x = 3 cm, the discrepancy was $p_{meas}/p_{theor} = 10$.

REFERENCES


1. Vineke. Zeitschrift für physik, 1958.
2. G. N. Abramovich, Theory of Turbulent Jets [in Russian], Fizmatgiz, 1960.


13 April 1964