GENERALIZATION OF THE CURRENT-VOLTAGE CHARACTERISTICS OF ELECTRIC ARC HEATERS

A. I. Zhidovich, S. K. Kravchenko, and O. I. Yas'ko

Inzhenerno-Fizicheskii Zhurnal, Vol. 13, No. 3, pp. 304–307, 1967

UDC 537.523.5

The Euler number can be used to take into account the automatic establishment of the arc length in electric arc heaters of the linear type and to generalize their current-voltage characteristics.

In [1] we reported some results of an investigation of geometrically dissimilar plasmatrons (arc plasma heaters) and gave generalized current-voltage characteristics in dimensional complexes corresponding to the dimensionless criteria $Ud\sigma_0/I$, $K = I^2/Gd\sigma_0 h_0$, Re, and D/d. A serious shortcoming was the incompleteness of the generalization, since the formulas included the electrode diameter in addition to these criteria. This was because we could not find a suitable criterion for generalization of the electrode processes affecting the arc length.

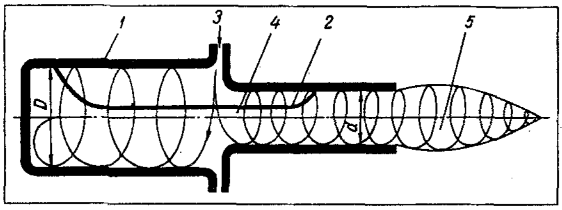

Fig. 1. Diagram of plasmatron with arc stabilized by gas vortex: 1) inner electrode; 2) outer electrode; 3) gas inlet; 4) electric arc; 5) plasma jet.

The arc length in heaters of the linear type depends on the conditions of breakdown of the cold gas layer at the electrodes. In view of this, the generalized formula in [2, 3] contained the Knudsen number, which is proportional to the dimensional complex 1/Pd. Such an approach assumes that, for each particular gas, the complex Ud/I for constant values of the numbers I^2/Gd, G/d, and D/d depends equally on P and on d. This assumption, however, has not been experimentally confirmed—the dependence on d is much stronger. Hence, we can conclude that the decisive role in establishment of the arc length is not electrical breakdown, but other processes.

We postulated that the main factors affecting the arc length in electric arc heaters of the linear type are heating processes and force interactions. The heating of the gas is taken into account by the criterion $K = I^2/Gd\sigma_0 h_0$ obtained from the energy equation [4, 5]. Force interactions are described by the equation of motion. For electric arc devices without external magnetic fields and with currents up to several thousands of amperes in steady-state operation, the force interactions are described by the criteria $Re = G/\mu d$ and $Eu = \rho \Delta P d^4/G^2$. The Reynolds number was taken into consideration in the generalization of the current-voltage characteristics of the arc, whereas the Euler number was neglected, despite the assumption that it might have some effect.

We carried out special experiments to test the effect of Eu on the current-voltage characteristics of an electric arc. To reduce the influence of Re, we had to carry out the experiments in the region of developed turbulence, where the Reynolds number degenerates. For this purpose, the experiments were conducted in the discharge chamber shown schematically in Fig. 1.

The heater consisted of two hollow cylindrical electrodes with a gas-conducting ring made of insulating material placed between them. One electrode was open at both ends and through it the heated gas escaped into the atmosphere; the second was in the form of a cup. The two electrodes were made of copper. They were cooled externally with water to prevent burnout. In addition, gas was injected tangentially into the chamber, and the vortex formed rotated the parts of the arc near the electrodes.

In the experiments, we varied the sizes of the electrodes, but the diameter of the open electrode was also less than that of the closed one. With this setup, the gas first entered the closed electrode, flowed along its inner surface, and then returned along the axis. The electric arc was blown into the electrode by the gas; the arc length depended on the gasdynamics of the flow and the electrical breakdown of the cold layer at the electrode. The countermotion of the jet and the electric arc moving under the action of the gas vortex promoted turbulence of the flow. The arc extended for a little distance into the open electrode, since the cold electrode layer of the preheated turbulent flow is very thin and rapidly breaks down. Hence, practically the whole arc burns in the closed electrode.

The experiments were conducted with direct current and with the open electrode as the positive one. The diameter of the closed electrode was varied from 20 to 35 mm, and that of the open one from 8 to 20 mm. The current varied in the range 100–850 A and the gas (air) flow rate was 6–18 g/sec. Measurements showed that the pressure in the chamber increased with reduction in the diameter of the open electrode and increase in current. The maximum pressure was 9.32 atm abs, and the minimum was 1.08 atm abs. The voltage increased with increase in pressure and electrode diameter. It decreased slightly with increase in current. The range of variation of the voltage on the arc was 260–610 V.

In the considered case, the pressure drop ΔP characterizes the outflow of heated gas through the open electrode, whereas the burning of the electric arc depends on the pressure in the closed electrode. Hence, it is better that Eu should contain the pressure P instead of ΔP. Then the Euler number

$$\mathrm{Eu} = \rho P D^4 / G^2.$$

In accordance with the above the expression for the generalized current-voltage characteristic can be put in the form

$$\frac{UD\sigma_0}{I} = f(\mathrm{K},\ \mathrm{Eu},\ \mathrm{Re}). \qquad (1)$$

Using an approximation in the form of power relationships and converting to dimensional complexes we obtain

$$\frac{UD}{I} = a\left(\frac{I^2}{GD}\right)^b \left(\frac{PD^4}{G^2}\right)^c \left(\frac{G}{D}\right)^e. \qquad (2)$$

This expression was used to generalize the experimental characteristics.

Treatment of the experimental data with initial values in the above-indicated ranges gave the values

$$a = 5.62\cdot 10^3 \frac{\mathrm{kg}^{0.42}\mathrm{m}^{1.98}}{\mathrm{A}^{0.68}\mathrm{sec}^{2.28}},$$

$$b = -0.66.\ c = 0.14.\ e = 0.06.$$

Figure 2 shows how satisfactory this generalization is. The figure shows the relationship

$$\frac{UD}{I} \Big/ \left(\frac{PD^4}{G^2}\right)^{0.14} \left(\frac{G}{D}\right)^{0.06} = f\left(\frac{I^2}{GD}\right). \qquad (3)$$

As the figure shows, the scatter of the experimental points lies in a range of 20%. The obtained result confirms the initial premises fairly well. First, instead of the four characteristic initial quantities (I, G, P, and D), we used only three criteria (K, Eu, and Re). This indicates that the processes reflected by these criteria are actually the dominant ones in the indicated conditions of burning of the arc. As we postulated, the Reynolds number is actually close to degeneration (the exponent e = 0.06). Hence, in a first approximation Re can generally be neglected. The scatter of points in this case is within a range of 25%. Hence, instead of the four primary quantities, we can use only two generalized ones.

The effect of Eu on the arc length can be represented as follows: with increase in diameter the thickness of the cold gas layer increases and, hence, breakdown occurs at a greater potential difference; with increase in pressure, the gas density increases and this also worsens the conditions for electrical breakdown. The increase in gas flow rate increases the turbulence of the flow and, hence, mixing of the gas in the heated layer. This facilitates electrical breakdown and the arc is shortened.

The power to which the characteristic dimension is raised is four times that of the pressure. Hence, Eu characterizes the relative effect of these quantities on the arc length better than the Knudsen number.

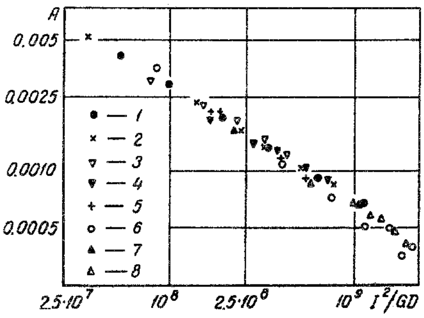

Fig. 2. Generalized current-voltage characteristic of linear plasmatron with air vortex stabilization: D = = 0.035 m, d = 0.008 m, gas flow rate 1) 0.006; 2) 0.010 kg/sec. D = = 0.035 m, d = 0.02 m, gas flow rate 3) 0.018; 4) 0.010 kg/sec. D = = 0.020 m, d = 0.014 m, gas flow rate 5) 0.018; 6) 0.006 kg/sec. D = = 0.020 m, d = 0.008 m, gas flow rate 7) 0.006; 8) 0.018 kg/sec. A = $= (ND/1)/(PD^4/G^2)^{0.14}(G/D)^{0.06}$.

As a whole, the results of this work show that the Euler number is probably the criterion which has been lacking for the satisfactory generalization of the characteristics of electric arc heaters.

NOTATION

I is the current, A; U is the voltage, V; D is the diameter of the inner electrode, m; d is the diameter of the outer electrode, m; P is the pressure, N/m^2; ρ is the density; σ is the electrical conductivity; h is the enthalpy; μ is the dynamic viscosity; Re is the Reynolds number; Kn is the Knudsen number; Eu is the Euler number; K is the energy number; a is the coefficient; b, c, and e are exponents.

REFERENCES

1. A. I. Zhidovich, O. A. Savel'ev, and O. I. Yas'ko, IFZh [Journal of Engineering Physics], vol. 11, no. 5, 1965.

2. G. Yu. Dautov and M. F. Zhukov, PMTF [Journal of Applied Mechanics and Technical Physics], no. 2, 1965.

3. G. Yu. Dautov and M. F. Zhukov, PMTF [Journal of Applied Mechanics and Technical Physics], no. 5, 1965.

4. S. S. Kutateladze and O. I. Yas'ko, IFZh, no. 4, 1964.

5. O. I. Yas'ko, IFZh, no. 12, 1964.

29 November 1966

Institute of Heat and Mass Transfer AS BSSR, Minsk