CURRENT-VOLTAGE CHARACTERISTICS AND EMF OF AN ELECTRIC-ARC HEATER OPERATING WITH VARIOUS GASES

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The stationary and dynamic current-voltage characteristics of an electric-arc heater with an argon, nitrogen, air, and oxygen stabilized arc are determined. An empirical expression for calculating the current-voltage characteristics for various working gases is proposed.

The ever growing application of electric-arc heaters in various branches of science and technology poses continuously growing requirements in regard to operational procedures and service life. For example, the use of plasmatrons for simulating the conditions encountered by a vehicle that passes through dense atmospheric layers of various planets involves electric-arc heating of inert and aggressive gases over a wide range of temperatures and pressures.

Specific design features of a heater and some characteristics of the generated jet are examined in [1, 2].

STATIONARY CURRENT-VOLTAGE CHARACTERISTICS

During the past few years, much attention has been given to the determination of the mechanism of arc burning in gas vortex-stabilized plasmatrons. When a portion of the electric arc is aligned with the axis of a hollow cylindrical electrode—as is the case in the plasmatron under study—arc burning is accompanied by a complex motion of the base spot across the inner electrode surface. This phenomenon is due to continuous arc shunting to the electrode wall [3, 4]. For a mean mass velocity of 850 to 900 m/sec of the gas through a cylindrical electrode, the mean axial velocity component of the cathode spot in the output electrode is on the order of 180 m/sec. Here, the electric-arc parameters are subjected to continuous changes. Under certain conditions, the voltage fluctuations may reach 40 to 50% of their mean value [3, 4].

Such an arc-burning mechanism indicates that, normally, the mean values of the current and voltage should be used in deriving the stationary current-voltage characteristics.

The burning of a plasmatron arc is influenced by a number of factors. Hence, the current-voltage characteristics depend on the flow rate of the working gas, the type of gas, the gas pressure and type of gas supply, as well as on the geometrical dimensions, shape, and arrangement of the electrodes, the material and polarity of the electrodes, the magnitude of the proper and external magnetic field, and other factors.

For plasmatrons with a self-adjusting arc length (the geometry and spacing of the electrodes have no significant effect on $U = f(I)$, all other conditions being equal, it may be assumed that the current-voltage characteristic is essentially determined by the physical properties of the gas referred to a certain characteristic temperature and by the flow rate of the gas.

The stationary current-voltage characteristics of a gas vortex-stabilized electric-arc heater were measured for the case where the output electrode serves as the anode. The arc current was determined by means of a wire-wound rheostat with a resistance ranging from 0.2 to 0.6 ohms, and was calculated from the voltage drop at 75 ShS type shunting devices (750 A, 75 mV), which was recorded within an accuracy of ±2.5% with a nine-loop 50-Simens oscillograph. The voltage was read directly at the electrodes between which the electric arc was burning and was recorded, within an accuracy of ±1.5%, with an oscillograph.

Figure 1 shows the stationary current-voltage characteristics for operation with nitrogen. As usual, the characteristics tend toward the high voltage-drop values with increasing gas flow rate.

The spread of the experimental points (Fig. 1) is typical for a plasmatron of this design [1, 8].

The family of stationary current-voltage characteristics determines the operating range of the parameters of a plasmatron of this type in the aerodynamic rotation of the base points of the arc. At currents above 1000 to 1200 A, the electrodes become unserviceable due to the onset of intense erosion. At currents smaller than a certain value $I_{\text{min}}$ [5, 6], the arc becomes unstable and extinguishes.

Figures 2 and 3 show the current-voltage characteristics shift toward the higher voltage-drop values when the flow rate of air and oxygen is increased.

An arc burning in argon (Fig. 3b) exhibits a peculiar behavior. The voltage drop at the arc is roughly 3 to 3.5 times less than for operation with oxygen and other gases. The stationary characteristic $U = f(I)$ of an argon arc in the plasmatron under study is horizontal ($U = \text{const}$). The spread of experimental points observed in this case (up to 25%) is an indication for unstable burning of the arc under these conditions.

DYNAMIC CURRENT-VOLTAGE CHARACTERISTICS

Of great interest for the operation of the plasmatron are its dynamic current-voltage characteristics; i.e., the characteristics measured when the current varies at a rate at which steady-state equilibrium cannot be established [5].

The dynamic current-voltage characteristics were measured with an H-359 two-coordinate ammeter, which made it possible to record the current as a function of the voltage.
Fig. 1. Current-voltage characteristics of a plasmatron employing nitrogen as the working gas (d_{an} = 15 mm; d_{cath} = 20 mm). Stationary: 1) GN2 = 2 g/sec; 2) 3 g/sec; 3) 4 g/sec; 4) 5 g/sec; 5) 6 g/sec; 6) 7.0–7.5 g/sec; 7) 10 g/sec. Dynamic: 8) 6 g/sec; 9) 8 g/sec.

Fig. 2. Current-voltage characteristics of a plasmatron employing air as the working gas (d_{an} = 15 mm; d_{cath} = 20 mm). Stationary: 1) Gas = 5.9 g/sec; 2) 11.5 g/sec; 3) 13.25 g/sec. Dynamic: 4) 3.4 g/sec; 5) 4 g/sec; 6) 6.5 g/sec; 7) 6.85 g/sec; 8) 8 g/sec; 9) 10 g/sec.