VELOCITY OF THE ELECTRIC ARC IN A PLASMATRON DISCHARGE CHAMBER

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An experimental investigation of the velocity of a high-current arc with air injection in the discharge chamber of a coaxial sectioned plasmatron is described. The experiments showed that the velocity of the cathode spot on the electrode surface depends on the arc current and on the external magnetic field strength. The air flow rate in the plasmatron chamber was 7.1 g/sec.

The time of continuous operation of plasmatrons with cooled copper electrodes is limited by the rapid erosion of the cathode, which is due mainly to the heat of the cathode spot moving over the cathode surface. Reduction of cathode erosion necessitates good heat-transfer conditions in the cathode spot.

Heat transfer in a cathode spot is affected by many factors: one of these factors is the velocity of the cathode spot on the electrode surface. Hence, an investigation of heat transfer and the associated motion of the cathode spot is an important current problem.

The movement of the cathode spot in the discharge chamber of a coaxial sectioned plasmatron was investigated with the aid of a special section consisting of two cooled hollow copper half-cylinders. A voltage of 826 V was applied to the plasmatron from a mercury rectifier; the coil current was supplied by a 220 V dc generator. The voltage was applied to the two halves of the section, to one of them through a 500 A/75 mV shunt.

A Siemens SO-09 loop oscillograph was connected to the shunt. The current in the oscillograph circuit was measured with a SMU-2 galvanometer with an internal resistance of 1.0 Ω. The maximum current which can be measured with this galvanometer is 200 mA, the maximum detectable frequency is 4000 Hz, and the sensitivity is 0.16 mm/mA. The experiments were conducted on a plasmatron connected up as shown in Fig. 1. The interelectrode gap was 6 mm.

When the electric arc is formed the arc spots have a rotational motion on the electrode surface due to the action of gasdynamic and electromagnetic forces: the anode spot moves over the surface of the inner electrode and the cathode spot moves over the surface of the split section, which acts as a cathode. When the cathode spot moves over the surface of the half-section connected through the shunt an electric signal is delivered to the oscillograph. When the cathode spot moves over the other half of the section no signal is received by the oscillograph. This periodic process is recorded by the oscillograph. The number of revolutions made by the cathode spot in unit time can be determined from the oscillogram.

If the number of oscillations n on length l of the tape is determined and the tape velocity v is known, the number of revolutions of the cathode spot in unit time can be calculated from the formula

$$\nu = \frac{nv}{l}; \tag{1}$$

ν is in hertz if the tape velocity and tape length are expressed, m/sec and m, respectively.

Once ν has been calculated, the angular and linear velocities of the cathode spot can be determined.

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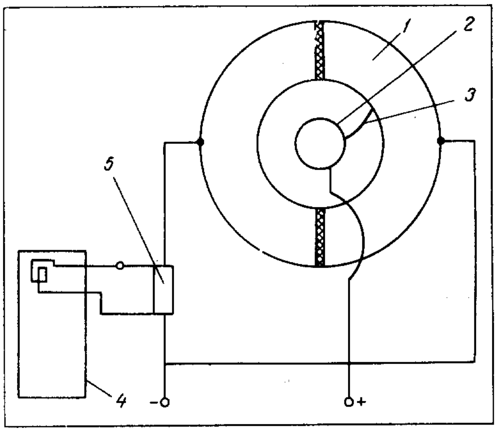

Fig. 1. Setup for measurement of arc spot velocity: 1) outer electrode; 2) inner electrode; 3) electric arc; 4) oscillograph; 5) shunt.

The experiments were conducted with two different directions of injection of air into the plasmatron discharge chamber. In the first case the air was injected tangentially into the chamber so that the gasdynamic and electromagnetic forces acted in the same direction ("cotorsion"). In the second case the air was again injected tangentially into the chamber, but the gasdynamic and electromagnetic forces acted in opposite directions ("counter-torsion").

The results of investigations of the cathode spot velocity in relation to current and the external magnetic field are shown in Fig. 2.

Figure 2a-d shows the cathode spot velocity as a function of current for external magnetic fields of 850, 1200, 1700, and 2900 Oe, respectively. The air flow rate was 7.1 g/sec.

In these experiments, with arc current in the range 100-800 A and the external magnetic fields given above, the cathode spot velocity was 65-250 m/sec with cotorsion and 50-250 m/sec with counter-torsion.

These graphs show that the cathode spot velocity with cotorsion was a little higher than with counter-torsion. This difference decreased with increase in the external magnetic field. When the external magnetic field strength was 2900 Oe, the difference was practically zero. The graphs also show that the cathode spot velocity in both cases varied linearly with current in the current range 100-800 A.

The reduction of the difference in velocities with counter-torsion and cotorsion when the external magnetic field is increased indicates that electromagnetic forces have a much greater effect on the arc velocity than gasdynamic forces in the given conditions.

Figure 3a shows the cathode spot velocity as a function of the external magnetic field for different arc currents.

With magnetic fields in the range 850-2900 Oe the cathode spot velocity varied from 70 to 150 m/sec for a current of 200 A, from 105 to 175 m/sec for a current of 400 A, from 130 to 200 m/sec for a current of 600 A, and from 160 to 250 m/sec for a current of 800 A. As the graphs show, the cathode spot velocity depends linearly on the external magnetic field in the current range 100-800 A.

Kukekov and Bron [1, 2] determined the arc velocity in control devices in relation to many factors, including the current and external magnetic field. The arc velocity was expressed in terms of the arc current and external magnetic field by the equation:

$$v_s = 35.6 \sqrt[3]{\frac{IH^2}{(1+0.4\,H^{0.3})^2}}\,.$$

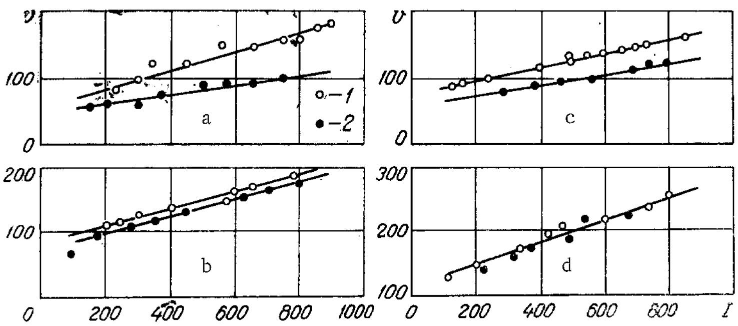

Fig. 2. Cathode spot velocity as function of current: 1) Co-torsion; 2) counter-torsion: a) H = 850; b) 1200; c) 1700; d) 2900 Oe.

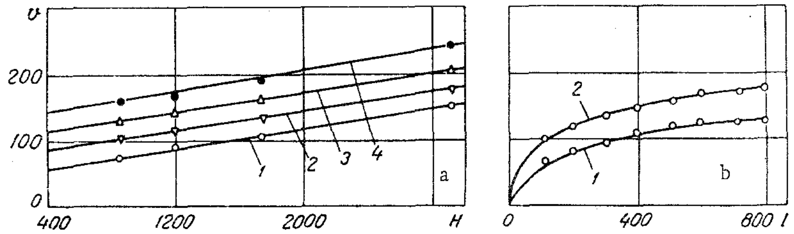

Fig. 3. Cathode spot velocity as function of external magnetic field (a) and comparison of theoretical and experimental values of cathode spot velocity (b): a) current: 1) 200; 2) 400; 3) 600; 4) 800 A: b) field; 1) 1000; 2) 2000 Oe.

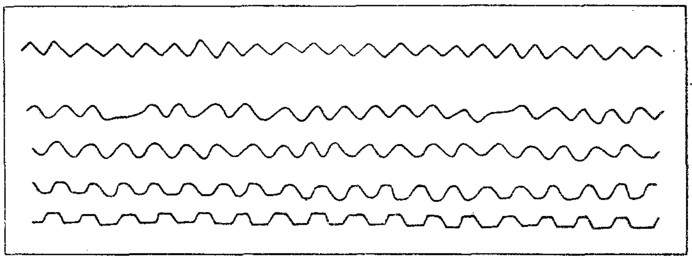

Fig. 4. Oscillogram showing variation of cathode spot velocity with current.

The experimental conditions under which the arc velocity was determined in the experiments by the authors of [1, 2] differed from the conditions in the experiments with the coaxial plasmatron, but the results in the current range 100-800 A with magnetic fields of 1000 and 2000 Oe are in good agreement with the relationship given by Eq. (2).

The points in Fig. 3b are the experimental results and the continuous curves are the calculated values.

At currents of 100-800 A and external magnetic fields of 850-2900 Oe the dependence of the cathode spot velocity in a plasmatron discharge chamber on the current and external magnetic field can be regarded as linear.

A large number of experiments showed that movement of the cathode spot over the electrode surface leads to shunting and, hence, the motion of the cathode spot is jumpy. The jumpy motion of the arc is revealed by high-speed photography [3, 4].

The mean arc velocity is of most interest for many practical applications. It is, in fact, the mean arc velocity which is measured by the method described in this paper, since shunting within one half-ring has no effect on the current passing through the shunt and, hence, has no effect on the result of the measurements. Shunting on the other half-ring affected the current passing through the shunt and this was revealed on the oscillograph trace (the periodicity became irregular).

The oscillograms obtained in measurement of the mean arc velocity could be misleading if shunting was a periodic process with a period which is a multiple of the arc rotation period, but the spot velocity would be different. Uncertainty of this kind could be introduced by the stroboscopic effect in measurement of the mean velocity by high-speed photography. We know, however, that shunting is a random process, represented by a normal distribution, and, hence, does not have a periodic effect on the arc velocity.

The deviation from the mean arc velocity due to shunting as the cathode spot moves is revealed by the oscillations recorded by the oscillograph. In cases of shunting within a half-ring the half-cycle of the loop oscillations is altered and, hence, the periodicity is disturbed. An example of this shunting effect is shown on the oscillogram (Fig. 4, second curve from the top). In the case of shunting between the half rings both the amplitude of the current and the length of the half-cycles are altered.

The mean lengths of the cycle can be determined from the recorded oscillations of the current passing through the shunt. If the number of oscillations is sufficiently high, the error in measuring the mean velocity is insignificant. The illustrated oscillogram shows that disturbance of the periodicity due to shunting is insignificant. Hence, the scatter of the experimental points is slight (Figs. 2, 3).

This means that the root-mean-square of the measurements is reduced in comparison with measurements of the mean arc velocity with photodetectors of various kinds, the signal from which is applied to an oscillograph after amplification by a factor of thousands, and there is no uncertainty like that introduced by the stroboscopic effect when high-speed photography is used.

NOTATION

v_s is the cathode spot velocity;
I is the current, A.
H is the external magnetic field strength.

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