CURRENT-VOLTAGE CHARACTERISTICS OF METALLIC ELECTRODES IN IONIZED GAS FLOWS

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Results of experimental investigations related to the current characteristics of cooled and uncooled metallic electrodes are given. The current-voltage characteristics of the electrode-plasma-electrode interval as well as the relation between the current flowing through the circuit and the temperature of the electrode surface are described. For the visual representation of the electrode characteristics the application of a three-dimensional coordinate system (I, U, T) is recommended.

Introduction. The operation of cooled metallic electrodes is characterized by the formation of a thin cold boundary layer at the electrodes. The current is forced to flow through this layer. The cathode, for example, must have a sufficiently large electron emission at temperatures where the thermal emission is negligible. At the same time, the effective conductivity between the electrodes must be much higher than the value corresponding to ion conduction. This question has not been studied sufficiently either theoretically or experimentally [1, 2].

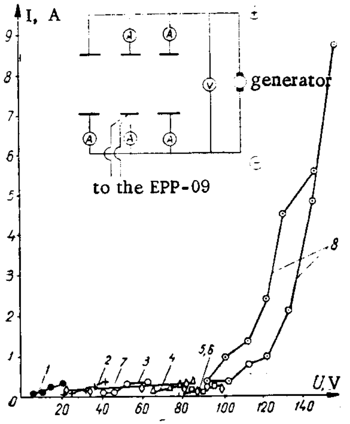

Fig. 1

The experiments have shown that a current can flow between two relatively cold metallic electrodes placed in the flow of the products of combustion of alcohol in preheated air with potassium seed added.

As can be concluded from our measurements described here, the processes taking place at the electrodes are significantly affected by the magnitude of the applied voltage and the surface temperature of the electrodes.

Experimental conditions. The ionized gas flow was produced by burning an alcohol solution of KOH in air preheated in an arc heater of 420 ± 20 kW capacity. The combustion of the alcohol was completed in the plenum chamber of the preheater. At an air flow rate of 60 to 65 g/sec through the arc heater the KOH alcohol flow rate was 7 ± 0.5 g/sec which corresponds to a stochiometric ratio of ~1. The potassium concentration in the combustion products was 0.9%.

The gas temperature was determined by measuring the reversal temperature of the potassium lines and was found to be 2600° K at the exit section of the duct. The average flow velocity based on the mass flow rate measurements was 280 m/sec.

Experiments were performed on two types of ducts: ducts with water cooled metallic (1Kh18N9T steel) electrodes, and ducts with uncooled metallic (1Kh18N9T or 20KP steel) electrodes. The duration of a run with uncooled electrodes has been chosen in such a way that the surface temperature of the electrode could never reach the melting temperature. Hence the electrodes worked in a transient thermal regime which made it possible to investigate the temperature dependence of the various characteristics.

Three pairs of parallel connected electrodes fed by a dc current supply were built in a duct of 25 × 70 mm^2 cross section and 180 mm active length. It was assumed that the two outer electrodes are sufficient to assure the uniformity of the electric field and current distributions in the region of the central electrode pair which was used for the measurements.

The insulator walls as well as the insulating segments between the electrodes were made of boron carbonitride plates. The assembly consisting of the electrodes and insulator walls was mounted between two thick copper plates, which served as heat reservoir, and were fastened to the plenum chamber of the arc heater.

The experimental system is shown schematically in the upper part of Fig. 1. The current was supplied by a 20 kW dc generator, the voltage was cycled (0–120–0 V) during the experiments with uncooled electrodes. Five to six cycles were made during each run (90 to 120 sec total time). It was assumed that the transient processes in the plasma take place at a sufficiently fast rate so that the plasma state could be considered as an equilibrium state in each time instant. The currents and voltages were registered by means of an N-700 oscillograph.

A platinum-rhodium thermocouple, press-fitted about 4 mm below the surface of one of the uncooled central electrodes, was used for temperature measurements. For avoiding electrical disturbances, the junction point was grounded. The thermocouple signals were registered by means of a EPP-09 potentiometer. For determining the true surface temperature from the thermocouple measurements, the temperature distribution in a semi-infinite slab with an insulated lateral surface was calculated. It was assumed that the heat exchange between the free surface of the slab and the environment can be described in terms of convection alone [3]. All experimental results cited here are based on this method.

Results of measurements. The current-voltage characteristics of the metallic electrode-plasma-metallic electrode region were measured for the water cooled electrodes. In this case, the surface temperature was estimated from the temperature rise of the cooling water and has remained below 650° K at the end of the run when the water temperature reached a steady state.

The total current-voltage characteristics between 0 and 120 V have been measured in a series of test runs, each of them covered an interval 5 to 20 V, 20 to 40 V, etc. The characteristic thus obtained is shown in Fig. 1. As can be seen, the dependence of I upon U has two distinct regions. In the first region ending at 80 to 90 V the curve is almost parallel to the abscissa axis. In the second region the slope of the characteristic dI/dU sharply increases. While an increase of the applied voltage from 0 to 80 V results in a current of 0.5 A, a further increase from 80 to 110 V increases the current output to 9 A, i.e., to approximately 20 times of the initial value. The tangents drawn to the characteristics in this region intersect the abscissa axis at the so called threshold voltages. Hence each characteristic has a prethreshold and post-threshold region. Noteworthy is a special feature of these characteristics: during each test run, independently of the initial value of the applied voltage, the current starts at zero and increases to only 0.3 to 0.5 A within the prethreshold region. The duration of the runs and thus the rate of heating of the duct walls was the same in all cases. Therefore, since during each test run the voltage was increased by the same amount, i.e., from 5 to 20 V, from 20 to 40 V, etc; and the same current was flowing through the circuit independently of the voltage level applied (see Fig. 1, curves 1, 2, 3, 4, 5, and 6), it is a plausible assumption that in this case the magnitude of the currents was determined by temperature effects. If this is so, then an increase of the voltage from 20 to 80 V should lead to the same current value (see curve 7 of Fig. 1).

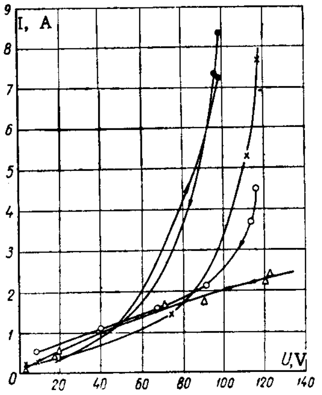

Fig. 2. ●) $t_{\text{electrode}}$ °K ~ 600, +) $t_{\text{electrode}}$ °K ~ 800, ○) $t_{\text{electrode}}$ °K ~ 900, Δ) $t_{\text{electrode}}$ °K ~ 1100.

Apparently, the difference between the two intervals of the current-voltage characteristics is due to qualitative changes in the processes taking place at the electrode. It is also possible that in the given case not only physical processes but also chemical reactions have played a significant role at the electrode surfaces.

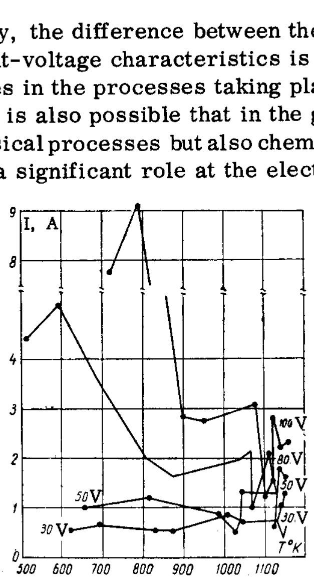

Fig. 3

It has been observed that even during relatively short test runs a 0.3 to 0.4-mm thick film has formed on the electrode surfaces; unfortunately we cannot say anything here about the chemical composition or the origin of this film.

In the experiments with uncooled electrodes, each point of the current-voltage characteristics has been measured twice: once during the voltage increase (from 0 to 120 V) and then during its decrease (from 120 to 0 V).

Since the duration of a single cycle was about 20 to 25 sec, the characteristics were taken at different thermal regimes and, as can be seen from Fig. 2, each run corresponds to a different interval of the electrode surface temperature. The current-voltage characteristics taken with different electrode surface temperatures are shown in Fig. 2.

Within the voltage interval here considered, the slope of the characteristics in the postthreshold interval significantly decreases with increasing electrode temperatures, while its change in the prethreshold region is insignificant. As the electrode temperature increases, the characteristics appear to straighten out, and at temperatures of the order of 1100° K they are practically straight lines. Obviously, the threshold temperature has no physical meaning in this case.

For analyzing this phenomenon, it is advisable to consider the relation between the total current flowing in the circuit and the temperature of the electrode surface (I, T) at a constant applied voltage (Fig. 3). At voltage values in the prethreshold range, 30 to 50 V, the current increases with increasing temperature but does not exceed a certain limit. The maximum current values are small. The situation is quite different in the postthreshold interval (80 and 100 V). In this case a clearly defined region with $dI/dT < 0$ appears. While at lower electrode temperatures ($T \approx 700°$ K) large currents are flowing in the circuit, they decrease sharply as the temperature increases. The current reaches a minimum at an electrode surface temperature of the order of 1100° K, a slight current increase can be observed at a further temperature increase.

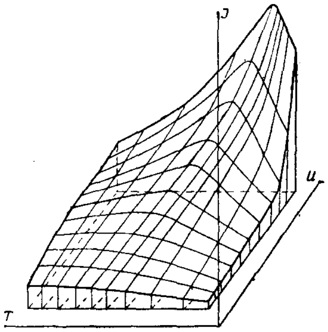

Fig. 4

This effect can be represented by means of surfaces in the I, U, T coordinate system (Fig. 4).

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