Investigation of the characteristics of an electric arc plasmatron with variable geometry electrodes

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Abstract. The study of the electric arc plasmatron was carried out. The energy characteristics of the plasmatron, thermal efficiency and current-voltage characteristics were experimentally investigated. The comparison of the energy characteristics with the plasmatron having no changing geometry of the electrodes was carried out.

1. Introduction

For stationary heating of gases to high temperatures \((3 \div 10) \cdot 10^3 \) K, electric arc plasmatrons are used. Electric arc plasmatrons are widely used in scientific research and industry. With the help of plasmatrons, it is effective to implement chemical and metallurgical processes, create low-waste production and complete processing of raw materials. Also, to obtain new materials with specified physical and chemical properties, to significantly reduce the metal consumption of equipment.

A new area of application of electric arc plasma torches is the utilization and destruction of various types of waste. Further expansion of the field of application of plasma torches and an increase in the efficiency of their use will be determined mainly by successes in the creation of reliable and easy-to-maintain technological electric arc plasma generators with a long service life of electrodes. [1].

The practice of using electric arc plasmatrons with variable geometry of smooth copper cylindrical electrodes has shown their high reliability when heating oxygen-containing media. In these plasma generators, the inner electrode is the cathode and the output electrode is the anode. [2]. This work is a continuation of research on thermal plasma generators of the school of Academician M.F. Zhukov.

Plasma-forming gas is fed into the plasma torch through the gas swirling device. The arc column is fixed by a swirling gas flow and is located on the axis of the electrodes. The radial part of the arc burns in the cavity of the inner electrode. This part of the arc is located in the zone of meeting of two streams of plasma-forming gas. In the output electrode, the anode arc section burns in the arc bypass zone. With increasing current, this zone shifts to the cathode, the arc length decreases, and the arc voltage decreases. Under these conditions, heat losses in the anode increase. The simultaneous voltage drop across the arc and an increase in heat losses, as practice shows, lead to the fact that when the current changes by 3 times, the useful power of the plasmatron changes by only 1.5 times, and the thermal efficiency, for example, at a current of 300 A does not exceed 65 - 70%.

2. Experimental setup to study plasmatrons

The structural diagram of the electric arc plasma generator is shown in Fig. 1. This circuit differs from the two-chamber circuit in that the output electrode is made with a change in the geometry of the
output electrode [3]. In single-chamber plasmatrons, a stepped electrode is used to obtain the current-voltage characteristic (CVC) of an arc with an increasing curve [2]. In such an anode, behind the step, the flow is interrupted, and the hot gas adjoins the wall in a limited region of the wide part of the anode (indicated by the dashed line). The anode section of the arc in this area is also adjacent to the electrode (here - the zone of preferential shunting of the arc). This ensures the fixation of the average length of the arc discharge when the current value changes. As a result, the steepness of the voltage drop across the arc decreases and a section appears with an increase in the I - V characteristic of the arc.

![Diagram of a two-chamber plasmatron with a stepwise expanding output electrode.](image)

Figure 1. Diagram of a two-chamber plasmatron with a stepwise expanding output electrode. The ratio \( \frac{d_1}{d_2} \geq 1.4, \frac{d_3}{d_2} \geq 1.5 \div 1.8. \)

The experimental studies of the plasmatron were carried out at the stand of the Institute of Thermophysics SB RAS. The electrical diagram of the installation is shown in Figure 2.

The power supply (PS) (Figure 2) is a controlled rectifier with an open-circuit voltage \( U_{xx} = 660 \) V. To duplicate the change in the arc discharge current, ballast resistance \( R_b \) from 1 to 10 Ohm is used in the form of a pipe-in-pipe water rheostat. The change in the position of the rheostat occurs by applying a 4 ... 20 mA control signal from the automation system to the controlled mechanism of movement of the rheostat rod.

To ensure a visible break in the power supply circuit, a load switch (VNP) is used. The plasmatron is triggered by a high-voltage (~ 10 kV) high-frequency (~ 10 kHz) oscillator, to which a discrete signal from the automation system is supplied, a high-frequency and high-voltage spark discharge occurs to breakdown the interelectrode gap of the plasmatron. Measurements of the arc discharge current and voltage are carried out by means of receiving signals from sensors, which are fed to the analog inputs of the controller, converted by normalizing converters into a 4..20mA signal. Duplicate measurements are made with dial gauges. The instrumental measurement error is \( \pm 1\% \).

The measurements of water and plasma-forming air flow rates are carried out by electronic controlled flow meters. Electronic flow meters are duplicated by RS-7 rotameters. The measurement accuracy of these parameters does not exceed 2%. The operation of the automatic process control system (APCS) is based on the principle of generating control actions on actuators by processing the received data (temperatures, current, voltage, etc.) from measuring instruments and sensors. The controller of the control system generates, according to the process control algorithm, the necessary control signals to the voltage regulator, which ensures the switching on or off of the switch, or generates a signal to the rheostat when the power of the plasmatron changes.

All APCS equipment is located in the control cabinet. To prevent dust, splashes and other foreign objects from entering the cabinet, as well as to prevent unauthorized access to the cabinet equipment, the cabinet can only be operated with the door tightly closed and locked. The door is equipped with a hermetic seal and provides adequate protection of the equipment in the cabinet from dust and moisture.
In addition, the tightness of the glands, through which the supply and signal cables are supplied to the cabinet, is ensured. The cabinet body is reliably grounded by connecting the protective ground wire to a special bolt located on the cabinet mounting panel and fixing it with a nut.

3. **Research results**

Figure 3 shows the I - V characteristics of the arc in the investigated range of air flow rates and the geometric dimensions of the electrodes.

The current-voltage characteristic (CVC) of the arc is the most important electrophysical and energy characteristic of the arc plasmatron. It determines the region of stable burning of the arc when changing the defining parameters: current strength, flow rate and type of plasma-forming gas, medium pressure, geometric dimensions of the plasma torch discharge chamber. According to the type of I - V characteristic (Figure 2) and the level of attainable values of voltage and arc current, the parameters of the power supply are determined, which ensure reliable operation of the plasmatron in a long-term mode.
Figure 3. Current-voltage characteristics of the plasmatron at various flow rates of the plasma-forming gas

It can be seen that the arc voltage increases with decreasing discharge current. At $I \geq 200$ A, the voltage is practically independent of the current strength and tends to increase. As the lines of equal power show, the plasmatron works stably in the power range of 40 ÷ 100 kW.

The main parameter of the efficiency of the electric arc plasma generator is its thermal efficiency (Fig. 4). In electric arc plasma generators, it is transferred to electrodes from arc radiation and convective heat exchange. Convective heat transfer between the plasma-forming gas and the electrode walls and, finally, conductive heat transfer from the cathode and anode arc spots. Heat from the outside of the electrodes is removed by a cooling liquid. The efficiency of the plasmatron is determined by the magnitude of the measured heat fluxes. In this case, the integral heat fluxes entering the electrodes and other water-cooled structural elements are determined without dividing them into components. The method for measuring heat fluxes is standard: it is necessary to know the flow rate and temperature difference of water at the inlet to the plasmatron and at the outlet from it.

Figure 4. Efficiency of the low-temperature plasma generator. 1 - plasmatron with a smooth electrode, 2 - plasmatron with a stepped electrode

It can be seen that the efficiency of a plasmatron with a stepped electrode is greater than that of a plasmatron with a smooth electrode.
4. Conclusion

The study showed that a two-chamber plasmatron with a variable geometry of the output electrode due to the fixation of the average arc length has a higher thermal efficiency than a plasmatron with smooth electrodes. Also, the power regulation during the operation of the electric arc plasma generator occurs in a higher range of current and voltage. At the same time, less erosion was recorded at the electrodes.

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