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Analysis of Physics Processes in the AC Plasma Torch Discharge under High Pressure

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Abstract. The paper is devoted to investigation of electrophysical processes in the electric discharge generated by a three-phase AC plasma torch when using a high pressure inert working gas. AC plasma torch design with end electrodes intended for work on inert gases at pressures up to 81 bar is studied. Current-voltage characteristics for different gas flow rates and pressures are presented. Physical processes characteristics of the arising voltage ripples which depend on various working parameters of the plasma torch have been investigated. Arc burning processes in the electric discharge chamber of the three-phase AC plasma torch at various working parameters were photographed.

As it is known, pressure is one of the main factors influencing the speed of chemical reactions. The same can be said about plasma-chemical reactions [1]. For example, it was found that the optimal conditions for the synthesis of NO in thermal electric arc plasma lie at temperature of 3000-3500 K and pressure of about 20 bar [2].

In addition, high pressure in the plasma chemical reactor allows quenching of the reaction products in the Laval nozzle, which greatly simplifies synthesis installation structure [3].

To date, electric arc plasma torches are the most suitable heat source for large-scale plasma-chemical plants from all of thermal plasma generating units [4].

Direct current systems are the most widely used, while electric arc AC installations are still exotic. However, due to the periodic change of polarity at the electrodes, they have a higher life time [5]. AC plasma torches using air as a working gas have been developed in IEE RAS. These kinds of systems are able to continuously operate to up to 2000 h. However development of AC plasma torches using higher pressures and understanding of the physical processes within those systems remain highly relevant [6-8].

Experimental setup

Figure 1 shows a schematics and a photograph of the electric arc AC plasma torch designed to operate at a high pressure of the working gas. Arc chamber 1 and three electrodes 4 are water cooled, the chamber is grounded. Compensation of thermal stresses appearing at the expense of arc chamber heating is realized by corrugated hose 2. Spiral guides 8 organizing the flow of coolant are arranged inside the cooling jacket 3.

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The working gas is supplied through the branch pipe 5 into the vortex chamber. The gas is fed inside the arc chamber through a series of openings arranged tangentially to its inner surface.

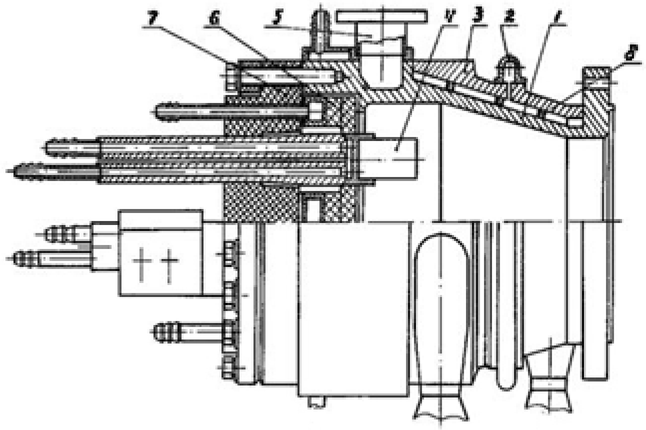

Figure.1 (a) Schematics of three-phase electric arc plasma torch: 1- arc chamber; 2- corrugated hose; 3- cooling jacket; 4- electrodes; 5- branch pipe; 6- insulators; 7- insulators; 8- spiral guides.

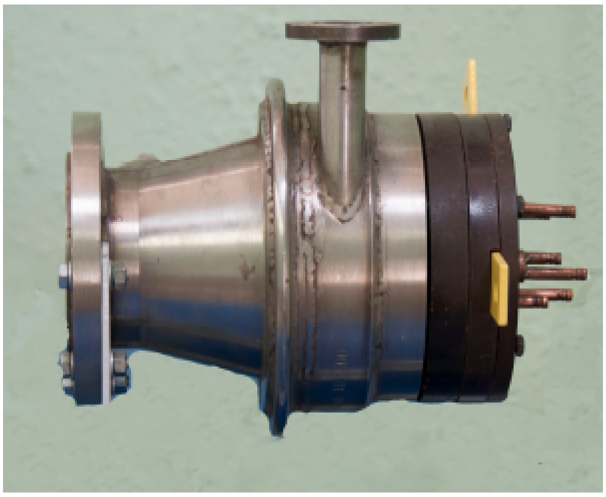

Figure 1(b) Photograph of three-phase electric arc plasma torch.

The light yellow elements are used for connection of power supply cable.

The electrode 4 is a copper body where a set of tungsten rods with diameter of 16 mm is installed. Electrode holders have channels for cooling water supply. Insulators 6 and 7 are used for their galvanic isolation from the chamber. Load voltage of the power supply is 800 V, short circuit current of the power supply varies from 300 A to 500 A.

Figure 2 shows the current-voltage characteristics of the plasma torch at different pressures.

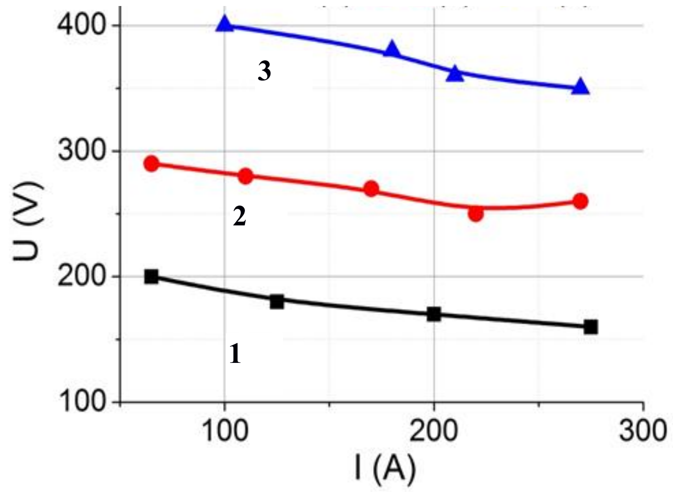

Figure 2. Current-voltage characteristics of the plasma torch at different pressures of the working gas in the chambers: 1 working gas flow rate 24 g/s, pressure 1 bar; 2 working gas flow rate 24 g/s, pressure 14 bar; 3 working gas flow rate 32 g/s, pressure 30 bar.

Optical scheme of high speed shooting is shown in Figure 3.

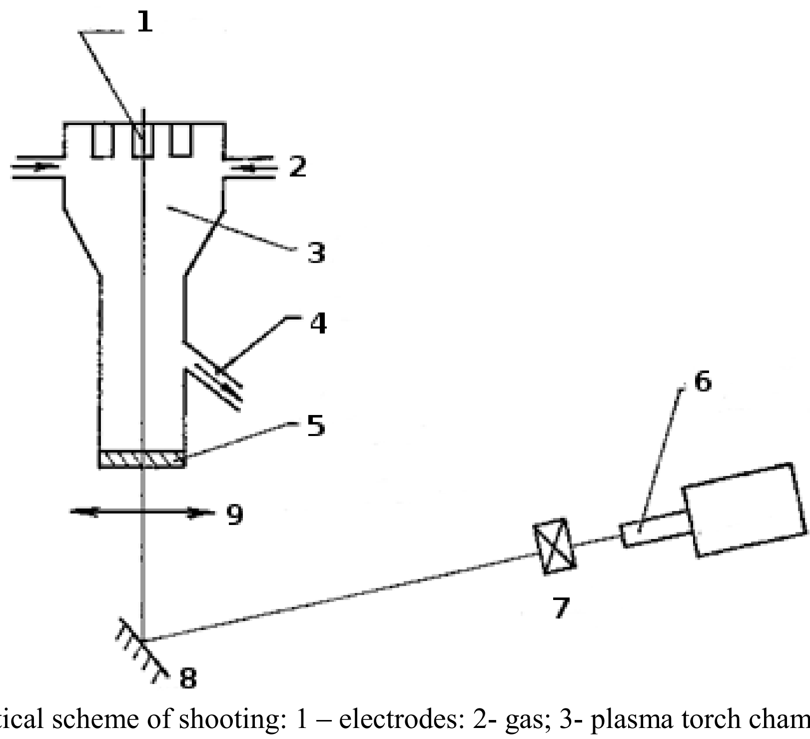

Figure 3. Optical scheme of shooting: 1 – electrodes: 2- gas; 3- plasma torch chamber; 4- exhaust gas; 5-quartz glass; 6-high speed camera; 7- shatter; 8- mirror; 9- lens

Single frame shooting was synchronized with the voltage on the arcs. Arc voltages and linear currents were recorded on the cathode oscilloscope. Light signals corresponding to the arc voltages were recorded on the film. The form of the arc voltages is decomposed in Fourier series, and RMS was calculated on the first harmonic. Linear currents are nearly sinusoidal. Current-voltage characteristics were recorded at the transition from the three-phase to single phase.

Physical processes in the plasma torch chamber were investigated using high-speed shooting at frequency of 3600 frames/s. Exposure time is 0.03 ms, period of power network is 20 ms. The speed of shooting does not allow seeing the commutation of the arc between the electrodes. Nitrogen was used as a working gas during the investigation of the described installation. The pressure in the arc chamber was varied in the range 1 – 30 bar.

Shooting was carried out at different modes and the most characteristic ones were included into the paper.

The analysis of experimental data showed the decisive role of gas-dynamic processes in the formation of a conductive channel of the arc and gas heating. We observed strong influence the gas flow rate on the arc shape and its emission characteristics, as well as on its stability. Furthermore, arc stability to a large degree depends on the current magnitude. Thus, it was found that at pressure of 1 bar and at arc current strength of 220 A the upper limit of the working gas flow rate at which a stable arc can be observed lies at 25 g/s.

The power supply has the output voltage 800V, short circuit current can vary from 300 A to 500 A. Adjustable inductance switched in each phase has been used.

Video frames from the plasma torch chamber were compared with different pressure therein during the investigation. Figure 4 shows the frames of reswitching of arcs from one electrode pair to another at atmospheric pressure. It can be seen that it is possible to identify both conducting channel, and convection flows of heated gas. As it is seen in the main number of frames the conductive channel is not seen. We can see only separate areas of heated up gas having non-uniform form. In the middle frame the conductive channel of several mm width can be seen.

Figure 4. Frames of reswitching of arcs in the plasma torch chamber at atmospheric pressure (root mean square value of arc current – 200A, working gas flow rate – 24 g/s)

On the other hand, by increasing the pressure the arc channel radiation in the visible region disappears, there is only gas glow (Figure 5)

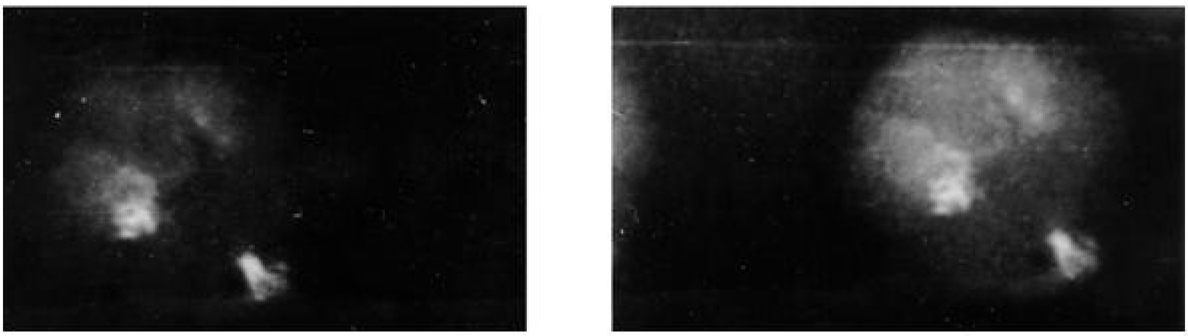

Figure 5. Frames of reswitching of arcs in the plasma torch chamber at pressure of 14 bar (root mean square active value of arc current – 260A, working gas flow rate – 24 g/s)

In Figure 5 it can be seen that the discharge current in the chamber does not live any traces, but only the glowing of near-electrode areas. It is necessary to have spectral measurement data for interpretation of the observed picture.

Based on studies of the three-phase AC plasma torch with nitrogen as a working gas it has been found that by increasing the pressure inside the chamber: the current-voltage characteristic has falling character. This can be explained by the fact that in the range of operating currents of the plasma torch the conductivity increases; arcs radiation disappears in the visible range; glowing of convective gas flows intensifies around the arcs.

Voltage increases at pressure increasing. This is due to the increase of strength on the arc and is likely due to contraction of the electric column. That is, the arc column diameter reduces and its temperature increases. That leads to increase in the arc voltage, but the average mass temperature of the gas decreases.

Absence of arcs glow in the visible range can be explained by a lower degree of dissociation of nitrogen molecules that converts radiation into ultraviolet range.

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