Application field and ways to control alternating-current plasma torch with rail electrodes

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Abstract. The paper deals with the investigation of parameters of the high voltage alternating-current plasma torch with rail electrodes. Usage of the injector and its variation allows controlling of operation of the ac plasma torch with rail electrodes. Also the possibility to protect the electric arc chamber without protective gas has been studied. It was found that increasing in the injector power causes the repeated breakdown at lower voltage and hence the arc dimensions decreases. The results of experiments are presented in the paper.

1. Introduction
Alternating current plasma torches with rail electrodes have found a wide use in experimental industrial installations for utilization of various substances [1–3]. An essential advantage of this type of plasma torches is the relative simplicity of design, high reliability and low cost. However, a significant disadvantage of these plasma torches is the impossibility of adjusting the power during operation, i.e., without stopping the installation. The possibility of controlling an electric arc in the electric discharge chamber of a three-phase 500 kW ac plasma torch by changing the parameters of the jet of the plasma injector is considered to solve this problem. Plasma injector is a single-phase 10 kW ac plasma torch which is an integral part of the three-phase plasma torch. They have a number of advantages such as simple design, low cost, low electric arc supply voltage of about 380–480 V [4]. This kind of plasma torch is shown in figure 1.

2. Design and principle of operation
The principle of electrodynamic motion of arcs in a field of its own current (railgun effect) is the basis of operation of plasma torches with rail-type electrodes (figure 2). Initiating of the arcs in the zone of minimum distance is due to the plasma injector which is an ac plasma torch.

Plasma injector power is 5–10 kW, flow rate of the plasma forming gas 2–5 g/s. When the injector works the plasma stream with the electron concentration of \( n_e = 10^{14} - 10^{16} \) cm\(^{-3} \) is set in a zone of minimum distance between the main electrodes of the plasma torch, that is sufficient for ignition of main arcs. Initiated arcs move along divergent electrodes at the speed of 10–30 m/s, depending on the current value, inclination angle of the electrodes, as well as from working gas flow rate and its method of supply. The arcs fill the most of the discharge chamber, making the movement in the longitudinal and transverse directions. This makes it possible to obtain a relatively high thermal efficiency of the plasma torch (efficiency depends
on operating conditions and can be up to 85%). In the near-wall zone where cold gas is fed, creating an insulating layer, the concentration of charged particles decreases sharply, and the arc extinguishes. The above mentioned process is repeated continuously, whereby at the outlet of the nozzle of the plasma torch the low-temperature (thermal) plasma jet with average mass temperature of about 1500–5500 K is formed.

Fast motion of the arc attachment point along the electrode under the action of electro-gas dynamic forces distributes the thermal load along the electrode length. This enables the use of water-cooled electrodes made of relatively low-melting material with high heat conductivity (copper tube). The plasma torch injector design is shown in figure 3.

The injector is a high-voltage single-phase alternating current plasma generator, comprising a body, ceramic nozzle and two electrodes. The body is made of stainless steel and is water-cooled. Two cylindrical channels converging in the discharge chamber are located in the body. Each channel has a tangential gas blowing, which comes from the common chamber. The discharge chamber ends with a ceramic nozzle.

The operating principle of the injector is as follows: 6 kV voltage is applied between the electrodes. The electric breakdown occurs between the wall of each channel and copper cone-shaped tips under the influence of high-voltage. Two short arcs ignite light and under the influence of the gas stream shift to the ends of the electrodes, and the arc burns in the electric discharge chamber. The process is repeated in the case of arc extinction.

Technical parameters of plasma torches of this type: supply voltage 6–10 kV; arc voltage drop—1100–1300 V; arc current 10 A; plasma-forming gas: air, argon, carbon dioxide; gas

Figure 1. Multiphase alternating-current single chamber plasma torch with rail-type electrodes working with a power of 220 kW and flow rate of 30 g/s.
flow rate is from 1 to 6 g/s. Three-phase alternating-current plasma torch with rail electrodes designed for power from 150 to 500 kW with operating current value is set by switching taps of limiting reactors, which is realized when the plasma torch power is turned off. Each operating
Figure 4. Dependence of temperature at the nozzle exit from power at different flow rates of plasma gas for the three-phase alternating-current plasma torch.

current value needs its own angle of inclination of the electrodes, which prevents arcing landing on the plasma torch body [5].

Figure 4 shows the dependence of power and temperature of the alternating-current plasma torch obtained for fixed values of the plasma gas flow rates.

The maximum average mass temperature at constant flow rate of the working gas, is proportional to the power of the plasma torch. Since a part of the working gas flow rate is directed to the electric arc chamber wall region, creating a cool air layer that prevents shunting of the arc on the body. The flow rate of the protective gas must be increased with the increase in power, which negatively affects and lowers the average mass temperature of the plasma. The absolute values of plasma jet temperatures are practically independent of the power of the plasma torch, which, together with the working gas flow rate, determines and can significantly affect the boundary of high temperature zone of the plasma jet. The change in operating current value in the plasma torch as stated above, is connected with the design change (opening angle) of the electrodes and change in flow rate of near wall protective gas.

The adjustable power injector is required in order not to change the design of electrodes in the process of power variation. Which means the ability of jet temperature regulation during operation and without stopping and changeover of the power supply.

The schematic diagram of the controlled power supply injector is shown in figure 5.

The power source consists of a transformer T (380 / 6000 V), inductors L₁, L₂ and thyristors VD₁, VD₂. That is the current limiting choke consists of 2 parts L₁ and L₂, and in the process there is shunting of the inductances, that allows regulation of current over a wide range. Non-shunted part of the choke determines the maximum allowable current through the injector.
Figure 5. Controlled power source: T—transformer; L₁, L₂—inductors; VD₁, VD₂—thyristors.

Figure 6. Dependence of the injector power versus current values at different flow rates.

3. Carrying out of the experiments

Figure 6 shows the dependence of injector power of the current value.

As it was established in the course of experiments varying the injector power at a constant flow rate of the plasma gas, it is possible to change the voltage level at which there is a breakdown of the inter-electrode gap and thereby limit the length of the arc path along the rail electrode [6].

Figures 7–9 show the oscillograms of arc movement along the rail electrodes depending on the injector power. The graphs show time change of the arc movement along the rail electrodes and the period between the new initiation of the main arc. The experiments were carried out on a model installation with a source open-circuit voltage of 2000 V, short circuit current 500 A and length of electrodes of 1 m. The electric arc chamber is absent, the motion of the arc occurs in the air. The velocity of arc movement was constant along the whole experiment as far as the current was unvarying.

The current value is constant, as long as plasma torch is powered by current supply. The voltage oscillogram represents main interest. Apparently from oscillograms can be seen that in the arc movement course on the dispersing electrodes the arc voltage grows and at the definite
Figure 7. Oscillogram of arc movement along the rail electrodes. Injector power 5 kW. The time of arc motion along the electrode during ignition and extinction is 350 ms, the breakdown voltage (arc occurrence) 1700 V.

Figure 8. Oscillogram of arc movement along the rail electrodes. Injector power 7 kW. The time of arc motion along the electrode during ignition and extinction is 300 ms, the breakdown voltage (arc occurrence) 750–1250 V.

voltage value the repeated arc ignition is taken place in a narrow interelectrode space. That corresponds to the voltage sharp reduction, and then the voltage growth is resumed before the following breakdown.
Figure 9. Oscillogram of arc movement along the rail electrodes. Injector power is 9 kW. The time of arc motion along the electrode during ignition and extinction is 100–150 ms, the breakdown voltage (arc occurrence) 1250 V.

As can be seen from the oscillograms, changing the injector power, it is possible to control the ignition voltage of the arc and the travel time along the electrode. That is, with increasing the power of the injector, the working area of the electrode decreases. Thus, leaving the same inclination angle of the electrode, it is possible to change the working area of the electrode. This helps avoid arcing on the wall as the arc current increases.

4. Conclusions
Operating parameters of the high-voltage alternating-current plasma torch have been studied. The possibility of controlling the parameters of the ac plasma torch with rail electrodes by changing the injector power is shown. By increasing the injector power the repeated breakdown occurs at a lower voltage, and as a consequence, the geometric dimensions of the arc are reduced, which allows protection of the electric arc chamber without use of the protective gas.

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