Arc initiation in plasma installations

V E Kuznetsov, A A Safronov, V N Shiryaev, Yu D Dudnik, O B Vasilieva and A V Pavlov
Institute for Electrophysics and Electrical Power of the Russian Academy of Sciences, Dvortsovaya Naberezhnaya 18, Saint-Petersburg 191186, Russia
E-mail: vld.kuznetsov@gmail.com

Abstract. The paper is devoted to a research of electric arc ignition devices in plasma torch of alternating and direct current. High-voltage alternating current plasma is used as one of ignition devices. Its power is 5–10 kW, the plasma-forming gas flowrate is 2–5 g/s. The plasma flow with electron concentration of $10^{14} – 10^{16}$ cm$^{-3}$ sufficient for main arc ignition is set in a zone of the minimum distance between the main electrodes of a plasma torch by injector operation. The second method uses a construction series of the direct current plasma torches. They were designed to transfer ac plasma torches with rail electrodes into a class of electrical installations with a supply voltage less than 1000 V. Their current-voltage characteristics and life tests are received. The cathode erosion is about $10^{-6}$ g/C, the anode erosion is $10^{-7}$ g/C. The pulse erosion injector is developed for an arc ignition in a direct current plasma torch. The pulsed injector is supplied from the capacitive storage.

1. Introduction
One of the main issues determining the high reliability and convenience in the operation of powerful plasma torches in the composition of electrophysical installations for various purposes is the issue of arc initiating in an electric arc chamber of a plasma torch. Conventional arc initiation methods and devices, such as wire shortening or moving rod [1], high-frequency breakdown and various ways of plasma injection into the discharge gap using a high-voltage discharge [2], have a number of significant disadvantages:

- disassembly of the plasma torch chamber before start up;
- presence of moving mechanical parts in the electric discharge chamber;
- additional electrical insulation of current-carrying parts and protection of the power supply from high-frequency high-voltage pulses;
- significant complication of the most heat-stressed assembly of the plasma torch-electrode with a simultaneous decrease in reliability and a number of others;
- the need to use high voltage, which, tightens the safety requirements of the plant operation.

In alternating current plasma torches with rail electrodes the arc initiation in the zone of minimum distance is due to the plasma injector [3]. The high voltage ac plasma torch is used for this purpose. Its power is 5–10 kW, the consumption of the plasma-forming working gas is of 2–5 g/s. When the injector [4] is operating in the zone of the minimum distance between the main electrodes of the plasma torch, a plasma flow with an electron concentration $n_e = 10^{14} – 10^{16}$ cm$^{-3}$, sufficient for ignition of the main arcs, is established.
Figure 1. Direct current plasma torch: 1—water-cooled case; 4—anode; 5—cathode; 6—fitting; 8—electric quick-detachable connector; 9—tip; 10–13—insulating bushes; 14—igniting electrode; 16—additional annular electrode; 17—nozzle.

2. Experimental installation
A series of direct-current plasma torch designs were developed to exclude the use of high voltage and transfer of power to installations based on a powerful three-phase plasma torch with rail electrodes at low voltages up to 1000 V. Their purpose is to ensure a reliable ignition of the main arc of a powerful three-phase plasma torch. In the course of experiments, plasma torches demonstrated stable operation, while the erosion of the cathode was of the order of $10^{-6}$ g/C, anode $10^{-7}$ g/C.

Direct current plasma torch in figure 1 consists of a water-cooled case, made of stainless steel with an annular cooling jacket and internal channels connected to the connections for water supply and removal, terminal anode for connecting the main power. In the water-cooled case there is a water-cooled electrode cathode with fittings and for water supply and removal, an electric quick-detachable connector, tip and insulating bushes. The igniting electrode with an additional annular electrode and a nozzle is placed between the electrode and the case, through the insulating bushes.

The plasma torch is connected to the systems: cooling system, plasma gas supply system, power supply system to the main arc ignition device.

Figure 2(a) shows the construction of an anode-cathode assembly with an arc ignition device for the plasma torch. The assembly consists of an electrical insulating bush mounted on the cathode and an additional electrode. Voltage from the ignition device is supplied to the cathode and additional electrode.

When the voltage is applied from the ignition device between the auxiliary electrode and the cathode, an electrical breakdown of the gap A takes place on the surface of the bush. A plasma blob is formed between the tip of the electrode and additional electrode, which under the action of electrodynamic forces and plasma-forming gas enters the gap B in figure 2(a) and its breakdown occurs and the main arc starts up between the electrode and the nozzle. The properties forming a plasma blob depend on the material of the dielectric bush and the material of the electrodes [5].

The ignition device is a capacitive storage device which is switched by means of a pulsed ignitron.
An erosive injector was developed for investigation and creation of an incendiary device, which is shown in figure 2(b).

The injector consists of a metal case in which a central rod electrode is fixed through the dielectric bush. The rod electrode and dielectric are buried into the housing and they form a cylindrical injection chamber with it. Power supply of the pulse injector is provided from the capacitive storage. At the same time, the energy stored in the storage passes into the energy of the discharge, part of which is expended on erosion of the surface layer of the dielectric and the rod electrode, and the main part for the heating and ionization of erosion particles. Particles making up the arc in the injection chamber are initiated in it and receive the axial acceleration due to both thermal expansion and electrodynamic forces. The formed plasma blob flies out, expanding from the injection chamber, which ensures the arc ignition between the electrodes of the plasma torch.

The schematic diagram of the experimental installation on which the investigations of the injector operation was carried out is shown in figure 3.

The power supply of the injector was carried out from a capacitor bank $C_1$ with a capacity of 100–500 F, charged to voltage of 1.5–3 kV, an ignitron was used as a key. The injector was placed in a sealed chamber in which two parallel rod electrodes with a gap of 10 mm were installed at a distance of about 70 mm from the discharge chamber of the injector. The delay time of the initiation of the arc between the rod electrodes relatively to the inclusion of the injector was recorded as a function of the energy stored in the condenser, the type of gas, and its initial pressure. For this purpose, the triggering of the oscilloscope sweep was synchronized with the appearance of a current in the circuit of the $C_1$-ignitron-injector capacitor and the moment of the appearance of the current in the capacitor $C_2$-electrode chain was recorded. The intrinsic discharge time in the injector had a duration from $7 \times 10^{-5}$ s up to $10 \times 10^{-5}$ s, the residual voltage on the capacitor $C_1$ is less than 100 V.

3. Investigation results

In the course of the experiments, a number of insulating materials were tested, of which a bush, that is shown in figure 2(b) was made, such as: viniplast, fluoroplastic and composites based on phenol-formaldehyde resins. The initial breakdown was carried out by applying graphite to the end of the bushing. The well gas-generating material viniplast turned out to be unsuitable
Figure 3. Schematic diagram of the installation for the investigation of the erosion injector: 1, 2—rod electrodes; C₁, C₂—pulse power capacitors; T₁, T₂—pulse current transformers; VL—arrester.

for this purpose, since after the discharge its surface restored the insulating properties. The best results were shown by dielectrics based on phenol-formaldehyde resins. So the injector with the use of fiberglass showed reliable operation at a resource of more than 1000 cycles, which is quite satisfactory. With this operating time, an internal cone was formed, which somewhat increased the volume of the injection chamber, which practically did not affect the operation of the injector.

The material of the rod electrode 9 in figure 1 was experimentally selected. The electrode was made of tungsten, copper, brass and steel. The best results from the point of view of the energy input to the discharge and the life time of the injector were obtained on a brass electrode.

Figure 4 shows the dependence of the plasma blob movement speed versus the pressure in the chamber on nitrogen and helium with the initial stored energy in the capacitor C₁ is 2 kJ.

The measurements were carried out at a voltage between the electrodes of 1500 V. The maximum value of the discharge current was 7 kA. Figure 5 shows the dependence of the breakdown voltage between the electrodes versus the pressure in the chamber. The working gas is nitrogen. The stored energy in the capacitor C₁ is 1 kJ.
Figure 4. Dependence of the plasma blob movement speed versus the pressure in the chamber.

Figure 5. Dependence of the breakdown voltage versus the pressure in the chamber.

4. Conclusion
Based on the carried out studies, an igniting device was constructed for alternating current plasma torch with a rod electrode which is a bush of a dielectric material based on carbon compounds that form a conductive channel at high temperature and an auxiliary electrode that passes through the bush. The capacitive storage for this device is a 100 µF capacitor with a charge voltage of 900 V. The stored energy is sufficient for reliable ignition of the arc with a distance between the anode and the cathode up to 10 mm. As it was established during the experiments, the arc ignition can be carried out at a working gas pressure of up to 1.2 MPa.
Acknowledgments
The work is financially supported by the Russian Foundation for Basic Research, grant No. 16-08-01073.

References
[1] Boatright W B, Sabo A P, Sebaches D J, Pinckneg S Z and Cureg R W 1976 J. Aircr. 13 67–8
[2] Dudnik Yu D, Borovskoy A M, Shiryaev V N, Safronov A A, Kuznetsov V E, Vasileva O B, Pavlov A V and Ivanov D V 2018 J. Phys.: Conf. Ser. 946 012167
[3] Rutberg Ph G, Safronov A A, Popov S D, Surov A V and Nakonechnyi G V 2006 High Temp. 44 199–205
[4] Kuznetsov V E, Kiselev A A, Ovchinnikov R V and Dudnik Yu D 2012 Nauchno Tekhnicheskiye Vedomosti Sankt Peterburgskogo Gosudarstvennogo Politekhnicheskogo Universiteta. Fiziko Matematicheskiye Nauki 2 100–4
[5] Bobashev S V, Zhukov B G, Kurakin R O, Ponyaev S A and Reznikov B I 2015 Tech. Phys. Lett. 41 964–7