Plasma injector for a three-phase plasma torch with rail electrodes and some results of its investigation

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Abstract. Plasma injector made on the basis of the alternating-current plasma torch designed for the three-phase ac plasma torch with 100–500 kW rail electrodes is studied. The construction of the plasma injector is examined. Different materials for manufacture of injector electrodes are investigated. Current–voltage characteristics of the injector are obtained. Investigations of the plasma jet are carried out, and the jet temperature dependence versus the gas flow rate and electric power of the injector is measured.

1. Introduction

At present, there are numerous investigations aimed at creating durable materials that can withstand electric arc impact in the atmosphere of various gas media or in a vacuum. This is due both to the development of electrical commutation equipment and, for example, spacecraft engines.

Accordingly, the scope of possible use of such materials is broad, but there are few published data. Alternating-current plasma torches with rail electrodes are widely used in installations for processing of various waste, as far as they have a number of advantages such as simple design, low cost, low electric arc supply voltage of 380–480 V [1–3].

The principle of electrodynamic arc movement in the field of its own current (railgun effect) is the basis a plasma torch operation. Rapid movement of the arc attachment along the electrode distributes the thermal load along the electrode length, which makes it possible to use the electrodes made of a relatively low-melting material with good thermal conductivity and water cooled (thin-walled copper tubes).

The injector creates a plasma stream providing electron concentration $n_e = 10^{14}–10^{16} \text{cm}^{-3}$ in the area of the minimum distance between the main electrodes 0.5 cm, which is sufficient to ignite the main arc with a relatively low voltage power supply 300–500 V. The resulting arc moves on diverging electrodes with velocity of 10–30 m/s depending on the size of the electrodes and current angle.

In the near wall area the concentration of charged particles decreases sharply and, thus, creates an insulating region, where the arc extinguishes, and the process repeats. As far as the arcs move along the electrodes their speed drops significantly. This is explained by a
linear decrease of the current magnetic field with the distance from the electrode which is not compensated by the increase of the arc length. Therefore, the electrodes are sharply divergent. Herewith the work area of the electrode at a current of, for example, 850 A is 6–7 cm.

The arcs which combustion mode has a diffuse character, fill a large part of the discharge chamber, moving in the longitudinal and transverse directions, making it possible to obtain a relatively high thermal efficiency of the plasma torch (up to 85% depending on operating conditions).

The presence of the injector and the rail-gun effect usage allow having a low voltage power supply and a relatively high voltage on the arcs, power factor is 0.6–0.7. While supposing to find possible that the shape of the arc voltage is close to sinusoidal, period and signal frequency value are stable and the value of the power factor is close to 1.

2. Injector design
Plasma injector is one of the main elements of the three-phase plasma torch [4], through which the arc ignition is carried out ensuring a reliable operation when changing the inter-electrode gap. The single-phase alternating-current plasma torch is used as a plasma injector. The design of the plasma torch is shown in figure 1.

The injector consists of the following components: body, bushing insulator, replaceable tips-electrodes and outlet nozzle. The body is made of stainless steel and it is water-cooled. Two cylindrical channels converging in the discharge chamber are located in the body. Each channel has tangential gas inlet openings.

3. Electrical characteristics of the injector
The following injector electric characteristics such as the ignition peak in anodic and cathodic phase, average arc voltage and rms current have been investigated.

Typical current and voltage oscillograms of the injector are shown in figure 2.
Figure 2. Current and voltage oscillogram of the injector; gas flow rate of 2 g/s.

Figure 3. Current–voltage characteristics of the injector.

Current–voltage characteristics of the injector built according to the results of experiments are shown in figure 3.

Figure 4 shows the dependence of plasma jet temperature in the inter-electrode gap of the three-phase plasma torch depending on the electric power of the injector at different gas flow rates. Reliable ignition of the main arc is realized at such temperature parameters of the plasma jet [5].
Figure 4. Dependence of plasma jet temperature in the inter-electrode gap of the three-phase plasma torch depending on the electric power of the injector at different gas flow rates.

Figure 5. Specific erosion for samples of different materials: 1—Cu; 2—steel 45X25H35C2; 3—steel 45X25H35C2; 4—steel 45X25H35C2; 5—composite material Cu–W; 6—composite material Cu–W; 7—composite material W–Ni; 8—composite material W–Ni; 9—composite material W–Ni–Fe; 10—composite material W–Ni–Fe; 11—alloy Cu–Mo; 12—alloy Cu–Mo; 13—aluminum; 14—aluminum; 15—aluminum; 16—electric steel; 17—D2Cu–CrC; 18—CrC–Al; 19—composite material 70 wt % Cu–30 wt % Fe; 20—composite material 70 wt % Cu–30 wt % Fe; 21—composite material 69.75 wt % Cu–30 wt % Fe–0.25 wt % Y2O3.
4. Injector electrode material
The considered design of a single-phase alternating current plasma torch as an injector has a significant advantage in comparison with a direct-current plasma torch. This is the simplicity of construction and the absence of an ignition unit. However, it was necessary to solve the problem of the durability of electrodes when working in air and other oxidizing environments. In the course of many years of research, existing materials were tested and new ones developed. Figure 5 shows erosion diagrams of various compositions which were examined as the electrode materials.

The erosion is measured in g/C. First, the loss of electrode weight in a definite time is measured. After that knowing the current, loss of electrode weight and working time the erosion value is counted. It should be noted that copper-based alloys and iron showed the best results for erosion resistance, manufacturability and cost.

5. Conclusion
Plasma injector has been developed on the basis of the single-phase alternating-current plasma torch. The best results as the electrode material are obtained by using a composite of copper and iron in a ratio of 30 wt % iron and 70 wt % copper. Reliable arc initiation is carried out at plasma jet temperature of 2500–3000 K at inter-electrode gap up to 10 mm.

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