Electric arc plasmatorch of a two-chamber scheme with reverse polarity of electrodes connection

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Abstract. The work is a study of the operating parameters of the plasma torch of a two-chamber scheme with reverse polarity of connection the electrodes. Classical erosion levels of 1.81×10⁻⁶ g Cl⁻¹ and 2.675×10⁻⁷ g Cl⁻¹ for the cathode and anode, respectively, were obtained. Also, on the reverse polarity of the inclusion, the voltage is obtained by 31.8% higher compared to the voltage with the direct polarity of connection.

1. Introduction
In the available literature there is a large amount of data on the operation of the plasma torches of the two-chamber scheme with the connection of direct polarity. At the same time, studies of work with the connection of reverse polarity is small. The purpose of this work was to fill in some of these gaps.

It is known that the time of non-stop operation of the plasma torches is limited by the lifetime of the electrodes, since their wear is the main reason for the forced stop for replacement. Auxiliary periphery of plasma torches is not subject to such thermal and erosion loads.

For example, at the cathode the current density in the cathode region of an electric arc in a medium of oxygen-containing molecular gases is ~ 10⁴ A·cm⁻², and volts is the equivalent of heat flux into the cathode $U_E \approx 10$ V [1]. Thus, the heat flux density at the attachment point on the cathode is 10⁵ W·cm⁻². No method of cooling the electrode, except for thermal emission, is unable to divert such a level of heat flux density without destroying it.

A common way to reduce the integral density of the heat flux into the material of the electrodes is the forced angular scanning of the gas-vortex stabilization of the arc. The essence of the method is in the tangential supply of plasma-forming gas to create rotation of the gas flow around the axis of the plasma torch. This effect causes the radial section and the reference spot of the arc to move in the direction of gas movement and creates a radial gas pressure gradient, which in turn creates Archimedean force acting on the axial section of the arc in the direction from the periphery to the center. Reducing the residence time of the arc at each point on the surface increases the total area of the arc attachment, reduces the heat flux density and, accordingly, reduces the level of erosion.

In the studies cited in [2] it was shown that the average specific erosion of copper tubular electrodes weakly depends on the current and in various experiments varies from 10⁻⁷ to 10⁻⁶ g Cl⁻¹. In the first approximation, it can be considered independent of the current in the range of 30–1000 A.

To implement an angular scan on both electrodes, a two chamber scheme with tubular electrodes is used. Plasma-forming gas in this case is fed into two vortex chambers located: 1 – in the blind end of the plasma torch chamber and 2 – between the electrodes.
2. Experimental plant
This study was carried out on a plasma torch with reverse polarity to turn on the electrodes. The scheme is shown in figure 1.

![Figure 1](image)

**Figure 1.** Scheme of two-chamber plasma torch with reverse polarity of electrodes connection.

Anode length 120 mm, internal diameter 30 mm. The length of the cathode is 229 mm, internal diameter 20 mm. The left blind end is equipped with a viewing window with quartz glass. This makes it possible to visually observe the behavior of the arc. The anode is on the left side, the cathode is on the right side. Plasma goes to the right. Between the left end and the anode is the first vortex chamber. Between the electrodes is the second vortex chamber. Plasma-forming gas is fed into the vortex chambers, shown in figure 1 by arrows. The material of the cathode and the anode is M1 grade copper. Air was used as a plasma gas.

3. Voltage dependence on work parameters
According to the data given below in equations (1–3) [3], the voltage for a single-chamber plasma torch of direct polarity connection is:

\[ U^+ = 1290 \left( \frac{I^2}{pd} \right)^{-0.15} \left( \frac{G}{d} \right)^{0.30} (pd)^{0.25} \] (1)

For a similar plasma torch of reverse polarity, the voltage is as indicated in equation (2):

\[ U^- = 1970 \left( \frac{I^2}{pd} \right)^{-0.17} \left( \frac{G}{d} \right)^{0.15} (pd)^{0.25} \] (2)

Calculations show an increase in voltage when switching to the reverse polarity of the connection within 4–7% when using the values of pressure, gas flow rate and amperage used in our experiments.

At the same time, there is a dependence for a two-chamber plasma torch of direct polarity of connection and there is no dependence for reverse polarity of connection:

\[ U^+_2 = 1360 \left( \frac{I^2}{pd} \right)^{-0.20} \left( \frac{G}{d} \right)^{0.25} (pd)^{0.35} \] (3)

These dependences suggest that an increase in voltage will occur when the connection will be switched to the reverse polarity of the connection in case of two-chamber plasma torch. However, in [3] it is argued that at high currents, > 300–400 A, the current-voltage characteristics of the arc
practically merge into one characteristic, and this gives grounds to use equation (3) to calculate the arc burning in a two-chamber plasma torch of reverse polarity. 

On the other hand in [4] it is noted that switching the plasma torch to reverse polarity gives a voltage increase of 1.1–1.5 times. However, this behavior of the arc is presumably due to a change in the degree of arc compression due to a change in the geometry of the vortex chamber due to different electrode sizes. Such changes wasn’t used in our experiments.

A study conducted on the same plasma torch without changing the geometry of the plasma torch channel with direct and reverse connection, shows that the experimental voltage is different significantly in the current range of 175–260 A. Figure 2 shows a comparison of the calculation according to equation (3) and experiment. The discrepancy is about 40%. Apparently, an additional study of this dependence is required to obtain a more accurate formula for the calculation of the arc.

4. Efficiency of plasmatorch
The second issue examined in this paper was efficiency.

According to the equation given in [2], the efficiency of a two-chamber plasmatorn is determined according to equation (4):

\[
\eta = \frac{1}{1-0.27\left(\frac{l^2}{pd}\right)^{0.27}(pd)^{0.30}(l^2/d^4)^{0.27}(T)^{0.5}} \tag{4}
\]

For a two-chamber plasma torch with different lengths and diameters of the electrodes, the following assumptions were made in [5]: \( d = \frac{l_1}{d_1} + \frac{l_2}{d_2} \).

The calculation shows that the efficiency should be 60.9% when using the experimental values of pressure, gas flow, current and dimensions of the electrodes. In experiments on the direct and reverse polarity of the connection, the efficiency values reached 75.5% and 81% respectively.

Efficiency and voltage data for reverse and forward polarity connections are also presented in table 1. Comparative analysis shows a slight increase in arc efficiency after switching to reverse
polarity with a similar current value. Further experiments with the inclusion of reverse polarity showed a stable level of efficiency in the range of 78–81%.

In regard to the voltage increasing is notable at the same current value after switching to reverse polarity of connection, which makes it possible to operate at a lower current with the same power due to a higher arc voltage. If we take into account that the level of erosion is largely determined by the magnitude of the amperage, then this is a definite advantage, since allows you to increase the lifetime of the electrodes.

| Voltage (V) | Amperage (A) | Efficiency (%) |
|-------------|--------------|----------------|
| Direct polarity of connection | 478 | 261 | 75.5 |
| Reverse polarity of connection | 630 | 258 | 81 |

**5. Electrodes erosion**

The third issue investigated in the work was the determination of the level of erosion of the electrodes. For this we used the gravimetric method. The two-chamber scheme of the plasma torch allows the use of tubular copper electrodes, which in turn provides a weak dependence of the level of erosion on the polarity of the connection, in contrast to plasma torches using end cathode with a tungsten insert.

An electrode was used for the study, which was in operation for about 20 hours. This is due to the fact that at the beginning of the electrode operation, surface burn-in occurs, during which specific erosion increases until a stable erosion process is formed. In work [1] it is shown that the level of specific erosion of the anode does not change during the whole period of operation, and the level of specific erosion of the cathode is set within 6–8 hours (operating current $I = 250$ A). In this regard, in order to avoid data corruption, an electrode with a sufficiently large number of operating hours was used.

Studies have shown the level of specific erosion of electrodes in straight polarity is approximately at the level of erosion of cold tubular electrodes in plasma torches of a two-chamber scheme with direct polarity of connection.

| Initial weight | After 1 hour | After 2 hours | After 3 hours |
|----------------|-------------|--------------|--------------|
| Cathode | 2669.15 | 2667.75 | 2666.30 | 2664.75 |
| Anode | 1275.50 | 1275.20 | 1275.05 | 1274.85 |

Investigations due working in reverse polarity showed the following values of erosion levels:

- The level of erosion of the cathode was $1.81 \times 10^{-6}$ g·Cl$^{-1}$.
- The level of erosion of the anode was $2.675 \times 10^{-7}$ g·Cl$^{-1}$.

**6. Findings**

- The experiment showed a significant (~ 30%) increase in arc voltage when switched on in reverse polarity. This gives grounds for using reverse polarity connections in order to increase the service life of the electrodes.
- Efficiency when switched on in reverse polarity has undergone a slight increase, which makes it possible to increase the service life of the electrodes by reducing the operating current.
The level of erosion has not changed significantly, which means that using the reverse polarity of the connection does not reduce the life of the electrodes.

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