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Double chamber linear circuit plasmatron

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The article presents the results of experimental studies of a double-chamber linear circuit DC electric arc plasmatron in experimental and industrial conditions. The electric arc plasmatron of the VORTEX-200 linear circuit with a rated power of 200 kW is designed for plasma ignition of a pulverized-coal torch, it's stabilization and oil-free ignition of pulverized-coal boilers of thermal power plants. The linear circuit plasmatron contains two water-cooled casings isolated from each other, one of which has a hollow cylindrical electrode - a cathode having swirlers of the plasma-forming gas at both ends, and the other has an output electrode - an anode-diffuser having a channel with a cylindrical segment at one end and the exit nozzle in the form of a diffuser at the other end. The power of the plasmatron, depending on the process parameters, can vary from 80 to 230 kW. The plasmatron has a stable powerful air plasma torch. Tests of such plasmatrons showed their high reliability and possibility of their operation in difficult conditions of thermal power plants (high level of dust and humidity, high temperatures near the boilers).

Measured volt-ampere characteristics of the plasmatron enabled us to determine the region of stable arc combustion from 350 to 475 A. Parameters of the plasmatron operation at it's nominal power of 200 kW and the flow rate of the plasma-forming gas of 1000 l/min are attained at currents not exceeding 450 A. The use of mechanical ignition of the plasmatron with a needle from a refractory material, instead of breakdown the inter electrode gap by an oscillator, increased the reliability of it's operation. The device for axial scanning of binding of the cathode spot of the arc, which allows us to increase the surface of cathode erosion many times, was developed. The use of azimuthal and axial scanning of the cathode spot of the arc of the plasma torch makes it possible to increase the service life of the cathode up to 200 hours with a service life of the massive anode exceeding 500 hours.

Keywords: plasmatron; plasma; double-chamber linear circuit DC; volt-ampere characteristics.

Introduction

Nowadays and in the foreseeable future (until 2100) the world power industry is focused on the use of organic fuels, mainly low-grade coals, whose fraction in the generation of electricity is 40%, and thermal energy is 24%. In Kazakhstan, the fraction of pulverized coal-fired power plants in the generation of electricity is 85%.

Therefore, an increase in energy efficiency of pulverized coal thermal power plants is a priority task for modern heat and power engineering. Plasma fuel systems (PFS) for oil-free ignition of boilers, picking up and stabilizing the combustion of a pulverized-coal torch meet these requirements [1, 2]. Recently, this plasma technology has become even more important due to the depletion of oil and gas reserves, a decrease in the quality of solid fuels and a slowdown in the growth of NPP capacities.

The technology of plasma coal ignition by PFS is based on the electro thermochemical preparation of fuel (ETCFP) for combustion. ETCFP is heating of the flow of a pulverized coal mixture by an air plasma torch with oxygen deficiency in a special chamber to a temperature exceeding the autoignition temperature of this coal. In this process an almost complete release of volatile and partial combustion and/or gasification of coal carbon occur. In the furnace, the fuel mixture or a highly reactive two-component fuel, consisting of combustible gas and coke residue, ignites when mixed with secondary air and steadily burns without using a second type of high-reaction fuel (gas or fuel oil) to stabilize the pulverized flare even in a cold furnace. The ETCFP process proceeds in the PFS. The PFS is a modified pulverized-coal burner with an electric arc plasmatron, the main element of the PFS, installed on it.

Plasmatrons also showed their effectiveness in the implementation of studies of plasma chemical technologies of pyrolysis, hydrogenation, gasification, hybrid (radiation-plasma) and complex processing of solid fuels, as well as cracking of hydrocarbon gases. The use of these technologies for the production of the desired products (hydrogen, technical carbon, hydrocarbon gases, synthesis gas, valuable components of the mineral mass of coals, including rare earth elements) corresponds to the modern ecological and economic requirements for basic industries [3-8].

The electric arc plasmatron with the VORTEX-200 linear circuit and a rated power of 200 kW is designed for plasma ignition of a pulverized-coal torch, its stabilization and oil-free ignition of pulverized coal-fired boilers at TPPs [1, 2]. The power of the plasma torch, depending on the process parameters, can vary from 80 to 230 kW. The plasmatron has a stable powerful air plasma torch. Tests of such plasmatrons showed their high reliability and possibility of their operation in difficult conditions of thermal power plants (increased dust and humidity, high temperatures near the boilers). The linear circuit plasmatron contains two water-cooled casings isolated from each other, one of which has a hollow cylindrical electrode - a cathode having swirlers of the plasma-forming gas at both ends, and the other has an output electrode - an anode-diffuser having a channel with a cylindrical segment at one end and the exit nozzle in the form of a diffuser at the other end.

Technological characteristics of the plasmatron

Experimental studies of the operation of the plasmatron and selection of its optimal technological parameters were carried out both at the experimental stand and on pulverized-angle burners under the conditions of oil-free firing of the BKZ-420 and BKZ-160 boilers of Almaty CHPP-2 and CHPP-3 [3]. Figure 1 shows the switching-on scheme of the plasmatron on the experimental stand.

The plasmatron gets power supply from a controlled thyristor three-phase rectifier - a power supply (PS) 1 operating in the mode of a current source. The negative output of the PS via the smoothing inductive valve 2 with regulated inductance and the ballast resistor 3 is connected to the terminal of the cathode 5 of the plasmatron. The ballast resistor rated up to 1 Ohm is used to limit the starting currents and is automatically shorted by the thyristor short-circuiter 4 when the plasmatron reaches the operating mode. The positive pole of the PS is connected to the anode terminal 6. The plasmatron is not started by the oscillator

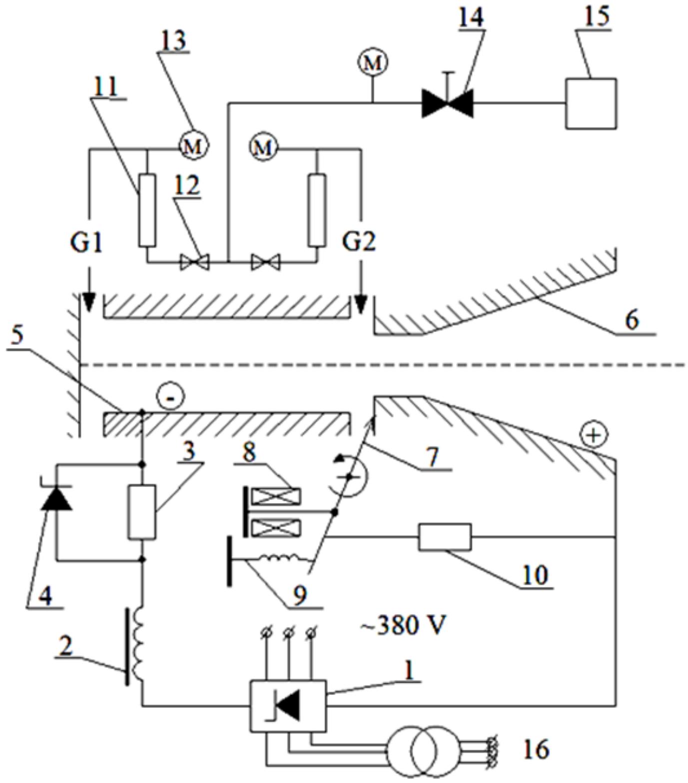

Figure 1. A scheme of plasmatron switching on the experimental stand. 1 is a controlled thyristor power supply, 2 is a smoothing valve, 3 is a ballast resistor, 4 is a short-circuit of the ballast resistor, 5 is a cathode of the plasmatron, 6 is the plasmatron anode, 7 is an ignition needle, 8 is a start relay, 9 is a return spring, 10 is a limiting resistor, 11 is air flow rotameters; 12 is regulating valves; 13 is manometers, 14 is a reducer, 15 is a screw compressor, 16 is a separating transformer.

providing a spark in the gap between the cathode and the anode, but by the closing needle 7 with the start relay 8 and the return spring 9.

To limit the starting current generating a spark and passing through the needle to a value not more than 5 A, the limiting resistor 10 of 100 Ω and a power of 15 W is used, which provides protection of the resistor from overheating during the start-up. The air supply with discharges G_1 and G_2 is provided by two parallel channels through the control valves 12 and rotameters 11 into both swirlers, one of which is located at the end of the cathode and the other in the gap between the cathode and the anode. Compressed air is provided to the plasmatron through a common control valve and a reducer 14 from the screw compressor. In order to ensure electrical safety in the experimental studies, a three-phase voltage of 380 V is supplied to the PS using regulating and measuring equipment through the separating transformer 16 with an isolated neutral such as TCZ-250 380/380.

The linear circuit plasmatron (Figure 2) works as follows. Cooling water is supplied to the cathode and anode assemblies, and plasma-forming gas-air is fed through the swirlers. DC voltage from the regulated power supply is supplied tothe terminal of the plasmatron-cathode and the terminal on the anode. A negative potential is supplied to the cathode terminal, and a positive potential - to the anode terminal. Then, the ignition needle, contacting the anode with the one end and connected through a current-limiting resistor to the terminal of the same anode, driven into the oscillating motion by the relay and the return spring, forms a spark in the arc gap between the anode and the cathode and an electric arc, which under the action of a vortex flow of the plasma-forming gas supplied through the swirler is carried to the cavity formed by the cathode and the anode.

The gas flow from the swirler located between the anode and the cathode is divided into two vortex streams: one part rises along the cathode, and the other part goes to the anode-diffuser with an optimum opening angle in the range of 26 to 30 degrees. Under the action of the vortex streams the cathode section of the arc together with the support cathode spot is subjected to azimuth scanning and rotates inside the cathode in a plane perpendicular to the axis of the plasmatron in which wall flows from both swirlers meet, and the inner part of the cathode develops as a narrow ring.

Figure 3 shows the plasmatron during its testing. The anode part of the arc binding, more distributed over the surface of the electrode in its conical part, also rotates under the action of the plasma vortex. On the axis of the cathode, in the cylindrical part of the anode, due to the vortex gas flows, an arc bunch is formed. The longer the length of the cylindrical part, the higher the arc voltage and the higher stability of its burning.

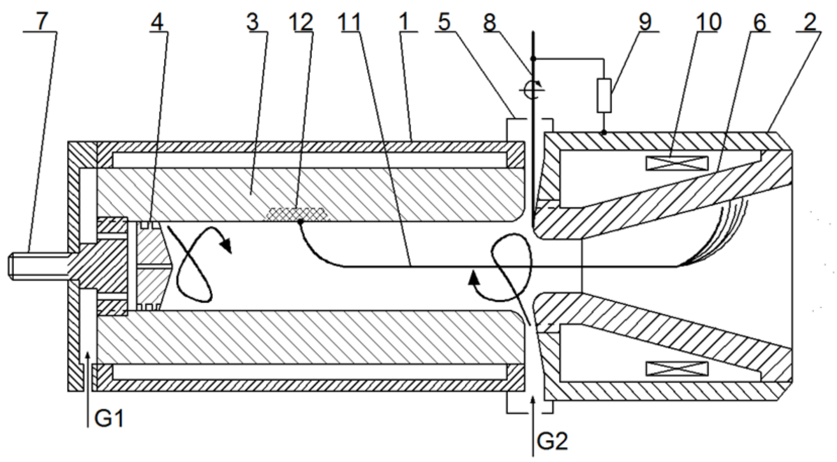

Figure 2. A scheme of a double-chamber plasmatron. 1 is a cathode body, 2 is an anode body, 3 is a cathode, 4 is a cathode swirler of plasma-forming gas, 5 is an intermediate swirler of plasma-forming gas, 6 is an anode diffuser, 7 is a pin of current lead, 8 is an ignition needle, 9 is a current-limiting resistor, 10 is an electromagnetic coil, 11 is an electric arc, 12 is the ring of the inner part of the cathode.

As it was shown by the thermodynamic and kinetic calculations of the ignition process in the plasma-fuel systems (PFS) installed in the working burners of the pulverized-coal boiler BKZ-420, at the capacity of the plasmatron up to 200 kW, the average mass temperature of the air-plasma torch generated by the plasmatron does not exceed 4000 K. This corresponds to the air flow through the plasmatron 1000 l/min (60 m^3/h). The total cross-section of the cathode swirler (G_1) and anode swirler (G_2) nozzles was determined experimentally from the calculation of the nominal air flow through the plasmatron at an inlet air pressure not exceeding 2 atm.

One of the main technological parameters of plasmatrons is their volt-ampere characteristics (VAC), which characterize the stability of burning of an electric arc discharge in the plasmatron. Figure 4 shows the current-voltage characteristic of the plasmatron with various operating parameters. Curve 1 characterizes the I-V characteristic of the plasmatron with the cross-section of the twist ring nozzle equal to 39.26 mm^2, the total air flow through the plasmatron of 875 liters/min, and the anode diameter (diameter of its inner cylindrical part) equal to 27 mm. It can be seen from the figure that the I-V characteristic in the studied range is slightly falling. When the current is increased by 100 A, the voltage drops by approximately 20 V. In order to provide a stable arc burning, in such cases, a ballast resistance with an increasing I-V characteristic is mounted in the power supply circuit of the plasmatron.

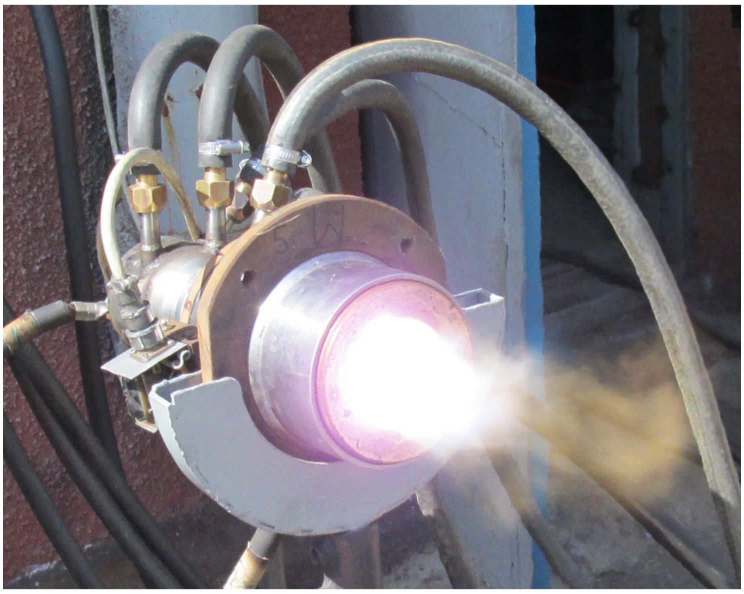

Figure 3. VORTEX-200 linear circuit electric arc plasmatron during the test.

VACs 2 and 3 correspond to the plasmatron with the twist ring nozzle section of 64.3 mm^2 and a total air flow through the plasmatron of 1000 l/min for different anode clamping diameters (27 and 24 mm, respectively). Figure 4 shows that the current-voltage characteristics 2 and 3 of the plasmatron for currents below 420 A are weakly falling, and with a further increase in the current, they begin to increase. It means that in the current range (350-475) A plasmatrons operate most stably. Curve 3 in the figure lies above curve 2, which is explained by an increase in the voltage with a larger clamping of the arc by the plasma-forming gas-air, as in mode 3 clamping of the inner cylindrical part of the anode was less than in mode 2 and was 24 mm against 27 mm.

Figure 5 shows the characteristics of the growth of the power of plasmatrons as a function of the arc current, corresponding to their IV characteristics (Figure 4). It can be seen that for all three cases the power produced by the plasmatron increases with increasing current, but for regimes 2 and 3 the power increases faster due to a higher voltage. The erosion of copper electrodes is determined by the arc current and sharply increases with its growth. Therefore, it is economically advantageous to raise the voltage and reduce the current at the same power. Figure 5 shows that for mode 3, a required power of 200 kW was obtained at currents not exceeding 420 A. It has been experimentally shown that a 10% gas flow G1 and its supply through the axis of the cathode swirler leads to approximately a 10% increase in the arc voltage. It is also necessary to note the reliability of mechanical arc ignition with a needle of refractory material, which has withstood several hundred starts with a single failure when the coal dust got into the annular gap between the anode and the cathode.

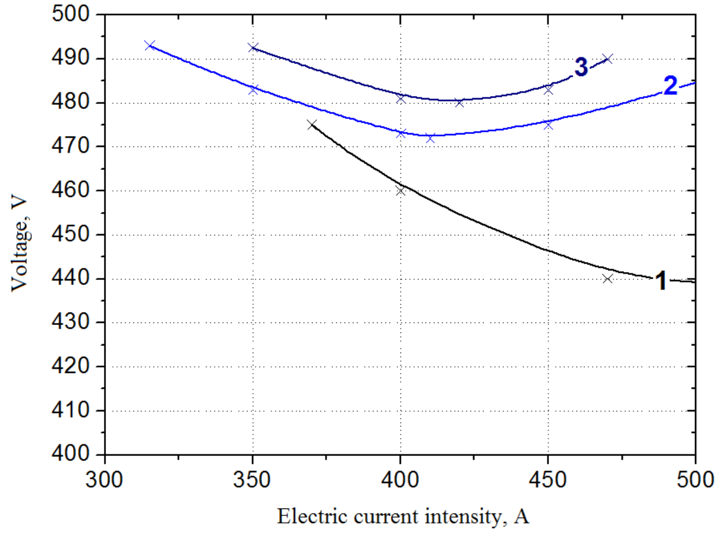

Figure 4. Volt-ampere characteristics of plasmatrons under different conditions. 1 - the cross section of the twist ring nozzles is 39.26 mm ^{2} , the anode clamping diameter is 27 mm, the total air flow through the plasmatron is 875 l/min. 2 - the cross-section of the nozzle rings is 64.32 mm ^{2} , the diameter of the anode is 27 mm, the total air flow through the plasmatron is 1000 l/min. 3 - the cross-section of the nozzle rings is 64.32 mm ^{2} , the diameter of the anode is 24 mm, the total air flow through the plasmatron is 1000 l/min.

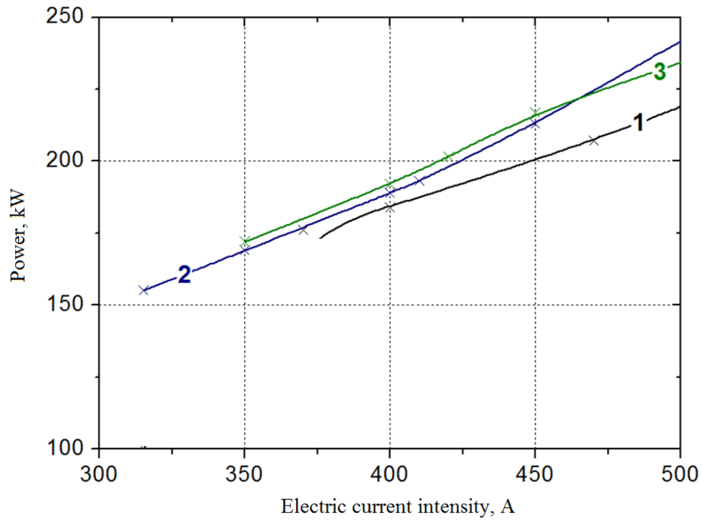

Figure 5. Characteristics of the power growth of plasmatrons as a function of the arc current corresponding to their volt-ampere characteristics. 1 - The cross section of the twist ring is 39.26 mm ^{2} , the anode clamping diameter is 27 mm, the total air flow through the plasmatron is 875 l/min, 2 - the cross section of the twist ring is 64.32 mm ^{2} , the anode clamping diameter is 27 mm, the total air flow through the plasma torch is 1000 l/min, 3 -the cross section of the twist ring is 64.32 mm ^{2} , anode clamping diameter - 24 mm, the total air flow through the plasmatron - 1000 l/min.

Scanning of the cathode spot on the inner surface of the cathode

The gas flow from the swirler located between the water-cooled anode and the cathode is divided into two vortex streams: the part rises on the cathode, and the second part goes to the anode. Under the action of the vortex streams the cathode section of the arc together with the support cathode spot is subjected to azimuth scanning and rotates inside the cathode in a plane perpendicular to the axis of the plasmatron in which wall flows from both swirlers meet, while the inner part of the cathode develops as a narrow ring. Figure 6 shows a photograph of the inner surface of a cathode, that has operated for more than 30 hours at currents up to 500 A, on which a dark ring of cathode erosion is observed, which appeared as a result of erosion of the electrode copper by a cathode spot. The depth of the annular cathode erosion was about 3 mm. According to the estimation at such anerosion the cathode operation resource does not exceed (60-70) hours.

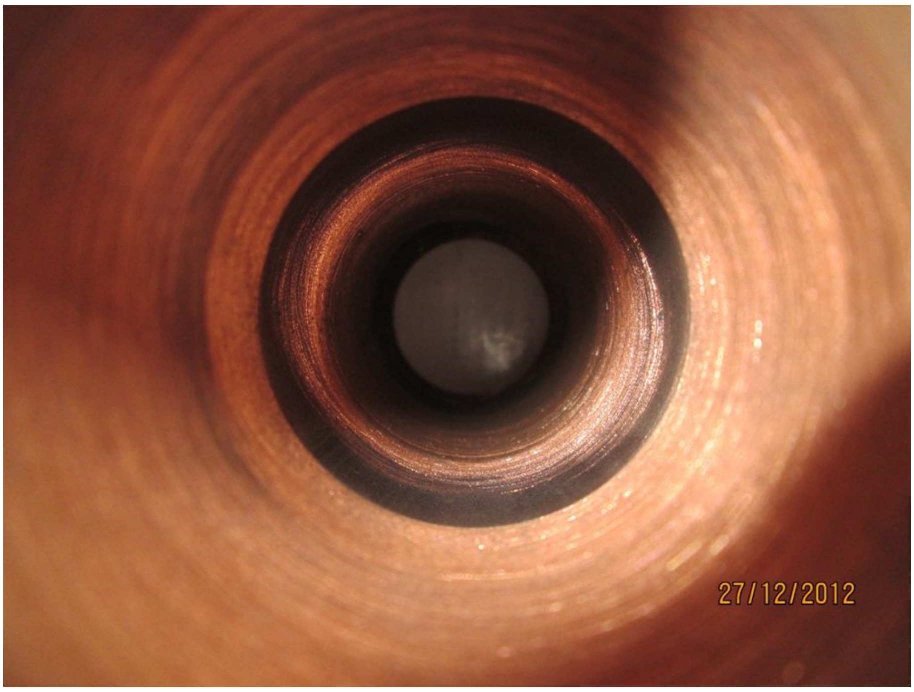

Figure 6. The internal surface of the cathode after 30 hours of operation at currents up to 500 A.

The erosion of the electrode is determined by the mass of the eroded electrode material. The operating life of the electrode depends, in turn, on the distribution of the removal of the electrode material from its surface as a result of erosion. It is known that the larger the eroded surface of the electrode, the higher the resource of its operation at the same current values [5-7].

To increase the cathode resource, the width of its surface area can be significantly increased by axial scanning of the near-electrode portion of the arc by changing the gas dynamic parameters, in addition to the azimuthal displacement due to twisting of the plasma-gas flow. Gas dynamic scanning is achieved by changing the ratio G_2/G_1, the air flows through the swirlers of the plasmatron, using an external device connected to them by nozzles, according to the sinusoidal law with a frequency from several hundredths to a few Hz and an amplitude of (10-20)% of the average values of G_1 and G_2. At the same time, one of the discharges G_1 or G_2 changes according to this regime, or G_1 and G_2 change in opposite phases. As the investigations have shown, the erosion zone (Figure 7) of the inner surface of the cathode along the axis of the plasmatron, and, consequently, the electrode resource can be increased several times.

As a result of the experiments, it was determined that a change in the ratio of G_2/G_1 taken as base (a), 15% (b), 20% (c), and 25% (d) leads to an increase in the distance from the cathode spot trace to the output end of the cathode, by 60% (b), 85% (c) and 100% (d),respectively. The annular trace of cathode spot attachment is shifted from 22 mm (mode a) to 45 mm (mode d). Taking into account that the annular trace of erosion on the surface of the cathode is (8-12) mm wide, a cyclic change in the ratio G_2/G_1 by 25% will lead to an increase in the width of the arc-binding ring by about 3-fold.

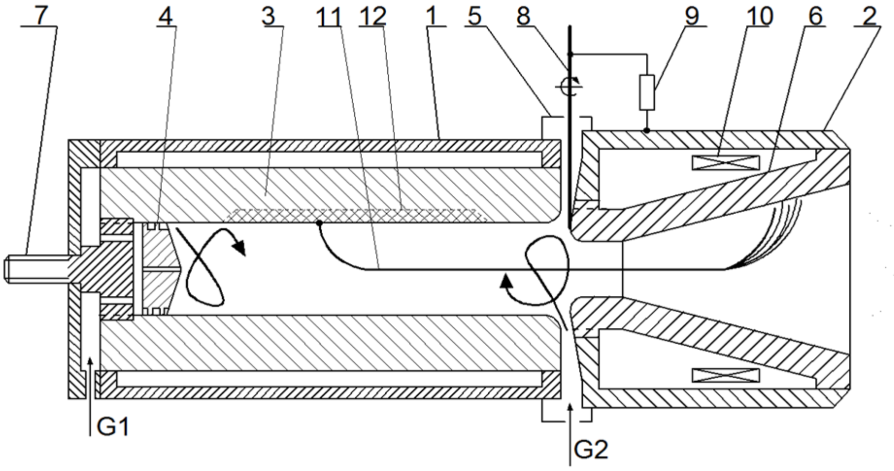

Figure 7. Plasmatron with an extended trace (12) of the cathode spot (11) with axial and azimuth scanning.

To implement the regime of continuous scanning of the cathode spot along the axis of the plasmatron, a scanning device (SD) of the cathode binding of the arc was made. The principle of scanning of the cathode arc binding is based on the change in the anode and cathode flux of the plasma-forming gas through the plasmatron. The change in plasma-forming fluxes in this device is due to a change in the cross sections of the channel for the plasma-forming gas.As the total gas flow (anodic and cathodic) must remain constant, the increment of gas flows along the anode and cathode channels must occur in the opposite phases (shifted relative to each other by 1800).

The scanning device is based on the principle of variation of the flow cross-section of the gas-air supply chain of the plasma-forming gas to the plasmatron by rotating a shutter of a special configuration. The operating principle of the scanning device is explained in Figure 8. In the cylindrical casing (1) there is a rotating shaft (2) with a bevel of a special shape, which, when rotating, covers the openings of the outlets (4). Through the inlet nipple (3), the plasma-forming gas is supplied to the scanning device. For simultaneous gas supply to the anodic and cathodic branches, two outlet nozzles (4) are installed in the device at an angle required to obtain a phase shift of the gas flows (90-180^{0}).

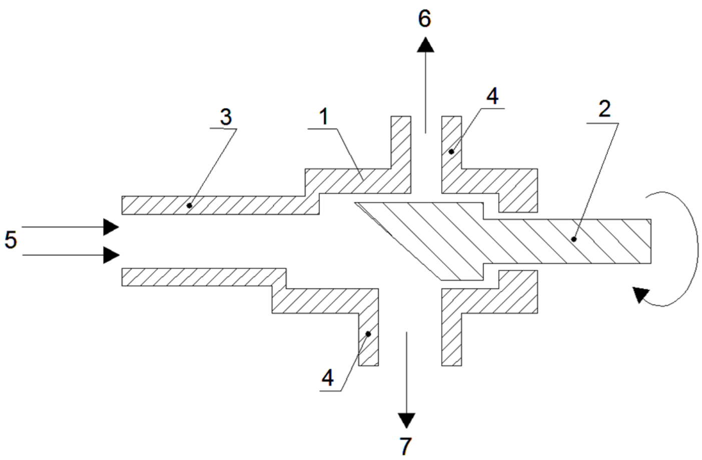

Figure 8. A scheme of the scanning device. 1 is a casing, 2 is a shaft, 3 is an inlet nipple, 4 is outlet nozzles, 5 is plasma forming gas, 6 is plasma forming gas to the cathode, 7 is plasma-forming gas to the anode.

The experimentally chosen period of pressure change is 30 s with a pressure change within the range of 0.6 - 1.5 atm for the anode and (0.6-1.3) atm for the cathode.

The scanning device was made of bronze to reduce the friction of rotating parts.The size and shape of the shaft cut determine the smoothness of the increment of the air flow and the lack of gradualness when passing from the maximum to the minimum values of its discharges. Rotation of the shaft is provided by an electric drive. In the scanning device, the RD electric motor was used with an additional worm gearbox, whose output shaft rotational speed provided the rotation of the SD shaft at a speed of 1 rpm. The scheme of switching of the scanning device in the control circuit of the plasmatron is shown in Figure 9.

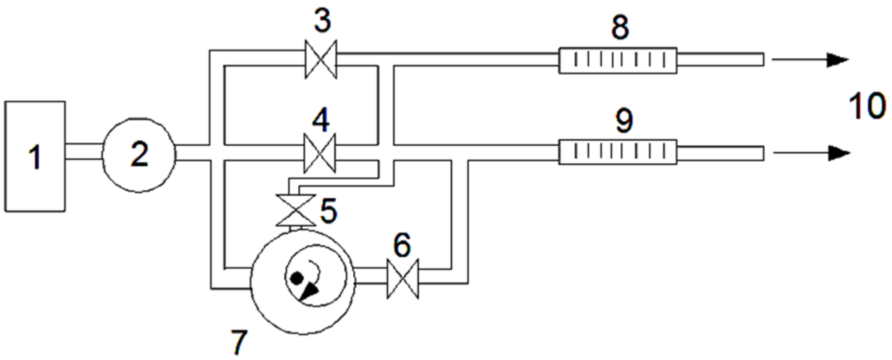

Figure 9. A scheme of switching of the scanning device in the control circuit of the plasmatron. 1 is a compressor, 2 is an air reducer, 3 - 6 are control valves, 7 is a scanning device, 8, 9 are anode and cathode rotameters, 10 is plasma-forming gas to the plasmatron.

The scanning device operates as follows. The plasma-forming gas (air) comes from the compressor (c) at a pressure of 6 atm with a nominal flow rate of 1500 l/min through the pressure reducer (R) and the valves B_1 and B_2 to the air flow rotameters in the anode and cathode channels (Rot. A and Rot. K). The valves B_1 and B_2 regulate the air flow at the anode and cathode in the starting mode (0.6 atm).On the same rotameters, in the opposite phase, additional air is supplied from the SD. The SD provides a smooth increase in the air flow from the starting mode to the operating mode (1.5 atm) and back through the anode and cathode channels in antiphase. Thus, the SD performs the function of increasing the pressure from the starting value (0.6 atm) to the working pressure (1.5 atm) with a further decrease in pressure. After that the cycle is repeated.

Tests of the scanning device with plasmotron VORTEX-200 showed the following characteristics:

1. Variation in the pressure in the anode circuit: (0.6-1.5) atmospheres;
2. Variation in pressure in the cathode circuit: (0.6-1.4) atmospheres;
3. Variation in air flow in the anode circuit: (570-660) l/min;
4. Variation in air flow in the cathode circuit: (350-500) l/min;
5. Time of increase of gas flow: 13 s;
6. Time of gas flow reduction: 14 s;
7. Time of stable maximum pressure on the cathode: 2 s;
8. Time of stable minimum pressure on the cathode: 1 s;
9. Dimensions (including electric drive) - 230 mm $\times$ 100 mm $\times$ 80 mm;
10. Weight of the scanning device with electric drive - 2.5 kg.

Figures 10 and 11 illustrate the effectiveness of the SD operation in increasing the surface of erosion of the cathode, which leads to an increase in the service life of the electrodes of the plasmatron. Figures show photographs of internal surfaces of cathodes with an annular trace of cathode spot attachment after 20 minutes of operation of the plasmatron at a current of 420 A in modes without scanning (Figure 10) and with gas-dynamic scanning of the cathode spot (Figure 11). Scanning the cathode spot attachment leads to a threefold increase in the surface of the erosion of the copper electrode, which corresponds to an increase in the life of the cathode to 200 hours. The life of the massive water-cooled anode is more than 500 hours.

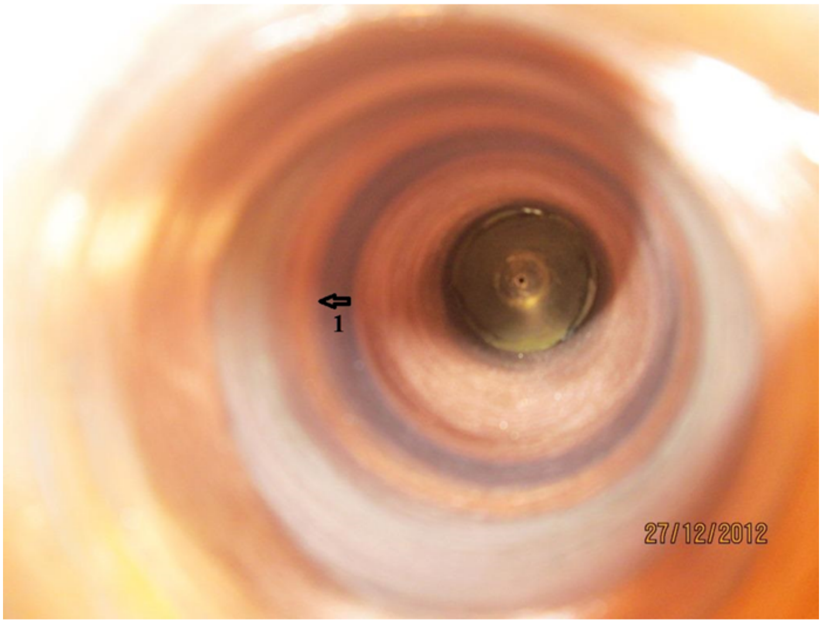

Figure 10. Internal surface of the cathode after 20 min of operation in the mode without scanning of the cathode spot. 1 - Annular trace of the cathode spot. The width of the cathode spot binding ring (arrow length 1) corresponds to 12 mm.

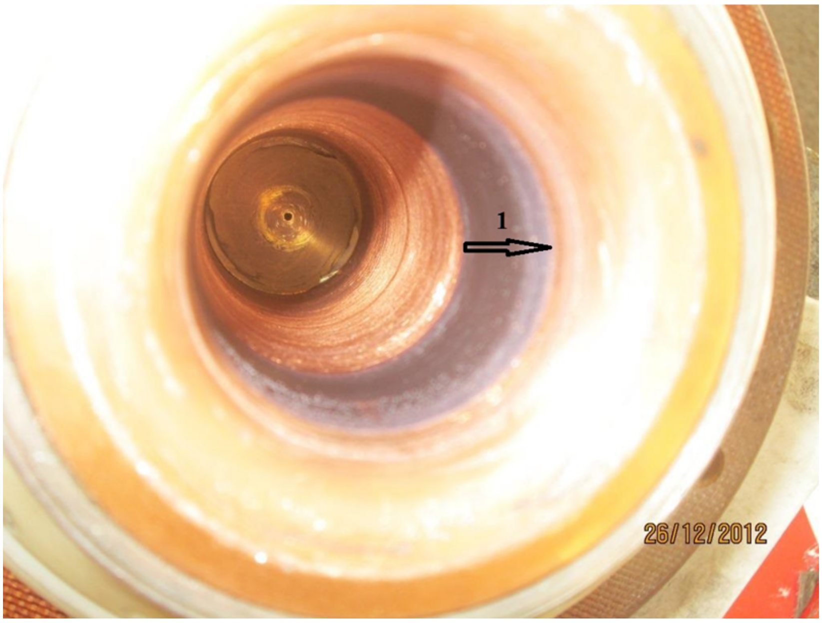

Figure 11. Internal surface of the cathode after 20 min of operation in the scanning mode of the cathode spot. 1 - Annular trace of the cathode spot binding. The width of the cathode spot binding ring (arrow length 1) corresponds to 23 mm.

Conclusion

The analysis of the experimental data obtained as a result of studying of commercial DC plasmatrons VORTEX-200 with copper water-cooled hollow electrodes: a cylindrical cathode and a diffuser-anode enables us to make the following conclusions.

An electric arc plasmatron with a rated power of 200 kW with a controlled range of 80 to 230 kW was created for the non-oil plasma ignition of a pulverized-coal torch in TPP conditions.

The measured volt-ampere characteristics of the plasmatron have made it possible to determine the region of stable arc combustion (350-475) A.

Parameters of the plasmatron operation at its nominal power of 200 kW and the flow rate of the plasma-forming gas of 1000 l/min (60 m^3/h) are attained at currents not exceeding 450 A.

The cylindrical channel of the output electrode is not less than one gauge long.

The opening angle of the diffuser lies in the range (26-30^0).

The use of mechanical ignition of the plasmatron with a needle made of refractory material, instead of oscillator discharge of the inter-electrode gap, increased the reliability of its operation.

The design of the plasmatron, if necessary, allows us to make a complete disassembly and assembly with the replacement of worn parts during (0.5-1.0) hours;

The device for axial scanning of the arc cathode spot binding has been developed, which allows us to get a manifold increase in the erosion surface of the cathode;

The use of azimuth and axial scanning of the cathode spot of the arc of the plasmatron allows us to increase the service life of the cathode to 200 hours.

The completed complex of studies of a plasma torch with the power of 200 kW makes it possible to extend the developed method of gas-dynamic cathode spot scanning to plasmotrons with a power of up to 500 kW.

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