Electrode Erosion in High Current Pulsed Discharge Initiated by Wire Explosion in High Density Hydrogen[1]

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Abstract – The experimental results of electrode erosion in high current high pressure arcs in dense gas media are presented. Parameters of the experiments are: initial pressure of hydrogen up to 35 MPa at current amplitude 400–1600 kA. Time of attainment of current maximum was varied from 40 to 70 μs. Discharge was initiated by wire explosion. Value of specific erosion achieved above 10^{-2} g/C.

1. Introduction

The knowledge of the quantitative characteristics and basic mechanisms of the electrode erosion is important for understanding of the processes occurring in the discharge chambers of high-power pulsed plasmatrons. The metal evaporated from the electrodes or ejected from them in the form of melt influences both the arc-discharge parameters (such as the electric field strength and the radiative and dynamical characteristic of the discharge) and the parameters of the working gas (the heat capacity, thermal conductivity, density, and viscosity). Studies of the processes of electrode erosion are also of considerable interest for the physics of high-current gas discharge.

In [1, 2], the erosion of copper, molybdenum, and titanium electrodes in pulsed oscillatory discharges was measured as a function of the charge at currents of up to 800 kA and charges of up to 70 °C. It was found that, at charges in range 10–40 °C, the erosion increased in a jumplike manner, while at charge lager than 40 °C, the measured dependences were linear for all the metals under study. In [3, 4] the erosion and destruction of the electrode at current of 100–500 kA and charges up to 25 °C were investigated. The erosion of one of the electrodes was observed to change substantially when changing the material or dimension of the opposite electrode [2, 5]. This is explained by an increase (or decrease) in the intensity of the action of the electrode jets from the opposite electrode [5, 6]. These observation agree with the results of [5, 7], where the electrode erosion was found to depend on the interelectrode distance. The simultaneous ejection of the cathode material from the entire surface of the electrode end was observed in [8]. These results indicate a nonuniform (with respect to time) ingress of the electrode material into the discharge channel. In [9] was reported about increase of specific erosion for steel electrode with increase charge transfer at initial gas pressure 1.7 MPa. In [10, 11] the data of electrode erosion research are presented for coaxial electrode system of powerful plasmatron at currents of up to 1600 kA and charges of 70–700 °C at initial hydrogen pressure up to 52 MPa. The electrode erosion depends linearly on the electric charge, so the specific erosion remains almost constant [11]. But the specific erosion also is linearly increased with increase current and gas temperature (embedded energy).

In this paper the data of erosion [11] are compared with electrode erosion in axisymmetric electrode system as the most close parameters on embedded energy and initial gas density.

2. Description of the experiment

The experiments were conducted at current amplitudes of 500–1600 kA and at initial hydrogen pressures up to 35 MPa. The discharge chamber was designed to operate at an initial gas pressure of up to 100 MPa, a pulsed pressure of up to 1000 MPa, and a gas temperature of up to 4000 K. Its geometry is typical of experiments with cylindrical *Z*-pinches, in which the wall of the discharge chamber serves as a return conductor (Fig. 1).

The anode is electrically connected to the discharge chamber. The inner diameter of the discharge chamber is 60 mm and can be reduced by using cylindrical inserts. The free volume of the discharge chamber was variable from 130 to 250 cm^{-3}. In the erosion experiments cylindrical inserts with inner diameter of 50 mm was used. The steel electrodes, placed with a spacing of 10–20 mm, were steel cylinders with a diameter of 20 mm and a semispherical end surface. An arc between the electrodes was initiated by means of a copper wire with a diameter of 0.5 mm and a mass of 0.03–0.10 g, which connected the cathode and the anode at the initial instant of time. Current pulse duration was varied by change of capacitor storage capacity. Capacity was varied from 2.2 to 13 mF.

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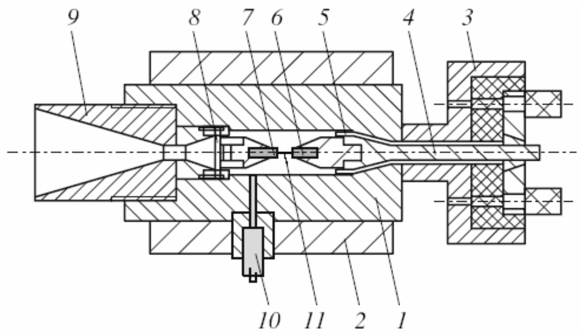

Fig. 1. Schematic of the discharge chamber: *1* – casing; *2* – band; *3* – current collector; *4* – current conductor; *5* – insulator; *6* – cathode; *7* – anode; *8* – diaphragm; *9* – nozzle; *10* – gas supply; *11* – initiating wire

The charging voltage of a capacitor bank was 8–12 kV, and the accumulated energy was 0.5–1.0 MJ. The duration of the current pulse was 100–150 μs, the amplitude was as great at 1.5 MA, and the rate of current rise was ~ 1010 A/s. The voltage drop across the arc was in the range of 3–5 kV, and the energy input into the arc was 50–550 kJ.

Prior to the experiment, the discharge chamber was pumped down to a pressure of 0.05 atm, and hydrogen was blown through them to guarantee the required purity of the working gas. The discharge chamber has a protective diaphragm, which opens after the end of the discharge current pulse. The pulsed pressure in the discharge chamber was as high as 250 MPa, and the diaphragm was disrupted at pressures of 120–150 MPa.

Electrodes were weighed before and after each shots. For the each shot new electrodes were used. Weighting was carried out by analytical balance AUW 220 D (production of Shimadzu, Japan, www.shimadzu.com). The analytical balance accuracy is 0.001 mg, but main error of weighting is uncontrolled mass movement at disassembling of electrode units after shot. But take into account large level of electrode erosion the weighting error apparently is only several percents.

3. Experimental results and discussion

Figure 2 shows the measured total erosions of steel electrodes versus charge. The erosions shown in Fig. 2 as well as dependences presented below, were obtained by processing the data from more than 40 experiments.

Figure 3 presents the total erosion of electrodes versus embedded energy into arc. We may approximate all points of total group by linearly dependence with good accuracy. The dependence means that the specific erosion is increased with embedded energy and charge. Also specific energy is increased with initial hydrogen pressure. The dependence of specific erosion versus initial gas pressure is presented in Fig. 4.

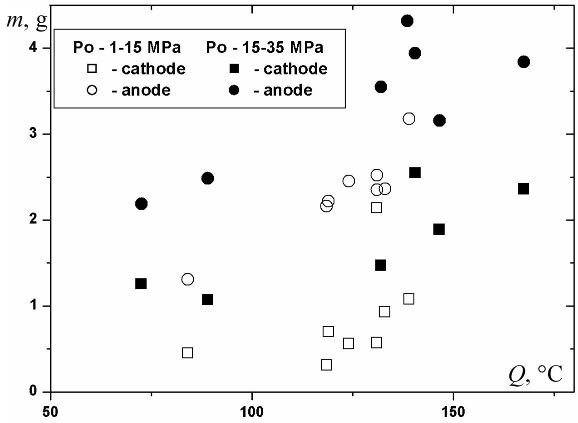

Fig. 2. Total electrode erosion as a function of the electric charge

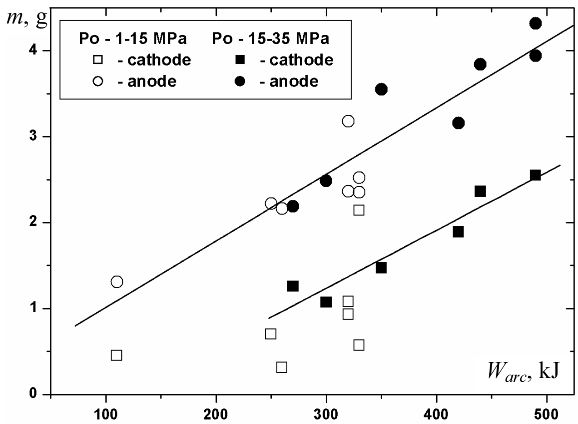

Fig. 3. Total electrode erosion as a function of the embedded energy

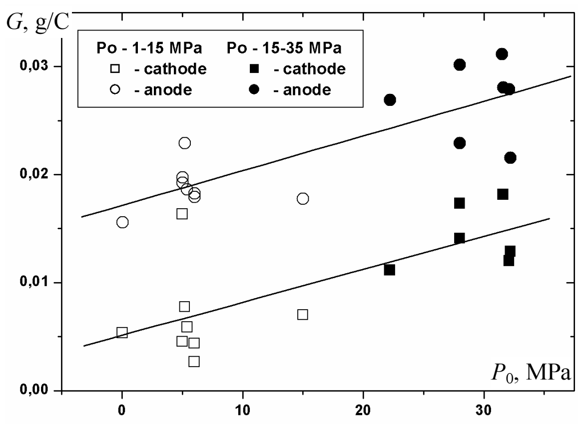

Fig. 4. Specific electrode erosion as a function of the initial gas pressure at embedded energy ~ 300 kJ

In Fig. 5, it is shown the specific erosion as a function total erosion.

The linearly dependence indicates that really total erosion (electrode weight losses) is proportional to square of charge transfer (consequently as square of current). The square-law of the embedded energy into arc versus the charge transfer is illustrated by Fig. 6.

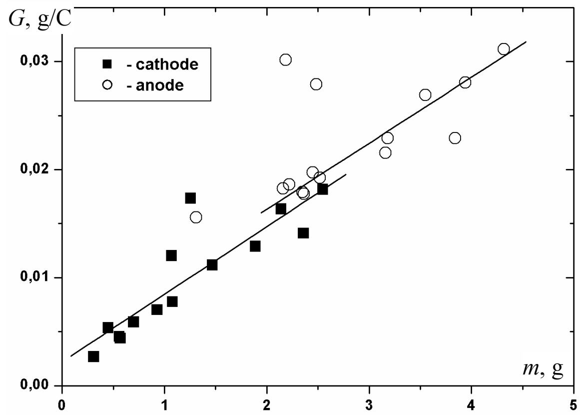

Fig. 5. Specific electrode erosion as a function of the total electrode erosion

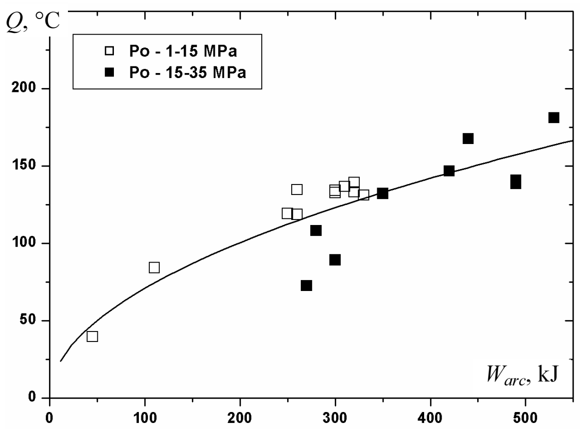

Fig. 6. Electric discharge as a function of the embedded energy

That character of the electrode erosion confirms theoretic model of electrode erosion in high pressure high current arcs [12]. In [13] the calculated coefficients of specific erosion (by energy) are presented. Its values are close to our data, but directly they couldn't compared because of coefficients in [13] set for energy embedded near electrodes.

But we can't easy separated part of embedded energy near electrodes. Although the electrode voltage drops [6, 14] at megampere current range are equal to about several kV and it is considerable share of total arc voltage.

The difference between the data of present data from the data [10, 11] is explained by differences in physics of discharge in this cases. In [10, 11] the arc moves under action of rail magnetic effect. Arc is cooled by turbulent heat transfer. Arc has low current density and low temperature. The discharge channel in *Z*-pinch geometry has high current density, high temperature [15]. The radiation losses from discharge play most role in energy balance [16] and for electrode erosion [12].

The anode erosion bigger the cathode erosion. This difference may be caused by intense thermal impact of the high-temperature gas flow escaping from the discharge chamber onto the anode, because it is situated in the nozzle part of the discharge chamber, while the cathode is situated at the bottom of the discharge chamber and is practically not subjected to the thermal impact exerted by the gas flow.

4. Conclusion

The experimental results of electrode erosion in high current high pressure arcs in dense gas media at initial pressure of hydrogen up to 35 MPa at current amplitude 400–1600 kA are presented.

The specific erosion of electrodes is increased with increasing of initial gas density and embedded energy onto arc.

The last statement supports the sentence about important role of radiation losses in energy balance and increasing of near electrode voltage drop with increasing gas density, current and current density.

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