Discharge between the jet and dropping liquid cathode and metal anode

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Abstract. Low-temperature gas-discharge plasma is investigated that is generated within the electrode space between the jet and dropping liquid cathode and metal anode at ambient pressure. The results of plasma composition, electrophysical parameters, electron concentration are presented, the discharge types are specified.

1. Introduction
In parallel with the study of discharges between solid electrodes [1-3], of high concern are discharges generated by direct or alternate current fields within the electrode spacing where a single or both electrodes are the liquids. This type of discharge is of high concern for both the sphere of fundamental studies and the discharge applications in various sectors of production [4-12]. Such industries as aircraft engineering, mechanical engineering, metalwork set urgent tasks to treat metal and item surfaces of different physical nature to improve their surface properties. At the same time, industries are up against such tasks as the surface combined treatment as well as the local section modification of item surfaces. To date, various surface machining technologies are applied for materials and items, namely mechanical, chemical, electrochemical and plasma techniques. Low-temperature gas-plasma discharge is the perspective technology of surface local treatment that is burnt between the jet and dropping liquid cathode and metal anode (item to be treated) within a wide range of pressure values. “The method is based on the impact of surged electric discharges that generate in the steam-plasma skin formed around the item immersed in the electrolyte. Unlike the electrochemical finishing in acidic solutions, electrolyte-plasma technology allows using environment friendly aquatic solutions of low-concentration salts” [13].

2. Experiment
The gas discharge between the jet and dropping liquid cathode and metal anode was studied at the pilot plant (Fig.1) with the direct current source and controlled DC voltage up to 4000 V at the rated current of up to 10A, where: 1 – electrolytic cell; 2 – electrolyte solution; 3 – metal plate for electropositive potential supply; 4 – gas discharge combustion area; 5 – metal cathode; 6 – jet and dropping liquid anode.
The following research methods were applied to address the tasks specified:

1. The process of gas discharge combustion was recorded by the digital photo- and video devices SONY FDR-AX33.

2. Gas discharge current and voltage oscillations were analyzed by the digital oscillograph GDS – 806 S.

3. The plasma emission spectrum of the HF capacitive discharge was defined by the fibre-optic spectrometer PLASUS EC 150201 MC with the goniosight to fix light rays within the wavelength range of 195 to 1105 nm. The spectral resolution of the device $\delta \lambda$ is 1 nm. The composition and concentrations of plasma electrons of HF capacitive discharge was evaluated with no reference to the particular area. The spectrum was interpreted by the line identification correlating the test spectrum against the NIST database.

![Figure 1. Pilot plant block scheme](image)

Combustion of the gas discharge within the electrode spacing was identified at the voltage of $U = 250 - 1000$В, current $I = 0.7 - 2.5$А, jet length $l_c = 30$ мм, ambient pressure $p = 10^5$Па, the current pulsation frequency $\nu = 30 - 100$Hz (Fig. 2), a copper plate $d_a = 1$ mm was taken as the anode. The discharge is generated in two system areas: 1 – at the border between the jet and dropping liquid cathode and copper anode, 2 – in the area of jet thinning, between the electrolyte drops as formed. The discharge generated in the area of jet thinning is due to that the potential supplied to electrodes results in the potential difference in the area between drops that emerge and disruptive discharge generates between them.
Figure 2. Oscilloscope pattern of the gas discharge current and voltage oscillation

The method of optical spectroscopy was applied to evaluate the plasma composition and electron concentration of the gas discharge. The device-based spectral spread (Fig. 3) was verified by the potassium atom K I - 766.2 nm. In both spectra, the minimal width of single lines was $\Delta \lambda_g = 1$ nm which is taken as the instrumental width. The emission spectrum analysis of the gas discharge indicates that different elements are available in the plasma test area: oxygen O I, hydrogen H I, natrium Na I, potassium K I, zinc Zn I, calcium ions Ca II, zinc ions Zn II, as well as nitrogen molecules N2+ (C-B) and hydroxyl OH (A-X). To define the electron concentration in the plasma of HF capacitive discharge, contours of hydrogen lines were analyzed in the Balmer series ($H_\alpha$, $H_\beta$, $H_\gamma$). To calculate the electron concentration $n_e$, the width of Voigt profile of hydrogen line was defined. The half-width of lines at the half-height was $\Delta \lambda_f = 1.4$ nm for $H_\alpha$, $\Delta \lambda_f = 1$ nm for $H_\beta$, and $\Delta \lambda_f = 1.2$ nm for $H_\gamma$. The value of $n_e$ by $H_\beta$ line was not calculated since its half-width appeared to be equal to the minimal width of single lines $\Delta \lambda_g = 1$ nm. In view of device-based spreading in assumption of the Voigt profile of the line to be registered, the Lorentz profile constituent of the $H_\alpha$ line is equal to $\Delta \lambda L = 0.661$ nm, and that for $H_\gamma$ line is equal to $\Delta \lambda L = 0.34$ nm. Values $\Delta \lambda L$ conditioned by the linear Stark effect correspond to electron concentrations of $n_e \approx 10^{15} - 10^{16} cm^{-3}$ order.
3. Results
1. The discharge combustion between the jet and dropping liquid cathode and metal anode was identified in two system areas: 1 – at the border between the jet and dropping liquid cathode and copper anode, 2 – in the area of jet thinning, between the electrolyte drops as formed.
2. The discharge current pulsation was defined within the range of $I=0.7-2.5\,\text{A}$, frequency $\nu=30-100\,\text{Hz}$.
3. The electron concentration $n_e\approx(10^{15} - 10^{16})\,\text{cm}^{-3}$ was identified.

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