The emergence and development of spark channels in the plasma column of a gas discharge between water-solution cathode and a copper anode

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Abstract. A gas discharge in air between water-solution cathode and a copper anode was experimentally studied. The conditions of the emergence and development patterns of spark channels in the plasma column of discharge were identified.

1. Introduction
In recent years, interest to the gas discharges with liquid electrodes has increased [1]. Much attention is paid to the variant of the liquid-phase cathode. In this variant, like a glow discharge, a volumetric plasma column is formed above the cathode. Burning modes with spark channels were detected in [2] and some integral characteristics of the discharge were investigated. The purpose of this work was a more detailed study of these regimes.

2. Experiment
The scheme of the experimental setup is shown in figure 1. The water solution is expiring from the tube \( l \) that installed vertically. The tube was made of dielectric material. Its internal diameter was 70 mm. A graphite plate for supplying a negative potential from the power source was mounted. Above of the tube was a round copper anode with a diameter of 100 mm. The anode was installed at different altitudes. Thus, the length of the discharge gap \( l \) varied within 4-7 cm. The water solution was played the role of a liquid cathode. It was a solution of sodium chloride in distilled water. In the experiments, solutions with a concentration by mass of 0.5 to 0.05% were used. Their specific electric conductivity \( \sigma \) was within the range of 2-9 mSm/cm. The mass flow rate of the water solution varied in the range 5-30 g/s. The water solution was cooled by forced circulation through a heat exchanger.

The discharge was supplied from a three-phase two-half-period rectifier with an output voltage of 3000 V. The voltage pulsations were smoothened by means of capacitive-inductive filter \( C-L-C \). The current was regulated with ballast resistor \( R3 \) by varying its resistance by a step from 50 to 200 \( \Omega \). High-speed video shooting was made by the Photron FASTCAM SA4 camera in the mode of 10000 frames per second.
3. The experimental results and their analysis

The spark channels are not regular. Their location, geometry and duration was varied randomly. As an example, a series of frames that cover the life span of a single spark channel are shown in figure 2. The first frame is a photograph of the discharge gap. As can be seen, the spark channel is generated near the metal anode and breaks into the direction of the liquid cathode (frames 1-5). After the discharge gap is closed, the spark channel expands (frames 6-9). At the same time, a branching takes place near the cathode. In the period of developed combustion, the binding to the liquid cathode is continuously changing (frames 10-17). In the middle part, bends are formed which are characteristic of a free electric arc. The binding to the anode is targeted and it is stationary. The disappearance of spark channel occurs almost instantaneously (frames 18-20).

It has been recorded that only a few are being developed from the bud. Some of them were lengthened by 2-3 cm and then disappeared (figure 3). The spark channels are spread from the copper anode at speeds of 100-150 m/s.

On video frames, the spark channels were turned out to be scarlet. This colour is characteristic for the Balmer spectral line $H_\alpha$. And in fact, at the time of the appearance of spark channels, the emission of hydrogen atoms was the predominant emission. At these times, in the panoramic spectra in the visible wavelength region, the spectral line $H_\alpha$ was the most intense.

A considerable amount of water vapor and also sodium is entering into the discharge gap from the liquid cathode. In all likelihood, thermal dissociation of water molecules into atoms takes place inside the spark channel. At the same time, hydrogen atoms can predominate among the radiating atoms (H and Na) in spark channel because the water solution used as the cathode, is highly diluted.
Figure 2. A frame by frame of video shooting of spark channel. The interval between frames was 0.1 ms.

The spark channel of scarlet colour is formed against the background of yellow radiation of sodium atoms. Such a picture indicates that, despite the appearance of spark channel, the space above the liquid cathode remains current-conducting in the larger part. In a short time of the existence of spark channel (on the order of several milliseconds), massive ions do not have time to reach the electrodes and continues their relatively slow motion, creating an ion current. Inside of spark channel, current flows is predominantly provided by electrons, which are much lighter than ions.

The origin of spark channels, apparently, is also due to the uneven distribution of electrons. Spark channels are appears where the concentration of electrons is high. The appearance of spark channels near the metal anode indicates that the current is closed to the positive electrode mainly by electrons.

The appearance of spark channels was recorded on oscillograms as abrupt current changes. In the intervals of stable combustion (without spark channels), the discharge current was 10-15 A, and the voltage is 2400-2700 V. During the existence of spark channels, the current was increased to 30-35 A. At the same time, the voltage was varied not so much. It decreased by 200-500 V at the time of the appearance of spark channels.
4. Conclusions
The occurrence of spark channels occurs under certain conditions. The specific electrical conductivity of the water solution serving as the cathode should be small. The discharge current must be considerable. In the case of a water solution of sodium chloride, the spark channels are necessarily appears at $\sigma = 2-5 \text{ mS/cm}$ and $I > 5 \text{ A}$.

References
[1] Bruggeman P J et al. 2015 Plasma Sources Science and Technology 25 053002
[2] Tazmeev Kh K and Tazmeev A Kh 2014 J. Phys.: Conf. Ser. 567 012035