Study of the cathode spot on a liquid electrolyte by using high-speed visualization and software of coloured images processing

B K Tazmeev\textsuperscript{1}, V V Tsybulevsky\textsuperscript{1}, R N Tazmeeva\textsuperscript{2} and G K Tazmeev\textsuperscript{2}

\textsuperscript{1}Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russian Federation
\textsuperscript{2}Kazan Federal University, Naberezhnye Chelny Institute, Naberezhnye Chelny, Russian Federation

E-mail: tazmeevb@mail.ru

Abstract. The processing of coloured images of concentration area of cathode spots, obtained as a result of high-speed visualization of gas discharge with a liquid electrolyte cathode, was performed. The polygon functions of empirical distribution for intensity code of color were constructed. A correlation was found between the radiation intensity and small-scale current pulsations.

1. Introduction

Currently, there is growing attention to sources of non-equilibrium plasma with liquid electrodes [1, 2]. As studies show, such plasma sources have a wide range of practical applications, for example, their use in optical emission spectroscopy makes it possible to quickly analyze liquid samples in the field tests [3].

However, it should be noted that the mechanisms of interaction of plasma with liquid electrodes are still not fully understood. This is especially relates for the processes of electric current passing through the “plasma-liquid” interface.

At low currents (within a few tens of milliamperes), the anode spot can manifest itself in the form of a stable figure with a certain pattern [4, 5] in the range of currents of 20–80 mA and a current density of 1 A/cm\textsuperscript{2}. Self-organization of the cathode spot is observed at low pressures [6]. In contrast to the case of anode, figure of cathode spot is vague and mobile. At atmospheric pressure, cathode spot takes on a round shape. In geometry of “needle-plate” electrodes, it is customary to consider it as a circle with a certain diameter [4, 6]. In the range of currents 10-100 mA, typical values of current density at liquid cathode are in the range of 0.5–2.5 A/cm\textsuperscript{2}.

At increased currents, the homogeneous of cathode spot glow is violated, and the spatial structure of discharge near cathode at currents of the order of 1A and more becomes multichannel [6-10]. Consequently, to describe the phenomena of charge and matter transfer at the “plasma-liquid” interface, local current densities must be taken into account. This will require reliable experimental data. In this regard, the purpose of this work was to develop a technique for studying cathode spot on liquid electrolyte by using high-speed visualization and MathCad software.
2. Experiment
The study of cathode spot on liquid electrolyte was carried out using by high-speed visualization. High-speed video shooting was performed with Photron FASTCAM SA4 camera at 10,000-20,000 frames per second. Its technical characteristics make it possible to study in detail the processes at “plasma-liquid” interface.

In figure 1 shows a fragment of diagram of an experimental setup and a photograph of an electric discharge device, in which an electrolyte flow was formed on a narrow slit. Water solution of sodium chloride with a weight concentration of 5 g/s was used as electrolyte.

![Figure 1. Experimental setup.](image)

The liquid electrolyte was supplied to the inside of cathode assembly 1. The outlet from it was closed by a cover 2, which had a slit gap of width $b = 2.5$ mm. The slit length was 35 mm. A graphite plate 3, was mounted inside cathode assembly, which was connected to the negative pole of power source. The discharge burned between electrolyte and water-cooled metal anode 4. Anode was made in the form of a long tube. It was oriented along slit and located above it at a distance of $l = 4$ cm. The information accumulated in video camera 5 was transmitted to computer 6.

3. Processing and analysis of results
The processing of coloured image in MathCad system was carried out using the RGB method. The image is represented by the sum of three components with red, green and blue colors. Using MathCad functions, coloured images were read from files and triple array M, was formed, containing three monochrome images representing the brightness of three indicated colors. As an example, fig. 2 shows triple matrix for one of video frames obtained in the shooting mode of 20,000 frames per second.

![Figure 2. Triple matrix (M) of red, green and blue components.](image)
Using the “submatrix” function, three arrays $R$, $G$ and $B$ can be selected from the matrix $M$, which carry information separately on each of three colors. As seen from fig. 2, gas discharge image is too bright in red. The spatial structure is poorly visible. In blue, the brightness is so low that the image is almost nonexistent. The most suitable for processing is array $G$. Processing of this array $G$ was carried out according to the specified algorithm [11, 12]. The area of concentration of cathode spots was selected for processing. In this area, the conventional feature of cathode spot was repeated with different frequency in the selected array. The frequency peaked at a specific value of intensity code of color. The processing results can be represented by the following approximating function

$$f = \frac{1000}{1.4795 \cdot g^2 + 5013.4 \cdot \ln g - 376.71 \cdot g}.$$  

(1)

Here $f$ – is the frequency of repetition of conventional feature of cathode spot; $g$ – intensity code of green color channel.

In figure 3 shows a graphical representation of the results obtained for a combustion mode of 1 A. As can be see, there is a clear maximum in the range from 108 to 118 units of intensity code. The results were similar in other current modes.

![Figure 3](image)

**Figure 3.** Dependence of frequency of hitting feature of cathode spot in a given interval of intensity code of color. Points – the results of processing of experiment. The solid line – calculation.

A characteristic feature of gas discharge with liquid electrolyte cathode is the presence of small-scale current pulsations [11]. The maximum of radiation intensity corresponds to maximum of current amplitude. Thus, a correlation is found between radiation intensity and small-scale current ripples.

4. Conclusion

As a result of studying discharge with liquid cathode by using high-speed visualization and software of coloured images processing in MathCad system, a range for intensity code of cathode spot color channel was determined. High-speed visualization was performed at frequency of tens of thousands of frames per second, which made it possible to reveal a correlation between frequency of changes in radiation intensity in the region of cathode spots and small-scale pulsations of discharge current. The polygon functions of the empirical distribution of intensity code of color were constructed, which can be used in modeling the processes at liquid cathode - plasma borderline.

References

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