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# Determining the Rate of Electric Discharge Creeping over a Water Surface

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**Abstract**—We examine various methods based on specific experimental results for finding the rate of propagation of a pulsed discharge over a water surface.

*Key words*: rate of discharge, electrical discharge, creeping discharge.

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## 1. INTRODUCTION

Discharges arising in air under atmospheric pressure between a spike located above a water surface and an electrode submerged in the water [1–4] are a particular case of a wide class of surface discharges propagating along a gas–liquid surface. As well, one of the characteristics of such discharges is the rate of their motion over the liquid surface, which is directly determined by the mechanism of the discharge' s propagation. In such a way, measuring the rate of motion of a discharge depending on various initial parameters is one of the necessary conditions for constructing the corresponding physical models of its propagation. Existing methods of ultrafast photography are significantly expensive and, in addition, require that the glow intensity of the discharge be high in order to accurately record it. The present work examines relatively simple methods that make it possible to determine the discharge propagation rate based on relatively simple experimental measurements.

## 2. EXPERIMENTAL

We conducted experiments on a setup whose scheme is depicted in Fig. 1. Industrial water (*2*) was poured into cuvette (*1*) with a dimension of 30 × 12 cm above which was placed a high-voltage negative spike-shaped electrode (cathode) (*5*). A flat grounded electrode (anode) (*3*) was placed directly in the liquid at the opposite side of the cuvette. As a power source of the electrical scheme, we used a pulsed modulator (*7*), which made it possible to obtain quasi-rectangular pulses with a duration of 10 μs to 1 ms. The output voltage of the power source in the pulse varied from 7 kW to 25 kW at a step of 250 V. The discharge current was limited by ballast resistor (*8*), the magnitude of which varied in the range of 1–8 kΩ. The drop in voltage at the discharge was determined by an ohmic voltage divider (*6*): $R_1 = 2$ MΩ and $R_2 = 1$ kΩ; and the discharge current was determined by a shunt circuit: $R_{sh} = 0.5$ Ω. The signal from the voltage divider and the shunt circuit fed into the two inputs of a Tektronics TDS-2004B digital recording oscillograph. The discharge was filmed with a digital camera.

## 3. METHOD OF RATE DETERMINATION

It is noteworthy that the process of the first breakdown and propagation of discharge from the cathode to be anode has a strictly non-steady-state character.

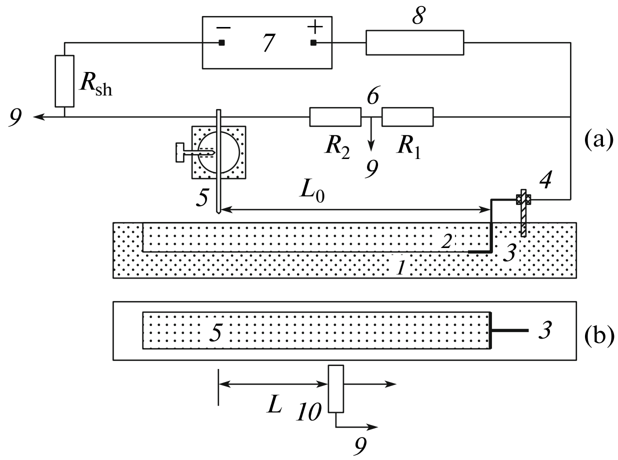


**Fig. 1.** (a) General scheme of the setup. (b) View from above. *1*—Plexiglas cuvette; *2*—liquid; *3*—anode; *4*—stand; *5*—cathode; *6*—voltage divider; *7*—power source; *8*—ballast resistor; *9*—to oscillograph; *10*—photomultiplier.

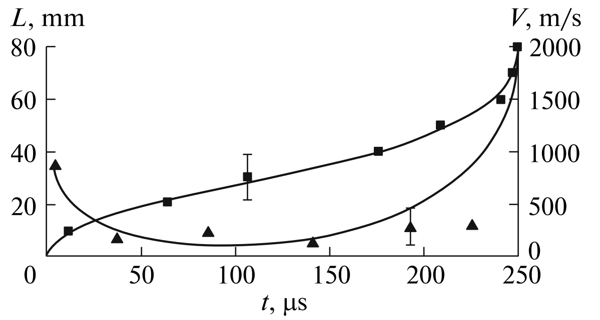


**Fig. 2.** Dependences ■ (length of discharge propagation) and ▲ (rate) on time obtained with a PM: $U_0 = 22$ kV, $L_0 =$ 10 cm, and $R_b = 1$ kΩ.

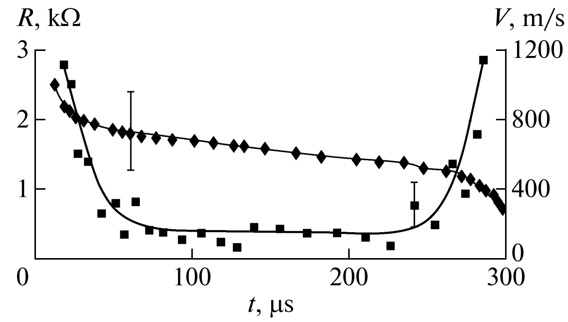


**Fig. 3.** Dependences ◆ (discharge resistance) and ■ (rate) on time. $U_0 = 22$ kV, $L_0 = 10$ cm, and $R_b = 1$ kΩ.

Therefore, in these experiments, the main parameter—the time of motion of the discharge between the electrodes [4]—was found as the average magnitude determined from the results of several measurements (three, five, or more). Then the mean statistical error was found, which was also taken as the measurement error. The values of measurement errors determined in this way lie in the range of 20–30%.

The simplest method is to determine the mean rate as the relationships between the length of the discharge gap $L_0$ at the time of discharge propagation $t_p$: $V = L_0/t_p$. As well, the time of propagation is determined experimentally from the oscillograms of current [4]. The main drawback to this method is that it is impossible to determine the rate of motion of the discharge at different moments in time with it.

One method of determining the rate of discharge is the use of a collimated photomultiplier (PM), which was set up perpendicularly to the discharge axis at various distances (L) from the cathode (Fig. 1b). Thus, repositioning the PM parallel to the discharge axis and measuring the delay time of the signal's arrival from the PM relative to the beginning of the discharge pulse—i.e., the time within which the discharge reached the location of the PM—we were able to construct dependence $L(t)$ (in actuality we measured the dependence $t(L)$). By differentiating this dependence, we are able to obtain the value $V(t)$. An example of this determination of the rate is depicted in Fig. 2. As is seen from these graphics, the rate is ~800 m/s at the start of the discharge's motion and it then decreases to 250 m/s, remaining there until almost the end of its propagation. Only near the anode does the rate increase to ~2000 m/s.

The next method of determining the discharge propagation rate is based on measuring the total discharge resistence and the portion of water remaining between the discharge and the anode, which is determined as the relationship of the measured current–voltage values. During motion of the discharge from the cathode to the anode, its intrinsic resistance increases, but the resistance of the remaining portion of water decreases. Since at any moment in time the resistance of any portion is proportional to the linear length of the area in which it is determined, it seems that the derivative of the full measured resistance over time is proportional to the rate of discharge and is determined by the following formula:

$$\frac{dR}{dt} = -\left(\frac{\rho_1}{S_1} - \frac{\rho_d}{S_d}\right)V,$$

where $\rho_d/S_d$ and $\rho_l/S_l$ are the resistance of the unit length of the liquid and the discharge, respectively. They are determined under the supposition that at the start, the entire current flows over the water and therefore the initial resistance divided by the interelectrode distance makes it possible to determine $\rho_l/S_l$, and the resistance at the end of the discharge's motion is the resistance of only the discharge channel. Quantity $\rho_d/S_d$ is determined analogously.

Figure 3 shows the time dependences of the resistance of the discharge and the rate of its propagation. As is seen from the figure, the rate at the beginning and end of motion of the discharge achieves ~1200 m/s; the rest of the time, it is ~200 m/s.

To determine the rate, we can also use the given filmings of a series of discharges at various pulse durations. Each frame represents a photograph, integral in time, of one discharge at a fixed pulse duration. On the basis of these frames, we determined the maximum distance at which a discharge was able to propagate within the time of the pulse, then we constructed from these data the dependence of the length of the discharge on the pulse duration ($L = f(t)$), and by its differentiation, we determined the rate of discharge motion at the given moment in time. These dependences are shown in Fig. 4a. It is clear that, like in the preceding cases, the rate of discharge is maximum from the area of the electrodes and remains nearly constant in the space between them.

Figure 4b shows a comparison of the rate values obtained by various methods under the exact same conditions in which the discharge was generated. As

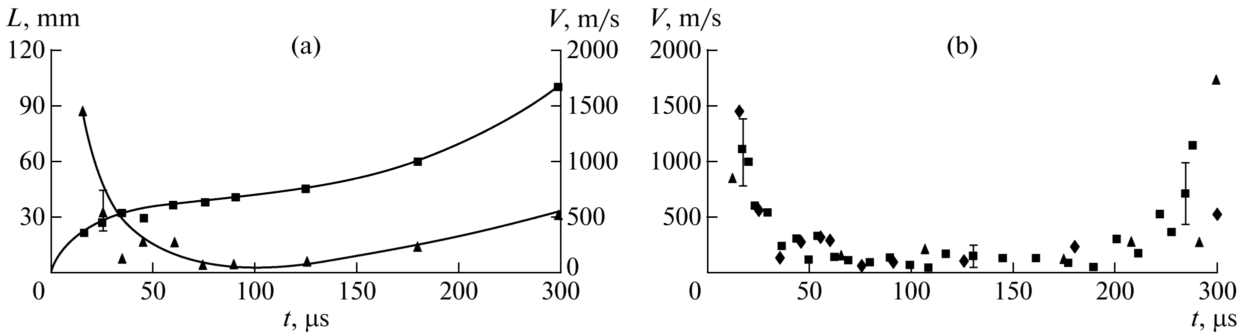


**Fig. 4.** (a) ■—Dependence of discharge length on pulse duration; ▲—dependence of discharge propagation rate on time. (b) Discharge propagation rate as a function of time: ▲—method with PM; ■—determination of the rate over full resistance; ◆—filming method at various pulse durations.

follows from the given dependences, the values of the discharge rate determined by various methods almost completely coincide. Note that the mean rate determined from the correlation $V = L_0/t_p$ for the initial conditions corresponding to Fig. 2 is 350 m/s; for Fig. 3, it is 400 m/s. The mean rate values obtained by this formula also correspond to the rate determined as the mean arithmetical value for the corresponding dependences.

## 5. CONCLUSIONS

Our experiments and the results thereof prove that it is possible to apply all of the studied methods to determine both the mean rate value of discharge propagation from the anode to the cathode and the instantaneous value of this rate and its dependence on time.


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## REFERENCES


1. H. V. Evtyukhin, A. V. Savelev, A. D. Margolin, and V. M. Shmelev, *Dokl. Akad. Nauk. SSSR*, 1989, vol. 307, no. 6, p. 1370.
2. V. P. Belosheev, Zh. Tekh. Fiz., 1998, vol. 68, no. 7, p. 44 [*Tech. Phys.* (Engl. Transl.), 1998, vol. 43, no. 7, p. 783].
3. A. M. Anpilov, E. M. Barkhudarov, V. A. Kop'ev, et al., *Fiz. Plasm.,* 2006, vol. 32, no. 11, p. 1048 [*Plasm. Phys. Rep.* (Engl. Transl), 1998, vol 32, no. 11, p. 968].
4. A. F. Aleksandrov, D. N. Vaulin, A. P. Ershov, et al., *Vestn. Mosk. Univ., Ser. 3: Fiz.*, 2009, no. 1, p. 95. [*Mos. Univ. Phys. Bull.* (Engl. Transl.), 2009, vol. 64, no. 1, p. 100].