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Determination of near-electrode voltage drops and average field in a discharge channel with a current amplitude of 1.3 MA in hydrogen at an initial pressure of 5 MPa

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The results of a study of a discharge in hydrogen at an initial pressure of ~ 5 MPa and a current amplitude of ~ 1.3 MA, initiated by the explosion of a wire, are presented. The mean value of the electric field in the discharge channel and the mean near-electrode voltage drop were determined in a series of experiments with steel electrodes in the range of interelectrode gaps from 1 to 2 cm at the moment of current maximum. The total near-electrode voltage drop was ~ 2.45 kV and the electric field strength in the discharge channel was ~ 0.6 kV/cm.

Keywords: megaampere discharge, hydrogen of high pressure, electric field and near-electrode voltage drop determination.

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The pulsed discharge with current of megaampere range is one of the effective and traditional methods to obtain plasma with the extreme parameters [1–3]. The discharge can be used as a laboratory model of astrophysical objects [4] for physical simulation of astrophysical jets [5] and radiation transfer in photosphere of stars [4], equations of state of substance [6] etc. High current discharges in gas with high density provide definite advantages when producing extreme states of substance [1], and in turn have some specific characteristics [1,7–9].

Values of near-electrode voltage drops and field strength in the discharge channel are one of the important parameters of the discharge determining its characteristics. The average value of these quantities is usually determined by the dependence of the voltage across the discharge gap on its length. For pulsed discharges the near-electrode voltage drops are determined extrapolating the dependence of the voltage across the discharge gap on length to its zero value at the current maximum, and the magnitude of the electric field is characterized by this dependence slope [8]. Other methods are possible to determine these values, for example using magnetic [10] or electric [11] probes.

For arcs with current of tens of kiloamperes for various gaseous mediums and electrode materials [12–14] the values of the near-electrode voltage drop do not exceed few tens of volts, and gradually increase with pressure increasing [8], mainly due to anode drop [11]. The electric field in the discharge channel also increase with pressure [8,9]. At the same time the total near-electrode drops exceed hundreds and thousands of volts at current rate of rise over 10^8 A/s and current amplitude over 50 kA in dense gas, especially for discharge in light gases [7–9,15].

The present paper gives data on average electric field strength and total near-electrode voltage drops for the discharge in hydrogen with current ~ 1.3 MA at initial gas pressure 5 MPa. These measurements amend measurements for other currents and initial pressures, previously published in [15–17].

The discharge in an axisymmetric cylindrical discharge chamber was initiated by the explosion of a copper wire with a diameter of 0.5 mm, stretched between hemispherical steel electrodes with diameter of 2 cm. The electrodes were positioned along the axis of chamber with diameter of 6 cm. Gap L between them was set from 1 to 2 cm with accuracy of 0.5 mm. The inner free volume of the chamber with electrode units was $\sim 250\,\mathrm{cm}^3$. Before the experiment the discharge volume pressure was reduced to 2.5 kPa and purged with hydrogen to ensure the required purity of the work gas. Voltage across the discharge load was measured using high-voltage resistance divider with transformer decoupling, which was connected to the load contacts. The current was measured using Rogowski coil. The measurement error did not exceed 5%. The detail description of the experiment unit with photo and design of the discharge chamber is given in [18] (electrode photo is provided in [19]). In each experiment we used six modules of capacitive energy storage [20] charged to 10 kV at total stored energy ~ 0.6 MJ. The experiments were performed under one series of test. The experiment parameters are provided in the Table.

Several current curves are given in Fig. 1. Corresponding to these experiments signals of voltage across the discharge gap are shown in Fig. 2. Graphs of signals *1* and *2* correspond to tests № 1 and 6 in Table with interelectrode gap 1 cm, of signals *3* — to test № 7 with gap 1.5 cm, of

Experiment parameters (L — interelectrode gap, P_0 — initial hydrogen pressure, $J_{\max}$ — maximum current, $V_{J\max}$ — voltage across discharge gap at current maximum)

Experiment number	L, cm	P_0, MPa	$J_{\max}$, MA	$V_{J\max}$, kV
1	1.0	5.0	1.25	2.8
2	1.0	5.0	1.3	2.95
3	1.0	5.0	1.2	3.2
4	1.0	5.0	1.35	2.85
5	1.0	5.4	1.35	2.9
6	1.0	5.2	1.4	3.2
7	1.5	6.0	1.2	2.75
8	1.6	7.0	1.15	3.2
9	2.0	6.0	1.2	3.7
10	2.0	7.0	1.2	3.45

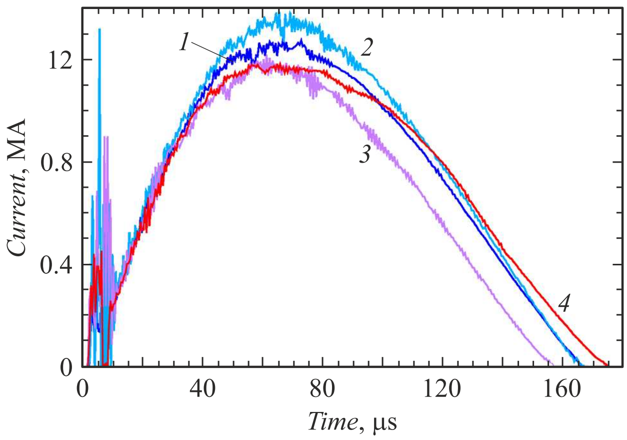

Figure 1. Discharge current at discharge in hydrogen at initial pressure ~ 5 MPa. Signals *1* and *2* correspond to interelectrode gap 1 cm, signal *3* — 1.5 cm, signal *4* — 2 cm.

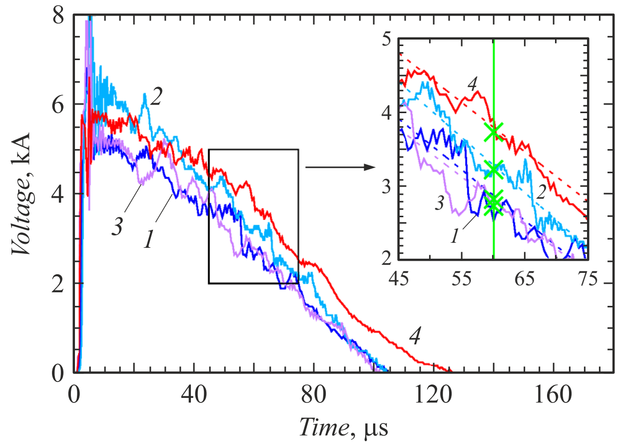

Figure 2. Voltage across the discharge gap during discharge in hydrogen at initial pressure ~ 5 MPa. Curves are designated as in Fig. 1.

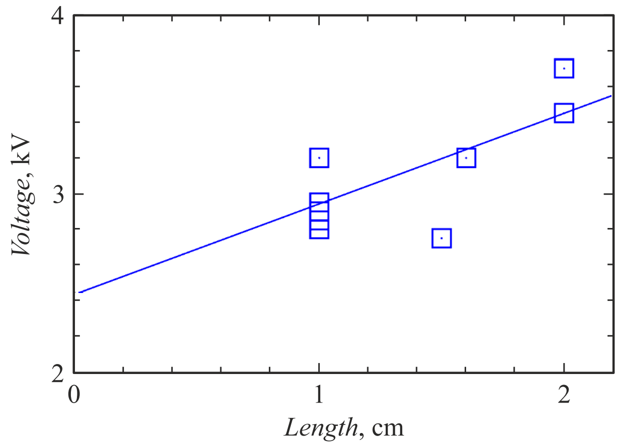

Figure 3. Voltage across the discharge gap at current maximum vs. discharge gap length for discharge in hydrogen at initial pressure ~ 5 MPa.

signals *4* — to test № 9 with gap 2 cm. Amplitude variations of discharge current and voltage at same initial conditions are determined by the feature of channel formation of megaampere discharge.

Voltage across the discharge gap $V_{J\max}$ at current maximum was determined by the linear approximation of the voltage signal by least squares method in a time interval 30 μs with center near current maximum ($t = 60\,\mu$s), as in insert in Fig. 2. The linear approximation procedure was necessary to average the voltage pulsations.

Voltage $V_{J\max}$ vs. discharge gap length is shown in Fig. 3. If we assume that at the current maximum the voltage across the discharge gap corresponds only to the active resistance, and homogeneous discharge channel is formed with the sizes of the regions, where near-electrode drops occur, that do not depend on the length of the interelectrode gap, then the cut-off value on the voltage axis 2.45 kV with the approximation of the discharge gap length to zero gives the value of the total near-electrode drops. Dependence slope 0.6 kV/cm reflects the average magnitude of field in the discharge channel.

So, the average electric field in the discharge channel and the average total near-electrode voltage drops were determined at the current maximum during the series of experiments with the discharge in hydrogen at initial pressure ~ 5 MPa and current amplitude ~ 1.3 MA at the current maximum using steel electrodes with the range of interelectrode gap of 1 to 2 cm. Total near-electrode voltage drops were ~ 2.45 kV, and electric field strength in the discharge channel was ~ 0.6 kV/cm. The indicated values are consistent with previously obtained values of the field and near-electrode drops for other values of current strength, rate of current increase and gas pressure [15–17].

Conflict of interest

The authors declare that they have no conflict of interest.

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