High-current channel characteristics in high-pressure gas

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High-current channel characteristics in high-pressure gas

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Abstract. Research results for discharge initiated by wire explosion in hydrogen at initial pressures up to 30 MPa and current amplitudes up to 1 MA are presented. Measurements of channel radius oscillation amplitude by magnetic probe diagnostics were made to calculate channel plasma parameters. The amplitude of channel radius oscillations was observed to decrease with growth of initial gas pressure and to increase with growth of current amplitude.

Pulsed gas discharge with current amplitude up to 0.1–1.0 MA, current rise rate \( \sim 10^{10} \) A/s, and initial pressure up to 30 MPa was investigated. Experiments were performed on a research facility which is described in detail in [1]. Discharge was initiated by copper wire explosion. The discharge chamber was designed with axisymmetric geometry. The energy source was a modular capacitive system [2]. Capacity of the energy storage was varied. It was 1.2, 2.4 or 4.8 mF. The charging voltage was varied from 1 kV to 15 kV. The energy input was up to 300 kJ.

Oscillations of the discharge channel and the influence of these oscillations on the plasma parameters in the channel were studied. The discharge has a very complex channel structure. The narrow axial high-temperature zone generates an X-ray flux. The surrounding gas decreases energy losses from the discharge channel contributing the channel plasma overheating. Acoustic oscillations in the discharge volume and channel radius oscillations produce X-ray radiation modulation by convergence of an acoustic compression wave on the discharge axis.

To estimate the amplitude of discharge channel radius oscillations, which cause the modulation of soft x-ray radiation (SXR), we used a specially developed magnetic probe [3,4] that can work at working gas pressures up to 30 MPa and currents up to 1000 kA. When estimating the probe signal, we took into account that the probe diameter \( d_{pr} \) = 0.3 cm is comparable with the diameter of the discharge channel. The value of the oscillation amplitude of the discharge channel radius was used to estimate the SXR intensity from its axial zone. A sketch of probe location relative to the channel is shown in figure 1.

In figure 2 oscillograms of a current and a voltage drop on the discharge gap are presented. Till the instant of current-carrying shell expansion up to the radius of probe position, the probe signal \( J_{pr} \) coincides with the full current value \( J \) in a circuit measured by the Rogovsky coil.

The discharge channel was considered to be cylindrically symmetric. To simplify the calculations, the coil probe was considered to be a square frame of area equal to that of the...
Figure 1. Scheme of magnetic probe location relative to the discharge channel: 1—discharge channel, 2—magnetic probe coil, \(r\)—channel radius, \(r_{pr}\)—distance from the discharge chamber axis to the probe coil.

Figure 2. Discharge in hydrogen at initial pressure of 5 MPa (4.8 mF with initial voltage of 12 kV): 1—full current \(J\) by Rogowski coil, 2—current \(J_{pr}\) by magnetic probe; the probe coil center was located 0.75 cm away from the discharge chamber axis, 3—voltage in the discharge gap.

real circular coil with a side length of 0.27 cm and installed at the same distance \(r_{pr}\) from the discharge axis to the edge of the frame as the real coil. Under the assumption of uniform distribution of current density, figure3 shows the channel radius \(r\) as a function of the ratio \(J_{pr}/J\). The computational error with such a modification does not exceed 2%.

Because the edge of the probe is located at a distance of 0.5 cm from the discharge channel
axis, the value of the current radius can only be measured if it exceeds 0.5 cm. Tables 1 and 2 show the discharge channel radius $r$, the amplitude of oscillations of this radius $\Delta r$, the rate of channel contraction $v_{\text{contr}}$ for different initial hydrogen pressures and discharge current amplitudes. It was supposed that except for a narrow central zone the current density in the channel is uniform.

The tables show that the discharge channel radius and the amplitude of its oscillations decrease with growth of initial pressure and grow with increase in discharge current amplitude. Unfortunately, the probe was damaged and it was impossible to record data at $P_0 \sim 5$ MPa and $J_{\text{max}} \sim 1.2$ MA, at which the SXR modulation was recorded earlier [5]. Therefore, the values of $r$ and $\Delta r$ for these parameters were obtained by extrapolation. For this case, the value $\Delta r = 0.20$ cm corresponds to channel radius contraction from $r_0 = 0.76$ cm to $r_1 = 0.56$ cm. With channel contraction from $r_0 = 0.76$ cm to $r_1 = 0.56$ cm, the magnetic force work is
expressed as $\Delta E = j_{Bav} \pi (r_0^2 - r_1^2) l (r_0 - r_1)$, where $B_{av}$ is the average value of magnetic induction at radius $r = 0.66$ cm, and $l = 1$ cm is the length of the arc channel. Then, $\Delta E = 1.02$ kJ.

For the earlier determined average concentration of metal ions of $\sim 10^{20}$ cm$^{-3}$ and the hot zone radius of $r = 0.1$ cm, assuming that at the time, when the compression wave converges to the center axis, the energy $\Delta E$ focuses in this zone and its temperature rises from the average value of several electronvolts up to 28–30 eV.

In some oscillograms, the time of the maximum SXR intensity does not coincide with the time of the maximum discharge channel contraction. Therefore, the maximum of radiation can occur at the expansion stage following the maximum contraction. In this case, the temperature of the central zone of the channel can increase several times because of the lower density than it was supposed in [5]. In [5], the radius was determined by the size of the melted zone on the electrodes and it was less then in the present work.

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