Comparison of megaampere channel temperature value measured by different methods at its maximal contraction in high density hydrogen

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Abstract. Comparison of discharge channel temperature in gaseous hydrogen of high density with current amplitude of ∼ 1 MA at initial gas pressure of 5–7 MPa, determined by two methods, was done under stage of its maximal contraction. In the first case determination of the temperature value of 72–73 eV was made by intensity of soft x-ray radiation from the channel for experiments with current amplitude of 1.1–1.5 MA. The estimation of the temperature on the basis of the data received by magnetic probe method and specified electric characteristics of the channel was of ∼ 140 eV for experiment with initial gas pressure of 5 MPa at current amplitude of 0.93 MA. The temperature determination by the last procedure has small accuracy caused by the limitation of the magnetic probe technique in determination of the channel contraction ratio and some assumptions for near-electrode voltage drops calculations by this way. Apparently, the channel temperature in stage of maximal contraction is of ∼ 100 eV.

Achievable extremal plasma characteristics in self-constricted high current channel stimulate an intense interest to high power pulsed systems [1]. In this paper we discuss plasma parameters of megaampere channel in high density hydrogen. In the discharge one or several channel radial contractions during period of a current were observed [2, 3]. The first contraction can be associated with radiative mechanism contraction [4].

The discharge plasma temperature for iron vapor channel surrounded by gaseous hydrogen of high density with current amplitude of 1.1–1.5 MA at current rise rate of 5 × 10¹⁰ A/s at the moment of its first most deep contraction was determined in [4]. The calculation was made on the basis of analysis of soft x-ray radiation (SXR) intensity from the discharge channel.

Previously, plasma parameters for the second contraction of the channel were estimated from data received with the help of magnetic probe diagnostics [5]. It was calculated a channel radius and electric field strength in the channel. And from this values the channel plasma parameters were received.

In this work, the temperature in the first channel contraction was estimated by procedure described in [6] based on the magnetic probe data.

The description of the experimental setup and discharge chamber design are presented in [4, 7]. Original technique of SXR registration was described in [4, 8]. The technique of magnetic probes measurements can be found in [6, 9].
In figure 1, the dependence of the discharge channel radius upon a time for various current amplitudes is shown. These data have been received as a result of processing of magnetic probes oscillograms as [6]. The probe design enables to track changes of channel radius value not less than of 0.5 cm. Nevertheless, we can observe start of channel contractions at 20-th microsecond for discharge with current amplitude of 590 kA and the beginning of two channel contractions with current amplitude of 930 kA.

For the current amplitude of 0.93 MA, the detailed analysis of characteristics of the second contraction made in work [6] shows that channel second contraction velocity to be close to speed of subsequent expansion. But the parameters of the first contraction are the object-matter of the greatest interest. From the magnetic probe signal, presented in figure 2 together with a current and a voltage across discharge gap for the experiment, it also follows that the first contraction begins approximately at 20-th microsecond. The dependence of the channel radius in time according to a magnetic probe data for this experiment is presented on a corresponding curve in figure 1.

In figure 3, some data from photometric sections of the discharge channel photostreak and the extrapolated curve of channel expansion after the first contraction are presented. Inclined dash blue line corresponds to the channel radius for various instants in time according extrapolation of a magnetic probe signal under the channel expansion after the first contraction. If we extrapolate the velocity of expansion near the 20-th microsecond, which corresponds to the first contraction, we shall receive the channel radius of 0.1–0.2 cm. In this time interval the radius, determined by level of photostreak brightness, is close to one determined by extrapolation of a magnetic probe signal. Its average value is of ≈ 0.15 cm. Besides, this value is close to radius of swollen zone of 0.2 cm in diameter, observed on a steel electrode surface after experiments with current of ∼ 1 MA [3].

Values of near-electrode drops, the inductance of a discharge contour and the current rise rate had been calculated for determination of the channel parameters at the first contraction moment. The value of the electric field strength in the channel was about 750 V/cm at channel
Figure 2. Oscillograms of signals for discharge in hydrogen with current amplitude 0.93 MA at initial pressure of 5 MPa: 1—total current by Rogowski coil; 2—current by magnetic probe; 3—voltage across the discharge gap; interelectrode gap of 2 cm.

Figure 3. The channel radius for experiment illustrated by figure 2: 1—measured by magnetic probe; 2, 3 and 4—by photostreak at relative brightness of 0.55, 0.6 and 0.65, correspondingly; inclined blue dash line mark the expansion channel after the first contraction; the horizontal dash line shows magnetic probe position $r_{pr} = 0.5$ cm.

radius of 0.15 cm and current of 400 kA at the moment of maximal contraction. The current density was $\approx 5.7 \times 10^6$ A/cm that corresponds to conductivity $\approx 6.8 \times 10^{15}$ cm$^{-1}$. Plasma pressure at the moment of contraction is approximately balanced against the magnetic forces, which was determined from values of a current and channel radius and was of $\approx 1140$ MPa.
According to work [10], such values of conductivity and pressure correspond to ion concentration $n_i \approx 2.5 \times 10^{18} \text{ cm}^{-3}$ and plasma temperature of $T \approx 140 \text{ eV}$ in the channel.

Determined earlier plasma temperature value of 72–73 eV [4] corresponds to channel radius of 0.3 cm. If one have taken into account an measurement error in the channel radius value, caused firstly by limitation of magnetic probe technique till to $r = 0.5$ cm and secondly some assumptions for near-electrode drops calculations, then apparently, plasma temperature at the moment of maximal channel contraction is of $\sim 100$ eV.

A number of the facts testifies the channel radius in stage of its maximal contraction can appear less aforementioned value and it will correspond to higher temperature. Above mentioned estimations are based on the assumption, that total discharge current flows within the limits of the aforesaid values of channel radius. This assumption requires additional verification.

Thus, the discharge channel temperature in high density hydrogen with current amplitude of $\sim 1$ MA at initial gas pressure of 5–7 MPa under stage of its maximal contraction has been determined by two methods. For refinement of the values are required further development of the diagnostics.

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