Plasma Acceleration in an Inverse Z-Pinch Geometry

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Abstract – Experimental investigations on electromagnetic acceleration of a hydrogen plasma have been performed in a reverse Z-pinch geometry. The load design was fixed which ensured an efficient energy transfer from the current generator to the radially diverging plasma. Biased ion collectors and the time-of-flight method were used to measure the energy spectrum of protons.

1. Introduction

Intense plasma flows can be used to study strong interactions of the light nuclei at low energies [1,2]. In this work, investigations on electromagnetic acceleration of hydrogen plasma to velocity of 10^8 cm/s have been performed in a reverse Z-pinch geometry [3]. The purpose of these experiments was 1) to fix the load design, which ensured an efficient energy transfer from the current generator to the radially diverging plasma and 2) to measure the energy spectrum of protons.

2. Experimental Apparatus

The experiments were performed on the MIG generator [4]. The generator produced a fast rising current (60 ns, 10–90%) with peak of 1.6 MA. The schematic of the load region is shown in Fig. 1. An annular gas puff is produced with the nozzle. The medium radius of the nozzle exit is ~15 mm, and the radius of the central rod is 6 mm. After the gas breakdown the current flows through the plasma shell and returns along the central rod. A current hogging structure (CHS) of squirrel cage type was installed at the radius of 45 mm. When the plasma shell passes the CHS, the current is switched from the plasma to the CHS.

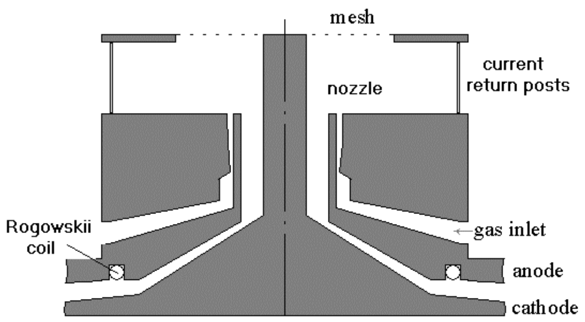

Fig. 1. Schematic of the load region

The load current and the current sheath dynamics were measured with a Rogowski coil and magnetic probes. The results of the probe measurements were compared with 0-dimensional model calculations of the plasma shell dynamics. The total ion energy of the diverging plasma flow was measured using a copper-foil resistive bolometer. Biased ion collectors and the time-of-flight method were used to measure the energy spectrum of protons [5].

3. Experimental Results and Discussion

The ion collector measurements showed that the photocurrent due to the plasma ultraviolet radiation is considerable up to t ~ 350 ns after the start of the current pulse. To separate photo- and ion currents it necessitated to move away the ion collectors for distance more than 40 cm. Fig. 2 presents the waveforms of 3 ion collectors located at the radii of 30 cm (D2), 129 cm (D3) and 157 cm (D1) for a typical shot. It is seen that as the distance increases from the photocurrent are separated at first a peak resulting from the main group of ions (D2), and then – a peak resulting from the group of fast ions. The time-of-flight method was used to reconstruct the energy spectrum of protons

$$\frac{dN}{d\varepsilon} \propto \frac{1}{1+\gamma(\varepsilon)} I(\varepsilon)\varepsilon^{-3/2}, \quad (1)$$

where $I(\varepsilon)$ is the collector current at time t when the ions with energy ε reach the collector

$$\varepsilon = \frac{m_p v^2}{2} = \frac{m_p}{2}\frac{l^2}{t^2}. \quad (2)$$

Here l is the distance from the CHS to the collector, m_p is the proton mass, $\gamma(\varepsilon)$ is the secondary ion-electron emission coefficient. In this work an aluminium collector and $\gamma(\varepsilon)$ measured in [6] were used. For the proton energies 4–30 keV $\gamma(\varepsilon)$ can be approximated by extrapolation

$$\gamma = 0.24\sqrt{\varepsilon(keV)} - 0.07 \quad (3)$$

within the deviation less than 2.5%. The energy spectrum deduced from the D1 collector's signal (Fig. 2) is shown in Fig. 3. The main ion group has rather a wide energy spectrum (3–10 keV). Apparently, the wide spectrum is the result of instabilities. A group of fast ions was observed together with the main group of ions. The fast ions have the energies at least up to 200 keV. Unfortunately, it is impossible to evaluate the comparative number of the fast ions since the fast ion current superimposes on the photocurrent.

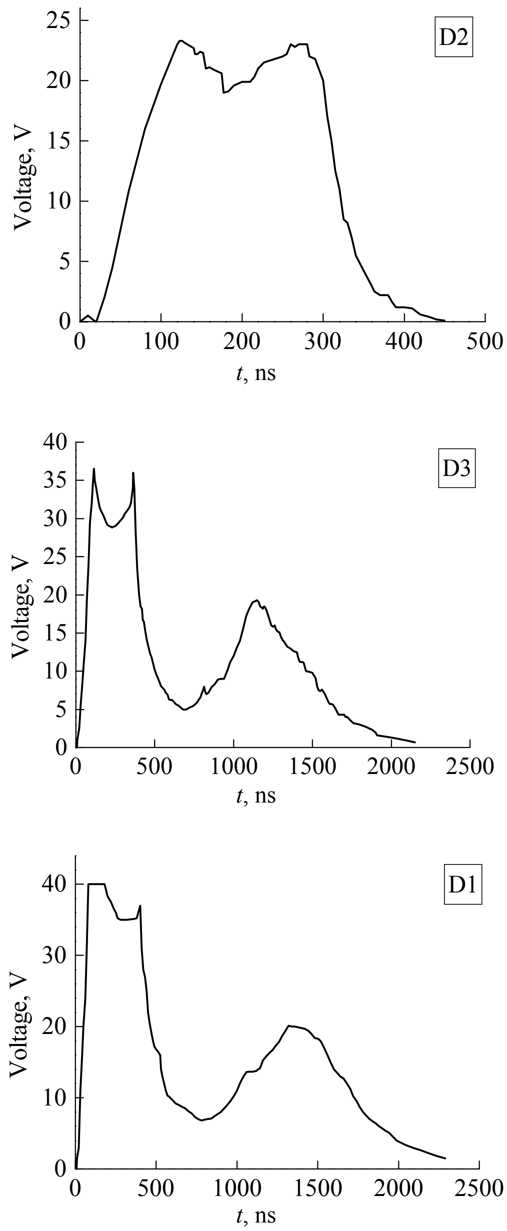

Fig. 2. Waveforms of 3 collectors located at the radii of 30 cm (D2), 129 cm (D3), and 157 cm (D1).

However, the presence of the fast ions with the velocities of $5 \cdot 10^8$ cm/s is doubtless since the proper collector current peak shifts in proportion to the source-collector distance (see Fig. 2). It seems reasonable to think that the fast ions are accelerated by the double-layer effect on the plasma-vacuum boundary [7].

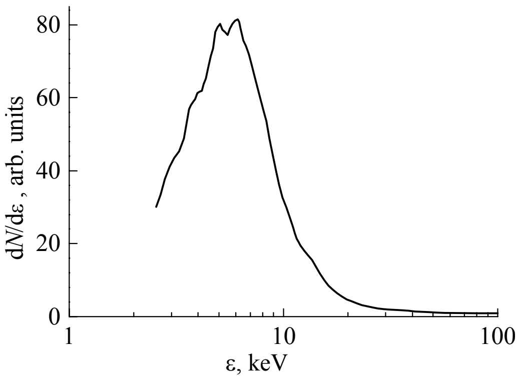

Fig. 3. Energy spectrum deduced from the D1 collector's signal (Fig. 2)

The total ion energy measurements realized with a resistive bolometer enable to normalize the ion energy spectrum.

4. Conclusion

A reverse Z-pinch geometry was used to study electromagnetic acceleration of a hydrogen plasma. It was shown that the main ion group has rather a wide energy spectrum (3–10 keV). The group of fast ions was observed together with the main group of ions. The fast ions have the energies at least up to 200 keV.

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