Images of a Plasma Focus Current Sheath With a Continuous Cylindrical Outer Electrode

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***Abstract*—Images of the roll-off, radial compression, final pinch, and after pinch stages of the current sheath (CS) of the dense plasma focus PACO (plasma autoconfinado) whose outer electrode is a brass cylindrical shell are shown. The different stages of the current sheath were measured with an image converter camera, 5-ns exposure time. The images of the CS evolution look similar to those previously obtained with an array of bars as cathode, as well as neutron yields and working pressures.**

***Index Terms*—Current sheath, neutrons, plasma focus.**

DENSE plasma focus devices (DPF) [1] produce transient dense plasmas when the energy of a high-voltage charged capacitor bank is delivered on a low-pressure atmosphere (commonly of deuterium) between two cylindrical coaxial electrodes. A current sheath (CS) driven by Lorentz force, runs along the gap between the electrodes. When the CS reaches the open extreme of the electrodes, the fully ionized plasma collapses on its axis (radial compression) forming a small (10 mm^3), hot (1–3 keV), and dense (10^{20} cm^{-3}) plasma column, 100 ns of life-time. At this instant, X-rays, neutrons, fast axial ions, and electrons bursts are emitted. In most DPF experiments, the outer electrode is formed by brass rods arranged in a circle. It is commonly thought that in this way the CS is formed smoothly and the DPF is more efficient. In addition, the use of a solid cathode is necessary for DPF experiments that require, for example, gas-puff operation. The purpose of this paper is to visualize possible differences of the CS evolution when the outer electrode of a DPF is a solid tube in comparison with one built with an array of bars. This paper was carried out in a Mather-type DPF device called PACO (plasma autoconfinado) [2] whose main constructive features are: 1) inner electrode (anode) of 40-mm outer diameter; 2) outer electrode (solid tube) of 100-mm inner diameter; and 3) length of both electrodes: 50 mm, a Pyrex coaxial insulator 15-mm long and 50 mm of outer diameter. The source of energy is a 4-μF capacitor bank charged at 32 kV. The fixed inductance of the circuit, that mainly comprises the capacitor bank, transmission line and insulator sleeve, is 56 nH [3]. The filling gas was deuterium. Several images of the plasma evolution in its radial compression stage were obtained. They are taken with a Cordin ICC Camera, 5-ns exposure time. Images of different discharge stages were acquired for different working conditions. Fig. 1(a) corresponds to the beginning of the radial compression stage. The deuterium filling pressure (p) was 1 mbar (the lowest of the present experiment) and no neutrons were detected. The image was taken 150 ns before the time of maximum compression (MCT). Fig. 1(b) shows the CS [for a different shot than Fig. 1(a)] in a more advanced stage than Fig. 1(a). The image was taken 200 ns before the MCT. In this shot, p was 2.4 mbar; no neutron yield (Y) has been measured. The CS is here slightly filamentary. In the PACO DPF, the pressure range for an efficient behavior respect to Y ($\sim 2\times 10^8$ neutrons per pulse, in average) is between 1 and 2 mbar, in both cathode structures. When the pressure is high, just in this case, filaments are present in the CS structure and consequently a slow evolution and a poor neutron yield are produced. Fig. 1(c) corresponds to a spontaneous shot—not triggered—when the capacitor bank was charged at 26 kV, $p = 1$ mbar; no neutrons were detected. This image was taken 100 ns before the MCT is reached. Here even if p is not high, the discharge voltage is low; then, the energy transferred to the CS is small, and therefore most of the current is concentrated across filaments, diminishing the efficiency of the device. Fig. 1(d) shows the CS 80 ns before the MCT in a discharge at 2 mbar. It can be seen that there is no filamentary structure. The neutron yield in this shot was $Y = 1.7 \times 10^8$. Fig. 1(e) corresponds to $p = 1.7$ mbar and was taken 100 ns before the MCT. In this shot, the device produced a neutron yield of 5.5×10^7. The CS is well-formed without filaments. Fig. 1(f) was taken 20 ns before the MCT at 2.4 mbar and no Y was measured. Fig. 1(g) was taken just at the time of the MCT, the neutron yield was $Y = 1.2 \times 10^8$ for $p = 1.63$ mbar. It can be noted a well-formed, smooth and without filamentary structure CS. Fig. 1(h) was taken 200 ns after the MCT at low pressure $p = 1$ mbar; here no neutron yield above the background was measured. In this stage the domed CS is largely evolved. The figure shows a small bubble at the top of the CS; possibly this bubble has a higher velocity than the CS and could be a shock wave generated by the plasma jet composed by the very energetic material expelled from the focus zone.

We conclude, comparing the results of this paper with previous ones [4], that no significant differences are observed in the CS shape and dynamics, either operating PACO with

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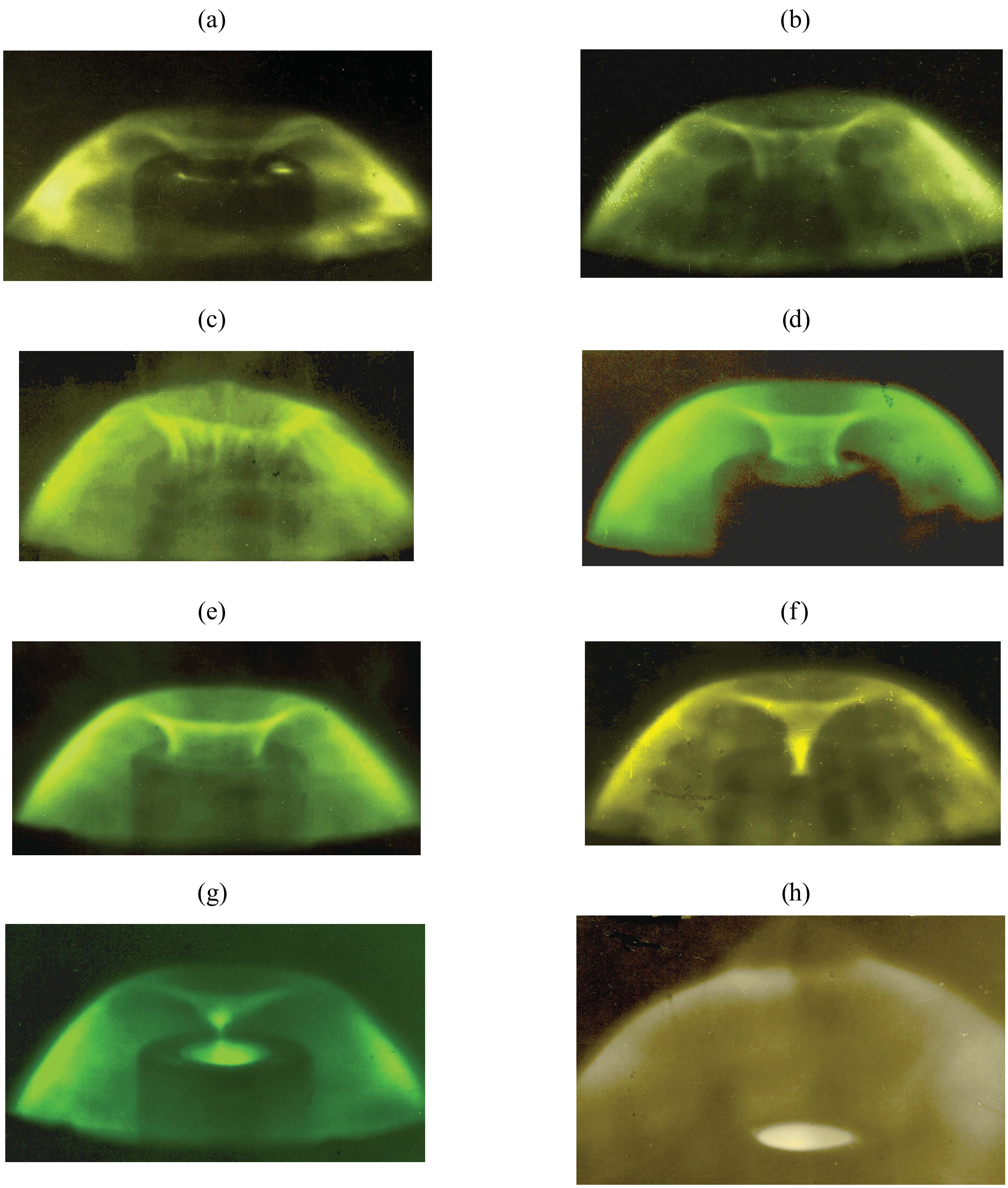

Fig. 1. Images of the PACO plasma focus CSs in different stages of evolution, at different deuterium filling pressures. Charging voltage $V_0 = 32$ kV, except (c), where $V_0 = 26$ kV. Δt is the instant of the picture minus the MCT instant. Exposure time: 5 ns. (a) 1 mbar $\Delta t = -150$ ns. (b) 2.4 mbar $\Delta t = -200$ ns. (c) 1 mbar $\Delta t = -100$ ns. (d) 2 mbar $\Delta t = -80$ ns. (e) 1.7 mbar $\Delta t = -100$ ns. (f) 2.4 mbar $\Delta t = -20$ ns. (g) 1.63 mbar $\Delta t = 0$ ns. (h) 1 mbar $\Delta t = 200$ ns.

a solid tube cathode (essential for gas-puff operation) or with a ring of bars (very useful to make some important plasma diagnostics). In addition, the optimum deuterium pressure range and the neutron yield are the same for both cathode structures.

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