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Energy and matter flows in a plasma focus discharge

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Abstract. The Plasma Focus is a type of z-pinch that is widely used for both basic research and applied tasks, e.g., as materials modification or research on intense plasma flows. Although the basic mechanisms of z-pinch compression are well-known, many of the processes that occur in the plasma focus have received less attention. This article is devoted to the study of plasma jets and some of its consequences in plasma focus discharges.

1. Introduction

Compared to similar types of pulsed discharges, the Plasma Focus (PF) possesses a number of advantages for the generation of neutrons and x-rays over other pulsed discharges, including the relative simplicity in the manufacture of the discharge chamber and the high efficiency of neutron and X-ray generation. Furthermore, plasma focus can generate a jet of plasma jet moving at a speed up to 10^7 cm/s. The latter feature can be used for laboratory simulation of astrophysical jets - narrow streams of plasma, up to several megaparsecs [1].

Initially, the plasma focus was a very promising line of research in nuclear fusion. Its neutron yield Y increased very rapidly with peak current I, as $Y \sim I^4$; the tentative conclusion was that the the neutron yield, and therefore the thermonuclear energy produced, is the square of the input energy. However, it soon became clear that the neutron yield saturates as the energy input approaches about 1 MJ [2].

Despite its long history, the processes underlying plasma focus formation are rather poorly studied. This is in part due to the short time scale of the relevant processes – at most a few microseconds - which are difficult to diagnose. As a result, optimization of the plasma focus for the different applications of interest still requires much further study.

The following research describes attempts to investigate the dynamics of deuterium plasma and energy flows in the plasma focus with numerical simulation, in the two-dimensional single-fluid MHD approximation.

2. Simulation results

The simulation shows two types of plasma flows: a jet extending along the axis of the chamber after the formation of the plasma focus; and the flow of rarefied plasma along the anode, which is observed during the whole discharge period.

Figure 1 shows the plasma parameters 1.44 microseconds after the start of discharge or 0.31 microseconds after the formation of the plasma focus proper. The plasma density is shown in the top of the upper plot (figure 1a). The axis of the machine contains a narrow plasma filament that is compressed by a magnetic field shown in the bottom part of the upper plot (figure 1b) This plasma

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feature is moving at a speed of about 10^7 cm/s (in the top of the lower plot (figure 1c)). Apparently, this speed is maintained by the pressure gradient of the magnetic field, seen in the bottom of the lower plot (figure 1b). The jet in this simulation is similar to the axial jet that is observed experimentally in a number of installations, such as the PF-4 ("Tulip", LPI RAS) [3].

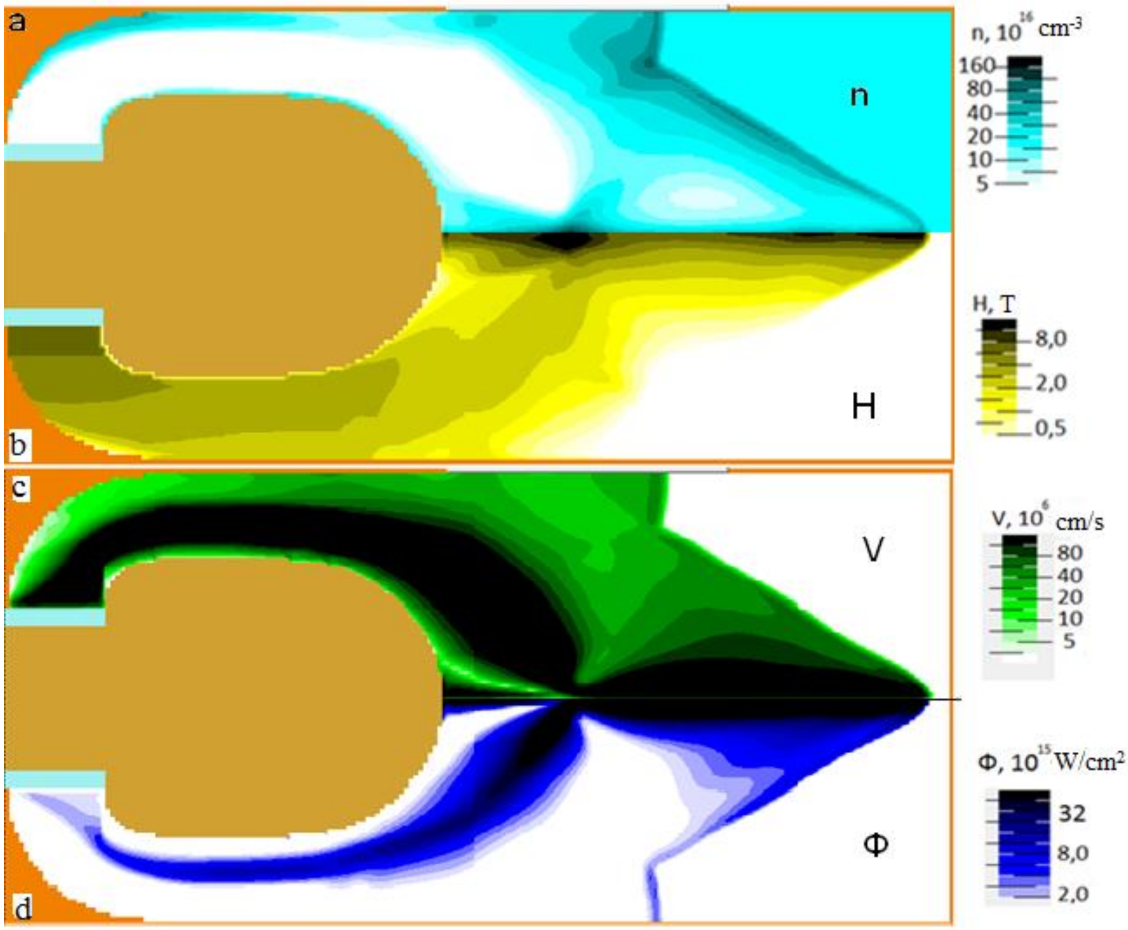

Figure 1. Distribution of plasma density (a), magnetic field strength (b), plasma velocity modulus (c), total energy flow density (d); t=1,44 microseconds.

In addition to the plasma jet on axis, a high velocity but tenuous plasma is observed to flow along the anode, toward the insulator to the left in the figure. The flow rate reaches 10^8 cm/s (figure 2), which exceeds the Alfvén velocity that is estimated to be up to $5 \cdot 10^7$ cm/s in this region. Such high velocities cannot be explained by the acceleration of the plasma by a magnetic piston, but can occur with the flow in a narrow channel. In [4] the conditions are described, under which the rate of flow of magnetized plasma in a narrow channel can exceed the speed of magnetosonic wave.

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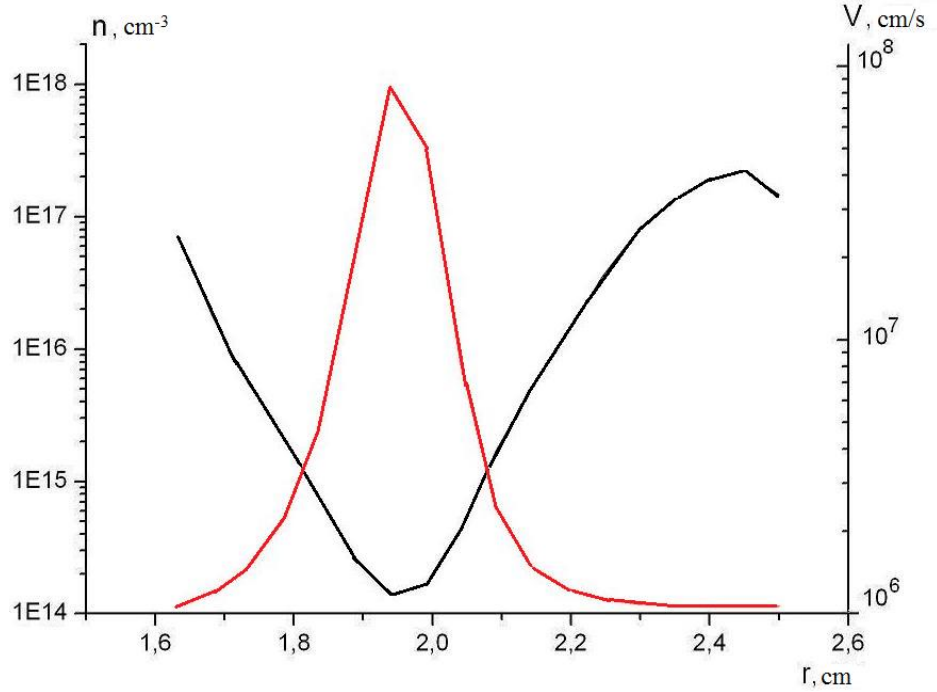

Figure 2. Density (black graph) and velocity (red graph) distribution in cross section z=2,5cm; at t=1.44 microseconds.

Unfortunately, the diagnosis of the pre-anode flow is difficult - low plasma density does not allow the use of optical methods, and the movement of dense current-carrying plasma sheath (CPS) at the initial stage of the discharge makes it difficult to use probes. However, this flow has a significant impact on the dynamics of the discharge, since it transports energy, both magnetic and kinetic, from the insulator to the current-carrying plasma sheath. A similar flow is also observed before the pinch formation. Thus, in figure 1d an uneven energy flow can be seen propagating along the anode. The energy flow is concentrated in a narrow channel, which affects the shape of the current-carrying plasma sheath before the pinch.

The reason for the flow collimation can be understood from (figure 2) - flow rate is limited by the inertia of plasma, and consequently, it reaches maximum in the minimum density area. This leads to a more rapid plasma sweeping and to further density reduction so that finally a narrow channel of low-density plasma is formed, in which the flow velocity reaches maximum.

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