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Laboratory simulation of astrophysical jets with Plasma Focus facility

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Abstract

A new series of experiments has been launched on the Plasma Focus type facility PF-3 in NRC Kurchatov Institute. The main goal was to study the mechanisms of the jet stabilization, due to which it can propagate at distances much greater than their transverse dimensions. The experiments with stationary gas filling revealed regimes in which a collimated highly magnetized plasma jet was formed, the head of which was no wider than several centimeters at jet propagation distances of up to 100 cm.

Introduction

Laboratory simulation of astrophysical processes is one the intensively developed areas of plasma physics [1]. Considerable progress in simulating the astrophysical processes has been achieved in recent decades due to new facilities with high energy density, which were developed within the framework of the program of inertial controlled fusion, e.g., the modern Z-pinch systems and high-power lasers. In particular, interesting results were obtained on a high-power laser in the LULI laboratory (Ecole Polytechnic), where it was shown that the superimposition of an external poloidal magnetic field can provide effective collimation of the plasma flow [2]. There are well-known studies on the Z-pinch installation MAGPIE (Imperial College London, Great Britain), which simulated some possible mechanisms of jet formation, the interaction of a supersonic, radiatively cooled plasma jet with an ambient medium, etc. [3]. In this poster, we substantiate the applicability of Plasma Focus (PF) facilities for such modeling and already obtained results [4]. We show that installations of this type have a number of preferences, which allow us to arrange the original experiments aimed at modeling the plasma outflows from compact astrophysical objects.

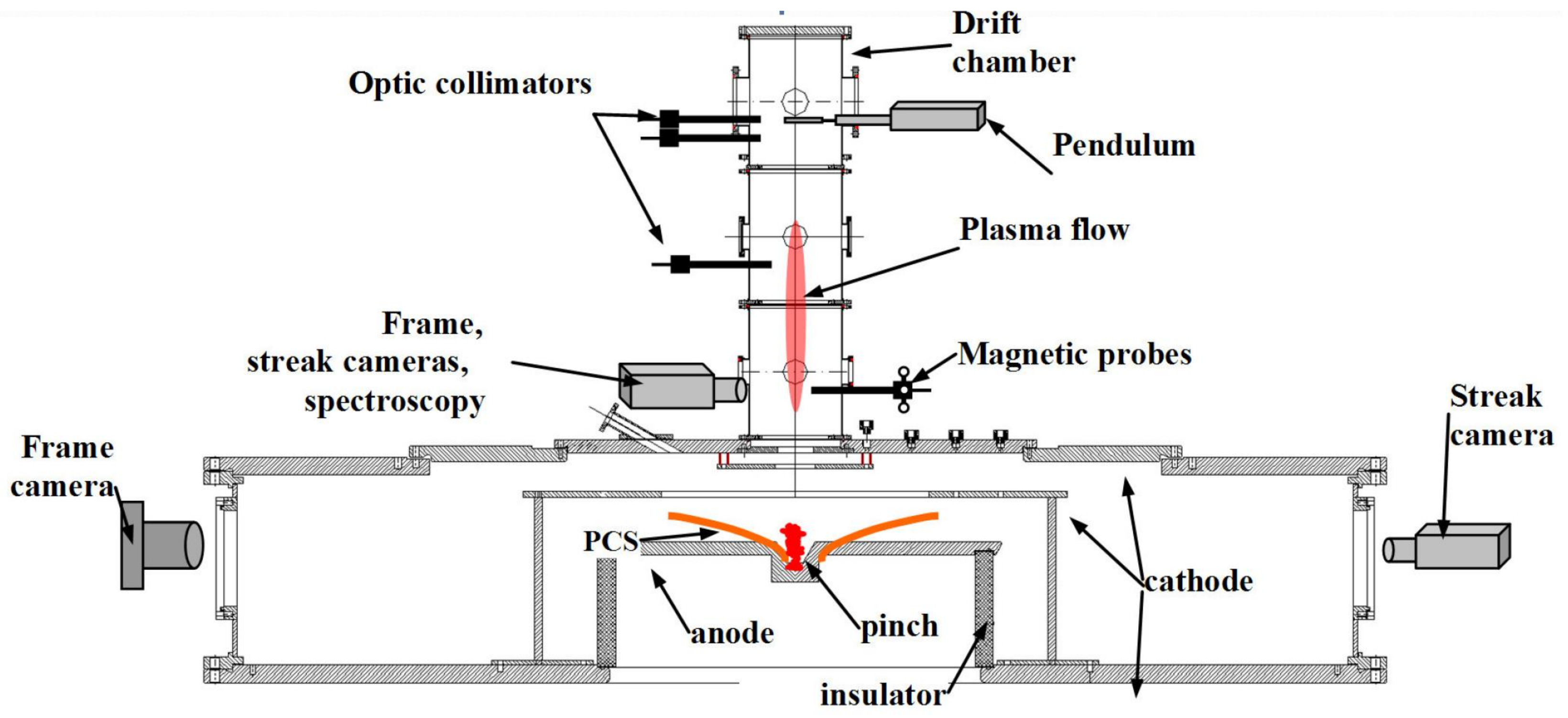

Fig.1 Scheme of the PF_3 experiment

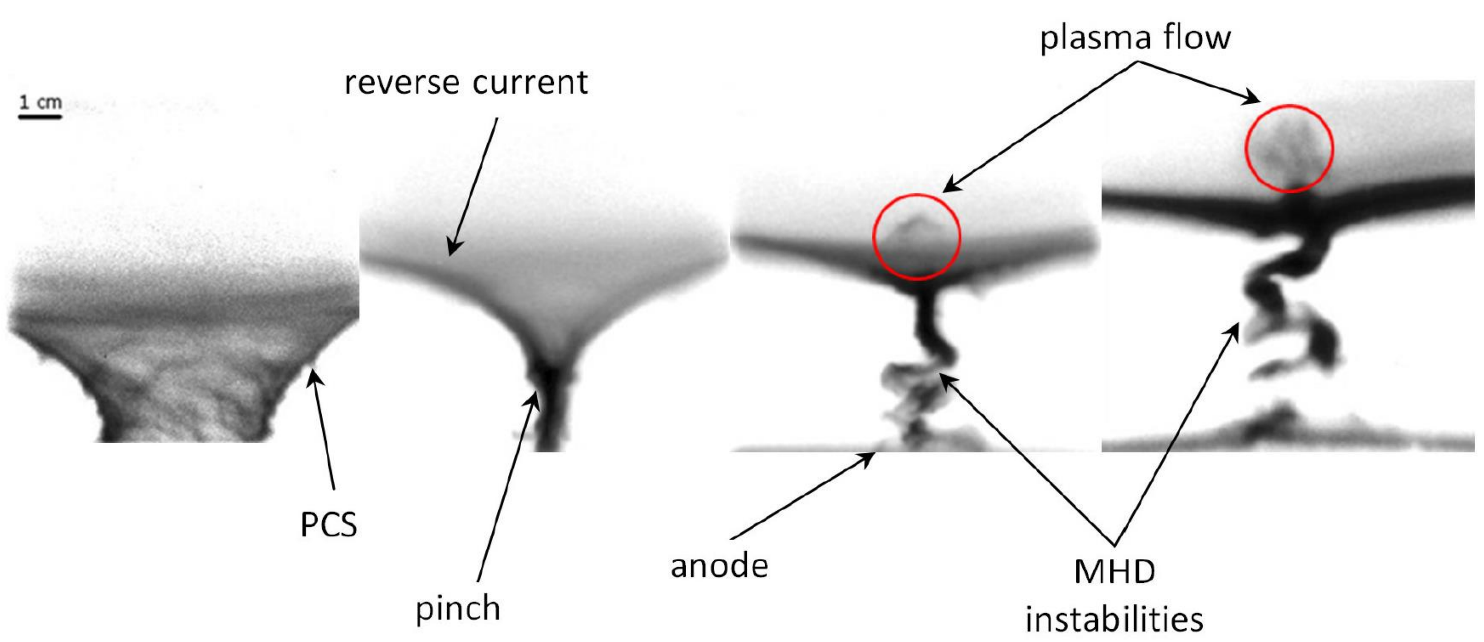

Fig. 2. Plasma-flow formation (from left to right): the stage of convergence of the plasma-current sheath to the axis, the pinch stage and the stages of the plasma flow formation. The pictures were obtained with optical frame cameras, exposure time is 12 ns [4]

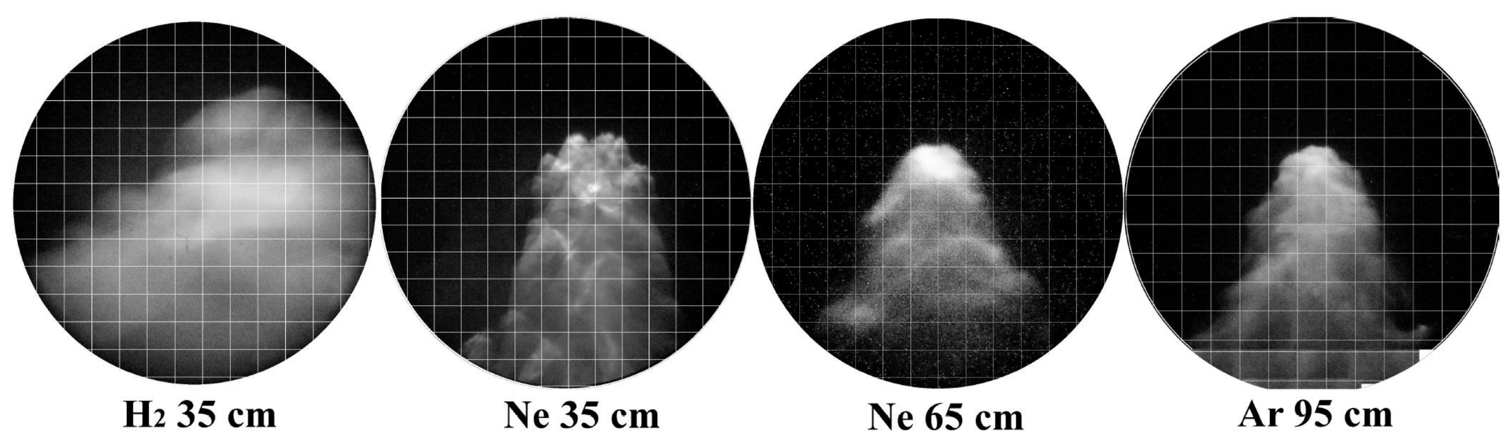

Fig. 3. Frame camera pictures of plasma flow front at different distances from the anode plane and at operation with different gases. Scale is 1 cm [4]

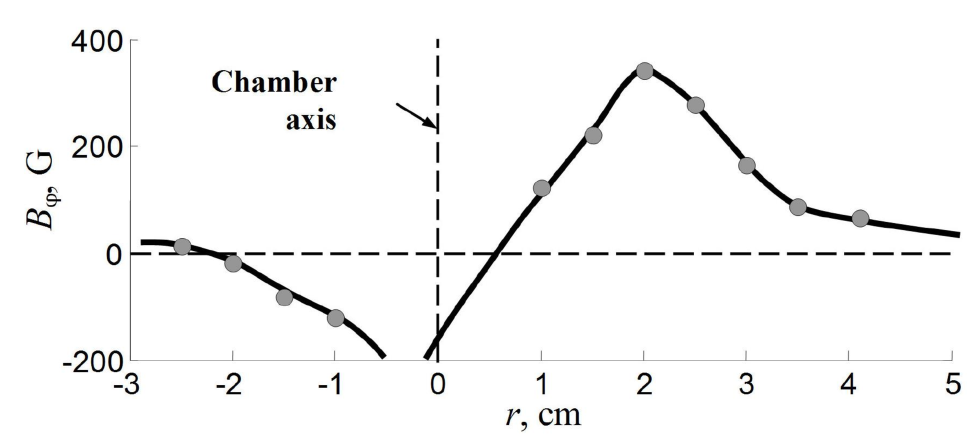

Fig. 4. Radial distribution of the azimuthal magnetic field in the plasma jet on PF-3 facility at a height of z = 35 cm from the anode plane [4, 5].

Plasma Focus Experiments

Plasma Focus (PF) is a source of intense plasma flows, which is widely used in various fields of science and technology. Here we present results of experiments devoted to the astrophysical jets simulation on the PF-3 facility in NRC Kurchatov Institute (see Fig. 1). Plasma flow is formed in the stage of pinching, which lasts several hundred ns, in the pinch area with a diameter ~1 cm and a length of (3-5) cm. After the preliminary pump-out, the chamber is filled with working gas (hydrogen, deuterium, helium, neon, argon) under a pressure of a few Torr. When the spark gap switches on, a high voltage is applied between the anode and the cathode, which leads to a break-down of the working gas. The resulting plasma output current-carrying sheath (PCS) moves under the action of the Amp`ere force. The stage of the flow formation is presented on Fig.2.

Advantages

The PF scheme has a number of advantages. First of all, there is the possibility to investigate the dynamics of the flow propagation in the ambient plasma at sufficiently large distances, more than two orders of magnitude greater than its initial transverse size. Second, the presence of the ambient plasma is an important factor that allows us simulating the interaction of the flow with the external environment. Finally, sufficiently large spatial dimensions of the flow (in comparison with the laser and Z-pinches experiment) made it possible to use magnetic probe techniques and allowed to investigate the special distribution of magnetic field and its time evolution [5]. The estimations of key dimensionless parameters (see Table 1) showed that the PF-type facilities really can be used to simulate the jets from YSO.

Table 1. Key dimensionless parameters

	YSO		PF-3 (35 cm above the anode)
Peclet	10^{11}	> 1, convective heat transfer	$> 10^7$
Reynolds	10^{13}	$\gg 1$, the viscosity is important	$10^4 - 10^5$
Magnetic Reynolds	10^{15}	> 1, magnetic field is frozen	~ 100
Mach ($V_{\rm jet}/V_{\rm cs}$)	$10 - 50$	> 1, the jet is supersonic	> 10 (for Ne and Ar)
β ($P_{\rm pl}/P_{\rm magn}$)	$\gg 1$ near source $\ll 1$ at 10 AU		~ 0.35 (for Ne and Ar)
density contrast ($n_{\rm jet}/n_{\rm amb}$)	> 1		$1 - 10$

Results

It was found that the compact plasma blobs move along the axis with the velocity $V \geq 10^7$ cm/s. This velocity is close to the velocity of plasma outflows from young stars. One of the main obtained results is finding the regimes with the formation of plasma object, preserving its compact size when spread over large distances. The transverse dimension of the flow head does not exceed a few cm at propagation distances more than 100 cm (see Fig. 3). This implies that there are mechanisms for stabilizing/confining the plasma flow. The flow density determined by the Stark broadening at the distance of 35 cm from the anode was $(2-4)\times10^{17}$ cm^{-3}, the electron plasma temperature of the jet was (2–8) eV. The concentration of the ambient plasma was $(2-4)\times10^{16}$ cm^{-3} [6,7]. Finally, with the help of magnetic probes, the distribution of magnetic fields has been studied. Several modifications of magnetic probes are made for measurements: N-channel magnetic probe for measuring the radial distribution of the azimuthal component of the magnetic field and 4-channel ($Bz, Br, B\phi$, optic) probe for measuring of three components of the magnetic field and optical radiation of plasma (with photomultiplier). It was shown that the plasma flow moves with the frozen magnetic field of the order (1–10) kG. Obtained radial distribution can be explained by the axial current in (1–10) kA flowing in the zone near the axis with the radius of (1–1.5) cm.

Acknowledgements

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