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Observation of the Evolution of Supersonic Plasma Jet Launched by a Coaxial Gun

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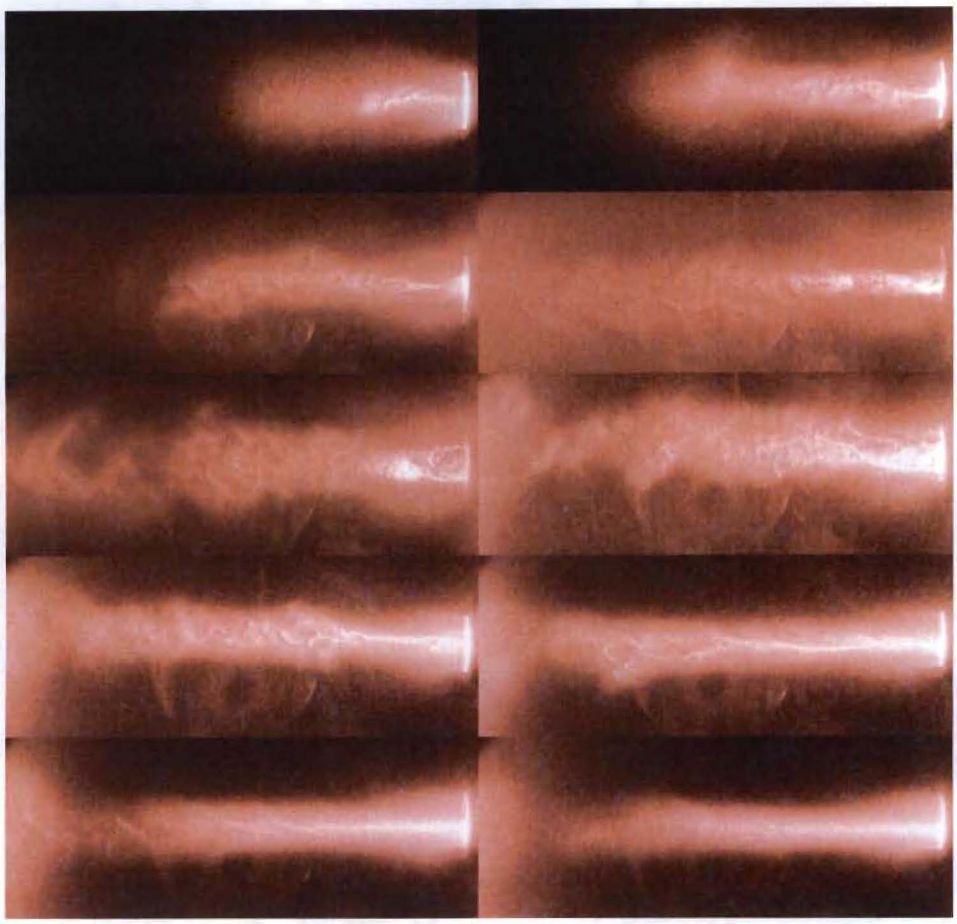

Figure 1. Evolution of a plasma jet launched in vacuum: shown from top to bottom and left to right are the images (in false color) of the plasma jet taken at 45, 55, 65, 70, 75, 80, 90, 100, 125 and 130 μs, respectively, after firing the coaxial gun. The exposure time was 1 μs for the top 4 pictures and 500 ns for the rest of them. Kinking (1st image) and filamentation of the plasma column (images 2 to7) are smoothed-out until the flow becomes almost laminar, as shown in the last 2 images. The maximum length of the plasma column is ≈ 1.25 m.

***Abstract* – Images of plasma jets launched in vacuum from a coaxial plasma accelerator are presented. The turbulent plasma jet which includes a multitude of filaments arbitrarily oriented along the propagation direction self-organizes into a more laminar flow later in time. The captured pictures of the flow have exposures of 1 microsecond or less and were acquired at 45 to 130 microseconds after firing the coaxial gun.**

Developed initially as an efficient and compact tool for helping the fusion community with obtaining high-density plasmas [1], coaxial plasma guns with cylindrical or planar geometry have quickly become useful tools for investigating fundamental plasma physics properties such as magnetohydrodinamic (MHD) instabilities [2, 3], flux rope merging and magnetic reconnection [4]. Moreover, they also

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found applications in accelerating microparticles to hypervelocities [5-7], fuelling tokamaks [8] or injecting high density plasma in magnetized target fusion experiments [9].

Plasma jets produced in a coaxial gun mainly built for dust acceleration to several km/s are presented. The gun design is relatively simple and is based on two coaxial electrodes, a center rod and an outer cylindrical shell, biased from a high voltage source [10]. A controlled amount of gas puffed between the electrodes just before an ignitron enters the conduction regime and closes the electrical circuit of the electrodes is highly ionized producing a peak current in the hundreds of kA. The current flowing through the center rod creates an azimuthally magnetic field **B**, given by Ampere's law. The radial current density **J** produced by the flow of ionized particles between the electrodes exerts an axial **J×B** force which accelerates the plasma to speeds in the tens of Km/s range. In the present experiment hydrogen gas has been injected by a small electromagnetic valve with 4 ms opening time. The applied voltage was 8 kV from a 1 mF capacitor bank, while the current peaked at 200 kA for shots lasting between 350 and 400μs. The relatively small coaxial gun (about 0.75 m in length) was connected sideway at the middle of a large vacuum tank with 1.5 m diameter and 5 m length trough a 0.85 m long bellow. In the present experiments no external magnetic fields were applied, although in other works, up to 100 Gauss could be generated from large coils. The produced plasma jet would enter the vacuum tank through a flange with 20 cm diameter, as seen in Fig. 1 and reach for the opposite wall of the tank.

The flow images were captured by a DICAM-PRO high-speed camera provided with a 16 mm f/4 fish eye lens. The camera was positioned at one end of the vacuum tank and had a perpendicular view on the flow. The camera recorded the full optical spectrum emitted by the plasma flow. The opening time of the camera shutter was set at 500 ns or 1 μs, and could be triggered at a chosen time delay by a digital pulse generator, after the shot was initiated.

The time-of-flight technique has been used to measure the plasma flow speed of about 35 km/s. It has been inferred from light-emission measurements with two fast photo-diodes positioned at fixed distances (0.9 m between them) from the gun exit. The flow is highly supersonic as its speed in the axial direction is several times its expansion rate in the transversal direction [7].

Within 30-40 μs of the discharge, a bright plasma column of about 1-2 cm in diameter surrounded by a diffuse plasma plume emerged in the vacuum tank. Later on, due to the plasma pressure gradient in the cross section of the flow, kinking of this column would take place, followed by its breaking into filaments. A close inspection of the flow structure reveals the existence of many twisted filaments with different lengths and orientations suggesting a fairly turbulent flow (images 2 to 8 in Fig. 1). As the flow evolved in time its cross section increased (images 2 to 6) and then suddenly started to decrease showing a tendency of self-constriction (images 7 to 10). This phenomenon is also visible by the clear delimitation of the flow in the last 4 images, compared to the other ones where the flow as a more diffuse aspect. After 125 μs, the flow became almost laminar, with a central column width of about 3 to 5 cm. Self-stabilization in the MHD activity in plasma flows has been observed in other experiments as well such as the ZaP [2], where equilibrium could be maintained by a high level of velocity shear in the flow. The average plasma density has been determined from spectroscopic measurements of the H_α line using a streak camera by collecting the light from the whole flow section at the exit of the coaxial gun. The inferred average values were situated between 1 and 3×20^{22} m. However, it is expected that the plasma density within the filaments could be even higher.

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