Plasma flows in expanding magnetic field: simulations, probe and Laser Induced Fluorescence (LIF) measurements

Å. Fredriksen [1*], N. Gulbrandsen[1], W. Miloch[2], A. Hansen[3], E. Scime[3]

[1] *Dep. of Physics and Technology, University of Tromsø, N-9037 Tromsø, Norway*
[2] *Dep. of Physics, Univ Oslo, Dept Phys, N-0316 Oslo, Norway*
3Dep. of Physics, West Virginia University, Morgantown WV 26506-6315, USA
(*) ashild.fredriksen@uit.no

We study the flow of plasma from a magnetized helicon plasma source region into a weakly magnetized, large cylindrical expansion chamber of 0.4 m^2. We have obtained potential measurements by means of a retarding field energy analyzer (RFEA) with an aperture which could be rotated with respect to the flow. From 3D PIC simulations, we have found that the difference between the plasma potentials (V_p) in the upstream and in the perpendicular directions with respect to the flow provides good agreement with the given flow parameters. From analysis of simulated data, we have found that the flow speed increases with increased downstream magnetic field. The findings are compared with recent LIF measurements of the downstream ion flow.

Plasma flows may provide important information about their driving forces and the dynamics of the particular plasma system, e.g. ExB-drifts, plasma thrust, or plasma expansion. The flow of plasma along expanding magnetic field lines occurs in many natural plasmas, like for instance plasma outflow from the solar corona or ion outflow from the polar ionosphere [1, 2].

Flows in plasmas also help lowering the threshold of instabilities [3]. The study of plasmas and instabilities with flows and ion beams is one of the main objectives behind the construction of the Njord device [4, 5], in which the flow measurements in this work are performed.

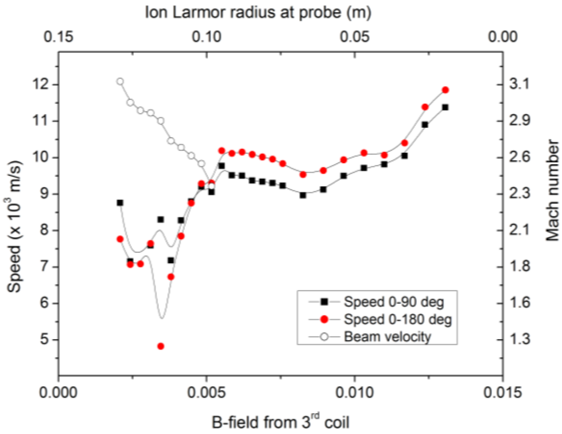
Particle-in-cell (PIC) numerical simulations were carried out in order to assess the feasablity of flow measurements by the RFEA-probe from measurements of plasma potentials in different directions with respect to the flow. We employed the DIP3D code, which was designed for simulations of objects in complex plasma environments[6]. For the present study, the code was upgraded to account also for an external uniform magnetic field [7] and collisions [8]. From the simulations, we found good agreement with the given, subsonic flow parameter when obtaining the flow speed from the simulated data by taking the difference between V_p measured in the direction up against the flow (upstream direction), and V_p measured in the direction 90° to the flow [9].

For the helicon plasma [4, 5], 400-600 W RF power and Argon gas fill pressure from 0.013 to 0.02 Pa (1.2 – 1.5 sccm) was used. The current in the first and second source coils were set to 5 and 7 A, respectively, providing a maximum magnetic field there of about 0.025 T. The current in a 3rd coil placed 25 cm downstream of the helicon source outlet, was varied between 0 and 30 A, resulting in a magnetic field between 0 and 0.012 T.

Experimental data was obtained by means of an RFEA which could be rotated 360° around its own axis [ref] and was placed in a radial port about 20 cm downstream from the helicon source outlet. At downstream magnetic field less than about 5 mT, an ion beam from an upstream electrical double layer (DL) was present in the data, forming a double-peak feature in the ion energy distribution[5, 10]. The beam energy could be extracted from the potential difference between the two peaks in the distribution, and its speed v_i deduced as $v_i = \sqrt{2\Delta V / m_i}$, where ΔV is the potential difference and m_i the ion mass. As the downstream magnetic field (and confinement) increased, the beam slowed down and disappeared after 5 mT.

By analyzing the prevailing background plasma peak in the ion energy distribution with the same method as for the simulated data, we found that the background plasma flow speed would increase from nearly zero at zero magnetic field to about 9×10^3 m/s at B = 5 mT, matching the speed of the beam just before vanishing. In Figure 1 a) the plasma flow along with beam speed is shown as a function of downstream magnetic field. The flow speed matches the beam speed quite accurately at the transition where the beam vanishes. For comparison, also the drift speeds obtained by taking potential difference between upstream (0^o) and downstream(180^o) are shown. The best match is found for speeds obtained as in the simulations.

a)



b)

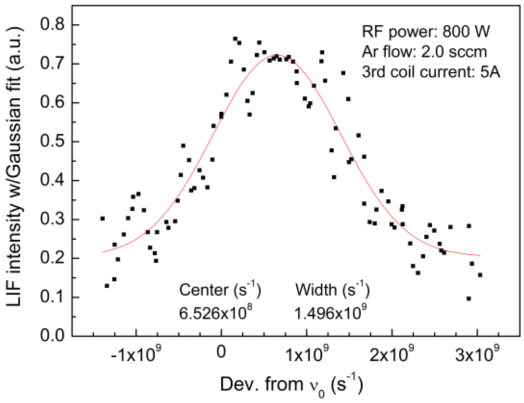


Fig. 1. a) Beam velocities (open circles), and background plasma velocities (filled squares and circles) from experiment, probe at z=51 cm plotted as a function of 3rd coil current, the latter obtained from the potential differences between RFEA pointing towards the source and at 90o (filled squares), and at 180o (filled circles) away from the source. b)

A comletely different method of obtaining drift speeds in plasma flows, is by means of Laser Induced Fluorescence [11, 12]. Recently, a LIF system was set up in our device, with a tunable Toptica diode laser, capable of a maximum output of 35 mW, pumping the 668.6138 nm, resulting in the 442.60 nm fluorescence radiation between the $4p\ {}_4D_{5/2}$ and the $4s\ {}_4P_{3/2}$ levels transition, which was detected by means of a photomultiplier tube (PMT) and a lock-in amplifier with its reference taken from a mechanical chopper, which also pulsed the laser beam going into the plasma. The wavelength from the laser was stepped by a voltage ramp from a Labview computer program and monitored contiuously by means of a Bristol Instruments wavelength meter. Wavelength and power from the fluorescence line was stored in a data file, with 200 steps over a total scanning range of 0.009 nm centered at 668.6138 nm. An example of the distribution obtained from the LIF measurements is shown in Figure 1 b). The velocities obtained from the LIF distributions will be compared to those obtained from the RFEA for further test of the accuracy of the flow measurements.

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