MEASUREMENTS OF ANOMALOUS CURRENTS TO A PLASMA DRIVEN DOUBLE PROBE

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Abstract

The first laboratory experiments are reported of anomalously high currents drawn by an electron collecting probe in a magnetized plasma stream. The currents exceed the theoretical values by Parker and Murphy (1967) by up to a factor of four. Measurements of the potential pattern around the probe indicate that the enhanced currents are possible because electrons **E**x**B**-drift into a local field-aligned current channel, in agreement with results from a computer simulation by Singh *et al*, 1997.

1. Introduction

Current collection to probes in magnetized plasma streams is a very complicated subject. Classical theory [1, 2] predicts currents of the order of the random current I_R to an unmagnetized, unbiased probe. Several recent results indicate, however, that higher currents can be drawn: laboratory experiments using pulsed probes in a stationary magnetized plasma [3], computer simulations of probes in a magnetized plasma stream [4], and observations from the tethered satellite TSS experiment [5]. Here, we present results from the first laboratory experiment on this subject in a streaming plasma. We have observed currents exceeding the classical theoretical values [1, 2] by up to a factor of four, and investigated the probe sheath structure which makes this large current collection possible.

2. The Experiment

A fully magnetized hydrogen plasma stream of 5 - 10 μs duration is produced in a plasma gun and made to flow across a magnetic field. Typical parameters are $n_e = 10^{18}$ m^{-3}, T_e = 7 eV, $v_{pl} = 3\text{x}10^5$ m/s, and B = 0.02 T. The parameters are such that the probe diameter (5 mm) is smaller than the ion gyro radius (0.16 m) but larger than both the electron gyro radius ($5\text{x}10^{-4}$ m) and the Debye length ($2\text{x}10^{-5}$ m). An electric field $\mathbf{E} = -\mathbf{v}\text{x}\mathbf{B}$ of strength $6\text{x}10^3$ V/m is induced across the flow (Fig. 1).

We have used two single probes oriented as shown in Fig. 1, and drawn a current I between them through a short-circuit external to the plasma chamber. In this configuration the plasma stream itself is providing the electromotive force to drive the current. The effective probe bias is Ed, where d is the distance across the magnetic field between the probes. We have found two different modes of operation. In the **normal current mode** one probe collects ions (the IC-probe) and the other collects electrons (the EC-probe). The current is limited by the ion saturation current to the IC-probe. However, for high enough bias Ed, a cathode spot often ignites at the IC-probe some time during the plasma shot. Since a cathode spot can deliver very large currents at low voltages, the IC-probe jumps to approximately the local

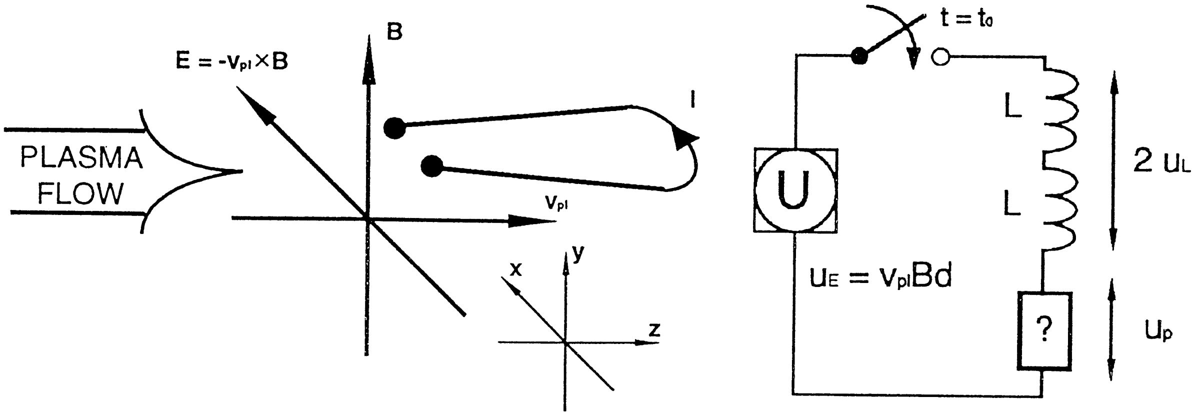

Figure 1. Left: The experimental arrangement. Right: an equivalent probe circuit, where the cathode spot ignition is symbolized by a closing switch, and the sheath between plasma and EC-probe is symbolized by a box with a question mark. The stray inductance of the cables is $2L = 4.4$ µH.

plasma potential, and the current becomes limited by the collection of electrons at the EC-probe. We call this the **high current mode**. The present paper is limited to the collection of electrons in the high current mode. The cathode spot operation and the current closure across the plasma stream will be discussed elsewhere. They are here regarded only as unspecified parts of an electric generator which drives the EC-probe.

The advantages of our arrangement compared to using an externally controllable generator are several. The cathode spot ensures a current closure into the plasma of the very high currents (approaching 100 A in some shots), the IC-probe gives the whole probe circuit a reference to the plasma potential which varies rapidly during each shot, and the inductance in the external circuit is minimized. Also, by varying the probe distance we can effectively change the applied potential into a range where interesting phenomena appear. The major disadvantage is that we can not sweep through the current-voltage diagram of the EC-probe at will. We have to accept the ranges of current and voltage that are spontaneously covered by each shot of the plasma gun.

3. Measured currents

In the left half of Fig. 2, the result from one such shot is shown. The left of the three smaller panels at the bottom shows the current I which was directly measured in the external circuit. The left vertical dashed line in this panel denotes the successful ignition of a cathode spot after several aborted attempts. The data in the top panel is taken from from this time on. The small panel to the right shows the density, measured by a specially designed plasma flow probe described in [6]. The vertical dashed line to the right in this figure denotes a time when independent density measurements by a microwave interferometer indicate that the density measurements become unreliable, possibly because of build-up of plasma that has hit the end

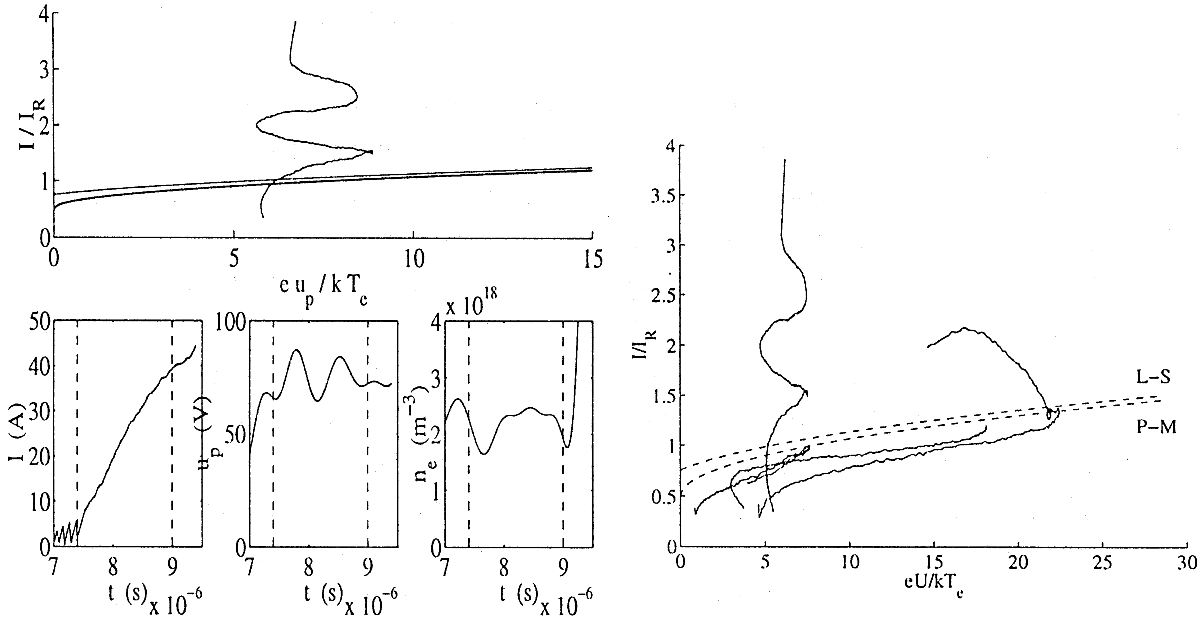

Figure 2. Left: comparison between the measured current and the theoretical values of [4] and [5], calculated for our plasma parameters. The currents are normalized to the random current I_R drawn by an unbiased probe in an unmagnetized plasma. The potential is normalized to kT_e/e. The upper figure is based on the data shown in the lower three panels. Right: several traces of measured currents, from different shots.

of the plasma chamber. This line marks the end of the time from which data is taken. The small panel in the middle shows u_p, the difference between the potential of the EC-probe and the local plasma potential. The most difficult parameter to obtain was the EC-probe potential, because the current derivatives after the ignition of the cathode spot were so large (tens of A per μs) that the stray inductance in the probe circuit had to be measured and taken into account. An equivalent probe circuit is shown to the right in Fig. 1; the measured potential in the external circuit was corrected for the inductive potential drop $L(\mathrm{d}I/\mathrm{d}t)$ to the EC-probe.

The top panel to the left in Fig. 2 shows the curve traced by the EC-probe in the normalized current-voltage diagram during this shot. For comparison, the theoretical values of [1] and [2] are included, calculated for our plasma parameters. In the panel to the right in Fig. 2, the same curve is repeated together with results from three other shots. These examples agree with the general picture we have after looking at a larger number of shots:

• Parts of the traces, always in the beginning after the ignition of the cathode spot, agree fairly well with the Parker-Murphy values. We call these **normal** high current cases.

• Sometimes, the traces depart abruptly from the theoretical curves towards higher currents, reaching up to four times the Parker-Murphy values. We call these **anomal** high current cases. These traces show a large spread between individual shots, indicating dependence on some other parameter besides normalized potential and current.

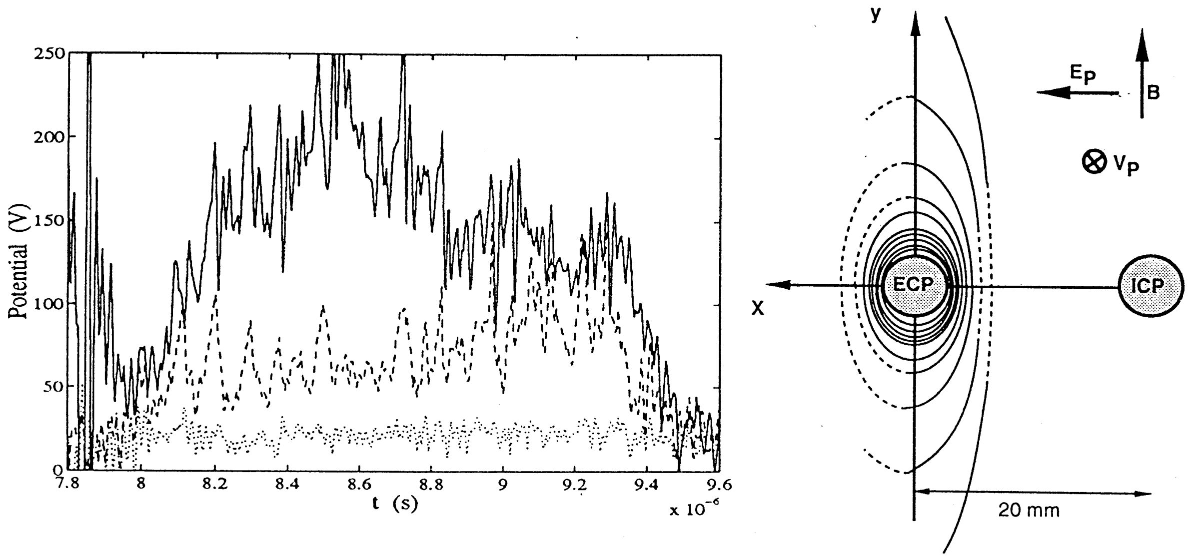

Fig. 3. Left: measurements of potential differences, relative to the electron collecting probe, at positions 2, 6, and 10 mm along **B** from the probe surface. Right: Potential patterns around the probe, at a time t = 8.5 μs, drawn so that they are consistent with measured potential differences (such as those shown to the left) between various other positions. The potential difference is ΔU = 20 V between adjacent lines.

4. Measured potential structures

To the right in Fig. 3 is shown a sketch of the potential structure around the EC-probe for parameters corresponding to the anomalous high current case. Although this structure is synthesized from a large number of individual shots, we believe that it is essentially correct. We have considered the electron's **E**x**B** drift patterns for different y coordinates into the region where they can be accelerated along **B** towards the probe surface, and found it very likely that this potential structure enhances the effective collection area of the probe enough to explain the anomalous high currents. We call the process drift collection. This, so far qualitative, picture is in agreement with results from a computer simulation by Singh *et al*, 1997.

Acknowledgements

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