Flow Profile Changes and Fluctuation Suppression in a Large Scale Helicon Plasma With Electrode Biasing

M. Gilmore, T.R. Hayes, S. Xie, and L. Yan
University of New Mexico, Albuquerque, NM, USA 87131

I. Introduction

Electrode biasing has been utilized to affect flow profiles and fluctuations in a large-scale helicon plasma. The goals of these experiments are 1) to develop empirical control over both azimuthal and axial flow profiles in order to study such nonlinear physics as the interaction between flow shear and turbulence near marginal stability, and the magnetic relaxation of dense spheromak-like plasmas in a background plasma with sheared flow; 2) to understand the detailed physics of these biased flow profiles; and 3) to understand in detail plasma potential profiles in the presence of strongly biased boundaries where subsonic sheaths may exist [1]. Two sets of bias electrodes are utilized, as illustrated in Fig. 1. A set of concentric rings mounted on a ceramic substrate terminates the plasma column, while a semi-transparent metal grid is placed at the source end. Plasma flows from the source through the grid into the main plasma column. The rings and grid can be biased with respect to (w.r.t.) each other, or each can be independently biased w.r.t. the grounded vacuum chamber wall.

II. Experimental Arrangement

Experiments were conducted in the linear HelCat (Helicon-Cathode) device, a 4 m long, 0.5 m diameter device with axial magnetic field, $B_{z0} \leq 0.22$ T, and dual plasma sources [2]. Experiments described here utilized the RF helicon source alone, which consists of a helical half-twist, half-wavelength antenna with an inside radius of 6.5 cm, operated at 10 MHz and 500 to 3500 W. Plasma pulses were ~ 200 ms long. $T_e \sim 5$ eV, across the plasma column, and the fill gas was argon. Typically, the ion sound speed, $c_s \sim 4\times10^3$ m/s, the ion sound gyroradius, $\rho_s = c_s/\omega_{ci} \sim 3$ cm, $\beta < 10^{-2}$, the ion-neutral collision frequency, $\nu_{in} \sim 2\times10^4$ s^{-1}, and $L_n/\rho_s \approx 2 – 10$, where L_n is the density gradient scale length.

A set of six concentric metal rings, spaced 7 mm apart and mounted on a square 15×15 cm ceramic substrate, were used to terminate the plasma column at z = 2.6 m from the helicon source [2,3]. Ring radii were ≈ 2.5, 3.0, 3.75, 4.5, 5.2, 5.9, 6.6 cm (plasma half maxium density radius ~ 6 cm, typically). While various ring biasing schemes have been utilized, this paper describes simple biasing where all six rings were connected together and biased w.r.t.

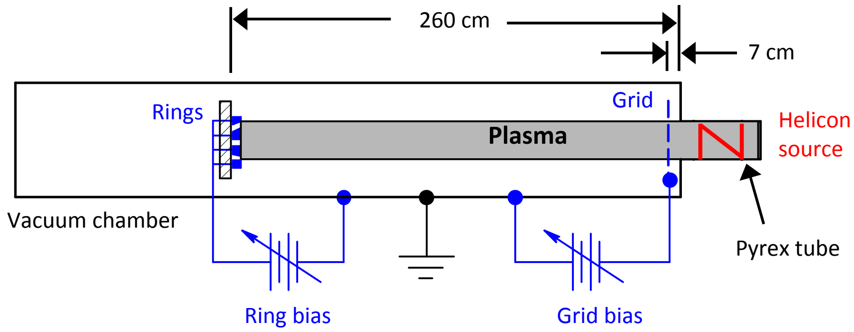


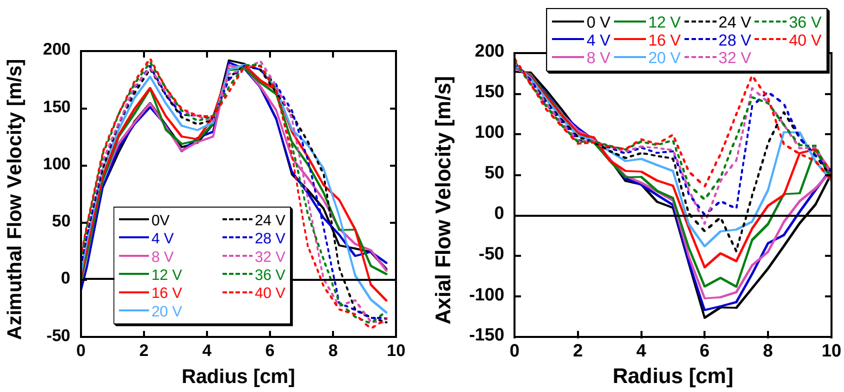
Fig. 1. Experiment schematic showing ring and grid bias electrodes.

the grounded vacuum chamber wall. Biasing between sets of rings changes the quantitative details of the basing results. However, the *qualitative* behaviour discussed here with all rings connected together remains unchanged. As the magnetic field, B_0, is increased, drift fluctuations in HelCat transition to a broader spectrum with more fully developed turbulence, as has been reported elsewhere [3]. These experiments, however, were conducted at low magnetic field (35-44 mTesla), so that dynamics closer to marginal stability could be observed. At higher B_0, similar effects to those discussed here were observed, but, again, the behaviour remains qualitatively the same.

III. Experimental Results

As either more positive ring or grid bias is applied, the ion flow profiles, as measured by a 7-tip Mach probe (6 tips plus a 7th reference tip, all in a double probe configuration) are observed to change as shown in Fig. 2. "Intrinsic" azimuthal flows are observed to be in the electron diamagnetic direction, with the most strongly sheared regions at the edge (outside the source radius, R = 6.5 cm) and in the central blue core region [5], R < ~ 2 cm. As more positive bias is applied, the edge flow reverses, eventually to the ion diamagnetic direction. "Downstream" (away from the source) axial flows are observed in the plasma center, while an edge return flow is seen at radii outside the source with no biasing. As positive bias is increased, the edge return flow is observed to reduce, then reverse to the downstream direction.

Fig. 2. Time-averaged plasma (ion) flow profile vs. V_{bias} measured by a 7-tip Mach probe. Left: azimuthal flow (positive values are in the electron diamagnetic direction), Right: axial flow (positive values are in the direction away from the plasma source). Ar, B_0 = 35 mTesla, $p_0 \approx 270$ mPa.



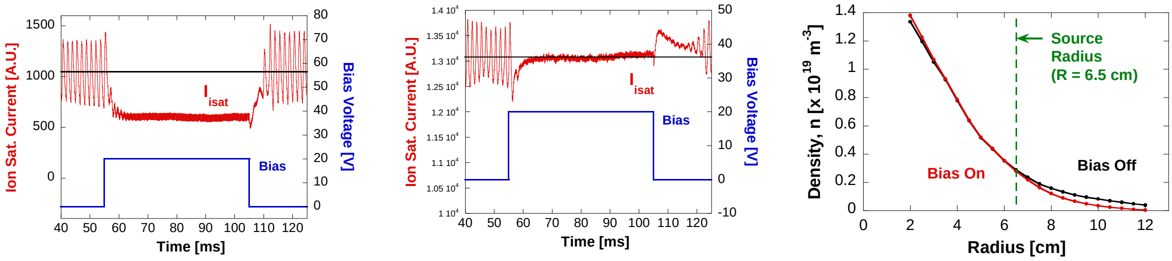
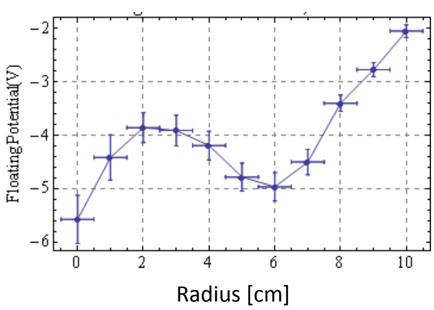


Fig. 3. Ion saturation current, I_{is}, vs. time and density profile change with a bias pulse of V ~ $4T_e$ applied during the steady state phase of the discharge. Left: I_{is} at plasma edge (R = 8.5 cm). Center: I_{is} at plasma center (R = 2.0 cm). Right : time-averaged half density profiles before and during bias pulse from probe and 94 GHz interferometer. Drift fluctuations suppress across the entire plasma radius during bias pulse. During the pulse, the average density drops at the edge (outside the source radius, at R = 6.5 cm), and increases slightly in the center, leading to a steepened density profile. P_{RF} = 1600 W, B_0 = 35 mTesla, $p_0 \approx$ 270 mPa (2 mTorr), Ar.

Suppression of drift wave fluctuations is also observed during positive biasing, as shown in Fig. 3. Here it can be seen that when a pulsed positive bias voltage of ~ $4T_e$ is applied to the rings, DW fluctuations are suppressed across the plasma radius. At the plasma edge – outside the source radius, R = 6.5 cm – the average ion saturation current drops, while in the center it slightly increases, leading to a steepened density profile during the bias pulse. We note that although the profile change is not large, the drop at the edge is clear in the raw I_{is} signals (*cf*. Fig. 3 left). Since HelCat is a relatively short linear device where parallel transport strongly dominates, this is a significant effect. We believe that this profile change is a result of reduced turbulent radial transport, and experiments are underway to quantify it in detail.

Changes in plasma floating potential are also observed during electrode biasing, as shown in Fig. 4 for the case of grid biasing. It can be seen that generally the floating potential becomes more negative across the plasma as grid bias becomes more positive. This may be a result of accelerating more energetic electrons from the helicon source region into the main plasma column, thereby pulling the potential more negative. More interestingly, jumps in time-average potential are seen between –8 and -6V, and 16 and 18V, which correspond respectively to the start of the suppression of DW's and the onset of a second instability. This second instability has been tentatively identified as a azimuthal shear-driven Kelvin-Helmholtz (KH) mode [3]. It is also interesting to note that at the highest positive biases, the floating potential changes occur mostly in the central blue core region. This may simply be because the plasma density is highest in this region, and more electrons can be accelerated through the grid.

Finally, the I-V characteristics of the grid and rings are shown for the case where a "parallel" bias voltage is applied *between* the grid and rings, with both electrodes floating



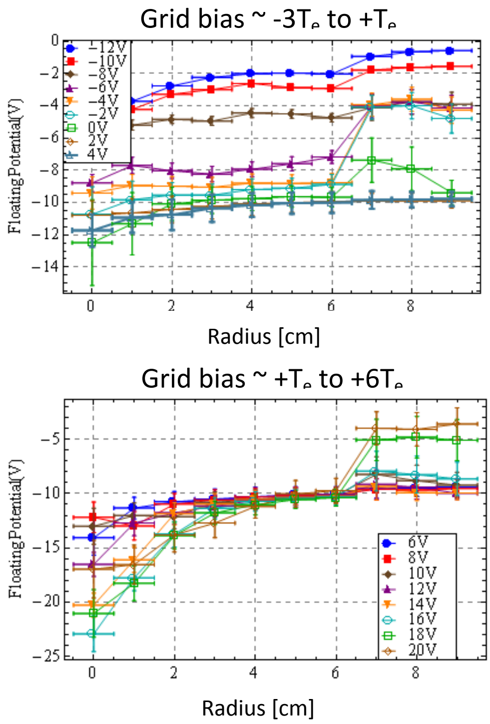


Fig. 4. Radial floating potential profiles during grid biasing. Above: reference case with no grid present. Upper right: moderate biases V ~ -3T_e to +T_e w.r.t. wall. Lower right: stronger positive bias: V ~ +T_e to +6T_e. Blue core region, R < ~ 2 cm exhibits negative potential well, and potential increases outside source radius, R = 6.5 cm. With more positive biasing potential decreases across plasma radius, with a jump at the edge between –8V and -6V, where DW's begin to suppress. At higher positive bias (lower), potential drops mainly in blue core region, with a jump at the edge between 16V and 18V, corresponding to the onset of a second instability. P_{RF} = 1600 W, B_0 = 35 mTesla, $p_0 \approx$ 400 mPa (3 mTorr), Ar.

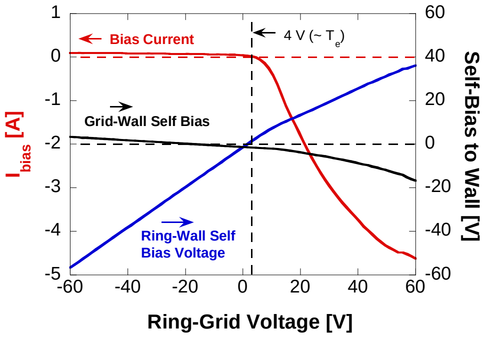


Fig. 5. Bias current and self-bias voltages on grid and rings during biasing experiments where a "parallel" bias is applied between the grid and rings, both of which float w.r.t. the wall (i.e. they self-bias). Bias current direction is defined as flowing from the plasma *into* the rings, through the power supply, then *out of* the grid returning to the plasma. Plasma parameters same as in Fig. 4.

w.r.t. the grounded vacuum chamber wall. Here it can be seen that the current exhibits a single probe characteristic. The grid electrode, which is presumably well connected to the plasma near the source, self-biases to near machine (wall) ground, while most of the bias voltage w.r.t. the wall appears at the downstream end of the device on the rings, where there is presumably a more resistive sheath present. Importantly, no fluctuation suppression is observed in such "parallel" biasing cases, which suggests that the primary suppression mechanism is associated with radial E-field, rather than parallel current.

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