CONFINEMENT, FLUCTUATIONS, AND ELECTRIC FIELDS IN THE H-1 HELIAC

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Abstract

Low density discharges produced by RF power of 50-100 kW at low magnetic field in the H–1 heliac are used to study transitions in confinement that are similar to those seen at high power in large devices. Probe diagnostics can be used to make detailed measurements of the profiles of plasma quantities, including the radial electric field. At transition, the density increases by a factor of about two, the density profile steepens, and the ion temperature increases. The transition is accompanied by a decrease in plasma turbulence and changes in the radial electric field.

1. INTRODUCTION

The H-1 heliac [1] is medium-sized helical axis stellarator experiment with major radius R = 1 m, average plasma minor radius a = 0.15–0.2 m. Its "flexible-heliac" [2] coil set permits extraordinary variation in the low-shear rotational transform profile in the range $0.6 < \iota < 2.0$ and variable average magnetic well. The ultimate design ratings of the H-1 facility are toroidal

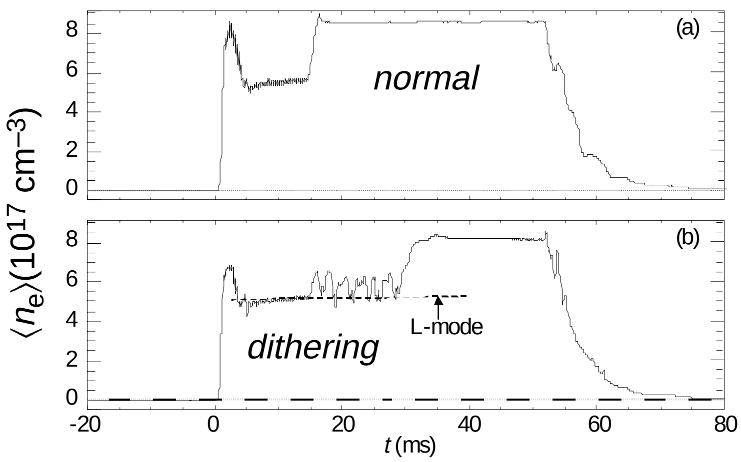

Fig. 1. Time trace of the line-average density in H-1 discharges showing normal and "dithering" transitions to high confinement.

magnetic field B = 1 T and heating power P ≈ 500 kW. However, during its initial operating period, experiments have been limited to lower magnetic field B ≤ 0.2 T and P ≤ 100 kW, and so have concentrated on studying confinement phenomena in low-density discharges. These discharges are produced in helium, neon, and argon using 50-100 kW of high-cyclotron harmonic helicon wave heating (f = 7 MHz) and typically have pulse lengths of 80 ms, electron densities n_e =0.5–2 × 10^{12} cm^{-3}, electron temperatures T_e = 10-30 eV, and ion energies T_i = 50-100 eV. These plasmas are diagnosed by a variety of probe and optical techniques. A particular advantage of operation at low magnetic field and temperature is that the interpretation of Langmuir probe data is simplified.

2. CONFINEMENT TRANSITIONS AND THE ELECTRIC FIELD

For magnetic fields above a critical value that depends on pressure and somewhat on magnetic configuration, the plasma undergoes a transition (Fig. 1) during which the line-average density doubles and the density gradient increases (Fig. 2), and the average ion energy increases markedly. These transitions can occur singly or as a sequence of forward/backward “dithering” jumps. They are accompanied by a deepening of the potential well, an increase in the magnitude of the inwardly pointing radial electric field a reduction in turbulence levels, and a reduction or even reversal in the (normally outward) fluctuation-induced particle flux (as measured using Langmuir probe techniques) [3,4]. These phenomena are remarkably similar to those seen during L-H transitions in larger tokamaks and stellarators with heating up in the megawatt range [5], making H-1 a useful model experiment.

As with any confined plasma, the radial electric field is determined by the constraint of quasi-neutrality and the balance of the outward ion and electron fluxes. In the low-magnetic-field regime in which H-1 is now operated, the ion gyroradii are quite large, ρ_i/a ~ 0.1–0.5 (depending on the working gas), and computational studies of ion orbits show that direct losses remain important even when radial electric fields like those measured in the experiment are included. Modelling studies suggest that this radial electric field is nonetheless roughly consistent with ambipolar ion and electron fluxes when both diffusive and direct losses are included [4].

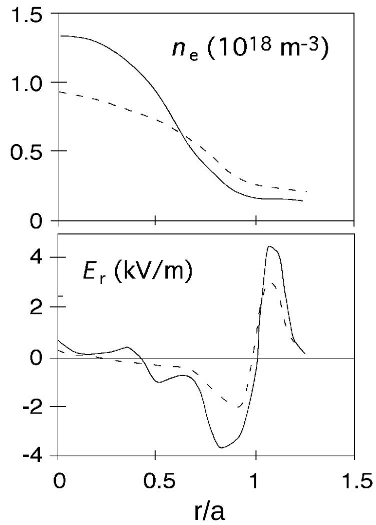

Fig. 2. Radial profiles of plasma density (n_e) and radial electric field (E_r) in H-1. Profiles taken 5 ms before (dotted) and 5 ms after (solid) transition to improved confinement. The plasma boundary r/a = 1 is determined by the last closed magnetic flux surface, and is also the location of the helicon wave antenna..

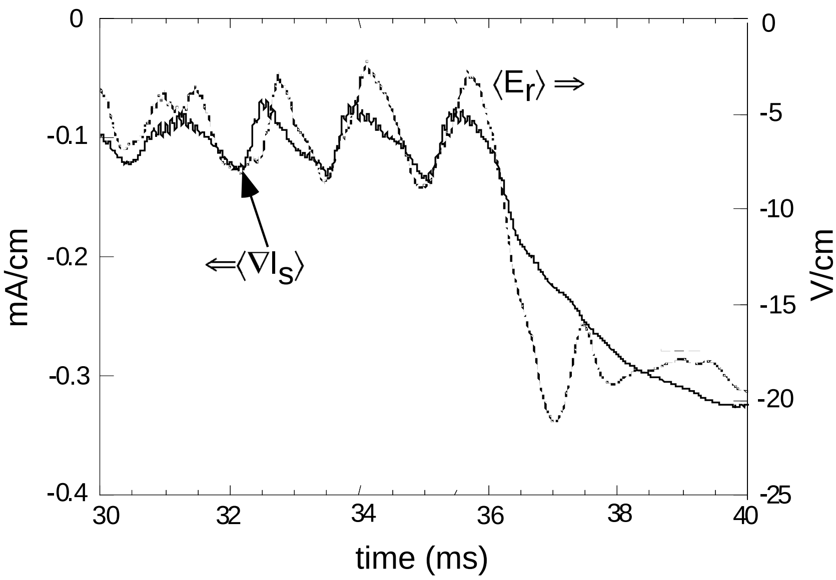

Fig. 3. Time traces of electric field and gradient of ion saturation current (measured with a Langmuir probe array) for a discharge with dithering transitions. The quantities are averaged over the radial region 0.25 < r/a < 1.

The transition to the high confinement mode exhibits a threshold dependence on magnetic field, pressure, and power. Analysis [4] of data from experiments in which the power was stepped up and down suggests this behaviour is compatible with a model in which the radial electric field is driven to a critical value depending upon the relative heating of the ions and electrons. Moreover, the jump to a higher electric field coincides with an increase in the ion pressure gradient. This is consistent with expectations for radial force balance applied in H-1 discharges.

The interplay between radial electric field and pressure gradient is illustrated graphically in an experiment that takes advantage of the dithering behaviour shown in Figure 1. A radial array of 24 Langmuir probes was used to measure the ion saturation current, electron temperature, floating potential, and plasma potential. Results from a sample dithering discharge are shown in Figure 3. The time traces show the spatially averaged radial electric field and the gradient of the ion saturation current—which we take as a proxy for the ion pressure, since

$$I_{si} \propto n_i \,(T_e + T_i)^{1/2}$$

and $T_e < T_i$ in these discharges. As the discharge changes back and forth between low and high modes, the average electric field and "pressure" gradient oscillate with only a small phase lag.

Probe studies are also being used to determine the possible role of the radial structure of the radial electric field in the transition to high confinement. Figure 4 shows data from an experiment in which the Langmuir probe array was used to measure plasma parameters at six radial locations during a confinement transition. Profiles of the electric field were taken at the four times shown in the figure. For this particular discharge, the radial electric field in the region of strong pressure gradient at $r/a \approx 0.5$ increases as the fluctuations die out during the transition to high confinement. It should be emphasised that this effect is not seen in every discharge, so that further experiments and extensive analysis will be required before drawing a conclusion that changes in gradients of the radial electric field coincide with the confinement transition.

Preparations are under way to increase the magnetic field to 0.5-1.0 T, to increase the low-frequency heating power to 250 kW, and to add 200 kW of 28 GHz ECH power. These improved

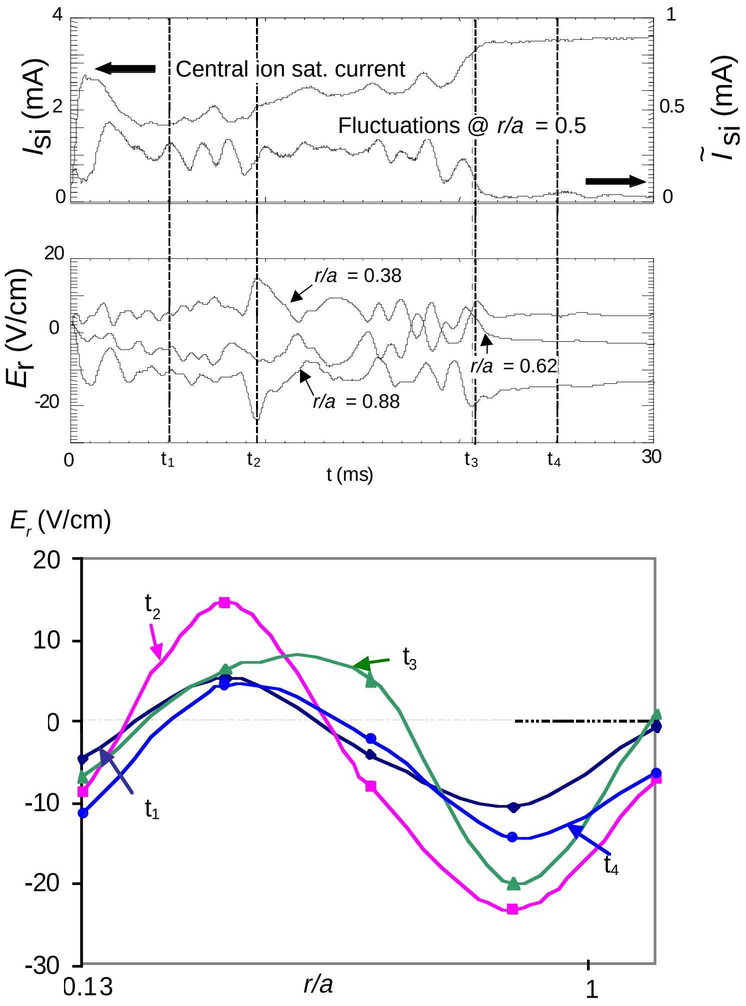

Fig. 4. (Top) Time traces of signals from Langmuir probe array during a discharge with a confinement transition at t_3 and (bottom) radial profiles of the radial electric field at the four times indicated in the time traces.

capabilities will permit the decoupling of electron and ion heating and experiments at higher plasma densities and temperatures.

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REFERENCES

[1] HAMBERGER, S. M. *et al*, Fusion Technol. **17** (1990) 123.

[2] HARRIS, J. H. *et al*, Nucl. Fusion **25** (1985) 623.

[3] SHATS, M. G., *et al*, Phys. Rev. Lett. **77** (1996) 4190.

[4] SHATS, M. G., *et al*, Physics of Plasmas **6** (1998) 2390

[5] WAGNER, F. *et al*, Phys. Rev. Lett., **49** (1982) 1408.