CONFINEMENT BIFURCATIONS IN THE H-1 HELIAC: FORMATION AND THE ROLE OF THE RADIAL ELECTRIC FIELD IN FLUCTUATION SUPPRESSION

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1. Introduction

Experimental studies of transitions to improved confinement in stellarators [1-4] have revealed a number of features of the transitions not observed previously in tokamaks, though some of them seem to be generic and independent on the machine details. One common feature is an active role of the radial electric field E_r. The formation and evolution of E_r in stellarators has been studied in the biased electrode experiments [5,6]. It has been shown that, in agreement with theory [7], E_r may bifurcate due to the non-linearity of the parallel viscosity at some critical poloidal Mach number. The E_r bifurcation may [5] or may not [6] be followed by a confinement improvement. In this paper we address the question whether such E_r bifurcation is an intrinsic feature of a transition, or, in other words, can there be a transition without E_r bifurcation.

An analysis of the threshold conditions for transitions to improved confinement in the H-1 heliac [8] has shown that in all observed experimental ways leading to confinement bifurcations (increase in the heating power P_{rf}, increase in the magnetic field B, or decrease in the neutral gas filling pressure P_{gas}), it is the radial electric field that systematically increases in L-mode prior to a transition. At some critical value of $E_r = E_{crit}$, a transition occurs and E_r (together with other plasma parameters) suddenly changes to become even more negative. A qualitative model of E_r formation suggested in [8] for the described H-1 experiments agrees with the parameter scan (P_{rf}, B and P_{gas}) results. Here we study the plasma behaviour when it is driven up to a bifurcation point, i.e. when E_r is only slightly lower than E_{crit} . This is related to a more general problem of a trigger for the L-H transitions and to the question whether $\boldsymbol{E}\times\boldsymbol{B}$ flow velocity necessarily bifurcates before the transition.

2. Experimental results

The dynamics of the L-H transitions is studied during the power-step discharges [8], where the rf power is increased in several steps. By adjusting the magnetic field and/or the neutral gas filling pressure (argon, in this case) it is possible to change the rf power level and even time at which transitions to improved confinement are observed. First, we consider a case when the power step "triggers" the transition. Shown in Fig. 1 is a time evolution of the plasma parameters. Shortly after the power step at $t \approx 32$ ms, the chord-average plasma density and the ion temperature increase. The fluctuation level drops and E_r (averaged over the radial range from $r/a = 0.4$ to 1.0) changes from about –6 V/cm to -12 V/cm across the transition. On a shorter time scale (Fig. 2) it can be seen, that the fluctuation level at the plasma periphery [Fig. 2 (c)] decreases before the fluctuations drop at $r/a = 0.5$ [Fig. 2 (b)] and nearly simultaneously with the increase in E_r [Fig. 2 (a)] and the electron density [Fig. 2 (d)]. It is hard to conclude from this, which parameter leads in phase.

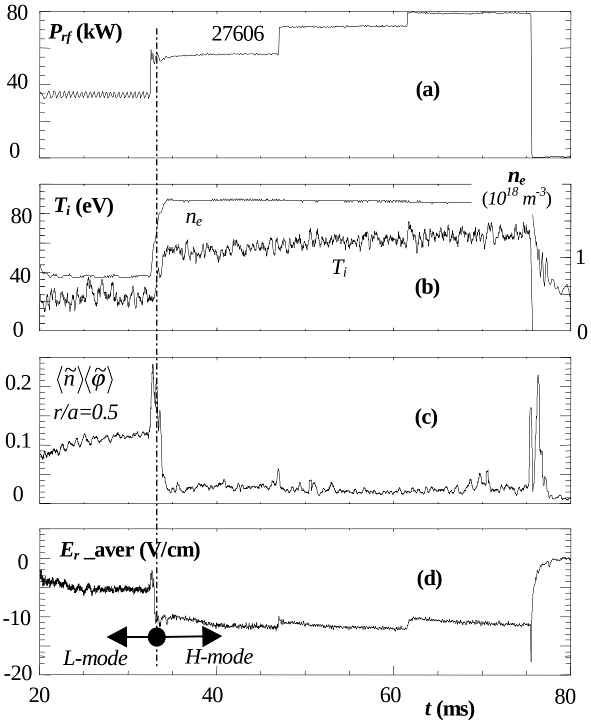

Fig. 1. Time evolution of the plasma parameters during the power step experiment: rf power (7 MHz) (a); ion temperature (central chord) and average electron density (b); fluctuation level (c); average radial electric field (d). $B = 0.07$ T, $P_{gas} = 4.8\times10^{-6}$ Torr

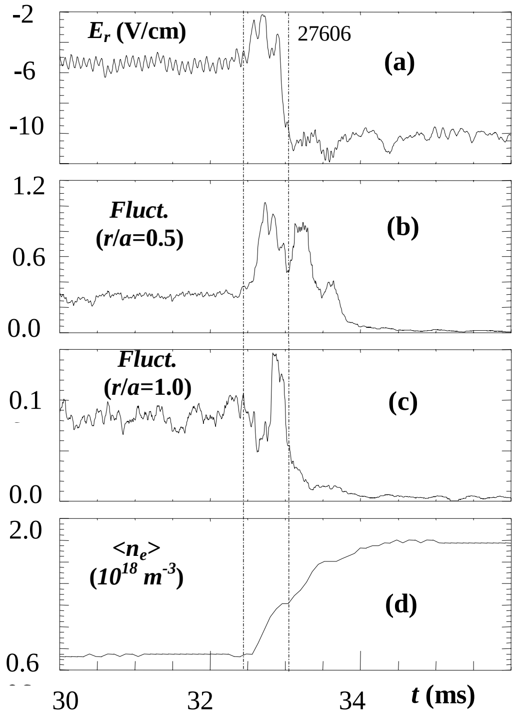

Fig. 2. Expanded traces of the plasma parameters, conditions of Fig. 1: average radial electric field (a); fluctuation level at $r/a = 0.5$ (b); fluctuation level at $r/a = 1.0$ (c); average electron density (d).

A second example, shown in Figs. 3 and 4, illustrates a spontaneous L-H transition, which does not coincide with the power step. In this case the power step at $t \approx 32$ ms brings plasma close to the bifurcation, but the spontaneous transition to H-mode occurs only at $t \approx 44$ ms. The electron temperature at $r/a = 0.3$ increases immediately after the power step, while the ion temperature increases much slower. This T_e increase leads to a higher ionisation rate in the inner plasma region and produces higher electron density. From $t \approx 33$ ms to $t \approx 43$ ms T_e does not significantly change, while T_i increases, leading to a gradual increase in E_r [Fig. 3 (e)]. When the radial electric field reaches $E_r \approx$ -12 V/cm (critical E_r in this magnetic configuration [8]), the transition occurs. On a shorter time scale (Fig. 4) it can be seen, that the radial electric field at $r/a = 0.75$ (the region of highest E_r) gradually increases from ~ -10 V/cm to ~ -17 V/cm, then the edge fluctuations are suppressed [Fig. 4 (d)], and only after that density and the ion temperature start increasing. This is followed by a further increase in E_r on a time scale of a change in $T_i\nabla n$.

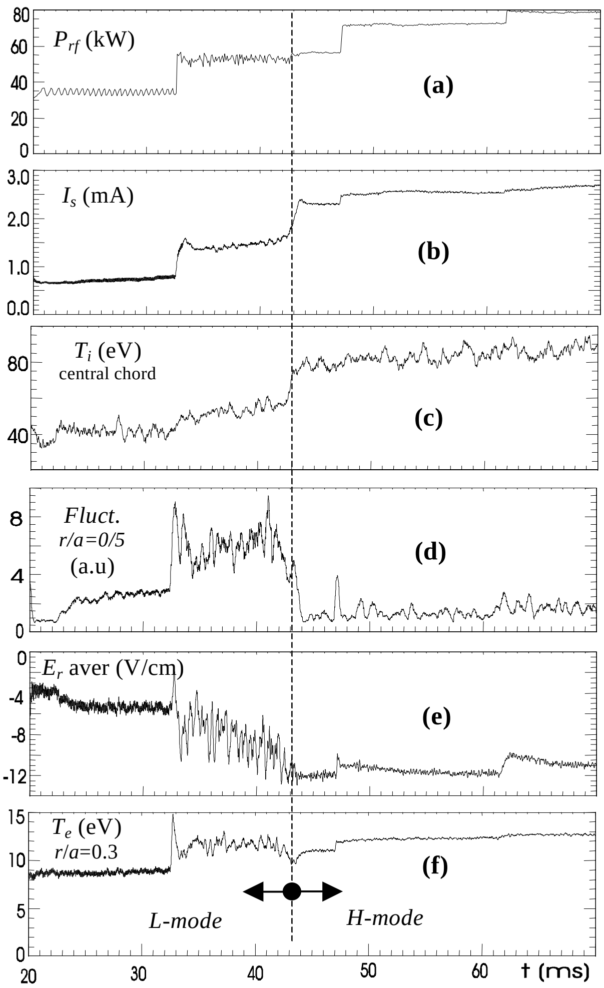

Fig. 3. Time evolution of the plasma parameters at $B = 0.069$ T, $P_{gas} = 4.8\times10^{-6}$ Torr

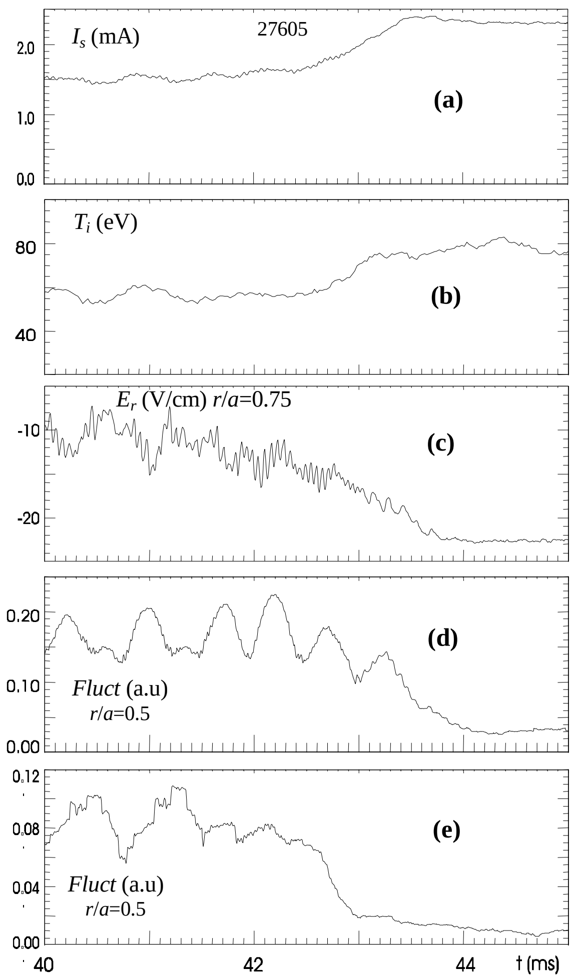

Fig. 4. Expanded traces of the plasma parameters at the conditions of Fig. 3.

3. Discussions

Presented results on the plasma dynamics across the L-H transitions in H-1 confirm a qualitative picture of the radial electric field formation discussed in [8]. Also, these results show that there is no bifurcation in E_r before the transition, or, more generally, it does not really matter if E_r changes fast or slow before it reaches the critical value. The evolution of E_r can be considered in two stages:

1. E_r is driven by the relative electron/ion particle loss. It increases up to E_{crit} until E_r or its derivatives (shear or curvature) affect the fluctuations. After the anomalous transport is reduced (first at the edge), the electron density and the ion temperature start increasing.

2. The increase in n_e, density gradient ∇n and T_i leads to a further increase in E_r to maintain the radial force balance: $E_r = (z_i e n_i)^{-1} \nabla P_i - V_{\theta i} B_\phi + V_{\phi i} B_\theta$. Here $z_i e$ is the ion charge, n_i is the ion density, P_i is the ion pressure, $V_{\theta i}$ and $V_{\phi i}$ are the poloidal and toroidal rotation velocities, respectively and B_θ and B_ϕ are the poloidal and toroidal components of the magnetic field. Since plasma bulk rotation velocities are low in H-1 [9], the increase in the ion pressure gradient is balanced by the corresponding increase in E_r .

We may thus conclude, that, in our experiments, radial electric field (or its spatial derivatives) may be **gradually** driven up to some critical value until fluctuations are suppressed. The confinement improves and E_r increases during the transition to balance the increased ion pressure gradient.

References

[1] V. Erckmann et al.: Phys. Rev. Lett. **70**, 2086 (1993)

[2] F. Wagner et al.: Plasma. Phys. Contr. Fus. **36**, A61 (1994)

[3] K. Ida et al.: Phys. Rev. Lett. **76**, 1268 (1996)

[4] K. Toi et al.: Plasma. Phys. Contr. Fus. **38**, 1289 (1996)

[5] S. Inagaki et al.: Jpn. J. Appl. Phys. **36**, 3697 (1997)

[6] H. Dahi et al.: Phys. Rev. Lett. **80**, 3976 (1998)

[7] K.C. Shaing: Phys. Fluids B **5**, 3814 (1993)

[8] M.G. Shats et al.: Phys. Plasmas **5** 2390 (1998)

[9] M.G. Shats et al.: Phys. Plasmas **4** 3629 (1997)