THE L-H TRANSITION ON TdeV WITH ELECTRON CYCLOTRON AND LOWER HYBRID HEATING

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Introduction

Well-controlled stationary H-modes have been obtained on the TdeV tokamak (R~0.83m, a~0.22 m, κ~1.1) with ECRH heating of ~0.5 MW. With the power presently available, these H-modes remain in the type III ELM regime [1]. Power thresholds are comparable with those predicted by the ITER scaling laws. A very pronounced threshold in edge density is observed, below which no L-H transitions occur. H-L transitions occur at significantly lower values of edge density. The effect of varying the distances between the plasma and various structures is investigated.

Characteristics of the experiments

Most of the experiments reported here were carried out with ECRH heating and with the ∇B drift towards the divertor (favorable for H-mode). ECRH power was launched at 110 GHz, such that it was deposited at the second harmonic at approximately 5 cm vertically from the plasma centre. The magnetic field was therefore kept constant at ~2 T on axis. Line-average densities were limited to below ~$6\text{x}10^{19}\text{m}^{-3}$ because at higher densities, refraction and cut-off limit the absorption in the central region of the plasma. The ECRH power applied was in the range of 200-500 kW. H-modes were also obtained with Lower Hybrid heating alone.

The main diagnostic for density measurements is a 9-channel submillimeter interferometer. Eight channels are used for the reconstruction of the density profile. The reconstruction employs knowledge of the normal density gradient at the edge, obtained from reflectometer measurements, and allows a good estimate of the density at the separatrix [2]. The plasma density is controlled by gas fuelling, mainly in the plasma chamber, and by divertor pumping with a pumping speed of ~5 m^3/s. So as to obtain steady-state H-modes in view of the density profile modifications by the additional heating power, one channel of the interferometer was used as a control signal, with an impact parameter of ~0.6 of the plasma minor radius.

Edge density dependence of L-H transition

An extremely strong dependence of the H-mode transition on the separatrix density was observed, as illustrated in Fig. 1. The input power throughout is constant. Repetitive L-H transitions during this shot occurred at precisely the same value of separatrix density, $1.5\text{x}10^{19}\text{m}^{-3}$ (Fig. 1a). The back transitions were all obtained at a lower value, $1.3\text{x}10^{19}\text{m}^{-3}$. During the H-mode, an increase of the type III ELM frequency with decreasing separatrix density is clearly observed, indicating that the power threshold is approached as the density decreases. These correlations are much less obvious when the line-average density n_{lin} is considered. When the separatrix density was held constant above the H-L threshold (Fig. 1b) steady-state H-modes were obtained for the duration of the heating power pulse. The dashed horizontal lines, indicating the separatrix density for the L-H and H-L transitions respectively are identical on both these figures.

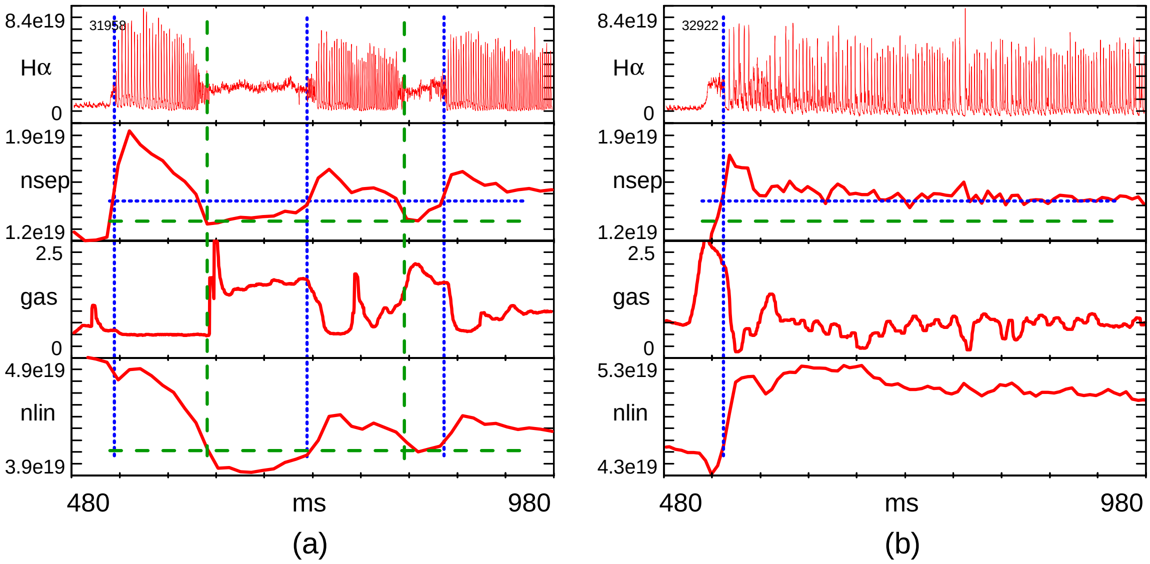

Fig. 1. $H\alpha$ emission, separatrix density, gas input rate, and line-average density plotted against time. (a) Repetitive H-modes, where the dotted lines indicate the separatrix density for L-H transition and the dashed lines that for H-L transition. (b) Steady-state (500 ms) H-mode with threshold separatrix densities from (a) indicated

Threshold for the L-H transition

In Fig. 2, the input heating power at the transition has been plotted against line average and separatrix density respectively. These plots include both L-H transitions for ECRH with favorable ∇B drift, ECRH with unfavorable ∇B drift, and Lower Hybrid heating with favorable ∇B drift. For the H-L back transition, only points for ECRH with favorable ∇B drift and OH alone after ECRH turn-off are plotted. In terms of the line-average density, the lower values of threshold power are consistent with the ITER H-mode power threshold scaling laws [3]. No significant hysteresis is obtained between L-H and H-L transitions, nor is there a significantly different power threshold for the two ∇B directions. In terms of the separatrix density, there is a clear separation between the L-H and the H-L threshold, as expected from the time traces discussed in the preceding section. The L-H transition for the “unfavorable” ∇B direction actually lies at lower values of separatrix density, comparable to those for the H-L transition with “favorable” ∇B.

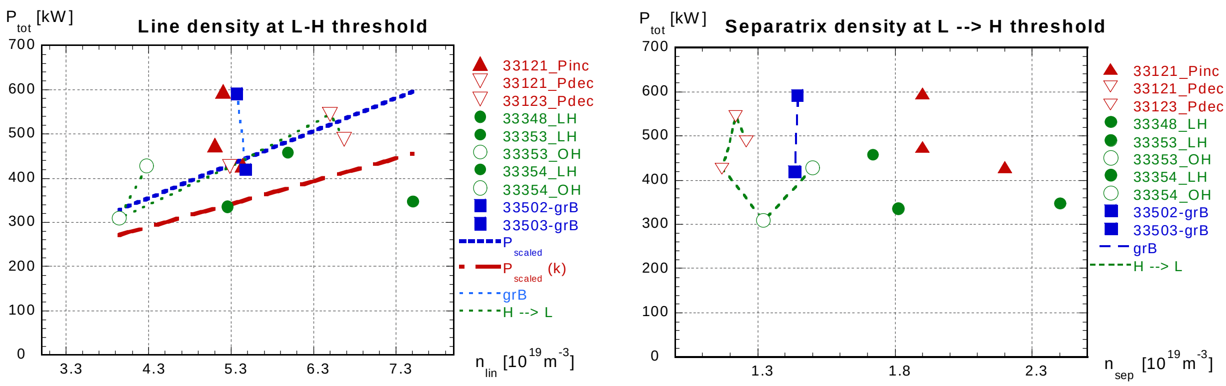

Fig. 2. Total input power vs. line average density (left) and separatrix density (right) at the L-H threshold. All values except for the two connected by an almost vertical dotted line are for ∇B drift towards the divertor. H-L transitions are connected by a dotted line and have open symbols. The ITER threshold power scaling laws are indicated for reference by thick lines, dotted without and dashed with elongation dependence

Variation of gaps

The TdeV tokamak systems are sufficiently flexible to allow a variation of the separatrix-baffle distance of the upper active divertor with only minor effects on plasma shape and safety factor, while maintaining identical divertor strike points and pumping geometries. Figure 5 illustrates the basic geometry of TdeV, and shows the extremes of the gap variation performed. The separatrix-baffle distance was reduced from 25% to 7% of flux (Fig. 5a). In another set of experiments, the outer limiter was advanced to 7% of flux. At the applied power of ~500 kW, the density scrape-off layer thickness in L-mode ($\Delta_{L\text{-}SOL}$) is about 15 mm at the midplane, or about 10% of flux.

H-mode with reduced X-point baffle separation

The effect of reducing the separation between the separatrix and the divertor baffle (Fig.5a) from 2.5 $\Delta_{L\text{-}SOL}$ to 0.7 $\Delta_{L\text{-}SOL}$ (25% - 7% of flux) is illustrated on Fig. 3a. As the distance is decreased, the time to H-mode transition increases sowewhat, from ~15 to ~19 ms, and is accompanied by a slight increase in ELM repetition rate. Only at the smallest distance of 0.7 $\Delta_{L\text{-}SOL}$ is there an appreciable increase both in time to transition (50 ms) and in ELM frequency (~x2). Both indicate that the power threshold has increased as the separation was reduced. It should be pointed out that the final step of reducing the baffle separation resulted in a strong increase in helium contamination (present from glow-discharge cleaning), which has, in other runs, also been seen to increase the ELM frequency.

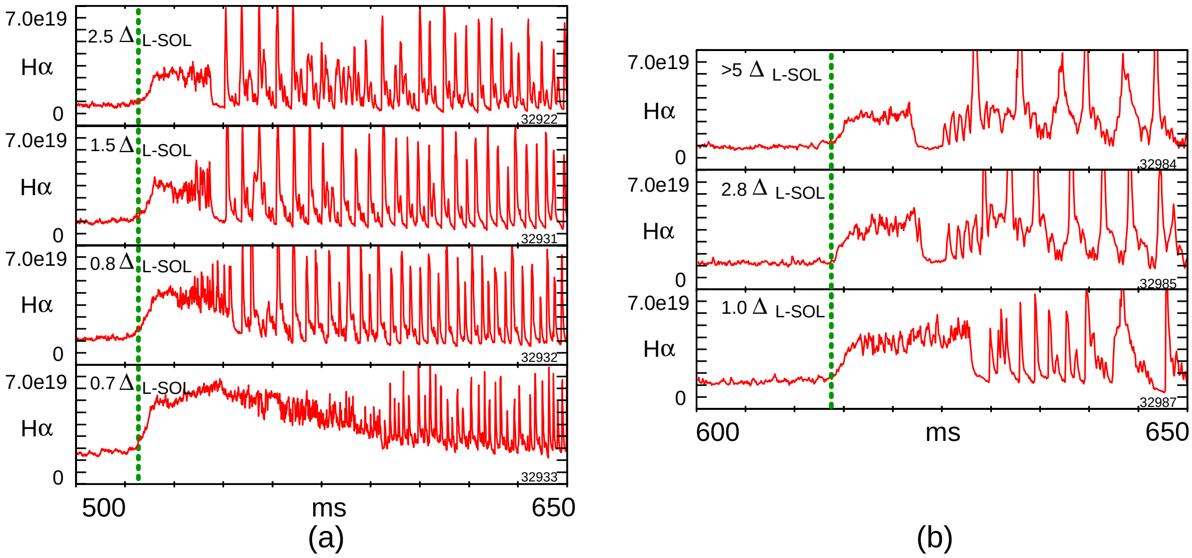

Fig. 3. *Hα* signals vs. time for, top to bottom, (a) decreasing separatrix – divertor baffle gap, (b) decreasing outboard separatrix – limiter gap.

H-mode with reduced outboard separation

The effect of reducing the separation between the separatrix and an outboard limiter (Fig. 5b) to $\Delta_{L\text{-}SOL}$ (10% of flux) is illustrated on Fig. 3b. The closest approach case (0.7 $\Delta_{L\text{-}SOL}$), for which an H-mode was also obtained, is not illustrated on the figure, because the very strong outgassing of helium from the carbon does not allow a direct comparison. Similarly to the previous section, the time to transition increases as the distance is reduced, from ~8 to 15 ms.

H-mode confinement with reduced gaps

In Fig. 4, the ratio of stored energy from diamagnetic measurements in H-mode to that in L-mode is plotted for the gap variations and for the same shot series described above. As the outboard separation is reduced, the confinement appears to degrade. However, an improvement in H-mode confinement over L-mode is observed as the separatrix to divertor baffle distance is reduced (as discussed above, the smallest separation had a much higher He content, and is therefore only joined with a dashed line).

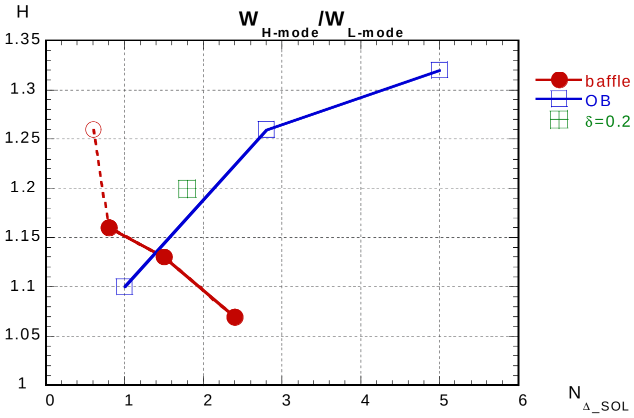

Fig. 4. Ratio of diamagnetic measurement in H-mode to that in L-mode plotted against gap width in $\Delta_{L\text{-SOL}}$. Round symbols for separatrix – divertor baffle gap, square for decreasing outboard separatrix – limiter gap. The higher triangularity case is also indicated (δ_{lower}=0.2 rather than δ_{lower}=0.1)

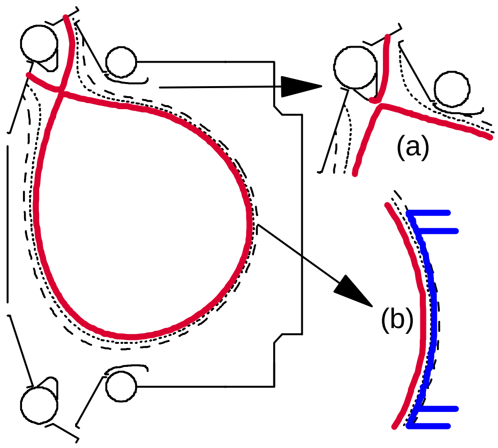

Fig. 5. Illustration of the magnetic geometry of TdeV indicating minimum gaps (a) and (b) for Fig. 3. Flux is plotted as 5% contours

Conclusion

Steady-state H-modes in type III ELM regime have been produced on TdeV with electron cyclotron and lower hybrid heating. The input power for L-H transition is consistent with the ITER threshold power scaling laws. In terms of line-average density, no hysteresis is observed between L-H and H-L transitions.

The L-H transition in TdeV is extremely sensitive to the separatrix density, which manifests itself as a threshold density below which no L-H transitions were obtained with the available power. In terms of separatrix density, there is a clear hysteresis between L-H transitions, which occur at a higher value than H-L transitions for the same input power.

In contrast to the experiments reported in [4], H-modes were obtained with an outboard separatrix-limiter distance less than or of the order of one density scrape-off length. The confinement at the smallest distance was reduced by about 10%. Reduction of the separatrix-divertor baffle distance in a similar fashion improved the H-mode confinement over a more open configuration.

Acknowledgements

CCFM is supported by the Government of Canada, Hydro-Québec, and INRS.

References

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