Recent H-mode Results on ECH Plasmas in Heliotron J

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Recent 70-GHz, 0.4-MW ECH experiments in Heliotron J have revealed the existence of the spontaneous confinement transition, like that of the H-mode, at rather low threshold line-averaged densities of 1.2–1.6 × 10^{19} m^{-3}. The transition was discovered in two edge-iota windows: one is 0.54 < $\iota(a)/2\pi$ < 0.56 at separatrix discharge plasmas and the other is 0.62 < $\iota(a)/2\pi$ < 0.63 at partial wall-limiter discharge plasmas. The energy confinement time for the separatrix discharge plasmas was found to be enhanced beyond the normal ISS95 scaling in the transient H-mode phase, being 50% longer than that in the "before transition" phase.

Keywords:

heliotron, stellarator, H-mode, transition phenomena, confinement improvement

The research program regarding Heliotron J (a low shear helical-axis heliotron having four periods, $\iota/2\pi$ = 0.557, R = 1.2 m, and a < 0.2 m) is focused on the establishment, characterization, and improvement of plasma confinement in the next-generation heliotron line [1,2]. The characterization of 70-GHz, 0.4-MW ECH plasma confinement in Heliotron J was studied with special regard to its magnetic configuration effects [3]. The experiments revealed that the energy confinement characteristics in the normal confinement mode (T_e < 1.5 keV, T_i^{CX} < 0.2 keV, $\bar{n}_e$ = (0.2 – 3.0) × 10^{19} m^{-3}, W_p^{diam} < 3 kJ, and B_0 < 1.5 T) indicate the existence of "good" confinement plasmas whose energy confinement time becomes 1.5–2 times longer than the ISS95 scaling [4]. At present, it is not clear whether these good confinement plasmas are essentially different from those of the traditional ISS95 scaling. Beside these good confinement plasmas, the spontaneous confinement improvement mode, like that of the H-mode, was recently discovered during the ECH with strong gas puffing in two edge-iota windows.

Figure 1 shows the time evolution of the observed H-mode behavior in which the sudden drops in both H_α and SOL probe signals and the subsequent strong rises in both line-integrated density and diamagnetic energy content were observed at the H-mode transition. In the case of the vacuum edge iota $\iota(a)/2\pi$ = 0.542, the peak increment of the plasma energy content was about 70% while that in the case of $\iota(a)/2\pi$ = 0.623 was about 30%. These confinement improvements remained transient on an energy confinement timescale and the post-transition steady-state phase was not yet attained. ECE measurements revealed that, after the transition, the core electron temperature inside r/a < 2/3 slightly increased or was well maintained despite the strong increase in density. On the other hand, in the SOL region, Langmuir probe measurements revealed that, after the transition, the SOL density fluctuation also dropped in the fre-

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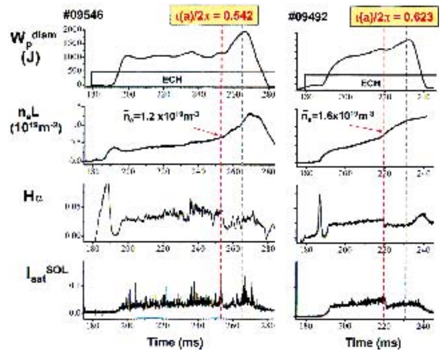

Fig. 1 Time evolutions of the diamagnetic energy content W_p^{diam}, the line-integrated density n_eL, H_α signal, and the Langmuir probe signal in the SOL, I_{sat}^{SOL}, for the separatrix plasma ($\iota(a)/2\pi$ = 0.542) and the partial wall-limiter plasma ($\iota(a)/2\pi$ = 0.623). H-mode transition (*red dashed line*) and its back-transition (*gray dashed line*).

quency range below 200 kHz.

From the iota scan (auxiliary vertical coil current scan) experiment, the two edge-iota windows for this transition were discovered, in which one window ($0.54 < \iota(a)/2\pi < 0.56$) was given by the separatrix discharge plasma and the other window ($0.62 < \iota(a)/2\pi < 0.63$) was given by the partial wall-limiter discharge plasma. The VMEC equilibrium calculation predicts that the change of the edge-iota value at averaged beta values less than 0.3% is < (–)0.020. The change of the edge-iota value at measured bootstrap currents of < 2 kA is < (+)0.015. These changes are compensatory so that, in this report, we choose the vacuum edge-iota value as a reference to the transition. It is noted that the boundaries of these two edge-iota windows are near the natural resonances of Heliotron J such as (i) the intrinsic n = 4, m = 7 (fourfold symmetry of Heliotron J) and (ii) n = 8, m = 13 and 15, and (iii) n = 12, m = 19, where m and n are the poloidal and toroidal mode numbers, respectively [4].

As for the threshold density, the minimum threshold line-averaged density was found to be in the range of $1.2–1.6 \times 10^{19}$ m^{-3}.

After the transition, with special regard to the comparison with the ISS95 scaling, the enhancement factor of the experimental global energy confinement time, H_{ISS95}, which includes the effect of dW/dt, has reached over 1.5 for the separatrix plasmas ($0.54 < \iota(a)/2\pi < 0.56$) while that for the partial wall-limiter plasmas ($0.62 < \iota(a)/2\pi < 0.63$) remains almost unchanged, as shown in Fig. 2. The reason for this difference is still an open question.

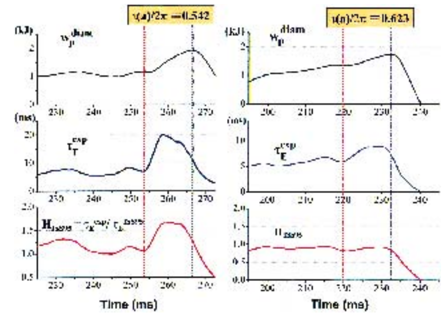

Fig. 2 Energy confinement time τ_E^{exp} and its enhancement factor, H_{ISS95}, at different iotas.

The present ECH confinement improvement is transitory in nature and the causes of its termination are still unclear. Based on observations, the termination events seem to fall into two groups: one is the higher density termination ($\bar{n}_e > 2 \times 10^{19}$ m^{-3}) and the other is the lower density termination ($\bar{n}_e < 2 \times 10^{19}$ m^{-3}). As for the higher density termination, a candidate mechanism is the 70-GHz ECH cut-off at central densities over $n_e(0) > 3 \times 10^{19}$ m^{-3}. The possibility of the termination due to the severe impurity influx and/or accumulation is limited, since the bolometer signal after the transition showed no marked increase as compared with the increasing density rate. Intermittent edge activities were often observed for the H_α and the SOL electrostatic probe signals during the improved confinement phase as shown, for instance, in the case of $\iota(a)/2\pi$ = 0.542 in Fig. 1. As shown in Fig. 2, at the timing when the plasma energy content is still rising, the termination sequence is considered to be already triggered, then leading to the back-transition. Unfortunately, the magnetic fluctuation data are not currently available, but the edge activities may become a candidate cause of the saturation and decrease of H_{ISS95}.

Thus, it is concluded that high performance of the H-mode in the helical-axis heliotron with a separatrix discharge configuration was attained by means of the confinement enhancement achieved over the ISS95 scaling as measured using plasma diamagnetism.

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