CONF-9706131--18

Fast Pressure Measurements of the Local Island Divertor on the Compact Helical System*

by

J. F. Lyon, C. C. Klepper, A. C. England
Fusion Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

and

A. Komori, N. Ohyabu, S. Masuzaki, T. Morisaki, S. Morita, H. Suzuki, K. Tanaka, O. Motojima,
National Institute for Fusion Studies, Oroshi, Toki 509-52, Japana

to be presented at the
European Physical Society Meeting
Berchtesgaden, Germany
9-13 June 1997

*Research sponsored in part by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

DISCLAIMER

Fast Pressure Measurements of the Local Island Divertor on the Compact Helical System

J. F. Lyon, C. C. Klepper, A. C. England
Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831 U.S.A.

A. Komori, N. Ohyabu, S. Masuzaki, T. Morisaki, S. Morita, H. Suzuki, K. Tanaka, O. Motojima, *National Institute for Fusion Studies, Oroshi, Toki 509-52, Japan*

Development of an effective divertor is critical for the viability of the stellarator (helical system) concept. Figure 1 shows the local island divertor (LID) concept [1] in which particle and heat fluxes are channeled to the back of the LID head by the magnetic field structure of an externally produced $m = 1$, $n = 1$ island that is outside the last closed flux surface. The leading edge of the LID head is protected from the outward heat flux from the plasma because it is located inside the 1/1 island and the particles that strike the target plates on the back of the LID head in the throat of the LID pump module are then pumped efficiently.

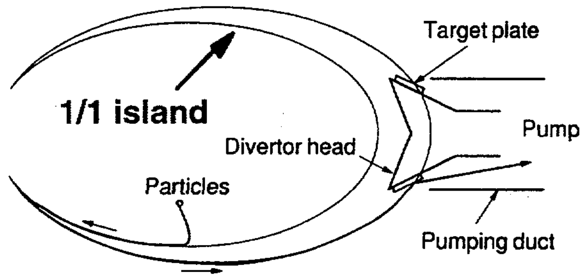

Fig. 1. The 1/1 magnetic island geometry and its relation to the LID chamber for O-point operation. The outer edge of the island intersects target plates on the back of the LID head.

A set of 16 coils was used to create a 1/1 island in the Compact Helical System (CHS). The current (I_{LID}) in the LID coils was chosen to position either the O-point or the X-point of the external 1/1 magnetic island at the location of the LID head. The principal diagnostic in this study [2] was an ASDEX-style ionization gauge [3] that allowed fast (~1-ms) measurements of the neutral pressure buildup behind the divertor head in the LID module.

1/1 Island Effect on Particle Pumping

A typical O-point island case is shown in Fig. 2. Ion Bernstein wave (IBW) heating was used for plasma initiation and neutral beam injection (NBI) was used for plasma heating. The on-axis field was 0.92 T and P_{NBI} was 0.82 MW in these experiments. The pressure p in the LID chamber and the electron density n_e peak just after the end of the gas puff. The second rise in the LID pressure (at ≈170 ms) after the plasma terminates is due to a second gas puff used to suppress runaway electrons during the magnetic field

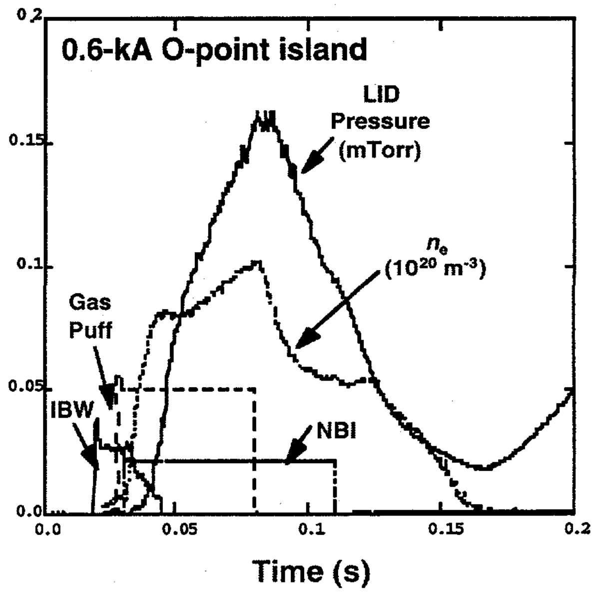

Fig. 2. An O-point island shot with I_{LID} = 0.6 kA.

rampdown. The LID pressure p lags the gas puff, the rise in n_e and the total particle flux into the LID chamber, $\Gamma = (S + C)p + V dp/dt$, because of the LID chamber pumpout time. Here V, S and C are the volume, pumping speed and conductance for the LID chamber.

The LID pressure is higher with O-point operation than with no island or X-point operation for a constant gas puff. The density is lowest and falls fastest after gas puff turnoff with O-point operation, as expected if particles exit the vacuum vessel faster, thus reducing the gas that can recycle to the plasma. With no 1/1 island, the density remains high until NBI turnoff. X-point operation gives intermediate behavior. The increase in p and the decrease in n_e demonstrate that the island is effective in moving particles from the plasma edge to the LID chamber.

The pressure in the LID chamber should increase as the 1/1 island size grows to encompass the LID head. However, too large an island could lead to the island intercepting the vacuum vessel wall or to ergodization of the island, and hence less effective diversion of particles into the LID chamber. With X-point operation, the amount of particles entering the LID chamber should not change with I_{LID} unless some particles are intercepted by the wall, or the balance between flow along field lines and diffusion across the field changes with I_{LID}. Lithium beam measurements of n_e in the plasma edge are consistent with a 1/1 island at the plasma edge [4].

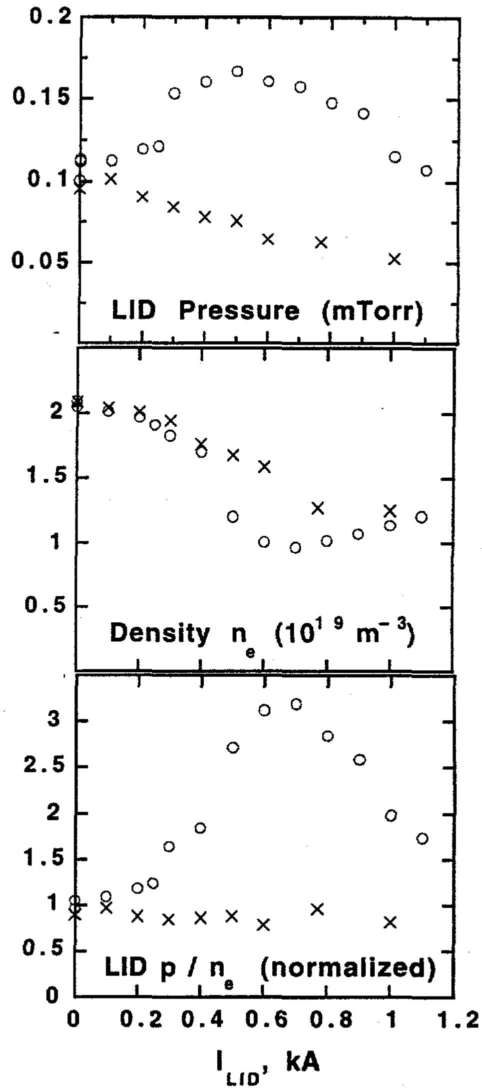

Fig. 3. The LID pressure and the plasma density depend on the island size and orientation. The normalized value p/n_e peaks at the design value for the O-point island size. The symbols "o" and "x" refer to O-point and X-point operation.

Figure 3 shows peak values for p and n_e (at gas puff turnoff) as I_{LID} is varied from 0 (no island) to 1.1 kA for a constant gas puff with O-point and X-point operation. The LID pressure for O-point operation peaks at $I_{LID} \approx 0.5$ kA whereas the X-point p falls monotonically with I_{LID} in approximately the same way as n_e falls as the island size is increased. Comparing the O-point and X-point pressures for the same n_e values shows that O-point operation has a much higher exhaust efficiency. The ratio p/n_e peaks at $I_{LID} \approx 0.6$-0.7 kA at a value >3 times the no-LID value while the X-point values remain roughly constant at the no-LID value.

The relation of the 1/1 island to the LID head can also be changed by moving the head through a fixed island. Figure 4 shows the variation of the LID pressure at gas puff turn-off as the LID head is moved inward with I_{LID} = 0 or 0.6 kA (O-point and X-point operation). The LID pressure increases exponentially with distance into the 1/1 island. The e-folding lengths of 2.2 cm (O-point), 2 cm (no LID) and 1.8 cm (X-point) are similar to the 1.6-cm to 2-cm decay lengths for the ion saturation current measured on the back of the LID head during the same radial scan [4].

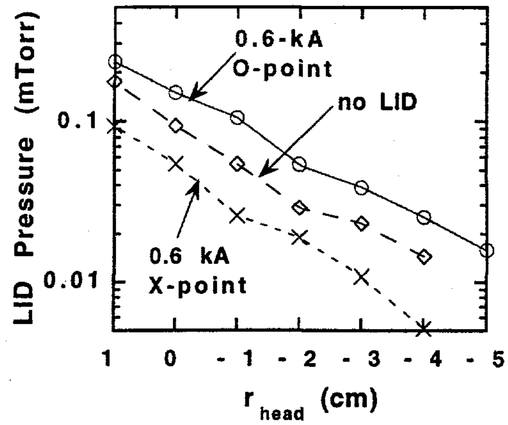

Fig. 4. The LID pressure falls exponentially as the LID head is retracted from the plasma edge. The 0.6-kA O-point values are larger than the no-LID and 0.6-kA X-point values.

The LID head was biased to determine if $\boldsymbol{E} \times \boldsymbol{B}$ drifts could be imposed on the plasma edge to affect the flow of particles into the LID chamber. Figure 5 shows that the pressure in the LID chamber is ~50% higher when −150 V is applied to the LID head for a short period (80 ms < t < 100 ms) during 0.6-kA O-point operation [5]. Although biasing the head improved the pumping efficiency, it did not affect the bulk plasma properties: the plasma density and the stored energy were unchanged. Biasing the LID head also led to a pressure increase in the LID chamber with I_{LID} = 0 and with 0.6-kA X-point operation. A similar observation was made by Evans et al. [6] when a small scoop limiter was inserted in the O-point of a small m = 7, n = 2 island on the TEXT tokamak. A large $\boldsymbol{E} \times \boldsymbol{B}$ island circulation velocity was postulated to compensate the effect of the large radial diffusion and to explain the larger than expected increase in the scoop pumping efficiency that was observed.

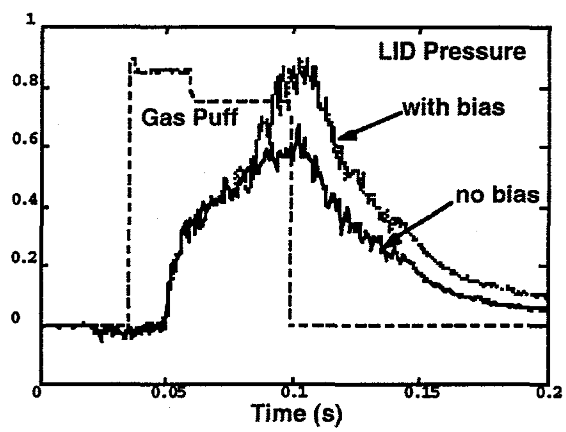

Fig. 5. Biasing the LID head improves the pumping efficiency for 0.6-kA O-point operation.

With no LID island, the particle exhaust is limited by the conductances to the vacuum vessel and LID chamber pumps. With an O-point island, additional particle flux is channeled into the LID pump chamber. The value for the particle flux Γ into the LID chamber from Fig. 2 is ≈3 torr·l/s, compared to ≈10 torr·l/s from the CHS gas puff. From the I_{LID} scan in Fig. 3, the ratio of particle fluxes into the LID chamber for optimized O-point operation vs X-point or with no 1/1 island is ≈3.6.

A value of $S + C$ = 16,000-20,000 l/s is obtained by requiring Γ = 0 when the ion saturation current and n_e decay to zero after gas puff turnoff. This in reasonable agreement with the values $C \sim 9000$ l/s and $S \sim 9000$ l/s obtained by comparing the time behavior of the pressure in the LID chamber (with and without the LID chamber cryopump) with the calculated time dependence of the pressure for a gas puff without plasma. The approximate agreement of the $S + C$ values with and without plasma suggests that the plasma flux into the LID pump chamber does not affect the flow of neutrals back into the CHS vacuum chamber (no plasma blocking occurs in the relatively wide channel into the LID pump chamber).

These experiments indicate that a local island divertor can be effective for particle control on a stellarator with a helical separatrix (a heliotron/torsatron). The next application will be on the Large Helical Device. The improvement in the particle exhaust efficiency using the LID head in combination with an O-point island is related to the change (as a result of the 1/1 island) in the density gradient at the plasma edge and the wall recycling [4]. The 1/1 island also has a significant effect on the main plasma properties, as seen by the similar variation of n_e with I_{LID} for the LID head fully retracted and the LID head inserted. The global plasma properties (stored energy, radiated power P_{rad}, density decay time) also change with I_{LID} and insertion or retraction of the LID head in a way that correlates with n_e. The value of P_{rad} is a sensitive indicator of the effect of the island on the plasma; it varies a factor of 5 as I_{LID} varies. However, Fig. 6 shows that $P_{rad} \propto n_e^2$, which implies that Z_{eff} is constant, for O-point and X-point operation independent of I_{LID}. Also W/n_e, which is proportional to the average plasma temperature and the energy confinement time τ_E, is the same for O-point and X-point operation and improves with island size for both cases.

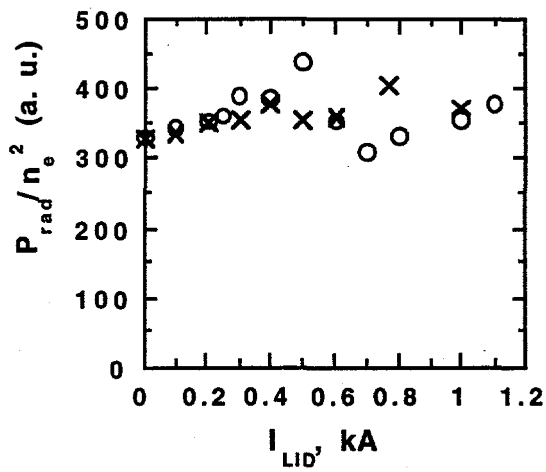

Fig. 6. P_{rad}/n_e^2 is independent of O-point (o) or X-point (×) operation with the LID head in.

References

[1] N. Ohyabu, et al., *J. Nucl. Mater.* **145-147**, 844 (1987).

[2] A. Komori, et al., *Proc. Plasma Physics and Controlled Nuclear Fusion Research*, Montreal, 1996, IAEA-CN-64/C1-2.

[3] G. Haas, et al., *J. Nucl. Mater.* **121,** 151 (1984).

[4] S. Masuzaki et al., "Edge plasma control using an LID configuration on CHS," *this conf.*

[5] A. Komori, et al., *Annual Report of National Institute for Fusion Science April 1995-March 1996*, ISSN 0917-1185, 218 (1996).

[6] T. E. Evans, et al., *Controlled Fusion and Plasma Physics* (Proc. 15th Eur. Conf. Madrid, 1987), Vol. 11D, Part II, 770 (1987).

Research sponsored in part by the Office of Fusion Energy Sciences, U. S. Department of Energy, under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corp.