§1. Local Particle Balance Analysis in the Closed Helical Divertor

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The local particle balance in the closed helical divertor was investigated. The effect of the in-vessel cryo-pump was observed to be so small that it is difficult to be observed in global plasma parameters changes.

Figure 1 shows the simple model for the analysis. The local particle balance can be expressed as below:

(a) without pumping (cryo-pump is not cooled)

$dP_d/dt = \Gamma_d - \Gamma_{ex}$

$\Gamma_{ex} \propto (P_d - P_0) \propto P_d$ (if $P_d \ll P_0$)

In steady state, $\Gamma_d = \Gamma_{ex} = C_d P_d$,

and $P_d/\Gamma_d = 1/C_d$. -- (1)

where Γ_d is the neutral particle flux from the divertor plate which is assumed to be equal to the ion flux to the divertor, Γ_{ex} is the neutral particle flux which escapes from the divertor region, P_d and P_0 are the neutral pressure in the divertor region and outside the region, C_d is the effective conductance between the inside and the outside the divertor region.

(b) with pumping (cryo-pump is cooled)

$dP_d/dt = \Gamma_d - \Gamma_{ex} - SP_d = \Gamma_d - C_d P_d - SP_d$

in steady state, $\Gamma_d = (C_d + S) P_d$,

and $P_d/\Gamma_d = 1/(C_d+S)$. -- (2)

where S is the pumping speed of the cryo-pump.

Figure 2 shows the C_d at 6I and 8I sections estimated from (1) as a function of the ion saturation current (I_{sat}) measured by the Langmuir probe which is assumed to be proportional to Γ_d. It shows C_d at the both sections are almost same. C_d decreases with increase in I_{sat} possibly caused by the plasma screening. Figure 3 shows the measured values of P_d/Γ_d at the 8I and 6I sections. They are almost same during the discharges in which the both cryo-pumps were cooled. It is reasonable because C_d in both sections are almost same as shown in Fig. 2. In the case of the discharges in which only the cryo-pump in 8I section was cooled, the P_d/Γ_d in 8I is about 12 % smaller than that in 6I section in which the cryo-pump was not cooled. This means the P_d for the same Γ_d is 12 % smaller in the pumping section, and this means the 12 % smaller recycling flux (Γ_{ex}) from the closed divertor region. To estimate the effect of the pumping on the total recycling, it is assumed that a half of the divertor flux comes to the inboard side divertor. Then the effect of the pumping at a toroidal section can be estimated as below:

12 (%)/10 (sections)/2 = 0.6 %.

In the 17th experiment campaign, the cryo-pumps in the four sections (6I, 7I, 8I, 10I) were activated at a maximum. So the maximum reduction of the recycling flux is 0.6×4=2.4%, and it seems difficult to be observed in global plasma parameters changes. From the results of the global particle balance analysis, the total pumped particle amount was around 3-4 % of the total injected hydrogen amount. This seems to be good agreement with the estimation.

Now the improvement of the pumping speed of the cryo-pumps is going on. The effect of the pumping can be expected to be larger by the improving.

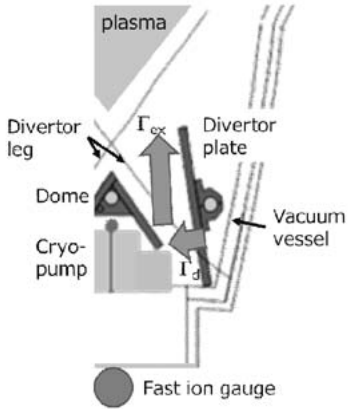

Fig. 1. Simple model for the local particle balance analysis

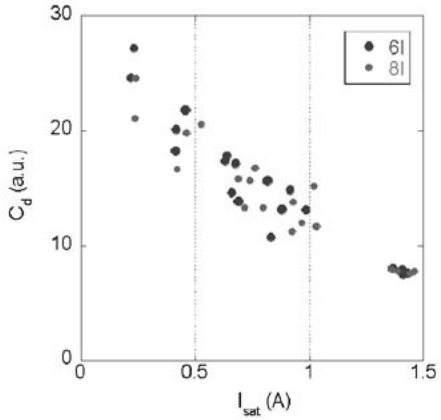

Fig. 2. Effective conductance C_d as a function of the divertor ion saturation current (I_{sat}).

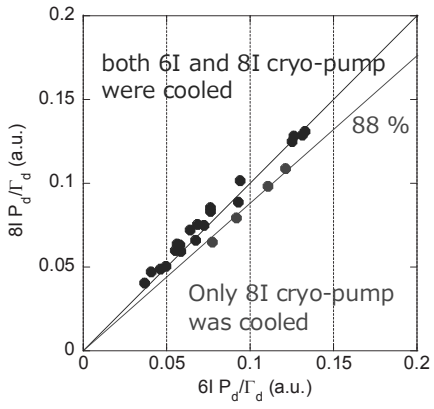

Fig. 3. P_d/Γ_d in 6I and 8I sections. Red circles show the data during the discharges in which the cryo-pumps in both sections were cooled. Blue circles show the data during the discharges in which only 8I cryo-pump was cooled.