§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)
\[ \frac{dP_d}{dt} = \Gamma_d - \Gamma_{ex} \]
\[ \Gamma_{ex} \propto (P_d - P_0) \propto P_d \text{ (if } P_d \ll P_0) \]
In steady state, \( \Gamma_d = \Gamma_{ex} = C_d P_d \),
\[ \frac{P_d}{\Gamma_d} = \frac{1}{C_d}. \] -- (1)

where \( \Gamma_d \) is the neutral particle flux from the divertor plate which is assumed to be equal to the ion flux to the divertor, \( \Gamma_{ex} \) 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)
\[ \frac{dP_d}{dt} = \Gamma_d - \Gamma_{ex} - SP_d = \Gamma_d - C_d P_d - SP_d \]
in steady state, \( \Gamma_d = (C_d + S) P_d \),
\[ \frac{P_d}{\Gamma_d} = \frac{1}{C_d+S}. \] -- (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 divertor ion saturation current \( I_{sat} \) measured by the Langmuir probe which is assumed to be proportional to \( \Gamma_d \). 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 \( \frac{P_d}{\Gamma_d} \) at the 8I and 6I sections. They are almost same during the discharges in which 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 \( \frac{P_d}{\Gamma_d} \) in 8I is about 12 % smaller than that in 6I section in which the cryo-pump was not cooled. This means the \( P_0 \) for the same \( \Gamma_d \) is 12 % smaller in the pumping section, and this means the 12 % smaller recycling flux (\( \Gamma_{ex} \)) 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:
\[ 12 \% / 10 \text{ (sections)} / 2 = 0.6 \%. \]

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.