Density Control Using the New Divertor Pumping Configuration in DIII-D

by
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The Changes to the Pumping Configuration Were Driven by the DIII–D Advanced Tokamak Program

- High performance “AT” plasmas benefit from:
  - High triangularity ($\delta$), double-null (DN) shaping $\rightarrow$ higher $f_{bs}$ and $\beta_N$
  - Application of ECCD ($\propto 1/n_e$)
    $\rightarrow$ Shape/maintain favorable current density profiles
    $\rightarrow$ Achieve 100% non-inductive current

- Density control in a high-$\delta$ DN shape is difficult to maintain if active particle exhaust is limited to only one divertor (pre-2006)
  $\rightarrow$ Solution: Modify hardware for pumping high $\delta$, DNs from both divertors

- Changes to the lower divertor pumping configuration were made during the 2005-2006 vent to implement this solution

- The new pumping configuration has improved density control in DN and near-DN shapes
Recent Modifications to the Lower Divertor Makes it Possible to Pump High-$\delta$ DN Plasmas from Both Divertors

- Prior to 2006, the lower divertor cryopump was poorly situated for removing recycled neutral particles from high $\delta$, symmetric DN$s$
- A shelf extension was installed in 2006 to serve as a conduit for neutrals between the lower outer divertor target and the pumping plenum
The Fractional Contribution of Each Cryopump to the Total Particle Exhaust Rate Depends on the Magnetic Balance

\[ F_{UP-IN} + F_{UP-OUT} + F_{LO-OUT} = 1 \]

- DN: \( F_{UP-OUT} > F_{UP-IN} \) & \( F_{LO-OUT} \)
- DN: \( \frac{F_{UP-OUT}}{F_{LO-OUT}} \approx 2.5 \)
- DN: \( F_{UP-IN} \) removes \( \approx 10\% \) of total pumped particles

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**Top View**

\( B_T - CW \)

- \( F_{UP-OUT} > F_{UP-IN} \) & \( F_{LO-OUT} \)

- \( \frac{F_{UP-OUT}}{F_{LO-OUT}} \approx 2.5 \)

- \( F_{UP-IN} \) removes \( \approx 10\% \) of total pumped particles
Reversing the Direction of $B_T$ Significantly Affects the Fractional Contributions of the Two Outer Pumps

$F_{UP-IN} + F_{UP-OUT} + F_{LO-OUT} = 1$

- DN: $F_{UP-OUT} \approx F_{LO-OUT}$ near DN
- DN: $F_{UP-IN}$ is still $\approx 10\%$

Top View

Fraction of Total Particle Pumping Rate

$dR_{sep}$ (cm)
Both Particle Drifts and Divertor Geometry Appear to be Important Factors in Pumping Behavior

- The difference in pumping “crossover” locations in the CW and CCW cases is qualitatively consistent with the roles of particle drifts in the SOL and divertor*:
  - $B_T - CW \rightarrow B \times \nabla B \downarrow$, $B_T - CCW \rightarrow B \times \nabla B \uparrow$

- But still not symmetric around $dR_{sep}=0$: May be due to differences in geometry between upper and lower divertors (e.g., neutral particle trapping)

Particle Pumping and Low Plasma Density Can Be Maintained in Both Upwardly Biased and Downwardly-Biased DN Shapes

- The total particle pumping rate was greater than the particle fueling rate from the beams
  ⇒ The “wall” was a source of particles at the time of measurement

- The combined particle exhaust of the two outer pumps remained nearly constant as dRsep was changed near DN

- The pedestal density was fairly insensitive to changes in magnetic balance
Initial Results at Controlling Density in DN AT Plasmas are Encouraging

- $\beta_N \approx 3.6$, HL89 = 2.6 during the high power phase
- Lower outer pump makes an important ($\approx 30\%$) contribution to particle control
- $\bar{n}_e$ and $n_{e,ped}$ are steady, and they are $\approx 20\%$ lower than previous DN densities with upper pumps only
The Modified Pumping Configuration Makes it Possible to do Experiments involving High Gas Throughput in High-δ DN Plasmas for Both B_T Directions

- Constant $\beta_N$
- Fueling typical of puff-and-pump scenarios
- <8% particle removal
- The two outer pumps compensate when the $B_T$ direction is changed
- Steady, $\bar{n}_e (CW) = \bar{n}_e (CCW)$

$\beta_N$ and $\bar{n}_e (10^{20} \text{ m}^{-3})$ graphs showing $B_T$ direction effects.

D2 Injection

HL89 ~ 1.8

$\bar{n}_e / n_{GW} \approx 0.7$
Summary and Conclusion

- Simultaneous particle pumping from both upper and lower divertors of high triangularity, DN plasmas is now possible in DIII-D
  - Characterized pumping WRT two key parameters: dRsep and B_T - direction
  - Demonstrated density control in high performance AT plasmas

- In addition to its value to the AT program, the new pumping capability is able to handle high gas throughput scenarios in DN and near-DN shapes, e.g, Puff and Pump in DN*

*T.W. Petrie, IAEA FEC 2006
New Lower Divertor Has Enabled Improved Density Control in High $\beta$, Double Null Plasmas
DIII-D Plasma Operation Produces a Wide Range in Neutral Pressure Inside the Lower Divertor Baffle

- $S_0 \Rightarrow$ pumping speed of pump
- $S_{\text{EFF}} \Rightarrow$ effective pumping speed
- $S_{\text{EFF}} \approx 0.5 \times S_0$
- Conductance is matched to $S_0$
Divertor Tile Heating is Much More Uniform in the New Lower Divertor

- Reduced tile gaps to ≈ 0.4 mm
- Alignment of tiles to ≤ 0.1 mm height differential
Definition of Magnetic Balance

\[ dR_{sep} = R_{LOW} - R_{UP} \]

- \( R_{LOW} \) = major radius of the lower divertor separatrix flux surface at the outer midplane
- \( R_{UP} \) = major radius of the upper divertor separatrix flux surface at the outer midplane

\[ dR_{sep} = -0.9 \text{ cm} \]
\[ dR_{sep} = +0.9 \text{ cm} \]