Divertor geometry effects on particle pumping in JT-60U and DIII-D

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41st APS Meetings, November 17, 1999, Seattle, WA
Divertor Geometry Effects on Particle Pumping in JT-60U and DIII-D

H. TAKENAGA, A SAKASAI, H. KUBO, N. ASAKURA, Japan Atomic Energy Research Institute, M.J. SCHAFFER, T.W. PETRIE, M.A. MAHDAVI, D.R. BAKER, General Atomics, S.L. ALLEN, G.D. PORTER, T.D. ROGNLIEN, M.E. RENSINK, Lawrence Livermore National Laboratory, D.P. STOLTER, C.F.F. KARNEY, Princeton Plasma Physics Laboratory — Several types of pumped divertors have been installed in tokamaks. It is important to compare the pumping characteristics with different divertor geometries for optimization of the divertor pumping scheme. In the W-shaped divertor of JT-60U with the pumping from the inner private flux region, the divertor pumping rate was estimated to be 2.4% of the divertor particle flux in the high density region, and it depended strongly on the main plasma density. In DIII–D with the pumping from the outer divertor region, a large divertor pumping rate was observed, due to the pumping configuration. Also a strong dependence on the main plasma density was observed. The comparison of the pumping characteristics between JT-60U and DIII–D will be presented based on analysis results using the UEDGE/DEGAS2 modeling.

Supported in part by JAERI and by U.S. DOE Contracts DE-AC03-99ER54463, W-7405-ENG-48, and DE-AC02-76CH03073.
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Introduction

Background

Divertor pumping is important for
- Density control in the main plasma for fusion power control
- Divertor control for effective heat removal
- Effective helium ash exhaust

Several types of divertor geometry are adopted in tokamaks
- Open, semi-closed and closed divertor
- Horizontal, inclined and vertical targets and dome
- Strike-point pumping and private flux pumping

Which is the best for pumping?

Objectives

To clarify the geometry effects on particle pumping.

Optimization of pumping scheme in a future machine
Divertor geometry in JT-60U

W-shaped pumped divertor

Inner private flux pumping (IPP)  1997~

Both side private flux pumping (BPP)  1999~

pumping port to cryopump  3 toroidal positions

Gap_in

Gap_out
Divertor geometry in DIII-D

Upper divertor (Baffled divertor)
  Outer strike-point pumping (UOP)

Lower divertor (Open divertor)
  Outer strike-point pumping (LOP)
  Private flux pumping (LPP)

Outer strike-point pumping
  Private flux pumping

Gap_out

Cryopump

Gap_out
Estimation of pumping flux in JT-60U

Inner private flux pumping
I_p=1.5 MA, B_T=3.5 T, q_95=3.94, Gap_in=3.5 cm

w pump
\[ \Phi_{\text{NB}} + \Phi_{\text{GP}1} = \Phi_{\text{absorb}} + \Phi_{\text{pump}} \]
w/o pump
\[ \Phi_{\text{NB}} + \Phi_{\text{GP}2} = \Phi_{\text{absorb}} \]

\[ \Phi_{\text{GP}1} - \Phi_{\text{GP}2} = \Phi_{\text{pump}} \]
\[ \Phi_{\text{NB}} = 1 \times 10^{21} /s \]
\[ \Phi_{\text{GP}1} = 1 \times 10^{22} /s \]
\[ \Phi_{\text{GP}2} = 3.9 \times 10^{21} /s \]
\[ \Phi_{\text{pump}} = 6.2 \times 10^{21} /s \]
\[ \Phi_{\text{absorb}} = 4.9 \times 10^{21} /s \]

Pumping speed ~31 m^3/s
Outer strike-point pumping

\[ I_p = 1.2 \text{ MA}, \quad B_T = -1.6 \text{ T}, \quad q_{95} = 3.0, \quad \text{Gap}_\text{in} = 3.1 \text{ cm} \]

\[ \Phi_{\text{pump}} = (\text{Pumping speed}) \times P_{D2} \]

\[ = 43.7 \text{ m}^3/\text{s} \times 0.39 \text{ Pa} \]

\[ = 16.9 \text{ Pam}^3/\text{s} \]

\[ = 8.45 \times 10^{21} \text{ /s} \]

\[ \Phi_{\text{NB}} = 2.7 \times 10^{20} \text{ /s} \]

\[ \Phi_{\text{GP}} = 6.9 \times 10^{21} \text{ /s} \]

\[ \Phi_{\text{absorb}} = \Phi_{\text{GP}} + \Phi_{\text{NB}} - \Phi_{\text{pump}} \]

\[ = -1.3 \times 10^{21} \text{ /s (fuelling)} \]
Density dependence

- DIII-D LPP data at $I_p=0.8$ MA is comparable or smaller than JT-60U IPP data.
- JT-60U BPP data is smaller than JT-60U IPP data, especially for low density case.
- Different dependence on plasma current in DIII-D LPP could be ascribed to different particle confinement.
In JT-60U, pumping flux/total D\(\alpha\), which indicates the pumping ratio, is comparable with that in DIII-D in the high density regime. However, it decreases in the low density regime.

In DIII-D, the decrease of pumping flux/total D\(\alpha\) is not observed.

The difference between JT-60U and DIII-D might come from the cryopump position.

In DIII-D, the difference for different pumping scheme is not obvious.
Gap dependence

- DIII-D LOP data is similar as JT-60U IPP high density data.
- JT-60U BPP high density data steeply decreases with Gap_out and is smaller than JT-60U IPP high density data at the same gap. It could be related to the back flow at the outer gap as shown in the inset due to in-out asymmetry.
- JT-60U BPP low density data becomes small due to strong in-out asymmetry even at small gap.
**UEDGE/DEGAS2 Modelling**

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- In this presentation, an iterative calculation between DEGAS2 and UEDGE was not performed.
- Pumping flux was calculated for various \( f_{pump} \) which is the pumping ratio at the pumping slot.
- The background plasma was fixed during \( f_{pump} \) scan.
  It means that the particle flux same as the pumping flux is fuelled to keep the plasma parameters.
Calculation mesh for JT-60U

UEDGE parameters
\[ n_{\text{core}} = 2.4 \times 10^{19} \text{ m}^{-3}, \quad P_{\text{core}} = 7.0 \text{ MW} \]
\[ D = 0.25 \text{ m}^2/\text{s}, \quad \chi = 1.0 \text{ m}^2/\text{s} \]
\[ R_{\text{recycl}} = 0.985 \]
Carbon yield = 0.5 \times (Haasz yield)

DEGAS2 parameters
\[ R_{\text{recycl}} = 0.995 \text{ (wall), 1.0 (under dome)} \]
\[ T_{\text{wall}} = 300 \degree \text{C} \]
Calculation results with fpump=0.1

Electron density [ m$^{-3}$ ]

Ion temperature [ eV ]

Electron temperature [ eV ]

Neutral density [ m$^{-3}$ ]
The calculated total $D_\alpha$ is smaller by a factor of 4 than experiment (Pcore of 7MA is different from the experimental value of 11MW).

The pumping flux/total $D_\alpha$ with fpump=0.08 is almost the same as experiment.
Both side private flux pumping

Particle balance

fpump = 0.1

$\Phi_{\text{recycl}} = 1.52 \times 10^{23}$

$\Phi_{\text{th-back}} = 8.69 \times 10^{21}$ (0.057)

$\Phi_{\text{th-pump}} = 6.49 \times 10^{21}$ (0.043)

$\Phi_{\text{inner-recycl}} = 9.5 \times 10^{22}$ (0.625)

$\Phi_{\text{th-back}} = 1.58 \times 10^{22}$ (0.104)

$\Phi_{\text{th-pump}} = 1.94 \times 10^{22}$ (0.128)

$\Phi_{\text{slt-pump}} = 1.45 \times 10^{22}$ (0.095)

$\Phi_{\text{slt-back}} = 1.30 \times 10^{22}$ (0.086)

Neutral density [ m$^{-3}$ ]

To pump with $fpump$
Comparison between inner and both side

- $\Phi_{\text{th-back}}$ is larger than $\Phi_{\text{th-pump}}$, which suggests the back flow at the outer throat from under the dome due to in-out asymmetry as expected from the experiment.

- However, pumping flux in both side private flux pumping is smaller by a only few percent than inner side private flux pumping at the same fpump.

- Calculated pumping flux/total $D_{\alpha}$ with fpump=0.05 is the same as experiments.
Calculation mesh for DIII-D

UEDGE parameters

- \( n_{\text{core}} = 2.75 \times 10^{19} \text{ m}^{-3} \)
- \( P_{\text{core}} = 5.0 \text{ MW} \)
- \( D = 0.2 \text{ m}^2/\text{s}, \chi = 0.4 \text{ m}^2/\text{s} \)
- \( R_{\text{recycl}} = 1.0 \)
- Carbon yield = 0.5 \times (\text{Haasz yield})

DEGAS2 parameters

- \( R_{\text{recycl}} = 1.0, T_{\text{wall}} = 30^\circ \text{C} \)
- \( f_{\text{ion pump}} \): pumping ratio for ion flux onto the pumping slot
- \( f_{\text{neutral pump}} \): pumping ratio for neutral at the pumping slot
Calculation results in DIII-D

Electron density [m^{-3}]

Ion temperature [eV]

Electron temperature [eV]

Neutral density [m^{-3}]
Comparison between JT-60U and DIII-D

Particle balance

\[ f_{\text{ion}}^{\text{pump}} = 0.1 \]

\[ f_{\text{neutral}}^{\text{pump}} = 0.1 \]

\[ \Phi_{\text{ion}} = 2.15 \times 10^{23} \]

\[ \Phi_{\text{recycl}} = 2.13 \times 10^{23} \]

\[ \Phi_{\text{inner recycl}} = 1.2 \times 10^{23} \]

\[ (0.563) \]

\[ \Phi_{\text{outer recycl}} = 9.2 \times 10^{22} \]

\[ (0.430) \]

\[ \Phi_{\text{th-back}} = 2.27 \times 10^{22} \]

\[ (0.105) \]

\[ \Phi_{\text{th-pump}} = 2.51 \times 10^{21} \]

\[ (0.012) \]

\[ \Phi_{\text{neutral}}^{\text{pump}} = 2.52 \times 10^{22} \]

\[ (0.117) \]

\[ \Phi_{\text{ion}} = 1.68 \times 10^{21} \]

\[ (0.008) \]

\[ \Phi_{\text{ion}} = 2.13 \times 10^{23} \]

\[ \Phi_{\text{pump}} / \Phi_{\text{ion}} = \text{neutral} \]

\[ f_{\text{pump}}^{\text{ion}} = \text{pump neutral} \]

\[ f_{\text{neutral}}^{\text{pump}} = f_{\text{pump}}^{\text{neutral}} \]

- The pumping ratio for DIII-D is larger by 30-50% than that for JT-60U with \( f_{\text{ion}}^{\text{pump}} = f_{\text{neutral}}^{\text{pump}} \), and is almost the same as for JT-60U with \( f_{\text{ion}}^{\text{pump}} = 0 \).

Data for JT-60U are plotted as a function of pumping ratio at the throat.
Summary

Experimental analysis
- Pumping flux / total $D\alpha$ in JT-60U is comparable with that in DIII-D in the high density regime. However, it decreases in the JT-60U low density regime.
- Pumping flux / total $D\alpha$ in the both side private flux pumping in JT-60U steeply decreases with increasing gap, and is smaller than that in the inner private flux pumping at the same gap.
- In DIII-D, the decrease of pumping flux / total $D\alpha$ is not observed, and the difference for different pumping scheme is not obvious.

UEDGE/DEGAS2 Modelling
- Back flow at the outer gap from under the dome was observed as expected from the experimental data in the both side private pumping in JT-60U.
- Pumping ratio for DIII-D is larger by 30-50% than for JT-60U at the same $fpump$. 