Investigation of Correlation Between RMPs and Density Pump-out on MAST and DIII-D

by
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RMPs suppress ELMs, but also lead to decreased particle confinement

• Resonant Magnetic Perturbations suppress ELMs

• RMPs reduce particle confinement, leading to a density pump-out

• Understanding this change in transport is important for performance in current and future devices
Internal coil (I-coils) system on MAST: 2 rows of 6 coils operated in n=3

- Experiments conducted in low collisionality H-mode
Internal coil (I-coils) system on MAST: 2 rows of 6 coils operated in n=3

Courtesy of E. Nardon (UKAEA)
ELM suppression and density pump-out as a result of RMP on DIII-D

- $D\alpha$ light
- Density
- I-coil current

SOLPS5 modeling

Low Triangularity

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ELM suppression and density pump-out as a result of RMP on DIII-D
ELM suppression and density pump-out as a result of RMP on DIII-D

Dα light
123302
123301

Density

\( \Delta n_e \)
Pump-out

I-coil current

kA

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No correlation between density pump-out and applied I-coil currents in DIII-D H-modes

ELM suppressed H-modes

\[ \Delta n_{e,\text{ped}} \times 10^{19} \text{ m}^{-3} \]

- Low triangularity, Even parity
- High triangularity, Even parity
- High triangularity, Odd parity

I-coil Current [kAt]

\[ \Delta n_{e,\text{ped}} \times 10^{19} \text{ m}^{-3} \]

Courtesy of E. Unterberg (ORNL)

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Correlation between density pump-out and applied I-coil currents in MAST L-modes

Trend in density pump-out with I-coil current magnitude, but large scatter in the data

Δ ne [m⁻³x10¹⁹]

I-coil current (kAt)

 Courtesy of A. Kirk (UKAEA)
Free streaming calculations for DIII-D show an increase in transport during RMP.

Free streaming particle transport $[m^2/s]$

TRIP3D: Vacuum field line tracing code

\[ D_\perp = \frac{N_{\text{open}}}{N} \frac{1}{N} \sum_{i=1}^{N} \frac{2L_i}{\Delta r_i^2} c_s \]

Error fields and $n=1$ C-coil correction

$n=3$ I-coil at 0 kA

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Free streaming calculations for DIII-D show an increase in transport during RMP

Free streaming particle transport \([m^2/s]\]

\[D_\perp = \frac{N_{\text{open}}}{N} \frac{1}{N} \sum_{i=1}^{N} \frac{\Delta r_i^2}{2L_i} c_s\]

\[D_M\]

\[D_{OFL}\]

\(n=3\) l-coil at 3 kA

TRIP3D: Vacuum field line tracing code

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Free streaming calculations for DIII-D show an increase in transport during RMP.

**Particle transport**

- **SOLPS5**: B2 is a 2D fluid edge code
- **EIRENE**: is a Monte-Carlo neutral code

**Calculated SOLPS5 profiles**

0 kA

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Free streaming as transport increase for RMPs gives good agreement with experiments

**Particle transport**

**Calculated SOLPS5 profiles**

**SOLPS5**: - B2 is a 2D fluid edge code
- EIRENE is a Monte-Carlo neutral code

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- **SOLPS5** - B2 is a 2D fluid edge code
- **EIRENE** is a Monte-Carlo neutral code

**Diagram:**
- Particle transport
- Calculated SOLPS5 profiles

**Graphs:**
- **Total diffusion [m^2/s]:**
  - 3 kA
  - \( \Psi_N \) vs. Total diffusion
- **Density [m^3]:**
  - \( \Psi_N \) vs. Density, with experimental data points

**Additional Text:**
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Quantifying magnetic perturbation allows direct comparison to density pump-out

Calculation of $D_{OFL}$

$$D_{\perp} = \frac{N_{open}}{N} \frac{1}{N} \sum_{i=1}^{N} \frac{\Delta r_i^2}{2L_i}$$

$D_M$

$D_{OFL}$

Error fields and C-coil correction

(DIII-D example as illustration)
Quantifying magnetic perturbation allows direct comparison to density pump-out

Calculation of $D_{\text{OFL}}$

$D_{\perp} = \frac{N_{\text{open}}}{N} \frac{1}{N} \sum_{i=1}^{N} \frac{\Delta r_i^2}{2L_i}$

$D_M$

$D_{\text{OFL}}$

(DIII-D example as illustration)

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Quantifying magnetic perturbation allows direct comparison to density pump-out

Calculation of $D_{OFL}$

Value used to investigate correlation

(DIII-D example as illustration)
Correlation of $D_{OFL}$ with $\Delta ne$ in L-mode on MAST

Integral of $D_{OFL}$

$R^2 = 0.90673$

- $\Delta ne \text{ [m}^{-3} \times 10^{19} \text{]}$

- Integral of $D_{OFL}$

- $\Delta$ Dofl phase Icoil

- Linear fit (Dofl)

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Correlation of pedestal density reduction with applied magnetic perturbations in DIII-D

Low collisionality H-mode plasmas with different shapes and RMP parities

\[ R^2 = 0.91278 \]

\[ \Delta n_e [\text{m}^{-3} \times 10^{19}] \]

\[ \text{Integral of } D_{OFL} \]

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Density pump-out increase linearly with increased $D_{OFL}$

Difference:
- H-mode versus L-mode
- Active pumping versus wall pumping
- Aspect ratio
- Rho*
- Collisonality
- Single versus double null
- Etc …
Discussion/Conclusion

• Vacuum code gives good match to experimental observations

• More precise calculation of magnetic perturbation in the edge leads to a correlation with density pump-out

• Including n=1 error-field correction and right parity and phasing of n=3 I-coil is important

• Technique can identify conditions where plasma response is important