Energy loss for grassy ELMS and effects of plasma rotation on the ELM characteristics in JT-60U

Energy loss for grassy ELMS and effects of plasma rotation on the ELM characteristics in JT-60U
Introduction
1. Introduction

2. ELM regime (higher)
   - Frequency dependence
   - Divertor heat flux
   - Collapse of T_e pedestal
   - Fluctuation properties
   - Pedestal characteristics
   - ELM control by toroidal rotation (at $\Omega_H$)

3. QH-mode regime (lower)
   - ELM control by toroidal rotation (at $\Omega_H$)
   - Requirement of counter NBI

4. Summary

Outline
Grassy ELM frequency is ~15 times higher than type I ELM frequency. Large ELM was replaced by high frequency ELMs. Similar frequency dependence to type I ELM. ELM frequency is higher than type I ELM frequency by high frequency ELMs. (Definition)

\[ P_{\text{sep}} = \text{abs} - dW/dt - Prad \]

- Grassy ELM
- Type I ELM (\times 10)

Diagram showing frequency and power over time.
Divertor peak heat flux was less than 10% of that in type I ELMs.

- ELM frequency: Grassy: 533Hz, Type I: 50Hz
- Divertor heat flux: Grassy: ~1.7MW/m², Type I: ~21MW/m²

Peak heat flux is almost inversely proportional to ELM frequency.
Narrower radial extent in grassy ELM

\[ \Delta T_e / T_e \] was similar to that in type I ELM, but much narrower.

\[ q_{95} \approx 6.1 - 6.7 \]
\[ \delta \approx 0.46 - 0.56 \]

Affected area is qualitatively consistent with the narrow radial profile of eigen function of most unstable mode. Example of stability analysis using ELITE, P. Snyder et al.

ELM energy loss for grassy ELMs was 0.4%-1.0% of \( W_{ped} \)

Evaluation by using change of kinetic energy from \( \Delta T_e \).

\[ \Delta W_{ELM} = \frac{3}{2} \int \left( 1 + \frac{7 - Z_{eff}}{6} \right) n_e^{ped} \Delta T_e dV \]

\( \Delta n_e \) was small.

using ELITE, P. Snyder et al.
ELM amplitude and frequency can be changed by toroidal rotation.

Larger counter rotation leads to smaller ELM and higher $f_{\text{ELM}}$.

New parameter for access to grassy ELM regime.

Absolute value? or sign?

No edge fluctuations were observed even in larger counter rotation phase.

Top of $T_{\text{ped}}$

Standard scenario

Small CTR-V

Large CTR-V

Toroidal rotation profile $(q_{95} \sim 4.9, 0.6 \sim 0.6)$

New parameter for access to grassy ELM regime.

Larger counter rotation leads to smaller ELM and higher $f_{\text{ELM}}$. 

JT-60U
QH-mode regime

Pedestal characteristics

Fluctuation properties

Requirement of counter NBI
\[ T^\text{ped} \text{ was also smaller in QH phase.} \]

Pedestal pressure in QH phase is smaller than in ELMy phase. Pedestal parameters were almost constant during QH phase.
Edge fluctuations may play an important role to reduce the pedestal pressure. Maximum amplitude of ~1% was observed at ~2 cm inside separatrix.

Ion saturation current at divertor target and edge density at outer mid-plane are also modulated with same frequency.
Partial QH phase was observed at almost no edge rotation with co-NB injection.

No toroidal rotation with co-NBI

QH phase with co-NBIs

Same edge fluctuations (fluctuations)

Better confinement

Smaller $P_{\text{rad}}$ $\sim 0.8\,\text{MW}$ ($\sim 1.5\,\text{MW}$)

$Z_{\text{eff}} \sim 2.8$ ($\sim 3.3$)

H $\sim 1.7$ ($\sim 1.5$)

Other conditions are not necessary conditions!

CTR rotation & CTR NBIs are not necessary conditions!

QH phase with co-NBI

QH phase with co-NBI

No edge rotation with co-NB injection

Partial QH phase was observed at almost
<table>
<thead>
<tr>
<th>Parameters?</th>
<th>Lower Ped ( r-p_{\text{sep}} \approx 2 \text{cm} ) (( \tau_e ))</th>
<th>Higher base D( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge fluctuations</td>
<td>Higher base D( \alpha )</td>
<td>( r-p_{\text{sep}} \approx 2 \text{cm} ) (( \tau_e ))</td>
</tr>
</tbody>
</table>

**Summary**

We have investigated type I ELM suppression mechanisms and effects of plasma rotation in attractive operational regimes with low-collisionality regime \( (v^e > 0.15) \) at JT-60U and effects of plasma rotation in attractive operational regimes with low-collisionality regime \( (v^e > 0.15) \) at JT-60U.