ELM Control by the SMBI Induced Pedestal Small Scale Turbulence


¹CEA, IRFM, France
²USTC, Hefei, China
³ASIPP, Hefei, China
⁴General Atomics, San Diego, USA
⁵SWIP, Chengdu, China
⁶UCSD, San Diego, USA
⁷WCI Center for Fusion Theory, NFRI, Daejeon, Korea
⁸Association EURATOM-FZJ, Jülich, Germany

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One of the major challenges for the magnetic fusion community is how to extract energy from the plasma core of the fusion reactor without damaging the plasma facing components, in particular the divertor plates.

Large edge instabilities, known as type-I ELMs, can eject a large quantity of particles and energy from the core plasma, causing significant erosion at the divertor target.

For ITER, in order to not damage the divertor plates, the peak heat load on the target plates is limited to 10MW/m² in steady condition and 20MW/m² in transient condition during Type-I ELMs. (A.S. Kukushkin, NF 2002, M. Sugihara, JPFR 2002)

Simulation and scaling predict the divertor peak heat load in ITER significantly exceeding the limit.

How to reduce the power flux density on the divertor plates is a critical issue.
ELM Control Technique

- Existing ELM control techniques:
  - Pellet pacing (P.T. Lang, NF 2003)
  - Resonance Magnetic Perturbation (RMP) (T. E. Evans, PRL 2004)
  - Other external perturbation fields (M.J. Schaffer, NF 2008)

- ELM mitigation using single pulse of SMBI has been demonstrated in HL-2A (W.W. Xiao, P.H. Diamond, X.L. Zou, NF 2012), then in KSTAR (W.W. Xiao, P.H. Diamond, W.C. Kim, NF 2014)

- SMBI Experiments in EAST: 1) Understanding of the mechanism of the ELM mitigation by SMBI; 2) Demonstration of the steady state operation with multi-pulses of SMBI.
Comparison of 2 H-mode plasmas with (red) and without (blue) SMBI
(400kA/LSN/LHW-1.5MW/ICRF-1.1MW)

- Strong reduction of the ELM amplitude with SMBI.
- ELM frequency increased of 5-10 times with SMBI.
- Energy confinement slightly degraded with ELM mitigation.
SMBI Pulse Length Effect on ELMs

The graph shows that the ELM mitigation effect increases with SMBI pulse length. The equation $A_{ELM} \times f_{ELM} = Const$ is used to represent this relationship. The colors and symbols on the graph indicate different pulse lengths for SMBI.
In EAST, ELM mitigation has been observed for single SMBI pulse with pulse length of 16ms, and not observed for single SMBI pulse of 12ms and shorter.

Accumulative effect of SMBI pulses for the ELM mitigation
Pedestal Turbulence

Doppler Reflectometry
- $f_0=74$GHz
- X-mode

Forward Scattering
- No spatial localization
- $\Delta k_\theta=0.8\text{cm}^{-1}$
- Large scale turbulence

Backscattering
- $\rho_\theta=0.9$
- $k_\theta=7.3\text{cm}^{-1}$
- Small scale turbulence

EAST
Anti-correlation between small scale turbulence and ELMs.

Existence of threshold in turbulence level for ELM suppression.

Correlation between large scale turbulence and ELMs.
Large scale turbulence (<400kHz) is triggered by the ELMs.

Intermittent small scale turbulence (>400kHz) busts prevent the formation of the ELMs.

SMBI influence time $\tau_\text{I}$ could be determined by the small scale turbulence duration.
Small Scale Turbulence Controlling ELMs

(a) Temporal evolution of $D_*$ with SMBI markers.

(b) Spectrogram showing frequency evolution.

(c1) Time evolution of $D_*$.

(c2) Time evolution of specific parameter.

(d1) Time evolution of another parameter.

(d2) Time evolution of another parameter.

(e1) Zoomed-in spectrogram.

(e2) Zoomed-in spectrogram.

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Particle Flux Driven by Small Scale Turbulence

Density gradient decreases with the enhancement of the particle transport inside the pedestal due to the small scale turbulence.
Structure of Small Scale Turbulence

EAST

$(k_\theta \sim 7.3\text{cm}^{-1}, m = 300, n = 66)$

![Graph showing turbulence properties with labels for amplitude, frequency, and time.]
Effect of Particle Deposition

Simple and purely transport model with Avalanche theory

Best results for the particle source deposition inside the pedestal.

Mitigation effect is better with CJI (Cold SMBI) than with SMBI

(T. Rhee, J.M. Kwon, P.H. Diamond and W.W. Xiao, PoP 2012)

(X.R. Duan, NF 2013)
Nonlinear Peeling Ballooning Model

- Nonlinear interaction between turbulence and ELMs.
- Extension of the Peeling Ballooning instability limit.

(P.W. Xi, X.Q. Xu, P.H. Diamond, PRL 2014)
Turbulence Effects on ELMs

- Fueling (SMBI)
- Small Scale Turbulence
  - P-B Instability Limit
  - Pedestal Density Gradient
- Particle Transport
  - Large Scale Turbulence
- ELMs
1) ELM mitigation with multi-pulses of SMBI has been demonstrated in EAST for quasi-steady state over 3 s.

2) Particles are deposited into the pedestal by SMBI in H-mode plasmas.

3) ELM mitigation is due to the enhancement of the particle transport in the pedestal, caused by intermittent small scale turbulence induced by SMBI.

4) A critical threshold on the small scale turbulence intensity is clearly observed for ELM suppression.

5) SMBI influence time is governed by the intermittent small scale turbulence.