Shape and Current Profile Effects on Runaway Electron Confinement

by
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with
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Conclusion

Appearance of post-thermal-quench runaway electrons depends critically on details of MHD fluctuations during the TQ

Part 1) Low-elongation, limited plasmas confine REs better than high-elongation, diverted plasmas

Part 2) In DIII-D diverted plasmas, variation in the target plasma current profile produces variation in TQ MHD, and thereby affects the final RE current amplitude
DIII-D and C-Mod RE Experiments Demonstrate Better RE Confinement in Limited Configuration

- Post-TQ RE current plateau sometimes appears, much more frequently in limited than diverted shots

- Second HXR burst at end of CQ occurs only for limited plasma shapes

For more on DIII-D RE experiments, see N. Eidietis invited talk (VI3.00001), Thursday at 3:00 pm
NIMROD: Inner Wall Limited DIII-D and C-Mod Simulations Show Incomplete Island Overlap

Large stochastic regions for LSN

Discrete n=1 islands for IWL, better RE confinement

Strong qualitative cross-device similarity for both configurations

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Appearance of RE Plateaus for Diverted Plasma Shapes is Very Unreliable on a Shot-to-shot Basis

Hypothesis: Variations in seed RE deconfinement due to MHD produces this shot-to-shot variation in RE plateau current
GATO Linear Stability Analysis Finds Relationship Between n=1 Eigenfunction and RE Plateau Current

Calculate radial profile of unstable n=1 mode after Ar pellet begins to cool plasma edge

Large RE current $\rightarrow$ Off axis peaked n=1 mode (one exception)

Small RE current $\rightarrow$ On-axis peaked n=1 mode (one exception)

Clue that MHD de-confinement is the critical issue

GATO analysis by M. Kornbluth and D.A. Humphreys

V.A. Izzo/APS/November 2011
RE Confinement Calculated Directly by NIMROD Simulations with Test-particle Drift Orbits

- Nonlinear resistive MHD simulation models cooling due to Ar pellet, TQ and CQ phase
- Trace population of RE drift orbits are calculated as the MHD fields evolve

- Curve of confined REs vs. time is obtained in every case; RE losses highly variable
- RE loss rate is computed as: $(dN_{RE}/dt)/N_{RE}$ (inverse of confinement time)
NIMROD Predicted RE Loss Rates Consistent with Experiment (with One Exception)

Cases with $I_{RE} > 100$ kA show expected trend vs. predicted loss rate

$$\log(I_{RE}) = \left[\log(I_{seed}) + \gamma_A \tau_{CQ}\right] - \gamma_{RE} \tau_{loss}$$

Cases with predicted loss rate > $4 \times 10^4$/s have negligible RE current

Single outlier: 137624

Also outlier in GATO analysis
Four Simulations with $q_0<1$ All Have Same Qualitative MHD Behavior

Solid curves have $q_0<1$

$\partial B_{n=1}/B$ vs. time

Amplitudes of $n=1$ vs. time have same qualitative trend, variations only in timing, peak amplitude

Radial profile of $\partial B_{n=1}/B$

Radial profile of saturated $n=1$ mode is nearly identical in every $q_0<1$ case
Expected Correspondence Between n=1 Mode Amplitude, Confinement for $q_0<1$

**Relationship between saturated mode amplitude and RE loss rate** is predicted by Rechester-Rosenbluth model for electron heat transport on stochastic fields:

$$D_{RE} \sim \left( \frac{1}{\tau_{RE}} \right) \sim \left( \frac{\partial B}{B} \right)^2$$

Fluctuating field amplitude correlates (0.93) with value of $q_{95}$, shows no clear systematic trend for any other current profile parameter considered.
Comment on ITER Implications

Two important time scales happen to be comparable in DIII-D...

but they may not scale the same

\[ \tau_{\text{loss}} \sim 0.1 \text{ ms} \]

\[ \tau_{\text{RE}} \sim 0.1 \text{ ms} \]

\[ \tau_{\text{loss}} \]

Time interval during which REs are lost.

Related to “re-healing” of flux surfaces after mode saturation.

\[ \tau_{\text{RE}} \]

RE confinement time when fields are stochastic.

Depends on saturated mode amplitude and machine size.

“Marginal confinement regime” may explain shot-to-shot non-reliability in DIII-D, but how do these times scale relative to each other? Do current profile details matter in the case of ITER?
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Appearance of post-thermal-quench runaway electrons depends critically on details of MHD fluctuations during the TQ

Part 1) Low-elongation, limited plasmas confine REs better than high-elongation, diverted plasmas
   → Supported by evidence from both experiment and simulation for both DIII-D and C-Mod

Part 2) In DIII-D diverted plasmas, variation in the target plasma current profile produces variation in TQ MHD, and thereby affects the final RE current amplitude
   → NIMROD successfully predicts the shot-to-shot variation in RE loss rates for all but one case, but relationship to equilibrium current profile is more complex than a single parameter (e.g. $q_{95}$ is important, but only for $q_0<1$)