Error field/Locked mode scaling experiment on Alcator C-Mod

R. Granetz, S. Wolfe, I. Hutchinson, T. Hender

ITPA/MD&C
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B-field scaling of locked mode error field threshold

- Scaling of $B_{err}/B_T$ locking threshold is needed to extrapolate to burning plasma and reactor regimes

$$\frac{B_{pen}}{B_T} \propto n^{\alpha_n} B^{\alpha_B} q^{\alpha_q} R^{\alpha_R}$$

- It is well-established that $\alpha_n = 1$

- From dimensionless scaling constraints,

$$\alpha_R = 2\alpha_n + \frac{5}{4}\alpha_B$$

- Therefore knowledge of $\alpha_B$ also determines the scaling with machine size
Scaling with B (and thus R) has significant uncertainty

- B-field scalings of threshold among various tokamaks show large disparity
  - C-Mod: $\alpha_B = -0.6 \pm 0.6$
  - JET: $\alpha_B = -1.2$
  - DIII-D: $\alpha_B = -0.96$
  - Compass-D: $\alpha_B = -2.9$

- Restricting dataset selection to same normalized density ($n/n_M$ or $n/n_G$) reduces disparity somewhat, but error bars are still large
Locked mode size/field scaling experiment

• Do a systematic, controlled parameter scan on C-Mod to clarify the B-field threshold dependence.
  — Fixed plasma shape
  — Fixed $q_{95}$ (ITER value is 3.1) drops this parameter from scaling law
  — Fixed $n/n_G$ (ITER ohmic target plasma = 0.17)
  — Vary $B_T$ (with $I_p \propto B_T$ and $n \propto I_p \propto B_T$) shot-to-shot
  — During flattop, ramp $B_{err}$ slowly to find locking threshold

• Determine $\alpha_B$ more accurately, and thus $\alpha_R$
Example of shot from locked mode run

In flattop of discharge, the applied error field (A-coil current) is ramped to find the threshold for mode locking.

Intrinsic error fields calculated as in S. Wolfe, PoP 12 (2005)
Example of shot from locked mode run

Locking indicators are:
• cessation of sawtoothing
• slight drop in density
• n=1 magnetic signature

Disruption often follows
Plasma parameters for this experiment

<table>
<thead>
<tr>
<th>Shot #</th>
<th>Time (s)</th>
<th>Btor (T)</th>
<th>Ip (MA)</th>
<th>nebar $\left(10^{20} \text{ m}^{-3}\right)$</th>
<th>q95</th>
<th>n/nG</th>
<th>Total B21 (mT) at threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1050301011</td>
<td>1.38</td>
<td>3.11</td>
<td>0.60</td>
<td>0.70</td>
<td>3.47</td>
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<td>0.39</td>
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<td>5.96</td>
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<td>1050301025</td>
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<td>6.91</td>
<td>1.41</td>
<td>1.46</td>
<td>3.37</td>
<td>0.16</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Scaling law to be fitted

\[ \frac{B_{pen}}{B_T} \propto n^{\alpha_n} B^{\alpha_B} q^{\alpha_q} R^{\alpha_R} \]

Since \( q \) is held constant, and \( R \) is fixed, and \( \alpha_n = 1 \),

\[ \frac{B_{21}}{n_e B_T} \propto B_T^{\alpha_B} \Rightarrow c B_T^{\alpha_B} \]

Fit \( c \) and \( \alpha_B \) to dataset
Locked mode threshold data and fit

\[ \alpha_B = -1.06 \pm 0.15 \]
Result

\[ \alpha_R = 2\alpha_n + 1.25\alpha_B = 0.68 \pm 0.19 \]

Implies threshold \( \tilde{B}_{21}/B \approx 0.9 \times 10^{-4} \) at ohmic density \( (2 \times 10^{19} \text{ m}^{-3}) \) of ITER target plasma

Caveats:

• Applied error fields were not dominant. Determination of intrinsic error fields relies on model and empirical data

• The universally observed linear density dependence of the locking threshold, which was relied on in this analysis, is not supported by theory.
Recent JET/C-Mod dimensionless identity experiments (same $\rho^*$, $\nu^*$, $q_\psi$, $\beta$) have been carried out, and these datasets can also be analyzed to get the B-field exponent ($\alpha_B$).

- JET shape
- higher densities
- different applied error field structure

These give a very different value: $\alpha_B = -2.0$ to -2.9

The reason for this discrepancy is not understood, but is being investigated. This work includes an 8 T run (discrepancy is primarily at high field), varying the sidebands and toroidal phase of the applied error field, and further testing of the model of the intrinsic error fields.