Comparison of Critical Values of $R/L_{Te}$ for ETG Modes Based on an Analytic Expression with GKS Simulations for DIII-D Discharges

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Motivation

- Understanding electron thermal transport remains a key area of study in the overall understanding of transport in tokamak plasmas.
- Electron Temperature Gradient (ETG) modes can lead to enhanced electron heat flux when coupling of these modes leads to the formation of so called streamers.
- Full gyrokinetic stability (GKS) code calculations can be used to find the critical electron temperature gradient scale length for ETG modes but the code requires significant computing time.
- An analytic expression for \( (R/L_{Te})_{crit} \) can be useful if accurate enough.

∴ Compare an analytic expression for \( (R/L_{Te})_{crit} \) with GKS code results.
Expression for \((R/L_{Te})_{\text{crit}}\) for ETG Modes From Jenko*

\[
(R/L_{Te})_{\text{crit}} = \max\{(1 + \tau)(1.33 + 1.91s/q) \\
x(1 - 1.5\varepsilon)[1 + 0.3\varepsilon(d\kappa/d\varepsilon)], 0.8R/L_n\}
\]

For magnetic shear \(s \geq 0.2\)

and normalized pressure gradient \(\alpha \leq 0.1\)

Where \(s = (r/q)(dq/dr)\) ; \(\alpha = -q^2R(d\beta/dr)\) ; \(\tau = Z_{\text{eff}}(T_e/T_i)\) ;

\(\varepsilon = r/R_0\) ; \(\kappa = \) elongation and \(R/L_n = (R/n)(dn/dr)\)

Experimental Profiles From DIII-D Discharges Used For Comparison

- Three pairs of discharges studied
  - L-mode vs H-mode: compares varying $T_e/T_i$ with both $T_e$ and $T_i$ varied
  - L-mode pair 107564 and 107567: vary $T_e/T_i$ with fixed $T_i$
  - L-mode pair 106740 and 106748: vary $s/q$ by varying $q$

- General discharge characteristics

<table>
<thead>
<tr>
<th></th>
<th>L-Mode</th>
<th>H-Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_T$ (T)</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>$I_p$ (MA)</td>
<td>0.8-1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>$n_e (10^{19}m^{-3})$</td>
<td>1.9-2.6</td>
<td>3.6</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>1.4-1.6</td>
<td>1.8</td>
</tr>
</tbody>
</table>
Comparison of L-Mode and H-mode Profiles

- $T_e$ (keV) for L-mode and H-mode
- $T_i$ (keV) for L-mode and H-mode
- $T_e / T_i$
- $n_e$ ($10^{19} \text{ m}^{-3}$)
- $Z_{\text{eff}}$
- $q$
Analytic Expression Agrees Reasonably Well With GKS Code And Shows Similar Trend Across Plasma

- Analytic expression not evaluated where $s < 0.2$
- The two most dominant terms in the analytic expression are the terms containing $\tau = Z_{\text{eff}} T_e / T_i$ and $s/q$
Alpha Values Are Close To But Typically Above The Model Criteria For Applicability

- The model is expected to be applicable to Tokamak discharges with $\alpha \leq 0.1$
Plasma Profile Comparison For $T_e$ Variation At Fixed $T_i$
Agreement Between GKS Code Results and Analytic Expression Remains Good with $T_e/T_i$ Variation

- Excellent agreement toward outside of plasma
- Agreement becomes worse in region where $T_e/T_i$ begins to differ in the two discharges

107564 Lower $T_e$ case

107567 Higher $T_e$ case
Plasma Profile Comparison At Two q Values

- $T_e$ (keV)
- $T_i$ (keV)
- $T_e / T_i$
- $n_e (10^{19} \text{ m}^{-3})$
- $Z_{\text{eff}}$
- $q$

0 0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1

0 0.2 0.4 0.6 0.8 1
Agreement Between GKS Code Results and Analytic Expression Remains Good At Low and High q Values

- Agreement improves toward outside of plasma where s/q is larger
Larger s/q Is Stabilizing For ETG Modes

- The critical $R/L_{Te}$ is larger at larger s/q

![Graphs showing the comparison between GKS code and analytic expressions for larger and smaller s/q values.](image)
$R/L_{T_e}$ Values From The Expression Are Systematically Below Values From The GKS Code, But Are Generally Within 30 %
When Averaged Over All Cases Studied A Slight Trend Toward Better Agreement Is Observed Toward The Plasma Edge

- Values from the expression are averaged by radial location over all cases studied

- Error bars represent $\pm 1 \sigma$ in the distribution
SUMMARY

- Critical $R/L_{Te}$ values for ETG modes from the GKS code were compared to values from an analytic expression developed in F. Jenko, et al., Phys. Plasmas 8 (2001) 4096.

- Although the region of applicability of the expression is marginally violated for the normalized pressure gradient $\alpha$ ($\alpha \leq 0.1$) for the experimental discharges studied, the expression agrees reasonably well with GKS code calculations.

- $R/L_{Te}$ values from the expression are systematically below values from the GKS code but are generally within 30% of GKS results with a slight trend toward better agreement toward the plasma edge.