EDGE GRADIENTS as COMPONENTS of the H-MODE TRIGGER

by
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APS- DPP Meeting
November 15-19, 1999
Edge Gradients as Components of the H-mode Trigger

R.J. GROEBNER, D.M. THOMAS, General Atomics, R.D. DERANIAN, University of Wales — Although the formation of the H-mode transport barrier can be understood in the context of ExB shear suppression, the physics which provides the trigger for the L–H transition is still not understood. Edge profiles of electron temperature, density and pressure, obtained from the DIII–D tokamak, are being examined for evidence of an H-mode trigger. Studies of these parameters with an inductive classification algorithm have shown that knowledge of the values of edge pressure and temperature gradients can be reliably used to determine if the plasma is in the L–mode or H–mode states, at least for discharges with a fixed magnetic equilibrium. This information is insufficient to prove that there is a causal link between these gradients and the transition. However, studies of the time histories of these parameters show a consistent pattern of the edge electron pressure gradient gradually increasing during the L–mode phase prior to the L–H transition. These results suggest that the edge pressure gradient may be a component of the trigger for the L–H transition.

1Supported by U.S. DOE Contract DE-AC03-99ER54463.

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Special instructions: DIII-D Poster Session 1, immediately following EK Synakowski

Date printed: July 16, 1999
Electronic form version 1.4
WHAT TRIGGERS THE H-MODE?

♦ I.E, what evolves during the L-mode so that an L-H transition occurs?
THE EXPERIMENTALISTS SAY:

- Power
- $T_e$?
- $T_i$?
- $?$
THE THEORISTS SAY: **EDGE GRADIENTS**

- Theoretical transport simulations which have achieved “H-mode” transitions require changes in **edge gradients**
  
  
  - $\nabla P_i, \nabla n_i$ - Hinton and Staebler, Phys. Fluids B5, 1281 (1993)
  
  - $\nabla P_i$ - Carreras, Newman, Diamond, Liang, Phys. Plasmas 1, 4014 (1994)
  
  
  - $\nabla P_i$ - Rogers, Drake, Zeiler, Rev. Lett. 81, 4396 (1998)
DO EDGE GRADIENTS REALLY CHANGE IN L-MODE?

♦ YES! YES! YES!

♦ During L-mode phase, as H-mode transition is approached:
  o Edge $\nabla T_e$, $\nabla P_e$ and $\nabla T_i$ increase in magnitude
  o Measured just inside the separatrix (within ~ 1 cm)
  o Increases are small when power threshold is low
  o Increases are large when power threshold is high
WHY SHOULD YOU CARE??

♦ Finally, we see something changing in the plasma, at the correct location, prior to the L-H transition
  - H-mode does not occur out of the “clear blue”
♦ These results make good contact with several theories
  - Thus, your favorite transition mechanism is probably consistent with these results (Reynold’s stress, transport bifurcation, diamagnetic stabilization)
Edge Gradients Are Evaluated from Fits to Edge Profile Data

♦ Edge electron profiles from Thomson scattering
♦ Edge ion profiles from CER system
♦ Fit edge T, n and P profiles with tanhfit function
♦ L-H transition occurs very near density symmetry point
♦ Therefore, evaluate edge parameters and gradients at density symmetry point
DEFINITION of KNEE and FOOT of an EDGE PROFILE

\[ Y = A \times \tanh \left( \frac{X_{\text{SYM}} - X}{H\text{WID}} \right) + B \]

\[ Y = Y + \text{SLOPE} \times (X_{\text{KNEE}} - X), \ X < X_{\text{KNEE}} \]

PEDESTAL = A + B
OFFSET = B - A
WIDTH = 2 \times H\text{WID}
DENSITY SYMMETRY POINT IS IN REGION WHERE TRANSPORT BARRIERS FORM

\[ n_e \left(10^{19} \text{ m}^{-3}\right) \]

\[ T_e \text{ (keV)} \]

\[ P_e \text{ (kPa)} \]

ELEVATION (m)

- 4 ms
+26 ms

\[ R_{\text{sep}} - 2\text{cm} \]

\[ \rho = 0.95 \]
For High Power Threshold, Edge Gradients Show Big Changes in L-mode

♦ High power threshold means that auxiliary power required to get H-mode is large relative to ohmic power

♦ For helium plasma with power threshold of about 5 MW,
  - $\nabla T_e, \nabla P_e, \nabla T_i$ and $\nabla P_i$ all increase by > 150% prior to L-H transition

♦ For $\nabla B$ drift away from X-point with $P_{th}$ of about 5.5 MW,
  - $\nabla T_i$ increases by nearly 165%
  - $\nabla T_e$ and $\nabla P_e$ increase by about 130% near the edge
EDGE $\nabla T_i$ AND $\nabla P_i$ INCREASE MORE THAN 150% in L-MODE of HELIUM PLASMA with HIGH H-MODE POWER THRESHOLD

$N_i$ (-25%)

$T_i$ (+150%)

$P_i$ (+80%)

$\nabla N_i$ (30%)

$\nabla T_i$ (180%)

$\nabla P_i$ (155%)

$P_{th} \sim 5 MW$
EDGE $\nabla T_e$ and $\nabla P_e$ INCREASE by 180% in L-MODE of HELIUM PLASMA with HIGH H-MODE POWER THRESHOLD.

- $N_e$ (+25%)
- $T_e$ (+95%)
- $P_e$ (+120%)

P$_{th}$ ~ 5 MW
EDGE $\nabla T_{CVI}$ and $\nabla P_{CVI}$ INCREASE DRAMATICALLY in L-MODE with HIGH H-MODE POWER THRESHOLD DUE to UNFAVORABLE GRAD-B DRIFT

$P_{th} = 5.5 \text{ MW}$

- $N_{CVI} (+45\%)$
- $T_{CVI} (+75\%)$
- $P_{CVI} (+165\%)$

- $\nabla N_{CVI} (40\%)$
- $\nabla T_{CVI} (165\%)$
- $\nabla P_{CVI} (255\%)$
$\nabla T_e$ AND $\nabla P_e$ INCREASE by 130% NEAR EDGE of L-MODE with REVERSED GRAD-B DRIFT with HIGH H-MODE POWER THRESHOLD

$N_e$ (+0%)
$T_e$ (+25%)
$P_e$ (+25%)

$P_{th} = 5.5$ MW

$\nabla N_e$ (-25%)
$\nabla T_e$ (130%)
$\nabla P_e$ (135%)

Max edge gradients

TIME (ms)

900 1150 1400 1650 1900 2150 2400 2650

% CHANGE

300 250 200 150 100 50 0

-50
For Low Power Threshold, Edge Gradients Show Small Changes in L-mode

♦ Low power threshold means that auxiliary power required to get H-mode is small relative to ohmic power

♦ Difficult to establish trends in edge parameters due to large fluctuations in data

♦ Establish trends with linear fits to L-mode data

♦ Even for low power threshold, $\nabla T_e$, $\nabla P_e$ and $\nabla P_i$ increase tens of percent in L-mode
COMPOSITE OF THREE IDENTICAL SHOTS SHOWS THAT EDGE ION GRADIENTS INCREASE IN L-MODE for LOW POWER THRESHOLD

\[ T_{CVI} (+30\%) \]

\[ P_{th} = 1.5 \text{ MW} \]

\[ \nabla N_{CVI} (60\%) \]
\[ \nabla T_{CVI} (35\%) \]
\[ \nabla P_{CVI} (130\%) \]
COMPOSITE OF THREE IDENTICAL SHOTS SHOWS THAT EDGE GRADIENTS INCREASE IN L-MODE for LOW POWER THRESHOLD

$N_e (+5\%)$
$T_e (+10\%)$
$P_e (+20\%)$

$P_{th} = 1.5 \text{ MW}$

$\nabla N_e (25\%)$
$\nabla T_e (45\%)$
$\nabla P_e (45\%)$

TIME (ms)
\( \nabla T_e \) and \( \nabla P_e \) Discriminate Between L-mode and H-mode Better Than \( T_e \) and \( n_e \)

♦ For a fixed magnetic configuration:
  o There is substantial overlap between \((T_e, n_e)\) pairs from L-mode and H-mode
  o There is much less overlap between \((\nabla P_e, \nabla T_e)\) pairs

♦ Thus, with high reliability, we know if we are in L or H-mode by looking at values of \((\nabla P_e, \nabla T_e)\) pairs

♦ For more info: Deranian, Groebner and Pham, “Inductive Classification of L-mode and H-mode Edge Parameters”, GA-A23149, submitted for publication
$T_e$ and $n_e$ PROVIDE MEDIocre DISCRIMINATION of L-MODE from H-MODE (based on about 30% overlap of data points)
\( \nabla P_e \) and \( \nabla T_e \) DISCRIMINATE VERY WELL between L-MODE and H-MODE (based on about 1% overlap of data points)
Conclusions

♦ H-mode trigger - *It’s GRADIENTS, friend*
  
o Subject to the usual caveats, of course

♦ Edge $\nabla P$ and $\nabla T$ increase during L-mode, as H-mode transition is approached - for electrons and ions
  
o Results consistent with several theoretical simulations of H-mode transition

♦ An operational space diagram based on $\nabla P_e$ and $\nabla T_e$ provides very good discrimination between L and H states