DEPENDENCE OF THE PERTURBED ELECTRON TRANSPORT ON HEAT FLUX AND Q-PROFILE IN THE NSTX H-MODE

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The $T_e$ profiles are observed to flatten with increasing beam power $P_{NB}$, in the ‘standard’ NSTX H-mode. In addition, at high power, the Type-I ELMs produce global, ms time scale $T_e$ crashes of large amplitude. To try and separate the roles of the heating power and $q(r)$ in these effects, we performed experiments in which the background, or preheat power and $q(r)$ were independently varied and the electron transport perturbed with $P_{NB}$ steps and Li pellets.

The results at fixed $q$ show that at high power the central $\chi_e$ reaches very large values, while at low power it strongly decreases. These trends are confirmed by the perturbative experiments. At high power the pellet cold pulse rapidly propagates to the plasma center, while at low power the pulse is strongly damped in the inner plasma.

The $q$ change at fixed $P_{NB}$ has also profound effects on electron transport. With the narrow $q$-profile resulting from early heating at high $P_{NB}$ (the ‘standard’ NSTX H-mode scenario), very large central $\chi_e$, together with global and rapid $T_e$ perturbations following pellet injection are observed. With the broader $q(r)$ resulting from heating at low $P_{NB}$, $\chi_e$ strongly decreases and the cold pulse slows down inside the $q=2$ surface. Since the magnetic shear is comparable in the two cases, these observations seem to suggest a role for low order rational-$q$ surfaces in NSTX electron transport.

As an explanation for the very large central $\chi_e$ observed with early heating at $P_{NB}$, we propose magnetic turbulence. This would be consistent with the two orders of magnitude gap observed between the electron heat diffusivity and the impurity diffusivity in the ‘standard’ NSTX H-mode.
Unusual broadening of thermal profiles with $P_{NB}$ in NSTX

Early heating, 1 MA, 4.5 kG, ELM-free/small-ELM H-modes, $t=0.4$ s

- With early heating at high $P_{NB}$ most of the $T_e$ gradient at $r/a > 0.6$
- Fast ion redistribution by MHD not a likely factor
- Lower density at lower $P_{NB}$ might play a role
Broadening mainly caused by rapid electron transport

- Very large change in magnitude, shape of $\chi_e$
- $\chi_i$ varies much less (around neoclassical)
- $v_t$, $\omega_{ExB}$ reduced at highest power
- q-profile narrows with increasing $P_{NB}$
- Study effects of heating and q-profile on the perturbed electron transport
Experiment: $P_{NB}$ and q varied and $T_e$ perturbed

I) $P_{NB}$ change at fixed q

- Preheat to 'freeze-in' q-profile -> step $P_{NB}$ and perturb with pellet
- 'Frozen-in' q-profile varied by varying preheat power
- Study both $\Delta P_{NB}$ and pellet perturbations

II) q change at fixed $P_{NB}$ (at the time of pellet)

- Preheat (420 ms)
- Pellet (450 ms)
- $P_{NB} (MW)$
- 4 -> 6
- 4 -> 2
- 6 -> 4
- 2 -> 4

- Beam slowing time

- $P_{NB}$ change at fixed q:
  - 4 -> 6
  - 4 -> 2

- q change at fixed $P_{NB}$ (at the time of pellet):
  - 6 -> 4
  - 2 -> 4
1) Large change in electron heating achieved at fixed-q

- $\omega_{\text{ExB}}$, $n_e$, also do not significantly change
Electron transport changes differently at $P_{NB}$ step/drop

- Central $\chi_e$ does not change much at 4->6 step, but large absolute values prevent substantial $T_e$ increase
- Central $\chi_e$ strongly decreases after 4->2 drop → discharges at $P_{NB} > 2$ MW likely far from marginal stability
- Within uncertainties, ion transport increases after 4->2 drop
Pellet perturbation further used to probe electron transport

- Pellet ablates near edge
- Small density perturbation
- Only few % equilibrium change
‘Multi-color’ SXR arrays used for fast $T_e$ measurement

Poloidal SXR diode arrays

Tangential ‘optical’ SXR array

Pinholes with filters

FO vacuum window to multi-channel PMT and current amplifiers

Optic fibers

$E > 0.6$ keV
$E > 1.4$ keV
$E > 1.4$ keV

$E > 0.6$ keV
$E > 1.4$ keV
$E > 2.2$ keV

$\Delta r \sim 2$ cm
$\Delta t \sim 2$ µs

$\Delta r \sim 4$ cm
$\Delta t \sim 100$ µs
Perturbative study confirms trends from power balance

- In 4->6 case the cold pulse reaches plasma axis in ~ 2 ms
- In 4->2 case pulse strongly damped inside r/a < 0.6, faster recovery of perturbed profiles in the outer plasma
- Rapid central electron transport at high P_{NB} confirmed also by ELM cold pulse measurements
II) Change in q at similar electron heating also achieved

- $\omega_{\text{ExB}}$ does not significantly change, but $n_e$ lower with 2 MW preheat
- q(r) differs, but magnetic shear similar
Electron transport strongly changes with q-profile

- With q-profile obtaining at low preheat power, $\chi_e$ decreases at 2->4 step, with electron ITB and slight shear reversal inside $q=2$
- With q-profile at high preheat power $\chi_e$ remains high even when $P_{NB}$ reduced
- Within uncertainties, ion transport follows similar trend
Strong q(r) effect seen also in cold pulse propagation

- Very rapid propagation through entire plasma at high preheat power
- Much slower propagation inside q=2 and ‘polarity reversal’ inside q=1 at low preheat power
- Important role of low order rational-q surfaces in NSTX electron transport?
Role of rational-q also evident in low $P_{NB}$, NCS L-modes

- Spontaneous $T_e$ increases when $q$ approaches rational values
- Zonal flow/magnetic geometry interaction model (M. Austin et al PoP 2006)
- Possibly explanation why $q(r)$ reverses also in ‘slow ramp’ L-modes
- So far however, effect seen only at low $P_{NB}$ (and $n_e$)
- Difficult to explain with electrostatic turbulence $\chi_e \gtrsim$ tens of $m^2/s$ at high $P_{NB}$
Is magnetic turbulence behind the large $\chi_e$ at high $P_{\text{NB}}$?

\[ D_{\text{magn}} \approx V_\parallel (\Delta B_r/B)^2 L_s \]

\[ D_i \approx \chi_i \approx \chi_e \sqrt{\frac{m_e}{m_i}} \]

\[ \chi_e / D_{\text{Ne}} \approx \Theta (10^2) \]

(Rechester & Rosenbluth 1978)

- $D_{\text{imp}} \sim$ neoclassical in high power H-modes (Delgado et al. PPCF 07)
- $\chi_e^{\text{pert}}, \chi_e^{\text{PB}}$ up to $\sim 100$ times larger
- Magnetic (stochastic) transport would explain gap
- $\mu$-tearing $\chi_e$ in the experimental range (K. Wong et al. this meeting)
GS2 calculations also point to micro-tearing drive

- Linear calculations only indicative of trends (2->4 case has in fact lower $\chi_e$)
- Central $T_e$ flattening at high $P_{NB}$ may nevertheless reflect saturated $\mu$-tearing
Summary

• Simple perturbative technique used to probe electron transport dependence on $P_{NB}$ and $q$

• Results suggest $T_e$ flattening consistent with low critical gradient in NSTX

• $\mu$-tearing possible mechanism for $\chi_e \gg \chi_i$, $D_{imp}$

• Large $\rho^*$ in NSTX could enhance q-profile / zonal flow effects such as ITB formation at low order rational-q surfaces

• Scaling of perturbed electron transport with $B_t$, $I_p$ and $n_e$ planned next