Status and Plans for C-Mod Lower Hybrid and Advanced Tokamak Program

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Unique Features of C-Mod for AT research

- In physics terms, “Steady-state” current drive implies pulse lengths $\gg$ current relaxation time $\tau_{CR}$. C-Mod can run 5 second pulses, longer normalized time than other divertor tokamaks.

- Other reactor-relevant features, particularly important for internal transport barriers, are
  - Strongly coupled ions and electrons. $\tau^{e-i} \ll \tau_E (T_e \sim T_i)$,
  - No core fuelling or momentum drive.
  - All RF heating and CD.

\[
\tau_{CR} = \frac{1.4a^2\kappa T_e^{3/2}}{Z_{eff}}
\]

Assumed: $Z_{eff}=2$, $T_e=6$ keV (ITER 19 keV).

Note: C-Mod has already run 3 sec pulses. Some pulse lengths are upgrades.
Current Profile Control: Lower Hybrid Current Drive system

- Designed for well controlled spectrum.
- Each antenna will have flexible $N_{//}$, variable over range 2-4.
- Variable between or during discharges using phase shifters.
- 2 launchers can have different spectra.
- Allows us to tailor spectrum for desired wave accessibility (depending on $n(r)$, $B$), and to control deposition and current drive profiles, including CD far off axis.

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2005</th>
</tr>
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<tbody>
<tr>
<td>Frequency</td>
<td>4.6 GHz</td>
<td>4.6 GHz</td>
</tr>
<tr>
<td>Source Power</td>
<td>3 MW</td>
<td>4 MW</td>
</tr>
<tr>
<td>Antenna</td>
<td>1 grille (4x24 guides)</td>
<td>2 grilles (4x24 guides each)</td>
</tr>
</tbody>
</table>
LH System nearly complete

- RF sources, power supplies, WG prepared by MIT.
- 12 Klystrons (3 MW) installed, tested in the C-Mod cell.

- LH Coupler and splitter fabricated by PPPL.
- Will be commissioned late 2003, following high power testing.
Example of an AT target scenario

- One of many optimized scenarios modelled with ACCOME.
  - \( I_p = 860 \text{ kA}, \) non-inductive.
  - \( I_{\text{LH}} = 240 \text{ kA} \)
  - \( I_{\text{BS}} = 600 \text{ kA} \) (70%)
  - \( \beta_N = 2.9 \)

\[
\begin{align*}
  I_p &= 0.86 \text{ MA} \quad I_{\text{LH}} = 0.24 \text{ MA} \quad f_{\text{BS}} = 0.7
\end{align*}
\]

- Double transport barrier
  - \( B_t = 4 \text{ T} \)
  - ICRH: 5 MW
  - LHCD: 3 MW, \( N_{t/0} = 3 \)
  - \( n_e(0) = 1.8 \times 10^{20} \text{ m}^{-3} \)
  - \( T_e(0) = 6.5 \text{ keV} \) (\( H = 2.5 \))

- Scenarios without barrier, or only an ITB, have similar performance.

\[
\begin{align*}
  q(0) &= 5.08 \quad q(95) = 5.98
  
  q_{\text{min}} &= 3.30
\end{align*}
\]

Summary

• Advanced Tokamak research will be an increasingly important part of the C-Mod program.
• Focuses on RF control of current, transport and pressure profiles in high density regime, for $t >> \tau_{CR}$, $B_T = 4$-$8$ T, $T_i \sim T_e$, $n_e \sim 1$-$5 \times 10^{20}$ m$^{-3}$.
• Initial LHCD system is nearly complete - 1st current drive and profile control experiments in 2004.

• AT research program also includes:
  – Internal Transport Barrier experiments (in progress).
  – Density control upgrades, including new cryopump.
  – Tests of mode conversion current and flow drive.
  – Divertor power handling at ITER-like fluxes.
  – Exploring and optimizing no-wall MHD stability limits.