Experiments on the Alcator C-Mod Tokamak Utilizing a Novel Lower Hybrid Wave Launcher


52\textsuperscript{nd} Annual Meeting of the Division of Plasma Physics
Chicago, Illinois
November 10, 2010
FY 10 Run Campaign has Successfully Advanced the Application of Lower Hybrid Current Drive on Alcator C-Mod

• Installed and commissioned new LH launcher
  – Achieved 1.1 MW injected power
  – Operates at high power consistently
  – Conditioned to high power in 1 day

• Investigated reason for reduction of CD efficiency at high density
  – Hard x-rays began to fall off rapidly as density exceeded $1 \times 10^{20} \text{ m}^{-3}$
  – Modeling had indicated SOL losses may be responsible
  – Changing magnetic equilibrium reduced losses

• Achieved full Current Drive
  – $I_p = 580 \text{ kA at } \overline{n_e} = 5 \times 10^{19} \text{ m}^{-3}$
  – Preliminary modeling with MSE constrained kinetic EFIT indicates achievement of reverse shear profile with $q_{min} > 1$
Novel Splitter Concept Incorporated to Improve Launcher Performance

Eliminated multi waveguide gaskets
Reduced rf losses in launcher
Eliminated multi window brazing
Reduced rf fields at waveguide mouth
Rapid Power Conditioning and Consistent Operation at High Power has Allowed Early Application of LHCD in Physics Experiments

- 400+ LHCD discharges since first operation in June
- Conditioned in 1 day
- Maximum shot-averaged power increased to 1.0 MW for 0.5 s
  - Peak power >1.1 MW
- 41 MW/m² across entire launcher, 47 MW/m² on center guides
LHCD at High Density is Sensitive to Plasma Topology and Position

- HXR emission increased in double null as compared to single null
- HXR emission significantly increased in limited discharges
  - Other high density (>10^{20} \text{ m}^{-3}) LHCD experiments all on limited tokamaks (Alcator C, FTU)
- HXR emission increased by operating with small (<5 mm) inner gaps in single null
- Increase in core plasma temperature with ICRF heating does not improve LHCD performance above density limit
- Increase in edge temperature with I-mode did improve performance
- Results support conjecture that SOL physics plays a critical role in the LHCD density limit

Wallace TP9.00082
Faust TP9.00081
Hard X-Ray Emission Increases in Edge Channels as Density Increases in Diverted Discharges

Horizontally viewing hard X-ray Chords

Detailed Hard X-Ray Presentation  Schmidt  TI2.00004
Variety of Diagnostics Applied to Characterize SOL

- LH SOL reflectometer system now operational
- Significant increase in measured SOL $n_e$ profiles during LH
- Systematic experiments under way to examine effect of LH on the SOL using reflectometer and scanning probes

Baek TP9.00079 Faust TP9.00081 Lau TP9.00084
Zero Loop Voltage Sustained for 0.5 s

- Zero loop voltage sustained for full length of LH pulse (0.5 s) at $n_e=0.5\times10^{20}$ m$^{-3}$, $I_p=520$ kA, $B=5.4$ T
- Current relaxation time $\sim 0.2$ s
- Some transformer recharge
- Current drive efficiency $\eta \equiv n_e I_p R_0 / P_{LH} = 1.5-2.5 \times 10^{19}$ A/(Wm$^2$)
- Sawtooth suppression increases temperature peaking

Parker TP9.00080
Bonoli TP9.00077
Equilibrium reconstruction constrained by 9 points MSE measurements and pressure profile, showing the shear reversal within the error bar due to the statistical error of pressure and MSE.

MSE pitch angle becomes stationary during the later half of LH pulse.
Full Wave Codes Being Developed and Applied to Calculate Power Deposition and Current Drive

Log $|E_{||}|$

LHEAF Code

Shiraiwa   TP9.00083
Lee         TP9.00078
Wright      JP9.00082

TORIC-LH

$N_{tor} = 1.9$

MSE constrained EFIT
Genray-CQL3D
LHEAF

$\frac{J_{tor}}{(A/m^2)}$

$X(cm)$

$Z(cm)$

log10 $|E_{2d_z}|$

levels
New Launcher has Allowed Rapid Progress on LHCD Research on Alcator C-Mod

• Power levels up to 1.1 MW rapidly achieved
  – Consistent high power application, not limited by launcher

• CD at high density improved by decreasing inner gap
  – Modification of SOL may be responsible

• Full current drive achieved with reverse shear profiles with good CD efficiency (≥ ITER Assumption)