Recent Advances in ICRF Experiments on C-Mod

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Key Results:
Demonstrated high power, phased antenna operation.
Observed sawtooth period variation with antenna phasing in both minority and mode conversion absorption scenarios.
D and E-port are 2-strap, fast wave antennas ($n_\phi=\pm 10$). J-port is a 4-strap, fast wave antenna with variable phasing.

- Heating phase ($n_\phi=\pm 10$) symmetric wave excitation.
- $+90^\circ$ ($n_\phi=7$) waves are launched co-plasma current.
- $-90^\circ$ - $n_\phi=-7$ waves are launched counter to plasma current.

With high power, phased antenna operation, the sawtooth period can be used as an indicator of

- Fast ions generated by D(H) minority heating and
- Localized driven current from D(\({}^3\)He) mode conversion (MCCD).
Demonstrated 5 MW ICRF Discharge

To improve antenna power handling

- Reduced or eliminated regions where the RF $E \parallel B$ and
- shielded the BN-metal interface from the plasma.

These modifications have allowed

- D and E-port antennas to routinely achieve 1.5 MW (10 MW/m$^2$) and
- J-port antenna to achieve 3 MW (11 MW/m$^2$) operation.

See FP1.002 Schilling
Observe Limited H-modes

Obtained H-mode while limited on the inner divertor.

- Measured steep edge density profile during H-mode.
- Observed density fluctuations.
- Edge temperature is clamped ~0.4 keV while limited.
- H-mode threshold ~4x higher than diverted case.

See FP1.005 L. Lin et al.
Antenna Performance is Independent of Phase

Series of limited L-mode discharges with on-axis H minority heating.

Saved energy is independent of antenna phase except that
- Sawtooth period depends upon phase.
- Density, $D_\alpha$, and radiated power traces are nearly identical.

Similar results were obtained for weak single pass absorption scenario ($D(^3\text{He})$).
Sawtooth Period Varies with Antenna Phasing

Sawtooth period is
- ~16 msec with +90°,
- ~5 msec with –90°, and
- 8-15 msec with heating phase.
- Consistent with variation of sawtooth period observed on JET with phased antenna operation.

Infer sawtooth period is being modified by fast minority ions.
- Heating is on-axis.
- Any minority current drive is small and on-axis.
- Implementing active charge exchange diagnostic in the near future.

See FP1.006 Tang
Sawtooth Period Depends on Antenna Phasing

Performed series of L-mode, D$^3$He discharges at 8 T to investigate mode conversion current drive.

- Power absorbed by electrons is ~0.3 MW, typically ~20% of total power.
  - With the deposition peaked near the sawtooth inversion radius,
    - Sawtooth period increases with Ctr-CD phasing and
    - Decreases with Co-CD phasing.

See GI02.005 Lin and GI02.006 Wright
For Ctr-CD phasing, the sawtooth period

- increases for deposition near the q=1 and
- has little or no change for deposition inside of q=1.

From TORIC modeling, the RF driven current is \(~10~kA\).

- Identified 50 MHz MCCD scenario with \(~90~kA\) driven.
Summary

• Demonstrated high power operation.
  • Achieved 5 MW operation for 0.5 sec.
  • Observed limited H-mode with power threshold 4x diverted scaling.

• Demonstrated flexible phase operation in both minority and mode conversion absorption scenarios.
  • Observed modification of the sawtooth period for both D(H) minority and D($^3$He) mode conversion scenarios.