Alcator C-Mod
Mini-Proposal

MP No. 522

Subject: Lower Ip Long Pulse L-mode and H-mode Advanced Scenarios

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Group: Integrated Scenarios, Advanced Tokamak

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Approved by: **Date Approved:**

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1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

Examine Lower Ip discharges at 450 kA to obtain higher bootstrap and non-inductive current fractions. Establish the energy confinement in the lower Ip plasmas. Utilize longer Ip rampup times (established in pre-physics phase) to control the q profile and non-inductive current fraction, with ICRF heating and LH heating/CD, both separately and together. Produce discharges both in L-mode and H-mode to determine advantages of confinement regimes.

2. Background

Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.

As part of the effort to develop advanced tokamak discharges on Alcator C-Mod a combination of lower plasma current, slower Ip ramps, early ICRF and LH heating/CD, and L/H-mode are being used to achieve high non-inductive current fraction with higher q plasmas, and ultimately higher betaN plasmas. In order to reach this a database of discharges utilizing these features is being developed to better understand the plasma response to these features, and provide information for optimization. Systematic scans like these are not only useful for future discharge development, they provide a much needed basis for simulations to project to new discharges. In the 2007 run campaign the 600 kA plasmas were produced with slower plasma current ramps, simultaneous injection of ICRF and LH power in the current ramp, and demonstration of the LHCD effects on the current profile. For the most part all discharges were L-mode, with some short H-mode periods, or late in the flattop H-modes when the LH system was already turned off. Discharges with only 0.4 MW of LH delayed the sawtooth onset by up to 175 ms, over ohmic discharges. The simulation of these discharges indicated that 200 kA of LH current may have been driven during the current ramp when the background DC electric field is significant, and then drops to about 65 kA in the flattop. When ICRF heating is combined with the LH the sawtooth onset time was delayed by 250-375 ms. Due to the higher electron temperature from the ICRF heating, the LHCD is estimated to be about 100 kA, for 0.4 MW of LH power. These encouraging results were reported at the APS[1]. The goal for this year is to expand this to the 450 kA regime. In addition, there are 2 important issues to be addressed, 1) removing the Ip transient in the rampup when crowbarring the OH, and accessing H-modes in the ramp and flattop.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

This experiment proposes to systematically study the plasma response to ICRF and LH heating/CD in discharges with slower Ip ramps, to establish techniques for producing advanced tokamak discharges with q profile control and high non-inductive current fraction. A systematic scan is proposed that injects ICRF only during and after the Ip ramp, injects LH only during and after the Ip ramp, and finally both ICRF and LH during the Ip ramp.

Examination of both L-modes and H-modes is of interest, with H-modes relying on some development to provide more reliable entry. The plasma current is fixed at 450 kA, sufficiently low to provide reasonable non-inductive current fractions, and to allow an extensive power and source scan. This should also lead to the loest density H-modes, which is an important consideration since effective LHCD into H-modes has yet to be demonstrated.

We will examine, in response to the heating level and timing, the li and surface voltage evolutions, sawtooth onset, kinetic evolutions of Te and n, and q profile information if available.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T for ICRF
Plasma Current: 0.45 MA
Working Gas Species: D, H-minority.
Density: Target 6-9e19 m^{-2} (cryopump not precluded).
Equilibrium configuration (if possible, refer to database equilibria): *slow Ip ramp discharges 1070712017 at Ip = 450 kA listed below*

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing:	J-port essential, 1.0-2.0 MW. D and/or E desirable, 1 MW.
LHCD Power, pulse length, phasing:	0.5-1.0 MW, variable phase (probably 90 deg), longest pulse available.
Pellet Injection (species):	no

Impurity blow-off injection: no
Diagnostic Neutral Beam: Highly desirable
Special gas puffing: NINJA (with D2) should be available.
Non-axisymmetric Coils (Connections, Current); Yes; optimized to reduce locked modes.
Other:

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Essential: Thomson, Magnetics, Hard x-rays, ECE, TCI, probes in LH grill.
Desirable: MSE, CXRS, SOL probes.

5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence Plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.

The run plan is for 1-2 run days targeting Ip (450 kA) . First the Ip ramp should be improved, H-mode access during the rampup should be attempted, and then a sequence of ramp rate, power, and timing scans.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

Begin with established discharge at 450 kA from last year, ohmic case is 1070712015 or 16. (5-10 shots)

1) request the Ip trajectory at crowbar time to continue Ip ramp rate the same as expected from pre-crowbar time, and more slowly transition to slower Ip ramp rate
2) move crowbar time earlier and do the same as above

Attempt to access H-mode during the Ip ramp (5-10 shots)

1) create flat spot in Ip(t) trajectory, after plasma is diverted, at various times in rampup
2) inject varying levels of ICRF power during the flat spot in Ip(t)
3) vary timing of flat spot, targeting earliest possible time, but only after divert time
4) other strategies to enhance the H-mode access in rampup?

Start with established discharges with slower Ip ramp: 1070712017-19 for 500 ms or new discharges established from above. Longer rampup of 1000 ms must be established for cases below.

1) 500 ms rampup to 450 kA (7 shots)
    a. ICRF only, 2.0-3.0 MW at 500 ms
    b. ICRF only, 1.0 MW at 200 ms
    c. ICRF only, 2.0 MW at 200 ms
    d. ICRF only, 3.0 MW at 200 ms
    e. ICRF only, H-mode in ramp, 2.0-3.0 MW

2) 500 ms rampup to 450 kA (3 shots)
    a. LH only, (maximum available) 0.5-1.0 MW at 200 ms
    b. Attempt longest LH pulses available

3) 500 ms rampup to 450 kA (7 shots)
    a. ICRF 1.0 MW at 200 ms, LH 0.5-1.0 MW at 200 ms
    b. ICRF 2.0 MW at 200 ms, LH 0.5-1.0 MW at 200 ms
    c. ICRF 3.0 MW at 200 ms, LH 0.5-1.0 MW at 200 ms
    d. ICRF 2.0-3.0 MW, H-mode in ramp, LH 0.5-1.0 MW at 200 ms

4) 1000 ms rampup to 450 kA (17 shots)
    a. same as above

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

These systematic experiments will establish the plasma response to early heating and current drive with slower Ip ramps, which is the basis for advanced tokamak discharges where the q profile is modified and the non-inductive current fraction is maximized. Results can be reported at APS, and provide information for publications as well as simulations and the 5 year plan.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

[1] C. E. Kessel[1], A. E. Hubbard[2] P. Bonoli[2], M. Greenwald, J. Ko[2], Y. Lin[2], R. Parker[2], A. E. Schmidt[2], S. Scott[1], J. Snipes, D. Terry[2], G. Wallace[2], R. Wilson[1], S. Wolfe[2], S. Wukitch[2], "*Simulations and Experiments on Modifying the q-Profile for Advanced Tokamak Discharges on Alcator C-Mod*", APS-DPP 49th Annual Meeting, November 2007, Bulletin of Amer. Phys. Society.