Alcator C-Mod
Mini-Proposal

Subject: Development LH assisted low $I_p$ ramp-up and documentation of an alternative path to RS regime.


Group: LH

Date: April 14th, 2014

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

The purpose of this mini-proposal is to develop and document an alternative path to reach the RS regime on C-Mod. Previously, most attempts to generate reversed-shear plasmas on C-Mod used LH injection during the plasma current flattop. Although this approach has the advantage of obtaining good control of the LH launcher coupling and better MSE current profile measurements, it restricts the length of full CD duration and involves a higher risk of causing MHD instabilities that degrade the current drive efficiency compared to other scenarios. A previous fully inductive (NI) LHCD experiment demonstrated that it is possible to freeze the current profile with the available off-axis LHCD power and reach a fully NI flat top phase [1]. Such a scenario may have the advantage of avoiding MHD, possibly ending up in a different flattop current profile. It is this scenario that we propose to explore in this half-day MP.

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

On C-Mod, we have demonstrated an operation regime (density and plasma current) where the plasma current is driven non-inductively (in principle) on a time scale long compared to the current penetration time. These regimes were reached using an Ohmic target plasma where the current profile had been fully evolved. The question arises what would be the behavior if the LHCD power is initiated during the current ramp-up phase, including MHD stability.

Freezing the current profile has been a popular recipe to generate advanced regimes on many tokamaks. On C-Mod, early ICRF/LHCD heating did slow down the q-profile evolution (MP522) but this, by itself, was not sufficient to generate an AT confinement regime. However, since Alcator’s LHCD system has sufficient power to dominate the steady-state current profile, with early LHCD injection the current profile should reach an new equilibrium with a substantial component peaked off-axis, thereby generating a favorable shear profile.
The previous attempt to launch LHCD during the plasma ramp-up was made in MP522 by C. Kessel and others. This MP was run before the current LH launcher was installed, and therefore LH pulse length was limited to 0.5s. As a consequence, the length of LHCD during the current flat top was only 0.2s, only comparable to the current-penetration time. Furthermore, the available couple power was only 500 - 600kW. While many of discharges from that run-day ended up at higher density due to ICRF in the later part of discharge, one particular discharge (1100221014) had clean flat low density (0.3x10^{20}m^{-3}) with a flat top current of 0.45kA.

This proposal is to extend this discharge with lower N/e (1.9 instead of 2.3) and higher LHCD power.

![Fig 1: Time trace of (top) line averaged density (m^{-3}) and LH power (kW), (middle) plasma current (MA), and (bottom) loop voltage (V) in1080221014](image)

### 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.

We would like to use 1080221014 (LSN, 5.4T, 450kA was this reverse field? If not, we should find a more recent similar shot) as a baseline discharge and obtain a long (>1s) stable LH coupling. Since major changes have been made on LH after the reference discharge (new launcher, new TPS) was made and we
haven’t attempted to couple LH power during the ramp-up so often, we expect this process take up to 10 discharges. We will use the launcher Langmuir probe as a reference signal and adjust launcher location, outer separatrix radius to maintain sufficient density (\(n_e > n_{\text{cutoff}}\)) in front of the launcher. LHCD will be turn-off at \(\sim 1.2\) s and the Ohmic MSE reference will be taken between 1.2-1.6s. The \(I_{\text{plasma}}\) and TF flattop will be extended to 1.6 s to allow 0.4s of Ohmic time for the MSE reference, and measure the current profiles at every 100ms after 0.5s.

Once s target discharge is made, we try three different \(N_r\) (75, 60, 90 deg.) and two plasma currents \((I_p \sim 500kA, \text{and} \sim 700kA)\), where the underline indicates that the number for initial development.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: \(5.4\) T
- Plasma Current: \(500kA\)
- Working Gas Species: D2
- Density: \(N_{\text{eL04}}\) of \(3-5 \times 10^{19}m^{-2}\)
- Boronization: no
- Equilibrium configuration (if possible, refer to database equilibria): #1080221014 (Gas puff after 80 ms needs to be removed)

4.2 Auxiliary Systems

- ICRF Power, pulse length, phasing: no
- LHCD Power, pulse length, phasing: \(1 - 1.2\) s, 90deg \((N//=1.9)\).
- Pellet Injection (species): no
- Impurity blow-off injection: no
- Diagnostic Neutral Beam: yes
- Special gas puffing: no
- Cryopump: yes or no
- Non-axisymmetric Coils (Connections, Current); please use what is used in recent LSN.
- Other:

4.3 Diagnostics

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

MSE, Thomson Scattering, Hard X-ray, LH probes, and ECEs

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.
We request a half day run for development of target plasma and minimum parameter.

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.

Shot #1 - #5

Set up 1080221014-like ramp-up discharge. 500kA, 5.4T, 0.3x10^{19} m^{-3}. Flat density program. No ICRF power.

LH conditioning. Request is 800kW level of LH power from 0.2 – 1.2s. We may ask even earlier start of LH power if the plasma shape and launcher density control seems okay. (We may also try even longer LHCD if sawtooth comes back quickly after LH turn-off)

Outer gap may need to be adjusted during I_p ramp to keep constant density at LH launcher.

Shot #6-#10 90 deg. phasing

Shot #11-#14 Try phasing at 65 deg.

Shot #15-#18 (If time allows,) higher current (650kA) will be tried.

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, an ITER request, or an external database.

This MP proposes to try different approach to reach RS regime. It may look similar to more standard receipt but it is different in the sense that current profile evolution will be more dominated by current drive instead of temperature (and resistivity). Possible positive outcome includes 1) possibility to avoid a dangerous MHD and widen operation regime of full NI discharge 2) spontaneous development of eITB and 3) demonstration of longest LHCD.

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