

Alcator C-Mod Mini-Proposal

MP No. 500

Subject: Development of Diverted AT Target Plasma with ICRF, LHCD and Current Ramp

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Group: AT

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Approved by:

Date Approved:

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 these experiments is to investigate the application of LHCD to current density profile alteration (q profile control) during the current ramp with ICRH. Ideal steady state profiles with an off-axis peak in the current density, generating a reversed shear q profile, for advanced tokamak (AT) scenarios may be most efficiently achieved by arresting and maintaining the desired reversed shear (RS) q-profile while applying ICRH. The lower hybrid system operating at moderate or high $n_{||}$ at 90 or 120 degree phasing would be used to drive current off-axis and thus maintain an RS profile. ICRF minority heating would ensure heating of the initial target plasma to multi-keV electron temperatures which would guarantee off-axis LH absorption. In order to reduce potential impurity influx, and to control the density, the target plasmas proposed here are diverted at an early time during the ramp, in contrast to the cases discussed in Mini-Proposal 495a.

2. Background

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

Advanced steady state operating regimes with RS q-profiles are predicted to have excellent stability properties against internal micro-instabilities (ITG, ETG), thus minimizing transport [7]. A further goal is to avoid the occurrence of the $q=1$ surface altogether so as to avoid sawteeth which can trigger NTMs. This may be achieved if the RS current profile is arrested during the ramp-up phase with off-axis current drive. With the application of early ICRH heating the desired configuration was already inferred from Alfvén cascades for short time durations (0.25 sec or less) in past experiments, but typically the RS state decayed away in times beyond 0.25 seconds. The likely reason for the rapid penetration of the inductive electric field was the injection of impurities as the plasma was typically limited on the inner wall during the ramping. Development of an early (< 200 msec) diverted plasma will be useful for AT studies for the reduced impurity accumulation it offers under high power ICRH operation. Removing the plasma from the inner nose, as was previously done in some cases, would significantly reduce the amount of high Z material entering the plasma. Furthermore, the diverted plasma will offer easier entry to H-mode target plasmas which are ultimately necessary for achieving high beta-normal, high bootstrap AT targets.

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.

The focus of the first half of the run will be on development of an early diverted plasma. Standard shots, such as our fiducial (1070619017), have a time of diversion of about 0.25 seconds. The coil currents will be incrementally modified with a goal of creating a diverted plasma at 0.15 seconds.

The LH system will be initially configured for moderate $n_{||}$ operation at 90 degree phasing. The ICRF system will use on-axis heating at 5.4 T with 78/80 MHz. We will first establish the functionality of the ICRH system before operation simultaneously with LHCD. Once good ICRH operation is established, (nominal 2.5 -3.0 MW of ICRH) the LHCD system will be applied and its power will be increased to the 0.5 MW level simultaneously with ICRH. Subsequently the powers will be increased as much as possible without arcing problems in either of the RF systems. Later operation will investigate farther off-axis LHCD at 120 degree phasing.

Monitoring of the development of the RS q-profile will be done via the excitation of Alfvén cascades by fast ions from ICRH. In addition, the temperature dependence of the initial minimum frequency (geo-acoustic deformation, see Eq. 1, MP 495a) would also provide further data on current theories of Alfvén Cascades [8]. Finally, triggering of mini-ITBs in the presence of RS profiles at rational q values on a longer time scale is an intriguing possibility (see JET [9], also in DIII-D-Max Austin [10]) and will be monitored by the FRCECE system.

Determination of the success of current profile control will be determined by the PCI and magnetics measurements of Alfvén cascade activity, by the enhanced radial X-Ray emission intensity (A. Schmidt), and the loop voltage evolution. The MSE diagnostic would be further tested in these experiments by comparing to the Alfvén cascade results. Early diverted plasmas will be explored here in an attempt to minimize Z_{eff} while increasing the electron temperature with ICRF heating as early as possible in order to exclude the lower hybrid waves from central power deposition. Far off-axis LHCD power deposition will be enabled by ultimately using 120 degree relative waveguide phasing once we succeed in coupling LH power efficiently at 90 degree relative phasing. The latter may require a second day of operations if discharge development will take up too many shots the first day.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T
 Plasma Current: ramp to 0.8 MA by 0.2 sec., and flattop to 1.0 sec.
 Working Gas Species: D₂, H minority (2%-4%)
 Density: 0.5-0.7 x 10²⁰ m⁻² (during the ramp-up, t<0.200 seconds)
 Equilibrium configurations (if possible, refer to database equilibria): 1070619017

4.2 Auxiliary Systems

RF Power, pulse length, phasing: LH: 0.5+ MW, 0.5s, 90 and 120 degree phasing
 ICRF: 3 MW +, 0.5 s, H minority, 78/80MHz, heating phasing; may need to start with J port and E port only.
 Pellet Injection (species): N
 Impurity blow-off injection: N
 Diagnostic Neutral Beam: Desirable, but not necessary
 Special gas puffing:
 Other:

4.3 Diagnostics

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

PCI and X-ray profile will be the primary diagnostics for these experiments. The high frequency magnetic pick-up coils, Thomson and ECE are also required to obtain additional cascade data, as well as monitor the electron temperature profile.. Neutron emission will be used to monitor T_i, and Hirex may be helpful to monitor the ion

temperature profile.

5. Experimental Plan

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.

These experiments require 1 run day in L mode. If successful, a second day would be requested to repeat in H-mode, with cryo-pumping for density control, and /or continue with 120 degrees relative waveguide phasing.

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.

(1) Develop target discharge with early diverted geometry. (14 shots)

(2) Apply ICRH at 0.1sec and beyond into 0.8 MA ramp-up plasmas developed in step 1. Ramp ICRH stepwise up to 3.0 MW. Observe sawteeth entry time. Monitor Alfvén cascade phenomena (4 shots).

(3) Couple LHCD at 90 degree phasing into target plasma from the results of step 2 and adjust timing of LHCD from 0.10 second and beyond; Extend pulse length to 0.5 seconds. Increase power to 0.5 MW. Observe sawteeth entry time and monitor Alfvén phenomena (4 shots).

(4) Increase power from ICRH and LH as much as possible and vary relative timing of LHCD/ICRH so as to maximize sawtooth delay beyond 0.3 seconds. (4 shots)

Total number of shots: 26

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.

Development of an early diverted plasma will be useful for future experiments investigating ramp-up scenarios. Successful application of LHCD and ICRH would indicate a possible path to AT target plasmas. Additional data with ECE indicating triggering of mini-ITBs would be a first in C-Mod, and could shed light on the connection between rational values of q_{\min} and ITB formation with $T_i \leq T_e$. Results should lead to several publications, valuable data to Eric Edlund's thesis and experimental basis to proceed with H mode as cryo-pumping is now available to control the density rise.

7. References

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

- [1] M. Porkolab, Proc. 16th High RF Power in Plasmas, Park City, UT.[Eds. S. J. Wukitch and P. T. Bonoli] AIP Proc, 787, 114 (2005).
- [2] H. L. Berk *et al.*, PRL **87**, 185002 (2001).
- [3] M. Porkolab, IEEE Transactions of Plasma Science, **34**, 229 (2006).
- [4] G.J. Kramer *et al.*, PPCF **46** (2004) L23-L29.
- [5] B.N. Breizman and S. E. Sharapov, PPCF **37**, 1057 (1995).
- [6] J. A. Snipes, et al, Phys. Plasmas, vol. 12 (2005) 056102.
- [7] C. Kessel *et al.*, PRL 72, 1212 (1994).
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- [9] E Joffrin *et al*, Nucl. Fusion 43 1167 (2003).
- [10] M.E. Austin *et al*, Phys. Plasmas 13, 082502 (2006).