Subject: Is H-mode threshold power reduced near double null and why?

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Group: Transport

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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.

Evidence of reduced H-mode power threshold, $P_{L-H}$, has been observed in C-Mod in discharges run in close proximity to double null (DN) magnetic topology. This experiment will attempt to verify this reduction, and to map out the dependence of H-mode threshold near DN. The implications for L-H transition physics will be examined through study of the edge conditions at threshold.

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

Plasma discharges show considerable changes when topology is changed so that the ion $\nabla B$ drift points away from, rather than toward the primary X-point [1]. One of these changes, notably, is that the power required for H-mode access rises by a factor of ~2. Figure 1(a) (adapted from [1]) demonstrates this with experimental data, obtained by performing controlled power scans at varied values of the magnetic balance parameter SSEP. SSEP is the midplane-mapped distance between the primary and secondary separatrices, and SSEP<0 corresponds to lower single null (LSN) discharges. These data were all taken with $B \times \nabla B$ directed downward. As SSEP is made positive (upper single null), $P_{Th}$ increases significantly. Figure 1(a) shows that this increase occurs over a narrow range in SSEP, so that the details of the $P_{Th}$ dependence when close to DN are not resolved. $P_{Th}$ could increase monotonically with SSEP, or have more structure.

Low aspect ratio tokamaks (LARTs) have observed significant reductions (~2x) in $P_{L-H}$ for DN configurations, relative to single null [2,3]. In addition, ASDEX Upgrade (AUG) reported more modest reductions in $P_{L-H}$ when very close to balanced DN [3]. Thus instead of varying monotonically with SSEP [blue curve in Fig. 1(b)], a local dip exists near...
SSEP=0. This dip is illustrated schematically by the purple curves in Figs. 1(b) and 2. Figure 2 also illustrates three sample trajectories with which an experiment might attempt to map out this dependence. The result from AUG was determined not by holding SSEP fixed and scanning power (trajectory #1), but by fixing power just below the nominal value of \(P_{th}\) in a discharge and slowly increasing SSEP (trajectory #2) until a L-H transition was obtained. Using this technique, H-mode was accessed near DN at \(\sim 30\%\) less input power than in LSN (with \(B \times \nabla B\) directed down). As it happens, a similar observation was made on C-Mod recently, in discharges with constant ICRF and swept SSEP. Figure 3 illustrates a series of 800kA shots in which the total power was varied shot to shot. H-modes were obtained for \(\text{SSEP} \sim 5\text{mm}\) with \(P_{rf} \geq 1.6\text{MW}\), but at \(P_{rf}=1.1\text{MW}\), a L-H transition was only obtained when magnetic balance was shifted toward DN. For \(P_{rf} \leq 0.7\text{MW}\), no H-modes were obtained. A similar observation, with a less complete power scan, was made on the previous run day in 1MA discharges.

### 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.

First, a shot-to-shot ICRF power scan with \(\text{SSEP} \sim 5\text{mm}\) will be used to bracket the H-mode threshold power in LSN. Next the power scan will be partially repeated, with SSEP scanned slowly during the shot toward USN. Since power can be held nearly constant during the L-mode phase, this threshold experiment will consist of near-horizontally moving trajectories, \(\text{e.g.} \ #2\) in Figure 2. If there is a significant drop in \(P_{th}\) over a very narrow range in SSEP, this is the way to find it. If this drop is seen, then the power scan should be repeated while transforming from USN to LSN (trajectory #3), in order to map out the other side of the valley. Because we are not trying to get very far up the USN portion of the curve, the required ICRF power will be modest.

Key things to look for in this experiment will be the onset of H-mode, and how it relates to input power and/or net power across the separatrix. Edge density and temperature profiles will be examined to determine whether these are affected by the topology changes. We will also want to monitor changes in edge flows and fluctuations, insofar as possible.

### 4. Resources

#### 4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field**: \(5.4\text{T}\)
- **Plasma Current**: \(1.0\text{MA}\)
- **Working Gas Species**: \(\text{D2}\)
- **Density**: \(n_{l04}=1e20\)
- **Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.):** none required
Equilibrium configuration (if possible, refer to database equilibria): Near DN plasmas with ability to shift SSEP from negative to positive, using ZCUR program. A good starting load might be 1091021028.

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: 0—2MW, 1s flat, heating phasing
LHCD Power, pulse length, phasing: none
Pellet Injection (species): none
Impurity blow-off injection: none
Diagnostic Neutral Beam: if available, modulate for CXRS
Special gas puffing: Ar for Hirex
Cryopump: no
Non-axisymmetric Coils (Connections, Current): The usual correction configuration
Other:

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

Required: TCI, edge and core TS, ECE, passive CXRS, Hirex Sr.
Desired: PCI, reflectometry, active CXRS, Upper and lower divertor probes
Unwanted: any NINJA puffing

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 ½ run day for this experiment.

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. Load 1091021028: 5.4T, 1MA, target nl04=1e20. SSEP is programmed flat at approximately -5mm. ICRF pulses will nominally last from 0.6 to 1.5s.
   (a). Ramp ICRF from 0 to 2MW to determine roughly $P_{th}$. (1—2 shots)
   (b). Program flat RF. Begin with the threshold value estimated from the first shot and step down by 0.2MW each shot until no H-mode is obtained. This will give a more accurate $P_{th}$. (4—5 shots)

2. Add a ZCUR ramp to the shot so that SSEP ramps up to +1mm from 0.9s to 1.5s. Continue to program flat RF. Start with the lowest power level used in Step 1(b) and continue to decrease power in increments of 0.2MW each shot. (4—5 shots)

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3. Modify ZCUR so that the flattop begins with SSEP=+3mm, then scans to -3mm over 0.9 —1.5s. Repeat the power scan from 2, and if time allows continue the scan at higher powers, up to the max available RF. (4—5 shots)

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.

Examining the sensitivity of $P_{th}$ to proximity to DN, and any accompanying changes in edge profiles and fluctuations, could provide insight about L-H transition physics. This would contribute to ongoing work by the ITPA L-H transition working group, and directly support associated joint experiments PEP-6 and PEP-26.

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


8. Figures
Figure 1: (a) Experimental measurements show clear increase in $P_{th}$ near DN. Normalization to a scaling law for ITER is used to account for strong dependencies on density and field. (b) The dependence of $P_{th}$ on SSEP could be smooth and monotonic (blue solid curve) or could have more structure (purple dashed), as suggested by LART and AUG results.

Figure 2: Operational trajectories for mapping out $P_{th}$ as a function of magnetic balance. Trajectory 1 represents the traditional method of fixing the equilibrium and doing power scans; imperfect control of SSEP is problematic. Trajectories 2 and 3 consist of fixing input power (much easier to hold constant) and scanning SSEP during a shot.
Figure 3: SSEP scans in 800kA discharges from run 1091022, in which magnetic balance was shifted from LSN (t<1.2s) to USN (t>1.2s). ICRF power required to access H-mode in LSN was ~1.5MW. At lower input power (i.e. 1091022035), the L-H transition occurs when SSEP becomes closer to zero.