Subject: Study of ICRF mode conversion flow drive and NTMs in high performance I-mode plasmas


Group: ICRF

Date: July 26, 2012

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

Study NTMs that occur in high-performance I-mode plasmas with ICRF mode conversion flow drive (MCFD). Try to maximize mode conversion flow drive by avoiding NTMs through tailoring sawtooth and/or varying plasma collisionality.

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

In a 2011 C-Mod experiment (1110316), ICRF mode conversion flow drive was studied in I-mode plasmas aiming at getting the maximum flow drive efficiency and also combining with the large intrinsic rotation in I-mode plasmas. In a typical shot shown in Figure 1, we used J-antenna at 50 MHz mode conversion to drive a large rotation in L-mode, and then apply D+E antenna (minority) heating to obtain L-I transition. Although the stored energy was doubled, the plasma rotation did not increase beyond the level achieved in L-mode. Coincidently, there were NTMs observed in the magnetic signals and ECE signals in these high performance I-mode plasmas. We suspect that the appearance of NTMs may have capped the maximum rotation that could be achieved. To drive larger rotation, we will need to either preventing the occurrence of the NTMs or control the NTMs after they appear.
Figure 1: Observation of NTMs in high performance I-mode plasmas.

For the plasmas that are conducive to MC flow drive, i.e., low density and high RF power, the plasma $\beta$ is also high and the collisionality is low. These criteria seem to coincide with the condition for NTMs as observed from other machines. For NTMs to appear, a trigger is also needed to flatten the bootstrap current profile within a magnetic island and produce a sufficiently wide seed island. In the shots on 1110316, the seed island was provided by large sawtooth crashes. Thus, if in some way, we can make the sawtooth crash smaller in amplitude, the NTMs may be avoided. This has been demonstrated in other machines, for example, Ref. [1].

The long and large sawtooth observed in the I-mode run was mostly due to the existence of a large population of fast H particles, produced by high RF power at low density plasma. On the other hand, the sawtooth period is rather sensitive the antenna phase and also the relative location of the MC layer or IC layer vs. $q = 1$ surface due to localized ICRF heating and current drive, which can affect local magnetic shear. As a result, by tailoring the fast particle energy or changing antenna phases or changing B field can affect the sawtooth period and magnitude and possibly avoid NTMs.
Figure 2: NTM (3/2 mode) onset criteria compared with result from DIII-D and ASDEX-upgrade. C-Mod data are obtained from runs 1110316 and 1110317. DIII-D and AUG curves are obtained from Ref. [2]. $\nu_{NTM} = \nu_i/\epsilon \omega_{ce}^*$. 

The $\beta$ threshold for NTMs to appear depends on collisionality (see Figure 2). This is one of the reasons that we rarely observe NTMs in H-mode plasmas in Alcator C-Mod. Doing density scan and power ramp-up would help identify the $\beta_N$ and $\nu_{NTM}$ boundary for the NTM onset.

Comparison of discharges with and without NTMs can also help determine the rotation braking effect (and also confinement degradation) of NTMs. For I-mode plasmas without NTMs, we expect to see large plasma rotation - by combining large intrinsic rotation and effective MC flow drive.

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, reproduce high-performance I-mode plasmas with NTMs and map out the onset RF power threshold for NTMs. Then lower RF power to produce I-mode plasmas without NTMs, and see whether we can generate larger rotation.
- Vary antenna phases, which can affect sawtooth, and compare NTMs and rotation.
- Scan density, and find the collisionality boundary for NTMs. Compare rotation.
- Scan B field (changing MCCD location for sawtooth) and affect NTMs onset.
- Maximize plasma rotation by avoiding NTMs in high performance I-mode plasmas.
4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: ~ 4.5-5.7 T, reversed magnetic field for easier I-mode access.
- Plasma Current: 0.8-1.2 MA
- Working Gas Species: D$_2$
- Density: n04 = 0.5-1.2e20 m$^{-2}$.
- Equilibrium configuration: 1110316010, reversed field LSN plasmas.

4.2 Auxiliary Systems

- RF Power, pulse length, phasing: > 4 MW. J at 50 MHz and phase variable.
- Pellet Injection (species): No
- Impurity blow-off injection: No
- Diagnostic Neutral Beam: yes (if available).
- Special gas puffing: B-side upper 15 PSI $^3$He. Also Ar puff for HIREX.
- Cryopump: No
- Other:

4.3 Diagnostics

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

Standard diagnostic set plus PCI (heterodyne mode for RF waves), HIREX, T$_e$ diagnostics (GPC/GPC2/FRCECE, Fast ECE, etc).

Desired diagnostics: $^3$He profile measurement from FICXS (if DNB is available) and fast TCI (if available)

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.

1 run day.

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.

Total 26-plus good plasma shots

1. (4 shots) B$_{t0} = 5.1$ T, I$_p = 1.0$ MA, n04 = 0.7e20 m$^{-2}$, with $^3$He puff for mode conversion and Ar puff for HIREX. Same shape as 1110316010. Reproduce NTMs and watch out rotation change. Shots development may be required to adjust the $^3$He puff length and also n04 in order to observe NTMs. Start with 150
ms $^3$He puff (PG2 = 100, from t = 0.2 to 0.35 sec) and then adjust the puff length based on PCI measurement. Try two types of RF power waveforms:

a. D+E antennas at 2.4 MW from 0.65 to 0.85 sec, then add J antenna at dipole phase power ramp-up to 2.4 MW from 0.85 sec to 1.3 sec, and then keep constant at 2.4 MW from 1.3 to 1.5 sec;

b. J 50 MHz dipole phase steady power 2.4 MW from 0.65 to 0.85 sec, then add D+E power ramp-up to 2.4 MW from 0.85 sec to 1.3 sec, and then keep constant at 2.4 MW from 1.3 to 1.5 sec.

2. (2 shots) same plasma as in Step 1, lower the 2nd part of the RF power to a constant level just above I-mode transition threshold but below NTM onset (if such a window for $P_{RF}$ exists). Check whether larger rotation can be achieved.

3. (2 shots) Same plasma as in Step 1, but J at $+90^\circ$ phase. Compare NTMs, sawtooth length/magnitude and plasma rotation.

4. (2 shots) Same plasma as in Step 1, but J at $-90^\circ$ phase. Compare NTMs, sawtooth length/magnitude and plasma rotation.

5. (1 shot) locked mode calibration for HIREX

6. (6 shots) Same RF power, $B_t$ and $I_p$ as in Step 1, vary plasma target density (step $\Delta n_l 0^4 = 0.1\times10^{20} \text{ m}^{-2}$), until no NTMs are observed at higher collisionality (or smaller sawtooth). Compare rotation behavior with/without NTMs.

7. (3 shots) J antenna at $+90^\circ$ phase (or $-90^\circ$ phase, based on the result from Step 2 and Step 3). Repeat density scan like that in Step 6.

8. (4 shots) Choose a shot from above that is marginal to NTMs, and vary magnetic field shot by shot ($B_{t0} = 4.8 \text{ T}, 5.4 \text{ T}, 5.6 \text{ T}, 4.6 \text{ T}$). Watch out NTMs/sawtooth and rotation.

9. (2 shots) Max plasma rotation. Choose a shot above that has no NTM but has significant flow drive effect, and then use max RF power > 4 MW (power antennas all at once).

10. If time permits, run shots with the same parameters in Step 9 but at higher $I_p$.

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.

- Maximize mode conversion flow drive in I-mode plasmas (New interesting physics if rotation cannot be increased even without NTM).
- Understand more of the NTMs on C-Mod, and explore the parameter space that NTMs can be avoided in high performance I-mode plasmas.
- Contribute to Y. Lin’s IAEA poster.
- Provide data for Ken Liao’s thesis research and Cale Kasten’s study on turbulence using fast TCI.

7. References

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