Alcator C-Mod

Mini-Proposal

MP No. _______

Subject: Joint experiments with JET on non-resonant n=2 magnetic braking

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Group: MHD

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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 goals of this experiment are

1. To measure the braking of plasmas on C-Mod and JET from applied error fields with matched n=2 spectra.
2. Direct comparisons of experimental data to calculations of non-resonant torque due to neoclassical toroidal viscosity (NTV).

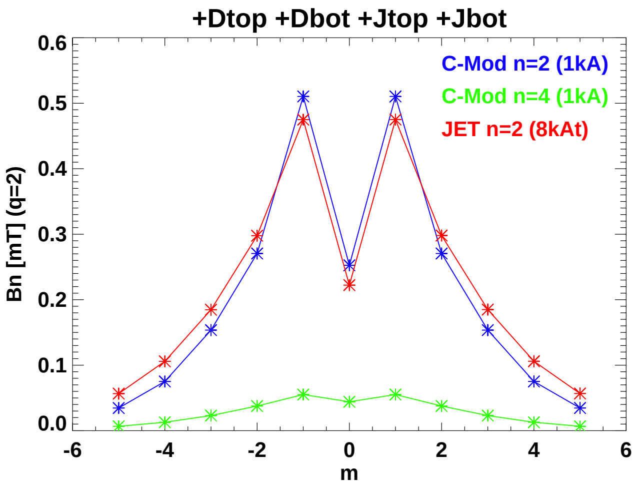
This experiment would form part of a quantitative cross machine comparison of non-resonant rotation braking, with the aim of validating theory and predicting the scaling with machine size. This work would form part of the IEA/ITPA joint experiment (MDC-12).

2. Background

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

It is known experimentally and theoretically that non-resonant helical fields can play an important role in damping plasma rotation (e.g. experiments with n=3 on DIII-D & NSTX and theories by Shaing et al, and Callen et al.). Recent experiments on JET using n=2 fields have also shown a braking effect.

The non-axisymmetric coils on C-Mod are capable of applying fields with a dominantly n=2 spectrum. Of the 4 four-coil n=2 configurations possible, the most pure n=2 spectrum is that obtained using the coils +Dtop +Dbot +Jtop +Jbot. This gives a dominantly n=2 field, with a small n=4 component. Configurations using the B coils introduce an odd-n component, due to the shifted positions of the B coils. A comparison with the applied spectrum on JET shows that the two match well, except that the n=4 component on JET is zero. However, calculations show that, on C-Mod, the viscous torque from the applied field is dominated by the n=2 component of the field, with the n=4 component only providing 1% of the total torque.



We note here that on JET, a coil current of 32 kAt was able to brake the core rotation by ~50% in a plasma with 9MW of NBI. At maximum A-coil current, almost the same amount of n=2 field is applied on C-Mod, which suggests that we should get significant braking from the n=2 coils on C-Mod.

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 target plasma is a RF heated H-mode plasma, with q_{95} in the range 3-4. We require central deposition for the RF, which suggests running at 5.4T, 800kA with Hydrogen minority heating using RF at 80MHz .We note that the non-axisymmetric coils will not be available for n=1 error field compensation, which precludes running at low density. Previous locked mode threshold scaling experiments at 4.1T, 800kA and 6.3T, 1.3MA in the 'JET shape' suggest that the line-averaged density needs to be above ~$1.3 \times 10^{20} m^{-3}$ at 5.4T to avoid locked modes. This suggests running line-averaged density ~ 2×10^{20} m^{-3}.

The basic approach would be to form a H-mode plasma with steady rotation, indicating that the plasma is in torque balance. This may require running after a boronisation. We would then apply an n=2 field using the non-axisymmetric coils. We can then measure dΩ/dt using the upgraded HIREX diagnostic and then compare the applied torque to that predicted from theory. A simplified version of the momentum equation is

$$\frac{\partial V_\phi}{\partial t} \approx \frac{V_{Ti}}{R_0 q} \sum \frac{n^2 \left| B_{m,n} / B \right|^2}{(m - nq + \nu_{eff})} (V_\phi - V_{NC}^*) + \eta (V_\phi - V_{\text{intrinsic}})$$

Where the first term on the rhs represents the torque from NTV and the second term represents, to lowest order, a restoring torque. The experiment would consist of applying various levels of applied field, measuring the braking effect and then validating this against theory.

The similar n=2 spectra in JET and C-Mod means the experiment is thus directly testing the NTV dependence on plasma parameters (p_i, R, B_T etc.) as the Bm,n terms are the same.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

Toroidal Field: 5.4 T
Plasma Current: 800 kA
Working Gas Species: D_2 + H_2 minority for RF heating
Density: 2×10^{20} m^{-3} line-averaged.
Equilibrium configuration (if possible, refer to database equilibria):

4.2 Auxiliary Systems

RF Power, pulse length, phasing: 4 MW, 80 MHz (central H minority heating)
Pellet Injection (species): none
Impurity blow-off injection: none
Diagnostic Neutral Beam: none
Special gas puffing: Argon for rotation diagnostic
Non-axisymmetric Coils (Connections, Current); n=2 configuration (+Dt +Db +Jt +Jb), max current.
Other:

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

Hirex Jr, Hirex III, Equilibrium magnetics, ECE. H_α.

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.

To achieve a good H-mode the experiment should be run post-boronisation. A parasitic test of the braking achievable from the A-coils would be useful, although the special needs for A-coil wiring might be problematic. If all is well, then 1 half day session would be required.

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.

First, we should establish a good steady state H-mode. We might need to adjust the density to achieve this. When a good target has been obtained, we would begin the scan of A-coil current. The braking torque predicted from NTV theory is proportional to the current squared, so we propose a seven point scan covering the range of applied torque uniformly. The order of shots thus would be 3.7kA, 3.35kA, 3.0kA, 2.6kA, 2.1kA, 1.5kA, 1kA in the A-coil. Any remaining shots would be used to fill in the gaps at the most interesting A-coil current.

Each shot would proceed as so. When the plasma rotation has reached a steady state, apply the A-coil current at a fixed level, ramping up as quickly as possible. When the plasma rotation again reaches a steady state, turn off the A-coil current as fast as possible. Measure the $d\Omega/dt$ in each phase. Repeat with different A-coil currents to perform a scan of applied field in order to measure the braking as a function of applied torque.

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.

The key results would be:

A direct measurement of the braking effect due to non-resonant error fields and a validation of NTV theory.

A comparison to results obtained on JET using almost identical error fields.

The work is likely to result in a conference presentation and journal paper.

7. References

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

Shiang, PoP 10, pp1443
Callen, MHD Topical Group meeting, ITPA, Chengdu, 2006
Zhu et al, PRL 96, 225002