Subject: Is it $q_0$ or $\nabla q$ which determines the direction of core rotation observed in LHCD plasmas?


Group: Transport, Rotation, LH

Date: May 1, 2014

1 Purpose of experiments

Include immediate goal of the experiments, scientific importance and/or programatic relevance. Refer to any relevant program milestones or ITER R&D commitments. This is the “sales pitch” for your use of a C-Mod run day.

The purpose of this experiment is to determine if it is the value of $q_0$ or the gradient $\nabla q$ which determines the direction of core rotation observed in LHCD plasmas. The underlying physics issue is the dependence of the residual stress, and its sign, on the q profile. Manipulation of the q profile with LH waves can then be used as a control knob for the toroidal rotation velocity profile.

2 Background

Discuss physics basis of the proposed research, prior results at Alcator or elsewhere, and any related work being carried out separately (in other Alcator C-Mod miniproposals).

Toroidal rotation changes due to lower hybrid (LH) waves have been observed [1, 2, 3, 4, 5, 6, 7, 8], with velocities in both the co- and counter-current directions. Even in plasmas with good core absorption of LH waves, the mechanism for rotation drive is not clear. Candidates include direct momentum input from the waves (calculated to be low), electron orbit loss, trapped electron pinch effects, resonant electron radial drift, and less direct causes such as the turbulent equipartition pinch or through modification of the q profile. A challenge of these accounts is to explain the rotation changes observed in both directions. Evidence for the role of the current density profile is suggested by changes in sawtooth behavior. LHCD plasmas which had sawtooth oscillations showed counter-current velocity increments, while in the co-current rotation increment discharges, the sawteeth were suppressed due to a significant change in the q profile.

The connection between the core magnetic shear scale length and direction of rotation increment is illustrated in Fig.1 where the change in the core rotation velocity with LHCD is shown as a function of the average value of $L_s$ (from MSE-constrained EFIT) near $r/a \sim 0.3$ for C-Mod discharges. There is an abrupt change in the LHCD rotation increment, going from counter- to co-, near $L_s \sim 2.3$ m, exhibiting a threshold behavior. A related threshold is seen as a function of the central inverse rotational transform, as is illustrated in Fig.2, where the change in core rotation frequency is shown depending on $q_0$. The null in $\Delta \omega$ is close to $q_0 \sim 1$. The use of the rotation frequency allows for direct comparison with the results
Figure 1 – The change in the core rotation velocity with LHCD (1.14-1.24 s) as a function of $L_s$ near $r/a \sim 0.3$ for C-Mod discharges.
Figure 2 – The change in the core rotation frequency with LHCD as a function of $q_0$. Dots: C-Mod, asterisks: Tore Supra, diamonds: JET, box: EAST.
from other devices; also shown in Fig. 2 are points from EAST [5], JET and Tore Supra, which fit well with those from C-Mod. These points generally occupy two quadrants in this operational space: counter-current rotation increments for plasmas with $q_0 < 1$ and co-current for $q_0 > 1$.

The purpose of this proposal is to determine whether it is the value of $q_0$ or the gradient $\nabla q$ (or even the sign of $q''$) that determines the rotation increment direction with LHCD. The previous results of Figs. 1 and 2 were from a variety of plasma currents; this proposal seeks to examine the rotation dependence on the $q$ profile at fixed plasma current.

3 Approach

What your experiment will actually do, and why you will do it that way. Describe the methodology to be employed and explain the rationale for the choice of parameters. 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 approach is to perform a shot by shot LHCD power scan (at fixed line averaged electron density of $0.7 \times 10^{20} / m^3$, plasma currents of 0.4 and 0.8 MA and magnetic field of 5.4 T) and measure the current density and toroidal rotation velocity profiles (and the electron density, ion and electron temperature profiles).

4 Resources

4.1 Machine and plasma parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal field</td>
<td>5.4 T</td>
</tr>
<tr>
<td>Plasma current</td>
<td>0.4, 0.8 MA</td>
</tr>
<tr>
<td>Working gas species</td>
<td>Deuterium (D$_2$)</td>
</tr>
<tr>
<td>Density</td>
<td>$\bar{n}_e = 0.7 \times 10^{20} m^{-3}$</td>
</tr>
<tr>
<td></td>
<td>$n\ell_04 \approx 0.4 \times 10^{20} m^{-2}$</td>
</tr>
<tr>
<td>Equilibrium configuration</td>
<td>Reference shot 1110128013, but longer flat top</td>
</tr>
<tr>
<td>(if possible, refer to database equilibria)</td>
<td></td>
</tr>
<tr>
<td>Pulse length, typical current and density waveforms, etc.</td>
<td>1110128013</td>
</tr>
<tr>
<td>(refer to database or sketch desired waveforms)</td>
<td></td>
</tr>
<tr>
<td>Boronization required?</td>
<td>if possible</td>
</tr>
<tr>
<td>(if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.)</td>
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4.2 Auxiliary systems

List requirements for the following Alcator C-Mod auxiliary systems:
ICRF (power, pulse length, phasing) N/A
LHCD (power, pulse length, phasing) 0.1 to 1.2 MW in 0.1 MW increments, 0.7 s
Pellet injection (list species) N/A
Impurity injection (laser blow-off) Not required. May piggyback.
Diagnostic neutral beam for MSE and CXRS
Special gas puffing argon seeding
Cryopump for density control
Non-axisymmetric coils needed for locked mode avoidance, and for locked mode calibration
(list connections and current)
Other None

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

HIREX-St, Hirex-Jr, MSE, CXRS, PCI, GPI, ECE, core and edge Thomson

5 Experimental plan

5.1 Run sequence plan
Specify total number of runs required, and any special requirements, such as consecutive days, Monday runs, extended run period (10 hours maximum), etc.

1 run day requested

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.

1st shot, locked mode for velocity calibration

run 5.4 T, 0.4 MA discharge with line averaged density of 0.7x10^{20}/m^3, measure toroidal rotation profiles, current density profiles, electron density, ion and electron temperature profiles.

repeat with 0.1 MW LHCD between 0.7 and 1.4 s

raise LHCD power in 0.1 MW increments shot by shot up to maximum (1.0 MW)? approximately 10 shots.

run locked mode

repeat shot by shot power scan at 0.8 MA

run locked mode
6 Anticipated results

Discuss possible experimental outcomes and implications. Indicate if the experiment 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.

paper and presentations at APS, TTF

ITPA TC-14

References