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Sawtooth pacing with mode conversion current drive on Alcator C-Mod

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Controlling sawteeth oscillations, either by suppressing them or pacing their period, may be a critical tool for achieving high performance in ITER and reactor plasmas, since the large crashes associated with long sawteeth stabilized by energetic ions or alphas particles can have detrimental effects on the discharge. In particular, it was shown they can provide seed islands for neoclassical tearing modes (NTMs) [7]. Long sawteeth have also large mixing radii compared to the minor radius, implying a significant rearrangement of the plasma core, which may lead to disruptions or increased particle and heat fluxes on the plasma facing components.

Localized current drive near the q = 1 surface has been shown to be an effective tool for changing the period of sawtooth oscillations [6]. Mode conversion scenarios in the Ion Cyclotron Range of Frequencies, which result in strong localized electron heating near the ion-ion hybrid layer in plasmas with multiple ion species, could be used to obtain the required driven currents. Mode conversion has been demonstrated in reactor relevant deuterium-tritium plasmas [9], and the technique scales favorably to these plasmas, contrary to Electron Cyclotron Current Drive (due to density limits), or Ion Cyclotron Current Drive (see [1]).

In this paper, we report on experiments on the Alcator C-Mod tokamak in which the period of sawtooth oscillations was varied with mode conversion current drive (MCCD).

SAWTOOTH CONTROL WITH MCCD

Alcator C-Mod is equipped with three ICRF antenna arrays [3], with a four-strap antenna capable of phased operation at powers up to 3 MW at the J horizontal port. This antenna can be used to obtain central mode conversion scenarios at 50 MHz for D,^{3}He plasmas for central magnetic field near 5.4 T. In the experiment reported here, the ^{3}He concentration was estimated to 20%, with a residual hydrogen content near 5 %. The central density was $\sim 1.7 \times 10^{20}\, m^{-3}$, and the total plasma current 600 kA.

In order to study the sawtooth response to localized MCCD, the mode conversion layer was swept through the inversion radius by ramping the toroidal field down from 5.2 to 4.8 T. The ^{3}He concentration does not vary much during a C-Mod discharge, and the change in

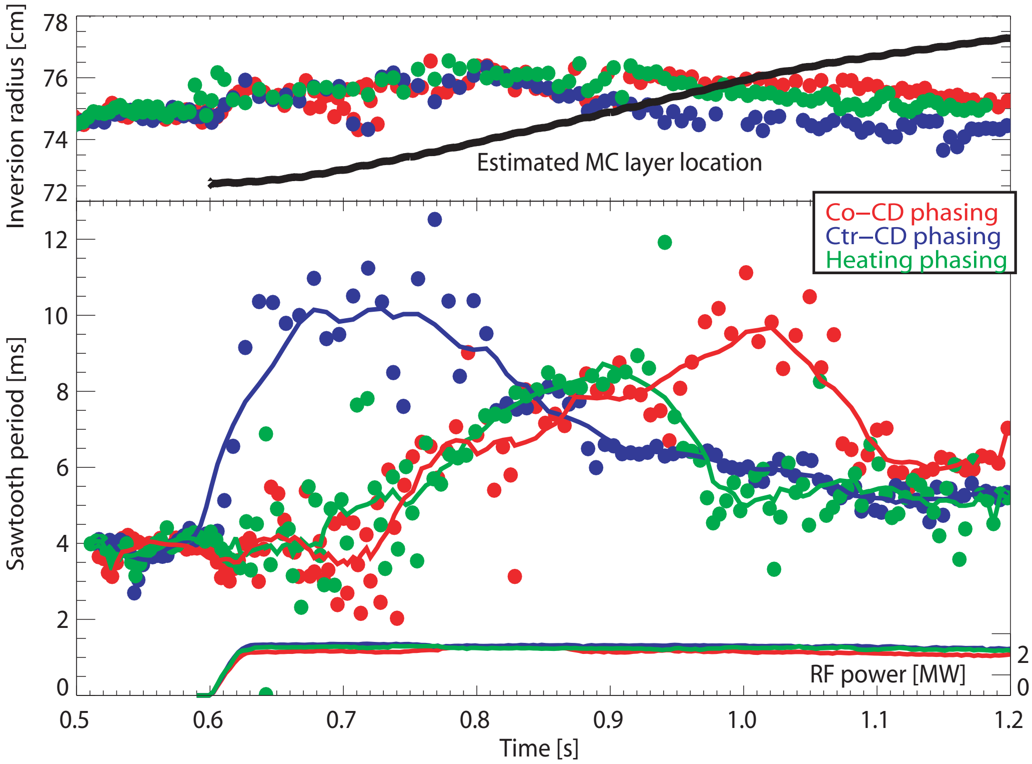

Figure 1: Evolution of the sawtooth period as the deposition location is scanned through the inversion radius, with co, counter current drive and heating phasings.

magnetic field moves the ion-ion hybrid layer on the inner side of the magnetic axis towards the high field side, or outwards in minor radius. The sawtooth response with 2.4 MW ICRF power for three different antenna phasings, co, counter-current drive and heating, is shown on Figure 1. In the three successive discharges, the phasing was the only control parameter varied. As seen on the figure, the sawtooth period is changed significantly, from 3 to 12 ms.

The observed sawtooth period evolution as the deposition location is varied in co and counter-current drive is consistent with the effect of localized current drive near the q = 1 surface observed in ECCD or ICCD experiments. While the ^{3}He ion cyclotron layer is also in the plasma core in these plasmas, the associated ^{3}He ion heating is weak and fast particle effects or ICCD can be ruled out as a dominant effect in these experiments. Thus, the experimental results reported here constitute the first clear demonstration of sawtooth control with MCCD.

TORIC SIMULATIONS AND ASYMMETRIES

In the discharge with heating phasing, a similar sawtooth period evolution was observed as in co-current drive, until .9 sec, when large injections occur and hinder the comparison. While the effect of localized electron on the sawtooth period, identified in ECH experiments

[8], another explanation is found in the driven current profiles predicted by the full wave code TORIC [4, 11] and the Ehst-Karney parametrization [5] for the current drive efficiency. As can be seen on Figure 2, TORIC predicts currents are driven in the co-current direction for heating (symmetric phasing). This results from up-down asymmetries in the mode conversion process, and poloidal field effects. Note that while the net MCCD currents only amount to about 10 kA out of 600 kA, the local driven current density is significant compared to the ohmic current density.

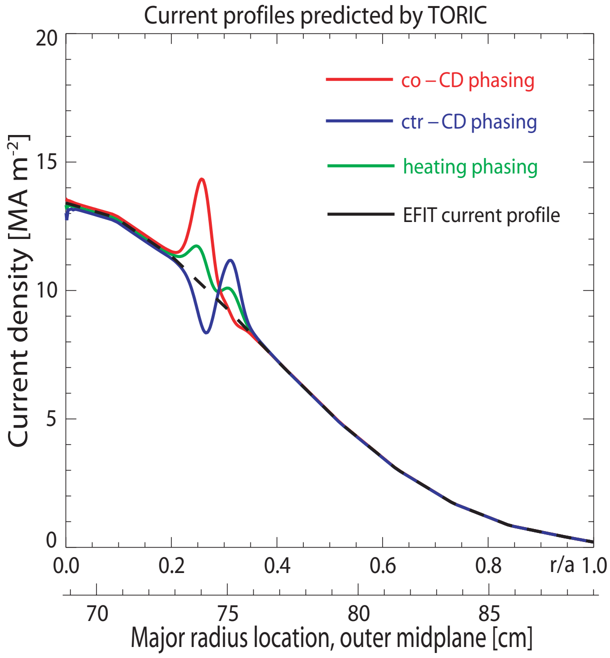

Figure 2: Driven current predicted by TORIC.

TRANSP simulations with the Porcelli model for the sawtooth period [10, 2] have been used to investigate which of the localized heating or MCCD currents dominates in the heating phasing discharge. Indeed, profile resiliency prohibits large changes in the conductivity gradients near the inversion radius, as confirmed from temperature profile measurements, and thus the current drive effect is expected to dominate. Two TRANSP simulations were performed, one without current drive, the other using the driven currents predicted by TORIC, using in both cases the experimental temperature profiles measured with ECE. Figure 3 shows the two terms in the relevant trigger condition $c_\star\gamma > \omega_{*i}$ in the Porcelli model in the two simulations.

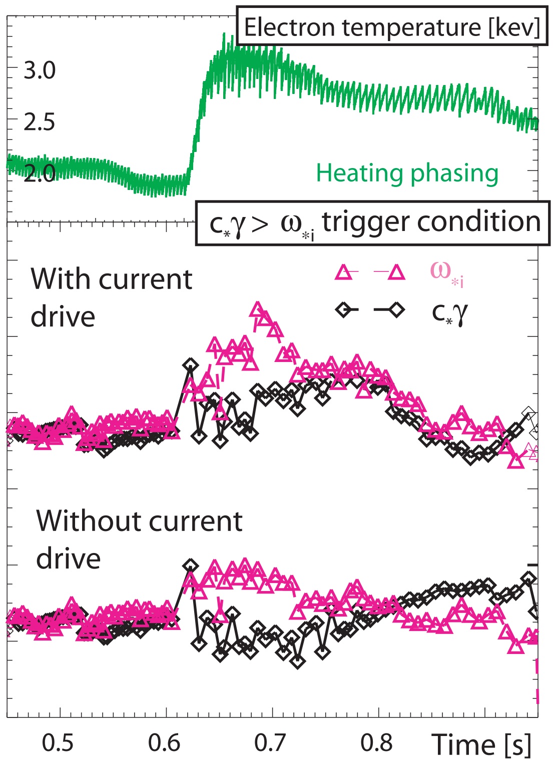

Figure 3: TRANSP simulations with the Porcelli model.

The agreement between the two quantities shows that the evolution of the current density is well captured by TRANSP from solving the current diffusion equation, as illustrated in the ohmic phase before .6 sec. As the RF is turned on, we see that the agreement is better when the driven current profile from TORIC is included, as opposed to the case where only heating effects are considered. This supports the conclusion that MCCD currents are being driven in heating phasing.

CONCLUSIONS AND FUTURE WORK

Sawtooth pacing with localized mode conversion current drive (MCCD) around the q = 1 surface has been demonstrated in experiments on the Alcator C-Mod tokamak. Future experiments will investigate the effectiveness of MCCD in modifying the period of long sawteeth stabilized by energetic hydrogen minority ions. The experiments will use up to 3 MW power at 80 MHz to create fast minority hydrogen ions, and another 3 MW power at 50 MHz to obtain MCCD in D(^{3}He,H) plasmas.

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References

[1] M. Laxåback and T. Hellsten. *Nucl. Fusion*, 45:1510, 2005.
[2] G. Bateman et al. *Phys. Plasmas*, 13:072505, 2006.
[3] P. Bonoli et al. *Fus. Science and Tech.*, 51:401–436, 2007.
[4] M. Brambilla. *Plasma Phys. Cont. Fusion*, 41:1–34, 1999.
[5] D. Ehst and C. Karney. *Nucl Fusion*, 31:1933, 1991.
[6] J. P. Graves et al. *Plasma Phys. Control. Fusion*, 47:B121–B133, 2005.
[7] R.J. La Haye. *Phys. Plasmas*, 13:055501, 2006.
[8] M.A. Henderson et al. *Fus. Eng. Des.*, 53:241–248, 2001.
[9] R. Majeski et al. In *Proceedings of the 12th Topical Conference on RF power in plasmas, Savannah, GA*, April 1997.
[10] F. Porcelli et al. *Plasma Phys. Cont. Fusion*, 38:2163–2186, 1996.
[11] J.C. Wright et al. *Phys. Plasmas*, 11:2473–2479, 2004.