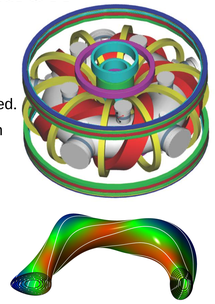
Introduction & Motivation

- Sawtooth oscillations are driven by the1/1 MHD mode, but other important aspects and not clearly understood.
- How do sawtooth properties depend on total and vacuum transform?
- Due to the unique nature of CTH, the vacuum and total transform can be varied.
- The size of the inversion radius and characteristics such as the rise and crash timescales are investigated as functions of the total and vacuum rotational transform.



Compact Toroidal Hybrid (CTH)

- l =2, 5 field-period torsatron with auxiliary toroidal field coils
- Operates as conventional torsatron with ECRH plasma generation
- Toroidal plasma current driven with an OH solenoid increases density and temperature

Parameters:

R_0 = 0.75 m P_{input} ≤ 30 kW ECRH a_{vessel} = 0.29 m n_e ≤ 5 x 10^{19} m^{-3} a_{plasma} ≤ 0.2 m
T_e ≤ 200eV B_0 ≤ 0.7 T β ≤ 0.5% I_p ≤ 80 kA Discharge duration – 0.1 s

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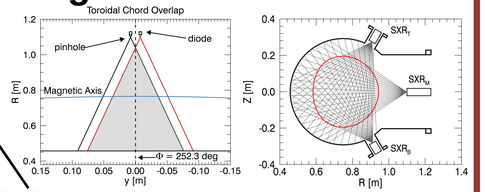
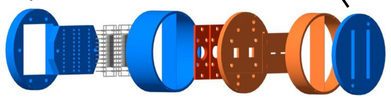
Two-Color Diagnostic on CTH





- 83% of each chord overlaps with the neighboring diode
- 2" in diameter
- Two AXUV20ELG diodes from Opto Diode Inc
- Al (1.0 um, 3.0 um) and C (0.5 um) filters
- Laser cut slits (changeable with vacuum break)
- Toroidal width of slit: 3.175mm
- Poloidal width of slit: 0.25mm

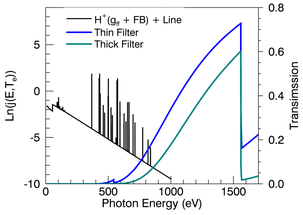
Theory of Two-Color SXR T_e

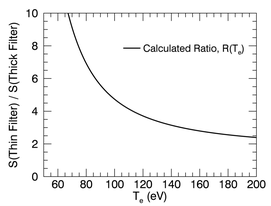
- Each filter has a different photon cut-off energy (**bold lines**) limiting the lower energy range of the bremsstrahlung radiation.
- The filters are 0.5 um C and 1.0um or 3.0 um Al. A 0.5um Al_2O_3 layer was assumed as the dominate impurity within both filters.
- The bremsstrahlung radiation was simulated using Atomic Data and Analysis Structure (ADAS) code[2] for: n_e = 2*10^{19} m^{-3}, T_e = 100 eV.

The SXR signal for each chord with a filter of thickness t_1 is calculated using the formula:

$$SXR(t_1) = k \int_0^\infty \mathrm{d}E \int_V j(E,T_e)A(E)T(E,t_1)\frac{\mathrm{d}\Omega}{4\pi}\mathrm{d}r$$

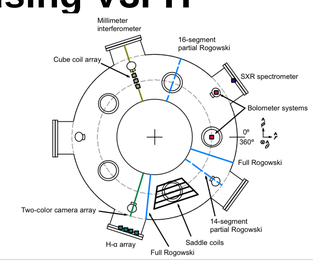
- A(E) is the absorption coefficient of the photodiode, T is the transmission of the filter, j is the bremsstrahlung radiation.
- The temperature is determined by comparing the ratio of experimental signals to the theoretical ratio.



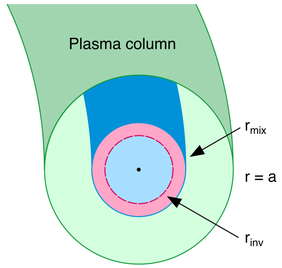


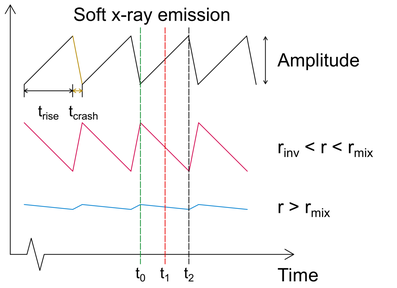
Reconstructions using V3FIT

- V3FIT[3] is used to reconstruct fully 3D plasma equilibriums.
- V3FIT determines the best fit for data signals calculated from the equilibrium model and experimental values.
- V3FIT uses VMEC[4] as the equilibrium solver for V3FIT.
- VMEC is an ideal MHD equilibrium solver. It can calculate the 3D closed nested flux surfaces in toroidal plasmas.
- Experimental values from 266 diagnostics including: Rogowski coils, cube coils, saddle coils, bolometer signals, and SXR signals are used to compute the equilibrium model.

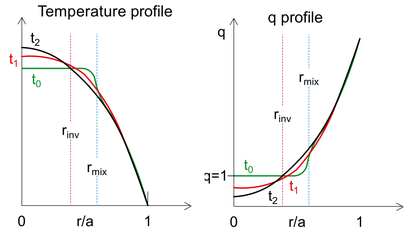


Sawteeth in a current-carrying stellarator

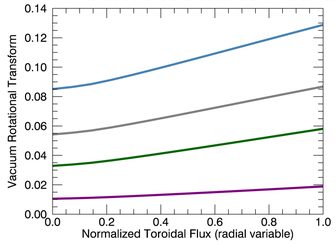


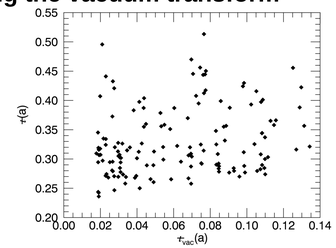


- The core of the plasma is heated ohmically, peaking the plasma current and temperature therefore letting q drop below unity.
- An m = 1, n = 1 MHD mode then grows until the core confinement is lost and expels energy to the outer regions.



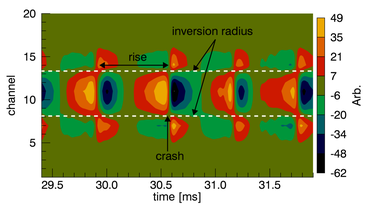
Sawtooth Scan – Changing the vacuum transform

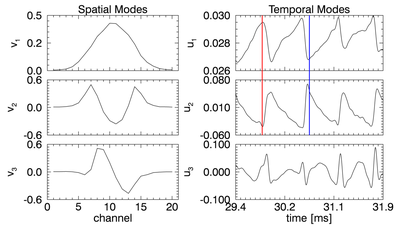




- Each dot represents a different sawtoothing discharge consisting of 3-5 sawteeth.

Biorthogonal decomposition used to find inversion radius

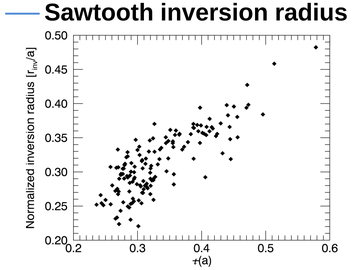


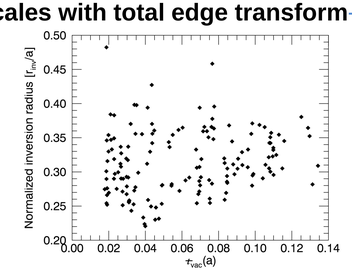


$$f(x,t) = \sum_n A_n v_n(x) u_n(t)$$

- Biorthogonal decomposition (BD) provides an empirical mode basis to characterize the sawteeth behavior.
- BD separates a spatio-temporal signal into two functions dependent on time or space.

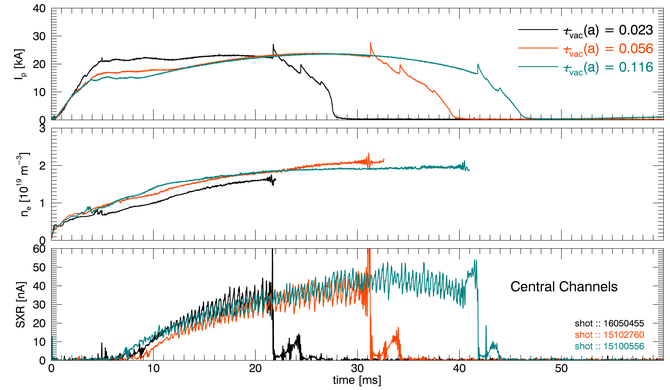
Sawtooth inversion radius scales with total edge transform



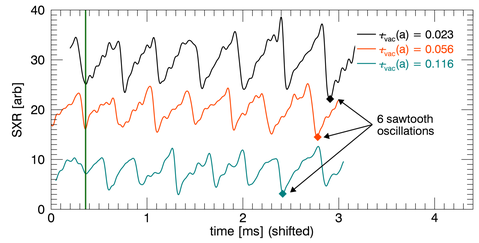


- Snider[5] found the ratio of the inversion radius to the plasma radius increased with increasing total rotational transform.
- This scaling is observed for sawteeth in CTH.

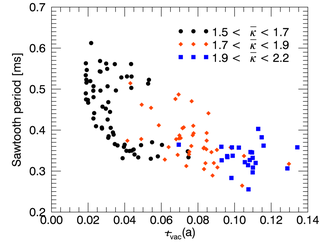
Investigations of Sawtooth Frequency

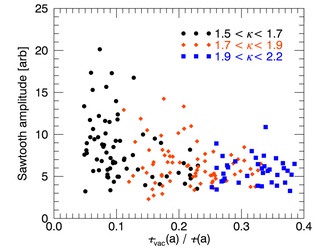


- Central SXR channel 3 ms after the start of the sawtoothing portion for each discharge.
- Sawtooth period and amplitude both decrease with application of higher 3D shaping.



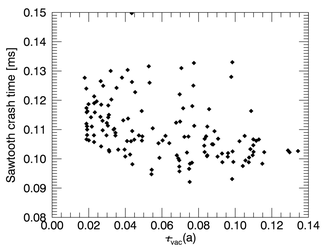
Shorter period sawteeth observed at higher levels of κ

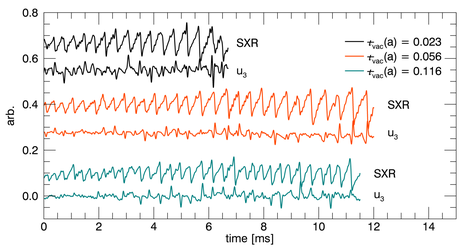




- The sawtoothing frequency appears to be independent of the total edge transform during a discharge, but depends on the vacuum transform of the stellarator equilibrium applied before the discharge.

1/1 mode dynamics appear unchanged with 3D shaping





- The sawtooth rise time increases with the vacuum transform, while the crash time does not.
- 1/1 mode dynamics observed throughout the sawtooth cycle, indicating partial reconnection.
- The 1/1 mode spikes in amplitude during each sawtooth crash.

References

1. G. Jahns, M. Soler, B. Waddell, J. Callen, and H. Hicks,, Nuclear Fusion, 18, 609 (1978)
2. H. P Summers, The ADAS user manual, version 2.6, 2004, see www.adas.ac.uk
3. J.D. Hanson, S.P. Hirshman, S.F. Knowlton, L.L. Lao, E.A. Lazarus, and J.M. Shields, Nucl. Fusion 49, 075031 (2009)
4. S.P. Hirshman and D.K. Lee, Comput. Phys. Commun. 39, 161 (1986)
5. R.T. Snider, Nuclear Fusion, Vol. 30, No. 11 (1990)
6. P. DeVries, et al. Proc. 28th EPS Conference on Controlled Fusion and Plasma Phy., vol. 25A (2001)