Abstract

Enhanced confinement (EC) periods in the Madison Symmetric Torus can arise spontaneously during standard discharges with sufficiently strong toroidal magnetic field reversal. These periods are characterized by a lack of sawtooth activity for periods of up to 20 ms. There are, however, smaller sawtooth-like events ("bursts") which occur. These bursts are edgelocalized, as opposed to the global nature of sawteeth. In this way, they are similar to discharges with Pulsed Poloidal Current Drive (PPCD) where current parallel to the magnetic field is driven externally. We have obtained line-integrated electron density and density fluctuation measurements by using far-infrared interferometry during these discharges. These data will be used to make comparisons between three types of discharges: standard shots with and without EC periods and PPCD shots. The density fluctuation amplitude is seen to drop during both PPCD and EC shots. EC periods can be separated into two types: those with regularly occurring "bursts" and those without. Changes in the density profile and fluctuation characteristics will be examined. In addition, density fluctuation behavior differences during sawteeth and "bursts" can be determined. Fluctuations are analyzed by conventional statistical tools in the time domain, frequency domain, time-frequency domain (wavelet), and phase space domain.

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Introduction

- Improved confinement through sawtooth suppression can be achieved in two ways on the MST. Pulsed Poloidal Current Drive (PPCD) uses an external circuit to drive edge parallel current. Enhanced Confinement (EC) plasmas are generated spontaneously from deep toroidal field reversal and good wall conditioning. Both exhibit intermittent increases in edge parallel current called bursts.
- Density fluctuations increase in amplitude during these bursts. The increase is first in the m=0 modes, then in the m=1 modes. This is similar to the behavior of the magnetic fluctuations.
- The amplitude and spectrum of fluctuations is similar in bursts in both EC and PPCD plasmas. Each is lower in amplitude than fluctuations during a sawtooth.
- Transport is greatly reduced during periods which are free from bursts. The density profile is observed to pinch inward and narrow during these periods.
- Periods of continuous bursting are characterized by sawtooth-like density fluctuation amplitudes and a degradation of confinement, leading to a broader density profile.



MST Far-Infrared Interferometer/Polarimeter System

Standard MST Plasmas Are Dominated By the Sawtooth Cycle.



• Sawtooth events drive dynamo current in the plasma edge while driving tearing mode fluctuations. This causes an increase in transport which broadens the density profile.

• During a sawtooth, the m=1 core resonant modes are excited first and then momentum is transferred to the m=0 edge resonant modes as shown below.



Sawteeth Can Be Suppressed by Externally Driving Poloidal Current (Pulsed Poloidal Current Drive or **PPCD**).



• Density increases dramatically during the PPCD period. (From about $4x10^{12}$ to $8x10^{12}$).

• Deep reversal (F~-2) is obtained.

• There is a dramatic decrease in loop voltage and magnetic fluctuation amplitude. There are still spikes of parallel current in the edge which will be referred to as "bursts". They are in general smaller in amplitude than sawteeth and are tied to the m=0 modes.



Enhanced Confinement (EC) Plasmas Are Standard Shots with Similar Features to PPCD.



• With deep toroidal field reversal (F~-1) and good wall conditioning, sawteeth can be suppressed without external PPCD. The result is an Enhanced Confinement or EC shot.

• The density increase in an EC is not as dramatic as in PPCD.

• EC plasmas exhibit the same sort of "bursts" as PPCD plasmas. They show up in the loop and poloidal voltages and in the m=0,n=1 mode amplitude.



Bursts, Burst Free Periods and Continuous Bursting



• Bursts can occur throughout the EC period resulting in a significant level of magnetic fluctuations.

• Some shots have periods of 2-3 ms without a burst event. These "burst free periods" are characterized by good confinement and low magnetic fluctuation amplitudes.

• Other shots can spontaneously enter a period of "continuous bursting" where magnetic fluctuations rise to sawtooth-like levels for extended amounts of time. Density Fluctuations Increase During Bursts in EC and PPCD Plasmas.

PPCD



EC



The Density Profile Broadens During Burst Events





Density Fluctuations During Bursts Exhibit m=0 and m=1 Characteristics.

Coherence and Phase of Density Fluctuations between Inboard (r/a=-0.62) and Outboard (r/a=0.83) Chords



- Fluctuations < 10 kHz are in phase and therefore m=0.
- Those > 10 kHz are phase shifted by π between inner and outer chords and are m=1.
- This behavior is also typical of density fluctuations during sawteeth.
- We can use this information to examine mode dynamics on a fast time scale without having to resort to correlation with magnetic signals.

Fluctuation Amplitude in Bursts is Reduced Compared to Sawteeth

Total Line Integrated Fluctuation Amplitude at the Peak of a Sawtooth or Burst Event



• The amplitude of density fluctuations is globally lower for bursts in both EC and PPCD relative to sawteeth.

• In all cases, the magnitude is larger on the edge chords.

• The following wavelet spectra show the differing behavior of tearing modes in sawteeth and bursts. Similarly to the magnetic signals, sawteeth are initiated by m=1 fluctuations while bursts are coincident with m=0 fluctuations.

Wavelet Spectra From Central Chords Show Sawteeth Are Dominated By m=1, EC Bursts By m=0.



Wavelet Spectra From Edge Chords Show No Clear m Dependence For Sawteeth or EC Bursts.



Bursts in EC and PPCD Plasmas Are Both Dominated By m=0 Fluctuation Activity On Inner Chords.



Edge Chords Show More Turbulence Than Inner Chords.



Bicoherence Plots Show More Mode-Mode Coupling in Sawteeth Than in Bursts For Edge Chords.



Peaking of the Density Profile Similar to that During PPCD is Observed in Enhanced Confinement Plasmas.



• During the burst free periods of EC plasmas, the density profile peaks, indicative of better core confinement.

• There is also a pinching inward of the plasma increasing the edge density gradient. This is also seen during PPCD.

• While the overall fluctuation level is low during the burst free period, there is still some turbulent activity as shown in the wavelet spectra below.

Fluctuations Decrease During Burst Free Periods



During Periods of Continuous Bursting, Density Fluctuations Increase to Sawtooth-Like Levels on All Chords.



- Magnetic fluctuations (m=0) are seen to increase greatly during periods of continuous bursting.
- Density fluctuations are also globally higher during these periods.

•The improved confinement is lost once this type of activity starts.

Wavelet Spectra During Continuous Bursting



• Both EC and PPCD discharges show an increase in wavelet power during continuous bursting periods as compared to improved confinement periods.

• Like the magnetic signals, the density fluctuation power is mostly in the m=0 (f < 10 kHz) range.





The Density Profile Broadens During Periods of Continuous Bursting



• Confinement is degraded during the continuous bursting by the high fluctuation level in this EC plasma . This leads to a broadening of the density profile.



Conclusion

- Improved confinement through sawtooth suppression can be achieved in two ways on the MST. Pulsed Poloidal Current Drive (PPCD) uses an external circuit to drive edge parallel current. Enhanced Confinement (EC) plasmas are generated spontaneously from deep toroidal field reversal and good wall conditioning. Both exhibit intermittent increases in edge parallel current called bursts.
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