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Ion Heating and Profile Relaxation During Sawtooth Events in the MST Reversed-Field Pinch

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Magnetic activity in the MST Reversed-Field Pinch (RFP) is punctuated by regular, sawtooth-like bursts, during which fluctuation amplitudes increase several-fold in about 100 μs (Fig. 1). Robust and global phenomena are associated with these discrete events, including anomalous ion heating, current profile relaxation, and plasma momentum (flow) profile relaxation.

Ion Heating

The spatial resolution of ion temperature measurements in MST has been dramatically improved using active techniques that employ state-of-the-art diagnostic neutral beams.[1] Majority T_i is measured with a Rutherford scattering diagnostic and minority T_i is measured via charge-exchange recombination spectroscopy.[2] In a plasma diagnostics context, Rutherford scattering refers to the scattering of injected beam atoms by plasma ions.[3,4,5] The energy distribution of the scattered atoms is determined by the velocity distribution of the ions. Thus, the ion temperature is determined from the measured width of the scattered atom energy distribution.

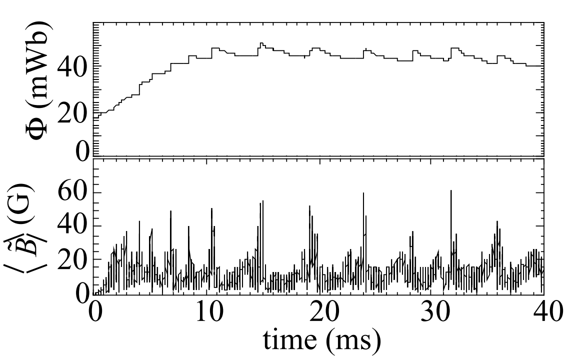

Fig. 1. Periodic sawtooth activity in MST illustrated by increases in toroidal flux and bursts in core magnetic fluctuations.

During a sawtooth, T_i typically doubles and a significant fraction of the energy stored in the equilibrium magnetic field is transferred into ion thermal energy (Fig. 2). Ion heating at the sawtooth crash is not simply due to enhanced transport, although the cause of such effective ion heating remains unknown.[6,7,8] As a next step, we will measure the local power deposition into the ions by correlating local measurements of ion current fluctuations and electric field fluctuations.

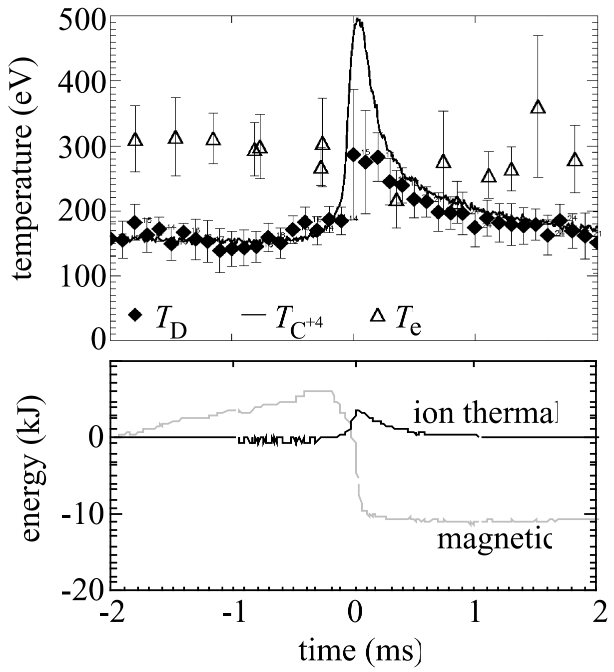

Fig. 2. Ion temperature spikes at the sawtooth crash (t = 0), while energy stored in the equilbrium magnetic field drops.

Current Profile Relaxation

It is a well-known result that a fully relaxed RFP plasma should obtain a uniform $J_{\|}/B$ profile.[9] Practically, the current profile is always somewhat peaked, but the increase in fluctuation levels that occurs during a sawtooth corresponds to transition to a more relaxed state with a flatter profile (Fig. 3).[10] This result, which reinforces Taylor' s relaxation theory, was obtained by equilibrium reconstruction[11] constrained by input from numerous diagnostics, including edge magnetic field (multiple pickup coil array), on-axis toroidal magnetic field (spectral motional Stark effect,[12] Fig. 4), toroidal current profile (FIR polarimeter[13]), plasma density profile (FIR interferometer), and electron and ion temperature profiles.[14]

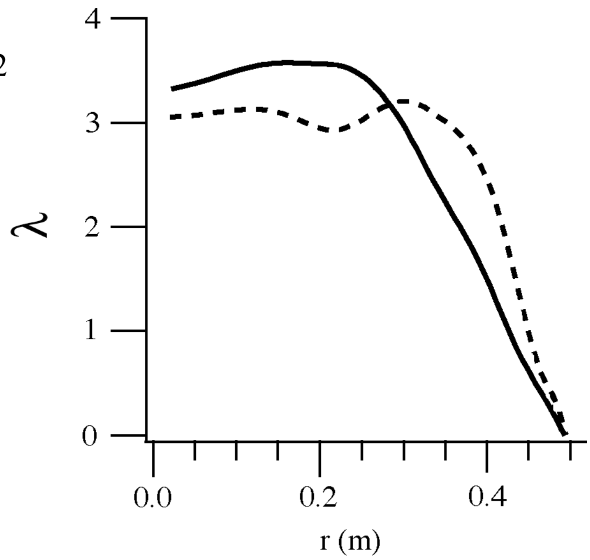

Fig. 3. Lambda parameter ($J_{\|}/B$) profiles for 0.25 ms before the sawtooth crash (solid line) and 0.25 ms after (dashed line), generated by an equilibrium reconstruction code.

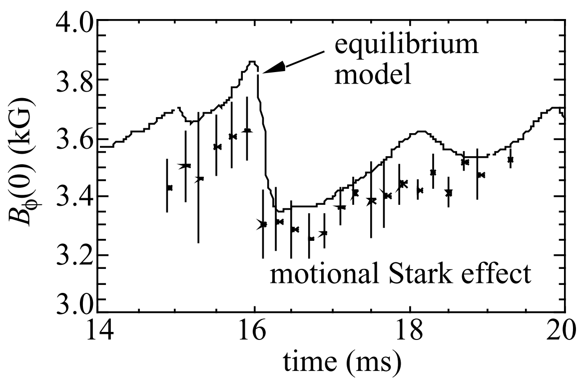

Fig. 4. Data points are central B_ϕ from the spectral motional Stark effect diagnostic.

Momentum Profile Relaxation

During a sawtooth we observe transport and relaxation both of the plasma *toroidal* and *poloidal* momentum. A theoretical treatment predicts that two-fluid MHD mechanisms will have a strong effect on the relaxation of the *parallel* plasma momentum, which is also predicted to exhibit relaxation similar to that of the parallel current.[15] There are strong indications that the plasma *toroidal* momentum transport is a result of nonlinear mode coupling through a term of the form $\left\langle \tilde{B}_{n=7}\tilde{B}_{n=6}\tilde{B}_{n=1} \times \sin(\delta_7 - \delta_6 - \delta_1) \right\rangle$.[16,17] Figure 5 illustrates how the plasma dramatically decelerates at the sawtooth crash, coincident with peaking of the nonlinear force term due to both mode amplitude increase and phase alignment.[18] This force term is internal to the plasma and causes a redistribution of plasma momentum, but no net

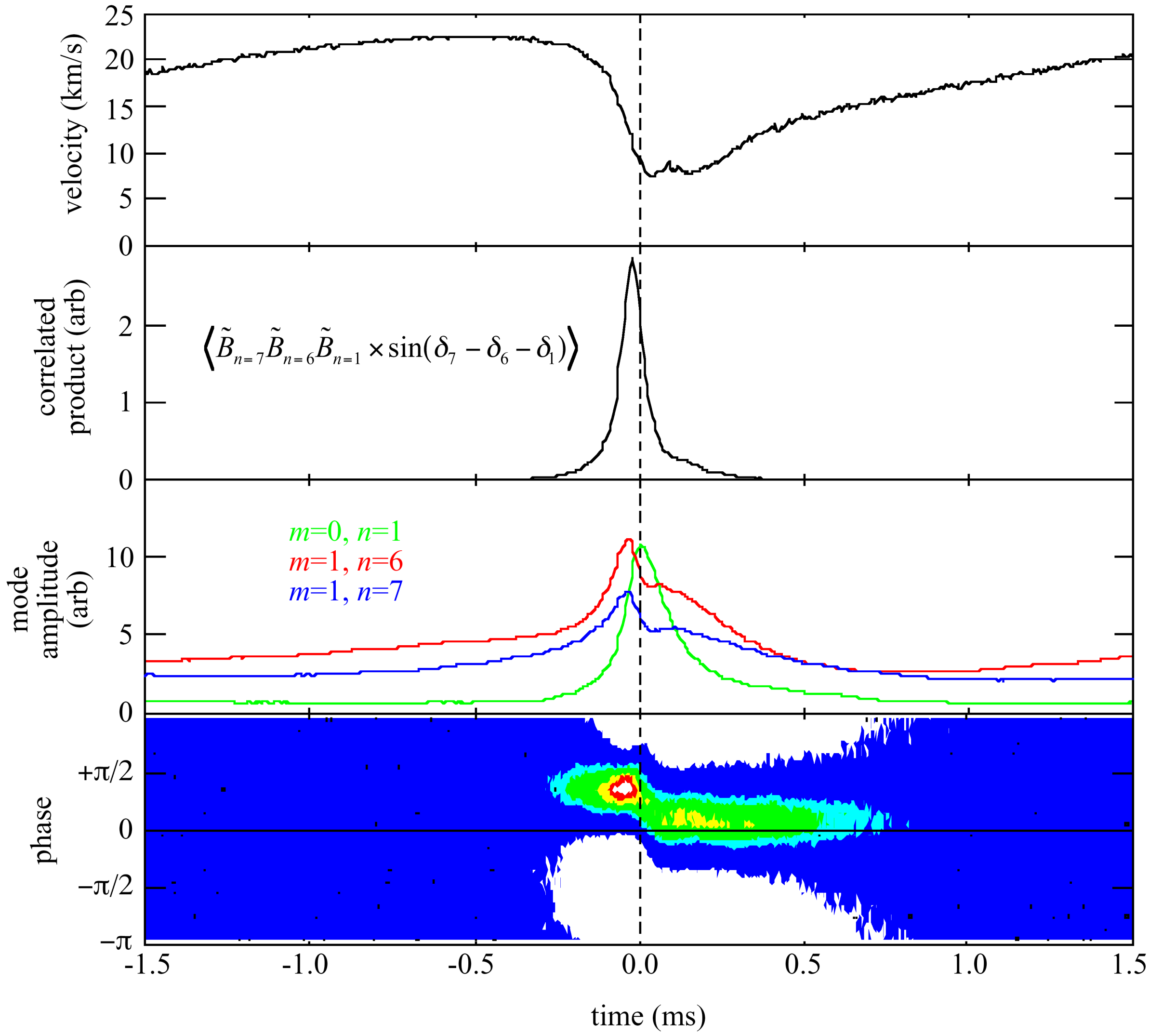

Fig. 5. The core plasma strongly decelerates at the sawtooth, while at the same time magnetic mode amplitudes increase and phase align to produce a large nonlinear force term.

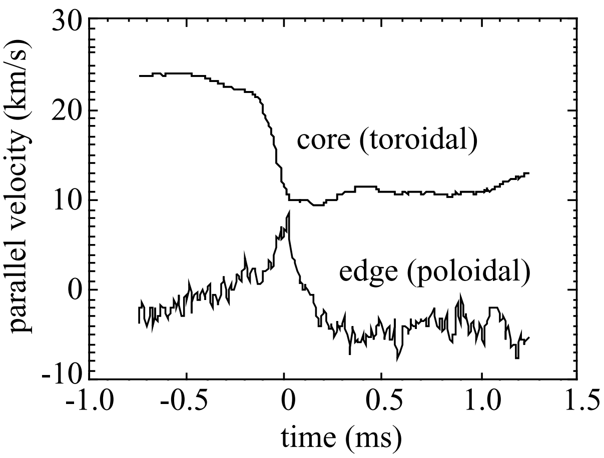

Fig. 6. The plasma parallel velocity profile flattens at the sawtooth crash.

loss. In this case, we expect to observe a reduction in the parallel velocity profile gradient at the sawtooth event; initial measurements with a combination of spectroscopic, magnetic, and Mach probe measurements indicate that this expectation is correct (Fig. 6). Experiments are now underway to locally measure the magnetic-fluctuation-induced torque.

Acknowledgement

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