The Role of the Magnetic Well Depth in the Sawtooth Instability* EX-S

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The sawtooth instability has defied an accurate theoretical description for many decades. Nevertheless, control of this instability is an important issue for an ITER burning plasma experiment. ITER is expected to operate at q~3 in an ELMy (sawtoothing) H-mode for burning plasma experiments. DIII-D experiments are investigating the nature of the sawtooth instability through its dependence on flux-surface shaping. At this time our best understanding of the differences discussed below is that the instability exhibits the behavior characteristic of a pressure-driven mode, with a violent expulsion of stored energy from the plasma, in the bean shape while it is a much milder, current-driven mode in the oval shape

DIII-D is conducting experiments to separate the roles of interchange stability and the internal kink in the sawtooth instability. The principal feature of the experiment is the use of the DIII-D shaping capability to change the magnetic well depth and separate the resistive Mercier Stability Criterion from the kink stability condition. This will serve to separate the magnetic drive, which is not expected to be sensitive to well depth, from the pressure drive. Examining two plasma shapes, an oval and a bean (Fig. 1), does this. In an oval, the Mercier criterion will be violated at $q_0 \gtrsim 1$ and in a bean it will be satisfied for $q_0 \lesssim 1$. The remaining discharge conditions are determined by diagnostic requirements; namely high quality MSE signals, ECE signals that span the mid-plane diameter, and CER data with 300 μs time resolution.

The sawtooth behavior is distinctly different in the two shapes. In the oval the pre-crash state is strongly helical. Raw observation, as well as phase analysis of the ECE signals indicated the reconnection results in an axisymmetric state. In the bean the phase analysis

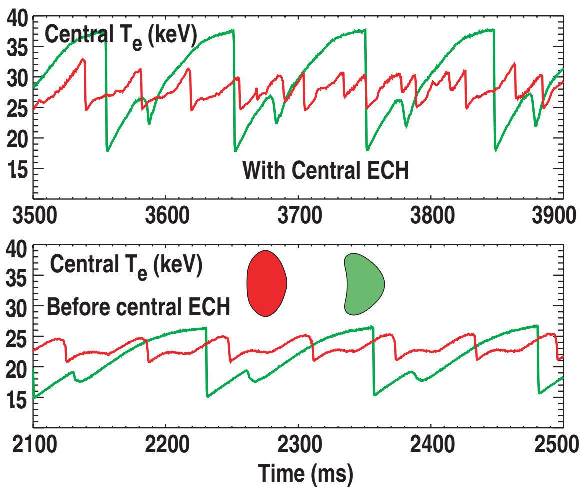

Fig. 1. Response to central electron cyclotron heating.

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indicates the pre-crash state is very nearly axisymmetric and the reconnection results in a strongly helical state. This is qualitatively confirmed by the $B\theta$ loops where a large precursor signal and virtually no post-cursor oscillations are observed for the oval. The exact opposite is seen for the bean. The raw MSE signals show that the reconnection in the bean displaces poloidal flux corresponding to a 300 G change in $B\theta$ while in the oval we can barely detect the flux displacement. There are qualitative differences in the ion behavior relative to the electrons. In the oval, the ion temperature sawtooth is substantially larger than the electrons. In the bean the ion sawtooth is smaller than the electron sawtooth and exhibits a qualitatively different behavior in that the ion temperature rise clamps at the time when the electron sawtooth reaches half its full amplitude. The ion and electron (and MSE) inversion radii are the same to within the experimental resolution. On the sawtooth crash there is a net energy loss of about 15% in the bean and no detectable net energy loss in the oval. The sawtooth inversion radii are similar in both shapes (ρ~0.3). The response to central ECH heating at low power is also quite different in the two shapes as shown in Fig. 1 where the top figure is with 1/2 MW of ECH and the lower panel is the same shots before the ECH is applied. In the bean the sawtooth amplitude is increased and the period is decreased. The oval is difficult to characterize except to say partial reconnections become more frequent and the variation from sawtooth to sawtooth is large. The difference in the q profiles between the two shapes is quite marked. In the oval, central q is quite flat, very near unity, and the difference before and after the sawtooth crash is miniscule. In the bean, central q drops well below unity as a sawtooth evolves and significant shear develops; after the crash has returned to a value near unity and is rather flat.

Equilibrium analysis will be reported, using a new EFIT capability where a constraint will force the flux surfaces to align the ECE profile (T_e will be a flux surface quantity.) This allows us to get accurate q profiles without doing “kinetic” (using the pressure profile from temperature and density measurements along with a calculated fast ion pressure) EFITS. The kinetic EFITS wash out too much structure in assembling the pressure profile and are sensitive to the mapping of data to flux coordinates from a previous equilibrium calculation. The initial results of this analysis have been highly successful. The resulting q profile for the bean, before and after the sawtooth crash are shown in Fig. 2. The dashed line shows the profile before the crash. The noticeable shear, resulting in a small island width, may explain why no island is detected in the electron temperate fluctuation analysis. The post crash profile is consistent with the observed helical state with a double island structure known to exist for about 30 ms. This analysis is constrained by 1) T_e is a flux surface quantity, 2) the thermal pressure outside ρ=0.7, and 3) the radial B_z profile from MSE. A similar analysis of the oval shows a large shearless central region and only a microscopic change in the q profile when the crash occurs. These features are in qualitative agreement with the phenomenology previously discussed.

Results of ideal stability analysis will be reported. A comparison of carbon expulsion from the core between the two shapes will be discussed. An important virtue of the sawtooth is its expulsion of impurities from the core. This effect differs in the two shapes.

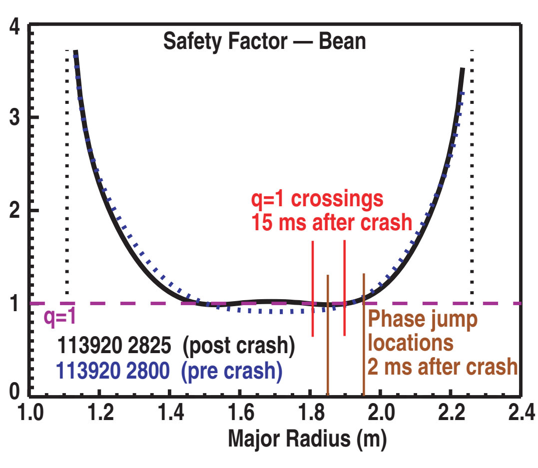

Fig. 2. q profiles before and after the sawtooth crash in the bean shape.