Comparison Between Sawteeth Oscillations in Bean and Oval Shaped Plasmas

Magnetic reconnection (the tearing and healing of magnetic field lines) is thought to be responsible for many disruptive events observed in plasmas. In particular, it is believed to play a role in the magnetic storms that periodically beset communication satellites, as well as in the sawtooth oscillations that limit the performance of fusion experiments. There is growing evidence, however, that pressure-driven instabilities also play a role in these disruptive events. We have conducted a series of experiments on the DIII-D tokamak aimed at clarifying the role of pressure-driven instabilities in the sawtooth oscillation.

The sawtooth oscillation is a commonly observed phenomenon that consists of the periodic ejection of a burst of heat from the center of the machine, followed by reheating. The DIII-D tokamak offers a unique capability for investigating the role of pressure-driven instabilities due to its extensive diagnostic capabilities and the unique flexibility of its magnetic configuration. Specifically, pressure-driven modes can be destabilized by increasing the elongation of the ring of plasma, giving it an elliptical cross-section. Conversely, they can be stabilized by increasing the triangularity of the ring's cross section. We will refer to the corresponding plasma shapes as the oval and bean shapes, respectively (Fig. 1). Changing the shape acts by modifying the relative length of the magnetic field lines in the region of bad curvature (on the outside of the torus) as opposed to the region of good curvature where the magnetic field is braced against the pressure (inside of the torus).

We have found that plasma shape controls the nature of the sawtooth oscillation. The most dramatic difference between the oval and bean shapes is in the ability of the electrons to confine heat. In the oval discharges, the electron temperature is spatially constant (i.e. fully mixed) in the sawtooth region and remains so throughout the oscillation. We have used a very powerful and focused heat source to investigate the transport of heat and find that in the bean shape, the localized heating produced a localized temperature increase. In the oval shape, by contrast, the heat is almost instantly redistributed throughout the sawtoothing region, leading to very little temperature rise (Fig. 2).

The different heat confinement properties for the bean and oval discharges have a decisive impact on the nature of the sawtooth oscillation. Specifically, the uniformity of the electron temperature in the oval results in an equally homogeneous current distribution. There is consequently little evidence for magnetic reconnection, consistent with the absence of drive. In the bean, by contrast, the electron temperature and thus the current are peaked in the center of the plasma. This drives a vigorous reconnection process. Unlike previous experiments on other tokamaks, we find that the reconnection always proceeds to completion.

The DIII-D experiment shows that electron transport is highly sensitive to the curvature of the magnetic field and offers new insight on how the stretching of the earth's magnetic tail by the solar wind may trigger the magnetic fluctuations that are observed in the near earth region at the beginning of substorms and that lead to electron showers at high latitudes. Details of this work were reported last year by Dr. E.A. Lazarus of Oak Ridge National Laboratory at the International Fusion Energy Conference and will be discussed in a poster by Dr. R.V. Bravenec of the University of Texas, at the APS-DPP meeting in Denver, October 24-28, 2005.

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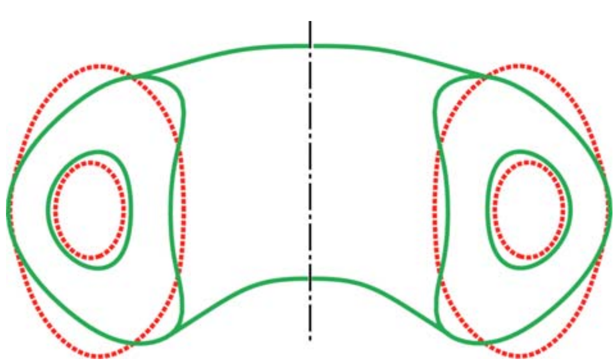

Fig. 1. Cross-section of the plasma showing the oval and bean shapes. The inner curves indicate the shape of the region where the sawtoothing takes place.

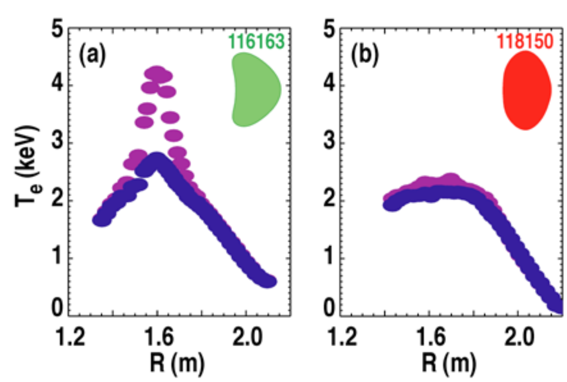

Fig. 2. Response of the temperature profile to focused heating. In the bean the temperature rises steeply in the heated region, while in the oval the heat is instantly diffused over a broad region so that the temperature rise is small.