Far-infrared imaging of tokamak plasma

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A 20-channel interferometer has been developed which utilizes a linear, one-dimensional microbolometer array to obtain single-shot density profiles from the UCLA Microtor tokamak plasma. The interferometer has been used to study time-dependent phenomena in the plasma density profile. Observations of the sawtooth instability clearly show the growth of the $m = 0$ mode from a localized oscillation ($r = 1$ cm) on axis to an oscillation of the entire plasma. Also, measurements during the initial startup phase of the discharge show evidence of hollow density profiles. In addition, a simultaneous measurement of the poloidal magnetic field has been developed which provides 20 channels of polarimetry. Interferometry and polarimetry both use the same imaging system and the spatial resolution of both measurements has been tested using plastic and crystal-quartz test objects. The signal-to-noise ratio for the polarimeter has also proved adequate for the expected Faraday rotation angle ($\alpha_{max} = 7°$, $I_p = 70$ kA, $n = 5 \times 10^{13}$ cm^{-3}).

A 20-channel interferometer which images the plasma phase distribution onto a linear, one-dimensional microbolometer detector array has been described earlier.[1,2] In this paper we would like to present detailed observations of plasma fluctuations in the UCLA Microtor tokamak. The interferometer channels are separated by 1 cm and look across the torus along a line of major radius. In the following discussion, channel 1 is the innermost channel and channel 20 is the outermost.

Proper tokamak conditions allowed us to observe a prominent sawtooth instability with the interferometer. Figure 1 illustrates the Microtor parameters required for this condition. The characteristic sawtooth x-ray emission behavior is evident on the soft x-ray monitor beginning approximately 35 ms into the shot. The maximum value of $\delta n/n$ at the central chord on this shot is nearly 5%. The occurrence of this behavior is highly dependent on the impurity conditions in Microtor; the instability appeared after the tokamak had been discharge cleaned and lasted only five shots. Subsequent shots had a similar density behavior but without the obvious presence of the sawtooth instability.

There is a noticeable expansion of the density profile coincident with the presence of the sawtooth instability as seen in Fig. 2. If we consider the pressure profile to be tied to the flux profile, then the broadening of the plasma profile can be interpreted as being due to flux being expelled from the tokamak. This would lead to the condition $q < 1$ near the magnetic axis. The appearance of the sawtooth instability is

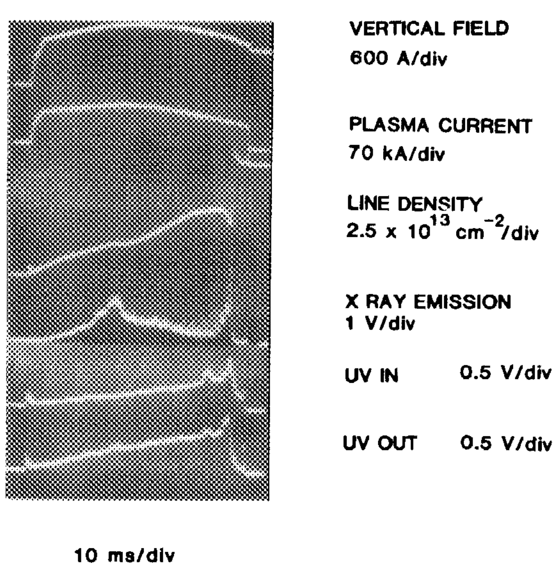

FIG. 1. Tokamak discharge in which the sawtooth instability is evident.

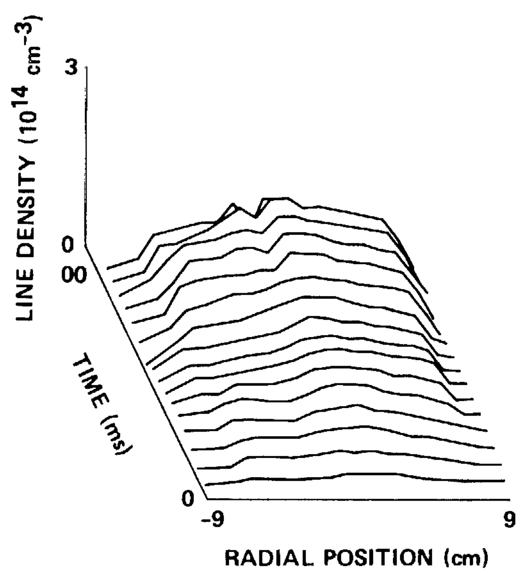

FIG. 2. Line density profile development with sawteeth.

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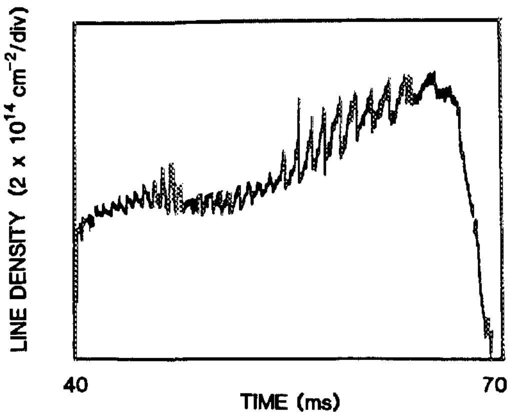

FIG. 3. Sawtooth fluctuations on channel 9.

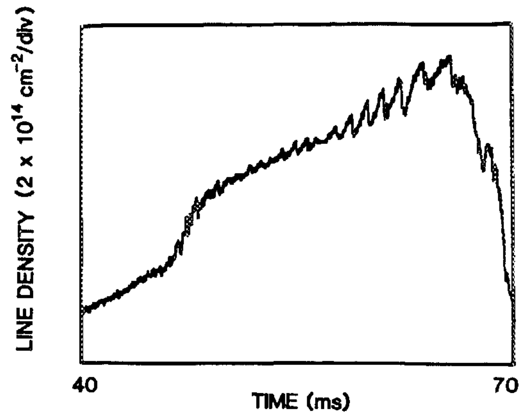

FIG. 5. Sawtooth fluctuations on channel 11.

dependent on the impurity level; the presence of the impurities increases Z which increases the resistivity so that, in turn, the current is decreased. The lower current means that the plasma is stable with respect to the $m = 1$ kink mode.

Now we will look at the sawtooth fluctuations in detail. Unfortunately, channels 2 and 6 were not connected to the phase comparators at the time this profile was acquired; a linear interpolation between channels was used to produce Fig. 2. Several interesting features can be observed from the raw data traces. For instance, Fig. 3 shows the output from channel 9 beginning 40 ms into the shot. The occurrence of each sawtooth (although not necessarily the phase) is highly correlated across the entire plasma. The sawtooth repetition rate at the onset of the instability is roughly 2 kHz and gradually decreases to about 1 kHz as the density increases.

Next we note that only the central channels show evidence of sawtooth fluctuations prior to $t = 50$ ms. Channel 10 (see Fig. 4) shows that the density fluctuations prior to this time are nearly 180° out of phase with those during later times. Channel 11 (see Fig. 5) shows a similar behavior except there is a transition period during which there are no visible fluctuations. These traces can be compared with that for channel 9 (see Fig. 3); note the absence of fluctuations prior to $t = 50$ ms.

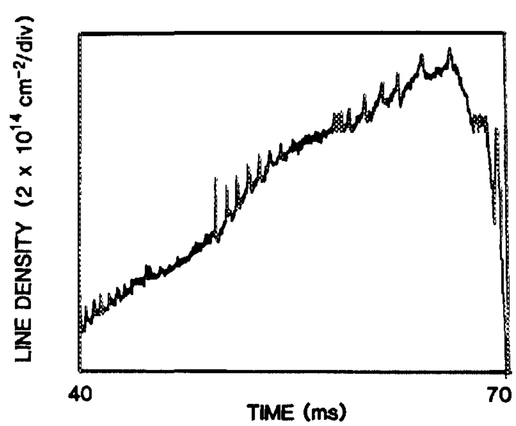

FIG. 4. Sawtooth fluctuations on channel 10.

These results can be readily explained and are consistent with the model presented by Kadomtsev.[3] The line density fluctuations show evidence of the growth of an instability within $r = r_s = 1$ cm which eventually drives an $m = 0$ mode in the rest of the plasma. A chord-averaged measurement along the central chord will show an integrated fluctuation amplitude. So the change in phase of the central fluctuations is probably due to the growth of the instability outside of $r = r_s$ with a phase opposite to that at the center. This result differs from soft x-ray measurements which, though apparently also chord-averaged, are more nearly local measurements since the dominant emission along a chord through the plasma comes from the point nearest the plasma center.

An interesting feature is the change of phase of the fluctuation on the innermost channel (not shown here). This is indicative of an asymmetry in the fluctuation profile since on the outside the sawtooth amplitude decreases gradually and reaches zero on the outermost channel. This is most likely related to the asymmetry of the q profile since $B_T \sim 1/R$.

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[1] P. E. Young, Ph.D. thesis, University of California, Los Angeles, 1984.
[2] P. E. Young (these proceedings).
[3] B. B. Kadomtsev, Sov. J. Plasma Phys. 1, 389 (1975).