DISCLAIMER

VARIETIES OF SAWTOOTH BEHAVIOR IN TFTR PLASMAS

V. K. Paré,* K. McGuire, R. J. Colchin,* P. C. Efthimion,
E. Fredrickson, K. W. Hill, G. Taylor, and N. R. Sauthoff

Plasma Physics Laboratory, Princeton University
Princeton, New Jersey
United States of America

CONF-850806--3

DE86 002219

Introduction

The side-viewing soft-x-ray camera on the Tokamak Fusion Test Reactor (TFTR) has made possible the observation of several different forms of sawtooth oscillation, which can be categorized according to their position in the plasma, sequence of occurrence, and patterns of associated MHD oscillation. Some insight into the plasma conditions involved can be gained by examining the waveforms in detail, along with electron temperature profiles from electron cyclotron emission measurements.

Waveforms

When TFTR is operated at high q_a and/or small (<60-cm) minor radius, the observed sawteeth are "normal" in that they involve a more or less linear rise of central temperature, a growing precursor MHD oscillation, and an absence of oscillation following the central collapse. These properties are consistent with the Kadomtsev model [1]. In operation at lower q_a and large (~80 cm) minor radius, the more complex patterns shown in Fig. 1 appear. Groups of "small" sawteeth may alternate during the steady-state portion of a discharge with groups of "compound" sawteeth.

Compound (also known as "giant" or "double" sawteeth) have been reported previously in TFTR [2] and in other machines [3–5]. In Fig. 2, traces from twelve x-ray detectors are plotted over the time segment indicated by the hatched band in Fig. 1. The segment includes the relaxation of a small sawtooth followed by a full cycle of a compound sawtooth. The period of the compound sawtooth is roughly twice that of the small sawteeth, and there is a subordinate relaxation that occurs about midway between the main relaxations.

The traces of Fig. 2 are further expanded in Figs. 3–5, each corresponding to one of the hatched bands on the time scale of Fig. 2. The relaxation of the small sawtooth is shown in Fig. 3. The waveforms are superficially like those of normal sawteeth; however, the precursor oscillations are typically smaller and are seen in a more restricted radius range. Also, there are often "successor" oscillations following the collapse.

*Permanent address: Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A., operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy, under Contract No. DE-AC05-84OR21400.

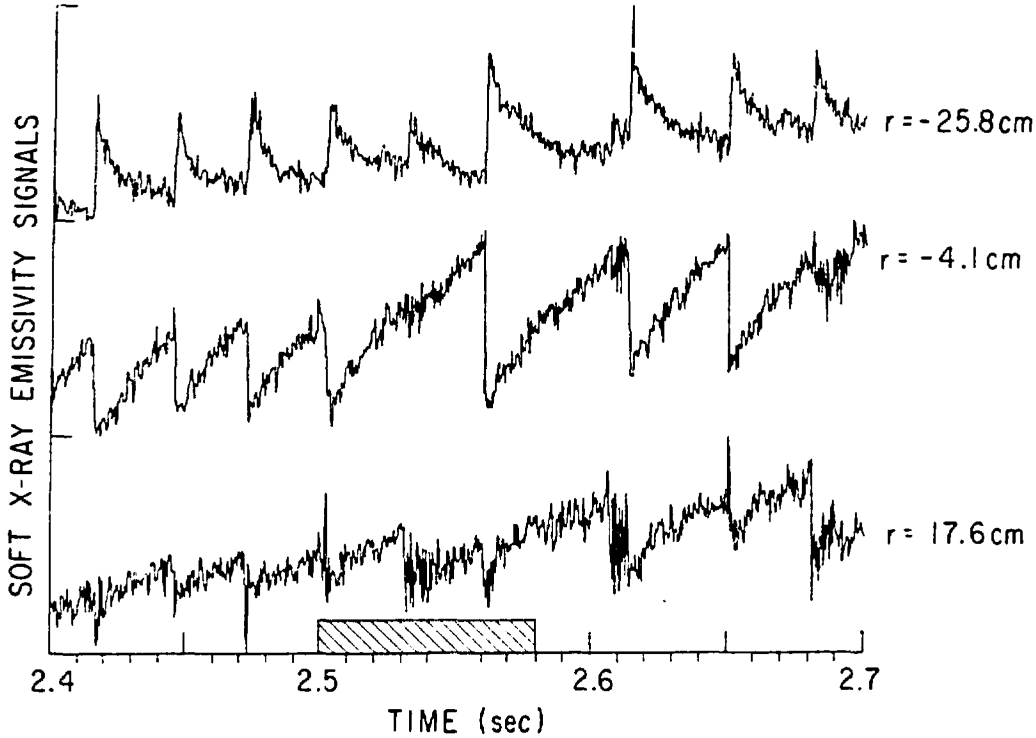

Fig. 1. **X-ray waveforms showing transition from small sawteeth to compound sawteeth.**

As shown in Fig. 4, the subordinate relaxation of the compound sawtooth is not visible at the center of the plasma and has a successor oscillation that is usually much larger than the precursor and may have a different frequency. The main relaxation, shown in detail in Fig. 5, has little or no visible precursor, reduces the central temperature significantly and quickly, and usually has a small but clear successor oscillation.

Figure 6 shows, for another compound sawtooth, waveforms from 33 viewing chords (digitized at too low a rate to resolve MHD oscillations). It can be seen that the subordinate relaxation does not involve the plasma center and that its inversion radius is greater than that of the main relaxation. Both of these properties of the subordinate relaxation are quite general for TFTR. In Fig. 6 the difference in inversion radii is about 5 cm, but 7 to 10 cm is more typical.

Profiles From Electron Cyclotron Emission Diagnostic

In Figs. 7 and 8, electron temperature profiles from the electron cyclotron emission (ECE) diagnostic are plotted for the times indicated on the corresponding small and compound sawtooth waveforms. It can be seen that all the precollapse profiles are relatively flat near the center and that the subordinate relaxation reduces the temperature only in an annular region about the center.

Discussion

The properties of sawteeth observed on TFTR, along with the associated plasma conditions, are summarized in Table I. Noting the long skin times listed, it is clear that the recovery phase of the sawtooth cycle must be affected significantly by the slowness of current diffusion. This would lead to flat or hollow current profiles near the center, which would be consistent with the T_e profiles shown. Such profiles could also yield q-profiles in which $q < 1$ only in an annulus, with two $q = 1$ surfaces. The annulus is presumably the site of the subordinate relaxation and may also be associated with the predominance of successor oscillations over precursors.

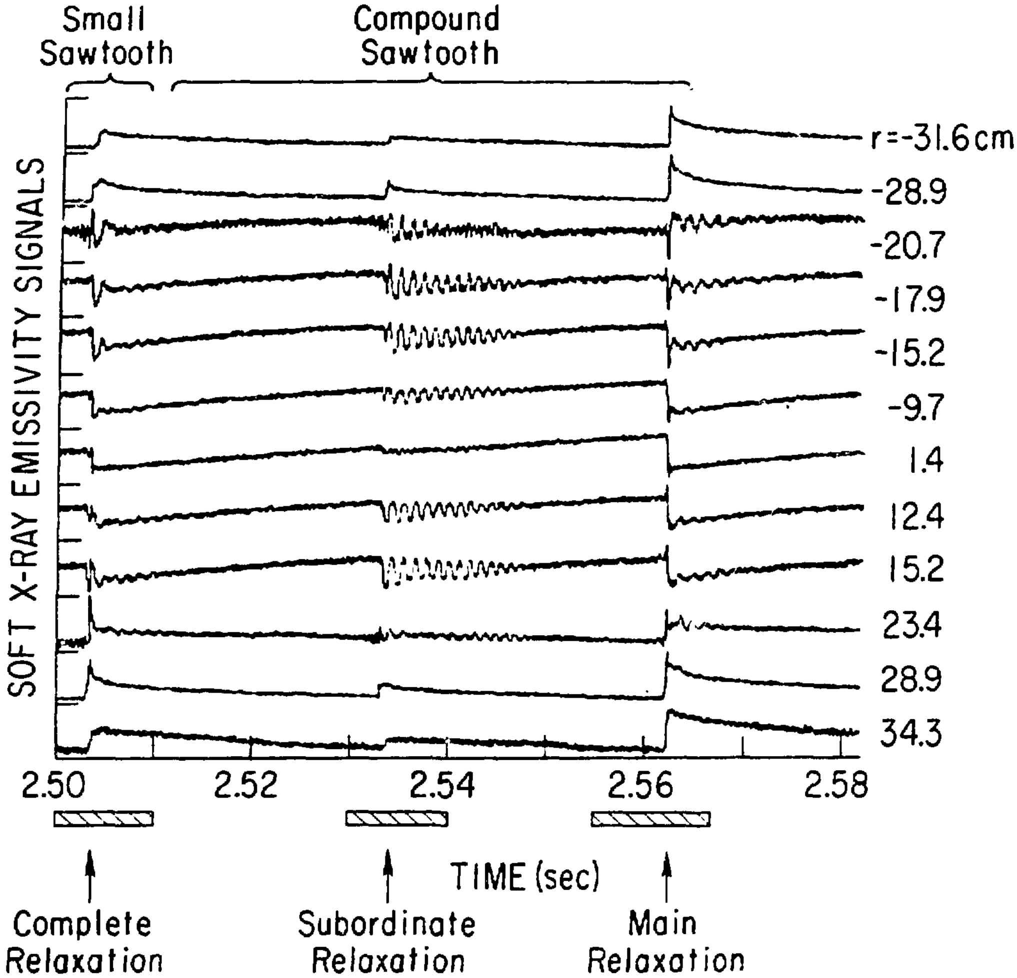

Fig. 2. *Waveforms in the time segment indicated by the hatched band in Fig. 1.*

Apparently the subordinate relaxation redistributes current so as to set up the conditions for the main relaxation, and the main relaxation produces a more hollow current profile that provides, depending on its exact form, the conditions for either another subordinate relaxation or a transition to a series of small sawteeth. Since small and compound sawteeth often occur in alternating groups during a discharge, the profiles leading to the small sawtooth and to the subordinate relaxation must not be very different and thus may both be hollow.

The precursor and successor oscillations are always found to be $m = 1$ modes.

Acknowledgment

This work was supported by the U.S. Department of Energy under Contract No. DE-ACO12-76-CHO-3073.

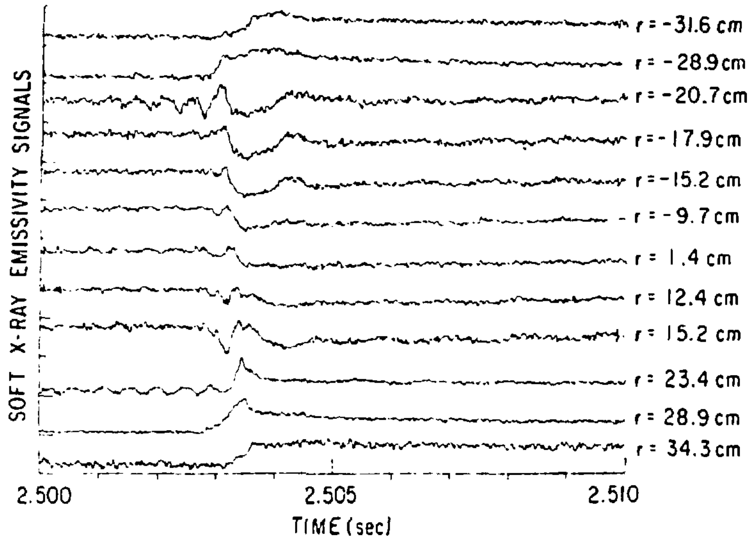

Fig. 3. Relaxation of a small sawtooth. The time range is that of the first hatched band in Fig. 2.

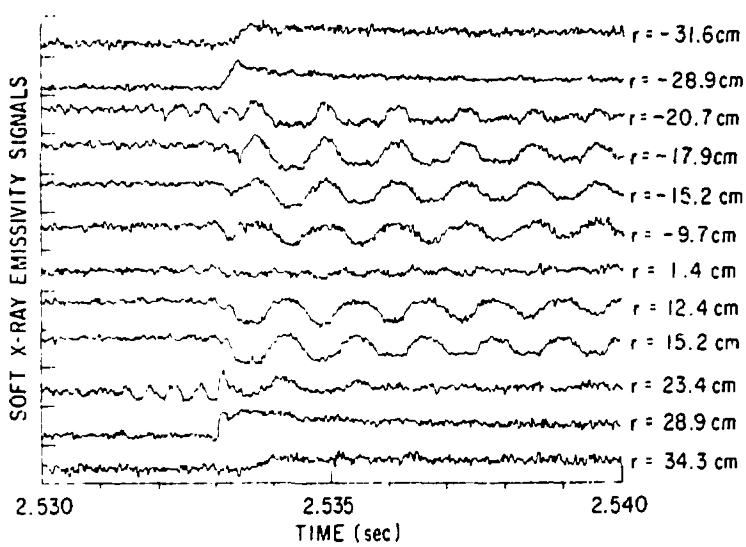

Fig. 4. Subordinate relaxation of the compound sawtooth. The time range is that of the second hatched band in Fig. 2.

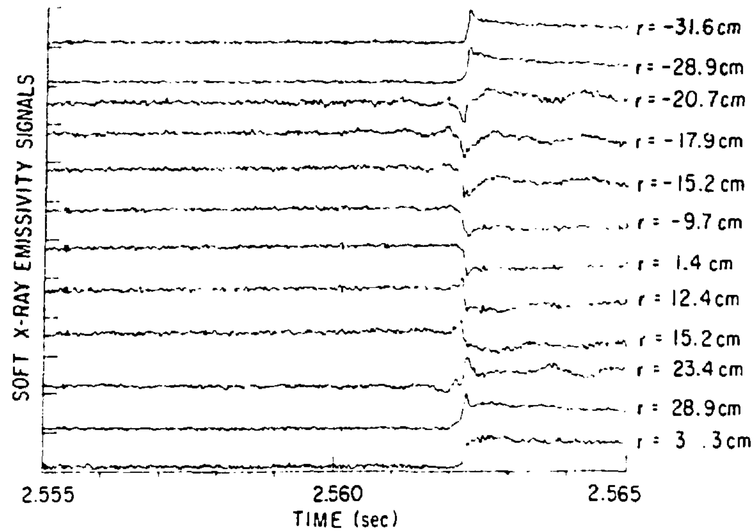

Fig. 5. Main relaxation of the compound sawtooth. The time range is that of the third hatched band in Fig. 2.

Table I
TFTR Sawtooth Summary

	Normal	Small	Compound: Subordinate	Compound: Main
Plasma conditions				
r_1, cm	10	20	25	20
a, cm	<60	>60	>60	>60
q	>4	<4	<4	<4
$\tau_{skin} = \mu_0 r_1^2/\eta$, s	~1	~2	~4	~3
Reconnection observations				
$m/n = 1/1$ precursors				
$\Delta A/A$ ($m/n = 1/1$)	Large	Small	Small	Very small
Growth time, ms	0.5	>0.1	>0.1	<0.1
$m/n = 1/1$ successors				
$\Delta A/A$	Very small	Med.-large	Large	Medium
Growth time, ms	N/A[a]	1	5–20	2–10
Reconnection characteristics				
Crash time, ms	0.1–0.5	0.1–0.5	N/A	0.03–1.0
Mixing zone	$\sim 1.4 r_1$	$\sim 1.4 r_1$	$\sim 1.4 r_1$	$\sim 2 r_1$

[a]N/A = not applicable.

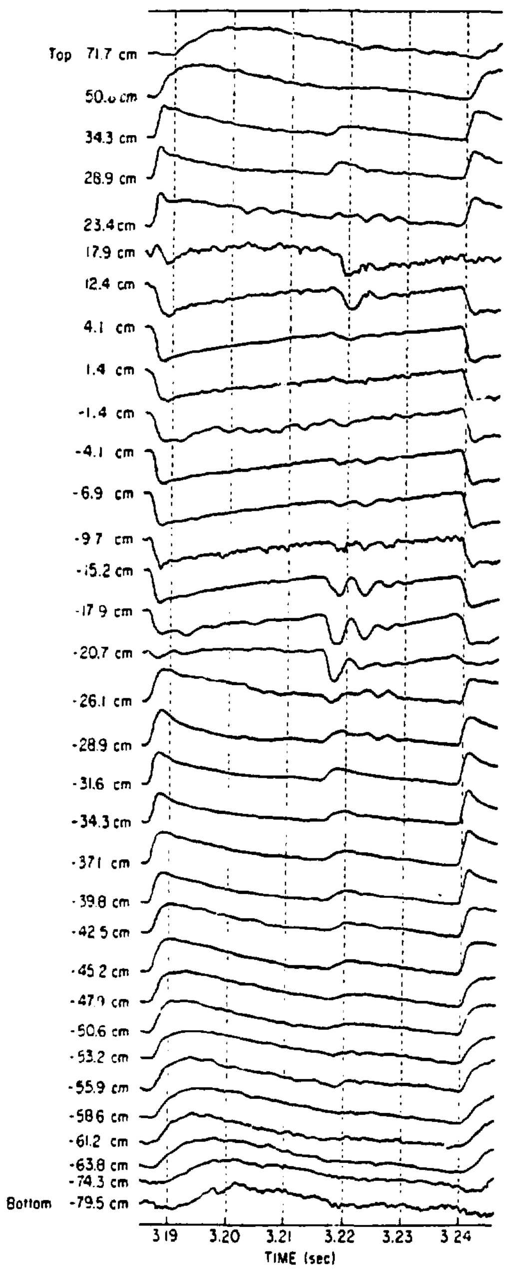

Fig. 6. Cycle of a compound sawtooth as seen in 33 viewing chords at the indicated tangent radii.

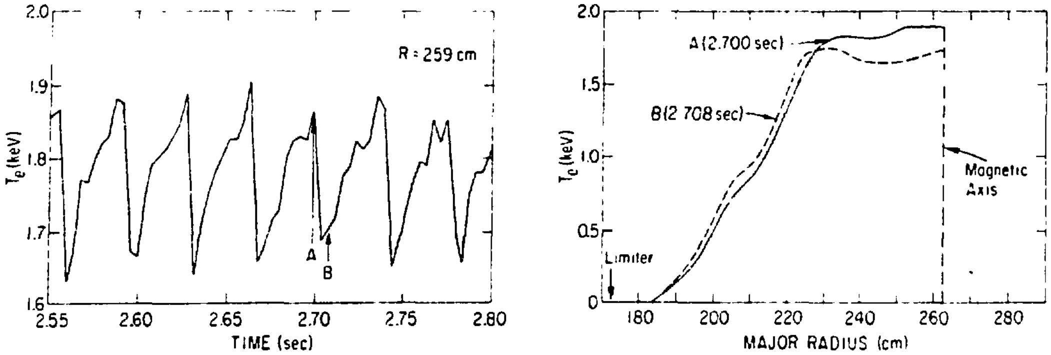

Fig. 7. Waveform of a small sawtooth and electron temperature profiles from ECE at the times indicated.

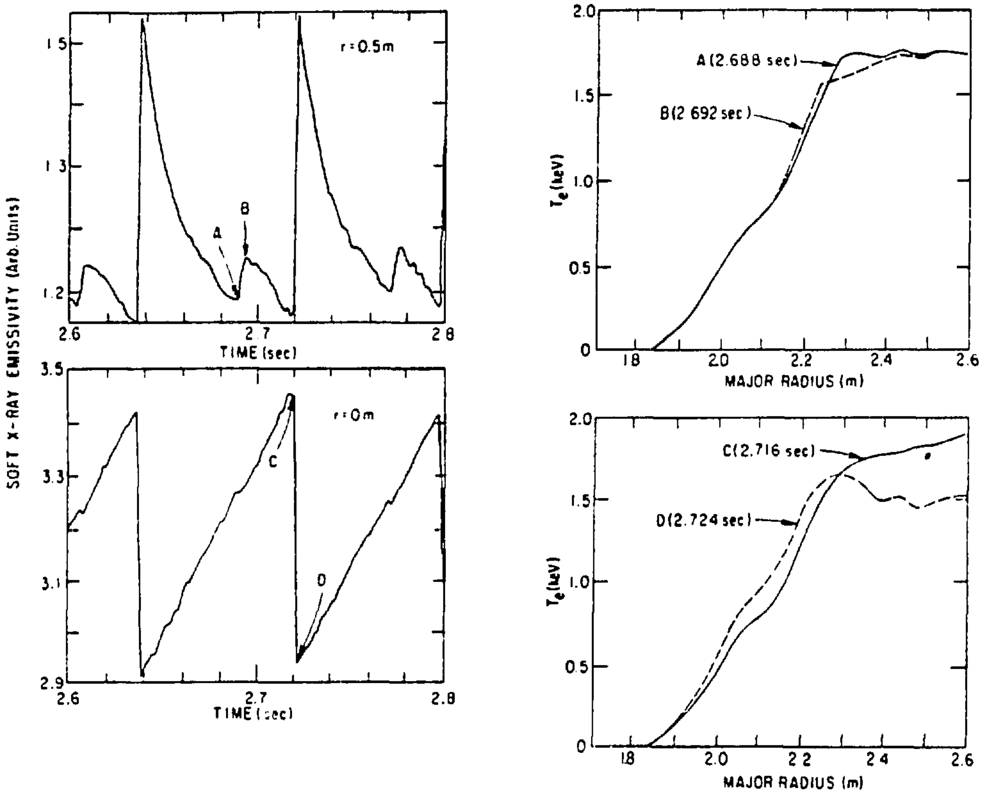

Fig. 8. Waveforms of a compound sawtooth and electron temperature profiles from ECE at the times indicated.

References

[1] B. B. Kadomtsev, *Fiz. Plazmy* **1**, 710, 1975 (*Sov. J. Plasma Phys.* **1**, 389, 1975).

[2] H. Yamada et al., Princeton Plasma Physics Laboratory Report PPPL-2213 (1985).

[3] W. W. Pfeiffer et al., GA Technologies Report GA-A16994 (1983).

[4] S. B. Kim et al., *Bull. Am. Phys. Soc.* **29**, 1395 (1984).

[5] D. J. Campbell et al., in: Proc. 12th European Conf. on Controlled Fusion and Plasma Physics, Budapest, 1985.