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COMPOUND SAWTOOTH STUDY IN OHMICALLY HEATED TFTR PLASMAS

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ABSTRACT

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Compound sawtooth activity has been observed in ohmically heated, high current, high density TFTR plasmas. Commonly called "double sawteeth," such sequences consist of a repetitive series of subordinate relaxations followed by a main relaxation with a different inversion radius. The period of such compound sawteeth can be as long as 100 msec. In other cases, however, no compound sawteeth or bursts of them can be observed in discharges with essentially the same parameters.

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1. INTRODUCTION

The sawtooth oscillation was first observed experimentally in the ST tokamak [1] and a theoretical model describing this oscillation was given by Kadomtsev [2]. Since then, sawtooth activity has been studied in many tokamaks and discussed in detail in relation to an unstable MHD mode and a thermal transport model [3].

Simple sawtooth oscillations observed in tokamaks are a series of $m = 0$, $n = 0$ relaxations, each with an $m = 1$, $n = 1$ precursor mode, where m and n are poloidal and toroidal mode numbers, respectively. In contrast, compound sawtooth activity has been observed recently in large tokamaks [4-7]. Each compound sawtooth consists of a series of subordinate relaxation followed by a large (up to 20%) main relaxation with a different inversion radius. These compound sawteeth are commonly called "double sawteeth" because of their approximate double period. Compound sawteeth appear frequently in ohmically heated TFTR plasmas with high plasma current ($I_p > 1.0$ MA) and/or high density ($n_e > 2.0 \times 10^{19} \text{ m}^{-3}$). However, compound sawteeth do not always appear in these particular discharge regimes. Instead small sawteeth can be present. Figure 1 illustrates sawtooth activity observed for TFTR. Figure 1(a) shows simple sawteeth (Type 1) which are observed in TFTR plasmas with small minor radii ($a < 60$ cm). The compound sawteeth (Type 2) shown in Fig. 1(b) are sometimes observed in bursts accompanied by small sawteeth (Type 3). Definitions in Fig. 1 are used for illustration purposes only. Table 1 illustrates the main features of the different types of sawteeth observed in TFTR.

In JET, the compound sawteeth have been observed in high current and high density discharges as in TFTR [6]. In Doublet III, they appear in the limiter discharges during neutral beam injection [5] and in TEXT they are observed

during ramping up of I_p and n_e [8]. It should be noted that for these conditions, flat or somewhat hollow current profiles are apt to be formed because of a long skin time in the central region of the plasma and/or a center-accumulation of impurities. Therefore, the compound sawteeth may be associated with flat or hollow current profiles.

At present, the compound sawtooth activity does not seem to detrimentally affect the global confinement in the TFTR plasmas. Actually, similar or slightly better confinement has been obtained for discharges where the compound sawteeth appear. Since internal disruptions limit the temperature rise in the plasma center, the compound sawteeth have the advantage of longer total period and a slightly higher $T_e(0)$ before the crash phase of the main relaxation. On the other hand, its large temperature variation and rapidly moving heat pulse can enhance the electron heat loss which could degrade the confinement. Indeed, at low q_a (< 4) the compound sawteeth in TFTR can affect the surface voltage and the total radiation power from the plasma (see Fig. 2). These effects may be an important issue in a reactor because they could cause a large perturbation of the power output.

A soft X-ray imaging system consisting of a multidetector array of surface barrier detectors has been used to study compound sawteeth in TFTR plasmas [9]. Sixty-four horizontal chords can be viewed with 2.5 cm resolution in comparison with the minor radius of the plasma of up to 83 cm. The sampling frequency is up to 500 kHz.

Characteristics of the compound sawteeth observed in the experiment are described in Sec. 2. Section 3 is devoted to the scaling study on the sawtooth period. These results are discussed in Sec. 4. Section 5 is a summary.

2. CHARACTERISTICS OF COMPOUND SAWTEETH

Although our investigations of compound sawteeth have utilized mainly the soft X-ray diagnostic, the slow ramp and rapid crash can be detected also by a variety of diagnostics. Figure 2 shows the typical compound sawtooth oscillations during the current flat-top phase. The amplitudes of the fluctuations of the ion temperature and the line-average electron density reach 5% and 2.5%, respectively. For the case of small sawteeth (Type 3), the fluctuations are half these values. The time from 1.5 sec to 2.0 sec is a transient phase as a current penetrates into the center. The $q = 1$ radius is small in this phase and the observed sawteeth appear to be like Type 1, i.e., simple sawteeth.

Empirically, it has been found that compound sawteeth tend to appear in the high current and high density discharges of TFTR. Sometimes, however, small sawteeth are only observed in a discharge that would normally have compound sawteeth. The compound sawteeth (Type 2) and the small sawteeth (Type 3) are sometimes observed in bursts during a steady phase of a discharge, although global parameters such as averaged temperature, density, Z_{eff} , and even the inversion radius of the sawtooth do not seem to change. These phenomena suggest that small or localized changes of plasma parameters affect the characteristics of sawtooth activity significantly.

Figure 3 shows the profile evolution of soft X-ray emissions. Unlike the discharge in Fig. 2, a steady-state current is achieved in the period shown due to a fast current rise. Bursts of compound sawteeth (Type 2) and small sawteeth (Type 3) are seen. This figure indicates that the main relaxation (Example C) of Fig. 1 flattens the central temperature profile and that the subordinate relaxation (Example B) affects only the intermediate radii of the plasma. It suggests that the main relaxation (Example C) is caused by a full

reconnection, including the hot core at the center, while the subordinate relaxation (Example B) is associated with a partial reconnection which does not affect the hot core.

Expanded views of one compound sawtooth (Type 2) are shown in Fig. 4. The $m = 1$, $n = 1$ precursor oscillation is found to be small. This may imply that the width of the $m = 1$, $n = 1$ island is small, that the two $m/n=1/1$ modes are present, or that the temperature profile is flat in the central region. It should also be noted that the inversion radii of the subordinate and the main relaxations are different and that the subordinate relaxation is not observed near the center. The inversion radius for the main relaxation is about 20 cm for this discharge, whereas for the subordinate relaxation, it is around 25 cm. The difference between these inversion radii is about 5 cm, although it is sometimes as large as 10 cm. The inversion radius of the subordinate relaxation is always larger than that of the main relaxation. The mode structure is different from that of the simple sawtooth (Type 1) observed in earlier tokamaks. The main relaxation is associated with a small amplitude $m = \text{odd}$ precursor mode and the subordinate relaxation has an $m = \text{odd}$ precursor with a larger amplitude $m = \text{odd}$ successor (i.e., oscillations after the crash phase of the sawtooth). These three kinds of $m = \text{odd}$ modes have approximately the same general frequency of 250 Hz for ohmically heated plasmas. The heat pulse due to the full reconnection has a ballistic-like effect up to 42 cm. It then spreads diffusively to the outer region. On the other hand, the heat pulse due to a partial reconnection is diffusive from a radius of 34 cm, perhaps because the released energy is small.

Figure 5 shows the relative sawtooth amplitude $\Delta A/A$ measured during the steady-state phase of the discharge shown in Fig. 3. Although global parameters of the plasma do not change during the measurement, three kinds of

relaxation phenomena are observed. Both the main relaxation and the complete relaxation are similar to the conventional complete relaxation (Example A). However, the complete relaxation has half the amplitude of the main relaxation (see Fig. 5). On the other hand, the subordinate relaxation is found to be localized in the intermediate radii and has an inversion radius larger than the others.

3. SCALING OF THE SAWTOOTH PERIOD

Some theoretically motivated scaling laws for the sawtooth period have been proposed [3,10]. These analyses assume that the relaxation period can be estimated from the growth of the resistive $m = 1$ tearing mode. Therefore, the sawtooth period is supposed to be dominated by the time the $m = 1$ magnetic island width grows to r_s , where r_s is the $q = 1$ radius. In Fig. 6, the sawtooth period obtained from the experiment is compared with the analytical prediction of McGuire-Robinson scaling [10]. Type 1 agrees well with the scaling. However, Type 3 does not tend to follow the scaling as the predicted value becomes larger, while Type 2 still lies on the predicted line. Therefore, sawteeth can also be classified by comparing their period with the scaling. This tendency is observed clearly in the case of large plasmas. The relaxation is apt to take place earlier than the predicted time for the large plasma discharges. This implies that the full reconnection may occur before the $m = 1$ island is predicted to grow to r_s [11]. A similar type of discrepancy between the experimental results and the scaling line has also been observed in the JET data [6].

The characteristics of the $m = 1$, $n = 1$ precursor mode of a sawtooth depends on whether their period follows the scaling (Fig. 6). Waveforms (a) and (b) correspond to Type 1 and Type 3, respectively. Case (a) is a

discharge with a relatively small minor radius, $a_p = 0.55$ m, and $I_p = 0.58$ MA and $T_e(0) = 1.76$ keV. In this case, the sawtooth oscillations seem to be of the conventional type, like those observed in earlier tokamaks. Case (b) is a larger plasma discharge with $a_p = 0.68$ m. The plasma current and the central electron temperature are also higher, $I_p = 1.2$ MA and $T_e(0) = 2.73$ keV. The toroidal field and electron density are almost the same for these cases. Since the radius of the $q = 1$ surface for case (b) is larger than for case (a) and the temperature is also higher, the resistive skin time (within the $q = 1$ radius) for case (b) is twice that for case (a) (0.88 sec for case (a) and 1.9 sec for case (b)). The sawtooth mechanism for these two cases appears to be different. The precursor mode causing the relaxation is found to be very small for Case (b) and the relative amplitude of $\delta A/A$ is 2.5% at the maximum, while that for Case (a) is up to 8%.

Another scaling from the sawtooth period (Type 1 and Type 3) has been obtained from TFTR. There appears to be a correlation between the sawtooth period and the total energy confinement time (shown in Fig. 7). It is found that the periods of Type 1 and Type 3 are approximately five times the energy confinement time. Better agreement is found if q is considered in the scaling. This scaling is quite empirical, but good agreement has been found in the ohmically heated plasmas of TFTR.

4. DISCUSSION

The small amplitude of the $m = 1$ precursor, the subordinate relaxation, and the scaling study of sawtooth periods indicate that compound sawteeth (Type 2) as well as small sawteeth (Type 3) cannot be explained by a simple Kadomtsev model [2]. Possible explanations include the double tearing mode [12] or partial reconnection theory [5,13]. A more detailed discussion of the modeling can be found in Ref. [14].

Although the mechanism of the compound sawtooth has not been understood theoretically, it is possible that this compound sawtooth activity is associated with the current profile. Because of the large volume and the relatively high electron temperature, the resistive skin time in the central region is considerably longer for TFTR than for earlier tokamaks. This suggests the existence of a flat or slightly hollow current profile even during a steady state, especially in high current and/or high density operation [7]. However, even if hollow current profiles were common in earlier tokamaks [15], no compound sawteeth were observed. The reason could be that the skin time was relatively shorter compared with the growth time of the $m = 1$ tearing mode.

Neglecting the effect of diamagnetic drifts, the $m = 1$ tearing mode growth rate γ can be represented as follows [16],

$$\gamma = \alpha^{2/3} / (\tau_R^{1/3} \tau_A^{2/3}) \quad (1)$$

where

$$\alpha = a_p \frac{dq}{dr} \Big|_{r_s} \quad (2)$$

Here a_p is a minor radius of the plasma, τ_R and τ_A are the resistive skin time and the Alfvén transit time, respectively. If α is assumed to be constant, the ratio of τ_R to $1/\gamma$ is estimated in terms of the magnetic Reynolds number S ,

$$\tau_R \gamma = \tau_R^{2/3} \tau_A^{-2/3} = S^{2/3} \quad (3)$$

The ratio of the measured Type 1 or Type 3 sawtooth period (τ_{saw}) to the predicted value (τ_{scale}) is shown in Fig. 8 as a function of $S^{2/3}$. The sawtooth period measured in the experiment does not follow the predicted value with increasing S . This tendency may mean that the characteristics of the relaxation change as S increases, or that the growth rate depends more strongly on S than predicted by Eq. (1).

As mentioned in Sec. 2, the partial relaxation during the compound sawtooth has a large $m = \text{odd successor}$ (e.g., Fig. 3). This successor oscillation is enhanced or triggered by a subordinate relaxation and then damps rapidly. This $m = \text{odd}$ burst is sometimes observed without a subordinate relaxation and looks similar to a fishbone oscillation due to high power neutral beam injection [17]. This $m = \text{odd}$ mode can thus stabilize itself without any rapid relaxation. Although a saturated $m = 1$ mode under particular conditions [18] and an $m = 1$ successor after an internal disruption [19] have been observed before, the exact mechanism for these phenomena is still under study.

Another unusual phenomenon for Type 2 and Type 3 is that its $m = \text{odd}$ precursor is very small and sometimes difficult to observe. One possible reason is that the temperature gradient around the $m = \text{odd}$ perturbation could be very small, since the temperature profile of TFTR plasmas is found to be flat or slightly hollow [7]; this would then give a very small perturbation on the soft X-ray signals. Another possibility is that if two $m = 1$ perturbations were present and 180° apart from each other, the effect of these perturbations could cancel each other somewhat and this would give small oscillations on the soft X-ray signal.

5. SUMMARY

Compound sawteeth, which cannot be explained by the standard Kadomtsev model, are observed in ohmically heated TFTR plasmas. They are a combination of a main and a subordinate relaxation and are sometimes interspersed among small sawteeth. A subordinate relaxation has an $m = \text{odd}$ precursor with a larger $m = \text{odd}$ successor. The compound sawtooth period follows McGuire-Robinson scaling, whereas the small sawteeth saturate against the theoretically predicted value in the high-magnetic-Reynolds-number regime. A correlation between the sawtooth period and the energy confinement time for Type 1 and Type 3 in TFTR plasmas has been found.

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REFERENCES

- [1] VON GOELER, S., STODIEK, W., and SAUTHOFF, N., Phys. Rev. Lett. 33 (1974) 1201.
- [2] KADOMTSEV, B.B., Fiz. Plazmy 1 (1975) 710.
- [3] JAHNS, G.L., SOLER, M., WADDELL, B.V., CALLEN, J.D., and HICKS, H.R., Nucl. Fusion 18 (1978) 609.
- [4] SNIPES, J., KOCHANSKI, T.P., KIM, S.B., RICHARDS, B., ROWAN, W.L., and PHILLIPS, P., Bull. Am. Phys. Soc. 28 (1983) 1034.
- [5] PFEIFFER, W., GA Technologies Report, GA-A16960 (1983).
- [6] THOMAS, P.R., WESSON, J.A., ALLADIO, F., BARTLETT, D., and BEHRINGER, K., et al., to be published in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 10th Int. Conf., London, 1984), IAEA, Vienna (1985).
- [7] EFTHIMION, P.C., BRETZ, N., BELL, M., BITTER, M., BLANCHARD, W.R., et al., to be published in Plasma Physics and Controlled Nuclear Fusion Research (Proc. 10th Int. Conf., London, 1984), IAEA, Vienna (1985).
- [8] KIM, S.B., SNIPES, J.A., KOCHANSKI, T.P., and POWERS, E.J., Bull. Am. Phys. Soc. 29 (1984) 1395.

- [9] HILL, K.W., VON GOELER, S., BITTER, M., DAVIS, W., DUDEK, L., et al., presented at 5th Topical Conference on High Temperature Plasma Diagnostics, Tahoe City, CA, September 16-20, 1984.
- [10] MCGUIRE, K. and ROBINSON, D.C., Nucl. Fusion 19 (1979) 505.
- [11] DUBOIS, M.A., MARTY, D.A., and POCHELON, A., Nucl. Fusion 20 (1980) 1355.
- [12] STIX, T.H., Phys. Rev. Lett. 36 (1976) 521.
- [13] PARAIL, V.V. and PEREVERZEV, G.V., Fiz. Plazmy 6 (1980) 27.
- [14] YAMADA, H., MCGUIRE, K., SAUTHOFF, N., to be published in Princeton Plasma Physics Laboratory Report.
- [15] HUTCHINSON, I.H. and MORTON, A.H., Nucl. Fusion 16 (1976) 447.
- [16] WADDELL, B.V., ROSENBLUTH, M.N., MONTICELLO, D.A., and WHITE, R.B., Nucl. Fusion 16 (1976) 528.
- [17] MCGUIRE, K., GOLDSTON, R., BELL, M., BITTER, M., BOL, K., et al., Phys. Rev. Lett. 50 (1983) 891.
- [18] DUNLAP, J.L., CARRERAS, B.A., PARE, V.K., HOLMES, J.A., BATES, S.C., BELL, J.D., HICKS, H.R., LYNCH, V.E. and NAVARRO, A.P., Phys. Rev. Lett. 48 (1982) 538.

- [19] SAUTHOFF, N., VON GOELER, S., EAMES, D.R., and STODIEK, W., in Proc. of the IAEA Symposium on Current Disruption in Toroidal Devices (Garching, 1979) c5.

Table 1

Sawtooth Type	Simple (Type 1)	Small (Type 3)	Compound (Type 2)	
Relaxation Type	Complete (Example A)	Complete (Example D)	Subordinate (Example B)	Main (Example C)
$m/n = 1/1$ Precursor Oscillation	Large	Small	Small	Very Small
$m/n=1/1$ Successor Oscillation	Very Small	Medium-Large	Large	Medium
Mixing Zone	$\sim 1.4 r_1$	$> 1.4 r_1$	$\sim 2 r_1$	$> 2 r_1$

FIGURE CAPTIONS

Fig. 1 Classification of sawtooth activities for TFTR plasmas. It should be noted that (a) and (b) are observed in different shots, during the current flat top.

Fig. 2 Compound sawtooth activity detected by a variety of diagnostics during current flat-top phase. The time evolution of the surface voltage, the neutron flux, the total radiation power, the electron density along an integrated central chord, and the soft X-ray emission along a central chord are shown.

Fig. 3 Time evolution of soft X-ray emission profile.

Fig. 4 Soft X-ray traces from a horizontal diode array on expanded time scale. Noteworthy variations activities which are especially distinguished around the inversion area ($r \sim \pm 20$ cm) are observed. The discharge parameters of this shot are $I_p = 1.4$ MA, $B_t = 2.8$ T, $n_e = 2 \times 10^{19} \text{ m}^{-3}$, $R = 2.55$ m, and $a = 0.83$ m.

Fig. 5 Radial profile of relative sawtooth amplitude $\Delta A/A$. Three kinds of internal relaxation measured in the same discharge (shown in Fig. 2) are plotted.

Fig. 6 Comparison of predicted and measured sawtooth period. Predicted values are calculated according to McGuire-Robinson scaling.

$$\tau_{\text{scale}} = 3 \tau_R^{3/7} \tau_A^{2/7} \tau_h^{2/7},$$

where τ_R is the resistive skin time, τ_A is the Alfvén transit time, and τ_h is the heating time. Open symbols are sawtooth periods of Type 1 or Type 3 and closed symbols are Type 2. Those for earlier tokamaks (PLT, T-10, TFR, and DITE) are also shown by crosses (Ref. [10]). Soft X-ray traces for two discharges labelled in the graph are also illustrated.

Fig. 7 Comparison of measured sawtooth period and total energy confinement time. Sawtooth periods are those of normal ones (Type 1).

Fig. 8 Relation between the ratio of measured sawtooth periods (Type 1 and Type 3) to predicted ones and that of resistive skin time to $m = 1$ tearing-mode growth time (which is proportional to $S^{2/3}$). Earlier tokamaks are PLT, T-10, TFR, and DITE (Ref. [10]).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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Fig. 5

Fig. 6

Fig. 7

Fig. 8

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