ON THE AMPLITUDE OF SAWTOOTH PRE-CURSORS AT THE ONSET OF NEO-CLASSICAL TEARING MODES.

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1. INTRODUCTION

Most observations of Neo-classical Tearing Modes (NTM) in JET experiments, occur in regimes where sawteeth are present. Recent JET experiments showed that it is possible to control the time of onset of the NTM by controlling the frequency of occurrence and the amplitude of sawteeth crashes using ICRH [1].

A clear correlation between the time of sawtooth crashes and the onset of NTMs was obtained from a database of pre 2000 JET experiments [2]. In this paper we study the correlation between sawteeth and other central n=1 MHD modes such as fishbones and the onset of the *m*=3, *n*=2 NTMs. In addition we study the amplitude of the n=1 sawtooth precursors around the time the NTM starts.

A larger database including 2000-2001 NTM studies is considered. This includes experiments for the study of shape effects on the NTM trigger [3], NTM studies in ASDEX-Upgrade similarity discharges, ITER like discharges and experiments to control NTMs by sawtooth control [1].

Only discharges, which are dominantly NBI heated, are considered. Studies show that large sawteeth in dominantly ICRH discharges can have a low β limit, β_N <1 and conclusions for these discharges may differ from these reached here.

2. *m*=1, *n*=1 AMPLITUDE

The amplitude of *m*=1, *n*=1 modes was obtained from observations of magnetic field perturbations induced on magnetic pickup coils using fast Fourier transforms and filter techniques. The acquisition frequency of these coils varies from 250 kHz to 1 MHz.

We consider the two sawtooth crashes that were nearest to the *m*=3, *n*=2 NTM onset. The sawtooth period was obtained from Soft X-ray emission traces.

Figure 1 shows the spectrogram for a discharge in which the (3,2) NTM is triggered just before a sawtooth crash, when a n=1 sawtooth pre-cursor is clearly observed. The amplitude of the sawtooth precursors for this pulse is shown in figure 2. It can be seen from figure 2 that the largest amplitude of the sawtooth precursor does not necessarily trigger the (3,2) NTM.

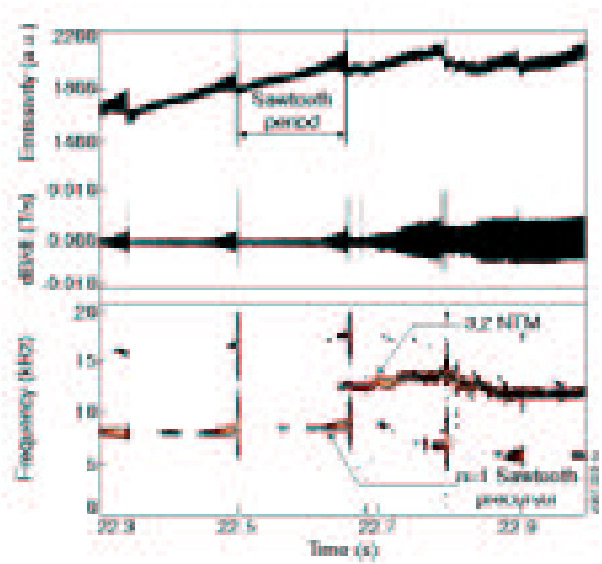

Figure 1: Signal from the Soft X-ray central emission, induced signal in a fast pickup coil from the shot #51995 and the correspondent spectrogram showing a (3,2) NTM triggered shortly before a sawtooth crash.

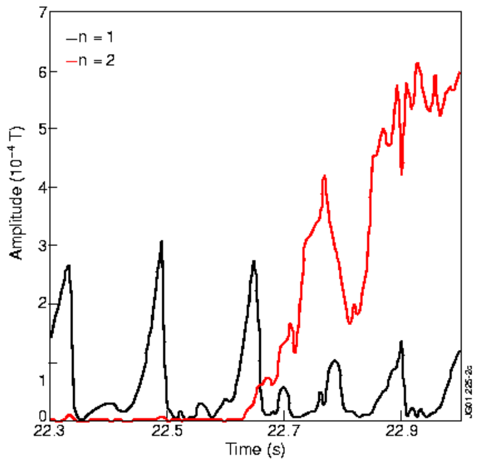

Figure 2: Amplitudes of the n=1 sawtooth precursor and n=2 NTM mode for the shot #51995

Figure 3 shows the spectrogram for a discharge in which the (3,2) NTM appears to be triggered by fishbones. The amplitude shown in figure 4, is of the same order as the sawtooth precursor amplitude seen in figure 2, and again seems to decay somewhat before the NTM is triggered.

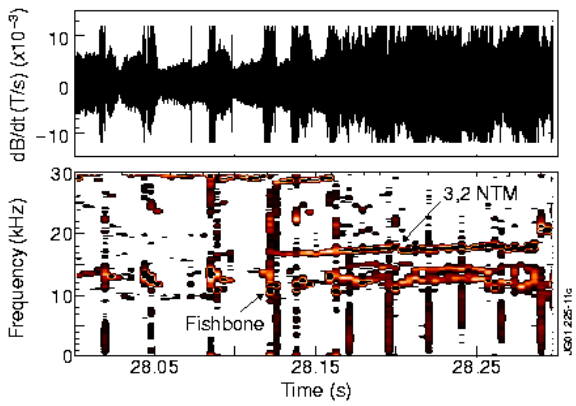

Figure 3: Induced Signal in a fast pickup coil from the shot #52083 and its correspondent spectrogram showing a NTM triggered in a discharge with frequent fishbones

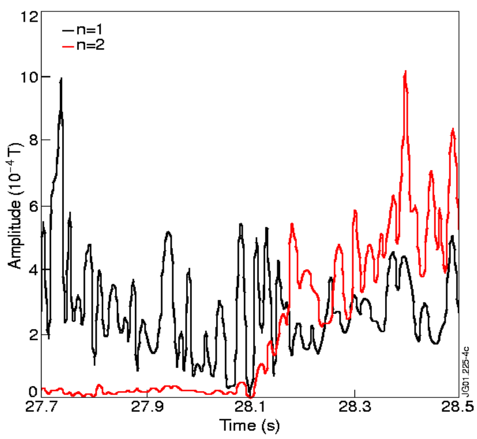

Figure 4: Amplitude of the n=1 fishbone bursts and n=2 NTM modes for the shot #52083

Figure 5, shows a pulse with edge B_p = 0.27 T similar to the previous two cases, a NTM is not observed. The amplitude of the sawtooth precursor is overall slightly lower than in figures 2 and 4.

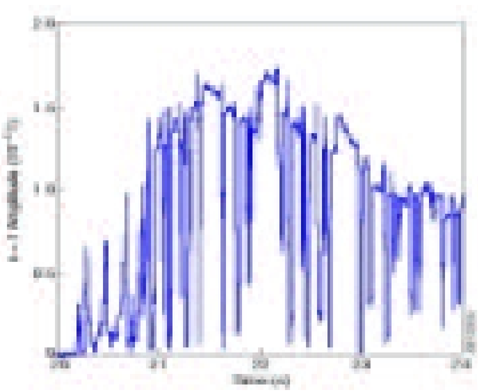

Figure 5: Amplitude of the n=1 sawtooth precursor mode for the shot #52002 where a NTM was not found

2.1 m=1, n=1 amplitude in function of normalised β

For this analysis we selected the pulses with values of δ between 0.25 and 0.3 and q_{95} between 3.0 and 3.5.

The mode amplitude of the sawtooth precursor nearest to NTM onset, increases with increasing β_N, (figure 6), though there is a large scatter in the data. The distribution in figure 6 does not change significantly if we take the amplitude of the previous sawtooth precursor.

The onset of NTM related to fishbones occurs for $\beta_N > 2.5$ while for sawteeth occurs with lower beta values, $\beta_N > 1.5$, in these dominantly NBI heated discharges.

The scaling of the amplitude versus β_N is qualitatively similar to the scaling of sawteeth in general [3].

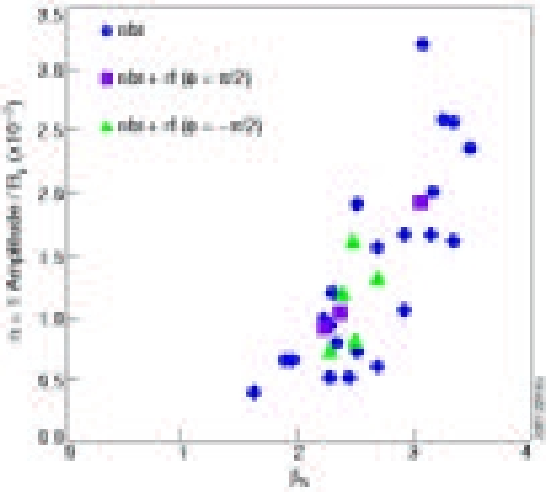

Figure 6: n=1, m=1 amplitude of the sawtooth precursor normalised by B_p at the edge of the plasma versus β_N.

2.2 m=1, n=1 amplitude in function of ρ*

The mode amplitude when the NTM is triggered increases with ρ*, figure 7. If the NTM threshold is due to the polarisation current or $\chi_\perp/\chi_{II}$ model, then one would expect the seed island amplitude to scale as ρ*. So in Fig. 7 a scaling of $br = \frac{1}{B_p} \alpha (\rho *)^2$ would be expected; it can be seen that such a scaling is not inconsistent with the data, though there is large scatter. However examination of previous sawteeth does not show any trend of increasing amplitude as the NTM is approached.

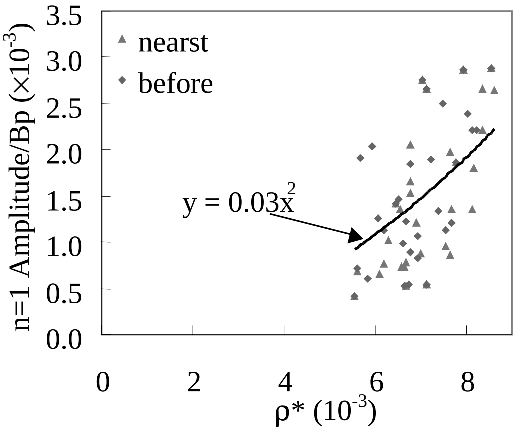

*Figure 7: n=1, m=1 amplitude normalised by ρ**

2.3 m=1, n=1 amplitude in function of sawtooth period

Figure 8 shows that the amplitude of the sawtooth precursor increases with the period, for the pulses with δ between 0.25 and 0.3 and q_{95} between 3 and 3.5.

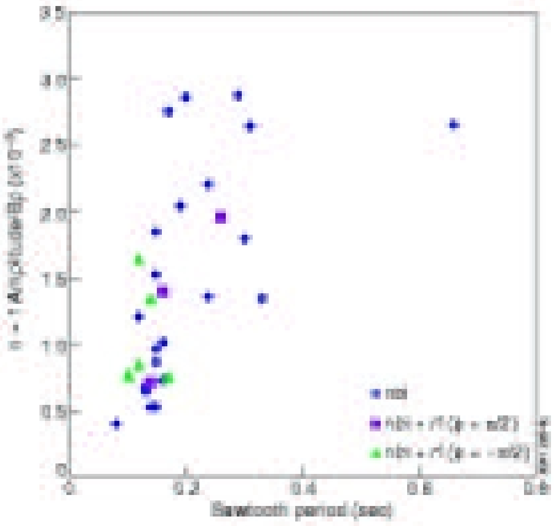

Figure 8: n=1 Amplitude of the sawtooth precursor normalised by B_p (a) versus the sawtooth period

3 NTM TRIGGER RELATION WITH SAWTOOTH CRASH

Mode coupling has been suggested as a possible mechanism for the onset of NTMs [5]. For the triggering of a *m*=3, *n*=2 NTM this requires either the n=1 sawtooth precursor as the driving mode in a three-mode non-linear coupling, or its n=2 component as the driving mode in toroidal coupling [5]. Figure 9 shows that the majority NTMs onset occurs before a sawtooth crash. Most are triggered in presence of central n=1 modes (and their n=2 harmonics). The peak around the sawtooth crash corresponds mostly to pulses with low β_N, and very long sawtooth periods with short precursor.

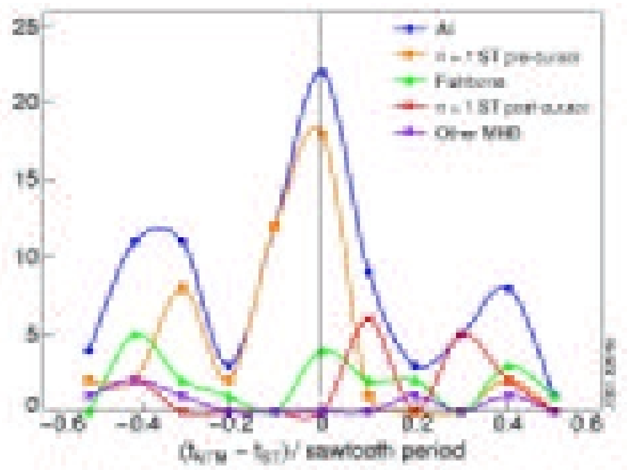

Figure 9: Distribution of NTM occurrence (89 discharges) with respect to the nearest sawtooth crash (dark blue). Distribution of cases occurring when a sawtooth precursor is observed (orange). Distribution of cases when fishbones are present (green). Distribution of cases with respect to n=1 sawtooth post-cursors (red).

4. CONCLUSIONS

In most JET experiments, with ELMy H-modes plasmas the NTM is found to occur associated with the sawtooth instability and in a minority of cases with fishbones. The required n=1 amplitude for the NTM onset appears to be independent of whether the NTM is triggered by fishbones or sawteeth.

The mode amplitude of the sawtooth precursor is not the only factor that determines the onset of the NTM. It has been found that there is no clear correlation between the amplitude of the sawtooth precursor and the time when the NTM is triggered. Other factors, which govern the resistive tearing, needed to form the seed island, such as the relative rotation between q=1 and q=3/2, need to be examined in future studies. In addition, the amplitudes of higher frequency modes (with $n \geq 3$) which are important for non-linear coupling need to be investigated.

REFERENCES

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[*] see appendix of the paper by J. Pamela “Overview of recent JET results”, Proc. IAEA conference on Fusion Energy, Sorrento, 2000