First indications of sawtooth pacing using modulated ICRH on TEXTOR

J.Ongena[1], K.Crombe[1,2], T. Wauters[1], E.Lerche[1], D.Van Eester[1], M.Vervier[1], and TEXTOR team[3]

[1] *Plasma Physics Lab, LPP/ERM-KMS, Brussels, Belgium, TEC Partner*
[2] *Department of Applied Physics - Gent University, Gent, Belgium*
[3] *Institut für Energie und Klimaforschung / Plasmaphysik, Forschungszentrum Jülich, Jülich, Germany, TEC Partner*

Introduction

Until recently, sawtooth activity was considered a non-desirable by-product of efficient heating of tokamak plasmas. The potential of MHD-activity such as sawteeth and ELMs to avoid impurity accumulation has however shown that their presence can also be used to our advantage.

It was shown earlier on TCV using modulated ECRH power [1] that sawteeth can be triggered by sudden crashes in the ECRH power. Whereas TCV demonstrated the possibility to perform sawtooth pacing using modulated ECRH, i.e. an *electron* heating scheme, sawtooth-locking often observed in ICRH power modulation experiments suggests that ICRH can force sawtooth crashes as well. Recent ICRF experiments in JET showed indeed that switching off ICRH in JET also triggers sawteeth, thus being a strong indication that an *ion* heating scheme could be equally effective (and possibly more relevant for fusion devices).

Experimental conditions

In plasmas on TEXTOR (R_0 = 1.75m, a = 0.46m) at B_t = 1.9 T and Ip = 400kA, H minority fundamental cyclotron heating in a D plasma was used to reach high single pass absorption (80-100%), at H concentrations between ~10-20%. ICRH heating at 29 MHz (resonance on axis) and power levels between 1-2 MW was used combined with 0.6-1.2 MW of D^0 co-NBI at an acceleration voltage of 50 keV. The ICRH system at TEXTOR consists of two generators each tested at delivering up to 2MW for maximum 14s. These two generators feed each separately one of the two antennae at TEXTOR, with each antenna consisting of a pair of straps. While the relative phasing of the straps is straightforward in antenna 1 (using a λ/2 difference in the feeding lines for the individual straps to obtain π phasing), the relative phasing of the straps for the antenna 2 is not fixed and depends on the load (determined by the plasma density profile in front of the antenna), as it is operated in the conjugate T scheme. For these experiments, Antenna 2 showed π phasing at low (~ 1-2 x $10^{19}m^{-3}$) and 0 phasing at high density (> 4 x $10^{19}m^{-3}$). As we operated at low density, π phasing and optimized conditions for heating were also realized for Antenna 2.

Results

Fig 1a shows main parameters for a TEXTOR discharge with modulated ICRH as used in these experiments. The shot is heated with a background of NBI-co with powers varying slightly from shot to shot around 600kW. On top of that we added modulated ICRH power in varying amounts from both ICRH antennae at TEXTOR. In the case shown here a sweeped frequency was used for the modulation, and both generators were modulated simultaneously at frequencies between 30 and 60 Hz. These discharges were part of a multi day experiment intended to condition the ICRH antennas for maximal power delivery. To optimize the wall conditions, boronization was applied before this experiment. Only hydrated diborane was available (B_2H_6) and thus it was difficult to keep the H concentration as low as needed for an optimal (H)D heating scheme. Typically we got concentrations of about 20% at the start of the experiment, gradually lowering to values around 12-13% in the discharges where modulated ICRH was used.

At plasma densities of about $2x10^{19}m^{-3}$ it was observed that the sawtooth frequency tunes in to the modulation frequency provided the natural sawtooth frequency is lower than the frequency at which the power is modulated. At higher densities, lower ICRH power compared to the total power and lower modulation depth, the effect was no longer observed.

An illustration is given in Figs. 2ab. Fig 2a shows that indeed sawteeth triggering occurs at every crash of the ICRH power in TEXTOR shot #120869 with following parameters H/(D+H) concentration ~13%, high power ICRH 1.6MW with 83% modulation depth, low power of NBI 0.6MW and low density of ~ $2x10^{19}m^{-3}$. A comparison with TEXTOR shot #120809 under less optimal conditions (reduced ICRH power of 1.2MW, high NBI power of 1.2MW, H/(H+D) concentration of 17% and high density ~ $4x10^{19}m^{-3}$ is shown in Fig 2b, where no sawteeth triggering is seen.

More details are revealed using a Fourier analysis, as shown in Figs 3a and b. Both figures show the frequency as a function of time of both the sawteeth and the modulation of the ICRH power. Fig 3a shows the Fourier Analysis of the full shot of Fig. 2b. Locking of the sawteeth to the frequency of the modulation starts when the modulation frequency becomes equal to the natural sawtooth frequency. A word of caution however is also needed, as shown in Fig 3b. In this shot no locking of the sawteeth was seen (as the ICRH modulation frequency stayed below the natural ST frequency). If one ‘maps’ the ST frequency of Fig. 3a on top of Fig. 3b, a similar time evolution can be seen (although at a different frequency range).

Conclusions

Although clearly further work is needed to confirm the results beyond doubt, encouraging first indications are presented about the possibility for sawteeth triggering using modulated ICRH. As the flexible and fully functional TEXTOR tokamak had to close down, a continuation of this set of experiments is no longer possible on this device. Further experiments are now planned on JET in the future. Such experiments, if successful, would then also provide information on the potential extrapolation of ICRH as a method for sawteeth triggering to larger devices.

References

[1] M. Lauret *et al*, 2012 *Nucl. Fusion* **52** 062002

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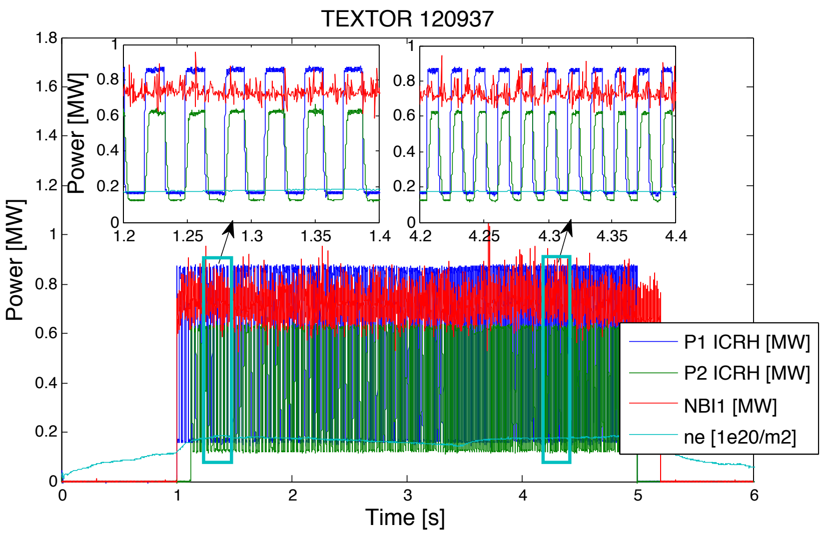

Fig.1 : Main Parameters of a typical discharge used for the study of sawteeth triggering by modulated ICRH power on both antennas in TEXTOR. Shown is the NBI-co Power, the plasma density and the ICRH power, which was modulated on both generators with a frequency varying between 30 Hz and 60Hz.

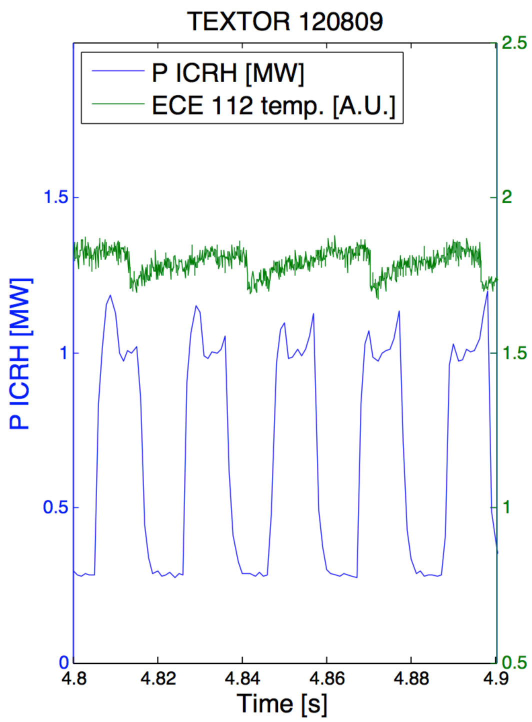

Fig. 2a: ICRH Modulation under non optimal conditions : no frequency locking of the sawteeth

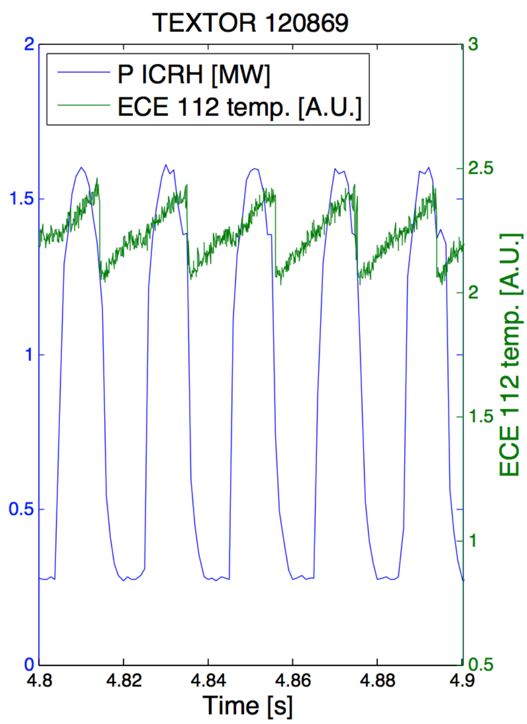

Fig. 2b: ICRH Modulation under optimised conditions : frequency locking of the sawteeth to the modulated ICRH power signal is observed

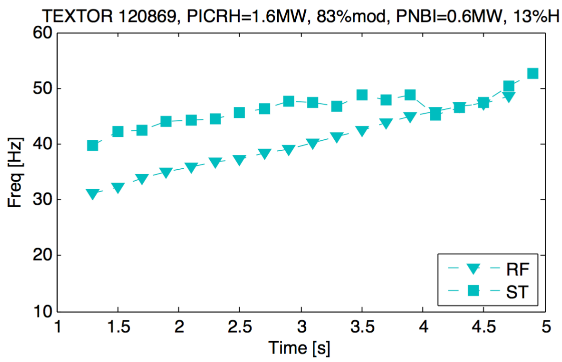

Fig. 3a: Fourier analysis of the locking of the sawteeth frequency with the ICRH modulation frequency

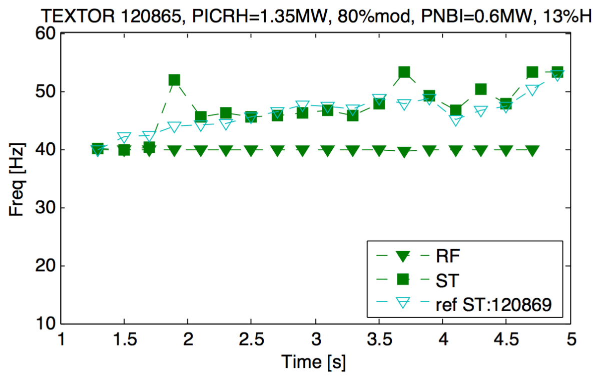

Fig. 3b: Illustration of a case where no locking is observed. Although at a different frequency, the time evolution of the sawteeth frequency is similar.