Max-Planck-Institut für Plasmaphysik

SAWTOOTH CRASH DYNAMICS DURING ECCD OPERATIONS AT W7-X (Confinement degradation and plasma loss induced by strong sawtooth crashes at W7-X)

M. Zanini*, H P Laqua, H Thomsen, T Stange, B Buttenschön, C Brandt, H Braune, K J Brunner, M Hirsch, U Höfel, J Knauer, S Marsen, N Marushchenko, K Rahbarnia, J Schilling, Y Turkin, R C Wolf, A Zocco, W7-X

[1]Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

1. Abstract

- Sawtooth-like crashes were observed during Electron Cyclotron Current Drive (ECCD) experiments for strikeline controls at the optimised superconducting stellarator Wendelstein 7-X (W7-X).
- A limited number of events have been related to a strong deterioration of the plasma performances and even to the premature termination of the experiment.
- The x-ray tomography shows a strong radiation increase starting from the edge and moving towards the inner plasma regions and an impurity influx could be identified afterwards. This results in a plasma cooling down and shrinking and eventually the coupling between the ECRH heating and plasma can be lost.

2. Introduction

- Wendelstein 7-X (W7-X) is a superconducting optimised low shear stellarator, which relies on the island divertor concept. The island divertor concept is sensitive to toroidal currents (such as bootstrap current or external current drive) which shift the position of the strikelines and therefore a proper toroidal current control is necessary. The toroidal current I_{tor} evolves on the timescale of τ =L/R, where L is the plasma inductance and R the plasma resistance, as follows:

$$I_{tor} = I_{tor}(t \rightarrow \infty)(1 - \exp(-t/\tau))$$

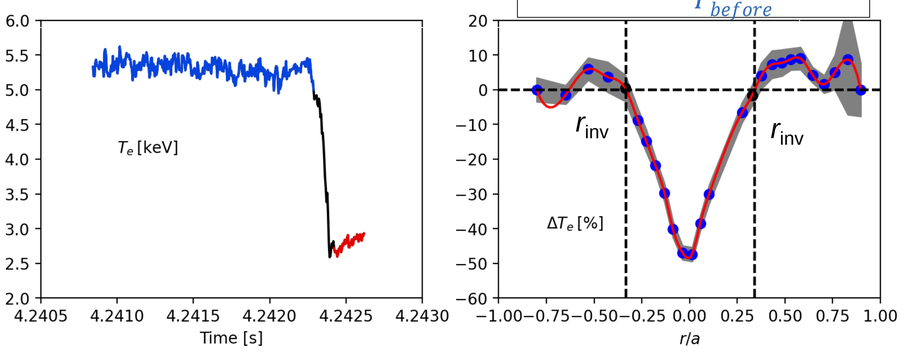
- Electron cyclotron current drive (ECCD) experiments have been conducted to evaluate the viability of current drive as an actuator for strikeline control [1].
- During ECCD experiments, periodic sawtooth crashes have been detected and a first experimental overview was presented in [2]. In this work we present the experiments in which strong sawtooth crashes led to a deterioration [3,4] of the confinement properties and eventually to the premature termination of the plasma discharge.

3. Diagnostic tools

Electron Cyclotron Emission (ECE)

- ECE Measures T_e along a 1-D LOS and is used to estimate the size of the sawtooth crash [5].

$$\Delta T_e = \frac{T_{after} - T_{before}}{T_{before}}$$



X-ray Tomography

- X-ray tomography [6] allows to reconstruct the plasma emissivity E_{SX} (proportional to $T_e^{1/2}\, n_e^2\, Z_{eff}$) in the poloidal plane and in this work was used to identify regions in which a strong increase of the soft x-ray emission was detected after a sawtooth.

HEXOS

- Four VUX/XUV spectrometers (HEXOS), detecting from 2.5 to 160 nm were used to study the emission of impurities, such as carbon, oxygen and nitrogen [7].

5. Conclusions

- Strong sawteeth can ionise impurities/neutrals at the edge
- Strong x-ray emission starting from the edge. N and O detected
- Plasma energy decreases fast. The plasma cools down
- Eventually the experiment can be terminated by bad ECRH-plasma coupling
- ECE data suggest r_{inv}> 0.5 a may trigger density increase→ possibility to control

[1]Y. Gao et al, Nuclear Fusion, ***59****, 106015, 2019*

[2] Zanini et al., Nuclear Fusion ***60,*** *106021, 2020*

[3] H. Thomsen et al, in 45th EPS conference on Plasma Physics, Prague, 2018

[4] K. Rahbarnia et al, in 46th EPS Conference on Plasma Physics, 2019

[5] M. Hirsch et al, EPJ Web of conferences, no. ***203****, 03007, 2019*

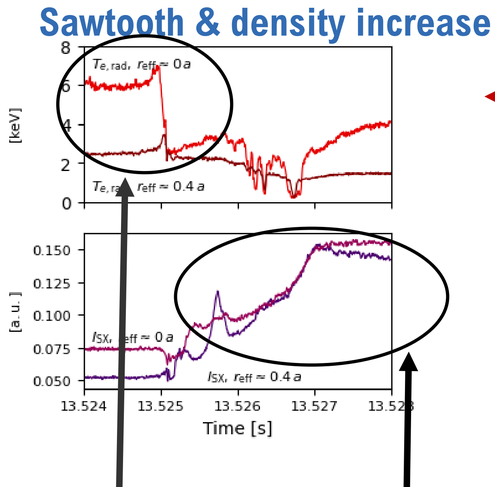
[6] C. Brandt et al, Fusion Enginnering and Design, no. ***123****, 887-891, 2017*

[7] H. Thomsen et al, Journal of Instrumentation, no. ***10****, P10015, 2015*

4. Experimental overview

Strong sawtooth crashes led in few experiments to a strong deterioration of the plasma performaces and even to the premature termination of the plasma discharge.

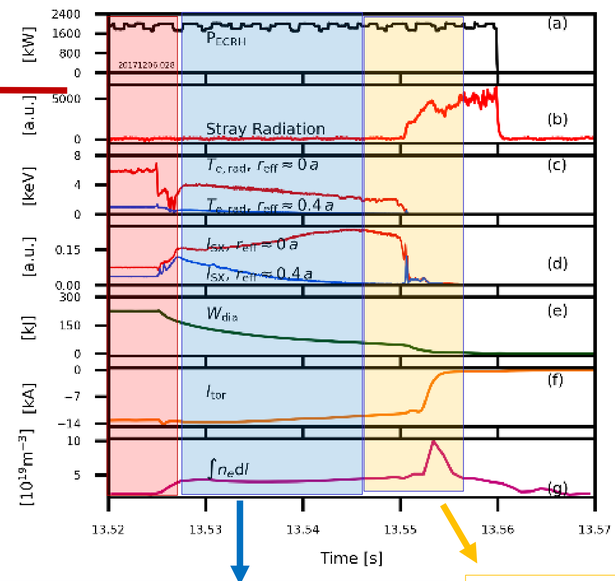
Sawtooth & density increase



1. Sawtooth →T_e decrease

2. I_{SX} increase→ n_e and/or Z_{eff} increase

20171206.028



3. Deterioration of the confinement

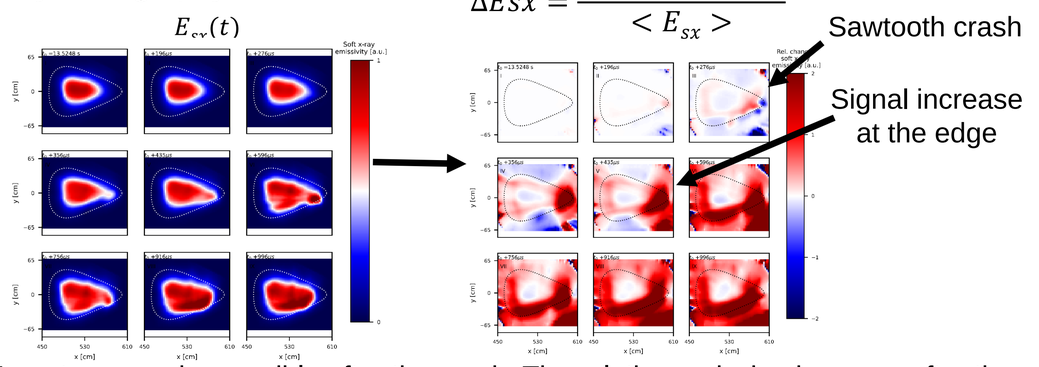
4. Low T_e→fast current dissipation

5. Low T_e→ bad ECRH absorbtion. This can lead to the experiment termination.

X-ray Tomography

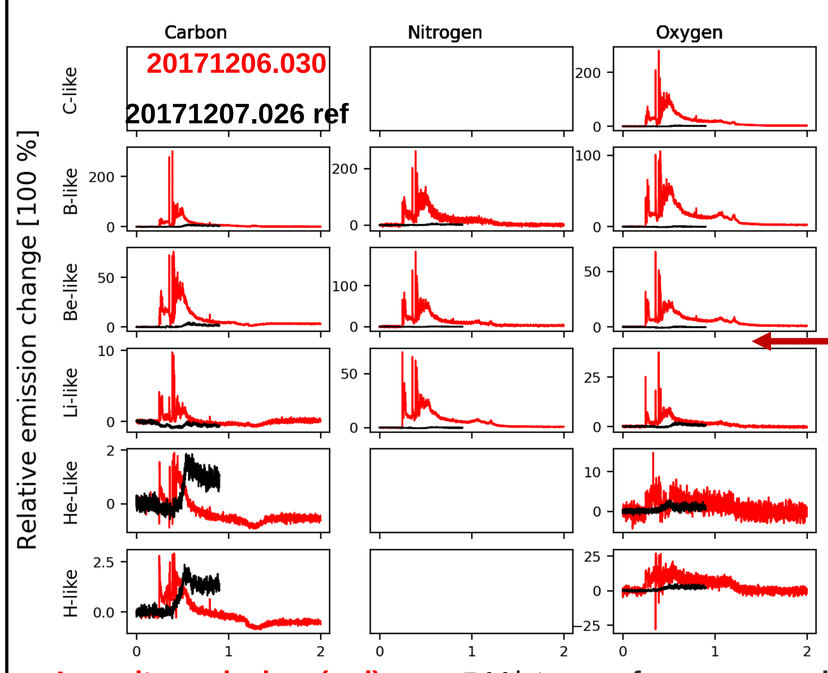
$$E_{sx}(t)$$

$$\Delta Esx = \frac{E_{sx}(t) - < E_{sx} >}{< E_{sx} >}$$



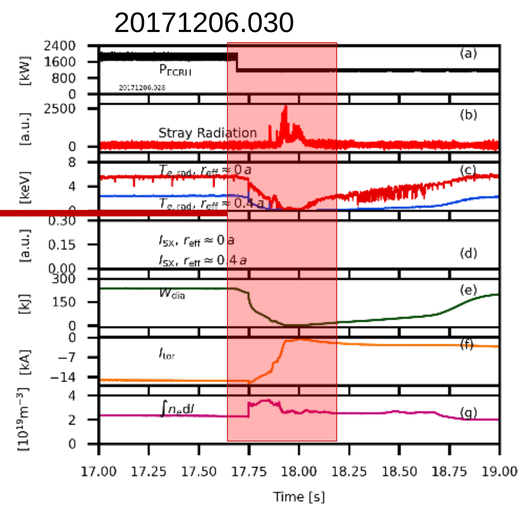
X-ray tomography possible after the crash. The relative emission increase after the sawtooth crash is plotted in the right plot. Strong increase starts from the edge

C,N,O Impurity emission with HEXOS



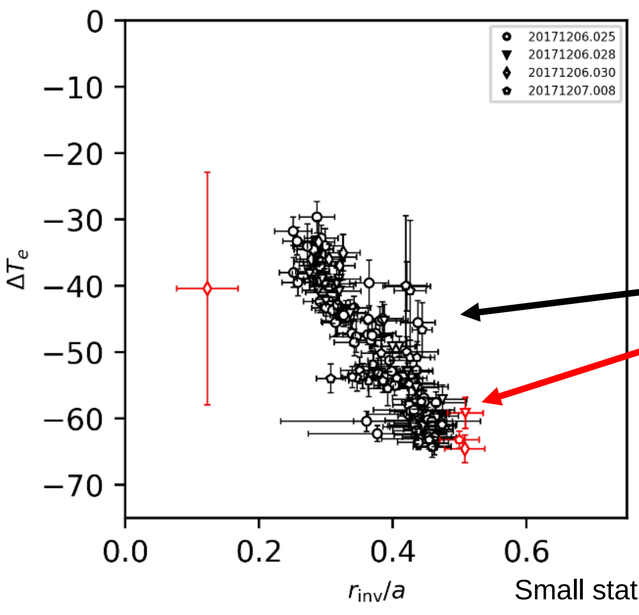
Similar experiment→ Impurity analysis possible after sawtooth and density increase. However, the plasma recovers aafterwards

20171206.030



Impurity emission (red) compared to a **reference experiment (black)** with T_e decrease, but no density increase. The emission line intensity for the **reference experiment** is not as strong as the one with density increase. Strong increase of C,N,O emission lines→it suggests impurity influx after the sawtooth crash

Role of I_{tor}



It was found [1] that size of the crashes increases with the I_{tor} .Large I_{tor} → large crash.

The size of the crashes (figure in section 2) at different I_{tor} and for different experiments was analysed. The majority of the crashes is not related to a density increase.

Black points: sawtooth crash

Red points: sawtooth and density increase

Few points. Still, r_{inv}> 0.5 a for all of them.

Small statistics but might be a reference parameter for the next experiments

*Corresponding author: marco.zanini@ipp.mpg.de

28th IAEA Fusion Energy Conference 2020/2021

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.