NTM seeding by strong internal events at different β_N in ASDEX Upgrade

V. Igochine[1], I. Classen[2], S. Günter[1], A. Gude[1], K. Lackner[1], M. Maraschek[1], R. M. McDermott[1], M. Sertoli[1], D. Vezinet[1], M. Willensdorfer[1], Q. Yu[1], H. Zohm[1] and ASDEX Upgrade team

[1]*Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching, Germany*
[2]*FOM-Institute DIFFER, Dutch Institute for Fundamental Energy Research, 3430 BE Nieuwegein*

In tokamak plasmas, large sawtooth or fishbone crashes typically produce fast relaxations of the core plasma density and temperature and provide the drive for magnetic reconnection at the neighbouring resonant surfaces with safety factors $q=m/n$, where m and n are integer numbers and represent the poloidal and toroidal mode numbers, respectively [1,2]. Magnetic reconnection rearranges the magnetic topology at the resonant surface. The drive for the mode could come predominantly either from current profile (classical tearing mode, TM) or from pressure profile (neoclassical tearing mode, NTM). The neoclassical tearing mode is metastable and can be triggered by other MHD events at much lower β_N values compared to the onset value where the noise is responsible for the seed island formation [3,4,5]. ($\beta_N = \beta\left(aB_t/I_p\right), \beta = 2\mu_0\langle p\rangle/B_t^2;$ $\langle p\rangle$ is the volume average pressure, B_t is the toroidal magnetic field, a is the minor radius and I_p is the plasma current.) Independent of the origin and the drive, the topology of the island structure remains the same in all cases. The drive for the seed of tearing mode is provided by background MHD instabilities (sawteeth, fishbones, ELMs, etc.), modification of the current profile or external magnetic perturbations [6]. When the critical island width is reached, the pressure profile becomes flat within the island, and the neoclassical drive takes over. Small islands are not able to provide significant pressure flattening and might be driven by other mechanisms [7, 8]. In this paper, only the mechanisms of the seed island formation by strong internal drives due to sawteeth or fishbones are investigated in detail. In this situation, internal instabilities provide the main drive for island formation, and driving forces due to gradients of the pressure and the current profiles are not important during the island formation process. This type of tearing mode seeding is considered to be one of the most important for future fusion reactors like ITER [9], because large internal events provide the strongest magnetic perturbations compared to other possible triggers and are thus able to trigger the mode already at very small normalized pressure values. Previous observations from different tokamaks, for example from JET [10] or TCV [11], report fast seeding of NTMs and large island widths directly after the crash based on analysis of magnetic and Soft X-ray (SXR) measurements. Such measurements show large amplitudes of the mode directly after crashes also in our experiments, but they do not allow us to distinguish between kink and tearing modes. Both types of modes produce the same signal if the helicity of the mode is the same, which is (m,n)=(2,1) in our cases. The magnetic signal is used in the following to extract the total amplitude of the mode. Contrary to integrated signals from SXR and magnetics, the electron cyclotron emission (ECE) signals provide local temperature perturbations. One can use the time traces of these perturbations to distinguish between tearing and kink character of the mode as shown in figure 1 and described in ref [12].

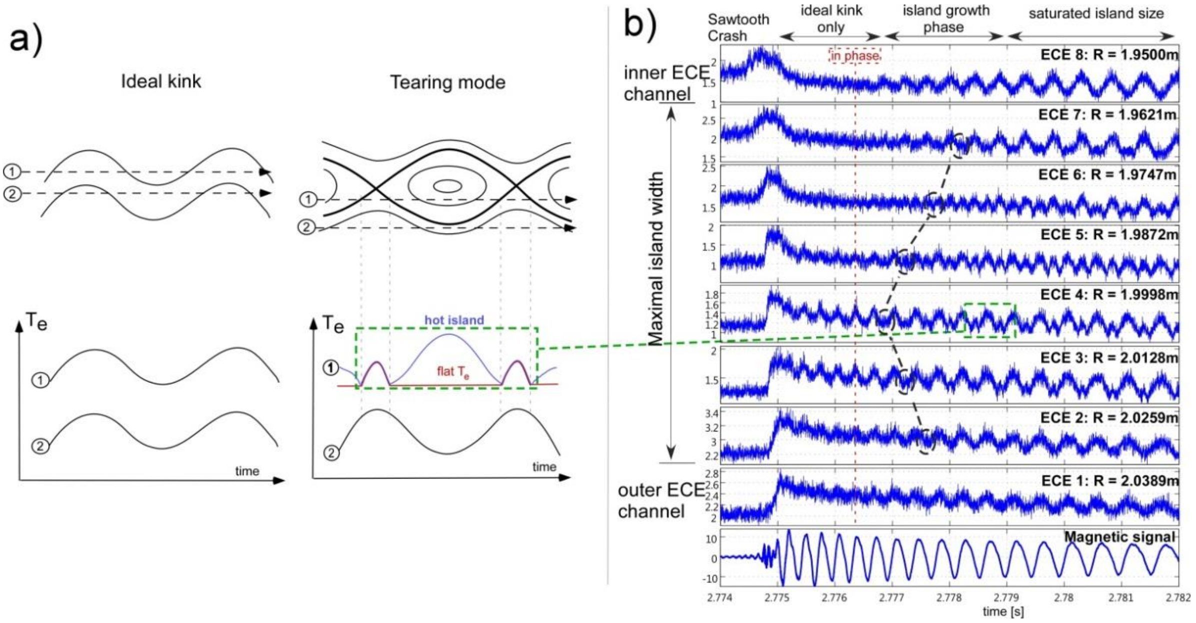

Figure 1. Identification of the island size from local ECE measurements. a) Schematic representation of the temperature perturbation for the ideal kink case, island with flat temperature inside and hot island case. b) Direct identification of the transition from ideal kink mode into hot island in different ECE channels for discharge 27257 at t=2.77s. The bottom time trace is the magnetic signal.

It is clearly shown by this example that a dominantly ideal mode, with the same helicity as the tearing mode, is generated by the crash at the resonant surface and produces a strong magnetic signal. The mode converts into a tearing mode only on a longer time scale. It is possible to summarize the information about the total amplitude of the mode (ideal+tearing) from magnetic signals and the evolution of the island width from ECE. The total mode amplitude, $A_{(2,1)}$, is extracted from the magnetic measurements as $A_{(2,1)} \sim \sqrt{b_{(2,1)}}$, where $b_{(2,1)}$ is the measured perturbation amplitude at the (2,1) frequency (figure 1b, the bottom time trace). The results are shown in figure 2 for tearing mode seeding in different plasmas.

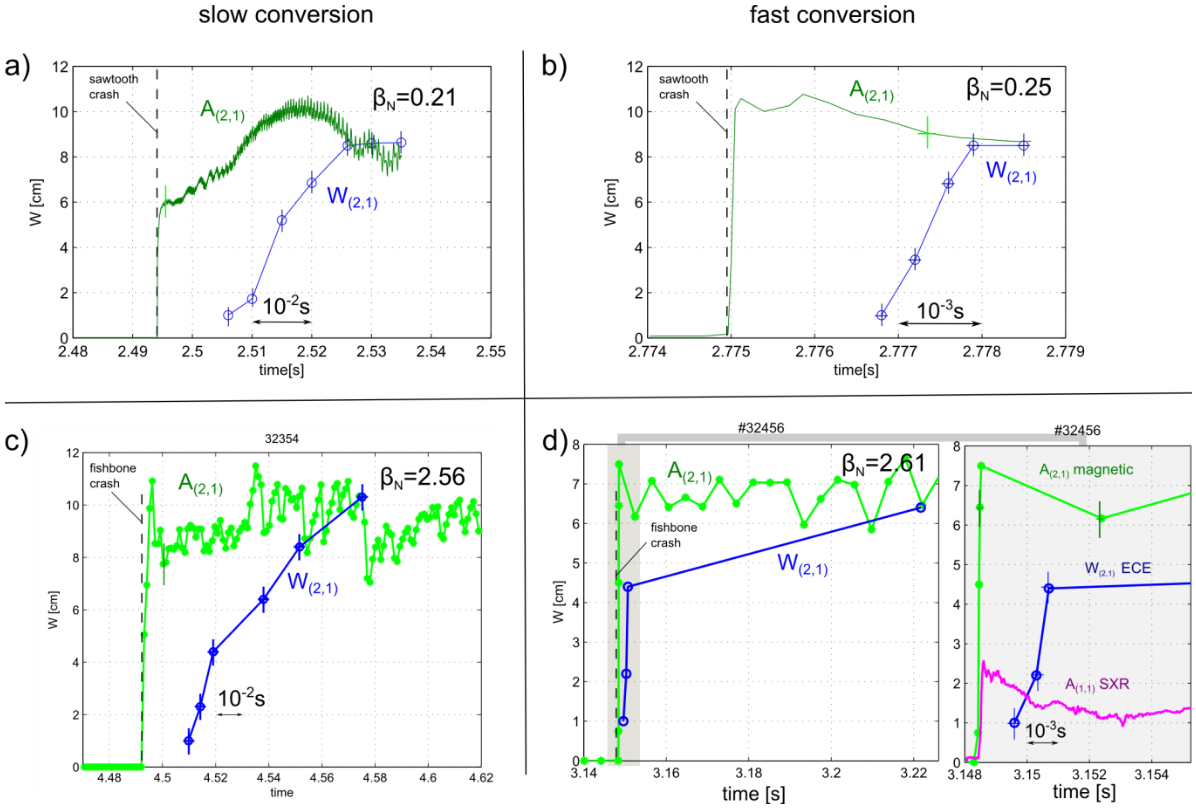

Figure 2. Comparison of the perturbation amplitude of the (2,1) mode from magnetic signals, $A_{(2,1)}$, and (2,1) island width , $W_{(2,1)}$, from ECE measurements for four different cases: a) #27257, t=2.5s, slow conversion in L-mode low β_N plasmas; b) #27257, t=2.77s, the same case as in figure 1b, fast conversion in L-mode low β_N plasmas; c) #32354, t=4.49s, slow conversion in H-mode high β_N plasmas; d) #32456, t=3.149s, fast conversion in H-mode high β_N plasmas; The mode amplitude from the magnetic signal is scaled to fit the island size from ECE at a later time point, when the saturated island size is reached. The error bars depend on the measurements resolution. The post-crash amplitude of (1,1) perturbation, $A_{(1,1)}SXR$, is extracted from SXR tomography and shown for case d.

Our analysis of the MHD information from SXR, magnetics and ECE during the seeding process shows that the simplified picture, which assumes the formation of a big island during the crash, has to be revised. A large tearing mode requires time for its formation and never appears during or immediately after the crash. The dominant mode after the crash is an ideal kink mode. The analysis presented is able to detect islands down to a size of 1.5-2cm and would unavoidably detect a big island formation during the crash if this would be the case. It is important to emphasise that no conclusions regarding the existence of a smaller island directly after the crash can be given. As mentioned before, small islands have no influence on the temperature profile. In that respect, the low level of our detection capability is set by the physical effect of the island on the temperature profile, and not be the diagnostic resolution. The main conclusions from our studies of the seeding process are the following:

1. An internal crash (sawtooth/fishbone) creates a kink mode at the resonant surface, where the island will be formed. This kink has the same helicity as the subsequent island. In our cases, this was always a (2,1) mode. The kink is coupled to the internal post-crash activity. It is also coupled to an external kink component, which makes it visible for the magnetic measurements.
2. This (2,1) kink mode converts into a (2,1) tearing on a much longer timescale $(10^{-3} - 10^{-2}s)$ compared to the crash time $(10^{-5} - 10^{-4}s)$. At the same time, this conversion is much faster compared to the single-fluid Sweet-Parker reconnection time (1-0.5s). Thus, two-fluid effects are important.
3. The island formation time does not strongly depend on the plasma conditions. The time scale ranges are similar for low β_N (L-mode) and high β_N (H-mode) cases. Thus, the forced reconnection during the seeding process is similar for classical and neo-classical tearing modes. The driving forces due to the profile drives are only important for the further island evolution. In low-beta plasmas where the neclassical drive is not important, the seeded tearing modes decay, indicating a negative Δ' in the Rutherford equation [5].
4. The perturbation amplitude required to seed tearing modes at high β_N is much lower compared to the low β_N case. (This was to be expected as high beta plasmas are more unstable with respect to both ideal modes and NTMs.)
5. For otherwise similar plasma conditions, a higher perturbation amplitude leads to a faster conversion time.

Acknowledgement

This work was partially funded by the Max-Planck/Princeton Center for Plasma Physics. 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 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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