Effect of ideal kink instabilities on particle redistribution

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1. Introduction

In tokamaks with an ITER like wall the W can migrate to the plasma core. Impurity accumulation in the plasma core can degrade the performance due radiation losses and dilution of the fuel. Experimental work devoted to study this problem shows that MHD activity can prevent the accumulation of impurities. Experiments at JET [1], where ICRH was used to control the *q* profile and maintain sawtooth activity lead to the conclusion that there is a correlation between central impurity peaking and the absence of sawtooth activity. In ASDEX U, it was shown that when central ECRH is employed to sustain a saturated (1,1) mode activity, tungsten accumulation is prevented[2].

Here, we use a numerical code that follows the exact trajectories to study the effect of a (1,1) kink mode on the dynamics of Ni and W ions [3]. The magnetic field employed to calculate the trajectories is the sum of the equilibrium plus the perturbation produced by the (1,1) mode.

2. Ni dynamics: chaos of magnetic field line.

Wesson et al. [4] performed an experiment at JET to study the transport in the sawtooth collapse. Ni introduced by laser ablation diffused inwards and accumulated around the inversion radius before the next sawtooth collapse. At the sawtooth collapse the Ni penetrated to the plasma core in a time of the order of 50 μs, approximately the same as for the electron temperature flattening. The fast penetration of the Ni was used by Wesson et al [4] to discard an ergodic interpretation of the transport during a sawtooth crash. We used parameters similar to those employed at JET [4]. A simulation with 10□Ni ions followed through all the sawtooth cycle was performed. In this case the Ni ions were placed in a ring with a radius of 0.5 m, a thickness of 0.1 m and centered at the plasma center. The Ni density around z=0 is plotted in fig 1. The particles are not affected if the electric field of the (1,1) mode is set to zero (fig. 1 a). When the electric field is included and only modes with the same helicity are present ("integrable" case) (fig. 1 (b) and fig. 1 (c)) the diffusion of the Ni ions to the plasma core is increased but no appreciable changes are found in the time scale of the crash (~50 μs).

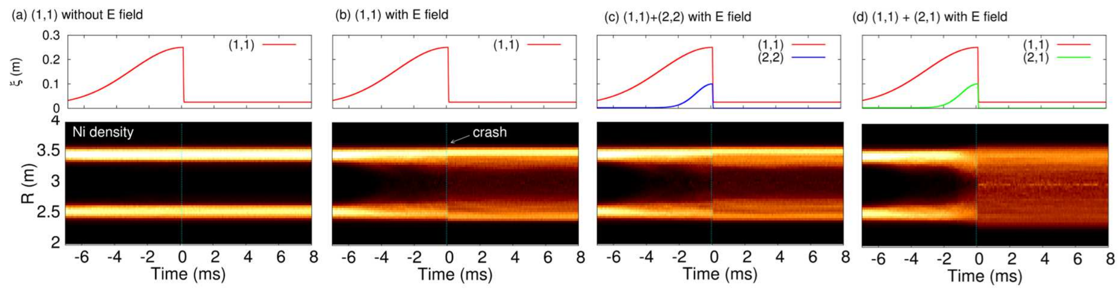


Figure 1: Evolution of Ni ions during one sawtooth collapse for different conditions.

However, when a (2,1) mode is also included a dramatic change occurs at the sawtooth collapse. A sudden diffusion of the Ni ions can be appreciated in fig. 1 (d). This is due to the presence of chaotic magnetic field lines and the electric field produced by the rotation of the mode [5]. We also made simulations for the other species, namely the electrons and D ions, around the crash. For the electrons we followed a collection of 10^5 particles uniformly distributed and for the D ions we set a parabolic initial distribution with 10^7 particles. The initial velocity is isotropically distributed and the initial energy is set to 8 keV for all the particles. In fig. 2 we show the temporal evolution of the central electron temperature, the central ion plasma density and the central nickel density. As can be appreciated, the electron temperature drops in the same time scale associated to the Ni penetration when a stochastic magnetic field is employed. The ion density also evolves in the same time scale.

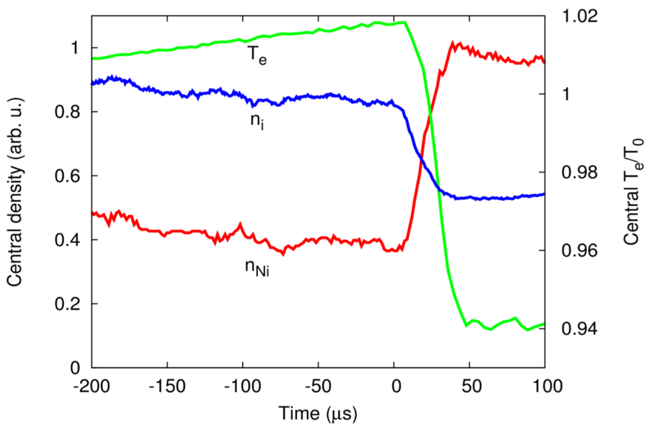


Figure 2: Temporal evolution of central electron temperature, central ion plasma density and central nickel density.

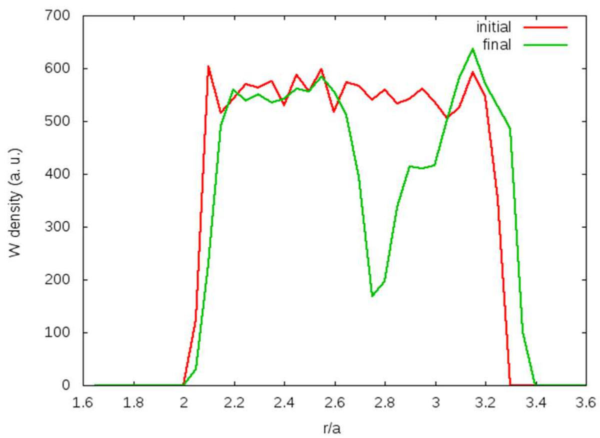
5. The tungsten experiment: saturated kink mode mitigating W accumulation

For W impurities, we studied the results of a series of discharges in ASDEX U with W plasma facing components. It has been reported in [2] that, in a typical H-mode discharge with central ECRH, a saturated (1,1) mode is present in between crashes. When the sawtooth crash occurs the W profile is flattened as it is expected. However, when a saturated kink (1,1) is present after the crash, the W profile becomes hollow before the next crash. Ref [4] discuss the interplay between the ECRH, the saturated kink and W accumulation. We will focus here on fig. 5c of that paper [2].

In this study we concentrate on the effect of a saturated kink on a uniform distribution of W ions. The kink is modeled as a (1,1) kink mode. The frequency of the mode is obtained from the experiment [2], and it is fixed at 10 kHz. We use an equilibrium with q=1 at r/a=0.4 (where a is the minor radius). This is larger than reported but not significant changes are expected and values close to the experimental ones will be explored in a future work.

The W ions are initially uniformly distributed in a toroid of minor radius 0.6 *a,* and centered at the major radius. A first numerical calculation was done setting the energy of the W ions to 2 keV and their initial velocity isotropically distributed. In this case the W density was not affected significantly by the kink. When the initial velocity of the W ions is such that their passing frequency is close to the frequency of the mode a change in the density profile can be appreciated. To simplify the problem the initial condition employed has all the particles with the same pitch and energy and uniformly distributed in a toroid of radius 0.6 *a*.

In fig. 3 a, we show the initial and final profiles of the W ions. The profile is obtained by averaging over the toroidal coordinate. The saturated (1,1) mode is active by 10 ms, and the mode amplitude was set to 7cm. In fig. 3b we show the 2D density distribution of Ni ions after 10ms. As in fig. 6, some asymmetries can be seen in the distribution do to the 1/R nature of the toroidal field.



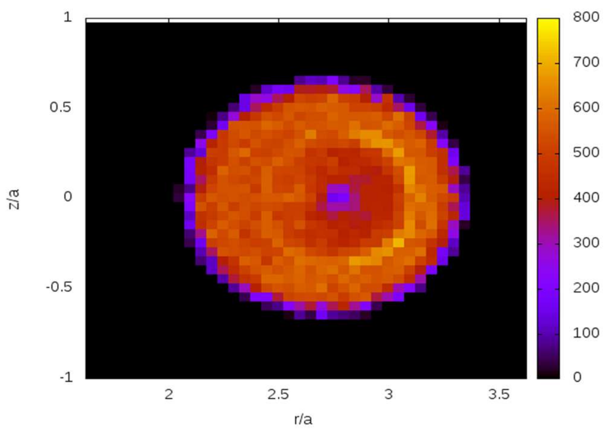


Figure 3: (a) Profiles of W density at z=0. Initial distribution in red and final distribution, after 10ms of a saturated kink, in green. (b) 2D W density distribution after 10ms of saturated kink.

When the initial energy is too far from the resonance energy the W ions are not expulsed from the plasma center and a similar situation occurs if we fix the ion energy and change the frequency of the mode. Using the same energy and pitch for all the W ions is justified because the thermal velocity of W ions (4.5 x 10^4 m/s) is smaller than the rotating velocity of the plasma (1.03 x 10^5 m/s). Since the thermal velocity of D ions (4.37 x 10^5 m/s) is much greater than the rotating velocity of the plasma a similar resonance condition is not possible.

5 . Summary and future work.

When an integrable model is used for the magnetic field lines in the sawtooth collapse most of the Ni ions remain close to the q=1 surface. Conversely, when modes of different helicities and sufficiently large amplitudes are included to produce stochasticity close to the q=1 surface, the Ni ions can reach the core. Simulations show that the electron temperature and the plasma density evolve in the same time scale. Do to their mass difference the electron motion is governed by the magnetic field while the ion motion is affected more by the electric force and the E x B drift. Due to Faraday's law both fields act on the same time scale and are controlled by the electrons.

When the initial velocity is isotropic (zero average velocity) the saturated mode does not affect the W distribution. When the initial velocity of the W ions is close to the rotation velocity of the mode the W ions are expelled from the plasma core. In a future work a resistive kink will be used to model the Ni experiment. The associated island of the resistive kink can change the dynamics of Ni ions at q=1. Our preliminary results show that a realistic velocity distribution is necessary to obtain an accurate description of W dynamics.

Acknowledgments

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References

[1] Nave M.F.F et al, *Nucl. Fusion* **43** (2003) 1204-1213.
[2] Sertoli M. et al, *Nucl. Fusion* **55** (2015) 113029.
[3] Farengo R. et al, *Phys. Plasmas* **21**, 082512 (2014) .
[4] Wesson J. A et al, *Phys. Rev. Lett.*, 79:5028-5021, Dec 1997.
[5] Firpo M-C. et al, *Plasma. Phys. Control. Fusion* **59** (2017) 034005.