Simulation of ELMs in JET

S.J.P. Pamela[1], G.T.A. Huysmans[1], M.N.A. Beurskens[2], G. Arnoux[2],
A. Kirk[2], T. Eich[3], S. Devaux[3], S. Benkadda[4], L. Frassinetti[5] and JET EFDA contributors[*]

[1] *Association EURATOM-CEA, F-13108 Saint-Paul-lez-Durance, France.*
[2] *JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK.*
[3] *Max-Planck Institut fur Plasmaphysik, EURATOM Association, Garching, Germany.*
[4] *PIIM,CNRS - Univ.Provence, Centre St.Jérôme, Case321, 13397 Marseille Cedex20,France.*
[5] *Association EURATOM-VR, Royal Institute of Technology KTH, Stockholm, Sweden.*
[*] *See the Appendix of F. Romanelli et al., Proc. 22nd Int. FEC Geneva, IAEA (2008)*

1. Introduction

The future tokamak ITER is expected to run routinely in type-I ELMy H-mode confinement regime. The ELMs are necessary in order to rid the plasma of its impurities. However, it is expected that ELMs in ITER could release up to 20MJ, which is not bearable for the presently designed tungsten divertor [1,2]. Hence, some techniques have been developed to control ELMs (RMPs, pellets, kicks), but there is at present poor understanding of how these tools provoke or mitigate the ELMs. In fact, the ELMs themselves are not fully understood. The linear stability of ELMs has been well established in the last two decades [3], but the understanding of the nonlinear properties of ELMs still requires some effort.

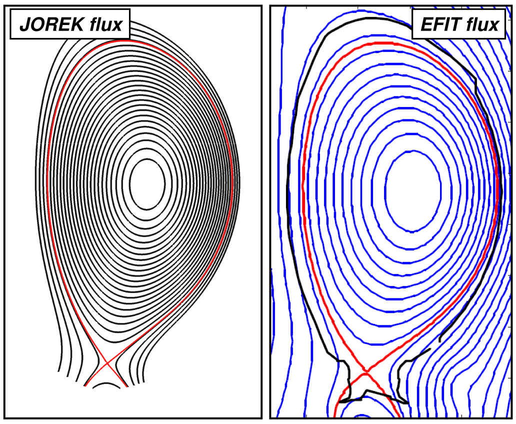
The nonlinear simulation of ELMs is already in reasonable qualitative agreement with experimental observation [4,5]. In particular, simulations show a filamentation of the plasma edge into the Scrape-Off Layer, and large amounts of energy arriving on the divertor in the form of small heat-flux structures near the strike point. In sight of using the simulations to obtain some predictions of ELMs in ITER, the MHD code JOREK [4,5] should first undergo a quantitative validation against experimental data. This paper aims at a first step towards this validation, by presenting simulations of ELMs for a given plasma pulse from JET. The long term goal being to extend the simulations to multiple shots analysis, both for JET and for other tokamaks.

2. From Experimental Data to Numerical Simulations

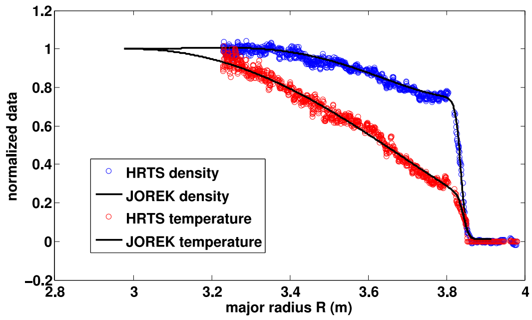
The JET pulse #73569 has been chosen as a first simulation basis because it is a type-I ELMy H-mode with good HRTS profiles (High-Resolution Thomson Scattering diagnostic [6]), and a good view of the Infra-Red camera on the outer divertor. For this pulse, the field was 2T, the density $n_e = 6.10^{19} m^{-3}$ at the magnetic axis and the temperature $T_e = 3keV$. In order to produce a simulation, one needs to solve the Grad-Shafranov equilibrium, so that three ingredients are needed: the pressure profile p, the current profile j, and the poloidal flux ψ on a closed boundary Ω around the plasma.

The pressure profile is obtained from HRTS, which gives the electron density and temperature. Since JOREK solves the two-fluid MHD equations with separate variables ρ, T_i and T_e, the ion temperature profile is assumed to be identical to the electron temperature profile. The HRTS profiles are all taken before the ELMs (80-99% of the ELM-period), and a fit is done over the profiles. This way, using multiple profiles ensures a good resolution in the pedestal, so that the pressure profile is reliable (see Fig.1b).

The global current profile is obtained from EFIT, with an additional bootstrap current calculated from HELENA, according to the pressure profile, following the Sauter method [7].



(a)



(b)

Figure 1: *a) compares the initial EFIT flux (right) with the JOREK equilibrium reconstruction (left). b) shows the density and temperature profiles from HRTS (circles) together with the profiles used in simulations (lines)*

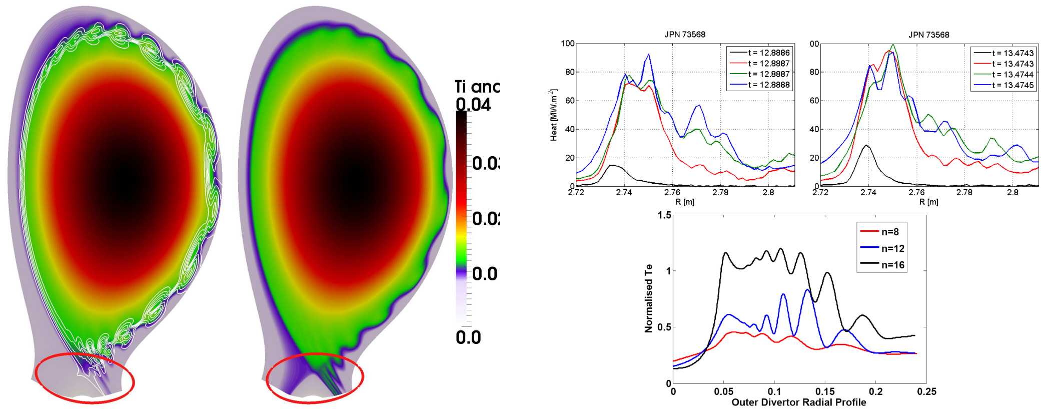
The flux ψ at the boundary is also taken from the EFIT reconstruction. Since there is yet no resistive wall boundary conditions in JOREK, this contour has been taken just outside the vacuum vessel wall, and close to the divertor. The resulting reconstruction of ψ is shown in Fig.1a next to the EFIT flux. Also shown in Fig.1b are the temperature and density profiles used in simulations, compared to the HRTS profiles. The reconstruction of equilibrium with JOREK is in reasonable agreement with the EFIT reconstruction and the HRTS diagnostic.

3. JET Simulations

The resulting JET equilibrium has a pressure profile very close to ideal ballooning stability limit, which is highly unstable with respect to resistive ballooning, so that the perturbation of toroidal mode numbers results in a pedestal collapse, which may be compared to an ELM. The simulations have been run for different mode numbers, varying the main plasma parameters (resistivity η, parallel thermal conductivity $\kappa_{||}$ etc...).

One first observes the distinction between T_i and T_e during the ballooning crash. The theoretical $\kappa_{||}$ for each species (implemented in the code) depends on the corresponding temperature and has a coefficient which depends on the species' mass, resulting in a faster conductivity for T_e. Namely $\frac{\kappa_{e,||}}{\kappa_{i,||}} \approx 40$. As a consequence, and as can be seen on Fig.2a, T_e is rapidly conducted to the divertor, where distinct stripes are observed near the strike point. This is not the case for T_i, which is convected into filaments like the density. T_e filaments are also observed, but less distinctively than T_i filaments.

These T_e stripes are important, because they are responsible for most of the energy arriving on the divertor. Similar stripes are observed in JET during ELMs. The common procedure to determine the dominant mode number of an ELM in JET relies partly on the signals from Mirnov Coils, but also on the number of stripes observed on the outer divertor tile. Simulations clearly show a relation between the mode number and the number of stripes, as seen from Fig.2b, although the number of divertor stripes is generally inferior to the mode number itself. This shows how simulations could be used in return to reinforce the interpretation of IR diagnostics in order to determine the mode number of an ELM in JET.



(a) (b)

Figure 2: *a) shows T_i filaments together with density contours (white) on the left, and T_e on the right. The red circles show the stripes of T_e on the divertor, which are less distinct for T_i. b) shows profiles of T_e on the divertor for different mode numbers. Different numbers of stripes are also observed for different ELMs in pulse 73569 (above).*

As another example of comparisons between simulations and experiments, Fig.3 shows the HRTS profiles before and after ELMs from shot 73569, and the profiles taken from simulation at the same position as HRTS, before and after a crash. The main interest of such a comparison is to look at the convective/conductive ELM losses, and the ELM-affected area, which gives the penetration of the ELM into the pedestal. As seen from Fig.3, the simulations are in reasonable agreement with experiments.

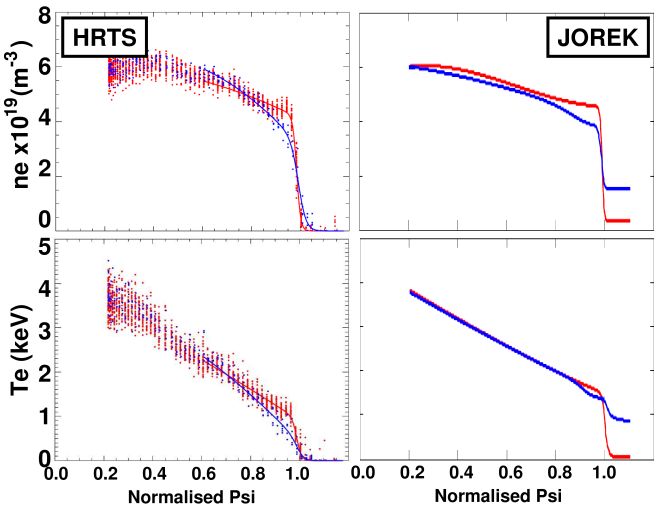


Figure 3: *The density and temperature profiles from the HRTS (left) compared to simulation results (right) for shot # 73569.*

4. Collisionality Scan

In the multi-machine collisionality scan done by Loarte [1], the ELMs size is shown to increase with decreasing collisionality. This result is most important for ITER, which should run at even lower collisionality than JET. It is therefore of interest to produce a collisionality scan with simulations, in order to check if simulated ELMs can reproduce the experimental scaling. Furthermore, such a scan could help understand why the ELMs size is increasing at lower ν^*.

To get such a scan with simulations, density and temperatures are varied together such that the total pressure profile does not change. This way, the ideal MHD stability properties of the plasma remain identical, but collisionality changes. The principal parameters that are affected by this scan are the resistivity η and the parallel thermal conductivity $\kappa_{\|}$, which vary as $\eta \sim \nu^{*\frac{1}{6}}$ and $\kappa_{\|} \sim \nu^{*-1}$. It is not yet possible to use the proper experimental values for η and $\kappa_{\|}$, due to limited numerical resolution, but recent progress in parallel computing, as with the HPC-FF, enables simulations with η and $\kappa_{\|}$ values closer and closer to experimental conditions.

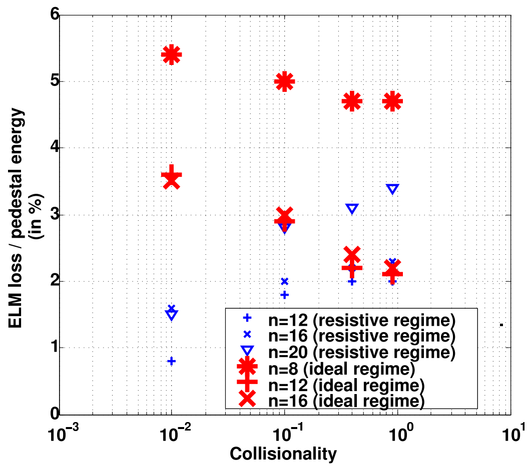


Figure 4: *A collisionality scan done for two different regimes. A resistive regime (blue) and a more ideal regime (red) with lower resistivity. The different signs stand for different mode numbers.*

A first scan has been done with collisionality varying from 1.4×10^{-2} to 0.9, with a resistivity varying from 5.10^{-8} to 10^{-7}. The result is that the ELMs size is decreasing with decreasing collisionality, which is mainly due to the fact the resistivity has a strong influence on the growth rates of the ballooning modes. Hence, in this resistive regime, the resistivity dominates the collisionality scan, and the result is opposite to that expected.

A second collisionality scan was then run with lower (a factor 10) resistivity (which comes a factor 20 from the theoretical Spitzer resistivity). However, at lower resistivity, the ballooning modes are stable to the pressure profile, so the pedestal width was reduced from 2.8cm to 1.5cm. The results of this second scan are closer to experiments, and the ELMs size is seen to increase with decreasing collisionality. Furthermore, the growth rates show that resistivity does not have such a strong effect anymore, so that the parameter of merit becomes $\kappa_{||}$, which evacuates more temperature from the pedestal at low collisionality. Hence, as collisionality decreases, $\Delta T_{ELM}/T_{ped}$ increases while $\Delta\rho_{ELM}/\rho_{ped}$ remains almost constant.

5. Conclusions

Simulations of ELMs were obtained for the JET pulse # 73569. The transition from experimental data to numerical simulations was presented, and basic features of ELMs simulations were analyzed. The stripes observed on the targets in simulations are similar to those seen in experiments. As an example of comparisons with experiments stood the fact that the number of stripes on the divertor increases with increasing ballooning mode number.

The second part of this paper presented a collisionality scan for ELMs for the base case of pulse 73569. At relatively high resistivity ($\eta \sim 10^{-8} - 10^{-7}$) the ELMs size decreases with decreasing collisionality, which is opposite to what is observed in experiments, at least for standard type-I ELMs. At lower resistivity ($\eta \sim 10^{-9} - 10^{-8}$), the regime is more ideal, so that the ballooning modes are really destabilized by the pressure gradient, not by resistivity. In this case, the ELMs size does increase with decreasing collisionality. It should also be noted that a resistive regime is not necessarily an artifact from simulations, and that the ELMs simulated for high resistivity could correspond to ELMs other that type-I.

Acknowledgments

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