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Numerical investigation of Impurity Seeded Radiation Enhancement in the Divertor region with Magnetic Perturbations in ASDEX Upgrade

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Introduction

Currently one of the most promising concepts for future fusion devices, such as ITER and DEMO, is the divertor tokamak, in which power and particles leaving the confined region are transported to the divertor targets. The power flux to the targets can locally exceed the tolerable target heat flux limit and it is therefore required that a large fraction of the power is dissipated before reaching the target. It has been shown in various experiments that this goal can be achieved by seeding low to medium Z impurities [2]. In [3] an empirical scaling formula for the power radiated by the nitrogen impurities has been found that depends linearly on the power decay length λ_q [1]. One way to increase λ_q could be the application of Magnetic Perturbations (MPs). MP coils were introduced at ASDEX Upgrade (AUG) and a number of other tokamaks to study their mitigating effect on Edge Localized Modes (ELMs) [4], intermittent high power flux bursts which can pose a serious risk for the targets. MPs can change the magnetic topology strongly and lead to the formation of stochastic regions inside the separatrix and finger-like deformations of the separatrix, so called lobes. To study numerically how the application of MPs affects the impurity radiation in the SOL and divertor, the edge code EMC3-Eirene [5] was employed to simulate an AUG L-mode deuterium bulk plasma with and without MPs. Subsequently nitrogen seeding simulations were performed on these bulk plasmas and the impurity radiation distribution between the MP-on and off cases considered in detail.

EMC3-Eirene simulations and deuterium bulk plasma

EMC3-Eirene is a code package consisting of the plasma fluid code EMC3 and the kinetic neutral code Eirene. Both, the fluid as well as the neutral part, employ a Monte-Carlo scheme to solve the underlying equations. This approach allows that the grid used for the simulations does

*See <http://www.euro-fusionscipub.org/mst1>.

not have to be flux aligned, making it possible to simulate the transport in complex 3D field geometries, such as those occurring in magnetically perturbed plasmas. For the perturbation field a vacuum approach was assumed, i.e. the MP field was added linearly to the equilibrium field and no response of the plasma was taken into account, which could shield the MPs partially [7]. The discharge used to model the bulk plasma was the low-density AUG L-mode 30639. In this discharge rigidly rotated MPs with a toroidal mode number of $n = 2$ were switched on between $t = 2.0s$ and $t = 4.4s$. For the MP-off and MP-on case the time points $t = 1.95s$ and $t = 4.3s$ were chosen, respectively. To create the simulation grid, which stores the information about the magnetic configuration, the equilibrium from the 2D equilibrium code CLISTE [6] for each time point was used. Due to the $n=2$ symmetry the grid for the MP-on case covered 180° . In the radial direction the grids ranged from $\rho_p \equiv \sqrt{\psi_N} \approx 0.89$ to $\rho_p \approx 1.06$, with ψ_N being the normalized poloidal flux. The input power in the simulations was given by $P_{net} = P_{tot} - P_{rad}$, where P_{tot} is the total heating power of the discharge at the respective time point and P_{rad} is the radiated power, and for the density the averaged separatrix density n_{sep} served as a boundary condition. The corresponding values used were $P_{net} = 0.84MW$, $n_{sep} = 0.7 \cdot 10^{19}m^{-3}$ for the MP-off case and $P_{net} = 0.72MW$, $n_{sep} = 0.6 \cdot 10^{19}m^{-3}$ for the MP-on case. For both cases the same constant particle and heat cross-field diffusion coefficients $D_\perp = 0.15m^2s^{-1}$ and $\chi_{e,\perp} = \chi_{i,\perp} = 0.9m^2s^{-1}$ were assumed. The nitrogen impurity simulations were carried out in a semi self-consistent way: An impurity tracing simulation was performed, in which a simplified set of fluid equations consisting of particle and momentum conservation equations, was solved. The impurity radiation is then taken into account in the plasma energy equation. Since it is not yet possible to include a fully realistic seeding impurity source in the simulations, it was assumed that nitrogen is sputtered by the main ions with a spatially constant sputtering yield $Y = -\Gamma_z/\Gamma_D$, where Γ_z is the impurity flux and Γ_D is the target deuterium flux. The power radiated by the impurities was constrained to $P_Z^{rad} = 0.2P_{net}$, which is achieved by the code by adapting Y iteratively. From the impurity radiation distribution one can draw conclusions about the effectiveness of the radiation in the divertor region.

Results

In Fig.1a the outer midplane temperature (top) and density profiles (bottom) for the bulk plasmas obtained from the simulation without (left) and with MPs (right) in dependence of ρ_p are shown. The simulation results are both compared to the experimental data from core and edge Thomson scattering. Here the edge Thomson scattering profiles were shifted by +1cm and those of the core by -4cm, a procedure always carried out in the present AUG campaign in order to align the data with the equilibrium. The simulation profiles for both cases agree

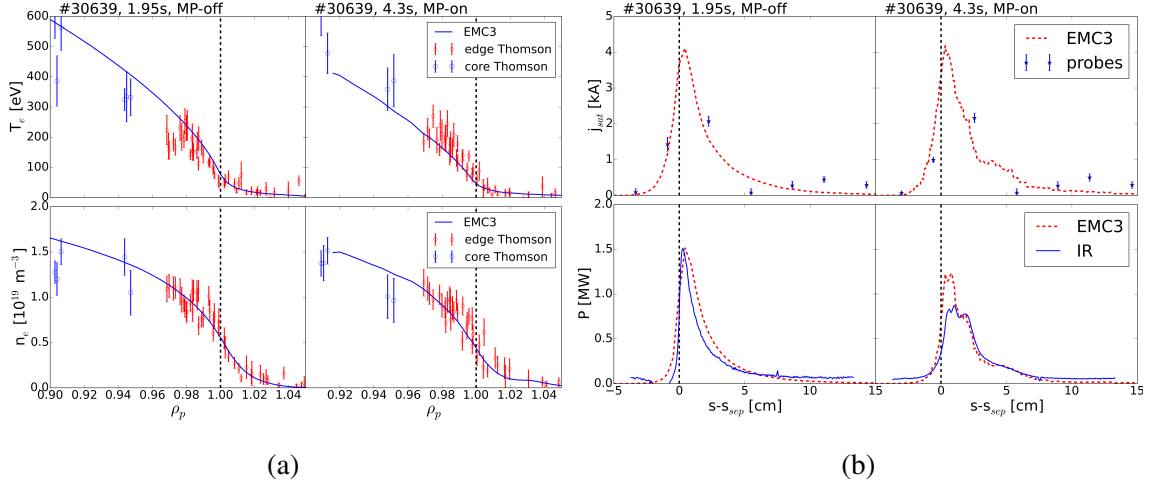


Figure 1: a) Temperature and density outer midplane profiles at $\phi = 11.25^\circ$ for the case without MPs (left) and with MPs (right). b) Target saturation current j_{sat} at $\phi = 168.8^\circ$ and power deposition profile at $\phi = 11.25^\circ$ for the case without MPs (left) and with MPs (right).

roughly within the errorbars with the Thomson scattering data, however, the temperature for the MP-on case is reduced by about 30% compared to the MP-off case in the simulations. In Fig.1b top the EMC3 outer target particle flux is compared to the saturation ion current density measured by the Langmuir probes at $\phi \approx 169^\circ$. The EMC3 outer target power flux is shown in the bottom row of Fig.1b together with the experimental power flux obtained from the 2D IR diagnostics at $\phi \approx 11.25^\circ$. For the MP-off case there is good agreement between the simulation results for the target heatflux and the experimental measurements, while for the MP-on case the EMC3 heat flux is higher near the separatrix than the experimentally observed one. It should be noted, however, that due to inaccuracies in the equilibrium reconstruction the IR profile was shifted along the poloidal direction by -2.3cm, such that a good agreement with the simulation results was achieved. For the case with MPs a modulation of the heat flux can be seen in the power deposition profiles of the simulation and the IR measurements. This footprint pattern on the target is a consequence of the magnetic lobes, and it has already been shown previously that EMC3-Eirene is able to reproduce these patterns [8].

In Fig.2 poloidal cross-sections of the impurity radiation without (left) and with MPs (right) are shown. For the MP-off case 48% of the total impurity radiation are radiated in the core, 47% in the SOL and 5% in the Private Flux Region (PFR). For the MP-on case 35% are radiated in the core, 58% in the SOL and 7% in the PFR. With other words, for the considered scenario and parameters, the effectiveness of the radiation in the SOL increases with MPs in the simulations which leads to a reduction of the core impurity radiation of about 25%.

Summary, Outlook

Deuterium bulk plasmas for a low density L-mode with and without MPs were simulated, assuming the vacuum approach. With the bulk plasmas, impurity simulations were carried out in a semi self-consistent way and the radiation distribution was investigated. For the case with MPs the radiation in the core was about 25% lower than for the case without MPs, showing that the effective change in transport associated with MPs could indeed enhance the impurity radiation in the divertor region. In the future L- and H-mode experiments with impurity seeding and MPs will be conducted at AUG and analyzed

in detail with the help of EMC3-Eirene. Furthermore it is foreseen to develop a more realistic impurity model, containing point sources and impurity recycling. Moreover, screening currents will be included in the simulation to mimic the plasma response, which may be the cause for the reduced temperature and density found in the outer midplane profile for the MP case.

Acknowledgment

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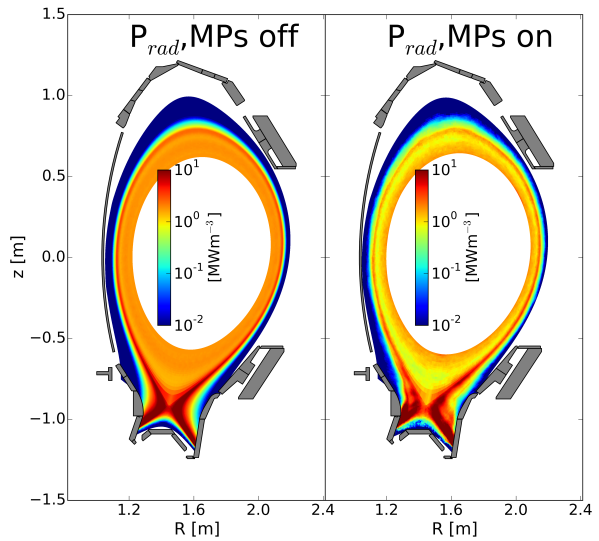


Figure 2: Nitrogen impurity radiation distribution for the case without MPs (left) and with MPs (right).