EMC3-Eirene simulations of the impact of Magnetic Perturbations on the neutral particle recycling in ASDEX Upgrade

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1 Introduction

Magnetic Perturbations (MPs) are applied at ASDEX Upgrade (AUG) [1] and many other divertor Tokamaks in the world [2] to mitigate Edge Localized Modes (ELMs), i.e. quasi-periodic expulsions of particles and energy that harm the surrounding plasma facing components (PFCs). The non-axisymmetric MP fields strongly modify the magnetic structure of the plasma edge and lead to the formation of so-called lobes, helical structures of enhanced particle and power fluxes. While we reported recently on simulations with the Edge Monte Carlo 3D-Eirene (EMC3-Eirene) code package aiming at describing the experimentally observed power deposition pattern (‘strike line splitting’) [3], here we present a more quantitative analysis of the simulations focusing in particular on the impact of the MPs on the neutral particle recycling. The kinetics of neutral particles, although not affected directly by the MP fields, depend very sensitively on the local plasma parameters in the scrape-off layer (SOL) in particular on the electron temperature. Given that the total recycling flux $\Phi_{div} = \int \vec{j}_{sat} d\vec{A}$ is significantly larger than typical gas-puff rates and several orders of magnitude larger than typical neutral particle fluxes across the separatrix, even small changes in the recycling behavior can potentially have a large impact on the discharge.

As in our previous analysis the principal tool applied to study the deuterium bulk plasma and neutral particle transport is the EMC3-Eirene code package. For any of the technical details the reader is referred to [3, 4] as well as the references therein.

2 EMC3-Eirene simulations

As in [3] (Fig. 2) the magnetic equilibrium of discharge AUG 26081 at 4.9 s was used to construct two computational grids, the first one including the MP fields (in vacuum approach), the second one not. The grids used here, however, are radially extended further outwards up to the secondary separatrix so that now a smaller amount P_{ob} of the input power $P_{in} = 1.65$ MW

run	I_{MP} [kAt]	D [m^2/s]	χ [m^2/s]	$\overline{n}_{e,sep}$ [10^{19} m^{-3}]	Φ_{div} [kA/e]	$\Phi_{i,conf}$ [A/e]	$\Phi_{i,conf}/\Phi_{div}$ [%]	P_{ob}/P_{in} [%]
A_{ns}	0	0.35	2.5	<u>2.01</u>	10.96	422.0	3.85	16.73
A_{Φ}	0	0.35	2.5	2.14	<u>15.39</u>	515.6	3.35	19.73
A_{MP}	4.5	0.35	2.5	<u>2.01</u>	15.39	523.3	3.40	17.14
B_{ns}	0	0.17	1.25	<u>2.01</u>	8.80	396.0	4.50	4.98
B_{Φ}	0	0.17	1.25	2.25	<u>13.28</u>	418.3	3.15	6.05
B_{MP}	4.5	0.17	1.25	<u>2.01</u>	13.28	399.7	3.01	5.08

Table 1: Results from a series of 6 EMC3-Eirene runs with a net input power of $P_{in} = 1.65$ MW. The underlined numbers were kept constant during the iteration process. The same transport coefficients for electrons and ions are assumed.

(i.e. a factor of 2 less than in [3]) is leaving the computational domain through the outer radial simulation boundary (values given in Tab. 1). Two sets of transport coefficients referred to as A and B, where $D_e = D_i = D$ and $\chi_e = \chi_i = \chi$ of A (the ones assumed in [3]) are twice as large as those of B, were assumed. To each run with MPs we compare two non-MP runs, one with the same (average) density on the (nominal) separatrix $\overline{n}_{e,sep}$ and one with the same Φ_{div}. The three cases are labeled by 'MP', 'ns' and 'Φ', respectively. As shown in Tab. 1, it is found that the MPs increase the total recycling flux by 40% in case A and 50% in case B when keeping $n_{e,sep}$ constant. Keeping on the other hand Φ_{div} constant $\overline{n}_{e,sep}$ is reduced due to the action of the MPs, a phenomenon known as 'density pump-out' in the literature [2].

3 Discussion

In order to understand this effect it is useful to analyze the particle- and power deposition profiles to the high-field side (HFS) and low-field side (LFS) targets shown in the first two rows of Fig. 2. At this toroidal position the maximum LFS peak heat flux value in the 2D heat flux pattern shown in Fig. 1 is located. Due to the influence of the MPs the parallel transport has a component radial to the flux surfaces (in the vacuum approach) leading to an enhanced particle- and heat flux to far SOL regions ($s - s_{sp,HFS} \geq 70$ mm) and an average increase of the electron temperature and density there in a certain poloidal distance to the target surface. As this causes an increase of the ionization rate coefficient it is more difficult for the neutral particles to penetrate this region and to cross the separatrix. This is shown by the last row of Fig. 2, where the result of a series of 70 Eirene simulations per target and configuration of a neutral particle point source Φ_n moving along the target surface (and being started in a direction parallel to the divertor leg separatrix) is shown. For every of this simulations carried out on the previously computed plasma background the total ionization rate $\Phi_{i,conf} = \int_{conf} S_i dV$ in the confinement region (inside the nominal separatrix) corresponding to this source is calculated and normalized to the neutral source, $f_{i,conf} = \Phi_{i,conf}/\Phi_n$. In particular for regions further away from the separatrix $f_{i,ion}$ is significantly lower for the MP case (red and blue solid curves) compared to the non-Mp case at the same $n_{e,sep}$ (red and blue dashed kurves). $\Phi_{i,conf}$ is also computed for the actual source profile given by the ion flux in the simulation. As shown in Tab. 1 an enhanced ionization source $\Phi_{i,conf}$ is required to maintain $n_{e,sep}$ =const. when turning on the MPs. So Φ_{div} is enhanced due to two effects, the required higher $\Phi_{i,conf}$ and the lower probability for the neutrals to reach the confinement region.

The enhanced radial heat transport is also responsible for the reduction of the peak heat flux density by approximately 20% on the outer target (the maximum value varying in toroidal direction by less than 3%), which has a small but obviously beneficial consequence for the target material integrity. The effect is about the same for the cases A and B.

It is interesting to note that a transition to smaller type-III ELMs is commonly observed in AUG [5] at very high gas puff rates. One might speculate that the ELM mitigation by MPs is due to a similar transition induced by the enhanced recycling flux at lower gas-puff rates (or line integrated densities). Since the PFCs store a certain amount of gas on a time scale of more than 100 ms until they saturate this could also explain the hysteresis effect of the ELM mitigation occurring on a similar time scale after switching on and also after switching off the coils (cf. Fig. 1 in Ref. [3]). If the enhanced recycling was responsible for the ELM mitigation it would furthermore be less surprising that in AUG the threshold for ELM mitigation does not depend on the resonance conditions of the MPs [1].

At the moment it is not fully clear, why both 'density pump-out' and 'density pump-in' are

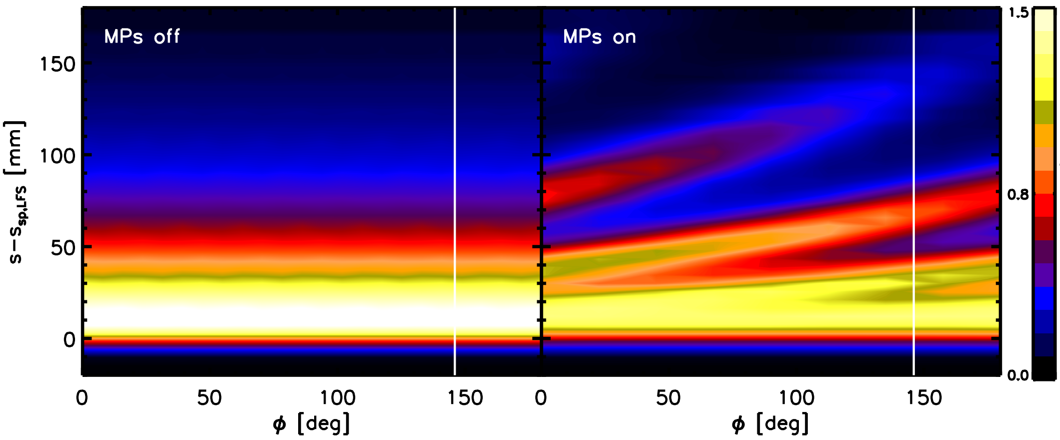

Figure 1: Power deposition profiles to the LFS target relative to the nominal strike point position $s_{sp,LFS}$ as a function of the toroidal angle ϕ for configuration B with (right) and without (left) MPs. The white vertical line indicates the toroidal position of the profiles shown in Fig. 2.

observed in AUG, but probably the MPs cause a re-distribution of the impurity radiation connected with a modification of the local n_e and T_e and therefore a modification of the neutral flux through the separatrix. Wolfrum et al. [6] pointed out the possible link between the detachment phenomenon occurring on the HFS in AUG and the density pump-in via particle transport parallel to the field lines on the HFS.

4 Summary and outlook

As a continuation of the study presented in [3] EMC3-Eirene simulations of the plasma and neutral particle transport on an extended grid were carried out for a net input power of $P_{in} = 1.65$ MW. Comparing simulations with and without MPs at a fixed (average) separatrix density of $\bar{n}_{e,sep} = 2.0 \times 10^{19}$ m^{-3} the total recycling flux at Φ_{div} was increased by 40% (case A) to 50% (case B) due to the action of the perturbation fields. The effect could be explained by the enhanced radial transport of particles and heat to the far SOL regions and the modified electron density and temperature there that are responsible for a reduced probability for the neutrals to reach the confinement region. A rather small but systematic reduction of the peak heat flux by about 20% was observed when the MPs are switched on.

For an improved quantitative analysis the inclusion of main chamber PFCs as well as the gas-puff valves and pumps is foreseen. In addition to that the study of the impurity transport and radiation will be instructive.

References

[1] Suttrop W. *et al.* 2011 *Phys. Rev. Lett.* **106** 225004

[2] Evans T. *et al.* 2008 *Nucl. Fusion* **48** 024002

[3] Lunt T. *et al.* 2012 *Nucl. Fus.* **52** 054013.

[4] Feng Y. *et al.* 2004 *Contrib. Plasma Phys.* **44**, No. 1–3, 57–69

[5] Suttrop W. *et al.* 1999 *Journ. Nucl. Mater.* **266–269** 118-123

[6] Wolfrum E. This conference.

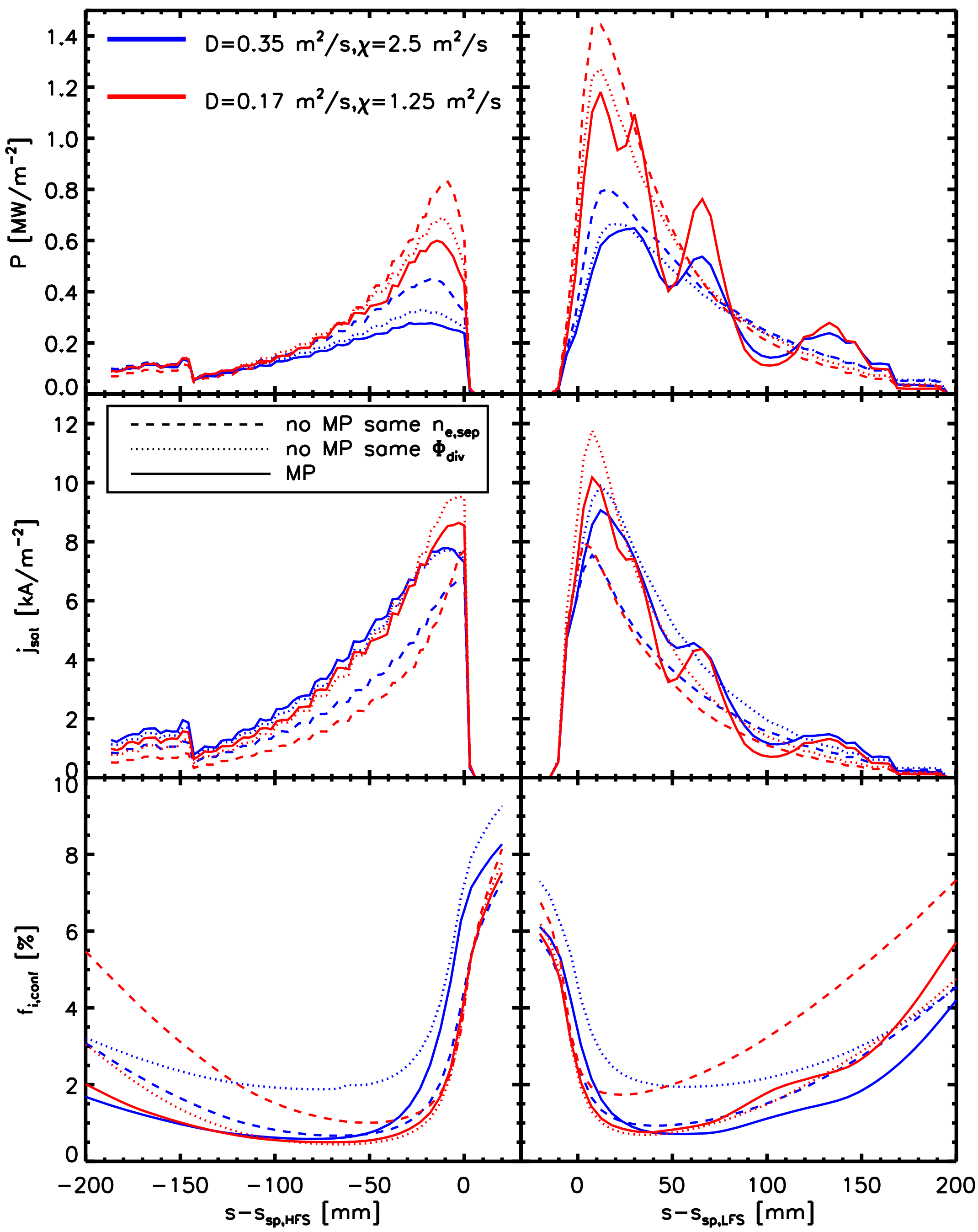

Figure 2: Power and particle deposition profiles to the LFS (right) and HFS (left) targets relative to the nominal strike point positions $s_{sp,LFS}$ and $s_{sp,HFS}$. The data is shown for $\Phi = 146^o$ the toroidal position of the peak power.