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B2-Eirene study of the effects of heating in a linear plasma device

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Introduction On the ITER divertor targets, extreme particle and energy fluxes of around 10^{24} $m^{-2}s^{-1}$ and 10 MWm^{-2} are expected. Therefore, relevant plasma surface interaction (PSI) studies in experiments, capable of controlled production of these extreme plasma conditions, are important. The linear plasma generator Pilot-PSI [1] is a pilot experiment to be succeeded by the larger device Magnum-PSI [2]. It consists of a cascaded arc that generates a magnetized hydrogen plasma with an axial magnetic field strength of up to 1.6 T over a distance of 55 cm. In contrast with tokamak experiments, the linear geometry makes it very accessible for diagnostics and in-situ surface analysis. The capability of realizing the ITER divertor conditions, extreme fluxes at low electron and ion temperatures of < 5 eV, with a beam diameter of around 2 cm makes Pilot-PSI unique.

The B2-Eirene code SOLPS4.2 [3], which is also used to model the ITER SOL and divertor plasma, has been adapted to simulate Pilot-PSI and Magnum-PSI, continuing the work presented in [2]. The two-dimensional multi-species fluid code B2 [4] describes the plasma. It is self-consistently coupled to the three-dimensional Monte Carlo neutral transport solver Eirene [5]. Figure 1 shows the cylindrically symmetric grid used for simulating Pilot-PSI.

An auxiliary heating is usually used in linear plasma generators to prevent the plasma beam from cooling down to the ambient gas temperature before reaching the target. Two heating scenarios are investigated in this paper: RF heating and ohmic heating. In Magnum-PSI, RF heating will be applied in the vicinity of plasma inlet. Closer to the target the beam will lose a considerable amount of its power, for instance due to molecule assisted recombination. In contrast to RF heating, ohmic heating (passing an electric current along the beam) can effectively heat the plasma over the whole length of the beam.

Implementation of heating scenarios RF heating close to the plasma source is taken into account by means of an increased T_e in the plasma beam at the inlet of the computational domain. The increase of input power follows from the increase in T_e at the inlet, where the

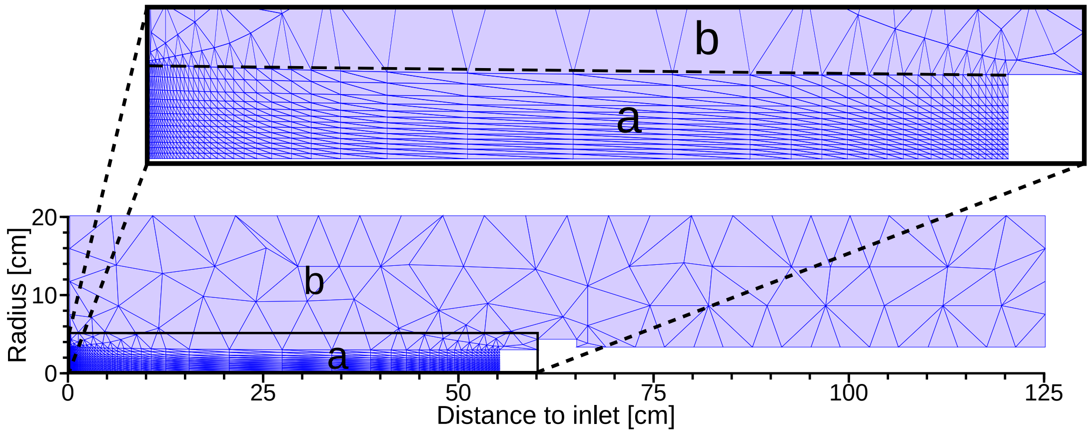

Figure 1: The cylindrically symmetric B2-Eirene grid for Pilot-PSI simulations. Below the complete grid is shown. The triangular grid of Eirene describes the whole computational domain, while the quadrangular grid of B2 is only defined in the region of the plasma, between the inlet at 0 cm and target at 55 cm. The dashed line in the enlarged view indicates the border of area *a*, where both the B2 and Eirene grids are defined, and *b*, which is only defined by Eirene.

contribution from parallel heat conduction can be neglected. Ohmic heating is implemented using a simple model for the electric conductivity. Instead of solving Poisson's equation with given electric potentials at the boundaries, we make use of the fact that the strong magnetic field gives rise to a large Hall parameter in most of the plasma beam: We assume the electric current to be strictly parallel to the magnetic field. Further, assuming that the target and a perpendicular plane at the plasma source are equipotential surfaces, the radial current density distribution $J(r)$ is fully determined by the parallel resistivity along each field line, i.e. integrated in the axial direction, $J(r) = -\Delta V / \int \sigma_{\shortparallel}(r,z)^{-1} dz$. The ohmic heating power density in each position is then $P(r,z) = \sigma_{\shortparallel}(r,z)^{-1} J^2(r)$. In the present implementation, we do not prescribe the bias voltage. Instead, we normalize the ohmic heating power density to a prescribed value of the total ohmic heating power. Due to the dependence $\sigma_{\shortparallel} \sim T_e^{3/2}$, the current density peaks in the center of the beam, while on each field line ohmic heating is highest where T_e is lowest.

The local resistivity and the corresponding integrals are calculated at every iteration of each time step, and therefore, self-consistently, the B2 code calculates which fraction of the total ohmic heating power will heat the plasma in which cell.

Results and Discussion To compare the two heating scenarios, three different simulations with a magnetic field of 0.8 T are performed, see Table 1. At the inlet the parallel velocity of v_p = 3 kms^{-1} and the particle density of $n = n_e = n_i = 4 \times 10^{20}$m^{-3} are prescribed. In the first

	(a)	(b)	(c)
Electron temperature (eV)	3	6	3
Ion temperature (eV)	1	1	1
Total input power (W)	288	504	488

Table 1: Boundary conditions at the inlet for the three different simulations. (a) is the reference simulation with typical source parameters for Pilot-PSI, (b) RF-heating, and (c) ohmic heating.

simulation, (a), the temperature of the plasma beam decreases to the ambient gas temperature before reaching the target. Hereto, we start with a relative low T_e of 3 eV at the inlet. To increase T_e in front of the target, the second simulation, (b), uses $T_e = 6$ eV at the inlet. Note that the particle flux at the inlet is constant in both cases, only the power flux is increased. The third simulation, (c), uses $T_e = 3$ eV at the inlet as in simulation (a), but in addition this case includes ohmic heating, such that the total power input is similar to case (b).

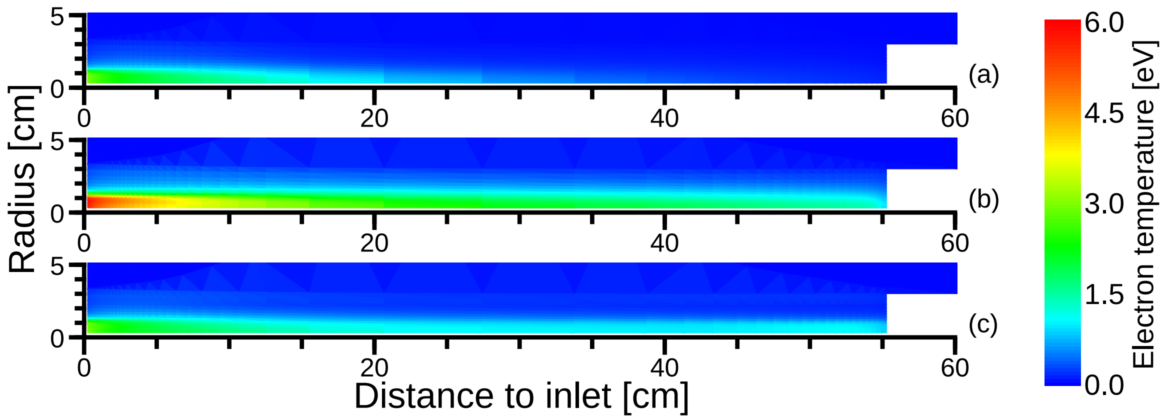

Figure 2: T_e-profile of the three simulations as given in Table 1. In (a), the reference simulation, T_e cools down to the ambient gas temperature before reaching the target. Additional heating is needed. In (b) and (c) the additional heating results in a higher T_e at the target of $\sim 1 - 1.5$ eV.

Figure 2 shows the T_e-profile for the three simulations. The first and most important observation is that without additional heating the beam cools to the ambient gas temperature well before reaching the target, while with additional heating, the beam reaches the target at around 1 to 1.5 eV. RF heating results in a slightly higher temperature at the target, compared to ohmic heating. However, there are two important positive results considering ohmic heating.

Firstly, T_e is approximately constant over a long distance of 35 cm (20 cm from the inlet to the target at 55 cm). Ohmic heating prevents the plasma from cooling down in this area. In the RF heating case T_e decreases over the whole domain from inlet to target. In simulations with total heating power halfway between the levels in case (a) and cases (b,c), we find that with ohmic heating the power reaches the target, whereas the beam does not reach the target if the same heating power is applied at the inlet.

Secondly, the radial profile of T_e in front of the target is generally different for both heating methods. Applying ohmic heating, the profile is flatter and radially decays sharper. Hence, the plasma conditions at the target will be similar over a larger surface area.

Conclusions We have implemented ohmic heating by means of an additional parallel current in B2-Eirene simulations of the Pilot-PSI and Magnum-PSI linear devices. A comparison of cases with additional RF heating and additional ohmic heating shows that both are feasible methods to prevent the plasma beam from loosing its power before reaching the target. In the RF heating case, T_e in front of the target is around 1.5 eV, whereas ohmic heating results in a lower value of around 1 eV. Thus, T_e in front of the target depends more sensitively on the RF power than on the ohmic power. Another difference between the two heating scenarios is the radial temperature profile. Ohmic heating tends to give a flatter profile, resulting in similar plasma conditions over a larger area of the target. Furthermore, in the axial direction ohmic heating yields a constant temperature over a large distance. In these two-dimensional simulations, there is no sign of narrowing of the current channel in the ohmic heating case.

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References

[1] G. J. van Rooij, *et. al.*, Appl. Phys. Lett. **90** 121501 (2007)

[2] M. Baeva, W. J. Goedheer, N. J. Lopes Cardozo, D. Reiter, J. Nucl. Materials, **363-365** (2007) 330-334

[3] V. Kotov, D. Reiter, A. S. Kukushkin, Report Jül-4257 (2007) http://www.eirene.de/kotov_solps42_report.pdf

[4] B. J. Braams, Ph.D Thesis, Rijksuniversitet Utrecht (1986)

[5] D. Reiter., M. Baelmans, P. Börner, Fus. Sc. Tech, **47** (2005) 172 and www.eirene.de