NEUTRAL GAS TRANSPORT AND PARTICLE RECYCLING IN THE W VII-AS STELLARATOR

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Introduction

In the W VII-AS stellarator plasma particle and power balance will be strongly affected by the distribution of the ion sources and charge exchange losses (similar as in W VII-A [1]), which are poorly known from experimental data. Furthermore, the control of the plasma density critically depends on the recycling processes in the plasma boundary region and at the limiters and walls.

Results for a model plasma

Before the W VII-AS operation was started, model plasmas were used to study the neutral gas transport behaviour with the 3D DEGAS code [2]. For a neutral source due to limiter recycling a simulation was performed to investigate to what extent the neutral density distribution is affected by the asymmetries of the flux surfaces and wall structures. The T_e, T_i and n_e profiles were taken from model calculations with the TEMPL plasma transport code ($T_e(0) = 1.9$ keV, $T_i(0) = 500$ eV, $n_e(0) = 2 \times 10^{13}$ cm^{-3} for an ECF input power of 720 kW) [3].

The typical cross section of the W VII-AS toroidal sector modelled for the neutral transport calculations is shown in Fig. 1. The limiter, the bulge for the NBI ports and the geometry of the magnetic surfaces (see Fig. 1) introduce asymmetries in the torus, which directly affect the neutral density distribution. Figure 2 shows the radial profiles of the neutral density at the poloidal angles $\theta = 0^o, 90^o, 180^o, 270^o$. As shown by the $\theta = 90^o$ profile, the neutral density has a maximum at the limiter face and drops by 2 orders of magnitude to the plasma centre. In the opposite direction with respect to the limiter, $\theta = 270^o$, the density is significantly lower, reaching a maximum of 1/3 of the limiter value. Along the horizontal chord, $\theta = 0^o$ and $\theta = 180^o$, the neutral density profiles are fairly symmetric up to a distance of ≈12 cm from the magnetic axis. The relatively high gradients of these profiles reflect the smaller plasma radius along this chord, associated with the asymmetry of the magnetic surfaces (see Fig. 1). Due to this asymmetry, the central neutral density is mainly determined by the neutrals penetrating the plasma in the horizontal direction. At $r > 15$ cm, well inside the scrape-off region, the profiles diverge from each other, reflecting the asymmetry introduced by the bulge. Within the bulge, the neutral density is fairly constant and amounts to roughly 1/4 of the limiter value.

In the following, results from neutral transport simulations are discussed for a typical deuterium discharge from the first months of W VII-AS operation.

Discharge parameters and Hα-monitoring system

The analysis is based on a ECF (70 GHz) heated deuterium discharge at the 2nd harmonic, with 1.25 T at the plasma centre and the external rotational transform ɫ being ≈ 0.53 at the plasma edge. Electron density and temperature profiles, measured by Thomson scattering, were available at 200 ms (Fig. 3). Stationary plasma conditions were maintained by one gyrotron heating with 150 kW input power and by external gas input linked to a feedback control of the plasma density. A plasma current induced either by ECF and/or by plasma pressure [4] was controlled and kept below ≈ 500 A by the OH-transformer. The measured T_e, n_e profiles covered a plasma radius extending up to the separatrix, which was located at r_{eff} = 17.5 cm, about 2.5 cm outside the last flux surface not intersected by the limiter. A clear-cut separation of the plasma from the scrape-off region is not possible for this particular discharge type with edge ɫ values close to the 5/9 resonance, because of the strong poloidal deformation of the flux surfaces crossing the limiter. A more effective limiting of the plasma is provided in this case by the separatrix, outside of which the open field lines lead to a flattening of the temperature and density profiles.

An absolutely calibrated Hα monitoring system [5] installed at W VII-AS yields information about particle recycling at both limiters (two toroidal positions for the bottom and one for the top limiter) and at two "triangular" magnetic surface cross sections close to and far from a gas feed inlet, respectively.

Results for first W VII-AS discharges

The DEGAS code simulation at the "triangular" cross section near the gas inlet was used to find estimates for T_e, n_e between separatrix and wall, which were consistent with both the measured gas input rate and Hα signal close to the gas inlet. These estimates were then used in the limiter and wall recycling simulations. The time histories of the measured Hα-signals from the limiters and the "triangular" cross sections are shown in Fig. 4a,b. The neutral fluxes and densities were estimated by scaling the calculated Hα emission rates to agree with the measured ones.

The calculated total refuelling rate of the plasma inside the separatrix due to limiter and wall recycling and to external gas feed amounts to 2.5 x 10^{20} ions/s. 83 % of this ionization source are provided by the limiter, 13 % by the wall and 4 % by the gas puffing. This corresponds to a global recycling coefficient of 0.96. From the calculated refuelling rates and a plasma ion content of 8.9 x 10^{18} particles inside the separatrix, as resulting from the measured electron densities (Fig. 3) and an assumed z_{eff} of 3, a global particle confinement time of 36 ms is estimated for this time of the discharge. The plasma refuelling efficiencies as fractions of the neutrals ionizing inside the separatrix are 0.65 for the limiter, 0.44 for the wall and 0.29 for the external gas source. The small values for the wall and gas puff sources are directly related to the large volume of the boundary region between separatrix and wall (more than twice the volume of the confined plasma). On the other hand, this has the advantage of improving the decoupling between the plasma and the wall, thus reducing the wall loading by high energetic charge exchange neutrals.

The given refuelling rates and efficiencies from wall recycling and gas puffing may have a considerable error margin due to their sensitivity to the unknown plasma density and temperature in the boundary region. Furthermore, the flux of ions incident to the wall at the position of the Hα viewing line may not represent a good average of the ion fluxes over the entire torus wall. However, these uncertainties do not strongly affect the global recycling coefficient and τ_p, since recycling from the limiter is the main refuelling mechanism to the bulk plasma.

Experimental indication of a recycling coefficient close to one for the discharge type discussed here is given after a second gyrotron is switched on for about 100 ms (see Fig. 4b). During that time a constant plasma density is maintained without any external gas feed and the Hα signals at the triangular cross sections close to and far from the gas inlet coincide (see Fig. 4b). The amplitude of all signals (Figs. 4a,b) is considerably higher than before the 2nd gyrotron was added. Considering that at stationary conditions the externally supplied neutral flux equals the fluxes absorbed by wall and limiters and that the absorbed fluxes linearly scale with the recycling fluxes, gas puffing proves to be a very efficient density control mechanism for high recycling ECF discharges.

For the same discharge, the calculated average neutral densities at the limiters and wall due to the recycling sources are 2.9×10^9 cm^{-3} and 3.9×10^8 cm^{-3}, respectively. The total ion power loss due to charge exchange with all neutrals is 3.1 kW. The total electron power loss due to ionization, excitation and dissociation is 2.0 kW.

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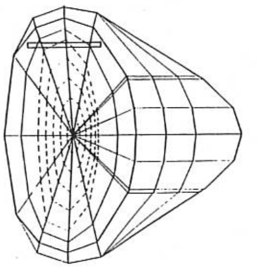


Fig. 1: Vertical cross-section of the modelled W VII-AS torus at the position of the module connecting flanges, including the wall, the bulge for the NBI ports, the flux surfaces and one of the limiters.

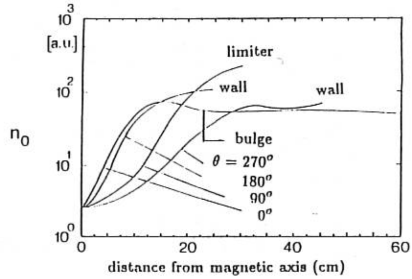


Fig. 2: Radial distributions of the neutral density at the poloidal angles $\Theta = 0^0, 90^0, 180^0, 270^0$ in the vertical cross-section shown in Fig. 1.

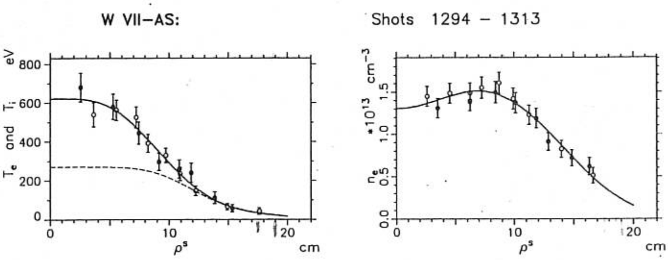
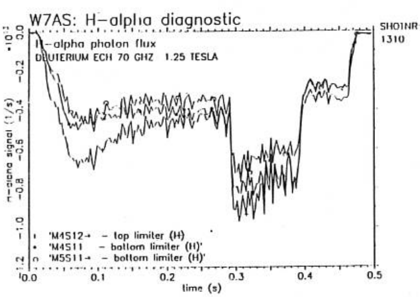


Fig. 3: Radial Te and n_e profiles vs. effective radius at Δt = 0.2 s from Thomson scattering. Full circles represent measurements on lh side of the profile.



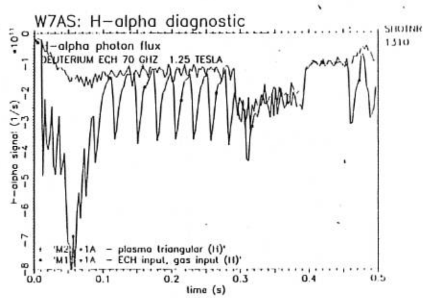


Fig. 4a: Hα-photon fluxes vs. time from ECE discharge looking at top and bottom limiter, plasma cross-section elliptical (a second gyrotron was switched on between 0.3 and 0.4 s).

Fig. 4b: Hα-photon fluxes vs time at two triangular plasma cross-sections, with and without gas inlet. The large spikes reflect the pulse sequence from the gas inlet.