FIRST CHARACTERIZATION OF THE NEW DIVERTOR IIb IN ASDEX UPGRADE

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Introduction

In 1997 the original "open" ASDEX Upgrade Divertor I (DIV I) was replaced by the rather "closed" LYRA-Divertor (DIV II). In support of ITER, this DIV II (Fig. 1, top) had been designed for optimal divertor volume losses, high pumping efficiency etc, if used in connection with a narrow class of well-fitting low δ equilibria. These expectations were, in fact, nicely confirmed during a several years run period [1,2].

In parallel to these optimised divertor studies, there was increasing interest in strongly shaped, especially higher triangularity plasmas, because of their improved confinement at high plasma density, the possible access to type-II Elms [3] etc. In the DIV II geometry, these plasmas could only be produced by positioning the outer divertor plasma leg on the top of the roof baffle located between the two curved vertical targets. Therefore some of the DIV II benefits were degraded, especially the power load characteristics and the pumping capability of the cryo-pump placed in the outer divertor region. To overcome this, the roof baffle and the outer part of DIV II were reconstructed (DIV IIb) to accommodate a large variety of plasma shapes with bottom triangularities (δ_{bot}) up to 0.48 (Fig.1, bottom), with the best strike point fitting to the pumping gaps obtained for medium δ equilibria.

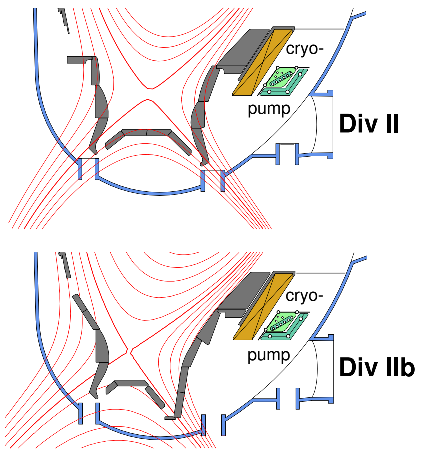

Fig. 1: *DIV II and the new DIV IIb with low and high δ plasma equilibria.*

Setup of Divertor IIb and Diagnostics

According to the positive experience with power handling in DIV II, ordinary fine grain graphite has been chosen for the outer strike point region [4]. The tiles are slightly tilted in toroidal direction (as they were in DIV II) in order to hide the leading edges. In the poloidal cross section (Fig.1, bottom), the outer strike-point module forms a straight line with larger poloidal angle to the flux surfaces. The resulting incidence angle of magnetic field lines has therefore increased from values below 2° to values around 4°. The inner part of the divertor strike point module remained unchanged, but at the divertor entrance a smooth transition to the inner heat shield is provided to minimize local hydrogen recycling there. The roof baffle is diminished at its outer part to allow the outer divertor plasma leg to hit the strike point module even for the highest triangularities. More details on the construction of DIV IIb can be found in [4]. The conductance to the cryo-pump is not affected by the new shape. Due to the simpler shape of the outer strike point module,

the diagnostic access is substantially facilitated. All diagnostics available already in DIV II (see [2] and references therein), were adapted to the new shape.
Operation with the new DIV IIb has been resumed successfully in April 2001 and about 200 successful discharges with different shaping and heating powers up to 10 MW have been performed till this conference.

Power Deposition and Divertor Radiation

Experiments in the DIV II configuration suggested that the "inward" reflection of neutrals at the vertical target was a key point for the reduction of the parallel heat flux by a factor of two [2]. Even shifting the strike points upwards by nearly 10 cm away from the V-shaped, narrow divertor corners to a region above the roof baffle had little effect on the heat flux profiles.
In DIV IIb the outer strike-point of the low triangularity equilibrium (which was the standard shape in DIV II) lies also clearly above the baffle region. Thermographic measurements show that the maximum heat flux perpendicular to the target is higher by 70% compared to DIV II for otherwise comparable low density H-Mode discharges. At least part of this increase is due to geometrical reasons because of the larger field line inclination at the target plates. But the total, integrated power load increased also by almost a factor of two. Figure 3 shows the fraction of the divertor radiation, i.e. the radiation below a virtual horizontal line through the X-point. For comparison the values for DIV I and DIV II are included also. According to spectroscopic measurements and modeling, the reduction of the power load in DIV II was attributed to strong carbon radiation in the dense divertor plasma [2]. This resulted also in a substantial increase of the total divertor radiation (compared to DIV I; see Fig.3) to values of about 40% almost independent from the input power [5]. Comparing DIV IIb and DIV II for low δ, similar radiation levels are found, although in DIV IIb the strike points are well above the baffled region, confirming the results from the z-shift in DIV II. Whether the increased heat-load in the divertor for these kind of discharge can be explained by a decrease in the main chamber radiation has still to be verified. For medium to high triangularity discharges the outer divertor leg is now placed on the vertical target instead on the roof baffle (horizontal) target. Since the radiation levels are

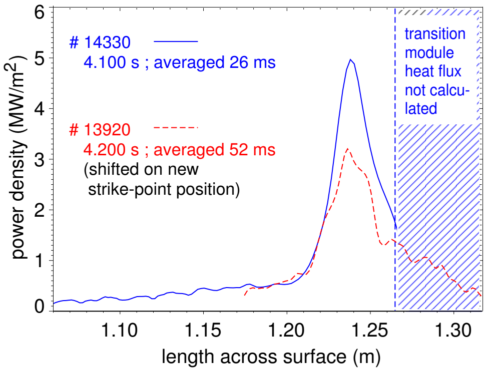

Fig. 2: *Heat flux at the outer strike point in DIV IIb (#14330, $\bar{n}_e \approx 6.6 \cdot 10^{19} m^{-3}$, solid line) and DIV II (#13920, $\bar{n}_e \approx 5.1 \cdot 10^{19} m^{-3}$) dashed line) during a 5MW NBI-heated H-Mode discharge*

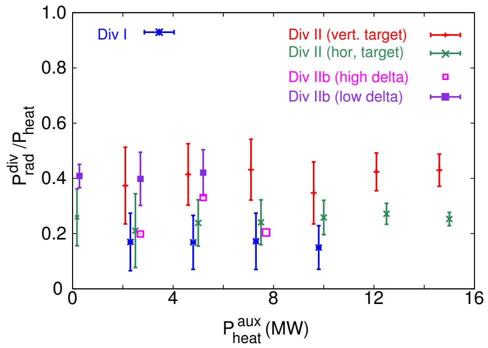

Fig. 3: *Fraction of the divertor radiation over the total heating power for different divertors and configurations.*

similar in this case, too, the lower values have to be attributed to more subtle effects like effective divertor depth than just the change in the target orientation.

Divertor Plasma-Parameters and Pumping Characteristics

Experiences in ASDEX Upgrade and JET [1] show that the the geometry of the divertor can strongly influence the plasma parameters in the divertor and to certain degree also in the plasma edge. This may diminish the operation window in terms of the formation of MARFEs, but early onset of detachment leads also to the desired strong reduction of the power flowing to the divertor plates. The divertor plasma parameters are measured by a set of Langmuir probes and complete profiles are achieved by sweeping the divertor fans. Figure 4 shows the the electron temperatures at the outer target in DIV IIb and DIV II during similar low density ($\bar{n}_e \approx 6 \cdot 10^{19} \mathrm{m}^{-3}$) 2.5MW NBI-heated H-Mode discharges. Whereas the maximum electron temperature at the separatrix is 10 eV higher in DIV IIb than in DIV II, it is quite similar in the SOL for both cases.

The neutral flux densities are measured by ionisation gauges at different locations in the vacuum vessel. Of special interest for the investigation presented, here are the fluxes below the divertor and in the outer midplane. First comparisons show that for the old standard configuration (low δ) as well as for higher triangularities no distinct differences in the neutral pressures are found, in contrast to simulations with the B2-Eirene code which predicted a reduction of the pump duct flux densities by up to one order of magnitude [7] for similar discharges. This might be explained by the fact that the divertor neutral pressure is mainly maintained by the colder inner divertor leg, the configuration of which remained unchanged, and that the plugging by the outer leg is still effective despite its large distance to the gap.

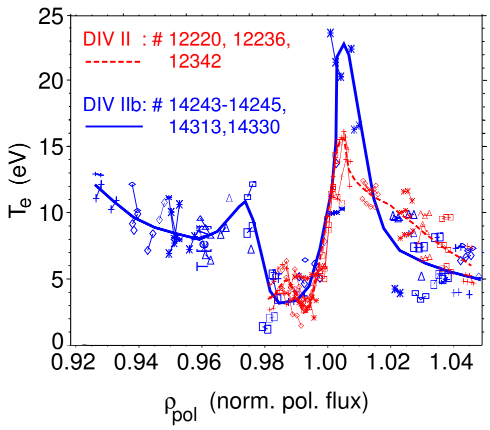

Fig. 4: *Electron temperature at the outer strike-point in DIV IIb and DIV II during identical 2.5MW NBI-heated H-Mode discharges.*

A key feature of DIV II was the high He compression accomplished by the the narrow divertor leg which hindered efficiently the back flow of neutral He [8]. This behaviour was reproduced by B2-Eirene model calculations, which predicted also a degradation of the compression accompanied by the strong decrease of the hydrogen flux density in the pumping plenum for comparable discharge conditions [7]. Following the procedure described in [8], the He compression in DIV IIb was evaluated from the He exhaust time constant via the three chamber model. The results confirm the trend predicted by the modeling, however the reduction is much smaller than expected from the calculations.

Divertor effect on the H-mode threshold

There is a clear reduction of the L-H transition power threshold for low triangularity conditions by about 20%. It can be excluded that this is only due to scatter in the data or to a surface conditioning effect because the threshold power is measured routinely since 1999 in a frequently repeated standard H-Mode discharge. First lithium beam measurements in the midplane indicate that the density at the nominal separatrix and in the scrape-off layer is lower, pointing out the importance of local edge parameters, as already seen after the change from DIV I to DIV II, where an increase of the threshold was found [1]. At the moment it is not clear whether these observations are due to the simultaneously installed tungsten coated central column (see [6]) or whether they have to be attributed to the new divertor geometry.

Summary and Outlook

The plasma operation was successfully started with the new DIV IIb and equilibria with $0.3 < \delta_{bot} < 0.5$ and additional heating powers up to 10MW were already used. The first characterization of DIV IIb revealed, that overall the beneficial behaviour of DIV II is essentially maintained. The transition from a well adapted case for one equilibrium, (as it might be the case also in ITER) to a more flexible experimental solution, which can accommodate the full range of desired equilibria in ASDEX Upgrade, caused only minor changes to the divertor performance. The increase of the power load is still acceptable even though the reason for it is not yet clear, because the divertor radiation for similar magnetic configuration is almost unchanged. The decrease of the divertor radiation in high triangularity discharges obviously cannot exclusively be attributed to the operation with horizontal target plates, as it was concluded during DIV II operation, since it is very similar also for the vertical target operation of these discharges in the new DIV IIb configuration. The plasma parameters at the outer strike point show only moderate changes. Nevertheless a significant reduction (20%) of the L-H threshold is observed pointing to lower densities upstream in the midplane as indicated by Li-beam measurements. In some contradiction to simulations with the B2-Eirene code, there is no strong reduction of the pump duct flux densities and the He compression for identical discharges. This may point to large influence of the inner divertor leg, the configuration of which remained unchanged. The reported behaviour will be examined in more detail in the future. In addition to a detailed charcterization of edge and divertor, an important question is to which extent the observed differences are caused by the simultaneous installation of large tungsten surfaces in the main chamber.

References

[1] H.S. Bosch et al., Plasma Phys. Control. Fusion, **41** (1999) A401

[2] A. Kallenbach et al., Nucl. Fusion 39 (1999) 901

[3] J. Stober et al., Proc. 27th. EPS Conf. on CFPP, ECA Vol. 24B (2000) p. 976

[4] O. Gruber et al., IPP Report 1/322, Garching, Germany (1999)

[5] J.C. Fuchs et al., J. Nucl. Mater. **290-293** (2001) 525

[6] V. Rohde et al., this conference, P1.042

[7] D.P. Coster et al., J. Nucl. Mater. **290-293** (2001) 845

[8] H.S. Bosch et al., J. Nucl. Mater. **290-293** (2001) 836