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Heat flux and radiation losses for different divertor geometries in ASDEX Upgrade

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Introduction

The divertor tokamak ASDEX Upgrade was operated up to now with two significantly different divertor configurations - an open and a closed geometry, respectively. The open divertor (DIV I) is characterized by flat horizontal divertor plates. The target material was fine grain graphite. The closed divertor (DIV II) was designed to test the physics of the proposed ITER divertor and to handle the increased heating power. Based on experimental observations and on modelling calculations with the B2–Eirene code a fairly closed, relatively deep and well baffled divertor was designed. The shape of the divertor plates and the roof baffle were optimized to improve the detachment properties and to reduce the target heat flux. The new closed divertor results in a heat flux reduction of about a factor of two compared to DIV I for comparable discharge conditions [1]. The significant reduction of the target heat flux is attained by an increase of the fraction of radiation inside the divertor due to carbon and hydrogen radiation [2].

In this paper we will present experimental results from thermographic and bolometric measurements showing the reduction of the divertor load in the DIV II situation.

Experiments

The geometry of both divertor configurations is shown in Fig. 1. DIV II was designed for plasma configurations with the strike point at the vertical plates, but the geometry allows also an outer strike point position at the horizontal top of the roof baffle. This feature was used to compare horizontal and vertical divertor configurations under in vessel conditions (wall condition, changed inner parts etc.) which are not changed by running comparable discharges with the outer strike point at the vertical and the horizontal target plate, respectively.

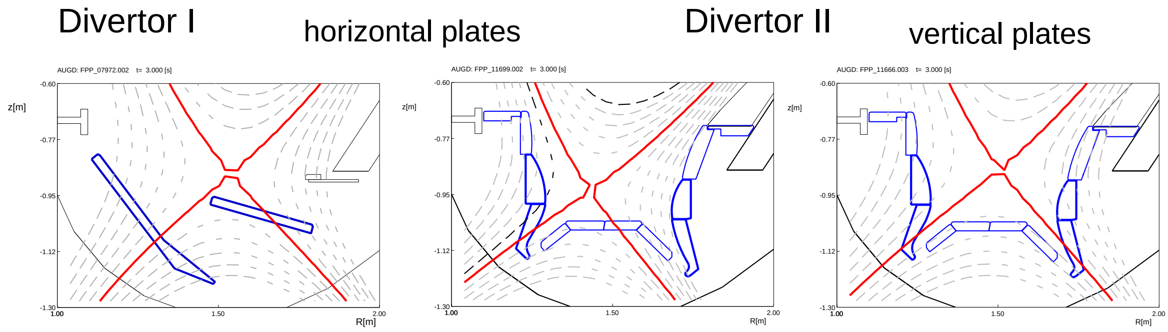

Figure 1 Open divertor I (left) and Lyra shaped divertor II with a closed configuration using vertical plates (right) and an open configuration using the horizontal plates at the top of the roof baffle (middle).

The heat flux to the divertor is routinely measured by fast IR line cameras with a time resolution of 260 μs/line and a spatial resolution of about 1.5 mm/pixel at the vertical and 3 mm/pixel at the horizontal plates. The strike point tiles are tilted to avoid hot edges. This tilting shadows the thermographically observed region at the inner strike point resulting in an underestimation of the heat flux to the inner strike point module.

The radiation losses from the plasma column as well as from the divertor region are monitored by 8 pinhole bolometer cameras with a total of 96 channels [3]. The poloidal distribution of radiation power density is reconstructed from the measured line integral of emissivity by a reconstruction method based on an anisotropic diffusion ansatz [3].

The poloidal and toroidal distribution of energy deposition is measured by cooling water calorimetry.

In this paper we will concentrate on data of H-mode plasma discharges with heating by neutral beam injection up to a power of 15 MW, a density variation from the natural density without gas puff up to densities of about $1\times10^{20}\mathrm{m}^{-3}$. The plasma current was 1 MA, the magnetic field strength -2.5 T. The direction of the $ion - \nabla\vec{B}$ drift points downwards.

Results and discussion

A main result of the DIV II geometry is the reduction of the heat load at the vertical target. Fig. 2 shows heat flux profiles from thermographic measurements for both divertor geometries including the horizontal target in the DIV II. The parallel heat flux is shown to eliminate geometric effects. The reduction of the maximum heat flux is more than a factor of 2 for comparable heating power. Bolometric measurements show that the fraction of radiation outside the divertor of about 50 % of the input power does not depend on the divertor configuration [1,4]. The reduction of target heat flux is due to an increase of radiation losses inside the divertor from 20 % of the input power in DIV I to 40 % in DIV II. This reduction is attributed to carbon radiation which reduces the electron temperature in the divertor so that hydrogen radiation becomes significant [2,3].

The DIV I situation can be reproduced in the DIV II divertor geometry if the outer strike point is at the roof baffle (horizontal target). In this case the power load to the outer strike point is doubled (Fig. 2) and the radiation losses inside the divertor are reduced to the DIV I level [6].

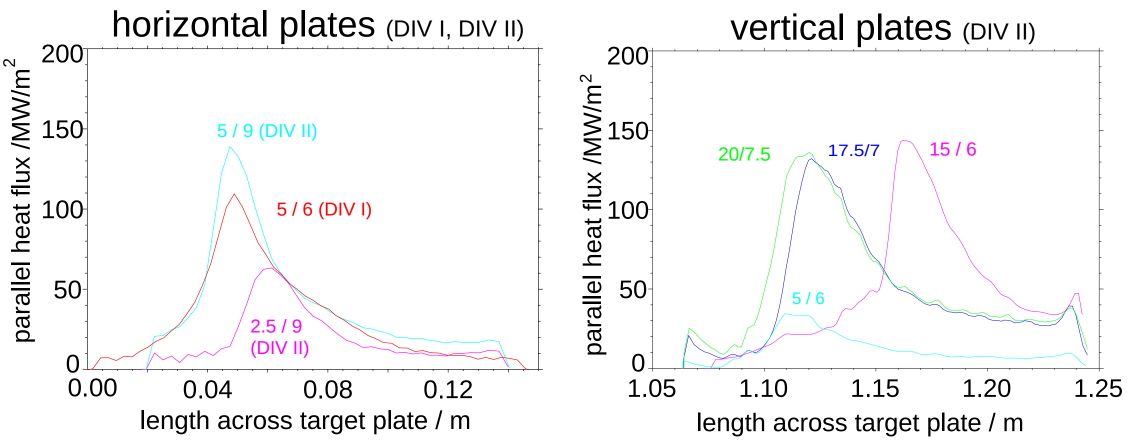

Figure 2 Parallel heat flux at the outer strike point for horizontal and vertical target orientation. The parameters are the heating power in MW and the line averaged density in $1\times10^{19}\mathrm{m}^{-3}$.

It is obviously from Fig. 2 that the heat flux at the divertor plate is reduced. Nevertheless, Fig. 2 reveals also, that for a given divertor configuration the maximum heat flux normalized to the input power varies. The dependence of the maximum heat flux at the outer target plate on global and local plasma parameters was investigated for DIV I. It was found that significant parameters for the heat flux behavior are the line averaged density and the safety factor (q_{95}). The following dependence was found [5]:

$$q_{max} \sim \bar{n}^{-0.77}\, q_{95}^{-0.27}$$

This parameter dependence derived for DIV I was used to normalize the heat flux measured at different densities and a weakly varying safety factor to a line averaged density of $1\times10^{20}\mathrm{m}^{-3}$ and a safety factor q_{95}=4 as it is shown in Fig. 3. The lines are linear fits trough the origin for the data points belonging to the horizontal divertor configuration (DIV I, roof baffle) and the vertical configuration (DIV II). For the vertical configuration (DIV II) two lines are shown which corresponds to different ICRH antenna positions. The normalized maximum parallel heat flux to horizontal divertor plates for a given heating power is the same in DIV I and Div II. It is about a factor of 2 higher than the high level data for vertical plates in and a factor of 4 higher than the data for vertical plates and the old ICRH antenna position.

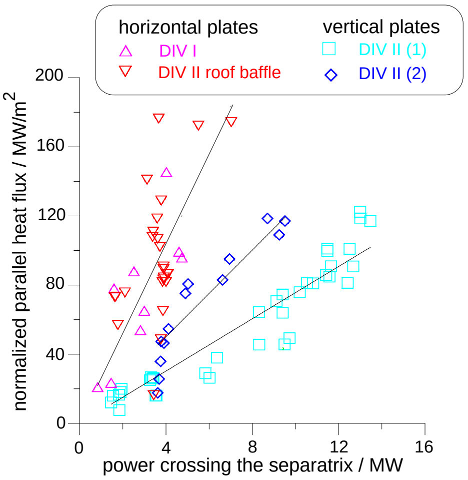

Figure 3 Maximum parallel heat flux at the outer target plate for horizontal and vertical target orientation vs. power crossing the separatrix. The ratio of the inclination of the fitted lines is 1:1.8:3.7.

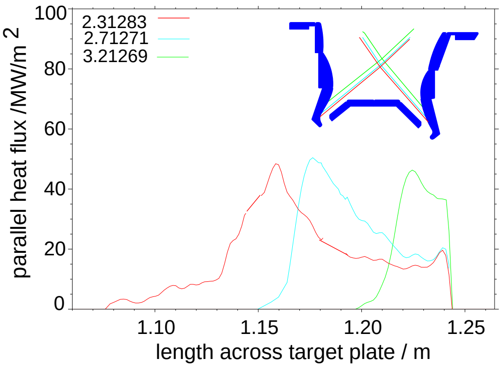

Figure 4 Heat flux profiles at the outer vertical target plate. The position of the strike point is moved from inside to outside the closed V-shaped divertor leg as indicated in the divertor contour. The increase of the heat flux at a position 1.23 m is due to edge effects at the end of the strike point module.

Wether or not this benefit from the vertical target position depends on the closure of the divertor was investigated by moving the outer and inner strike point upwards from a position well inside the V-shaped divertor leg up to a vertical position above the top of the roof baffle. The maximum heat flux as well as the decay length is nearly constant for the different positions, revealing that the heat flux reduction at the vertical plates is due to the vertical position itself and not due to the closeness of the divertor leg.

The ICRH antenna was redesigned and its midplane position was moved outward by 2.5 cm to allow medium and high triangularity configurations after a first operation period with DIV II. In the following operation period the maximum heat flux to the outer divertor tends to be higher and the energy confinement time seems to be lower for comparable discharges. The influence of the antenna position onto the plasma parameters and the divertor heat flux was investigated by moving the plasma from the standard position in two steps of 1 cm each towards the antenna. Lowering the distance to the ICRH antenna reduces the maximum heat flux and increases the ELM frequency (Fig.: 5). The ELM averaged maximum heat flux is reduced by about 20 %. The energy confinement time goes down by about 8 %. Both effects are caused by a change of the edge density and temperature profile as measured by Li beam diagnostic. The separatrix density and the density gradient is increased when the distance to the carbon protected ICRH antenna is reduced. The electron temperature at the separatrix and in a 4 cm region inside the core plasma decreases.

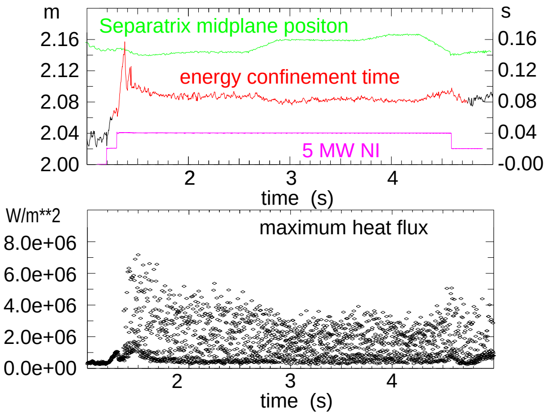

Figure 5 Time slices of energy confinement time, separatrix position at the outer midplane (top), and maximum heat flux at the outer strike point (bottom).

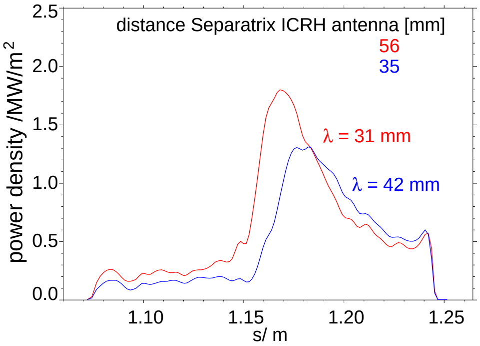

Figure 6 Heat flux profiles at the outer vertical target for 'normal' (56 mm) and reduced (35 mm) distance to the ICRH antenna.

Summary

A significant different behavior of horizontal and vertical divertor configurations is measured by bolometry and thermography. Vertical divertor plates results in a decrease of the target heat flux and an increase of the divertor radiation. The change is about a factor of 2 and did not depend on the closeness of the divertor.

The maximum heat flux is reduced and the heat flux profile is broadened if the distance of the outer separatrix to inner parts (ICRH antenna) is reduced (but as large as about 5 temperature decay lengths). due to a change in the density and temperature edge profile.

References

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