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Heat flux decay length in the midplane of ASDEX Upgrade

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Abstract

Power exhaust is a crucial issue for next step fusion devices since the heat flux to first wall elements has to be kept below a technically feasible limit. A crucial parameter in this context is the perpendicular heat flux decay length in the scrape-off layer (SOL). In this paper, a direct measurement of the midplane decay length in the poloidal divertor tokamak ASDEX Upgrade by continuously varying the magnetic configuration from a lower single null (SNL) through a double null configuration to upper single null (SNU), i.e., switching of the particle and heat flux continuously from the lower to the upper divertor, while monitoring the divertor particle and heat flux in the lower divertor is presented. The decrease of the signal measured at the outer lower divertor target plotted versus the midplane distance of the two separatrices results in e-folding lengths for the midplane heat flux. The decay lengths found are comparable to decay lengths derived from heat flux profiles measured at the divertor plates and mapped to the midplane.

Keywords: ASDEX-Upgrade; Divertor; Edge transport; Heat flux

1. Introduction

The fusion experiment ASDEX Upgrade is a medium size divertor tokamak with a lower and upper divertor for energy and particle exhaust. One of the main topics for research is the particle and energy transport in the scrape-off layer (SOL) and the plasma edge with the goal of understanding the energy loss processes in the SOL and the divertor region. The installation of a closed lyra-shaped divertor (DIV II), based on experiments with the open divertor I (DIV I) and code calculations (B2-Eirene code), reduces the peak target heat load at the divertor plates by about a factor of 2 for comparable plasma conditions [1]. The knowledge of the heat flux profile in the midplane and at the target plate is an essential for model validation and to understand the heat transport in the SOL of tokamaks. Normally, the heat flux data from the divertor are mapped to the outer midplane, if no direct measurements exist. It was shown for ohmic discharges that this method is reliable on the condition that the divertor is not detached [2].

In this paper, we present midplane heat flux decay lengths measured by redirecting the heat flux from the lower divertor to the upper by changing the plasma configuration from single null plasma with an active lower divertor into a configuration with an active upper. First, we will discuss the main features of the fast plasma control system as far as it is relevant for the experiments. In Section 2, we describe the experimental conditions as well as the discharge and SOL properties. In Section 3, we will present and discuss experimental results from different diagnostics measuring the plasma properties in the divertor. The paper is closed with a summary.

2. Plasma configuration and shape control

Plasma shape and position in ASDEX Upgrade is controlled by a fast digital system. A large set of magnetic pick up coils inside and outside the vacuum vessel is the input for the online calculation of the magnetic configuration using a function parameterisation (FP)

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PII: S 0 0 2 2 - 3 1 1 5 (0 0) 0 0 6 0 0 - 0

algorithm [3]. The FP recognises four qualitative different plasma configurations: inner limiter, outer limiter, upper single null (SNU) and lower single null (SNL).

The double null configuration is not considered as an independent magnetic configuration. It is established briefly during the change between the single null configurations. For each of the standard configurations a lot of plasma shape parameters can be controlled independently.

The experiments under consideration require a change between two different plasma configurations according to the FP algorithm. That's why it was necessary to use only such parameters for plasma control which vary continuously when the plasma configuration is switched. Spurious configuration jumps could be avoided by feed forward programming the control currents for shape control during discharge phases near the double null configuration. Away from the double null configuration plasma shape and position was feed back controlled.

3. Experiments

In this paper, we focus on an H-mode discharge in deuterium. It was the last discharge of a series performed to optimise the configuration and for conditioning the upper divertor. The plasma configuration starts and ends with the outer strike point at the top of the roof baffle in the lower divertor (SNL) (Fig. 1). In between, the SNU configuration was established for about 1 s. Additionally, we present results of an earlier, much less optimised experiment in hydrogen, starting with the strike points at the vertical plates of the lower divertor. The temporal behaviour of global plasma parameters is shown in Fig. 2 for both discharges. Other parameters are listed in Table 1.

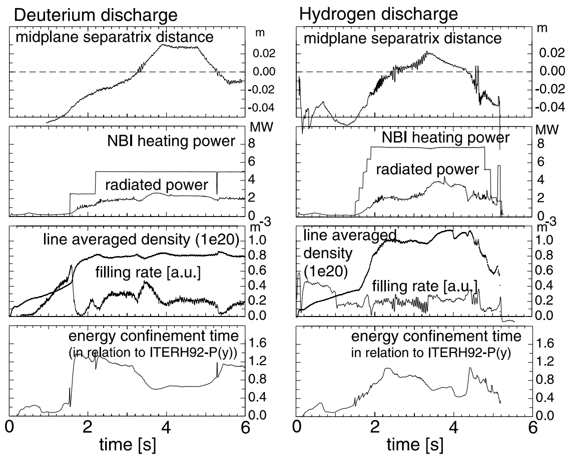

Fig. 2. Temporal behaviour of discharge parameters.

Table 1
Global discharge parameters

Fill gas	Hydrogen	Deuterium
Plasma current (MA)	1	0.8
Magnetic field strength (T)	−2.5	−2
Safety factor (q_{95})	4.4	4.7

The plasma divertor interaction is monitored by a set of different diagnostics. The heat flux to the lower divertor is measured by fast IR cameras, the H_α radiation in both divertors is detected by photo diodes. The power deposited to the lower divertor was calculated from the measured heat flux profile by integration over the divertor area. Midplane profiles of the density were measured by the lithium beam diagnostic, and the plasma radiation is monitored by a set of bolometer arrays, covering the whole plasma column and the divertor regions.

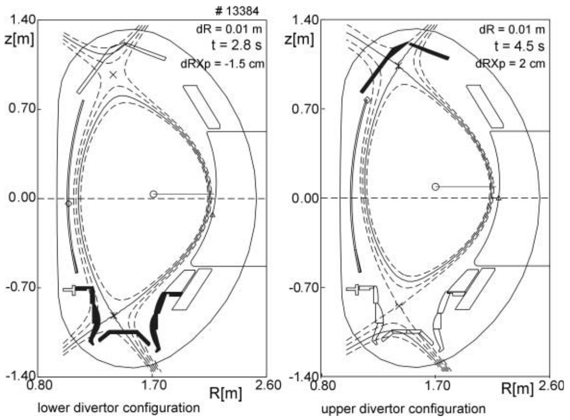

Fig. 1. Single null configuration with active lower (SNL) and active upper divertor (SNU). The midplane distance between the active and the inactive separatrix d*RXp* is −1.5 and 2 cm, respectively.

4. Results and discussion

The decay of the power to the outer lower divertor with varying distance between the two separatrices in the midplane is shown in Fig. 3 for the deuterium discharge. A midplane distance of zero reflects the double null configuration. At this point the power crossing the separatrix flows into the lower and the upper divertor simultaneously. From this figure, we could conclude that half of the separatrix power flows in each divertor.

Heat flux profiles measured in the outer divertor and mapped to the midplane for different distances of the two separatrices are shown in Fig. 4. This figure reflects the reduction of the peak area and height with the reduction

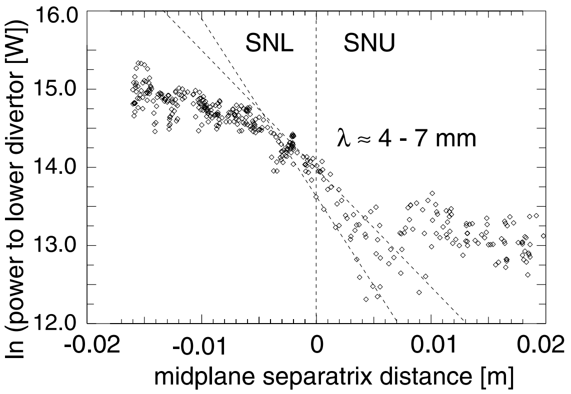

Fig. 3. Total power to the lower divertor versus midplane separatrix distance for the deuterium discharge (natural log scale).

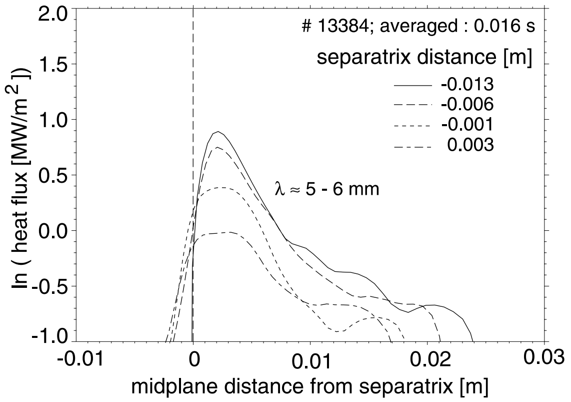

Fig. 4. Divertor heat flux profiles mapped to the midplane for the deuterium discharge.

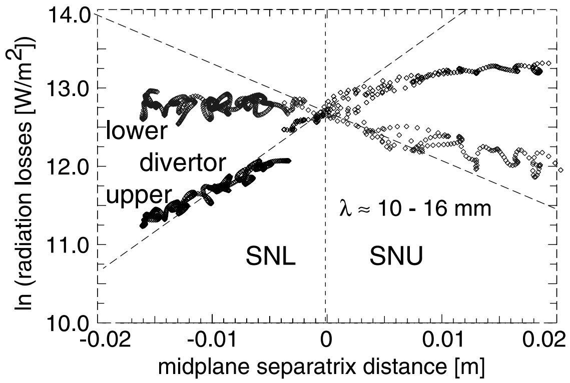

Fig. 5. Plasma radiation near the strike points in the upper and lower divertor versus the midplane separatrix distance.

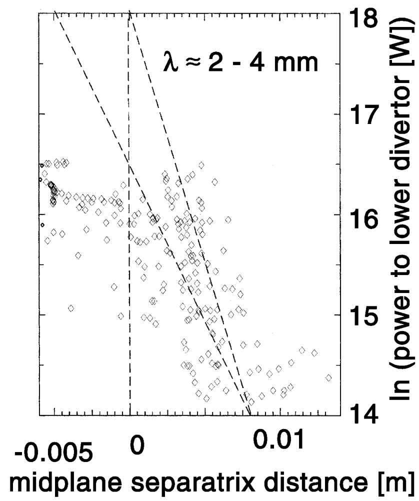

Fig. 6. Total power to the lower divertor versus midplane separatrix distance for the hydrogen discharge.

of the separatrix distance without a significant change of the decay length. The decay lengths derived from Figs. 3 and 4 are $\lambda = 4$–7 and $\lambda = 5$–6 mm, respectively.

The decay of line integrated radiation measured by bolometer channels near the strike points in the upper and lower divertor are shown in Fig. 5. The resulting decay lengths are higher by more than a factor 2 compared to the heat flux decay lengths. Such higher decay lengths were also found in the H_α and carbon (CIII) radiation from the divertor. The target heat flux profiles consists of two components (Fig. 4), a steep part near the separatrix and a flat tail away from it. The interaction of power flowing in this flat tail with the working gas and impurities might dominate the radiation signals, resulting in a longer decay length.

The heat flux decay lengths in the hydrogen discharge are $\lambda = 2$–4 mm as derived from the configuration change experiment (Fig. 6) and a mapped divertor profile, respectively. The plasma radiation in the divertor decays with $\lambda = 6$–10 mm.

The experiments show that the decay lengths derived from the configuration change and from profile mapping are comparable. This holds for the deuterium discharge as well as for the hydrogen discharge. From this follows that the divertor and the midplane is coupled, despite the fact that the density is about 0.75 of the Greenwald density limit for both discharges.

The decay lengths in hydrogen are about a factor of 2 lower compared to the deuterium results. Although, both discharges are not comparable in terms of the control scenarios used, we will discuss this unexpected result shortly. An analytical model, based on electron heat conduction and energy conservation [4] results in the following parameter dependence for the electron temperature decay length in the SOL, $\lambda_T \sim (n\chi_e)^{7/9}P^{-5/9}$.

For the given discharge parameters (Fig. 2, Table 1) follows that the ratio between the hydrogen and deuterium decay length is mainly affected by the ratio of the perpendicular electron heat conduction coefficient, χ_e. This means, that the shorter heat flux decay length in hydrogen comes from a lower electron heat conduction coefficient.

Edge transport scalings, performed recently for hydrogen and deuterium discharges in ASDEX Upgrade [5] reveals that χ_e becomes smaller with increasing plasma current at the same fraction of Greenwald density. This tendency is reproduced by our experiments. Nevertheless, the absolute value of the perpendicular electron heat conduction coefficient in hydrogen is a factor of 2 higher for comparable discharge parameters. This will be checked during the next experimental campaign in hydrogen by running a discharge with the same parameters as for the deuterium case reported here.

The change from the SNL to the SNU configuration was accompanied by a reduction of the plasma stored energy and the energy confinement time expressed in ratios of the ITER scaling (ITERH 92-P(y)) (Fig. 2) by a factor of 2. The ELMs changed from type-I to type-III. The confinement recovered when the SNL configuration was established again. A conditioning of the upper divertor by five consecutive shots did not improve the energy confinement significantly. A reduction of the density could retain the type-I ELMs and reduce the energy confinement loss to 0.8 of the SNL situation. The measured electron density profiles show a flattening of the density profile in the SOL (doubling of the decay length) for the SNU configuration (Fig. 7) at constant gas filling rate.

The measurement error for the electron temperature profile was too high to quantify a possible reduction.

The effect of the configuration change on the plasma performance and the edge parameters increases with the distance from the SNL situation. Trying to draw a separate decay near to and away from the SNL situation in Fig. 3 would give the shorter decay length far from the SNL configuration which is in contradiction to the increased density decay length.

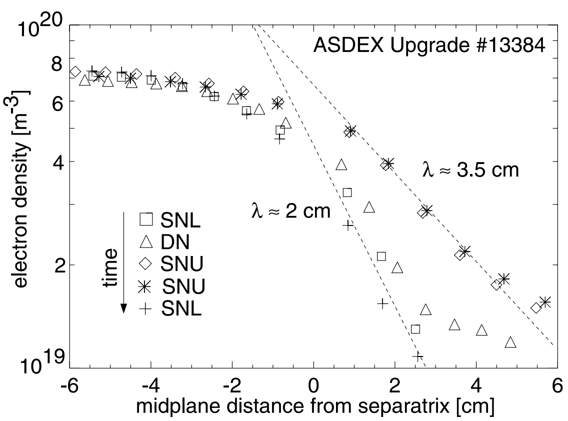

Fig. 7. Electron density profiles in the SOL for the deuterium discharge.

Systematic investigation of the effect of a reversed magnetic field was performed in ASDEX Upgrade for the DIV I situation [6]. It was found that the H-mode threshold is increased by a factor of 2, if the ion grad B drift points away from the *x*-point. The change from SNL to SNU configuration changes the ion grad B drift direction from pointing towards the active divertor to pointing away from it. This might explain the change of type-I elmy H-mode to type-III elmy H-mode for the SNU situation and the loss of confinement, but has not been investigated systematically up to now.

5. Summary

Configuration change experiments were performed to redirect the power crossing the separatrix from the lower divertor to the upper divertor. The reduction of the power to the lower divertor was measured by a thermography system. Heat flux decay lengths were deduced from the decay of the total power deposited in the lower divertor in dependence on the midplane distance of the two separatices. The decay lengths found are comparable to decay lengths derived from heat flux profiles measured at the divertor plates and mapped to the midplane. For the experiments under consideration the decay lengths of the main profile peak are $\lambda = 4$–7 mm and $\lambda = 2$–4 mm for deuterium and hydrogen, respectively.

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