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Langmuir probe measurements of particle and heat fluxes at the JET MkII-HD divertor targets

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1. Introduction

In the divertor of JET a new load bearing plate (LBSRP) has been installed at the outer target allowing operation at high input power and triangularity with plasma equilibria close to the ITER-shape. To determine the power and particle fluxes arriving at the new target tiles a set of triple probes has been installed allowing particle fluxes and electron temperatures to be measured with a temporal resolution of 0.1 ms and a spatial resolution ~1 cm. In earlier campaigns, significant erosion of the probes has been observed. This introduces not only an inaccuracy in the measurement of the particle flux, but more importantly also on the electron temperature measured using sets of triple probes. In order to re-assess the effective probe collection area and to monitor the probe erosion a specially designed probe calibration pulse has been performed on a regular basis since the installation of the new probes in the shutdown period before the 2006-2007 experimental campaigns.

Type-I ELMs, which are currently thought to be unavoidable in the planned ITER baseline scenario, will have a severe impact on the lifetime of plasma-facing components, in particular on the divertor. Recent experiments at JET have therefore aimed at the development of mitigated ELM regimes using active techniques such as impurity seeding or external magnetic field perturbations. The effect on the divertor targets during these experiments will be shown in sections 3 and 4.

2. In-situ calibration of divertor probe diagnostic

The divertor target probes at JET are mounted in the toroidal gaps between tiles and protrude ~2mm beyond the tile surface. They are poloidally distributed in 28 locations, of which 10 have two additional pins in separate toroidal but the same poloidal locations providing a triple probe arrangement (see Fig. 1). The electron temperature is related to the difference of the return voltage and floating potential, which is corrected for two unlike pins: $T_e = (V_{ret} - V_{fl}) / \ln(1 + A_2 / A_1)$. An uncertainty in the probe collection area can lead to significant inaccuracy in the T_e measurements. For example, if A_2 is overestimated by 50%, T_e would be underestimated by 70%. The pins, which are wedge shaped, have poloidal and toroidal extensions of 2.1 mm and 7.8 mm

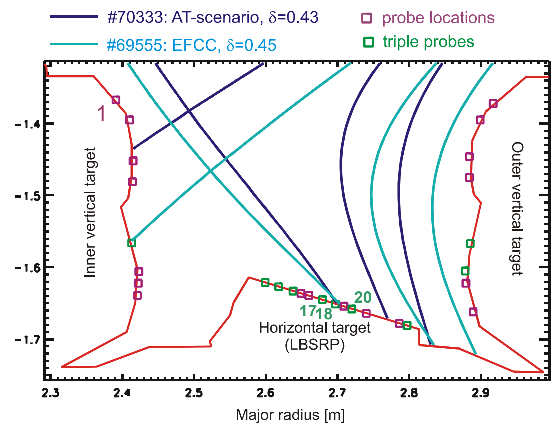

Fig. 1: Divertor with the equilibria used in the ELM-mitigation experiments.

respectively. The angle of the slope facing the magnetic field line is sufficiently steep to avoid non-saturation of the ion current. The inclination angle of the field line with the surface is determined by the equilibrium code EFIT. During regular ohmic probe calibration pulses (PCP) the strike points are swept over all probes to assess the degradation of the probe areas. The good agreement of the electron temperature profiles measured during the various pulses shows that good reproducibility is achieved from pulse to pulse even if they are often separated by a large number of other discharges. The probe area correction factors are found from the ratio of the ion saturation profiles of the present PCP with the first PCP executed during the restart phase just after the probe installation. Figure 2 summarizes the evolution of the probe areas of four probes for all PCPs. The averaged probe erosion for all poloidal positions is shown in Figs. 3-4. (red bars). Zones of large erosion can be attributed to divertor regions with higher power load over the campaigns, which is roughly represented by the campaign-integrated total duration of the strike point intersection weighted by the total input power, where an equal power sharing of inner and outer divertor has been assumed. The particular large erosion of the pins on the inner upper vertical target is probably due to the proximity of the X-point in high triangularity discharges which leads to a low recycling condition and high strike point temperatures (in contrast to the more usual vertical target discharges run in the past characterised by a high recycling and cold divertor plasma).

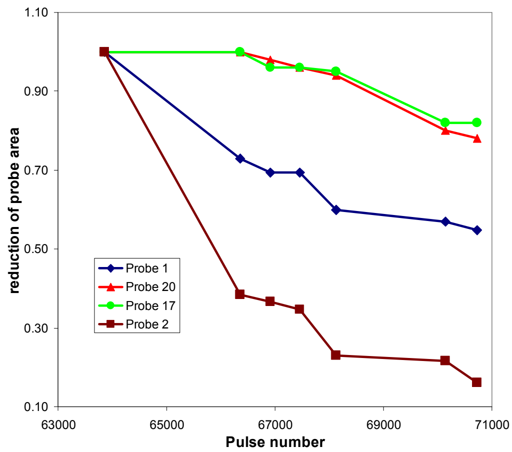

Fig. 2: Decrease of probe areas versus probe calibration pulse number.

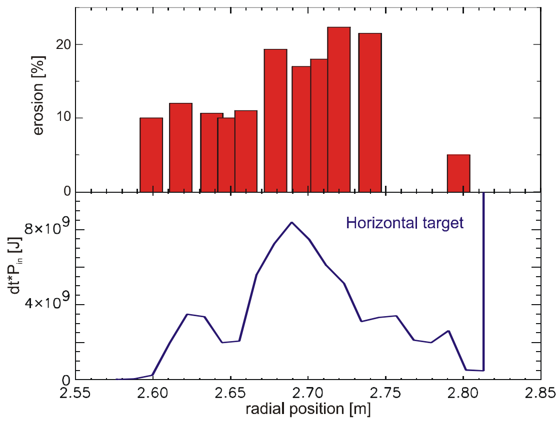

Fig. 3: (a) Erosion of probes at LBSRP and (b) campaign integrated power load to target.

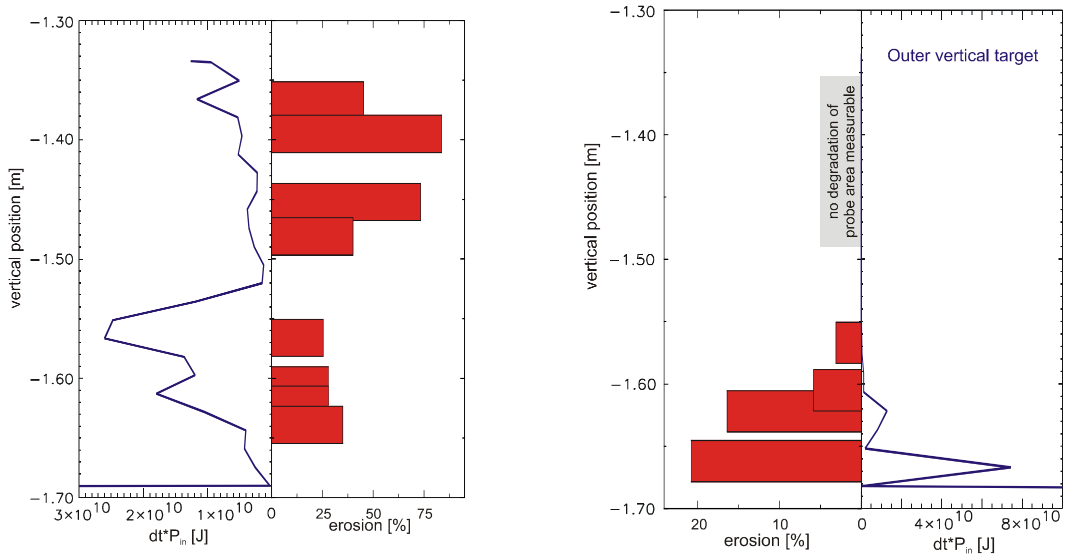

Fig. 4: Erosion at vertical inner target (left) and vertical outer target (right) together with campaign integrated power loads.

3. Impurity seeding in ITER-like advanced tokamak scenarios

Advanced tokamak scenarios cause high divertor power loads mainly due to their operation at low density and high input power. Extrinsic seeding using Ne and N_2 injection has been attempted in the recent campaigns in order to find AT scenarios which will be compatible with the planned all-metal ITER-like wall at JET [1, 2]. The plasma shape was optimised for the characterisation of the edge and divertor properties (see Fig. 1). In these plasmas, performed at I_p=1.9 MA, B_t=3.1 T, q_{95}=5.5, δ=0.43, $\langle n_e \rangle$=1.1x10^{20} m^{-2} and total input power of 23 MW, Type-I ELMs release 290 kJ of the pedestal energy, dW_{ELM}, at a frequency of about 54 Hz. With Neon-injection the radiative power fraction has been raised from 18% to 54% causing the ELM-frequency to increase to 100 Hz, similar to that found in more conventional impurity seeded H-mode discharges [3].

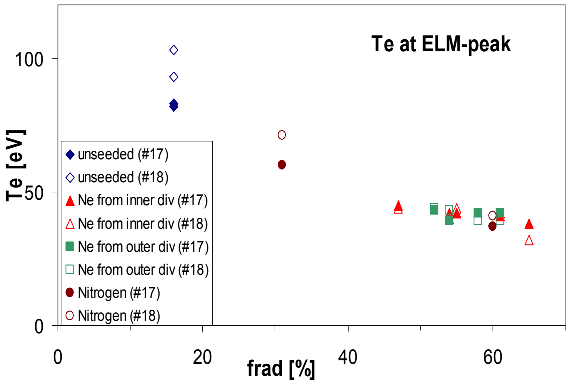

Fig. 5: T_e measured by probe 17 and 18.

At the outer strike point, the electron temperature at the ELM-peak is drastically reduced to ~30 eV, independent of the seeded impurity species or the puff location (Fig. 5). The seeding also reduces the inter-ELM electron temperature from ~25eV down to ~10 eV. At first sight, the power flux density onto the target (Fig. 6), derived from the parallel heat flux via $P_{sur} = 8 J_{sat} T_e \sin\theta_\perp$, indicates a reduction of the ELM-bursts onto the target. However, it is important to note that also the field line inclination angle with the target, $\theta_\perp$, also changes with increasing radiation (Fig. 6), which is probably due to a change in the edge currents caused by the lower edge pedestal temperature.

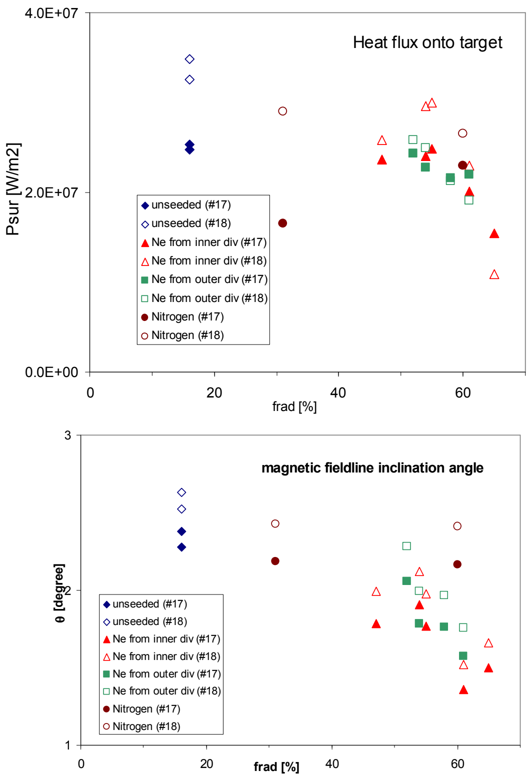

Fig. 6: Heat flux on target and decrease of fieldline inclination angle with increasing frad.

4. ELM-mitigation using external magnetic perturbation coils

Ergodization of the plasma edge by using an externally applied magnetic perturbation field is a promising technique for ELM mitigation [4]. It has recently been successfully applied on JET in a variety of plasma shapes at low and high triangularity by operating the four error field correction coils (EFCC) in an n=1 configuration [5]. The data reported here refer to high triangularity discharges with δ=0.45 and the outer strike point placed in the middle of the LBSRP (Fig. 1). During the flat top of a Type-I ELMy H-mode discharge (I_p=1.8 MA,

B_t=2.16 T, q_{95}=4.4, P_{NBI}=9.5 MW, P_{RF}=1.0 MW, $<n_e>=1.3x10^{20}m^{-2}$), currents of 2kA*16 turns have been applied. At these plasma currents and input power ELMs appear with f_{ELM}~30 Hz and dW_{ELM}~130 kJ. During the EFCC-phase the ELM-frequency strongly increases to about 90Hz with dW_{ELM} dropping to values which lie within the noise of the signal. The loss of core and edge density during the error field application, often referred to as pump-out effect, is not seen as increased particle flux at the divertor in either the inter-ELM phases or at the ELM-peak (Fig. 7). The particle flux and heat flux is strongly reduced during the EFCC-phase (red curves), since less particles are lost during the ELMs. This is seen also by the decrease of the density drop in the edge interferometer channel during the ELM (from 2.8 x 10^{18} m^{-2} to 1.4 x 10^{18} m^{-2}). It is important to note that the electron temperature remains unaffected (Fig. 7), also in between ELMs. Since the EFCCs create a toroidal asymmetric perturbation a phase scan has been carried out to rule out possible contrary effects at other toroidal locations. The observations in these discharges are similar to the one shown here. It is worth mentioning that the interaction of the ELMs with the outer wall is also diminished as observed by the outer wall guard limiter probes.

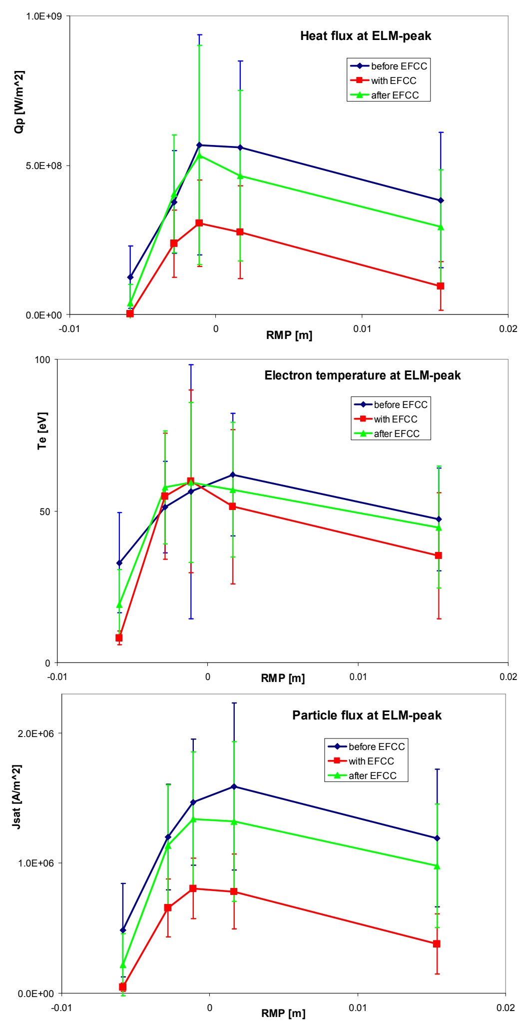

Fig. 7: Profiles at outer divertor during EFCC-experiments.

5. Conclusions

Significant erosion of the divertor probes has been observed in correlation with typical strike point locations. This must be taken into account in the analysis of triple probe data.

With enhanced edge radiation the electron temperature at the divertor can be significantly dropped. Although the ELM-peak heat flux along field lines remain constant, in Neon-seeded discharges the current profile seems to be altered resulting in smaller field line inclination angles, which lead to lower power flux density at the target, as seen not only by Langmuir probes but also by Infra-Red cameras [6].

On the contrary, external magnetic perturbation field experiments have shown to mitigate the ELMs solely by reducing the particle losses during the ELM. The electron temperature at the target remains high, but at least no significant increase, as it could be expected for pulses with an ergodised edge, could be observed within the spatial resolution.

[1] X. Litaudon *et al.*, this conference I5.001.

[2] M. Beurskens *et al.*, this conference P1.163.

[3] S. Jachmich *et al.*, Plasm. Phys. Contr. Fus. (2002), p. 1879.

[4] T. Evans *et al.*, Nature of Physics 2 (2006), p. 419.

[5] Y. Liang *et al.*, accepted for publication by Phys.Rev.Letters (2007); this conference I5.004.

[6] G. Arnoux *et al.,* this conference P1.023.