Characterisation of power flux reduction in the Wendelstein 7-X divertor plasma with Langmuir probes

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Introduction In its present operation phase, OP1.2, the optimized stellarator Wendelstein 7-X has ten symmetric, inertially cooled test divertor units. These are located in the upper and lower half of the five identically shaped modules and intended as a robust component to prepare for the operation of the steady-state capable high heat flux divertor in OP2.

To investigate the observed reduction of power flux onto the target we will show three types of measurements and an exemplary experimental program.

Figure 1 situates the diagnostics in a common frame. It is a detail of the CAD model showing the horizontal target in module 5 and schematically the locations at which the data presented herein were collected.

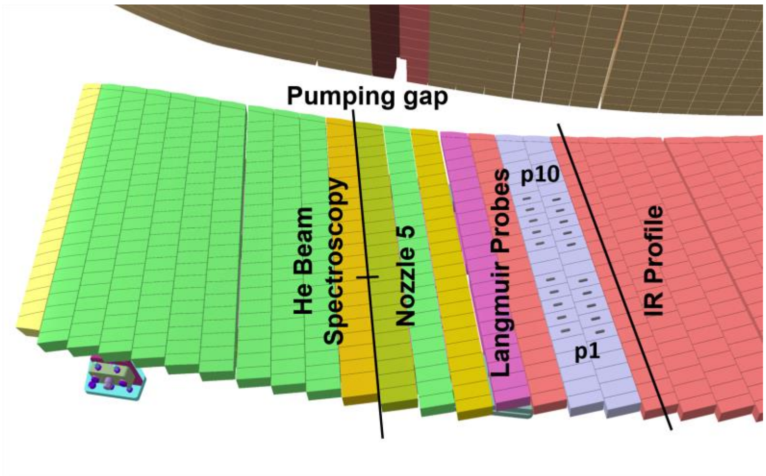


Figure 1: Location of selected divertor diagnostics

The pumping gap is approximately parallel to the toroidal direction. The Langmuir probes are embedded into the fingers composing the target, which are approximately parallel to the poloidal direction. Of the two toroidally separated arrays of probes, we actively biased the one appearing to the left in the Figure. The probe tips are facetted to make an angle of between 3 and 6 degrees with the magnetic field, depending on the configuration. We operated the ten probes as single probes with a 500 Hz sinusoidal sweep frequency and sampled current measurements with 100 kHz.

The infrared cameras observe all 10 divertors along their entire length [1], providing surface temperature data. From these the THEODOR code [2] can calculate a heat flux density q. To compare the poloidal distribution of q with the poloidal profile of the Langmuir data, we consider it only along the line labelled 'IR profile' in Figure 1.

Five nozzles of the 'Thermal Helium Beam' are located along the indicated line for injection of gases for edge fuelling, seeding and spectroscopic observation [3]. The lines of sight of the spectroscopy system are parallel to the indicated line at different heights above the target surface. In the presented experiments, we utilized nozzle 4 in module 5 for hydrogen fuelling while measuring the electron temperatures with an identical system spectroscopically in module 3 above nozzle 5.

Experimental program 20171207.011 was part of a series of experiments on detachment and executed in the 'standard' magnetic field configuration (EJM-252 index 1) which places the strikeline of highest heat fluxes close to the pumping gap and provides optimal diagnostic coverage. In addition to the mentioned edge fuelling from 2.7 to 3.1 s, the gas supply system and pellets fuelled the discharge with hydrogen.

Figure 2 shows an overview of the discharge with measurements from module 5 upper divertor. The first sub-plot shows q along the 'IR Profile' line with the red lines indicating the positions of the Langmuir probes. The strikeline is visible near the pumping gap as soon as ECRH heating is present, but shifts away and vanishes at around 3 s when edge hydrogen fuelling commences. We measure a significant power flux reduction from above 2.5 MW/m2 to below 0.5 MW/m2. The fourth plot traces the ECRH power and line integrated density measured by the interferometer. The power flux reduction occurs and is sustained at constant heating and near constant high density until the end of the discharge. The second and third plot show temperatures and densities determined by fitting to a simple exponential Langmuir model, $I=I_0*\exp([V-V_f] /T_e)$, and interpolating the values for plotting. We will investigate three time points more closely: One before the edge gas injection at 2.5 s which we label 'pre-detachment', one just after the gas injection at minimum heat flux and 3.1 s, labelled 'power detachment', and one before the end of the discharge at 3.7 s labelled 'partial power detachment'

Analysis procedure The shallow incidence angle of the magnetic field causes the sheath from which the Langmuir probe draws its current to grow with increasingly negative bias voltage, adding a linear trend to the characteristic.

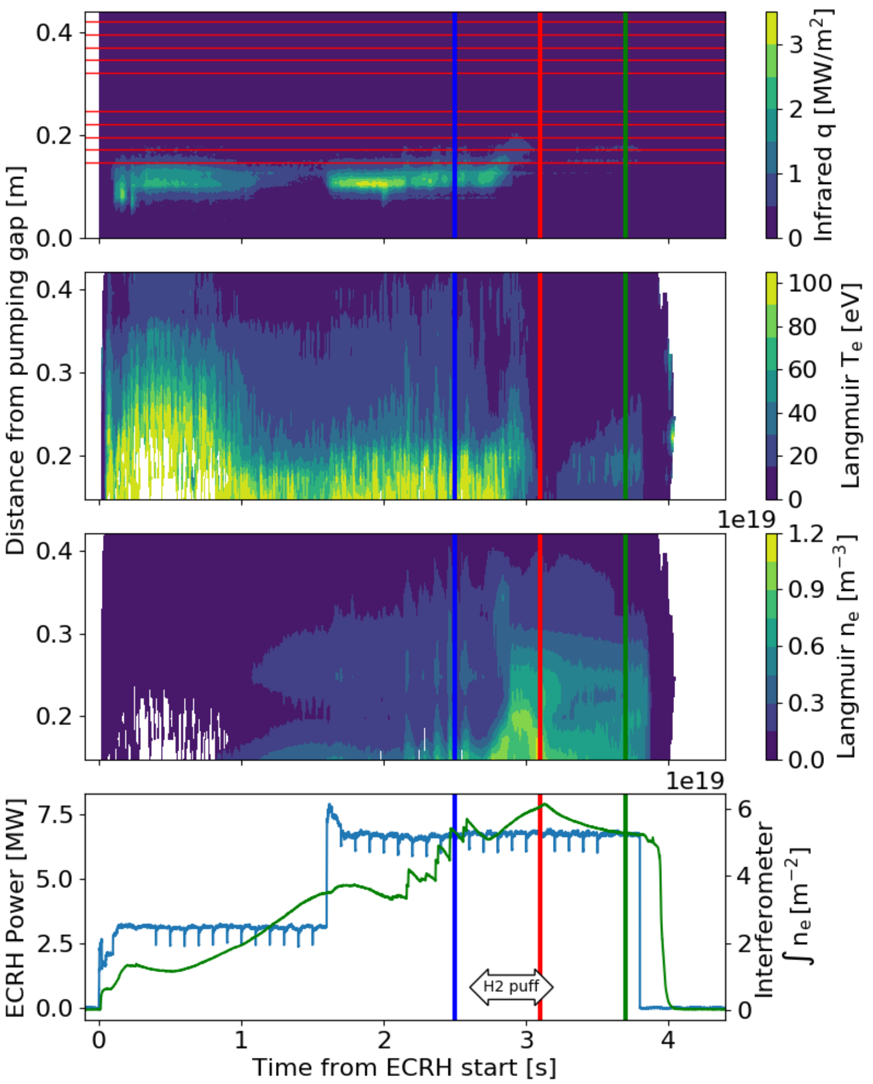
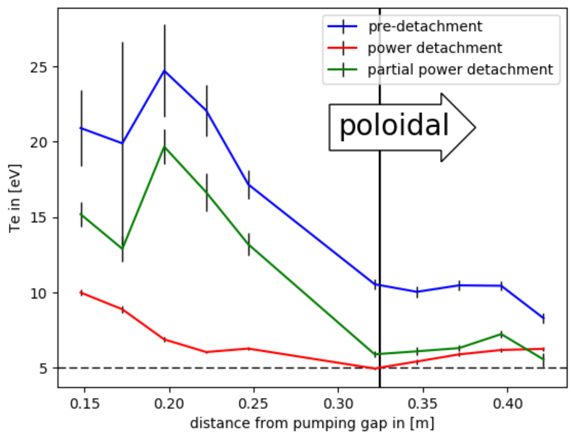


Figure 2: Overview of selected measurements in module 5 upper divertor during discharge 201707.011 Time points 'pre-detachment', 'power detachment' and 'partial power detachment' marked in blue, red and green respectively.

Not accounting for this causes overestimation of temperatures and densities. This can be seen in Figure 2 where temperatures at the 'power detachment' time remain above 20 eV which is difficult to reconcile with the high radiated power fraction measured by the bolometers at this instant [4]. Measurements of the flush mounted divertor probes employed at ASDEX Upgrade are evaluated based on the model of Weinlich and Carlson [5], which rigorously accounts for the effect of sheath expansion. We have not yet fully implemented this model in our analysis, but, as an intermediate approach, we subtract the ion current from the characteristic entirely in a first step and then fit the electron current as a function of temperature and a potential only. We applied this method for the poloidal Te profile shown in Figure 3, and in contrast to Figure 2 temperatures down to 5 eV are found.



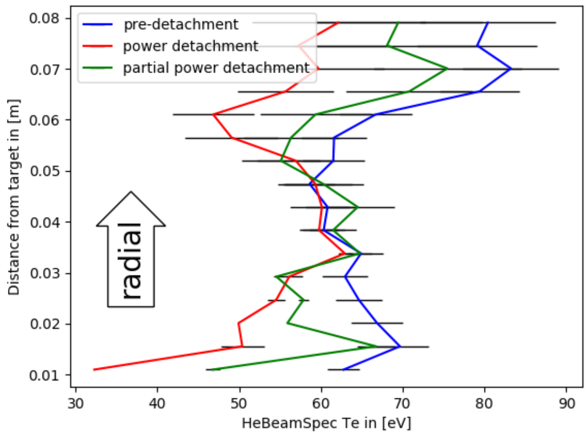


Figure 4: Poloidal profile of Divertor Temperatures **Figure 3: Radial profile of He beam temperatures**

Discussion The temperature determined at the 'power detachment' time point is sufficiently low for the reduction of the heat flux due to recombination of fuel and impurity ions to be a possibility. The subsequent rise in temperature around the 'partial power detachment' time could be the result of an influx of neutrals from the wall resulting in a radiation zone less localised to the divertors [4]. To investigate this we combine the results of the Langmuir probes with those of the thermal helium beam spectroscopy diagnostic. The evolution of the radial profile shown in Figure 4 in time broadly matches that of the Langmuir temperature timetraces. The absolute values are however significantly higher, which is surprising given the short distance parallel to the field of some tens of centimetres between the measurement location and the target. This is likely due in part to the different measurement position mentioned above and the asymmetry between the targets. Better matching cases exist and are reported at this conference by Barbui P4.1018. To assess the underlying processes more thoroughly, we will consider results from additional diagnostics and discharges. The boronisation planned for the upcoming OP1.2b campaign will permit greater control over the edge conditions and power detachment process by changing the wall from a source of fuel into a sink.

References and acknowledgement

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