Scrape-off layer width of parallel heat flux on tokamak COMPASS

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Edge plasmas in the divertor configuration were studied on the COMPASS tokamak. The dependence of the decay length of the parallel heat flux $q_{||}$ was measured at different values of plasma current and line-averaged density. We have found that $q_{||}$ decreases with both the plasma current and the line-averaged density, which is in agreement with previous results achieved on the JET tokamak.

Keywords: tokamak, edge turbulent transport, Scrape-Off layer, Langmuir probe, Ball-pen probe

1 Motivation

In the Scrape-Off Layer of tokamaks (SOL) located at the plasma edge between the separatrix and the tokamak wall, the power decay length is one of the key parameters determining the heat load on the plasma facing components.

Recent experiments on the JET tokamak revealed striking difference between discharges limited by inner and outer wall not only with respect to the SOL width but also in the characteristics of the fluctuations, supporting an enhanced radial transport near the outer midplane. Radial profiles in the inner wall configuration are broader than in the outer wall or divertor configuration. Also the amplitude of the fluctuations is significantly larger. The dependence of the SOL e-folding length on the JET main plasma parameters was also investigated and a modest inverse dependence on both the plasma current and the line-averaged density was found [1]. Interestingly, the scaling of the edge turbulent transport was found to be significantly different in limited and diverted discharges. However, the JET database is very limited and needs to be confirmed. Experiments on the middle size tokamak COMPASS [2], operational in the IPP Prague, provide a unique opportunity to contribute to the understanding of the issues described above taking advantage of the device flexibility and the well diagnosed edge plasmas.

2 Characterization of the experiment

Several diverted plasma discharges were performed with different values of plasma current and the line-average density.

The SOL plasma was diagnosed using the horizontal reciprocating probe manipulator allowing to measure the radial profiles at the plasma edge by fast moving the probe head in and out of the plasma. The probe head consisting of three Ball-Pen probes (BPP) and two standard Langmuir probes (LP), which is depicted in Fig.1.

Fig.1: Picture of the probe head exploited in the described experiments. As it is seen, the shield of the probe head is made of graphite to survive the heat flux.

The BPPs were left floating, allowing direct measurements of the plasma potential [3] at three poloidal locations. One Langmuir tip measures the floating potential. The remaining Langmuir probe is charged negatively to measure the ion saturation current. From these signals, additional plasma parameters can be determined, such as the electron density, the electron temperature [4], the poloidal phase velocity of the plasma fluctuations at two different (poloidal) positions and the fluctuation induced radial particle flux. All these quantities are determined with the temporal resolution of 0.5 μs.

3 Radial profiles at the plasma edge

The radial profiles of the floating and plasma potential and the ion saturation current in the divertor configuration are shown in Fig.2.

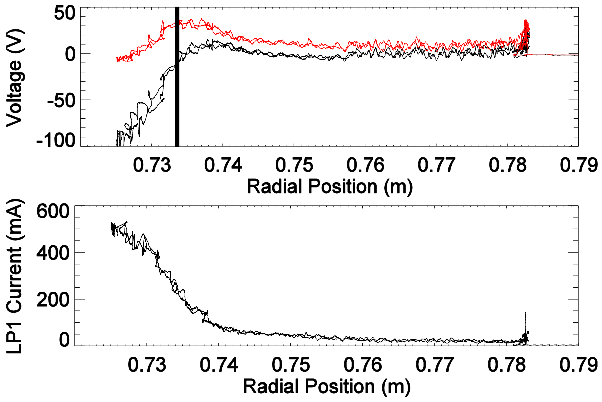

Fig.2: Radial profiles directly measured with the probe pins. Top panel – floating (black line) and plasma potential (red line), bottom panel – the ion saturation current, #6024.

The maximum of the plasma potential seen in Fig.2 corresponds to the radial position of the separatrix.

The radial electric field E_{rad} is derived as $E_{rad} = -d\phi/dr$, where ϕ is the plasma potential, directly measured by BPP. According [3] the electron temperature T_e is then obtained as $T_e = [\phi - U_{fl}]/2.2$, where U_{fl} is the floating potential of the Langmuir tip. The heat load to the first walls is determined by the plasma parallel heat flux, $q_{\parallel} = \gamma n T_e c_s$ which is proportional to the product of I_{sat} and T_e. The radial profile of this quantity in the SOL region is expected to be exponential $q_{\parallel} \sim \exp(-r/\lambda_q)$. The decay length λ_q of this radial profile is then determined.

Typically, the poloidal rotation caused by $E_{rad} \times B_{tor}$ drift changes direction at the separatrix. Thus, its position is often labelled as the velocity shear layer.

4 Determination of the separatrix

In order to determine the position of the separatrix more precisely, we have decided to calculate the radial profile of the poloidal velocity of the potential fluctuations and look for the position of the velocity shear layer. A cross-correlation analysis of the signal fluctuations of two poloidaly separated ball-pen probes, BPP1 and BPP2, has been performed. For each time interval we took the time lag at which the cross-correlation function between the two signals was at maximum. This corresponds to the time that fluctuations take to go from one BPP to the other. The result of the cross-correlation analysis is seen in the top panel of Fig.3.

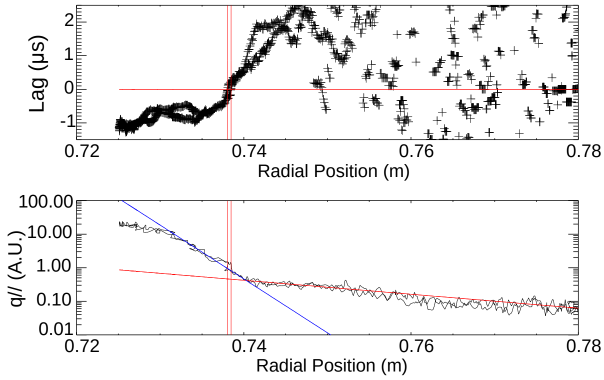

Fig.3: Radial profiles of the time lag and parallel heat flux for #6024. The position of zero time lag clearly corresponds to the separation between the two different exponential regimes.

Finally we can determine the position of the velocity shear layer that is the position at which the time lag profile crosses zero. Taking this position in consideration as the separatrix location yields a good candidate for the inner boundary in the data analysis. In Fig.3 two vertical lines were placed at the positions of the zero cross (way in and out) and they clearly mark the separation of two exponential regimes in the parallel heat flux profile. This process might be further refined by accounting for the small diamagnetic drift component [5].

5 Results and Discussion

L-mode discharges with different values of plasma current and line-averaged density were selected and the parallel heat flux decay length λ_q determined. The dependence of the parallel heat flux decay length λ_q for a current scan at constant density is plotted in Fig. 4.

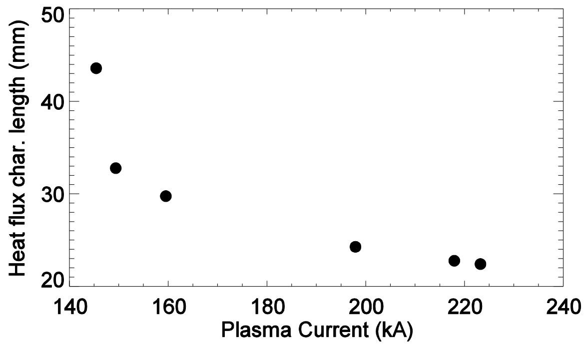

Fig.4: Dependence of the parallel heat flux decay length λ_q on the plasma current for shots #6023, 6024, 6091, 6092, 6093, 6103 with $n_e \sim 5\ 10^{19}\ m^{-3}$.

Figure 5 shows the decay length λ_q as a function of the line-average density for two values of the plasma current.

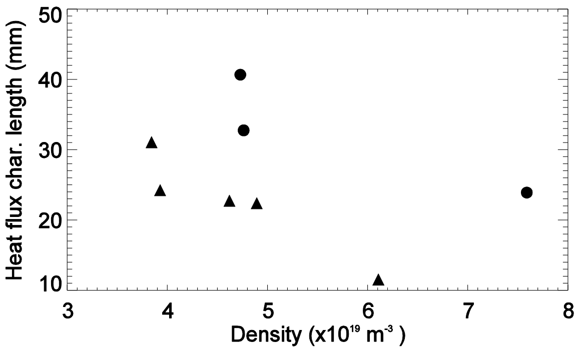

Fig.5: Parallel heat flux decay length versus the line average density. Circles: I_p = 155 kA, (# 6023, 6024, 6028); Triangles: I_p = 220 kA, (#6084, 6086, 6093, 6103, 6105).

It is evident that the decay length λ_q decreases noticeably with the line average plasma density. A possible explanation of observed dependences is based on the turbulent nature of the particle and heat transport across the magnetic field lines. The observed shortening of the decay length with I_p and n_e is probably related to reduction of the level of turbulent fluctuations the SOL with both of I_p and n_e.

For future, a few more discharges would be required to enlarge the existing dataset. More attention has to be paid to detail analysis of probe's signals during the motion of the probe head in and out of the plasma. Furthermore, the ultimate position of the probe head in the plasma has to be adjusted properly for each discharge scenario. Too deep probe position has to be avoided for two reasons:

- The Langmuir tips become emissive due to the heat flux and measure the plasma potential instead of the floating potential in this case.
- Too deep position may cause the disruption.

Finally, simultaneous analysis of plasma fluctuations would be beneficial to understand better the underlying physics.

6 Conclusions

The dependence of the parallel heat flux decay length λ_q was determined in the COMPASS tokamak for different plasma currents and densities in divertor configuration. A correlation study of the signal fluctuations of two neighboring BPPs was made in order to determine the position of the velocity shear layer and consequently the position of the separatrix. The ion saturation current and electron temperature was used to calculate the parallel heat flux $q_{||}$. An exponential profile was fitted to the SOL region to determine the profile's decay length. An inverse dependence on the scaling of this quantity was found for both the plasma current and the line-averaged density. Finally, we conclude that achieved results are in agreement with previous JET results.

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