

Infrared measurements of the heat flux spreading under variable divertor geometries in TCV

R. Maurizio¹, B.P. Duval¹, S. Elmore², N. Fedorczak³, A. Gallo³, B. Labit¹, F. Nespoli¹, H. Reimerdes¹, U. Sheikh¹, C. Theiler¹ and the TCV and EUROfusion MST1 Teams

¹ *École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), 1015 Lausanne, Switzerland*

² *CCFE, Culham Science Centre, OX14 3DB Abingdon, United Kingdom*

³ *CEA Cadarache, IRFM, F-13108 Saint-Paul-Lez-Durance, France*

Introduction

In a divertor tokamak such ITER, a significant fraction of the heating power continuously leaves the plasma core across the separatrix and enters the scrape-off layer (SOL). In the SOL heat is primarily transported along magnetic field lines towards the divertor targets. The resulting heat fluxes on the material surface are particularly high in the vicinity of the strike points (SPs), where the separatrix intercepts the divertor target. The mitigation of the peak heat flux at the target is currently a crucial research topic. One mitigation strategy is based on the optimization of the divertor geometry, which, for example, can be performed by changing the target flux expansion (f_x) or the divertor leg length. The former is defined as the ratio of the distance between two flux surfaces evaluated at the target ρ_t and upstream at the outboard midplane ρ_u , namely $f_x = d\rho_t/d\rho_u$. This paper presents a study of the influence of the outer divertor leg length on the heat flux profiles at the targets for low-confinement (L-mode), single-null (SN) plasmas. The investigated divertor configurations, together with the corresponding inner and outer leg connection length L_{\parallel} profiles (the L_{\parallel} is defined as the length of the magnetic field lines from the outer midplane, where the majority of heat enters the SOL, to the divertor target) are shown in figure 1. The outer divertor leg L_{\parallel} was varied by varying the vertical position of the magnetic axis z_{mag} while keeping the plasma shape and divertor configuration (e.g. f_x) similar. When the plasma is moved upwards, the outer connection length L_{\parallel} increases. The scan has been performed with ohmic heating only, at multiple values of plasma current ($I_P = 130$ to 340 kA) and ohmic power ($P_{\Omega} = 130$ to 400 MW), constant Greenwald fraction ($n_e/n_{GW} \approx 0.2$), both in forward field (ion ∇B drift downwards) and reversed field (ion ∇B drift upwards).

Experimental setup and diagnostics

The heat flux on the material surfaces in TCV is measured using Langmuir Probes (LPs) and InfraRed (IR) thermography. With the analysis of the LP measurements for this experiment having been presented in [1], this paper focuses on IR measurements. The TCV IR thermography system consists of two IR cameras. A recent upgrade of the system has improved its

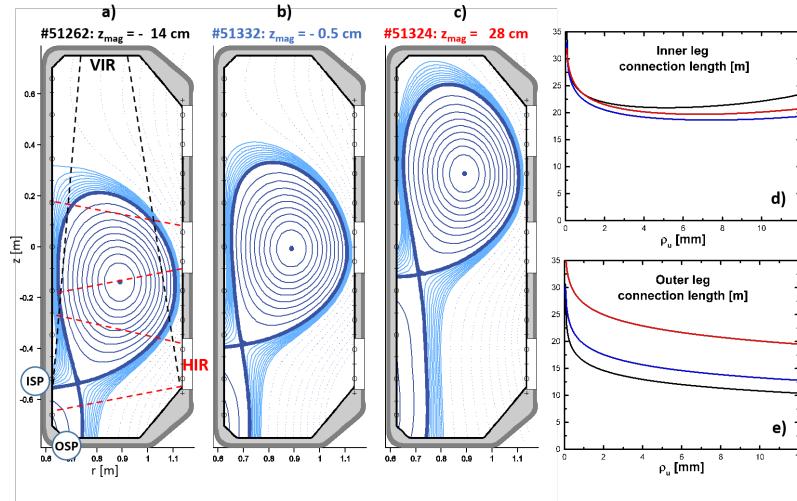


Figure 1: Scan of z_{mag} in forward field: poloidal views of the magnetic reconstruction (a-c) and $L_{||}$ profiles for both the inner (d) and outer (e) divertor leg as a function of the outboard midplane distance to the separatrix, ρ_u . The field-of-views of the VIR and the HIR (lower and middle plane ports) are also indicated.

capabilities for measuring divertor heat loads in multiple magnetic geometries for both strike points simultaneously. The first IR camera (Vertical InfraRed, VIR) is mounted on the top of the machine and images the vessel floor with the outer strike point (OSP) of a typical SN plasma (see figure 1). The acquisition rate and spatial resolution are 400 Hz and 2.5 mm in full-frame respectively. The second camera (Horizontal InfraRed, HIR) is mounted on a lateral port and images a portion of the central column with the inner strike point (ISP). The rate of acquisition and resolutions are 200 Hz and 0.8 mm in full frame and using a 25 mm focal-length lens. The HIR field-of-view can be doubled by using 12.5 mm focal-length lens, while reducing the spatial resolution by a factor 2. The camera can be alternatively mounted on the lower or mid plane port, figure 1a). The upgrade of the TCV IR system also involved the data analysis improving the correction for the shaking of the video during the discharge and the contamination from non-thermal light for the VIR.

Results

A direct comparison of the heat flux profiles from different shots requires first to decouple the spreading effect of the target heat flux profile due to any variations in the f_x from variations of the profile due to the increased $L_{||}$. The technique adopted here is to map the target heat flux profile on the outboard midplane in two steps. Firstly, flux surfaces in the SOL are labeled by the upstream coordinate ρ_u , which is defined as the outboard midplane distance to the separatrix. Secondly, the parallel (along field lines) heat flux on the target is computed by considering the field line grazing angle γ ($q_{||,t} = q_{\perp,t} / \sin(\gamma)$) and it is projected upstream, $q_{||,u}^* = q_{||,t} \cdot B_{tot,u} / B_{tot,t}$.

The quantity chosen as ordering parameter is the *average connection length*: this is obtained by

averaging the outer leg L_{\parallel} profile in the first 2 mm of the SOL (figure 1). IR measurements clearly indicate that an increase of the outer L_{\parallel} induces a drop of the total power reaching the floor (figure 2a) but even a larger decrease of the peak heat flux (figure 2b) resulting in an increase of $\lambda_{int,u}$ (defined as $\lambda_{int,u} = \frac{1}{\max(q_{\parallel,u}^*)} \int q_{\parallel,u}^* d\rho_u$), discussed later, for both forward and reversed field (figure 2c).

The parallel heat flux profile is parametrized by the convolution of a decaying exponential and a Gaussian [2]; in figure 4 the experimental $q_{\parallel,u}^*$ profile with the fitting curve for three plasma positions (forward field) are presented. The decay length of the exponential is indicated by $\lambda_{q,u}$ (SOL-power fall-off length), the width of the Gaussian by S_u (spreading factor). The trend for $\lambda_{q,u}$, shown in figure 3a), is consistent with that for $\lambda_{int,u}$; also, no clear dependence of the spreading factor S_u on L_{\parallel} is found, figure 3b). Both results confirm the LP analysis ([1]) and are similarly not predicted by diffusive models. According to purely diffusive models, a longer L_{\parallel} obtained by increasing the divertor leg length should result in a greater cross-field diffusion in the private-flux region and should lead to a greater S_u . Conversely, the influence on the SOL power decay length is not expected to be so strong as the core plasma does not change. The inner divertor heat flux profile displays a double-peak shape in forward field, as reported for JET [3] and TCV [4], which may be caused by enhanced $\vec{E} \times \vec{B}$ drifts in the SOL. An extension of the standard heat flux profile parametrization is here proposed by adding a sink-source function to the usual parametrization, shown in figure 4: the power missing from the separatrix region (negative part of the profile, 'sink') is found on the far-SOL region (positive part, 'source'). Analytically, the function is the superimposition of two half-wavelets functions via the Heaviside step function; the areas of the two are constrained to be equal for the conservation of the total power. The extended parametrization allows to extract the usual parameters $\lambda_{q,u}$ and S_u from a doubly-peaked profile the equivalent Eich profile (shown in figure 4, black dashed-line).

The effect of the outer leg connection length on target heat flux spreading is being investigated with two orthogonal approaches: (1) a divertor leg length scan at constant current (presented above), (2) a plasma current scan at fixed shape, since L_{\parallel} depends negatively on the current. Results from (2) are consistent with (1): $\lambda_{q,u}$ is found to increase with L_{\parallel} , namely with lower

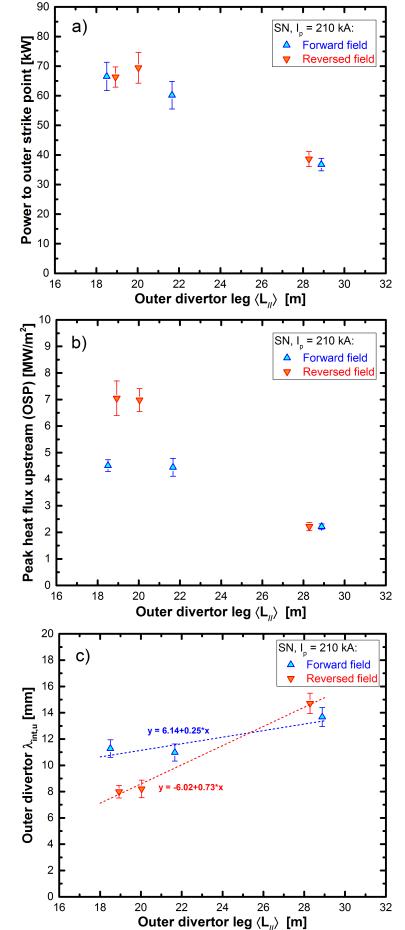


Figure 2: Power to outer strike point (a), peak value of $q_{\parallel,u}^*$ (b) and $\lambda_{int,u}$ (c) as a function of the outer leg L_{\parallel} , in forward (blue) and reversed field (red).

I_P . The dependence between $\lambda_{q,u}$ and plasma current is $\lambda_{q,u} \sim I_P^{-0.515}$, similar but weaker than previous scalings, $\lambda_q \sim I_P^{-9/8}$ [2].

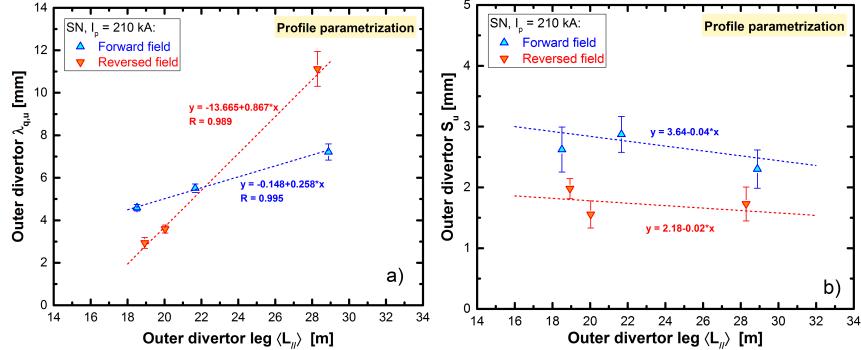


Figure 3: Outer leg $\lambda_{q,u}$ (a) and S_u (b) as a function of the outer leg connection length.

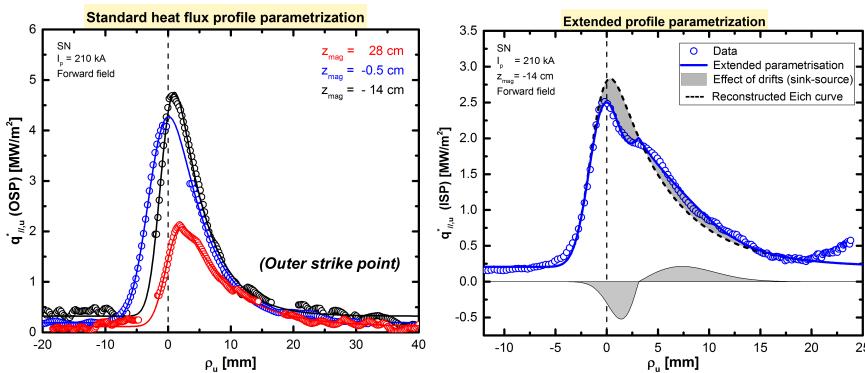


Figure 4: Example of parallel heat flux profiles mapped upstream for the outer (left) and inner (right) strike point. In the latter, the extended profile parametrization is also presented.

Conclusion

The dependence of target heat flux spreading on the outer divertor leg connection length, for SN L-mode deuterium plasmas, has been investigated in TCV: the preliminary results, quite unexpected, indicate that the connection length influences positively the SOL power fall-off length while no effect on the spreading factor is seen. Further investigations are currently underway to interpret these outcomes.

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