

Heat flux measurements on graphite samples in RFX-mod

N. Visonà^{1,2}, A. Canton², P. Innocente²

¹ Università degli studi di Padova, Padova, Italy

² Consorzio RFX, Associazione EURATOM-ENEA sulla Fusione, Padova, Italy

mail: nicolo.visona@igi.cnr.it

Introduction. The study of plasma-wall interactions (PWI) is interesting in the perspective of a fusion reactor because the behavior of the first wall (FW) can influence directly the plasma core and the achievable fusion power. In particular the FW has to be able to manage the intense, hot plasma exhaust.

Experiments have been carried out in RFX-mod ($r/R=0.46/2$ m) in order to investigate the plasma edge of the circular shaped reversed field pinch (RFP) configuration from a heat flux point of view analyzing the heat distribution on three graphite samples inserted as limiters up to 12 mm inside the plasma. About half hundred deuterium pulses were executed with plasma current: $0.6 \div 1$ MA, plasma density: $0.5 \div 3 \times 10^{19} \text{ m}^{-3}$ ($n/n_G < 0.7$), reversal parameter F : $0 \div -0.12$ and peak temperature up to 1500 °C. The samples had two different shapes, one with a corner and one curved, and were also made of two different types of graphite, the Mersen 5890PT which is the same as the present FW, and the Toyo Tanso IG-15 with incremented heat conductivity. An infrared camera (200 Hz resolution) has been set up and used to evaluate the temporal and spatial heat flux distribution from temperature measurement.

Temperature map on the samples. The heat print on the samples was different depending on several parameters, first of all the shape of the interacting surface. While the angular

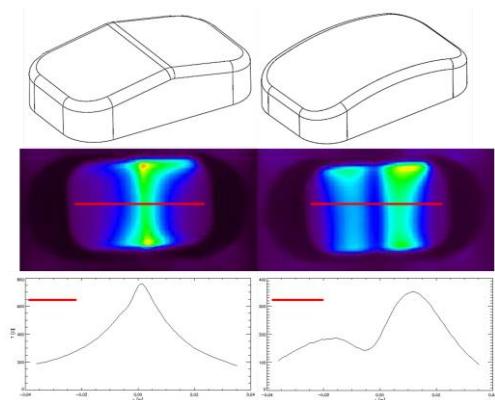


Fig. 1: samples geometries, IR images and temperature profiles along a line.

sample had the maximum interaction on the corner (incident to the plasma), the curved one had two peaks away from the top (tangent to the plasma) as shown in fig. 1. This is a known result and is explained by the fact that the heat flux is carried to the plasma surface mainly by convection (parallel to the plasma surface) and there is only a small fraction that is diffused (perpendicular). Another thing that is immediately seen is that the electron drift side is always significantly hotter than the

other especially at low values of density as $n/n_G < 0.2$. This was already been seen in RFX and in other RFP experiments [1] and it is recognized as a signature of the superthermal electrons.

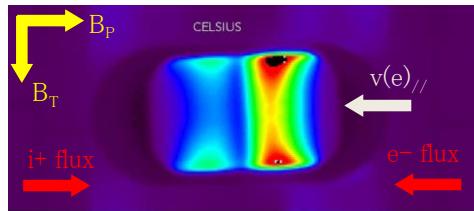


Fig. 2: sample orientation in the plasma velocity. In fact these electrons lay in the high energy tail of the energy distribution at the edge and can contribute to the sustainment of RFP configuration reducing the requirement to the turbulent MHD dynamo.

Heat decay length. IR images have been analyzed with the THEODOR code [2] in order to numerically solve the heat conduction inverse problem and to extract heat profiles from temperature maps evolving in time. Given the surface heat power profile (q_s) computed along a line, neglecting the perpendicular heat diffusion, the plasma parallel heat flux has been computed considering the local slope (α) of the samples by the relation: $q_{//}(x) = q_s(x) / \sin(\alpha)$. The approximation of a negligible perpendicular heat flux has been made as a starting point. The heat decay length and the heat peak have been evaluated assuming a heat exponential decay using the usual relation for the parallel heat flux in the SOL $q_{//}(r) = q_{//}(r_0) \exp[-(r-r_0)/\lambda_q]$ [3] where λ_q is the heat decay length and $q_{//}(r)$ is the heat measured at a distance $r-r_0$ the top of the sample outwards; in particular the distance along the sample has been converted in radial distance.

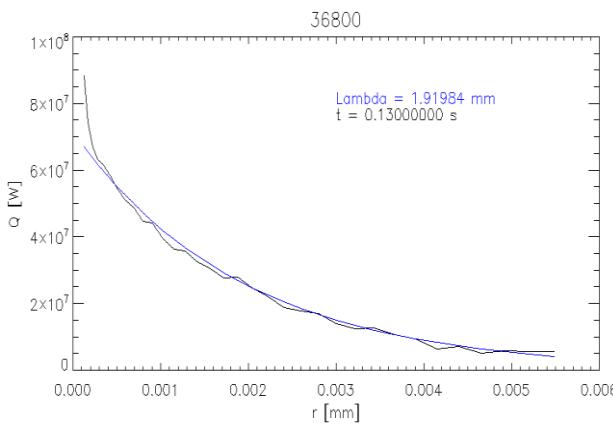


Fig. 3: radial dependence of measured parallel heat flux and computed exponential fit

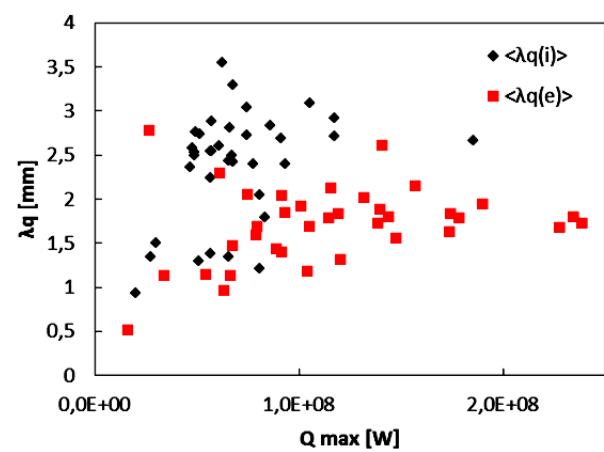
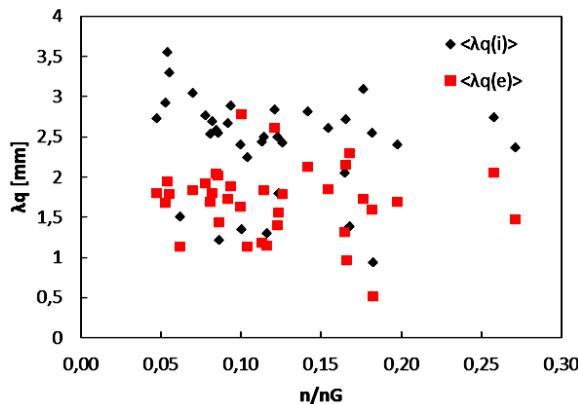
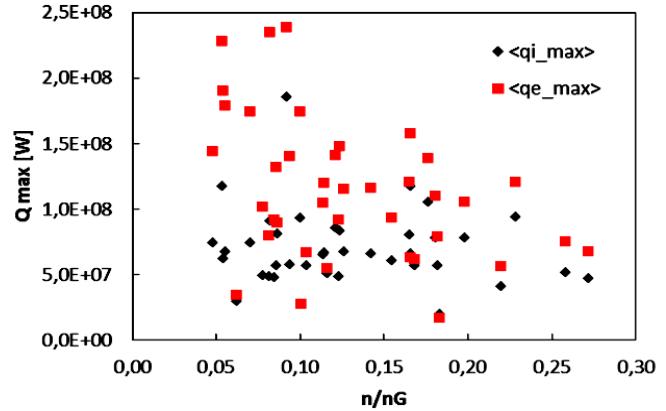


Fig. 4: computed λ_q versus $q(r_0)$ for the ion and electron sides (averaged on single shots).

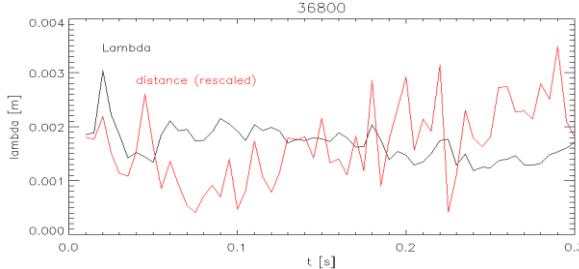
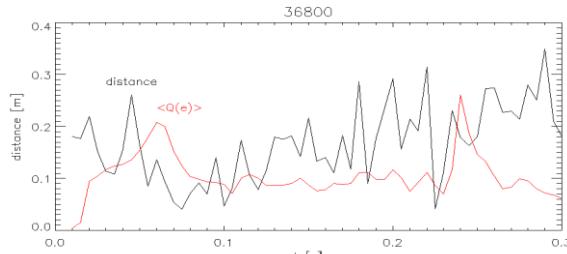
In fig. 3 it can be seen that the exponential decay describes very well the radial dependence of the parallel heat flux in the RFX-mod SOL. This confirms λ_q as a good parameter to analyze plasma transport in the SOL, for this reason it has been used to study the dependence of SOL transport on plasma parameters. Fig. 4 shows the dependence of λ_q from the heat peak,

indicating that larger values of the heat peak correspond to larger heat decay lengths, and it is also dependent on the side; every point in this graph corresponds to a different pulse and is a global average of a side of the sample in time. For the curved sample, inserted at 12 mm closer to the plasma from the surface of the FW, average heat flux have been found around 50 MW, with peaks as high as several times the average while values for λ_q are around 2 mm on average for the electron side and around 3 mm for the ion side. Fig. 5 shows that λ_q does not depend from n/n_G and fig. 6 shows the correlation between the heat peak and n/n_G . While $q(r_0)$ is constant for the ion side, higher values of the heat peak are seen for the lowest values of n/n_G in the electron case, this can be caused again by the superthermal electrons.

Fig. 5: λ_q versus n/n_G for the ion and electron sideFig. 6: $q(r_0)$ versus n/n_G for the ion and electron side

One aspect that makes the study of SOL parameters in the RFP devices challenging is the lack of a well-defined interaction point and consequently of the last closed flux surface (LCFS). The problem is mainly related to the toroidal local deformations of plasma surface but also to

existence of true flux surfaces. Since the toroidal field at the edge is nearly zero and perpendicular transport is not negligible, when the plasma is strongly deformed in one toroidal section, it is not obvious that far from that toroidal section the heat power is ‘confined’ on the same flux surface. To get an indication on what defines the plasma boundary (and so the SOL region), the heat load and decay length have been compared to the local plasma shift and the local distance of the LCFS due to the deformation at all the toroidal locations

Fig. 7: $\lambda_q(e)$ compared with LCFS distance (rescaled) from sample in a discharge.Fig. 8: distance compared with heat averaged on the e^- side surface and rescaled to fit in the graph.

evaluated from magnetic signals [4]. In fig. 7 it is shown the time dependence of the plasma distance and $\lambda_q(e)$, while in fig. 8 the distance is plotted together with the average heat load on the electron drift side. The results of this first analysis do not show a correlation between these parameters, further work is necessary to include also the perpendicular component of the heat flux and better estimates of the position on the plasma with respect to the sample.

Correlations with plasma parameters.

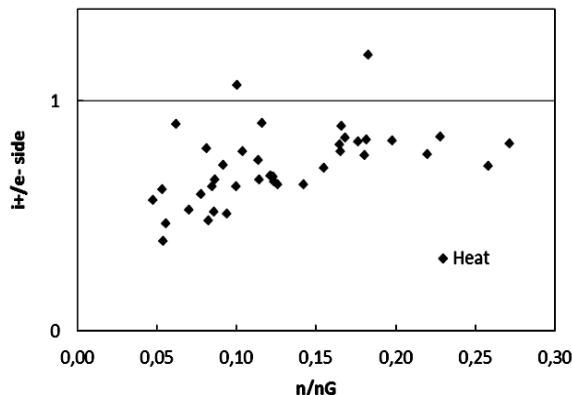


Fig. 9: heat ratio between sides versus normalized density

flux on the electron side. The few points above 1 refer to low interacting situations.

Conclusions. An experimental campaign has been done at RFX-mod in order to measure heat flux parameters of the plasma edge in the reversed field pinch configuration with a circular deuterium plasma during medium power discharges. Three graphite samples have been inserted in a limiter configuration and the measures were obtained with an IR camera. The heat dynamics has been numerically extrapolated from time and space dependent temperature maps to calculate heat flux and it has been possible to evaluate average heat loads around 50 MW with peaks up to several times the average, and also to calculate the heat decay length, λ_q , with values around 2 mm for the electron drift side and 3 mm for the ion side. A strong asymmetry in heat fluxes between ion and electron drift side at low density ($n/n_G < 0.2$) has been recognized as a distinctive sign of superthermal electrons, which are high energy electrons accelerated in the plasma core and escaped to edge due to low collisionality.

References.

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The dependency of temperature asymmetry on plasma density is shown in fig. 9, where the ratio of the average heat flux between the ion and electron side has been plotted against the ratio between the plasma and the Greenwald density. The data show an asymptotic dependence approaching 1 for values of $n/n_G > 0.2$ where the heat flux tends to be equal in both sides, while for $n/n_G < 0.2$ the vast majority of points shows a much higher heat