*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.003 (2005)*

Visualisation of the deposited layer on the Toroidal Pumped Limiter of Tore Supra using IR data during disruptions

Y.Corre[1], C. Brosset[1], E. Dufour[1], D. Guilhem[1], C. Lowry[1], R. Mitteau[1], P. Monier-Garbet[1], B. Pégourié[1], E. Tsitrone[1], S. Vallet[1]

[1] *Association EURATOM-CEA, DRFC, CEN Cadarache, 13108 St Paul lez Durance, France*

1. Introduction: Measurement of heat flux deposition on the main plasma facing components is an essential issue for safety and also to validate models that describe transport of particles and energy in the scrape of layer. The procedure to deduce the heat flux from the IR surface temperature measurements is often complicated by the presence of a surface layer of low thermal conductivity resulting in a higher temperature for a given flux [1]. The presence of the surface layer is also matter of concern considering the edge plasma wall interaction, as a potential source (release of deuterium and hydrocarbon) or sink (sticking and retention processes) of particles. We propose here to visualize the deposited layer on the Toroidal Pump Limiter (TPL) using IR data during disruptions. The area size and shape are, and this is the main advantage of using IR data during disruptions, investigated during the experimental campaigns.

2. The wide angle infrared measurement in Tore Supra: This system [2] allows 2D measurement of temperature over a 60° toroidal section of the actively cooled TPL located at the bottom of the vacuum vessel of Tore Supra. The sampling rate is 50 Hz but the exposure time is shorter and adapted to the signal intensity. For each pixel the camera electronics chooses the best exposure time. Three exposure times are used: 340μs for surface temperature measurement ≤ 300°C, 65μs when $300 \leq T_s \leq 800$°C and 11μs when $T_s \geq 800$°C. The exposure time switches automatically during the time window of the frame (= 20 ms) to the next and lower exposure time when the pixel is overexposed. As a consequence, if the temperature distribution over the TPL exceeds 300°C, then a single frame will contain areas recorded at a different time in function of the selected exposure time. The system is therefore limited for measurement of fast event such as disruption (when the variation occurs into the 20ms time window). In Tore Supra, the energy release during disruptions is in most of the case fast (< 10 ms) and high enough to illuminate the deposited layer very rapidly. The IR images analysed in this paper have been voluntarily truncated when the temperatures gets too high (when $T_s \geq 300$°C), allowing us to get an instantaneous picture of the TPL temperature distribution truncated at 300°C.

3. Viewing of the deposit using IR images during disruptions: Only disruptions triggered by density limit have been analysed. Assuming that the energy release during the disruption is mainly lost with radiation processes implies the deposited heat flux on the TPL to be uniform. In such circumstances, the TPL is uniformly wetted which makes the deposit easily visible using the IR images. This is illustrated in Fig. 1 (a) showing the variation of temperature (ΔT obtained by subtracting the image *during* and *before* the disruption) during the disruption #34500 at t=12,6s. Disruption causes sometimes displacements of the endoscope system, it has been necessary to adjust both images *before* and *during* to correctly get the ΔT frame.

The signature of the deposited layer as shown in Fig. 1 appears clearly on the leading edges of the tiles (it enables us to reconstruct the geometry of the TPL) and also on the top of the tiles in some particular areas. Deposited layer covering the top of the tiles are over lined in Fig. 1a (it is plotted using the white line contour where ΔT ≥ 100°C)[1]. A periodic pattern[2], consequence of the large ripple of Tore Supra, is clearly observed on the TPL. This pattern is the negative film of the heat flux deposition pattern, i.e. the sum of convective, fast particles and radiation deposition. The observed deposition pattern is mainly composed of two separates areas at the frontier of the net erosion zone as described in [3]. These two zones have been labelled S_1 and S_2 in the figure above. The resulting IR deposition pattern is compared to the photography presented in Fig. 1b. IR images agree very well with the photography. Four zones presenting distinguishing features can be described separately:

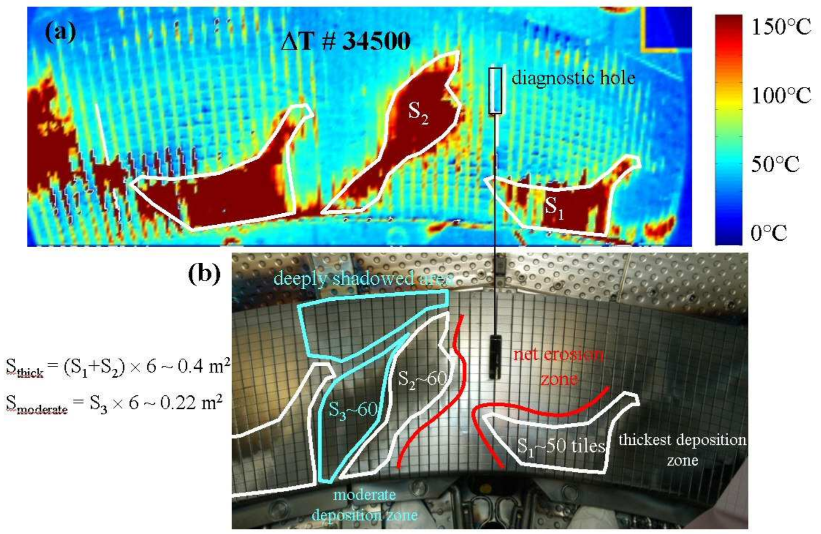

Figure 1: (a) Increase of temperature on the TPL during the disruption as measured by the wide angle IR camera. (b) Same part of the TPL without plasma.

- The thickest deposition zone viewed by the IR system during disruption (ΔT > 100°). This area is also visible on the photos taken during a visual inspection as solid grains, flakes, and thick films [4].

[1] ΔT has been truncated when the temperatures gets too high (when $T_s \geq 350°C$), as described in section 2.
[2] The periodicity is confirmed with the two wide angle IR cameras looking at two different sections of the TPL.

- The net erosion zone which doesn't show any deposit, except in the gap between the tiles.
- The moderate deposition zone, which shows a moderate increase of temperature during disruption (few tens of degrees). This area is well seen on the photo as a very thin and well attached layer.
- The deeply shadowed area which shows a small increase of temperature during disruption and no particular deposit on the photo.

The picture of the carbonaceous deposits seen during disruptions (about 15 disruptions have been analysed in the range of pulses from #31465 to #34500) that has been presented above is globally constant on the centimetre scale.

4. The cooling time constant: The thermal response for a given heat flux is intrinsically dependant of the surface layer properties: ρ, C_P, κ, e, H, where ρ is the density, C_P the specific heat, κ the heat conductivity, e the thickness of the layer and H the heat transfer coefficient.

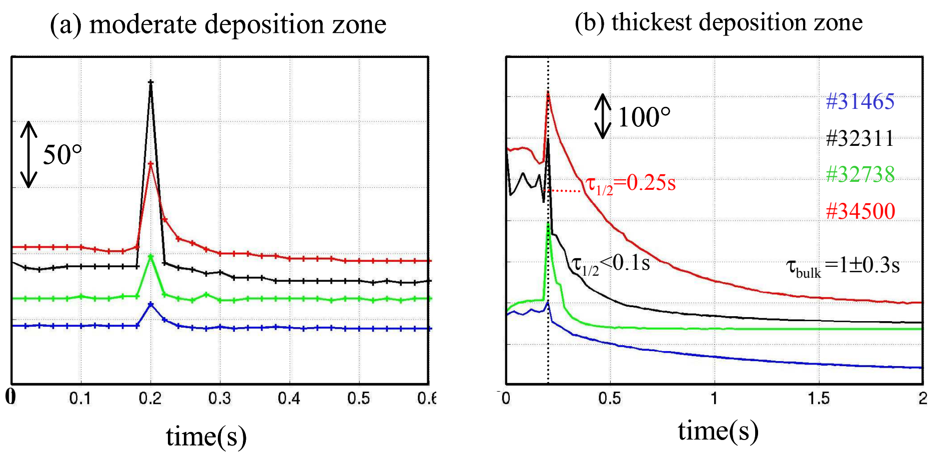

Figure 2: Temperature as measured by the IR wide angle camera on the moderate (a) and the thickest (b) deposition zone. Data have been artificially synchronized and shifted in the temperature scale to make the comparison easier.

Even if it remains difficult to deduce or measure these parameters, the cooling time constant gives some indication related to the thickness and the adhesion of the layer. Fig. 2 shows the temperature evolution during the disruption in the moderate (a) and in the thickest (b) deposition area. In the moderate deposition area, the heating and cooling time constants are very sharp $\tau_{cool} \leq 20$ms. This is the characteristic of a very thin and well attached layer (consistent with the visible observation). In the thickest deposition zone, the heating time constant due to the disruption is very sharp as well, whereas the cooling time constant is much longer due to the cooling of the bulk. In this zone the cooling time constant is varying in the range of 0.1 to 0.5s, significantly shorter than the tile expected time constant typically 1±0.3s [5].

5. Cartography of the deposit: As shown in the previous section, the detailed properties of the surface layer are very difficult to characterise separately. Assuming that the response of the layer is varying as a function of the heat flux it is possible to map the global TPL thermal response using different intensities of disruption. Fig. 3 shows the average normalized ΔT that is obtained using three disruptions: #31465 (small disruption with Ip=0.6MA and W_{dia}=0.1MJ) ; #33393 (medium disruption with Ip=1MA and W_{dia}=0.1MJ); #34500 (strong disruption with Ip=1MA and W_{dia}=0.3MJ). The contour plot indicates the degree of sensitivity of the surface layer as a function of the position on the TPL. The area delimited in red is very sensitive to the heat flux, possibly the thickest and/or the less sticky area on the TPL.

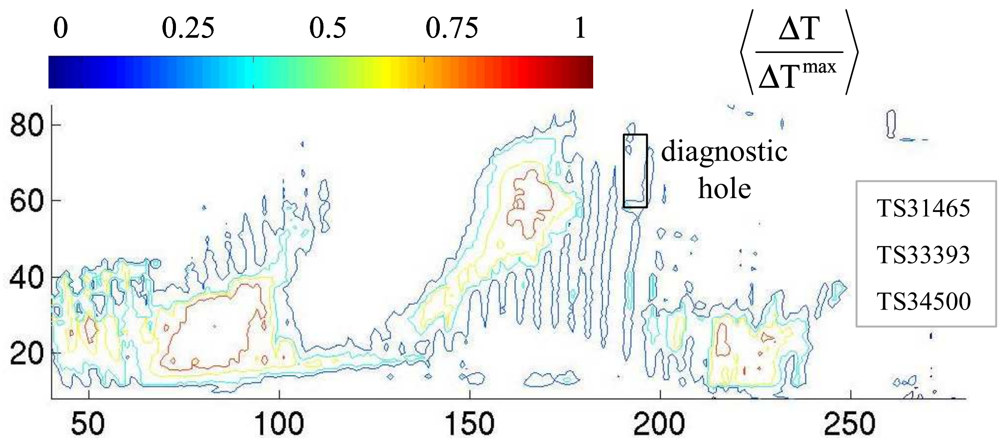

Figure 3: Average of the normalized ΔT measured during a small, a medium and a strong disruption.

6. Conclusion. IR images monitoring during disruption is a powerful tool to visualise the deposited layer. The general pattern of the deposited layer viewed on the TPL is more or less constant on the centimetre scale over ~ 4000 pulses. The surfaces of the thickest and moderate deposition zone have been estimated to be in total onto the entire TPL ~ 0.4 and 0.22 m^2 respectively. The thickest deposition zone shows different thermal intensities for a given heat flux possibly related to the thickness and/or the adhesion of the surface layer. Sharp heating and cooling time constant in the moderate deposition zone are indication of a very thin and well attached surface layer.

References:

[1] P. Andrew et *al*., Plasma Phys. Control. Fusion **37** (1995) 17
[2] R. Reichle. Nucl. Fusion **43** (2003) 797-804
[3] R. Mitteau et *al*., Physica Scripta. Vol. T111, 157-162 (2004)
[4] C. Brosset et *al*., J. Nucl. Mater 337 – 339 (2005) 664 – 668
[5] R. Mitteau et *al*., 16th International Conference on Plasma Surface Interactions in Controlled Devices (PSI 2004, Portland, USA), to be published in J. Nucl. Mater