Heat Loads On Tore Supra ICRF Launchers Plasma Facing Components

S. Brémond, L. Colas, M. Chantant
B. Beaumont, A. Ekedahl, M. Goniche, P. Moreau, R. Mitteau

Association EURATOM-CEA, CEA/Cadarache, 13108 ST PAUL-LEZ-DURANCE, France

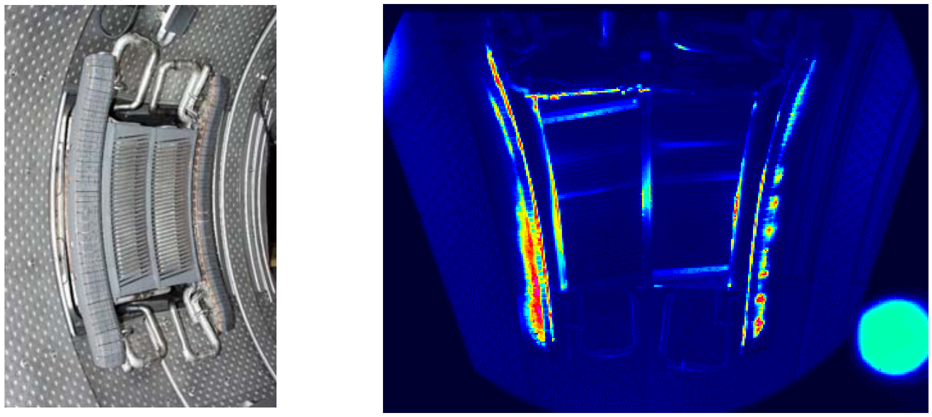
Abstract. Understanding the heat loads on Ion Cyclotron Range of Frequency launchers plasma facing components is a crucial task both for operating present tokamaks and for designing ITER ICRF launchers as these loads may limit the RF power coupling capability. Tore Supra facility is particularly well suited to take this issue. Parametric studies have been performed which enables to get an overall detailed picture of the different heat loads on several areas, pointing to different mechanisms at the origin of the heat power fluxes. Lessons are drawned both with regards to Tore Supra possible operational limits and to ITER ICRF launcher design.

Keywords: Ion cyclotron resonant heating, heat loads, edge plasma physics.
PACS: 52.35.–g , 52.35.Hr, , 52.40.Fd, 52.40.Kh , 52.50.–b

1. INTRODUCTION

Limitation in operation due to hot spots and possibly erosion of IC Launchers (ICL) parts were reported in several present tokamaks. On Tore Supra (TS), such events occurred in 1998[1,2], which was overcome with some modification of the Faraday shield electrical connections, but still, very high temperature were observed on recent high power medium duration pulses (8 MW 20 s), very close to the PFCs limits. The issue may be even more critical on ITER due to foreseen 10 MW/m^2 ICRF launcher power density, typically a factor of 2 or 3 higher than the current operating values, and to long pulse duration. The critical issue is not in the mean heat loads to be withstand by ICRF PFCs, but in the peaking of these loads on some small specific areas.

Tore Supra is particularly well suited to tackle this issue because i) the three TS ICRF launchers are now monitored with a new infrared imaging system with 1cm x 1 cm spatial resolution and 20 ms time resolution[3], ii)the TS ICRF launchers PFCs are water cooled. As a consequence, power heat fluxes can be inferred from steady state temperature and energy cross-checked with calorimetric data, iii) the TS ICRF launchers can reach high power density over the Faraday screen surface (8 MW/m^2 very routinely and up to 11 MW/m2 quiet currently)[4], have long pulse capabilities (60 s at 8 MW/m^2), and are radially movable. The TS ICRF launchers PFCs consists of CFC private limiters on both side of the launchers and of a B_4C coated Faraday screen (see Figure 1).



A) **B)**

FIGURE 1. A) Picture of one ICRF launcher in Tore Supra vessel **B)** IR typical picture

A general analysis of both IR and calorimetry data over TS 2004 experimental campaign was performed, focusing on two high performance pulses (8 MW 20s and 4 MW 60 s of coupled ICRF power) and a series of dedicated pulses where parametric studies were carried out varying parameters such as rate of private/ total ICRF power and LH power, plasma density and current, and plasma - start-up limiter -launcher gaps. Whenever possible, change on parameters was performed during the pulse to avoid any possible biasing of the analysis. Several heat loads areas on the ICRF launcher PFCs were defined and systematically studied.

A brief inventory of expected heat loads from past experimental results and associated modeling can be made: apart from convected and radiative heat loads, two types of heat loads due to fast particles generated by IC and LH launcher near fields play a role: Fast ions produced by RF voltage rectification (sheath effect) near IC launcher were already shown to explain hot spots on the IC launcher FS corners[1]. In particular, the move of related hot spots from bottom right FS corner to top left FS corner when the plasma current and magnetic field was reversed in the framework of the CIEL upgrade of TS was explained by the development of convective cells due to radial gradient of the rectified voltage cross with the magnetic toroidal field. Fast electrons produced by stochastic acceleration near LH launchers were also evidenced to be responsible of hot spots on IC launcher magnetically connected to LH grill waveguides (with the same poloidal periodicity as the LH waveguides)[5]. The radial extension of the electron beam was found to be of the order of 10 mm. To end the list of possible heat loads, RF ohmic losses, fast particles from the core plasma and acceleration of particles on parasitic resonant layers can also be mentioned.

2. HEAT LOADS CHARACTERISATION

Many data were analyzed and only highlights can be given in this paper. From an overview of calorimetric data, it can be said that: i) heat fluxes on each ICL guard limiter range from 0.5 to 2.5 % of the total injected power, which would results in up to 15 MW/m^2 at present maximum total power (10 MW) if all the fluxes were to be focused on the leading edge (but it is not the case). ii) heat fluxes on each ICL Faraday screen range from 0.3 to 1.5 %, which results in up to 1 MW/ m^2 mean heat flux over the FS surface at present maximum total power. Some correlation are found between IC private power and FS mean heat flux, but not systematically and less clearly on one launcher. The RF ohmic losses are checked to be negligible by comparison of similar shots with/without IC power on one launcher. Radiating power which can be estimated around 0.05 MW/ m^2 at present maximum power (assuming a typical 20% of radiating power) is also negligible with regards to other heat loads.

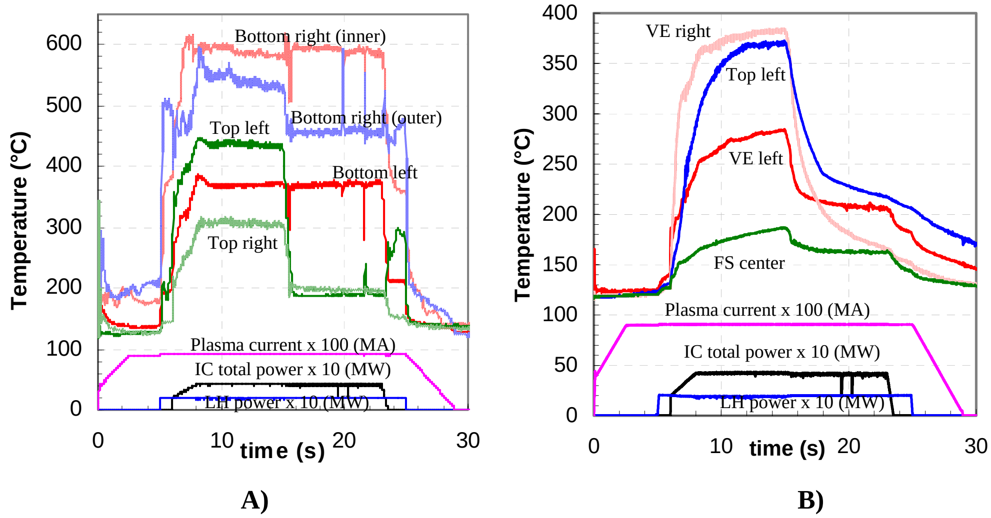


FIGURE 2. EFFECT OF IC TOTAL/PRIVATE/LH POWER A) Guard limiters time traces **B)** Faraday screen time traces (IC launcher switched off at 15 s at constant total IC power)

From parametric studies, it can be deduced that bottom areas of ICL guard limiters are mainly sensitive to total convected power. The warming up is found to be lower at high density and large plasma-launcher gap, as expected from convected power scaling, but i) differences between ICL is observed on IR data maximum warming up that are not consistent with calorimetry, and variable discrepancies between left/right side, confirmed in this case by calorimetry, are observed not due to geometrical misalignment. These observations are considered to be related to the effect of low thermal conductivity carbon type deposits –whose thickness could be related to the guard limiter lifetime in the vessel – and will be cross-checked in the next campaign after cleaning up of parts of these areas. Yet, the preferential collection of convected power on bottom areas is still to be clearly understood. ii) some specific areas are sensitive to LH power as expected when magnetic connection exist between ICL and LH launchers, but it is observed a much lower effect on the IC launcher located on the electron side of the LH launchers.

Top areas of ICL guard limiters are mainly sensitive to private IC power, especially on the left side. The warming up is found to be lower at large plasma-launcher gap. This is consistent to fast ions generated near IC launcher (maximum effect in the top left corner) but the same differences between ICL as observed on bottom areas is found.

Moving to the FS, it is confirmed that top left corner of FS is mainly sensitive to private IC power, with warming up lowering at lower density and larger plasma-launcher gap as already found in previous scalings. Differences between ICL are once again observed.

Vertical edges of the FS are found to be mainly sensitive to private IC power, but also with (total) convected power and LH power in case of magnetic connection between IC and LH launchers. Warming up is sensitive to start-up limiter radial position for the launcher that is shadowed and the effect of LH power is found to be very sensitive to IC to LH radial gap.

3. CONCLUSION

As an outcome of this study, in particular of the analysis of high performance pulses, it is found that the most critical items for TS operation are localized heat loads on the FS screen top left corner and vertical edges. Warming up close to maximum temperature limit originally set for protection of the PFCs is found on high power pulses, but no erosion was observed after detailed inspection of the launcher in TS vessel. Yet, the associated heat loads could be limiting for TS operation in the future, and some dedicated work is under progress to improve the understanding of these power fluxes, pointing out the importance of getting a better knowledge of particle flows in the scrape of layer. This work is also relevant to prepare the design of ITER IC launcher: Further experimental and modeling work is believed to be crucial in order to draw practical ways to optimize for instance the Faraday screen (and possibly the RF configuration) design, in order to reduce heat loads due to fast ions generated near ICL[6]. The result of this work could be tested on next TS IC launchers that are under discussion

REFERENCES

1. Becoulet, M., and al., "Edge plasma density convection during ion cyclotron resonance heating on Tore Supra, *Physics of Plasmas*, vol.9 n°6 (2002) p.1-14 (2002).
2. Colas, L., and al., "Hot Spot Phenomena on Tore Supra ICRF Antennas Investigated by Optical Diagnostics", *Nuclear Fusion*, vol.43 (2003) p.1-15 (2003).
3. Guilhem, D., « Infrared surface temperature measurements for long pulse operation, and real time feed-back control in Tore-Supra, an actively cooled Tokamak", submitted to Journal of Quantitative Infrared Thermography.
4. Brémond, S., and al., "High power density and long pulse operation with Tore Supra ICRF facility", *Fusion Engineering and Design*, vol.66-68 (2003) p.453-460 (2003).
5. Goniche, M., and al., "Enhanced heat flux in the scrape-off layer due to electrons accelerated in the near field of lower hybrid grills", *Nuclear Fusion*, vol.38, n°6 (1998) p.919-937 (1998).
6. Colas, L., and al., "Theory and Practice in ICRF Antennas for Long Pulse Operation", this Conference.