Comparison of fast electron generation in front of passive-active and fully-active multijunction LH launchers in Tore Supra

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Introduction. The ITER-relevant Lower Hybrid (LH) launcher in Tore Supra, based on the passive-active-multijunction (PAM) design, is now extensively used in the Tore Supra programme together with the fully-active-multijunction (FAM) launcher. Experiments have been conducted with the aim to compare the two launcher designs and to validate the modelling tools in key areas needed for extrapolating to an LH launcher design for ITER, such as LH wave coupling [1] and non-inductive current profile [2]. This paper focuses on a third aspect, i.e. the harmful effect of parasitic electron acceleration in front of the launcher mouth [3], known to potentially cause a localized power flow of several MW/m^2 [4].

Experimental results. Experiments have been carried out to measure the intensity of the fast electron beam in front of the FAM (denoted C3) and PAM (denoted C4), by the means of a Retarding Field Analyser (RFA) [5], magnetically connected to the launchers, in nearly identical plasma conditions and at same injected power (1.4MW). This corresponds to a power density of 9MW/m^2 for C3 and 13MW/m^2 for C4, taking into account the surface area of the active waveguides (0.16m^2 for C3 and 0.11m^2 for C4). The RFA was mounted on a vertically reciprocating probe drive, situated on top of the torus. The analyser was biased to collect only supra-thermal electrons with energy greater than 200eV. Steps in plasma current between I_P=0.7MA and 1.1MA were carried out, in order to change the magnetic connection between the RFA and the launchers. The edge safety factor q_a varied between 5 and 3 (Fig. 1a). A detailed radial-poloidal mapping in front of a waveguide row could thus be obtained [6]. One can note in Fig. 1b that the fraction of reflected power behaves differently on C3 and C4 during the q_a-scan. This is explained by the fact that the electron density in the scrape-off layer (SOL) decreases when the edge safety factor decreases [7], and that the coupling on the two launchers have different characteristics [1, 8]. In particular, C4 (PAM) maintains low reflection coefficient (RC~2%) over the entire scan. Eleven plunges were made with the RFA in each shot. As described in [5], higher average collector current was obtained with C3, which indicates that a higher electron flow was generated in front of the C3 launcher mouth. This is consistent with the infrared (IR) imaging of the hot spots on the launcher side protections (Fig. 2), which shows that the temperature increase is higher on C3, in particular

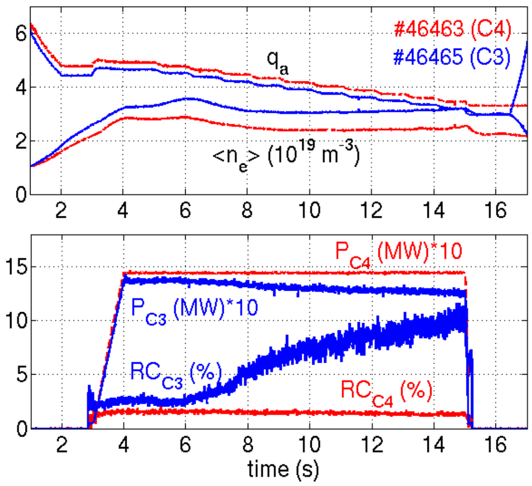

Fig. 1: Plasma pulses with q_a-scan for C4 (#46463) and C3 (#46465).

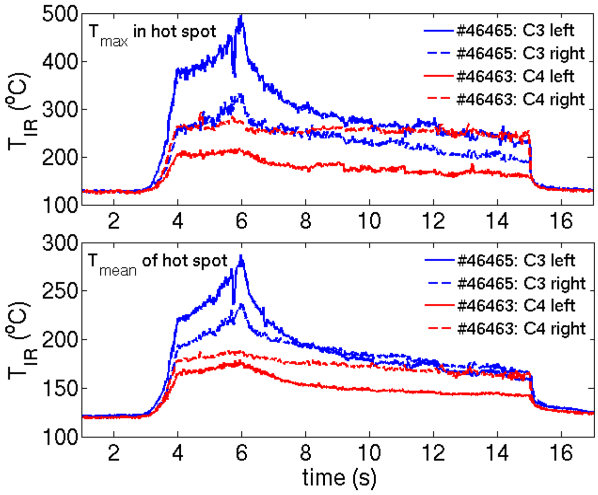

Fig. 2: Infrared (IR) measurements of the hot spots on the inner zones of the launcher side protections.

during the first phase up to 6s, where the density in front of the launchers is highest. The hot spots appear on the inner zone of the left and right side protections, at the poloidal location of each waveguide row. The hot spots extend 3-4cm poloidally, i.e. half of the waveguide height.

Modelling of the power flow. Thermo-mechanical analysis, using ANSYS software, has been made to evaluate the power flow in the LH produced hot spots on the launcher side protections, based on the IR temperature increase. The ANSYS modelling shows that the hot spot is consistent with a power flow that extends 10mm toroidally along the protection tile. The peak perpendicular power flow is found to be 4.0MW/m^2 for the time frame 4s-6s in #46463, whereas the average power flow in the 10mm wide spot is 2.0MW/m^2. For C3, the power flow is thus higher, since the temperature increase is higher.

An independent estimate of the difference in power flow between C3 and C4 is obtained by a particle in cell (PIC) code [3, 9] that computes the electron dynamics in the electric field in front of the LH launchers. The code uses the electric field from the ALOHA code [8] as input. For the pulses in Fig. 1, the peak electric field reaches 3.5kV/m, both on C3 and C4, when using a density at the launcher mouth of $n_e = 2\times10^{17}$m^{-3}. A model with two density layers, characterized by λ_{n1} = 2mm and λ_{n2} = 20mm [1], was used in ALOHA. In order to use an average electric field, $|E_z|$ was multiplied by a factor $2/\pi$ to take into account the sinusoidal distribution in the poloidal direction. The background electron temperature in the SOL was chosen as 10eV. Based on the average electric field values, a parallel electron flow of 8.7MW/m^2 and 15.3MW/m^2 is obtained at the position of the side protections on C3, when the density in front of the launcher is 2×10^{17}m^{-3} and 4×10^{17}m^{-3}, respectively (Fig. 3a). The corresponding values for C4 are 6.7MW/m^2 and 10.0MW/m^2 (Fig.3b). The computed power flows are 30-50% higher for C3 (FAM) than for C4 (PAM), which is consistent with

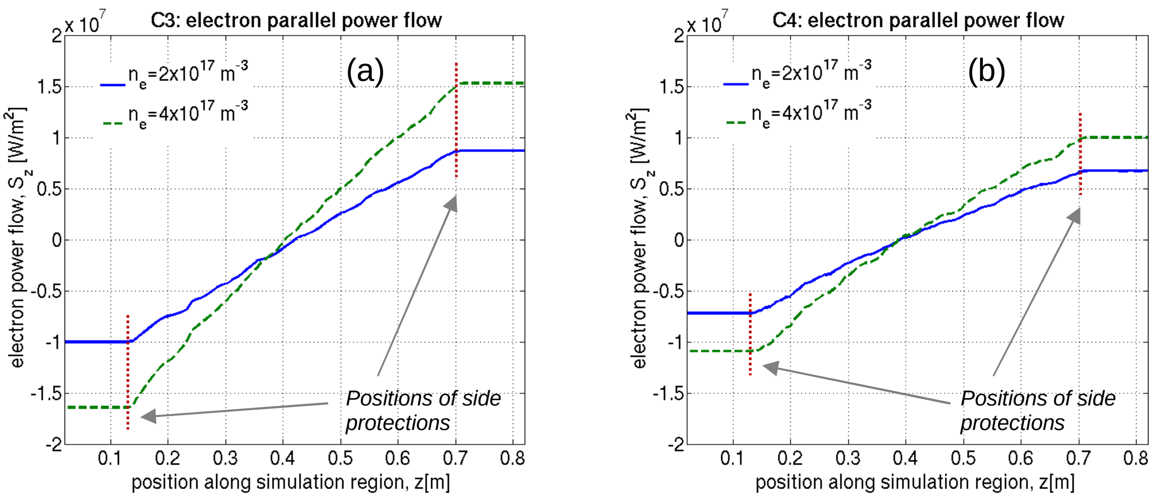

Fig. 3: Simulated parallel power flow along the toroidal extension of the launchers for C3 (a) and C4 (b).

experimental data from both the RFA and the IR imaging. Even though the electric field from ALOHA decreases with increasing edge density, the power flow is found to increase, due to the fact that the power flow scale as n_e. Indeed, the IR data in Fig. 2 show more intense hot spots at higher density. Converting the parallel power flow from the PIC simulations into a perpendicular power flow, assuming an angle of 20° between the incident field line and the surface of the side protections, one would obtain 2.3MW/m^2 and 2.8MW/m^2 for C4.

High power experiments. The experiment described above was carried out in a particular plasma configuration, where the curvature of the field lines did not match the toroidal shape of the launchers. Degraded coupling conditions (especially on C3) and higher heat load on the lateral multijunctions and the side protections are found to occur in such conditions. In optimum coupling conditions, both the C3 and the C4 launchers have operated at a power density of 24-25MW/m^2 (25MW/m^2 being the nominal value). Fig. 4 shows the temperature of the hot spot on the launcher side protections in the highest power pulses on C3 (3.8MW, 24MW/m^2) and C4 (2.8MW, 25MW/m^2), respectively. The maximum hot spot temperatures are comparable, or even lower, than those obtained in #46463 and #46465 (Fig. 2).

Summary and outlook. Experimental results from RFA and IR measurements indicate that the PAM launcher design generates lower fast electron flow than the FAM design, in similar plasma conditions and at the same power. This is in agreement with test electron modelling of the electron power flow, using the electric field from the ALOHA code, which yields that the power flow is 30-50% higher for FAM than PAM at moderate power and density at the launcher mouth above 2×10^{17}m^{-3}. Also at high power density (24MW/m^2), the IR temperatures are found to be lower on PAM than on FAM.

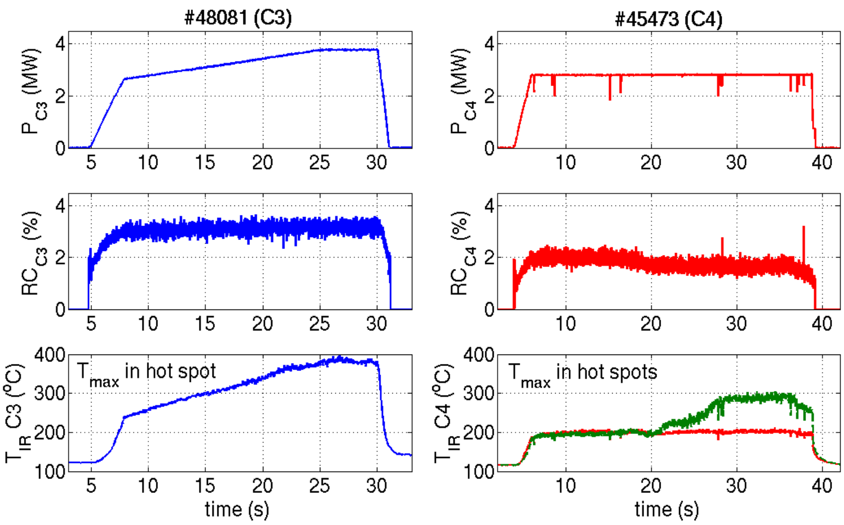

Fig. 4: Maximum achieved power on C3 (left) and C4 (right). The two IR temperature curves for C4 correspond to two different waveguide rows, which behave differently as the plasma moves away from the launcher [10].

By rounding the waveguide septa, the electric field at the launcher mouth can be reduced. Simulations predict that the power flow can decrease by a factor of ~7 by rounding the waveguide septa on the PAM [11]. Such modification, which can be envisaged on the PAM since it has sufficiently wide septa, may allow reducing significantly the localised power flow in the SOL. This is foreseen to be tested in a future campaign in Tore Supra.

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