RF coupling and antenna heat load control during combined LHCD and ICRH in Tore Supra

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The recent experiments in Tore Supra has focused on the optimisation of the RF heating systems (ICRH and LHCD) in order to achieve their maximum power levels simultaneously over long durations (up to 30s). This leads to injected power levels in the range of 10MW, which is representative of ITER operation in terms of average power density and heat exhaust capability. The chosen plasma scenario was I_P = 0.8-0.9MA, B_T = 3.8T, which will allow a full current drive scenario after an upgrade of the LHCD system (the CIMES project [1]).

Successful operation has been achieved up to 9-10MW for 20-30s, using real-time control of the antenna front face temperatures and security on the Cu and Fe brightness. The wave coupling was optimised for the two RF systems simultaneously, while at the same time minimising the hot spot formation due to interaction by fast particles (stochastic diffusion of fast ions with large orbits due to the magnetic ripple, RF sheath effects in the case of ICRH and acceleration of electrons in the near-field in the case of LHCD). The five RF antennas (three ICRH and two LHCD antennas) are monitored by dedicated infrared cameras, viewing the antennas and their side limiters. Several zones on the antennas, corresponding to different physical mechanisms of hot spot formation, are included in a real-time controller which acts on the power on the different antennas, depending on the mechanism involved. Another real-time safety system reacts to the brightness level of the Cu et Fe spectral lines, using a novel dedicated spectrometer.

The optimal working points for the LHCD and ICRH systems change when combining them. Local modification of the scrape-off layer density around an ICRH antenna impacts on magnetically connected LHCD antennas. The LH coupling either improves or deteriorates locally, depending on the relative radial and poloidal position of the LHCD waveguides and the ICRH antenna. The surface temperature related to the acceleration of electrons in the near-field of the LH wave evolves accordingly, i.e. it either increases or decreases as a response to the increase or decrease in scrape-off layer density.

When increasing the injected power level above ~9MW, the discharges often terminated by a sudden, large influx of impurities, arriving after a quiet phase longer than the time constant of the actively cooled plasma facing components. It is worth noting that the plasma scenario allowed good coupling of both RF systems, good absorption of the ion cyclotron wave (H-minority heating) and that no breakdowns in front of the antennas were observed prior to the disruption. In addition, the radiated power remained low during the discharges (~20% of the injected power), indicating a good overall conditioning of the vessel. Boronisations were regularly performed. Several hypotheses for the impurity influx are being analysed: unexpected localised heat flux on plasma facing components (not monitored by the infrared safety systems) due to fast particle losses, outgassing in remote areas, and flaking of over-heated poorly adherent carbon deposits which enter the plasma edge.

[1] F. Kazarian et al., this conference.