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Combined high RF power and pellet fuelling experiments in Tore Supra

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1. Experimental set-up

A new pellet injector designed and built by PELIN laboratory (St Petersburg, Russia) was recently implemented on Tore Supra. It allows to inject a continuous stream of deuterium pellets at high frequency (up to 10 Hz) with a very good reliability (~98%) [1]. The pellets can be launched through one of the four guide tubes allowing injection from the High Field Side of the torus (HFS horizontally or oblically), vertically (VHFS) and from the Low Field Side (LFS). When the pellets are injected during LHCD, suprathermal electrons produced by the wave strongly increase the ablation rate and thus reduce dramatically the pellet penetration depth. The pellet - LHCD scenario developed on Tore Supra is based on a simultaneous feedback on the density and a pellet synchronised notching of the LH power to avoid this suprathermal electrons ablation. Such a scenario allowed to obtain very long pellet fuelled discharges (up to 2 minutes) in Tore Supra [1]. Data from X-mode reflectometers and a FIR interferometer are combined to give density profiles with a time resolution of 1 ms. Standard CCD cameras and fast Hα measurements (1μs) are used to measure the pellet penetration depth and the ablation rate assuming its proportionality with Hα emission.

2. Combined pellet injection and high heating power experiments

Preliminary experiments were performed to combine pellet injection and high heating power, with the following parameters : plasma current 0.6-0.9 MA, density in the 80%-90% Greenwald limit range and total heating power up to 11 MW, with ICRH up to 8MW (hydrogen minority heating scheme) and LHCD up to 2MW; the pellet size and speed were respectively about 3.5 10^{20} atoms and 500m/s and the pellets were injected from the LFS. A typical discharge is illustrated on Fig.1. The LH power was notched as indicated in section 1 and the ICRH power exhibited large oscillations, which are discussed in section 3. In this scenario, the electron temperature profile is weakly perturbed by the pellet injection, as shown on Fig.2, where the modification of the density, pressure and bootstrap current profiles are also displayed. To reach long discharges at high density in Tore Supra, it is important to optimize the bootstrap fraction, the current driven by the LH wave being limited by the available power. The bootstrap calculation has been performed using the NCLASS code available inside the CRONOS [2] package. The simulation has been made every ms at the rate of the electron temperature experimental data from ECE. Despite a significant increase of the density gradient (for ρ>0.6) following the pellet injection, the bootstrap current remains constant due to the low electron temperature in the outer part of the discharge. By injecting from the HFS, it should be possible to get a better alignment of the radial locations of ne and Te maximum gradients, taking benefit of the favourable **∇B**-drift. During these preliminary experiments at high power, it has been possible to control the plasma density by pellet injection during 30s discharges with a reduced level of RF power (total power up to 6 MW).

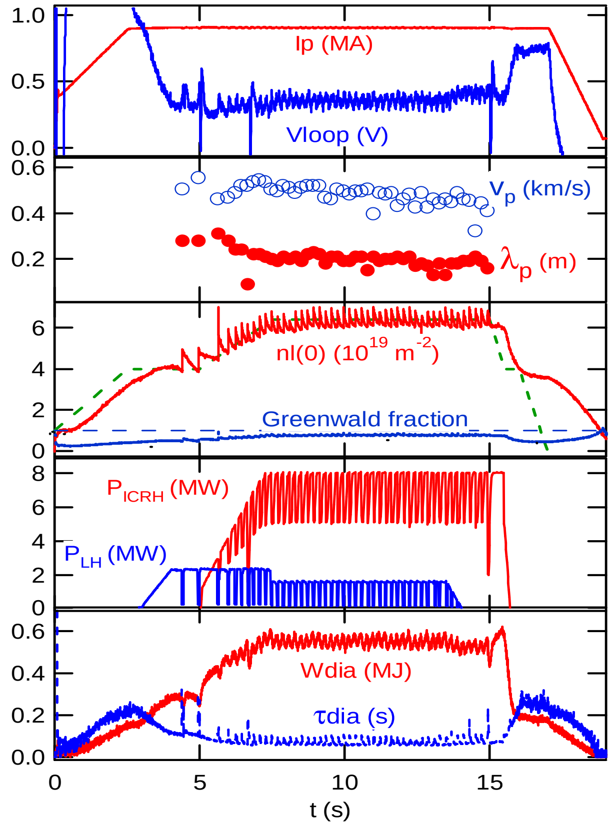

Fig.1. : plasma and pellet parameters for #TS33952 pulse. From top to bottom : plasma current and loop voltage – pellet speed and penetration depth – central line density with feedback reference and Greenwald fraction – ICRH and LH powers – plasma energy content and confinement time.

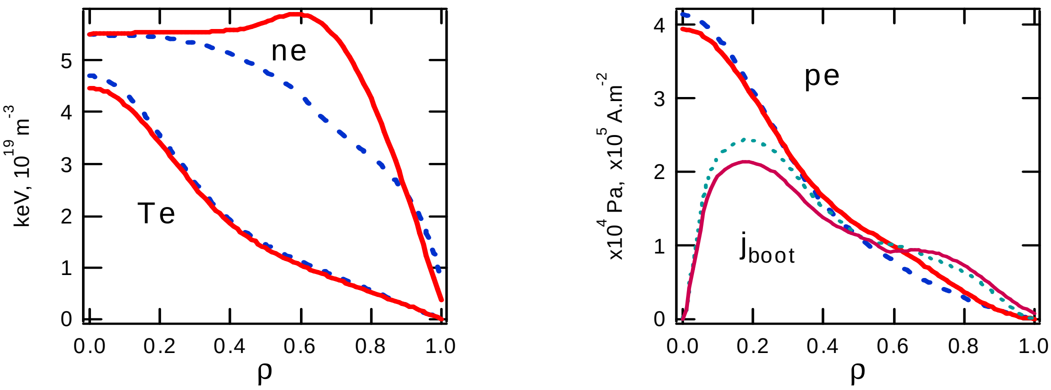

Fig.2. : ne, Te, electron pressure and bootstrap current profiles before and after pellet injection for #TS33952 at 10.94s (just before injection) and 10.99 (~50 ms after injection)

3. Effects of pellet injection on wave heating

The coupling of the IC power is strongly dependant on edge plasma conditions. Thus, an effect of the pellet injection, which induces an important and very fast increase of edge density (ablation duration is about 500 µs in Tore Supra), was expected. Fig 3 shows the

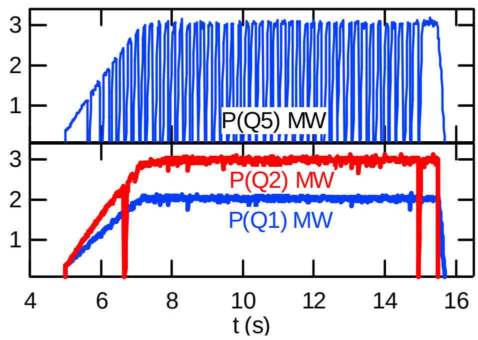

Fig.3 : ICRH power for pulse 33952

power injected by the 3 antennas during the pulse 33952. The power injected by the Q1 and Q2 antennas is quite stable but the power delivered by the Q5 antenna is switched off by the IC plant protection system (maximum ratio of reflected over forward power) at each pellet injection. The difference in behaviour can be correlated to the difference in toroidal location of the antennas relatively to the injection port: the Q1 and Q2 antennas are located at the opposite of the pellet injection port whereas Q5 is closer (~1 m) and magnetically connected to it. It can be observed that even on Q5, the left and right straps are not affected the same way by the pellet injection: The left strap (the closest to the pellet injection port) experiences, before the power switch off, a more important increase of the reflected power than the right one. These observations are believed to be related to a fast increase of the edge density on the trajectory of the pellet (reinforced by the ∇**B**-drift) that leads to a fast increase of the antenna RF loading (as the distance between the straps of the antenna and the RF cut-off density layer [3] is decreased), that leads to a fast impedance mismatch of the IC antenna (feedback matching by motorised capacitors cannot react on such time scales), that is to say to a fast increase of the reflected power to the RF generator which triggers the IC plant protection system decreases..

4. Matter deposit induced by pellet injection

<u>4.1 Vertical and LFS injection comparison</u> : Vertical and LFS injections have been compared in 20s ohmic plasmas (1.4 MA). The experimental density profiles before and 2-3 ms after ablation are shown for 2 typical pellets on Fig 4-left. The speed and mass were 150 m/s and 2.5×10^{20} atoms but an erosion of 20% in the vertical guide tube of the pellet injected vertically must be taken into account. Despite the smaller size of the pellet in injected vertically, both matter deposition profiles are similar.

<u>4.2 Modelling</u> : The HPI code [4], based on a NGPS ablation code coupled to a fast ∇**B**-drift calculation, has been used to calculate the effective matter deposit for the two pellets described above. The comparison of the calculated and experimental profiles is shown on Fig.4 – right : the calculated and experimental penetrations are in good agreement and the locations of the maximum of the two matter deposition profiles compare well for the two pellets. Nevertheless the calculated profiles are slightly narrower and, although the experimental deposit was deduced from the difference of two density profiles separated by only 3 or 4 ms, a transient increase of the transport coefficients must be considered. To

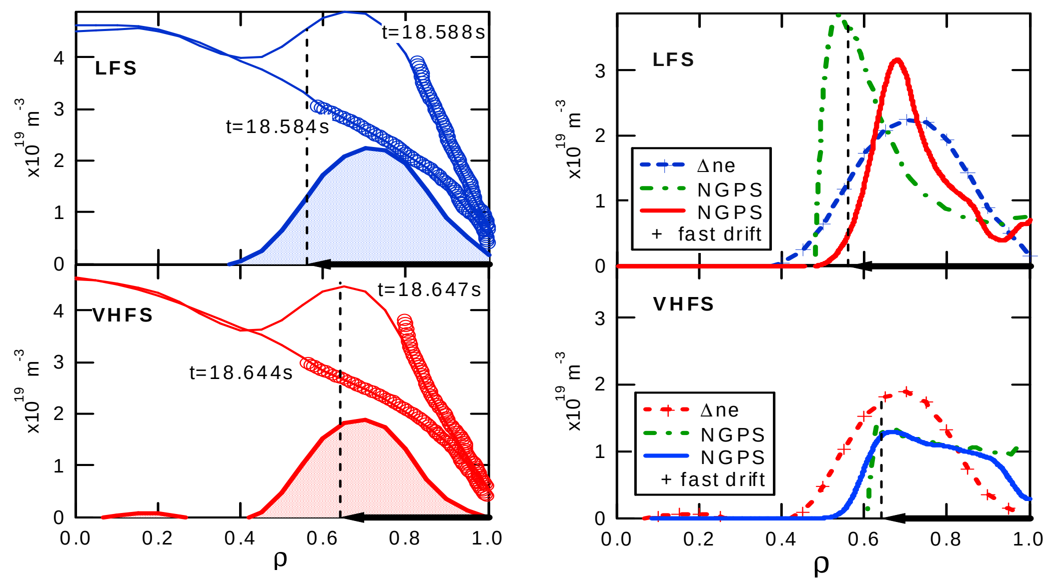

Fig.4 : - left, experimental density and matter deposit profiles (circles: direct profile from reflectometers, solid line : combined IR and reflectometers data) for pulses 32926 (top, LFS) and 32928 (bottom, VHFS). The arrows indicate the penetration depths given by a CCD camera.
- right, experimental matter deposit profiles, calculated NGPS ablation profiles and calculated NGPS+fast drift profiles for the same two pellets.

reproduce the density increment and the behaviour of the density profile after the injection, both the diffusion coefficient and inward pinch had to be increased by a factor of ~7 during the homogenization phase and by a factor 3 during the few 100 ms of the relaxation phase.

4.3 Measurement of the ablation cloud electron density by spectrometry : A high time resolution spectrometer (100 µs) has been installed on Tore Supra to measure the electron density in the ablation cloud from Stark broadening. First results show an important Stark broadening (~1 nm) for a pellet (350 m/s, 2 10^{20} atoms) injected from the LFS into a plasma heated by 4 MW of ICRH and 2 MW of LH, which corresponds to an electron density in the ablation cloud of about 1.2×10^{23} m^{-3}. In such conditions 3 to 4 spectra can be recorded during ablation and the electron density is observed to increase, which confirms also previous results obtained on JET with the same spectrometer [5].

References :

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