

Effect of magnetic field on pellet penetration and deposition in ohmic Tore Supra discharges.

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Introduction

Accurate modeling of tokamak fuelling is a subject of crucial importance for a safe extrapolation to ITER. Recently, a scaling law was proposed for the penetration of HFS-launched pellets in ASDEX-Upgrade, exhibiting a significant dependence on the magnetic field [1]. To confirm/infirm this point, we study the effect of magnetic field and rational q surfaces location on pellet penetration and deposition in Tore Supra, using the CRONOS integrated modeling code [2]. Tore Supra plasma discharges with LFS pellet injection (discharges 45072-45085 and 45716-45734) are simulated (it must be noted that launching the pellets from the LFS allows to avoid a possible pre-cooling of the plasma due to plasmoids previously deposited and drifting in front of the pellets). The CRONOS code – including the pellet module - is used to simulate these experiments. The pellet ablation in the hot plasma is described using a NGPS pellet ablation model [3] and the homogenization and drift of the deposited material by the HPI2 pellet ablation/deposition code [4].

Experimental conditions

In these discharges ($I_p = 0.6\text{MA}$; $n_l = 3 \times 10^{19}\text{m}^{-2}$; $\langle T_e \rangle = 1\text{keV}$), the toroidal magnetic field was varied from 1.9 to 3.8 T. A consecutive train of pellets with 4 to 6 pellets per discharge (0.7 mm and 1 mm equivalent radius, estimated from the increase of the plasma particle content) was applied during the current plateau, the time delay between two injections being long enough for the profiles (density and temperature) to relax completely. The experimental pellet penetration was estimated from CCD camera pictures and the deposition profile from a combination of IR-interferometry and reflectometry measurements (see an example in Fig. 1).

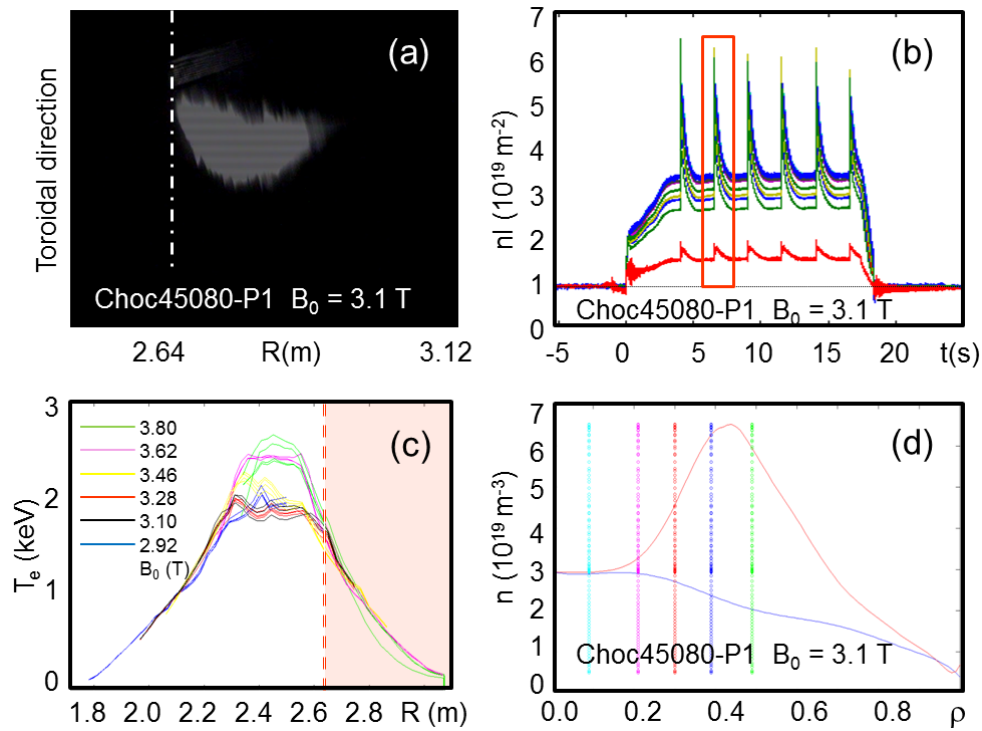


Figure 1: (a) CCD picture of a pellet ablation cloud (the white line indicates the pellet penetration); (b) time traces of interferometry measurements; (c) temperature profiles for different values of the magnetic field (the shadowed region is that where the pellets penetrate); (d) reflectometry measurements (dotted lines) and corresponding density profiles before and after pellet injection ($\delta t < 1\text{ms}$), the dotted vertical lines indicate the radii where the interferometry lines intersect the equatorial plane.

Pellet penetration

The experimental pellet penetrations (λ_p) are plotted as a function of the magnetic field in Fig. 2 (blue stars), together with those simulated taking into account (green triangles) or not (red circles) the modification of the plasma profiles at the pellet location due to the plasmoids previously deposited. Since the present data is relative to pellets injected from the LFS, no pre-cooling of the plasma by plasmoids drifting in front of the pellet is expected, and the only weak effect is the modification of the profiles due to the ablated material already homogenized. No significant dependence of the pellet penetration on the magnetic field B_0 is measured: a thorough statistical analysis yields a dependence $\lambda_p \propto B_0^{(1.7 \pm 2.1) \times 10^{-2}}$ for the experimental penetrations and a dependence $\lambda_p \propto B_0^{(2.8 \pm 1.8) \times 10^{-2}}$ for the simulated ones.

Both values are close to that predicted in [5]: $\lambda_p \propto B_0^{2 \times 10^{-2}}$, and incompatible with the strong variation published in [1]: $\lambda_p \propto B_0^{-4 \times 10^{-1}}$.

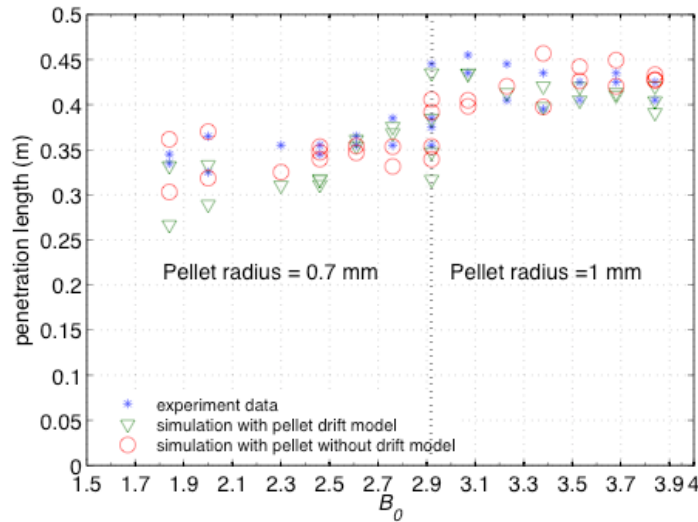


Figure 2: Pellet penetrations λ_p vs. magnetic field B_0 : experiment (blue stars), simulated without taking into account profile modification due to the plasmoids already homogenized (red circles), taking into account the profile modification (green triangles).

Pellet deposition

CRONOS has been used to simulate current diffusion and pellet deposition profile, taking as input fitted density and temperature profiles from the experiment. In the used pellet model, the drift of the homogenizing material down the magnetic field gradient is stopped due to the cancellation of the charge separation by parallel, resistive currents flowing along field lines connecting the positively and negatively charged parts of the cloud. The shorter the connecting field line, the more efficient is the drift braking efficiency. It follows that a correlation is expected between the maximum of deposition and the position of simple rational surfaces [6]. The simulated deposition profiles are compared with observations in Fig. 3 for two values of the magnetic field: $B_0 = 3.8$ T (Figs. 3a and 3c) and $B_0 = 2.9$ T (Figs. 3b and 3d). Globally, it can be seen that the simulated average displacement is slightly overestimated in both cases. This is possibly due to an underestimation to the pellet initial masses or velocities, but also to the fact that the HPI2 code overestimates the displacement in the case of low pressure plasmas. Conversely, the half-height of the profiles are well reproduced.

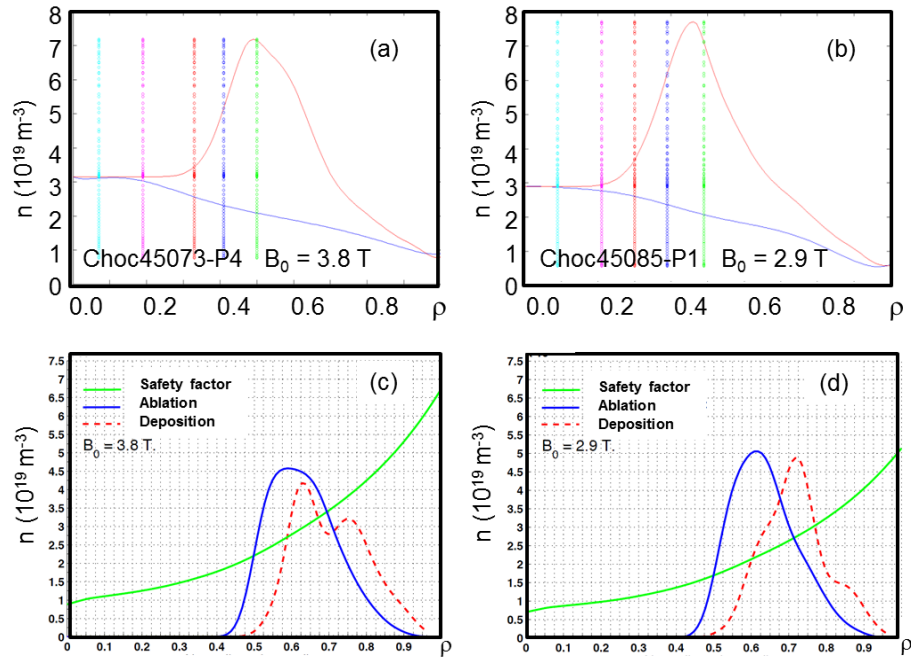


Figure 3: (a) pre- (blue) and post-pellet (red) density profiles for a magnetic field $B_0 = 3.8$ T; (b) simulated counterpart for $B_0 = 3.8$ T: ablation profile (i.e. deposition profile in the absence of drift), deposition profile with drift (the safety factor profile is also shown); (c) pre- (blue) and post-pellet (red) density profiles for a magnetic field $B_0 = 2.9$ T; (d) simulated counterpart for $B_0 = 2.9$ T.

Summary

Trains of pellets were injected from the LFS in ohmic Tore Supra discharges, the only varying parameter being the magnetic field, in order to study the dependence of the pellet penetration and deposition on this parameter. It is found that the simulation results of pellet penetration agree well with experimental data and that no significant dependence on the magnetic field is observed. Predicted deposition profiles display a shape in good agreement with those measured but the global displacement is slightly overestimated.

References

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