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Investigating particle transport during pellet injection in RTP.

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Introduction

The work on pellet injection at RTP has focused on the interaction between the ablation cloud and the plasma on the ablation time scale (below 200 μs). For this work the development of a new diagnostic (called the fiber array diagnostic) was crucial. This diagnostic views the emitted visible light of the ablation cloud along narrow lines of sight (3.5 mm wide) crossing the pellet trajectory. During the last year first results of this diagnostic have been published [1, 2]. A clear radial outward drift was observed of (part of) the ablation cloud with a velocity up to 10 km/s, i.e. much higher than the pellet velocity (0.5-1 km/s), and in opposite direction (directed to the low field side). An example of this kind of observation is shown in Fig. 1. In this paper the results

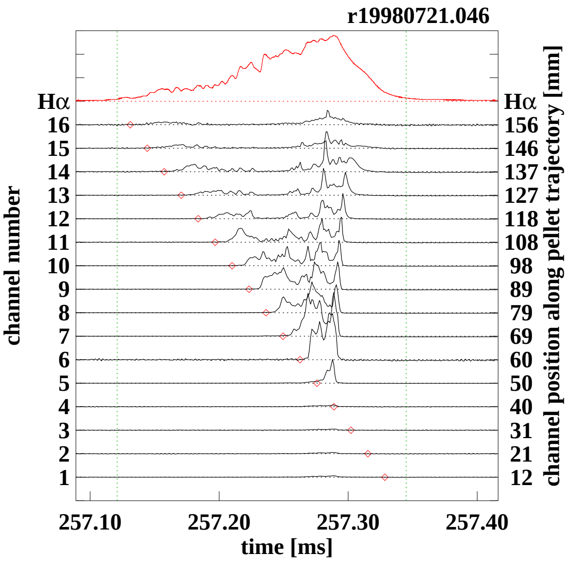

Figure 1: Example of the pellet ablation process as observed by the fiber array diagnostic at RTP (a/R=16.4/72 cm). The diamonds indicate the expected passage times of the pellet using the measured pellet velocity and timing in the injector. The vertical dashed lines indicate the moments that the pellet passes the limiter radius and the plasma center (if it would penetrate that far). The top trace is the wide angle H_α monitor. A clear peak is seen at the passage of the pellet at each channel. Also additional peaks can be recognized which are correlated on separate channels, and indicate an outward moving cloud. The peaks around 257.295 ms show the presence of a light source which moves much faster (7.7 km/s) than the pellet and in opposite direction. ($n_e(0) = 5.6 \times 10^{19}\ m^{-3}$, $T_e(0) = 1500$ eV, $I_{pl} =$ -81 kA, $B_{tor} = 2.02$ T, $v_{pellet} = 732$ m/s, $m_{pellet} = 1.25 \times 10^{19}$ atoms, 320 kW central ECRH).

are analyzed of plasma shots under very different conditions. First the results of the fiber array diagnostic are shown for a pellet injected radially in the mid plane into a low density plasma. Second a pellet injected off-axis below the plasma center is analyzed. Both discharges represent a number of similar discharges. Both cases yield indications of enhanced radial particle transport during pellet injection.

Injection in a low density plasma

A picture completely different from Fig. 1 is seen when a pellet is injected into a low density plasma (see Fig. 2). This plasma is in the slide-away regime, in which usually a characteristic long tail on the wide angle H_α signal can be seen. This makes it impossible to determine the pellet penetration from this signal. The fiber array signals show that the penetration is about 65 mm and that the pellet is surrounded by a large ablation cloud. Note that the signals are largest and have the longest duration towards the edge of the plasma (channel 16). The cloud vanishes first on channel 11, then on 12, then on 13 etc. These measurements suggest that a continuous flow of ablated matter leaves the pellet, and travels to the plasma boundary.

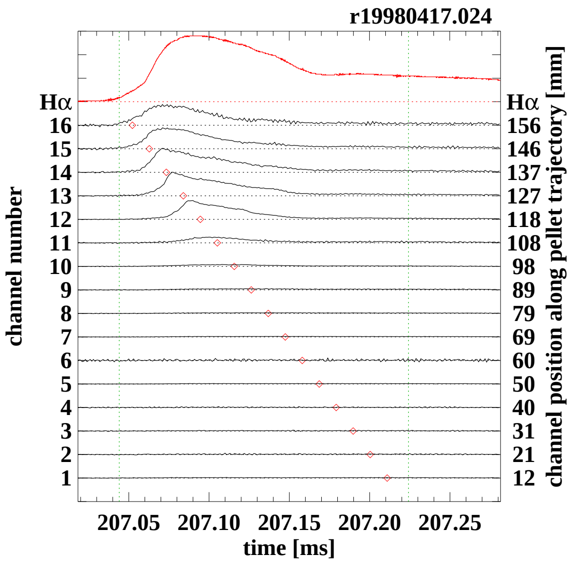

Figure 2: Example of the pellet ablation process as observed by the fiber array diagnostic at RTP for a low density plasma (plotted in the same way as in Fig. 1). A very different behaviour is seen now. A continuous stream of ablated matter seems to flow from the pellet to the plasma boundary.
($n_e(0) = 1.9 \times 10^{19}\ m^{-3}$, $T_e(0) = 790$ eV, $I_{pl} = 104$ kA, $B_{tor} = 2.01$ T, $v_{pellet} = 910$ m/s, $m_{pellet} = 1.8 \times 10^{19}$ atoms).

This only ends when the pellet is completely ablated, and therefore the light emission stops first at the more central channels. The long tail on the wide angle H_α diagnostic may then be caused by the large amount of cold plasma present in the scrape off layer. Additional support for this hypothesis is the fact that these low density shots always show a very poor fueling efficiency (between 30 and 50 %). For this example the fueling efficiency was 35 %, determined using a 19 channel FIR-interferometer 5 ms after injection. Usually for higher density Ohmic plasmas the fueling efficiency is close to 100 %.

Off-axis injection

A second case of fast cross field transport is observed when a pellet is injected off-axis, passing 56 mm below the magnetic axis of the plasma (see Fig. 3). On T_e and n_e profiles taken by Thomson scattering (see Fig. 4) at the closest approach of the pellet to the plasma center a high n_e peak is seen inside the pellet radius (at one side of the profile only). This region coincides with a low T_e area seen in the T_e profile. At the other side of the profile the large gradients coincide with the calculated pellet position.

The question that remains to be answered is what is the most likely path that this high density region followed from the pellet to the place of observation.

A first assumption is that the ablatant follows the magnetic field lines. The Thomson scattering diagnostic is displaced toroidally by 60° relative to the pellet in counter-current direction and 300° in current direction. The times needed to travel the toroidal distance in both directions, assuming an (ion thermal) velocity of 10^5 m/s, are 7.5 μs and 37.7 μs for these distances. From this delay it is deduced what the pellet position was at the time of ablation of the matter forming this high n_e region.

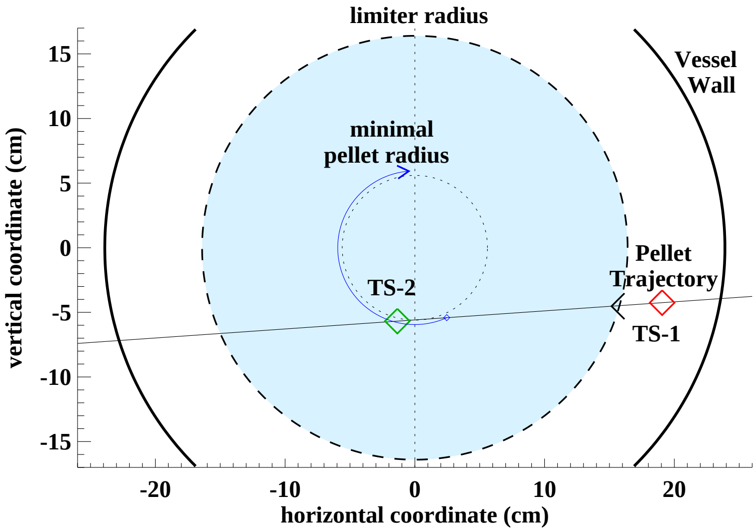

Figure 3: Schematic drawing of off axis pellet injection, in a poloidal cross section of the tokamak. The diamonds indicate the pellet position at the times that the profiles shown in Fig. 4 were taken by the Thomson scattering diagnostic. The shaded area is the plasma. The dashed line represents the chord viewed by the Thomson Scattering diagnostic, but note that this diagnostic is displaced by a toroidal angle of 60° from the pellet injector. The curved blue arrow indicates a poloidal projection of the most likely 3-dimensional path of the high density.

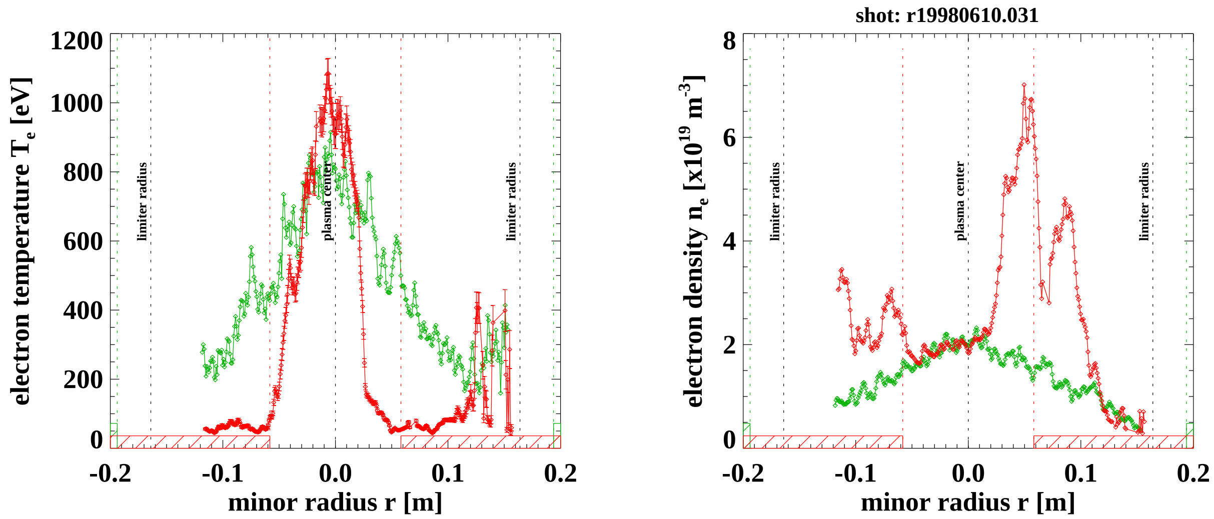

Figure 4: Profiles of electron temperature and density measured by Thomson scattering. The high (green) T_e profile and the low (green) n_e profile are taken just before the pellet enters the plasma. The lower (red) T_e profile and the higher (red) n_e profile are taken 200 μs later. The actual radial pellet position at the time the second profiles are measured, is indicated by the bar at the bottom of the plots. A clear high n_e low T_e region is seen between r=3 and r=6 cm, so inside the pellet radius. ($n_e(0) = 2.0 \times 10^{19}\ m^{-3}$, $T_e(0) = 850$ eV, $I_{pl} = 78.5$ kA, $B_{tor} = 2.17$ T, $v_{pellet} = 1013$ m/s, $m_{pellet} = 1.86 \times 10^{19}$ atoms, injection angle = 4°, impact parameter = 56 mm).

Taking the estimated q=1.5, a poloidal displacement of the high density may be expected of 40° in the counter-current direction and of 200° in the current direction due to the rotational transform. For the movement in the current direction this is sufficient to explain why the high density is observed by the Thomson scattering diagnostic (see Fig. 3). For the counter-current direction a further poloidal movement of 13.6 cm is needed before the density is in sight of the diagnostic (it has to be poloidal and not vertical, because the plasma center is still hot). This would mean an additional poloidal velocity of 18 km/s which seems unrealistic.

Furthermore, a radial inward movement is needed of about 25 mm, which would imply a radial velocity of at least 3.3 km/s or 0.66 km/s if this too would take place within the same 7.5 μs or 37.7 μs. If the high density has traveled in current direction this radial displacement may occur when the ablatant is passing at the high field side of the plasma center (see Fig. 3). If this is the case the effect is comparable to the previously observed drifts of the ablation cloud towards the low field side, and the drift probably took place in a much shorter time than the mentioned 37.7 μs, This explains the much lower drift velocity of 0.66 km/s, compared to the drift velocities between 3.5 and 10 km/s found in [1]. The signals from the fiber array diagnostic for this shot are shown in Fig. 5.

A notable difference with Fig. 1 are the very long pulses on channels 1 to 5. The cloud is not traveling towards the plasma edge, since beyond channel 6 nothing is seen anymore. This indicates that the drift stops, or that the cloud is completely ionized, and ceases to exist.

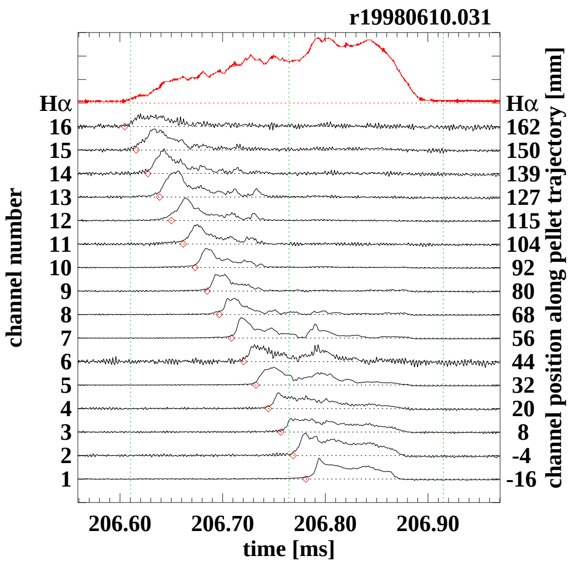

Figure 5: Example of the pellet ablation process as observed by the fiber array diagnostic at RTP for an off axis injected pellet (plotted in the same way as in Fig. 1). The main difference with Fig. 1 are the prolonged pulses seen on channels 1 to 5.

Conclusion

A fast outward flow of the pellet ablatant is observed which can occur in bursts or continuously (low n_e case). This effect probably causes the low fueling efficiency of pellet injection if a non-thermal electron population is present. If this flow occurs poloidally far from the pellet it may show up as an inward radial drift. These drifts are probably driven by local electric fields [1] but since no experimental data is available on these fields not much can be said about it. Measuring this local electric field (if possible) should be a first priority in future pellet experiments before we can hope to understand the transport processes around an ablating pellet in more detail.

Acknowledgement

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References

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