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Pellet Drift Effect Studies at JET

F. Köchl[1], D. Frigione[2], L. Garzotti[3], G. Kamelander[1], V. Parail[3], B. Pégourié[4]
and JET EFDA contributors*

[1]*Association EURATOM-ÖAW/ATI, Kegelgasse 27/3, 1030 Vienna, Austria*

[2]*Association EURATOM-ENEA, Frascati Research Centre, 00044 Frascati, Italy*

[3]*Association EURATOM-UKAEA Fusion, Culham Science Centre, OX14 3DB Abingdon, UK*

[4]*Association EURATOM-CEA, CEA/DSM/DRFC, Centre de Cadarache, 13108 St-Paul-lez-Durance, France*

1. Introduction

Due to the ∇B induced drift of the pellet ablated material, the pellet deposition profile and fuelling efficiency depend on the pellet injection location [1]. The cloud of ablated material surrounding the pellet is displaced along the magnetic field gradient, leading to deeper penetration into the plasma for pellet injections from the high field side (HFS) of the torus, as compared to pellet fuelling from the low field side (LFS). According to previous studies [2,3], this drift effect can be used in JET-sized plasmas to obtain superior core fuelling characteristics. To clarify this issue, a statistical analysis of pellet experiments at JET has been carried out with the objectives (a) to verify if the observed drift displacement is systematic, (b) to obtain an estimate of the typical displacement length, and (c) to study the influence of particle transport effects like diffusion on the measured pellet deposition profile. For this purpose a database of pellets injected in JET plasmas since 1999 has been set up and one well diagnosed shot featuring pellets from three different injection locations, has been analysed in detail. A comparison of the pellet drift displacement with simulation results is given in section 3, whereas the fuelling efficiency is analysed in section 4.

2. Statistical Analysis

For the first time a set as wide as possible of pellet injection experiments at JET since 1999 has been systematically studied. In the first step, the pellet injection data were checked for consistency and reliability. The correct pellet entry times were derived and verified by the temperature drop measured by two ECE edge channels. The profiles for the pellet ablation (i.e. the pellet-induced density increase before the drift effect takes place) have been reconstructed from the H_α spectrometry data. The deposition profiles (i.e. the distribution of the drifted pellet material) were obtained by taking the difference of the post- and pre-pellet LIDAR Thomson scattering density measurements. For the study of the particle transport effect, the profile data have been divided according to the time delay between the moments of pellet injection and LIDAR measurement. Finally, the profile barycentres were calculated, and compared to determine the drift displacement. The results for LFS and HFS injections are

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* See the Appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006).

shown in Fig.1. For all undisturbed pellet events, a clear systematic outward displacement of the deposition profile has been measured. For LFS injections, it is in the order of ~15 cm, whereas the average drift in HFS injections amounts to only ~5 cm. This difference can be explained by the inclination of the HFS pellet injection line with respect to the normal of the flux surfaces and a drift towards increasing plasma pressure for HFS injections, leading to a decrease of the driving force for the drift motion. Unfortunately, the statistical sample is rather small (LFS: 29 pellets, HFS: 42 pellets, i.e. 10% of the overall pellet shot database), which can be explained by the high background noise and precedent pellet injection interferences, but also the bad relative timing of the LIDAR signal. The results presented in Fig.2 are based on a broader data set (LFS: 56 pellets, HFS: 106 pellets), obtained with less severe filter algorithms. Because of particle transport effects, the measured particle drift increases with time for injections from the HFS and decreases for pellets from the LFS direction. Within ~100 ms, the deposited pellet material is transported to regions with lower density in the plasma core, until it is completely mixed with the background plasma.

3. Simulation Results

JET shot 58337 is an L-mode discharge fuelled with 8 pellets for each injection line (LFS, HFS, and vertical HFS = VHFS). It serves as an example for the analysis of the ablation and deposition profiles with pellet simulation tools [4]. Two representative pellet injections have been simulated with the stand-alone pellet code HPI [5] (Fig.3). A new homogenisation routine, based on the model described in [6], which determines the evolution of the ionised clouds of ablated material and the resultant drift motion, has been developed and combined with the NGPS [7,8] ablation module in the JETTO transport code, allowing the simulation of pellet deposition in a more realistic geometry. The code uses a standard solver [9] to integrate the set of ordinary differential equations describing the cloud dynamics. With this code, all pellet profiles for the shot under consideration have been calculated and compared with experimental data from the interferometer. The average barycentres for each profile and injection series are displayed in Fig.4. Despite the limited spatial resolution of the interferometer inverted profiles, there seems to be good agreement with the simulation. The pellet code predicts the expected pellet drift effect, but the drift displacement is rather small compared to Fig.2, which is due to the ablation maxima situated close to the plasma edge.

4. Fuelling Efficiency

The fuelling efficiency in shot 58337 was compared by quantification of the averaged density increase at the beginning of a pellet injection series, by estimate of the steady state density level, at which the particle loss equals the averaged pellet particle fuelling rate, and by calculation of the average relaxation time of the particle content. To this purpose, the high time resolution interferometer signal has been analysed. The results are displayed in Tab.1

and illustrated in Fig.5 and 6. As can be seen, the fuelling efficiency is improved for HFS injections. The typical particle relaxation times are bigger by > 100 ms for inboard injections.

5. Conclusions

The pellet statistics have demonstrated the existence of a drift displacement in all analysable pellet experiments at JET, dependent on the injection direction, of the order of 0.1 m. However, the statistical sample is not wide enough to perform a more detailed analysis and more experiments will be needed in the future. For the exemplary shot no. 58337, the characteristics of the pellet drift effect could be reproduced by simulations. The fuelling efficiency is enhanced for HFS injections. To find out if the drift effect still plays a role in large-scale tokamaks like ITER, advanced pellet-focused simulations need to be undertaken. The new pellet algorithm presented in this paper could serve as a good basis for this project.

Acknowledgements

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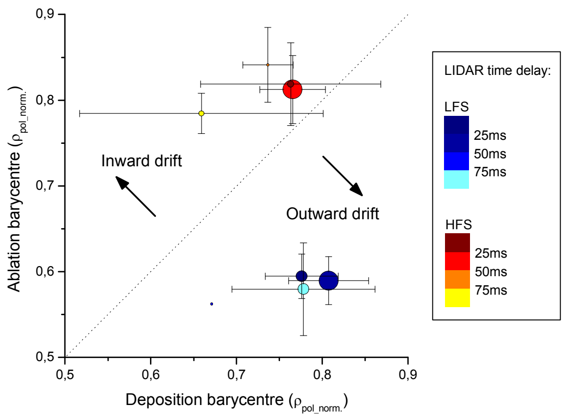

Figure 1 – Average barycentres for the pellet ablation and deposition profiles in the JET pellet database, plotted in dependence of the pellet injection direction and the relative timing of the LIDAR. The size of the circles corresponds to the amount of analysed data. The black squares indicate the position of the average barycentres of the JET exp. #58337.

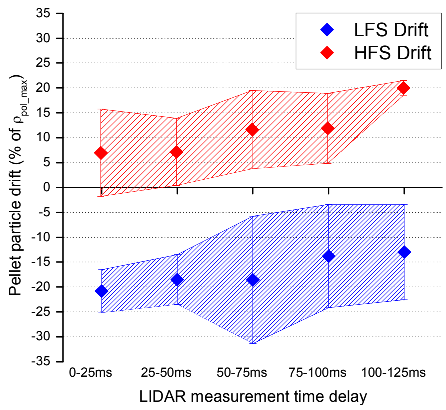

Figure 2 – Average pellet particle drift in JET pellet experiments for LFS and HFS injections and its dependence on the LIDAR measurement delay due to particle transport (diffusion etc.).

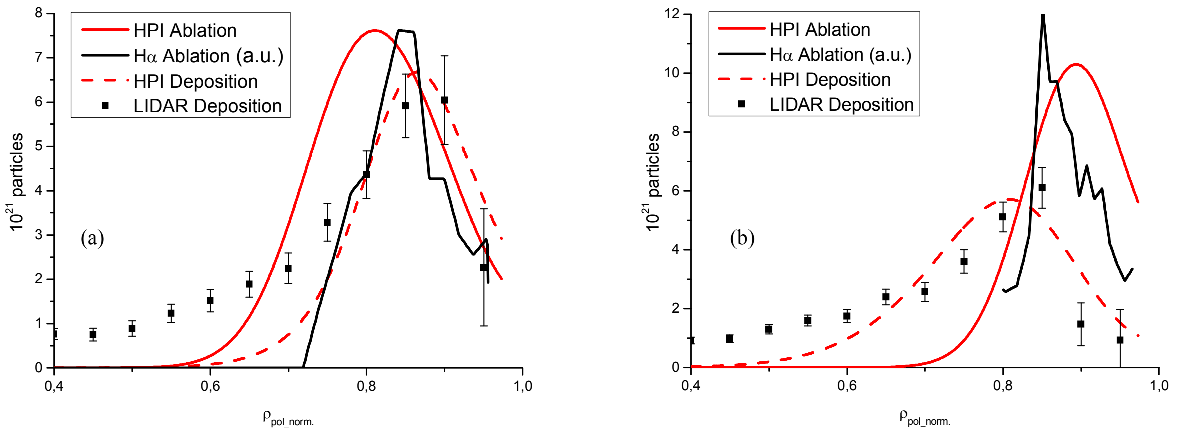

Figure 3 – Comparison of the pellet ablation and deposition profiles, calculated with HPI, with the measurement for two representative pellet injections from the LFS (a) and the HFS (b) in the JET experiment #58337.

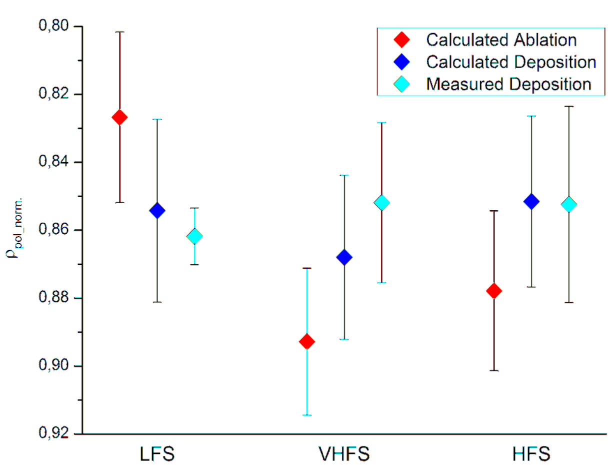

Figure 4 – JET experiment #58337, average calculated particle ablation (red) and deposition (blue) barycentres for each pellet injection direction, compared to the average barycentres of the deposition profiles derived from the interferometer signal (cyan).

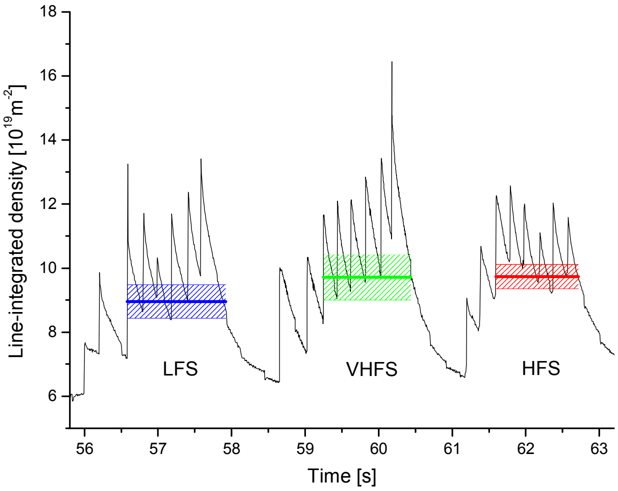

Figure 5 – Time evolution of the line-integrated density signal KG1V/LID3 in the JET experiment #58337, and the density equilibrium level for each pellet injection series (blue: LFS, red: HFS), calculated with the averaged local density minima in the equilibrated phase.

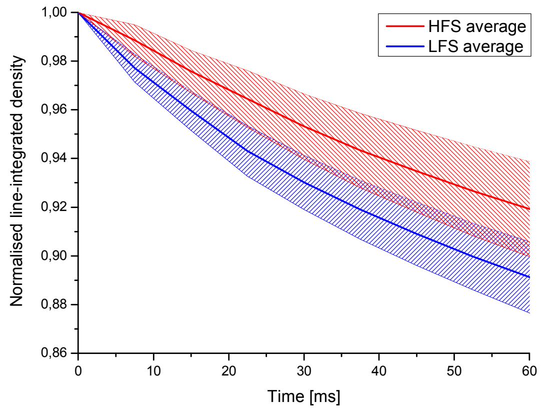

Figure 6 – Averaged normalised line-integrated density decline right after a pellet injection for the LFS and HFS series in the JET experiment #58337. The particles seem to be better retained in the HFS case.

	Line-integrated density increase grad.	Line-int. avg. density in equilibrium state	Avg. particle content relaxation time
LFS	$5.8 \cdot 10^{19}$ $m^{-2}s^{-1}$	$(8.96 \pm 0.53) \cdot 10^{19}$ $m^{-2}s^{-1}$	0.65 ± 0.12 s
VHFS	$6.5 \cdot 10^{19}$ $m^{-2}s^{-1}$	$(9.71 \pm 0.72) \cdot 10^{19}$ $m^{-2}s^{-1}$	0.75 ± 0.29 s
HFS	$6.1 \cdot 10^{19}$ $m^{-2}s^{-1}$	$(9.73 \pm 0.38) \cdot 10^{19}$ $m^{-2}s^{-1}$	0.91 ± 0.27 s

Table 1 – Quantities related to the relative fuelling efficiency in dependence of the pellet injection direction in the JET pellet experiment #58337.