Characterisation of the pellet cloud drift in stellarators

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Cryogenic pellet fuelling efficiency in hot magnetically confined plasmas is largely influenced by the drift properties of the high-pressure pellet cloud. In tokamaks, due to the axially symmetric magnetic field, a radially outward drift is the dominant process, so inboard side injected pellets can fuel with better efficiency [1]. In the much more complex (non-axially symmetric) magnetic field of stellarators, the advantage of the inboard side pellet injection does not necessarily apply [2], thus detailed investigations are needed to characterize the drift processes and therefore the fueling properties. In addition to fueling pellets, impurity pellets - even millimeters in size – are also injected into the plasma mostly for diagnostic purposes. These pellets behave in a similar way to cryogenic pellets and therefore are also well suited for drift studies: they are also shielded by a dense cloud, which also drifts from time to time. Experiments were done in the W7-X and TJ-II stellarators injecting both cryogenic and impurity (tracer-encapsulated solid pellet, TESPEL) pellets into the plasma.

The present study concentrates on W7-X experiments with cryogenic fueling pellets injected from the outboard of the stellarator at the AEK30 port. The pellets are injected horizontally (z=-160mm) by a blower gun pellet injector using a single-screw extruder. The pellet size is adjustable between 2 and 3mm while the pellet speed between 200 and 800m/s. Single pellets can be requested on demand or continuous operation up to 5Hz is possible. The observation of the ablating pellet is done through the AEQ21 tangential port using a wound fibre optics (800x1000 fibres) and a Photron SA5 fast framing camera. To track the pellets and to study pellet cloud dynamics, a Region of Interest (ROI) of 96x128 pixels was recorded with 325.5kHz framerate and 0.4µs exposure time. This ROI covers the whole pellet trajectory and the drifting cloud movement. The camera was equipped with an Hα or Bremsstrahlung interference filter.

A database containing about 190 intact pellets was built using the experiments preformed during the OP 2.3 campaign. It contains for each pellet the experiment number, the camera frame range, the magnetic geometry and the heating power (both NBI and ECRH). In this contribution magnetic geometries with sufficient number of pellets, namely the standard and the high iota are compared both for forward and reversed magnetic field.

First the pellet trajectory was determined where we assumed that the pellet is located at the position of maximum radiation and it does not leave the poloidal plane of its injection. The position of the maximum radiation was taken for each frame and converted to the major radius, vertical coordinate (R(t), z(t)). Since the R(t), z(t) are not always linear functions of time a second order polynomial was fitted to both R(t) and z(t). Fig.1 shows the histogram of the accelerations obtained from these fits. In the radial direction the typical acceleration is positive for all cases, that is, the pellet is decelerated which - according to the rocket effect - is the signature of an outboard pellet cloud drift. Pellets are accelerated typically downwards (negative values), except the reversed high iota case, where no typical acceleration direction is observed. Accordingly, downward pellet cloud drift is expected.

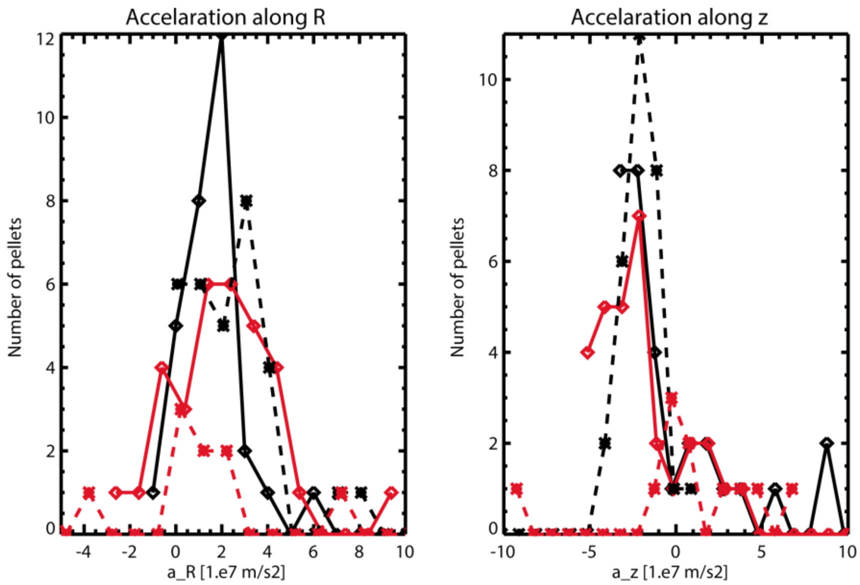

Fig.1. Histogram of the pellet acceleration in the major radius (left) and in the vertical (right) directions. Black curves are the standard, red curves are the high iota configuration, solid lines denote the forward magnetic field while dashed lines the reversed ones. Note, that the radial positive acceleration is equivalent to pellet deceleration.

To reveal the pellet cloud dynamics, the images were averaged both along the horizontal (close along the major radius) and vertical pixel coordinates (close along z) and the resulting 1D radiation distributions are plotted against time. Such distributions can be found on Fig.2 for standard magnetic configuration for forward (left figures) and for reversed (right figures) magnetic fields. The ‘ridges’ e.g. on the upper left figure represent consecutively erupted drifting clouds, which – in this case – move in the downward direction with a speed higher than the pellet. The red curve on the plots is the location of the maximum radiation as a function of time. The lower left figure shows that the same clouds are moving outward. The situation is not so clear for the reversed field case: the outward drift is less pronounced: reduced movement is seen. It seems to be that both reduced upward and downward drifts can be observed. It is worth noting here again that the accelerations in both cases indicate downward drifts. Further studies are needed to clarify this, presumably by developing an algorithm that tracks individual drifting clouds instead of averaging.

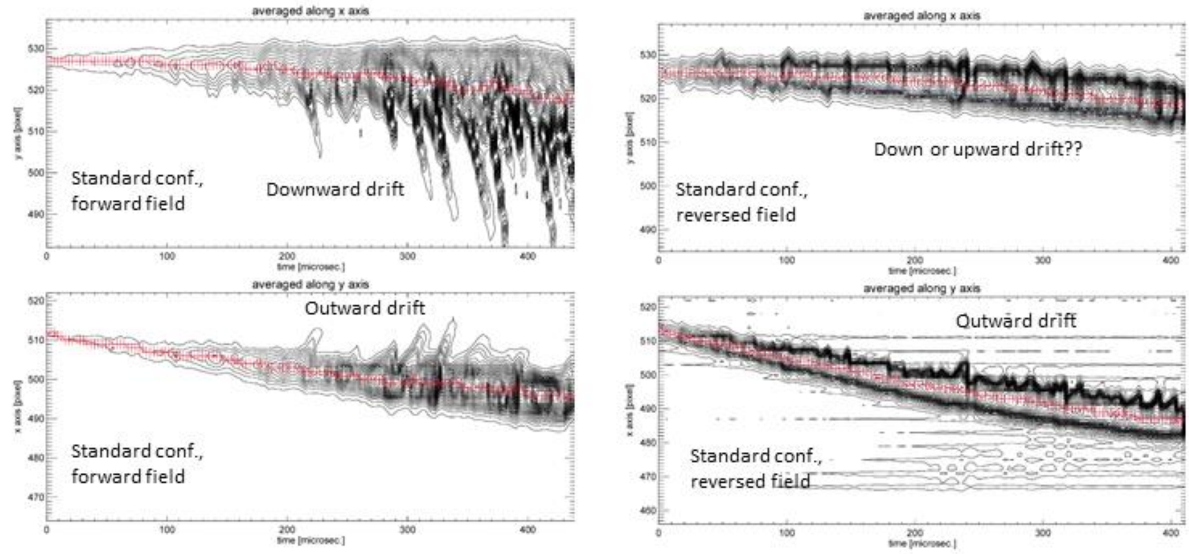

Fig2. Upper figures: images of a pellet movie averaged along the horizontal pixel coordinate and the radiation is plotted as a function of time and the vertical pixel coordinate. Lower figures: images averaged along the vertical pixel axis and plotted as a function of time and vertical pixel coordinate. Standard magnetic configuration, left figures at forward magnetic field, right figure at reversed field.

The high iota configuration shows similar behavior to the standard one: in the forward field, drifting clouds are clearly detectable moving downwards and outwards. In the reversed field, drifting clouds are visible for a much shorter time, so it is more difficult to detect the direction of movement. All we can say is that radially they always move outwards, vertically both directions occur, if at all, cloud movement in this direction is detectable.

We can conclude that in all cases the light emitted by pellet clouds fluctuates. Where drifting clouds can be clearly observed, the intensity of visible radiation is clearly higher. According to this, the radiation has local maxima which are associated with each drifting cloud. That is, the time elapsed between the local maxima gives the separation time of cloud eruption. Since the vertical movement of the pellet is more visible, we searched for local maxima in these averaged images, and we also shifted the fitted trajectory vertically, usually downwards, and took the cut of the figure along this curve. This way the fluctuation was much larger and it was easier to find local maxima. The results are summarized on Fig. 3. where the probability of the separation time between the consecutive cloud eruption is plotted for the four cases discussed. It looks like that the typical separation time falls in the range of 10-15µs. We also investigated whether the separation time depends on how deep the pellet is in the plasma, but we found no significant differences. This may be because we did not decompose the data according to plasma temperature at the location of the pellet, which determines the ablation rate and thus the pressure of the pellet cloud.

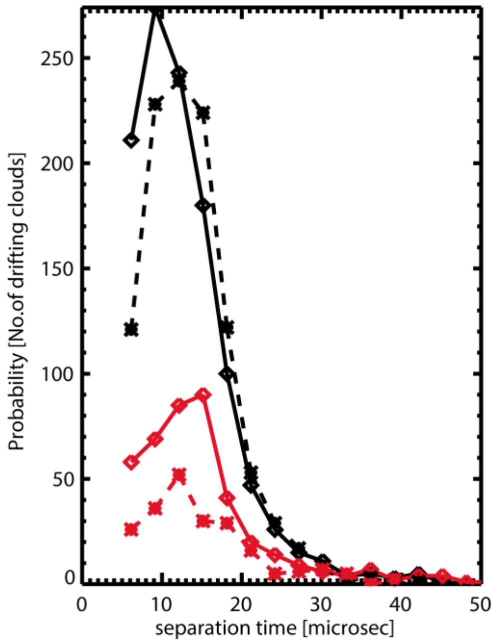

Fig.3. Histogram of cloud eruption separation time. Black curves are for the standard, red curves are for the high iota configuration, solid lines denote the forward magnetic field while dashed lines the reversed ones.

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