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Investigation of pellet-plasma interaction on ASDEX Upgrade

S. Kálvin[1], É. Belonohy[1], K. Gál[1], G. Kocsis[1], P.T. Lang[2], G. Veres[1],
ASDEX Upgrade Team

[1] *KFKI–Research Institute for Particle and Nuclear Physics, EURATOM Association, P.O.Box 49, H–1525 Budapest–114, HUNGARY*

[2] *Max–Planck–Insitut für Plasmaphysik, EURATOM Association, Boltzmannstr. 2, 85748 Garching, GERMANY*

Recently cryogenic hydrogen isotope pellets were used not only for tailoring the core profile but also for edge plasma control (Edge Localized Mode - ELM - pace making) by means of frequent small and shallow penetrating pellets [1]. Therefore the detection of the distribution of the pellet cloud with high spatio-temporal resolution has more than a pellet-plasma interaction centered importance. For these ELM control investigations the understanding of the underlying processes depends highly on the information regarding the localization of the pellet during the ELM. High resolution ablation profiles and pellet path measurements at different pellet parameters (mass and velocity) are required to understand the mechanism of the ELM triggering.

The delay between the time when the pellet crosses the separatrix and the ELM onset detected by the Mirnov diagnostics was investigated by injecting pellets with different velocities from the high field side of the ASDEX Upgrade tokamak [2]. In this contribution the results obtained with 240 m/s and 600 m/s velocity pellets are presented. For our investigations, usually a lower single null (LSN) configuration was used with $\mathrm{I_P} = 1\mathrm{MA}$, $\mathrm{B_t} = -2.7\mathrm{T}$, $\mathrm{q_{95}} = 4.9$, $\kappa = 1.6$, $\delta^{\mathrm{u}} = 0.12$ and $\delta^{\mathrm{l}} = 0.37$. Stable and robust operation in the type-I ELM regime with low natural ELM frequency $\mathrm{f^0_{ELM}} \sim 25 - 45\mathrm{Hz}$ (depending on the actual wall conditions) was achieved by keeping the auxiliary heating power just above the L-H transition power threshold. Typically 5 MW neutral beam injection (NBI) power was applied. Impurity accumulation and density profile peaking was prevented by modest (1- 2 MW) central deposited ion cyclotron resonance heating (ICRH). Pellets were injected with a frequency of 6Hz, that was much smaller than the natural ELM frequency so that the natural ELM cycle was not destroyed by the plasma fueling. Every one of the injected pellets triggered an ELM independently of its velocity and its relative phase in the ELM cycle. An observation system was developed at the ASDEX Upgrade tokamak to detect the spatial distribution and the time evolution of the visible radiation emitted by the pellet cloud during the pellet ablation. The light emitted by the cloud surrounding the pellet was detected both with photodiodes and fast framing digital cameras.

The photodiodes detect the time evolution of the light emitted by the pellet cloud (pellet monitor signal) which is proportional to pellet ablation rate [3]. If this signal exceeds a predetermined comparison level, the digital cameras are triggered after a predefined delay (see Fig.1). For each pellet the cameras record 3-5 snapshots onto the same frame using an exposure time of 5-10 μs and a period time of 100 μs. In order to get the time of each exposure during the plasma discharge, the camera trigger signals were stored as well. This allowed us to determine the position of the pellet cloud [4] attached to the pellet itself [5] and to match the time of the given snapshot. Thus, at given times the position of the pellet is known. On the other hand, based on these data the time when the pellet crosses a certain flux surface, especially the separatrix can be calculated. For the determination of the separatrix position, there were two magnetic equilibrium reconstruction used.

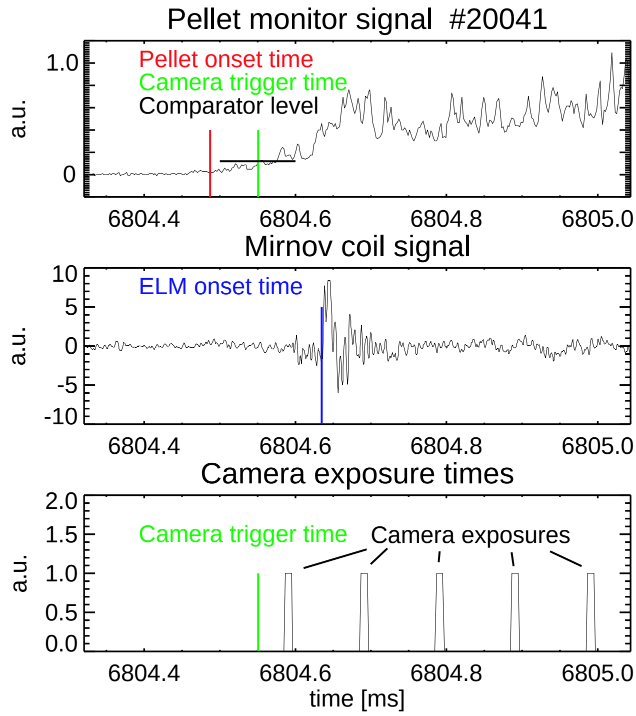

Fig. 1. The time evolution of the pellet monitor signal, the Mirnov coil signal and the camera exposure times. For the definition of the different time markers refer to the text.

One of them is the 'Function parametrisation of magnetic equilibrium' (FPP) [8] and the second one is the 'Reconstruction of magnetic equilibrium with CLISTE Code' (EQI) [9]. In the shot analysed, there is a $\approx$ 2.5cm difference between the separatrix positions along the designated pellet path using the above mentioned magnetic reconstructions. From the pellet monitor signal and from the Mirnov coil signal two onset times (the pellet onset time and the ELM onset time that, are shortly after the beginning of the pellet ablation and the ELM activity, respectively) were computed by setting an appropriate threshold.

Fig. 2 shows the result of the evaluation of the camera pictures for two discharges with 240 m/s and 600 m/s pellet velocities, respectively. The black rhombs in this figure represent the position of all pellets injected into the discharge. The red triangles and crosses are the crossing points of the individual pellet trajectories and the separatrix calculated from the EQI and the FPP magnetic reconstruction, respectively. It is worth to note here that slow (240 m/s) pellets are radially accelerated, therefore their trajectories are curved. The change in the separatrix position on the pellet trajectory is due to the movement of the plasma and the variation of the trajectory itself from pellet to pellet. The blue squares represent the pellet position at the pellet onset time. The distance between the separatrix and the pellet position at the pellet onset are nearly the same for both velocities, which indicate that in this early phase of pellet ablation the time evolution of the ablation rates is similar in the case of these pellets. The green squares show the position of the pellets at the ELM onset. The blue line denotes the designated pellet path.

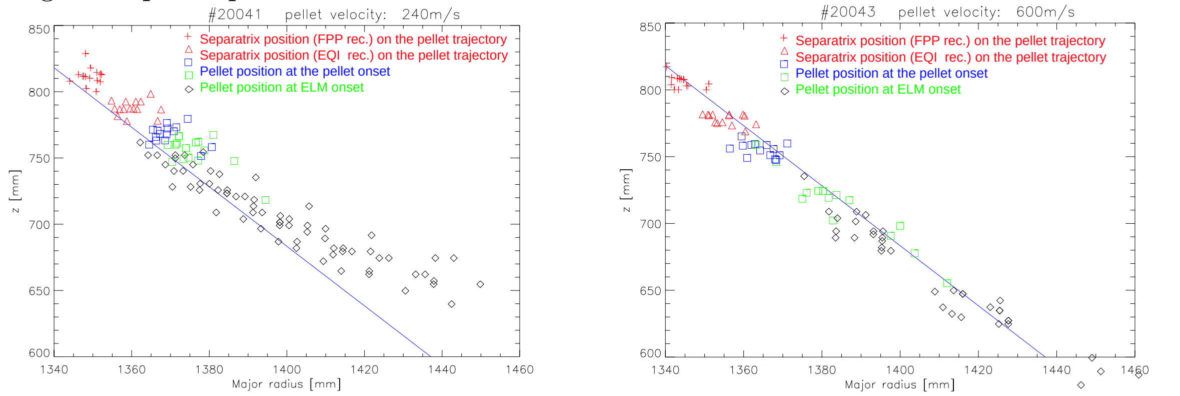

Fig. 2. The result of the evaluation of the camera pictures for two discharges with 240 m/s and 600 m/s pellet velocities, respectively. The different symbols show the position of all pellets injected into one discharge. The different colors refer to different typical times.

As it was shown before, knowing the time when the pellets cross the separatrix, the delay between this time and the ELM onset time can be calculated. These delay times (blue and red rhombs) are shown on Fig.3 for the two velocities as a function of the time elapsed after the previous - natural - ELM. For elapsed times less then 5ms, the delay times are higher as the plasma may not have had enough time to recover after the previous ELM collapse.

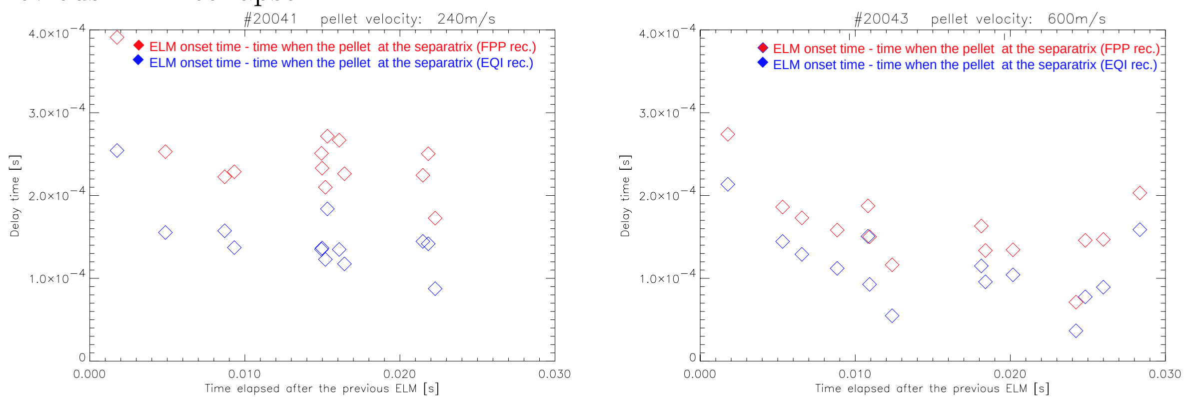

Fig. 3. The delay between the time when the pellets were at the separatrix and the ELM onset time for the two velocities as the function of the time elapsed after the previous - natural - ELM.

If the elapsed time after the previous ELM is greater than 5ms, these delay times seem to be constant, therefore one can regard these events as similar ones. The average values for the different velocities can be seen on Fig. 4 as a function of the inverse of the pellet velocity. The error bars indicate the standard deviation of the average values.

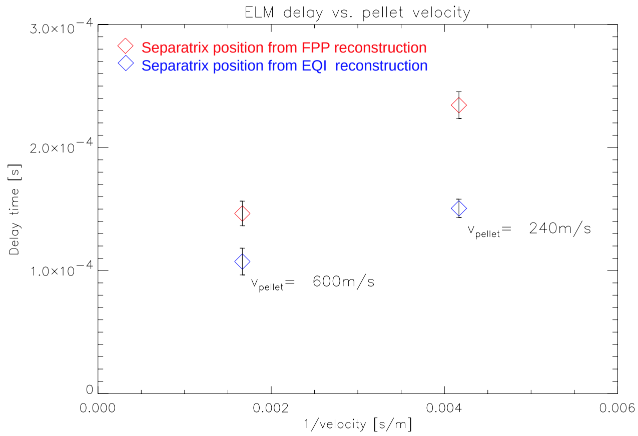

Fig. 4. The mean value of the delay between the ELM onset and the time when the pellet crossed the separatrix as a function of the inverse velocity.

It is clear that the ELM is triggered somewhere between the separatrix and the position where the pellet was at the ELM onset. Mapping these points to the plasma temperature profile (The FPP magnetic reconstruction was used.), this region is the pedestal of the plasma [6]. In order to obtain precisely the range of the ELM "trigger location", as a hypothesis we assumed that the perturbation of the plasma caused by the pellet can develop into an ELM if the pellet reaches a certain position, probably in the pedestal of the plasma. At this position an instability is triggered and after a certain T_0 time determined by the spread of the perturbation and/or the growth of the instability, an ELM is released [7]. As the pellet is a moving object, we expect that the τ time delay between the time when the pellet crossed the separatrix and the detected ELM onset to be $\tau = \delta/\mathrm{v_p} + \mathrm{T_0}$, where δ is the distance of the "trigger location" from the separatrix and $\mathrm{v_p}$ is the pellet velocity. Using the above determined averaged time delays, we estimated that $\mathrm{T_0} \simeq 80\mu$s and $\delta = 1.5$cm or $\delta = 4$cm along the pellet path taking the separatrix position calculated from the EQI or FPP magnetic reconstruction, respectively. Consequently we can also state that the pellet triggers the ELM when only a minor part of its mass is ablated in the plasma. Nevertheless we have to note that all the consequences of this speculation have to be taken as preliminary, since measurements with only two velocities were evaluated. Furthermore very careful error estimation of the obtained delay times has to be performed considering not only the statistical errors but also the uncertainties and the systematic error of the localization of the pellets and other possible error sources (e.g. the determination of the separatrix position and its relation to the plasma temperature and density profile).

References

[1] P.T. Lang et al., *Nucl. Fusion* **43**, 1110 (2003).
[2] P.T. Lang et al., *Rev. Sci. Instrum* **74**, 3974 (2003).
[3] D. H. McNeill et al., *Phy. Rev. Letters* **55** 1398 (1985)
[4] G. Kocsis et al., *Rev. Sci. Instrum* **75**, 4754 (2004).
[5] S. Kálvin et al., *31st EPS Conf. Contr. Fus. and Plasm. Phys., London, 2004* P-5.150
[6] K. Gál et al., *32st EPS Conf. Contr. Fus. and Plasm. Phys., Tarragona,2005* P2.098
[7] P.T. Lang et al., *32st EPS Conf. Contr. Fus. and Plasm. Phys., Tarragona, 2005* O4.003
[8] P.J. Mc Carthy , *14st European Conf. Contr. Fus. and Plasm. Phys Madrid, 1987* Europhysics Conference abstract **11 D-III** (1987) 1286
[9] P.J. Mc Carthy et al., *IPP Report* **5/85** Max-Planck-Institut fur Plasmaphysik, Garching, Germany (1999)