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Simulation of Pellet Induced Perturbations in Fusion Plasmas for Fueling and ELM Triggering Scenarios

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It is well known that beside plasma refueling by pellets, they can as well be used for ELM triggering [1]. Rising the ELM frequency by external pacemaking results in a reduced ELM energy, which is essential for the divertor lifetime in ITER and a future fusion reactor. Neither the exact mechanism of the ELM release by the pellet nor the reduction of the ELM energy with rising frequency are yet fully understood. This contribution presents simulations of pellet ablation for ELM triggering experiments aiming at the better understanding of these phenomena.

Several experiments were done to investigate the ELM triggering mechanism, which are presented at this conference [2, 3]. The last of them is concentrated on the determination of the time delay between the ELM onset and the instant when the pellet crosses the separatrix. For this purpose pellets with a nominal particle content of $1.6 \cdot 10^{20}$ atoms has been injected with different velocities from the magnetic high field side in ASDEX Upgrade. In shot No #20041 the pellets were injected with 240m/s velocity and in shot No #20043 with 600m/s velocity, respectively. We have to note here that due to losses in the pellet injection system the net particle content which enters the torus in the first shot was $\sim 9 \cdot 10^{19}$ and in the second one $\sim 7.2 \cdot 10^{19}$ [4].

One tool to monitor the pellets is a photodiode which detects the time evolution of the light emitted by the pellet cloud. This signal (pellet monitor signal in the followings denoted by D_α) is considered to be proportional to the ablation rate $\dot{N}$ ($D_\alpha \sim \dot{N}$) [5].

The pellet monitor signal was collected for each pellet event in the last ELM triggering shots (20041 and 20043). To have a reasonable base to compare the experiment with the simulations, we averaged these signals for each shot, because the particle content of the pellet cannot be determined exactly [4]. The averaged pellet monitor signal for the above mentioned shots will be compared with the results of the simulations.

The simulation of the pellet ablation process is also helpful in understanding how the pellet vaporizes in shots where ELMs are triggered. The simulations were done using a hybrid model [6] which describes the formation of the neutral cloud according to the NGS ablation model and the dynamics of the ionized cloud part treated by a one-dimensional Lagrangian cell code.

As we did not have for each pellet event in each shot detailed density and temperature profiles we made calculations considering the profiles obtained for similar plasma parameters for a combination of the shots No #20037 and No #20113. The temperature is the leading parameter which determines the ablation ($\dot{N} \sim T_e^{1.6}$), accordingly we plotted it and the corresponding ablation rate as a function of the distance from the location of the injection, and as a function of the poloidal flux coordinate. These are shown in Figure 1. and Figure 2. where the position of the separatrix and the pedestal top are also indicated.

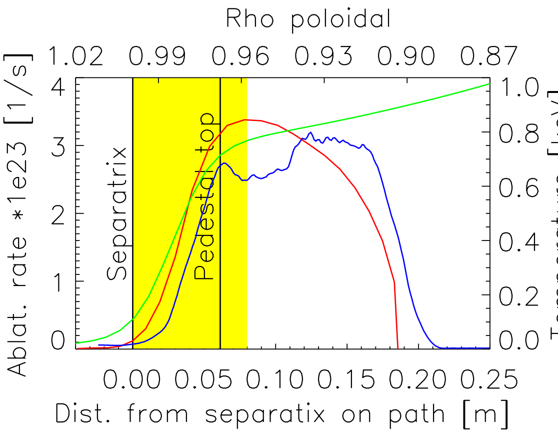

Figure 1: *The calculated ablation rate (red) and the corresponding plasma electron temperature (green) on the pellet path as a function of the distance from the separatrix and as a function of poloidal flux coordinate. The pellet monitor signal is plotted with blue for shot no #20043 (velocity 600m/s).*

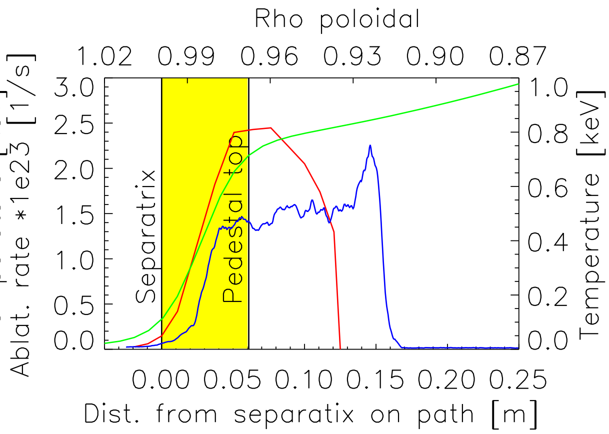

Figure 2: *The calculated ablation rate (red) and the corresponding plasma electron temperature (green) on the pellet path as a function of the distance from the separatrix and as a function of poloidal flux coordinate. The pellet monitor signal is plotted with blue for shot no #20041 (velocity 240m/s).*

The above mentioned figures shows the comparison of the calculated and measured ablation rates also. As it has been mentioned above the pellet monitor signal is considered proportional to the ablation rate, so its integral should equal the particle content of the pellet ($\int \dot{N} dt = const * \int D_\alpha dt$). To make a proper comparison we normalized the pellet monitor signal to its integral to give the "measured" ablation rate.

The shape of the calculated ablation curve and the average of the pellet monitor signal are similar. In the beginning the pellet monitor signal increases smoothly afterwards there are several jumps in the signal which can indicate either the presence of some instability which modifies the ablation rate nor the fact that the ablation rate ceases to be proportional to the light emitted by the cloud. The increase of the calculated ablation rate is similar to the pellet monitor signal, but between the two curves in the pedestal region there is a distance of ≈1.5 cm. This shift can be due to the fact that the plasma position e.g. the separatrix position can differ from each pellet even in the same shot and we have used for calculation the temperature and density profiles of an other shot. In both cases we indicated the region (with yellow), where the pellets were during ELM release in the above mentioned experiments [2,3]. The pellet particles ablated in this region will trigger the ELMs, while the remaining part of the pellet will serve fueling purposes.

As experiments proved pellets injected in ASDEX Upgrade trigger ELMs for all technically achievable velocities. We calculated the ablation rate for the most frequently used pellet velocities (240, 600 and 1000m/s), which means different pellet sizes also (the particle content is $9 \cdot 10^{19}$, $7.2 \cdot 10^{19}$, $3.1 \cdot 10^{19}$ and pellet radius is $7.2 \cdot 10^{-4}$, $6.6 \cdot 10^{-4}$, $5 \cdot 10^{-4}$ m). In the pedestal region, where the pellet radius determines the ablation rate for the same temperature, the ablation rate is similar for slower pellets, while the fast pellets with small radius ablates moderaltely as it can be seen on Figure 3. The recent experiments shows [2,3] that all the pellets trigger ELMs which reach the pedestal top. All of the above mentioned pellets will cross this region, which is in accordance with the observations. To answer the question if the pellet have to meet the pedestal top, we made a scan of the pellet mass at constant velocity in our calculations. For this purpose we computed the ablation rate for smaller pellets with 600m/s velocity. The calculations were made for pellets with a particle content of $7.2 \cdot 10^{19}$, $3.6 \cdot 10^{19}$, $1.8 \cdot 10^{19}$, $9 \cdot 10^{18}$, $4.5 \cdot 10^{18}$ and the ablation rates are shown on Figure 4. To check the above assumption we would need at least 16 times smaller pellets (orange) for this velocity than it is technically achievable in ASDEX Upgrade. If even smaller pellets would trigger ELMs this would exclude the assumption that the pellet should reach the pedestal top.

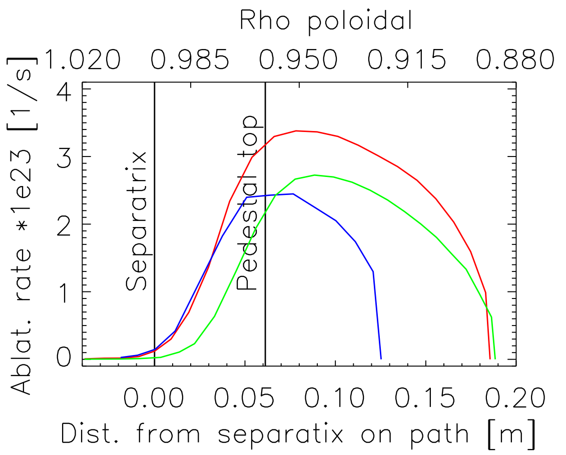

Figure 3: *The calculated ablation rate for pellets injected with 240m/s (blue), 600m/s (red) and 1000m/s (green) velocity.*

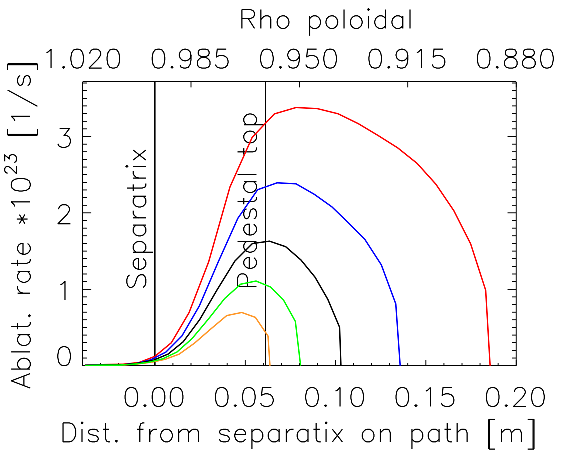

Figure 4: *The calculated ablation rate for pellets injected with 600m/s velocity with a particle content of* $7.2 \cdot 10^{19}$ *(red),* $3.6 \cdot 10^{19}$ *(blue),* $1.8 \cdot 10^{19}$ *(black),* $9 \cdot 10^{18}$ *(green),* $4.5 \cdot 10^{18}$ *(orange).*

The question what intrinsically arose is how the pellets will trigger the ELMs in ITER. The pellet size and velocity for ELM pacemaking, and as well for fueling purposes in ITER has been estimated by A. R. Polevoi et al. [7]. Ablation rate calculations for the pellets sizes published in this article have been performed. We supposed that the shape of the temperature and density profile as a function of the poloidal flux coordinate is similar as in ASDEX Upgrade, because these profiles scale with the machine size [8]. The temperature and density profiles were determined by using these quantities from shot No #19031 which had a wide pedestal.

This paper presents pellet ablation studies for ELM triggering experiments. It has

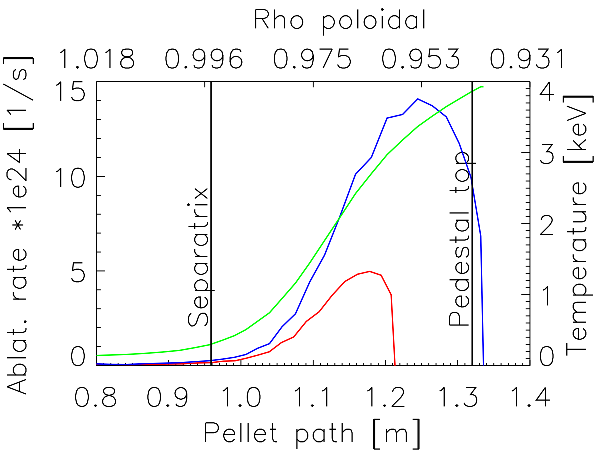

Figure 5: *The electron temperature on the pellet path and as a function of poloidal flux coordinate for an ITER like plasma. The ablation rate on the pellet path and as a function of the poloidal flux coordinate for 300m/s, small pellets ($2 \cdot 10^{21}$) is plotted with red and for 500m/s, big pellets ($5 \cdot 10^{21}$) with blue.*

The ablation curve and the penetration depth have been calculated for the two pellet sizes which are expected to be used in ITER ($33mm^3$ with $2 \cdot 10^{21}$ particles and $92mm^3$ with $5 \cdot 10^{21}$ particles) and two velocities 300m/s and 500m/s, respectively. It has been obtained that smallest and slowest pellets will penetrate approximately 20 cm inside the separatrix, reaching the rho poloidal value of 0.98, which is situated in the pedestal region. Big and fast pellets will penetrate deeper, reaching the 0.95 value of the poloidal flux coordinate, which is considered to be enough for core fueling [7]. The ablation rate for two pellets as a function of the pellet path and the corresponding temperature profile is shown in Figure 5. The poloidal flux coordinate is also shown.

been found that the ablation in the pedestal region can be described fairly good by the code, while in the core plasma, where the temperature gradient is smooth, according to the pellet monitor signal, the time dependence of the ablation rate is not smooth anymore. This difference needs to be analyzed in future work. The pellet particle content to check the question whether it is necessary for the pellet to reach the pedestal top to trigger the ELMs has been estimated for 600m/s pellets. Calculations for ITER like plasma were also performed for published [7] pellet particle contents and velocities. The pellets with a particle content of $2 \cdot 10^{21}$ will ablate in the pedestal region while the big pellets containing $5 \cdot 10^{21}$ particles will reach the core plasma, even if the drift effects are not taken into account in the calculations. It is very likely that at least the bigger pellets will trigger ELMs in ITER.

References

[1] P. T. Lang, Nucl. Fusion **44**, 665 (2004)
[2] S. Kálvin et al, this conference
[3] P.T. Lang et al, this conference
[4] P.T. Lang, Rev. Sci. Instrum., **74** (2003) 3974
[5] D. H. McNeill, J. Nucl. Mater. **162-164**, 476 (1989)
[6] K. Gál et al., Europhys Conference Abstracts Vol. 28G, P-5.149.(2004)
[7] A. R. Polevoi, Nucl. Fusion **43**, 1072 (2003)
[8] A. Kallenbach, J. Nucl. Mater. **337-339**, 381 (2004)