IMPROVEMENT OF BEAM-HEATED DISCHARGES BY REPETITIVE PELLET FUELLING IN ASDEX

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Introduction : Experiments with repetitive pellet injection were performed on the ASDEX tokamak to study additionally heated high-density divertor discharges using pellets of different sizes as a fuel source. This paper reports pellet-refuelled L- and H-mode deuterium discharges. In preceding investigations with multiple pellet injection, especially in ohmic heated discharges, a long-lasting period of peaked electron density profile and considerably improved global energy confinement were obtained. In recent experimentation L-mode plasmas could be created which show advanced plasma performance in relation to the common gas fuelled and neutral-beam-heated (NBI) discharges. These large pellet refuelled plasmas were characterized by moderately centrally peaked electron density profiles, high edge recycling, reduced sawtooth activity, central impurity radiation and significantly improved energy confinement. At a heating power of 2.5 MW the H-regime could be attained together with injection of small pellets.

Experimental Parameters : ASDEX is a tokamak with a major radius of 1.65 m and minor radius of 0.40 m. The poloidal plasma cross section exhibits nearly circular shape. The discharge parameters were typically $B_t = 2.2T, I_p = 380$ kA and $q_a = 2.7$. The line-averaged target electron density ranged from $\bar{n}_e \sim 1 \times 10^{13} cm^{-3}$ to $\bar{n}_e \sim 8 \times 10^{13} cm^{-3}$. The pellets with about 4.5×10^{19} or alternatively 1.5×10^{20} deuterium atoms each were accelerated by a centrifuge to a velocity of approximately $600 \frac{m}{s}$ [1]and yield penetration depths of roughly half the plasma radius. Normally up to 40 pellets were injected with a repetition rate of 30 ms. The additional gas puffing is not reduced during the pellet injection. Pellet ablation and penetration were monitored by photodiodes with D_α/H_α line filter and plasma photography. The power of the hydrogen beams is scanned from 0.35 MW to 3 MW in co-direction. When large pellets were applied, the heating power was technically limited to 1.35 MW. In typical cases of good confinement ASDEX was carbonized.

Experimental Observations : In earlier investigations combining injection of small pellets and strong NBI no remarkable density build-up could be produced [2]. Up to 70% of the injected pellet mass was missing in the discharge and nearly all the ablated mass left the plasma in between two pellets (fig. 1a). The sawtooth activity increased and the energy confinement time ($\tau_E = W_p/(P_{heat} - dW_p/dt)$) degraded to values comparable to the gas puff case. The electron density and temperature profiles behaved also like in the gas puff L-regime. In recent experimentation with increased pellet size and limited NBI power it was possible to improve significantly the plasma performance of the L-mode. The operational density range is extended to $\bar{n}_e = 1.3 \times 10^{14} cm^{-3}$. During the heating phase the plasma stored energy from beta measurements increased by a factor of about 2 (fig.1b) although still up to 50% of the measured pellet mass is lost during injection [3]. The situation with respect to the pellet ablation and penetration depths ($\sim$ 22 cm) corresponded to the ohmically heated discharges. Typically the sawteeth continued through the pellet injection but the period increased and the sawteeth lock to the pellets. When the pellet injection repetition rate is enlarged close to the sawtooth periode, the sawtooth activity could nearly be suppressed (in OH discharges the sawtooth dynamic can vanish completely). Under these conditions maximum Murakami paramters ($M = \bar{n}_e R/B_t$) of $10 \times 10^{19} m^{-2} T^{-1}$ were achieved. In parallel, the energy confinement time improved by approximately 40%. A weak density dependence as in the gas puff case and no saturation of the energy confinement were observed in the explored density range (fig. 2).

Pellet injection is able to generate strongly peaked electron density profiles ($n_e(0)/\bar{n}_e \approx 2$). This effect indicates a change of the particle transport properties of the discharge, as seen with pellet injection into ohmic discharges. The electron temperature profile shape, on the other hand, exhibits no remarkable change compared to the pre-pellet phase. With increasing beam heating power,the electron density profile peaking in the L-mode becomes less prominent (fig. 3), and the energy confinement degrades (fig. 4) [4]. The confinement degrades much faster than the density profile peaking. At 1.35 MW neutral beam power the profile peaking is close to the standard gas refuelled L-mode discharge.

In the first H-regime experiments together with injection of small pellets (penetration depth of pellet $\sim$ 12 cm) the plasma performance is very similar to the gas puff case: density build-up takes place typically for the H-phase even without gas puffing and in between the pellet cycles. Starting at $\bar{n}_e = 8 \times 10^{13} cm^{-3}$, the density could be increased to $\bar{n}_e = 1.2 \times 10^{14} cm^{-3}$ by pellets and the intrinsic H-properties. The electron density profile showed the typical H-type shoulder and no pronounced profile peaking ($n_e(0)/\bar{n}_e = 1.25$). There was no sawtooth activity. Typical values of the energy confinement time were 70 ms at $\bar{n}_e = 5 \times 10^{13} cm^{-3}$ and 40 ms at the maximum density $\bar{n}_e = 1.2 \times 10^{14} cm^{-3}$.

Strong accumulation of high-Z impurities and central radiation (when sawteeth could be suppressed) were found in L- and H-shots with successful density build-up. The discharges often terminated through radiation collapse, in particular when Kr is puffed into the discharge to smother the sawteeth. Absolute bremsstrahlung measurements demonstrated that Z_{eff} stays nearly constant at $\sim$ 1.5 in most of the plasma cross-section during pellet injection [5], indicating that there is no low-Z accumulation.

References :

[1] W. Amenda, R.S. Lang, J. Phys. E: Sci. Instr. 19, (1986), 970
[2] M. Kaufmann et al., to be publ. in Nucl. Fusion, IPP Report 1/242, July 1987
[3] A. Carlson et al., this conference
[4] O. Gruber et al., this conference
[5] K.-H. Steuer et al., this conference

Figure Captions :

1 : The density build-up of two pellet-refuelled and NBI-heated discharges is shown. In conjunction with the successful density build-up of discharge #21427 the global energy confinement time increases during pellet injection to $\sim$ 65 ms. The increase of the diamagnetic beta (dashed-dotted curve) is also shown. When small pellets are injected (#18913), neither a high density nor improved confinement is attained.

2 : Global energy confinement time as a function of the line-averaged electron density of pellet-refuelled (a) and gas-puff-refuelled (b) deuterium discharges at different NBI heating powers. The confinement time and electron density of pellet-refuelled discharges reach values which are considerably higher than those of the standard gas-puff case.

3 : Peaking factor (ratio of the peak electron density to the volume-averaged electron density) as a function of the total plasma heating power P_{tot} of pellet-refuelled discharges. This power is the sum of the ohmic input power P_{OH} and the absorbed neutral-beam power: $P_{tot} = P_{OH} + 0.9 \times P_{NBI}$. The peaking factor at $P_{tot} = 0.5$ MW corresponds to pure ohmically heated discharges with injection of small pellets. When NBI power is applied, only discharges refuelled via large pellets are considered. The peaking factors at $P_{tot} = 0.5$ MW and 1.0 MW are determined during stationary density phases. The other values are ascertained close to stationary density conditions.

4 : Global energy confinement time as a function of the total heating power P_{tot} of pellet-refuelled discharges (see also caption of figure 3). All energy confinement times are determined at a line-averaged electron density of $\bar{n}_e = 1 \times 10^{14} cm^{-3}$.

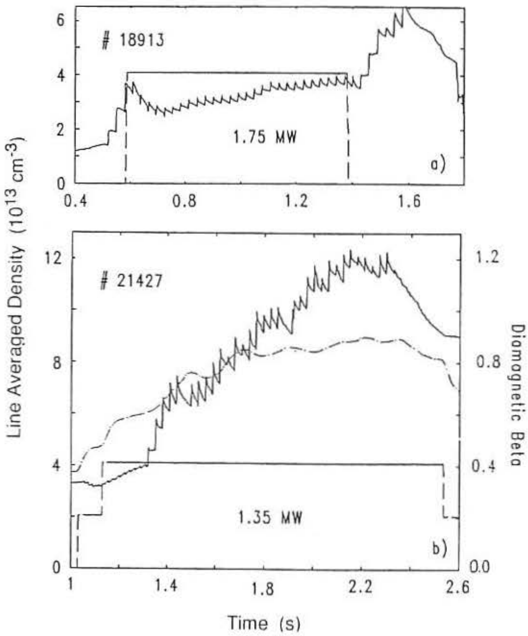

Fig. 1

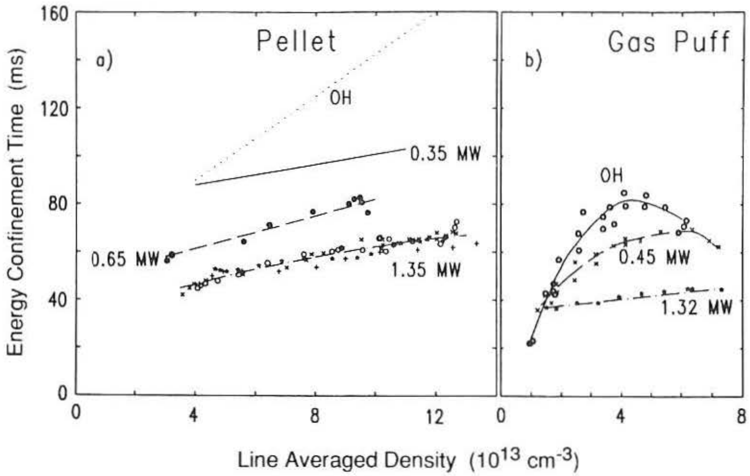

Fig. 2

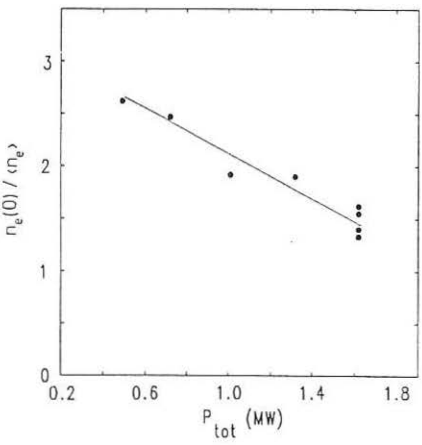

Fig. 3

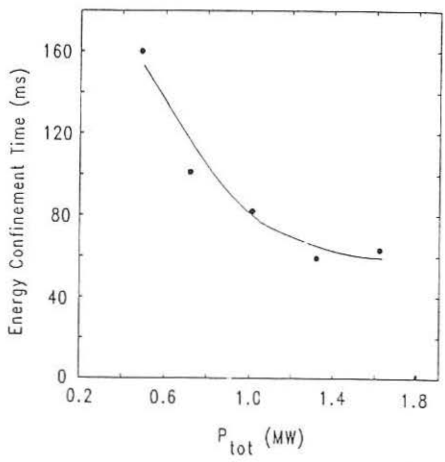

Fig. 4