MASS LOSS WITH PELLET REFUELLING ON ASDEX DURING NEUTRAL INJECTION HEATING

A.Carlson, K.Buechl, O.Gehre, M.Kaufmann, R.S.Lang, L.L.Lengyel, J.Neuhauser, V.Mertens, W.Sandmann, ASDEX TEAM, PELLET TEAM, NI TEAM

IPP Garching, EURATOM Association, Fed. Rep. of Germany

I. INTRODUCTION

Shortly after injection of a pellet into an ASDEX discharge (1) with neutral injection heating, a large quantity of plasma is lost by some mechanism much faster than that normally active. The measured increase of particles in the target plasma (with about 1 msec time resolution) corresponds to only about half the measured number of particles in the pellet. Other measurements verify that the pellet particles do indeed penetrate deep into the target. The nature of the plasma cloud produced by the pellet is understood in general, but the further interaction of the cloud with the target plasma can be very complex. Two mechanisms to account for the observed loss are proposed: an outward drift due to toroidal geometry and finite resistance, or transport from instabilities driven by the large pressure and density gradients or the corresponding large current perturbation.

The geometry of pellet injection on ASDEX (major radius R = 165 cm, minor radius a = 40 cm) is shown in Fig. 1. Hydrogen or deuterium pellets are injected radially inward in the equatorial plane. The pellet mass is deposited radially as neutral gas over a distance $\delta_{rad} = 10 - 30$ cm. The neutral gas expands poloidally (and toroidally) to a thickness of $\delta_{pol} = 1$ - 2 cm before it is ionized. Thereafter, the plasma cloud expands mainly along field lines with the acoustic speed, so that the length δ_{tor} increases with time. The cloud streches once around the torus ($\delta_{tor} = 2\pi R$) after a time interval of about 0.1 msec. Thermal equilibration occurs on a time scale of about 0.3 msec. The pellet cloud has a particle content less than or comparable to that of the target plasma, but is geometrically much more compact. Since energy is transferred to the cloud with the thermal speed of the target electrons, but the cloud expands only with its own acoustic speed, the pellet cloud acts as an energy sponge, resulting in beta, as well as density, one to two orders of magnitude larger than that of the surrounding plasma. Beta should remain roughly constant between ionization and the attainment of thermal equilibrium, the effects of expansion and heat flux approximately cancelling.

II. EXPERIMENTAL OBSERVATIONS The number of electrons in the ASDEX plasma at 1 msec intervals is determined using a four-chord FIR interferometer. The accuracy of these measurements is verified and improved by comparison with Thomson scattering profiles and lithium beam measurements of the edge density. The number of atoms in each pellet is measured in flight using a resonant microwave cavity. The fueling efficiency η is defined as the step increase in the target electron content divided by the pellet atom content. For ohmically-heated (OH) discharges, $\eta_{OH} = 100\%$ with an accuracy of $\pm 10\%$, that is, all the pellet mass can be found in the target plasma after the injection. For neutral-injection-heated (NI) discharges (1.3 MW, L-mode), $\eta_{NI} = 50\%$. (η during other heating methods has not yet been investigated.) The interferometer and pellet mass signals are plotted for one ASDEX disharge in Fig. 2. Note that the jumps in the interferometer signal are about twice as large during the OH phases at the beginning and end of the discharge, than they are during NI, although the pellets all have about the same mass.

The simplest explanation, that only half the pellet mass penetrates the plasma in the NI case, the rest being ablated already in the scrape-off layer, is contradicted by observations of H_α light. Photodiode measurements (shown in Fig.3) and photographs show ablation primarily 5 to 20 cm inside the separatrix, not in the scrape-off-layer, for NI as well as OH. We are thus forced to the conclusion that a large quantity of plasma, corresponding to half the pellet mass or up to half the target plasma, is lost over a radial distance of around 10 cm in a time less than 1 msec. This corresponds to a diffusion constant greater than $10^5 \text{cm}^2/\text{sec}$, which is one to two orders of magnitude larger than that found in ASDEX under normal conditions (e.g. between pellets), so that a different and much more effective particle transport mechanism must be involved.

Measurements of the plasma energy show a step-like decrease at the time of each pellet injection during NI. Assuming that it is distributed evenly among the electrons and ions lost, this energy difference corresponds to a temperature of around 140 eV. This relatively low temperature, roughly twice the temperature at the separatrix, indicates that the energy loss is mostly convective and that the particles lost probably come from the pellet cloud (although a significant fraction of the target plasma might have such a low temperature after giving up its heat to the pellet). Furthermore, the small energy loss indicates that the particles are lost perpendicular to the magnetic field, since a parallel loss mechanism (such as ergodization of the flux surfaces) would certainly result in large conductive energy losses.

Various diagnostics of the plasma edge and divertor chamber show elevated signals after injection of a pellet. The signals rise rapidly and then decay with a divertor time constant of 3–5 msec. The short rise time of the signals (< 0.1 msec for the Langmuir probes) is further evidence that the loss occurs very rapidly.

III. CANDIDATE LOSS MECHANISMS

An estimate of the initial ideal MHD perturbation produced by the cloud indicates a global $n = 1$ displacement with an amplitude of a fraction of a millimeter only. The simplest dissipative mechanism that could explain the rapid loss is the torus drift of the localized finite beta cloud in resistive MHD. The gradient and curvature of the toroidal magnetic field result in vertical drift currents within the pellet cloud. These currents must return through the target plasma, whose finite conductivity results in a voltage difference, and therefore a vertical electric field, across the pellet cloud. The electric field causes the cloud to drift outward so that some fraction of it is lost. The loss continues until the pellet cloud has distributed itself poloidally, at which time the net outward drift stops. The total currents involved are of the order of several tens of kiloamperes. Order of magnitude estimates of the E×B drift velocity easily yield values above the 10^5 cm/sec required to produce substantial losses within the 0.2 msec available. This shows that non-turbulent resistive loss could be significant, so that this mechanism deserves more careful consideration. However, it is not clear that this model will be able to satisfactorily explain the observed difference between NI and OH discharges.

A second candidate mechanism is loss due to resistive instabilities of various kinds. Tearing, driven by the large currents related to the pellet perturbation, and ballooning, driven by the pressure gradients at the edge of the cloud, are commonly discussed, but a quantitative assessment of the expected anomalous transport is not available. We note, however, that the fact that the pressure profiles before pellet injection are much closer to the ideal ballooning limit during NI than during OH could possibly provide an explanation for the difference in mass loss for the two cases.

The clarification of the mechanism responsible for the rapid loss of plasma during pellet refuelling will aid the design of pellet systems for future experiments, but more important, it may help our general understanding of particle transport processes in tokamaks.

References

(1) Kaufmann, et al.,"Pellet Injection with Improved Confinement in ASDEX", to be published in Nucl. Fusion. See also contributions from V. Mertens and from L.L. Lengyel, this conference.

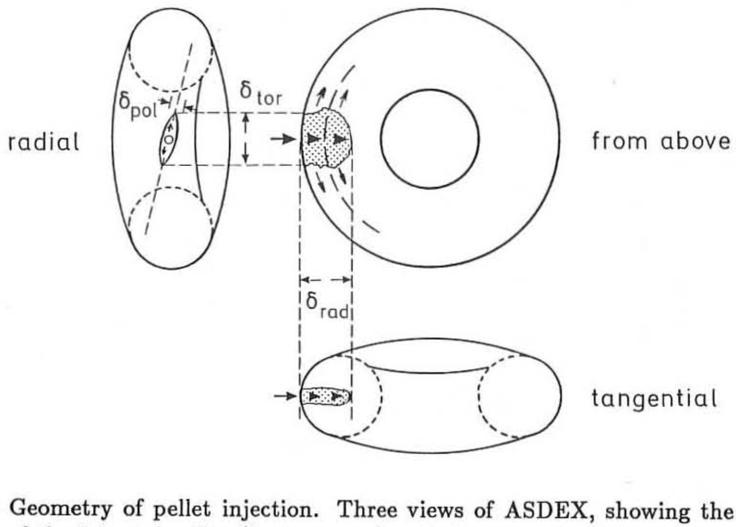

Fig. 1: Geometry of pellet injection. Three views of ASDEX, showing the path of the injected pellet (large arrows) and the expansion of the pellet cloud (small arrows) along field lines (broken line).

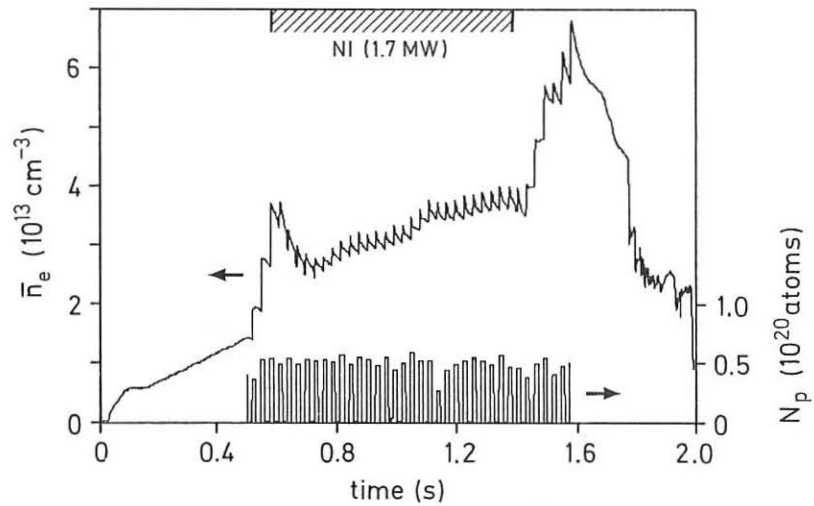

Fig. 2: Interferometre and pellet mass signals for ASDEX discharge 18913. The jump in density during ohmic heating (the first three and the last five pellets) is about twice as large as during neutral injection heating, although the pellet mass is constant.

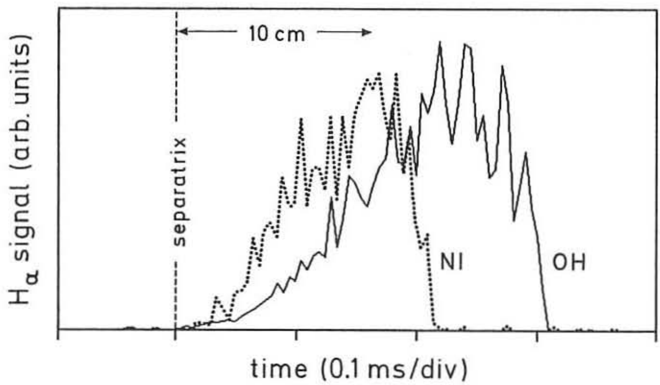

Fig. 3: Photodiode measurements of H_α light for the second and ninth pellets of ASDEX discharge 18913. The second pellet, injected in the OH phase, penetrated 18 cm (distance = (620 m/sec) $\times$ time); the ninth pellet, injected during NI, penetrated 13 cm.