EDGE DYNAMICS IN PELLET-FUELLED INNER-WALL JET DISCHARGES

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I. Introduction

Pellet fuelling has shown itself to be an effective means for obtaining low Z_{eff} peaked density profiles in ohmic plasmas [1]. Further uses of pellet fuelling may develop when tokamaks enter their DT burning phases. Then the above factors and the correct species mix become crucial for achieving the largest Q value. A necessary corollary for the success of sustained pellet fuelling is good hydrogen removal from the plasma edge. Methods to control the edge exhaust have included various wall conditioning techniques and special limiter or divertor configurations. For any of these approaches to be optimized, an understanding of the basic processes of hydrogen transport in the plasma and in the walls must be developed.

In this paper we report on the density behaviour in JET during pellet-fuelled inner-wall discharges without auxiliary heating. Certain discharges, characterized by minor disruptions at the q=2 surface, show a ten times more rapid decay of the plasma density than previously observed. We show that this is related to the combined effects of plasma and wall properties.

The time evolution of the plasma density is simulated by a 1-d plasma transport code which includes the effects of minor disruptions on both particle transport in the plasma and recycling behavior at the wall. As a starting point for the analysis we use transport coefficients from previous studies of the density profile evolution of neutral-beam and ICRF- heated JET outer-limiter discharges [2]. Several-fold changes in the particle transport and reflection coefficients during the minor disruptions are required to fit the present experiment. The detailed description of hydrogen transport in JET walls and limiters is in a companion paper [3].

II. Experiment

Deuterium pellets (4e21 atoms) were injected into deuterium discharges formed with JET in the inner-wall configuration [1]. The target plasmas had central electron densities and temperatures of 2e19 m^{-3} and 3 keV, respectively. Immediately after injection the plasma parameters were: B_ϕ =2.8T, I_ϕ =3.0-3.5 MA, R_0=3.00 m, a=1.15 m, b=1.61 m, $q_{cyl}(a)$=5.0, $T_e(0)$=1 keV, and $\langle n_e \rangle$=4-5e19 m^{-3}. The distance from the last closed flux surface to the outer limiter was 7 cm. The time evolution of the volume-average electron density (from a 5-chord IR interferometer array) and edge electron temperature (from 2-nd harmonic ECE) are shown in figure 1 for two discharges, 9226 and 9238, which had similar macroscopic plasma

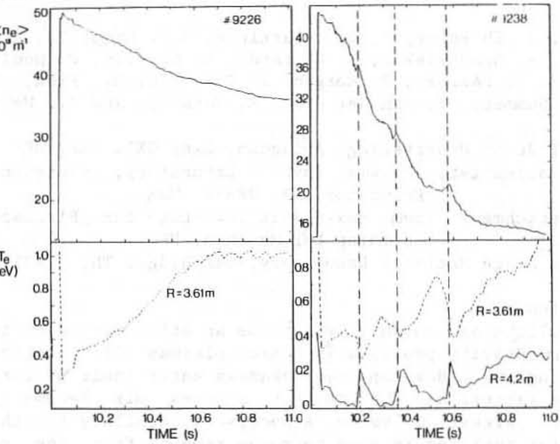

Fig. 1. Time evolution of the volume-average electron density, $\langle n_e \rangle$, and the electron temperature at R=3.61 and 4.2 m for two discharges, 9226 and 9238. The latter was characterized by minor disruptions at the q=2 radius, R=3.85 m. The high edge temperature for 10.05>t>10.7 s is an artifact, known to be due to 2-nd harmonic overlap in ECE.

parameters. The first discharge is typical of those which did not have minor disruptions. The electron density decays smoothly with about a 2 s e-folding time. The electron temperature falls when the pellet is injected, and recovers slowly, in about 1 s.

In contrast, the density in discharge 9238 decays in a scallop-like manner, with an overall e-folding time of 0.25 s. As ascertained from both ECE and soft x-ray measurements, this discharge undergoes several minor disruptions (at t=10.195, 10.355, and 10.58 s) with phase inversion radii at R=3.85 m. This position is coincident with the location of the q=2 surface calculated from magnetics. The rapid decay of plasma density- at rates up to 3e21 atoms/s- occurs only if the disturbance from the disruption propagates to the inner-wall radius. Within 15 ms after the initiation of each disruption, the edge temperature has risen above 100 eV where it remains for about 50 ms. It is typical that a series of 3-4 such minor disruptions occurs following pellet injection into discharges of this type and that during each disruption $\langle n_e \rangle$ falls about 0.7e19 m^{-3}. The electron density on axis falls about 15% during the first 15 ms after each disruption. Concurrent with the rise in $T_e(a)$ is a rise in $n_e(r>.8a)$, as shown in fig 2. However, the D-α emission from the inner wall decreases during the disruptive phase, indicating a decrease in deuterium reemission from the inner wall in spite of the expected increase in flux to the wall due to the increases in edge density and temperature.

Other mhd activity occurred in both types of discharges. Sawteeth preceded and followed pellet injection. "Snake" oscillations [4] were also present after the pellet but ended before the disruptions. No precursor

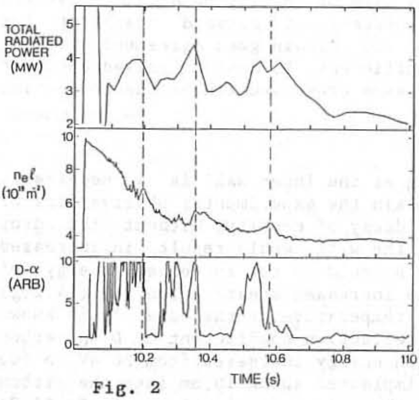

Fig. 2

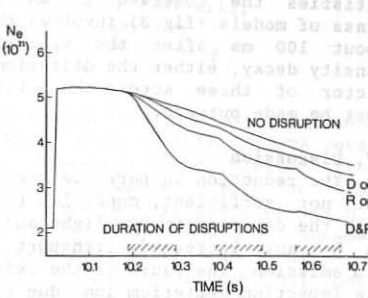

Fig. 3

Fig. 2. Line-integral electron density, $n_e l$, at R=3.75 m, D-α emission from the inner wall, and total radiated power for discharge 9238.
Fig. 3. Calculated time evolution of N_e for four cases: no disruptions; particle reflection, r, changed from 0.85 to 0.07 for 100 ms during the three disruptions; D changed a factor of 3 for 100 ms during the three disruptions ; and changing both r and D during the disruptions.

oscillations to the disruptions were observed, though minor sawteeth at q=1 immediately preceded many.

III. Modelling Plasma Behaviour

Previous studies of density evolution in JET showed the need for both diffusive and convective terms in the particle transport equation. The diffusion coefficient varied with radius from 0.3 m^2/s on axis to 1.0 m^2/s at the edge, and the convective term (inward) increased from 0 m/s on axis to 0.6 m/s at the edge. These combine to give a calculated global confinement time of about τ_p=0.35 s. The confinement of pellet-fuelled particles is 50% longer due to their (calculated) deposition near the plasma core. The apparent confinement time, $\tau_p^*=\tau_p/(1-R)$, due to the finite reycycling, R, is about 2 s, giving R=0.82. The observed rapid decay of density in the plasma core during the minor disruptions shows the need to increase the transport rate of particles out of the plasma. As noted earlier, the drop in D-α emission shows that the recycling (which includes direct particle reflection) drops. In all the models we have tried, agreement with the experiment is only obtained when R drops to $\leq$0.15.

We have considered two classes of models for particle transport by the disruptions. The first assumes an instantaneous rearrangement of the density. For this class we achieve reasonable agreement between the calculated and measured volume-average densities if either of two rearranged density profiles are used: a 15% drop on axis with those particles placed outside the q=2 surface; or a flattening of the density profile for $\pm$30 cm around the q=2 surface. However neither of these satisfies the observed 15 ms decay time of density on axis. The second class of models (fig 3) involves the increase of outward transport for about 100 ms after the disruption. To obtain good agreement with the density decay, either the diffusion coefficient, D, must be raised about a factor of three across the entire plasma cross-section or the convection must be made outward.

IV. Discussion

The reduction in particle recycling at the inner wall is a necessary, but not sufficient, condition to explain the experimental observations of both the decrease in D-α light and the decay of density. Without the drop in R any increased transport to the wall would result in increased D-α emission. The cause of the reduced R could be the increased energy of the impacting deuterium ions due to the increased sheath potential ($\simeq 4.2T_e$) associated with the increased electron temperature at the edge. It is known from beam-solid studies [5] that the reflection coefficient of D on carbon does drop from about .7 to .1 as the ion energy increases from 20 eV to 500 eV. These energetic ions are then implanted about 10 nm into the carbon tiles of the inner wall. If the carbon there is sufficiently cool (T<400 C) the implanted deuterium will remain trapped until its concentration exceeds 0.1-0.4 of the carbon density. If the temperature of the carbon is slightly higher then it may serve as a temporary reservoir only [3], releasing the implanted deuterium at a rate determined by the diffusion of D in carbon.

Minor disruptions occur in JET in a variety of configurations including outer limiter discharges. In that case no drop in density is observed and the D-α emission is seen to rise. We speculate that the cause for this difference is the limiter temperature which is measured to be > 700 C. In contrast the temperature of the inner wall is < 350 C.

Theories of minor disruptions, under development [6], have magnetic reconnection only within the islands located at the q=2 surface. The islands are thought to be only a few cm in width. Hence these theories offer no explanation for the particle loss from the plasma core.

Discharges with minor disruptions do not have particularly good energy confinement. It thus does not appear desirable to provoke minor disruptions as a way to enhance pumping. However, the apparent connection between high sheath potentials and better wall pumping does suggest that edge plasma heating, or alternatively negative biasing of large area limiters, may provide a suitable solution, at least in the short term, to the problem of hydrogen exhaust at the plasma edge.

V. References

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