EFFECTS OF ACTIVE PUMPING AND FUELLING ON DIVERTOR PLASMA DISCHARGES IN JET

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Abstract: This paper presents an overview of the experiments carried out to study and characterise the influence of active pumping on the main plasma and divertor parameters during the JET MkI 1994-95 experimental campaign. Results are presented for pure Deuterium plasmas; for a study of impurity retention and flows effects see [1].

1. NEW FEATURES OF THE FUELLING AND PUMPING SYSTEMS OF JET

Gas can be introduced into the vessel from 10 individually controllable modules, which provide a distributed source for the plasma, with up to $5x10^{22}$ D^o s^{-1} steady state fuelling capability. Six modules provide fuelling in the main SOL, and the remaining four modules, located in the divertor, fuel gas into the private flux region.

Active particle removal during plasma discharges is provided by a toroidally continuous cryopump [2], located below the divertor plates (figure 1). The cryopump operates at 4.6 K, therefore all gases but H_2 and He are pumped by cryosorption. The pump is equipped with an in-situ Ar spray system, to allow pumping of He and H_2 by cryotrapping (Ar frosting). The effective Deuterium pumping speed of the cryopump on the vacuum vessel is about 160 m^3s^{-1}, while it is about 240 m^3s^{-1}, or $\approx$ $1x10^{25}$ atoms $mbar^{-1}s^{-1}$ at the LN shields (gauge 5, figure 1). The pump capacity is $\approx$ 300 discharges.

2. DEUTERIUM PUMPING DURING PLASMA DISCHARGES

2a. Particle removal in Ω, L and H mode regimes - Due to the toroidal gaps between tiles in the MkI divertor target, particles are pumped for all separatrix positions on both the horizontal and vertical divertor target plates. The particle removal rate varies only by a factor of two, for any separatrix position (figure 2).

The removal rate is directly proportional to the neutral pressure in front of the cryopump, which in turn, depends on the plasma density and confinement regime.

In Ohmic and L mode discharges, the pressure in the divertor increases with the plasma density whilst, in Elm-free H modes, both the D_α and the pressure in front of the pump are low (typically $\approx$ $5x10^{-4}$ mbar), due to the improved particle confinement, and decoupled from the main plasma density. However, higher particle pumping is observed during ELMy H modes, when pressure bursts in the divertor are measured $\approx$ 10ms after the D_α spikes. The integral particle removal associated with isolated giant ELMs can be of about 30% of the typical plasma particle content. For normal type I ELMy discharges, the integral particle removal associated to one ELM varies, up to approximately twice the net plasma inventory loss. This indicates that some of the particles removed by the pump are originated by plasma induced desorption from material surfaces [3]. The particle removal rate also depends on the type and duration of the ELMs and on the "baseline" recycling level (i.e. on the discharge configuration, density and fuelling). Hence, either an equilibrium between particle input and removal or net wall depletion is achieved. In the case of short, high power and low recycling discharges, net wall depletion is generally not observed.

2b. Neutral pressure in the divertor and fuelling effects (see also [4]) - The plasma configuration sketched in figure 2 was used to carry out detailed comparison between pump on and off, and to assess the effects of the gas inlet location (#31584, pump off, top fuelling; #31585, pump off, divertor fuelling; #31725, pump on, top fuelling). These discharges had volume average density of $3x10^{19}m^{-3}$. In figure 3, the neutral pressure profiles (gauge 4, figure 1) are compared to those of the ion flux J_{sat}, measured with a triple Langmuir probe sitting at the same poloidal location in the outer strike zone. The characteristic decay length of the ion flux λ_{Jsat} is ≈ 2.5cm, while λ_o for the sub-divertor neutral flux is approximately 15cm, for both the pump on and off cases. This result is consistent with neutral recirculation playing an important role in determining the neutral distribution. The broad pressure profiles explain the good pumping obtained in every magnetic configuration. For #31584, we compared the integrated ion and D_α fluxes at the outer strike zone to the neutral flux as measured by the ionisation gauges below the divertor target: these are about $4.6x10^{22}s^{-1}$, and all agree to within 25%. When the plasma detaches [5,6], the equivalence between ion flux and neutral pressure in the divertor no longer holds. Therefore, active particle exhaust is maintained also for detached plasmas. The location of the gas inlets (top or divertor, pump on or off) does not strongly affect either J_{sat} at the target or the neutral pressure (with the exception of the private flux region). The integrated fuelling efficiency decreased with the pump on from ≈ 10% to 2%.

2c. Effects of active pumping on plasma parameters - H-mode discharges with active pumping are characterised by a reduction of the D_α intensity both in the main chamber and in the divertor and by an increase in the plasma stored energy, central ion temperature T_i and neutron rate R_{DD}.[7, 8 and 9]. These changes are more pronounced in plasma configurations with a medium-high "intrinsic" level of recycling. The improved performance can be correlated with the changes in the density profiles, in particular for ELMy H modes, the edge density (inside the separatrix) is generally reduced, and more peaked temperature profiles are measured. This is consistent with reduced recycling from the wall, and an improved neutral beam penetration. Changes are also observed in the divertor parameters (J_{sat}, n_e and T_e) with the pump on: target profiles become steeper by approximately 20% in-between ELMs, while during ELMs, the n_e profiles become steeper and T_e profiles are broader. The *integrated* ion flux to the target decreases by a factor of ≈ 2, the *peak* electron temperature T_e in both strike zones increases by approximately the same amount, whereas the *peak* density n_e is down by a factor of 2 at the inner target and is a factor of 3 to 4 at the outer target.

2d . Density control during H modes - With the pump on, density control in steady state is achieved during ELMy H modes, both for neutral beam only and neutral beam+gas fuelled discharges. In contrast to pump off cases, where the steady state plasma density is determined by the beam fuelling and the ELM characteristics, the combination of fuelling and pumping allows the steady state density of H-mode discharges to be varied by a factor of two (figure 4).

3. He PUMPING

The Ar frost technique, used in He transport and exhaust experiments, has proven to be difficult, and this has limited the amount of useful data obtained. In contrast to DIII-D [10], we find that the Ar spray contaminates the plasma facing surfaces, leading to Ar contamination of the discharges and disruptions. Two to three pulses are required to recover normal divertor plasma operation. The He pumping speed S_{He} depends on the D^o load on the Ar layer (figure 5) and also on the flow rate of D^o. In particular we have evidence of "recovery" of pumping speed between plasma pulses. This would indicate that D^o and He diffuse into the 10μm thick Ar layer in the time between discharges (≈ 30min).

Even before the He is injected (1×10^{20} He atoms), the amount of Deuterium used to fuel is typically around 5×10^{22} D^o, corresponding to an $Ar/(D^o+He)$ of about 20. Around this ratio and below, S_{He} starts to decrease exponentially, with loss of effective pumping.

4. SUMMARY

The JET divertor cryopump has been routinely used during the 1994-95 campaign.

The plasma parameters and confinement regime both affect the pressure in the divertor, and therefore the particle removal rate. The strongest pumping is observed during ELMy H modes. Depending on the nature of the ELM and fuelling, true steady state or net wall depletion can be achieved. Broad neutral pressure profiles are measured in the sub-divertor region, consistent with the high transparency of the MkI target, and explain the weak dependence of the particle removal rate on separatrix position.

Plasma performance is improved with active pumping. The reduction of the main chamber recycling and of the edge density are correlated to the peaking of the temperature profiles and increased fusion reactivity. With the pump on, the combination of fuelling and pumping allows density control during steady state ELMy H modes.

Ar frost is very effective in pumping He, but only at low D^o and He loads. Ar contamination of the vessel and saturation of the layer have limited so far its application for He exhaust experiments.

5. REFERENCES

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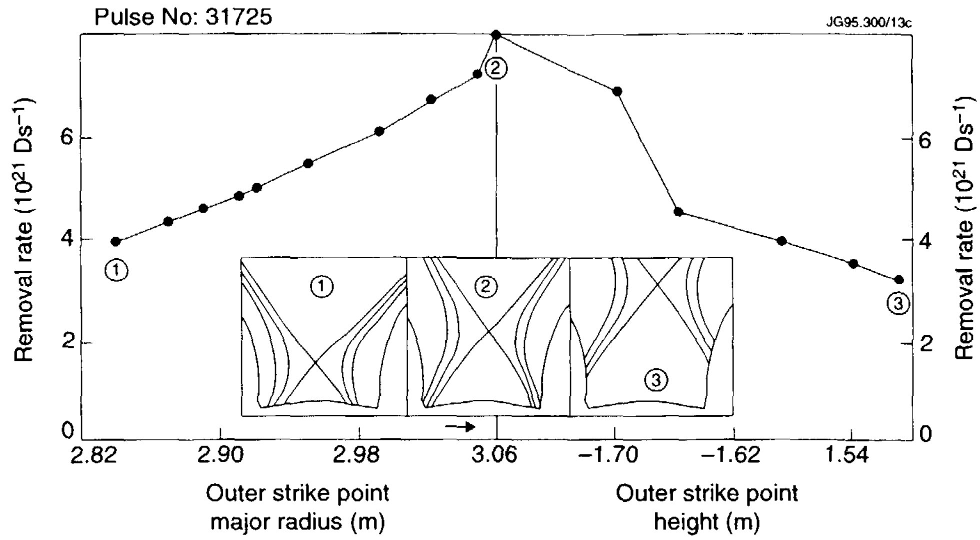

Figure 2: particle removal rate in atoms per second as function of the separatrix position, on the horizontal (a) and vertical plates (b). Pulse # 31725, 2MA/2T. The sweep of the separatrix is carried out over 10s. Maximum pumping is obtained with the divertor strike point located in the outer corner of the target.

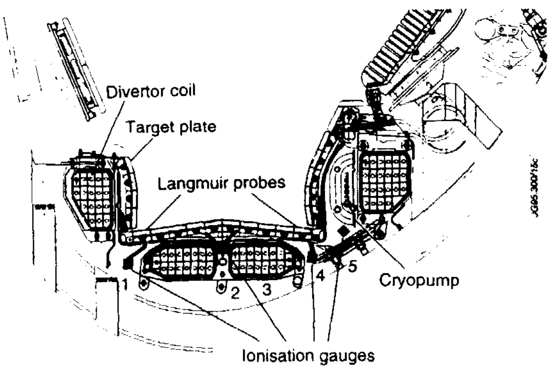

Figure 1 : location of the cryopump and of the fast ionisation gauges in the sub-divertor region. The rows of tiles in the Mark I divertor are separated by gaps, accounting for approximately 10% of the total area.

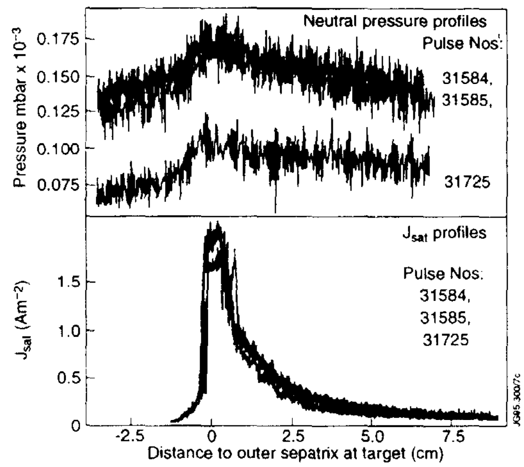

Figure 3: neutral pressure profiles and ion flux profiles for pulses 31584, 31585 and 31725, 2MA/ 2.8T. The profiles are mapped to the sweeping of the outer separatrix.

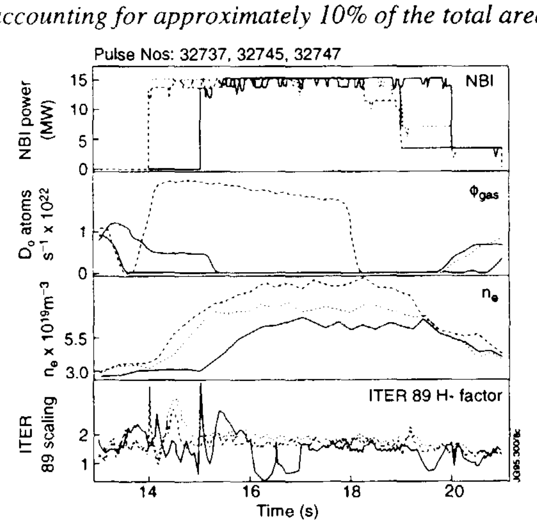

Figure 4: NBI power, D^0 fuelling rate, plasma density and H factor (ITER89P L mode) for pulses #32737 (corner eq. no gas), #32745 (centred eq., no gas) and #32747 (centred eq, gas fuelled), all at 3MA/2.8T.

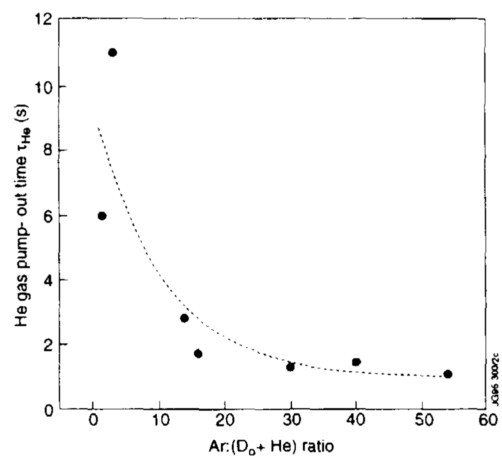

Figure 5: variation in He gas pump-out time τ_{He} as function of (D^0+He) load on the Ar layer. Note : $S_{He}=V_{Torus}/\tau_{He}$