The Influence of Divertor Geometry on JET Discharges

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1. Introduction

The JET Mark I pumped divertor can be operated with the strike zones either on the horizontal or vertical section of the divertor target, allowing a study of the influence of divertor geometry on the scrape-off layer (SOL) and the main plasma. Predictive modelling for JET [1,2] had shown large differences between the characteristics of the SOL and divertor plasma for the two configurations, associated with their different recycling patterns. The horizontal divertor directs the recycling neutrals towards the outer part of the SOL, while the vertical divertor should concentrate them towards the separatrix. For the vertical target, this effect should lead to lower neutral leakage from the divertor, more peaked density profiles in divertor and main SOL, and inverted electron temperature profiles at the divertor, with lower separatrix electron temperature than for the horizontal targets. These characteristics should also lead to detachment of the separatrix divertor plasma at lower main plasma density for the vertical divertor than for the horizontal one. A series of experiments has been carried out in JET to test these predictions (typical magnetic configurations are shown in Fig. 1), comparing plasmas in all confinement regimes, toroidal field directions, with/without cryopump and for a wide range of plasma densities. We only consider here discharges without cryopump to differentiate between purely geometrical effects and those associated with differences in pumping for the various configurations [3].

2. Measured Ion Flow and Temperature Profiles at the Divertor Plate.

Ion flow profiles at the divertor plate for low density Ohmic and L-mode discharges are more peaked when the separatrix is on the lower part of the vertical plate, compared to the horizontal divertor, and similar to the horizontal for the upper part of the vertical plate (see Fig. 2). The difference in the shape of the electron temperature profiles is less clear but the uncertainty of this measurement is larger. As the density increases, the horizontal plate ion flow profiles develop a peak near the separatrix, becoming more similar to the vertical case (upper and lower). The temperature profiles become very flat for both configurations, but the simple interpretation of these measurements becomes questionable under such conditions [4]. If the density is increased further, divertor detachment is obtained at similar densities for horizontal and lower vertical plate configurations. A difference found between horizontal and vertical divertor is that, while for horizontal plate discharges strike point sweeping does not affect detachment (i.e. the detached divertor plasma profiles follow the strike point movement), for vertical plate configurations the degree of detachment depends on which part of the target the strike point lands, being greater for the lower vertical plate than for the upper part (see Fig. 3). Similar observations are found for H-mode discharges, although the comparison of the detailed shape of the profiles at the divertor target is more uncertain because of the distortion caused by the presence of ELMs.

3. Main Scrape-off Layer Density Profiles

Predictive modelling has shown that a vertical plate divertor should lead to a narrower density profile in the main SOL. This effect is associated with the intrinsic recycling pattern of a vertical divertor, which concentrates the recycling neutrals near the separatrix, depleting the outer part of the SOL. This prediction has been observed in the experiment, but the difference in density e-folding lengths depends very strongly on the plasma density and input power, the difference being largest (up to a factor of 2) for L-mode discharges with 4MW of NBI additional heating.

4. Effects of Divertor Geometry on the Main Plasma

Although some of the predicted profile modifications due to the divertor geometry are observed at the divertor and the scrape-off layer, the main plasma parameters are very similar for equivalent discharges in the two configurations. Radiation levels and patterns are similar in both configurations apart from the trivial differences associated with the location of the divertor strike zones. No clear correlation has been found between the level of recycling, as determined by the D_α intensity in the main chamber (which should reflect the level of neutral leakage from the divertor) and the strike zones being on the horizontal or the vertical section of the plate. Fig. 4 shows the main plasma parameters and divertor ion flow for two additionally heated (4 MW) L-mode discharges on the horizontal and vertical target. No noticeable difference between these discharges is observed (similar examples exist for Ohmic and ELMy H-mode discharges).

5. Modelling of Divertor Geometry Effects

EDGE2D-U/NIMBUS [5] modelling of discharges (assuming purely diffusive perpendicular particle transport) on the horizontal and vertical divertor plate has been performed for the discharges described in sections 2 and 3. The values for the perpendicular diffusion coefficients have been obtained from detailed modelling (assuming a pure plasma and a non-coronal approximation for impurity radiation or with full fluid treatment of all carbon ionisation stages) of low density Ohmic discharges : $D_\perp = 0.12\ \mathrm{m^2/s}$, $\chi_{\perp e,i} = 1.3\ \mathrm{m^2/s}$. These coefficients are kept constant for all the simulations and the value of the separatrix density, power into the SOL and divertor radiation adjusted to match the experiment. The results for the ion flow profiles at the plate for L-mode conditions are shown in Fig. 5. The agreement between modelling and experiment is good in the lower density range of Ohmic and L-mode discharges but as the density increases (before detachment starts in the experiment) the model predictions diverge from experiment. The predicted main SOL density e-folding lengths exceed those measured by more than a factor of 2 and the peak ion flows at the plate are underestimated by a similar factor. Modelling does not describe the experimental approach to detachment for the vertical and horizontal divertors. From these calculations, the main plasma density at which detachment starts (ion flow at divertor drops with increasing main plasma density) should be a factor 2 to 3 lower for the vertical plate divertor. This is not supported by the experiment, where detachment is observed at the same densities for both horizontal and vertical divertors.

Work is in progress to explain the discrepancies between model and experiment along the following lines (presently, none of them provides a satisfactory explanation for all differences observed) : a) Existence of a particle pinch in the SOL [6], b) Unsatisfactory baffling of the structures surrounding the divertor, c) Neutral recirculation caused by the 3-D structure of the JET Mark I divertor (not included in the modelling presented here), d) Inadequate modelling of impurity dynamics in the SOL and divertor for highly radiative divertors.

6. Conclusions

Detailed experiments have been carried out in the JET Mark I divertor to assess the effect of divertor geometry on the divertor SOL and divertor plasma. While steeper SOL density and ion flow profiles at the plate are observed in the experiment, as expected from modelling predictions, no significant differences in the main plasma parameters are correlated with the discharges being diverted on the horizontal or vertical plate. In particular, the predicted (with a purely diffusive model for perpendicular particle transport) access to detachment at lower densities for the vertical plate divertor does not take place in the experiment. Whether this disagreement is due to the recirculation of hydrogen neutrals in the experiment being strongly influenced by the real 3-D structure of the divertor (not included in the model) or to SOL transport processes, is not clear. It is of paramount importance to assess this point quantitatively, as the physical basis of all advanced divertor designs relies on the strong influence of divertor target geometrical effects which has not been corroborated by the JET Mark I divertor experiments.

7. References

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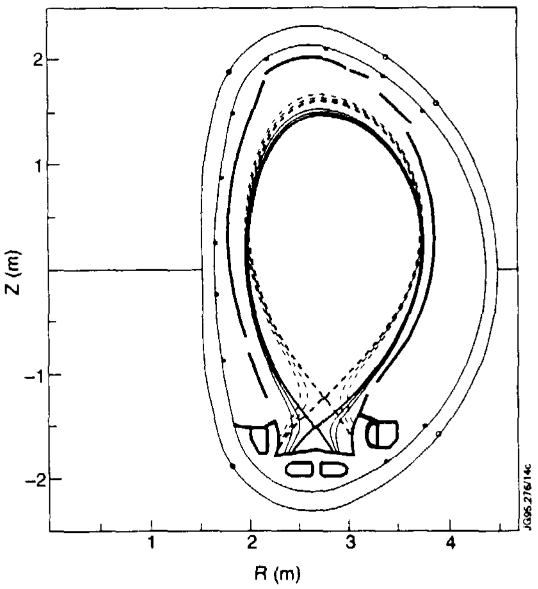

Fig. 1. MHD equilibria for two representative discharges on the horizontal and vertical section of the divertor target

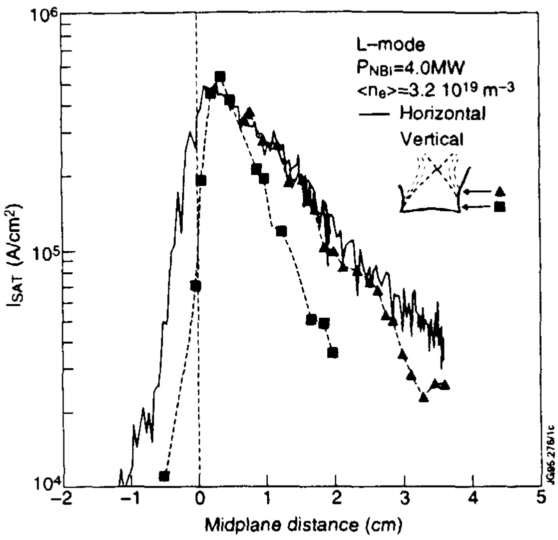

Fig. 2. Ion flow profiles for similar low/medium density discharges on the horizontal and vertical plates versus midplane distance.

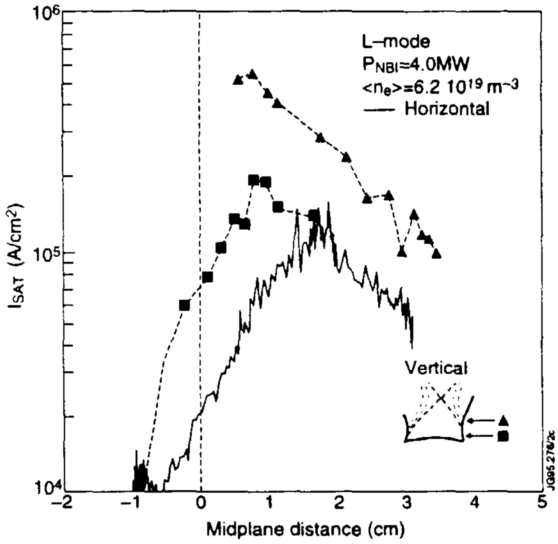

Fig. 3. Ion flow profiles for similar high density discharges on the horizontal and vertical plates versus midplane distance.

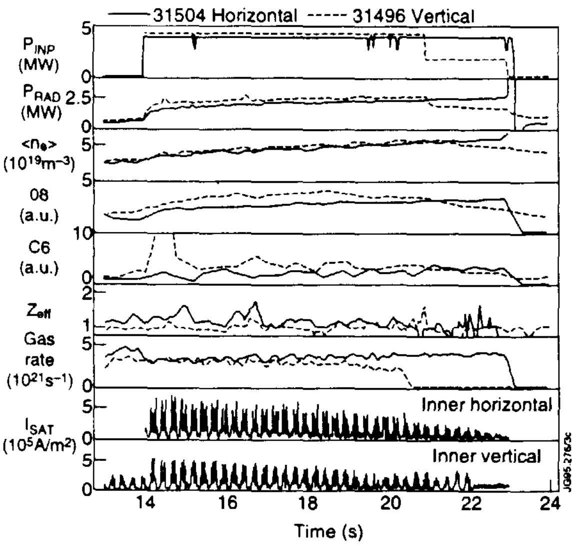

Fig. 4. Main plasma and divertor parameters for two similar discharges on the horizontal and vertical plates

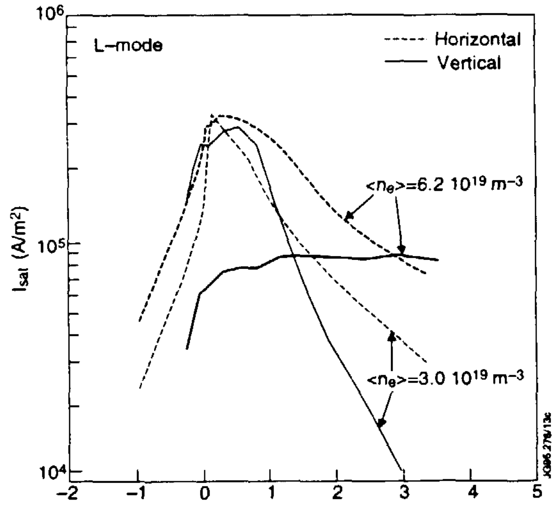

Fig. 5. Modelled horizontal and vertical divertor ion flow profiles for medium and high density L-mode conditions.