Turbulence Studies in the JET Scrape-off Layer Plasmas

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1. Diagnostics

Turbulent particle transport and its radial correlation have been studied in the scrape-off layer (SOL) plasmas of the JET tokamak with Mark-II divertor by using a specially adapted Langmuir probe. The probe head is installed on a reciprocating probe drive at the top of the machine. The tips on the probe head have been arranged in two groups of three which are radially separated 1.3 cm (figure 1), and have a poloidal separation of 2.3 cm between both groups of tips. Simultaneous measurements of fluctuating poloidal electric fields and ion saturation current (I_s) have been used to evaluate the turbulent radial particle transport (Γ_{ExB}), neglecting temperature fluctuations, and its spatial correlation between the two radial positions. Radial profiles of fluctuation parameters and particle transport are obtained by several reciprocations into the plasma during each discharge. An additional probe is available for simultaneous measurement of the time averaged density, electron temperature and electric potential profiles at the same poloidal position but toroidally displaced.

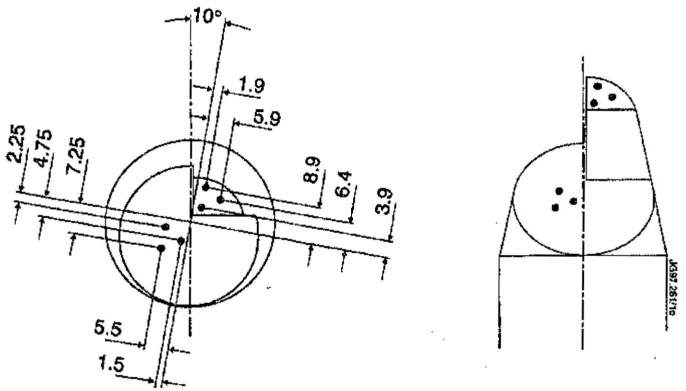

Figure 1. JET reciprocating Langmuir probe for fluctuation measurements.

2. Basic Characteristics of the Fluctuations

Measurements for JET (Mk-II) ohmic discharges (I_p= 2-2.6 MA, B_T= 2.6 T, $\bar{n}_e$= 1-2x10^{19} m^{-3}), both in limiter and divertor phases, with this reciprocating probe show that the electrostatic fluctuations and the induced radial particle transport have the same basic characteristics as observed in the SOL on other machines, i.e., normalised fluctuation levels in the ion saturation current ($\tilde{I}_s/I_s$) decreasing from 40% far out in the SOL to 10% near the separatrix with broad frequency spectra dominated by frequencies below 50 kHz. The mean frequency of the fluctuations increases as the probe moves inside the plasma (figure 2) and there are non-gaussian distributions for I_s and, most prominently for transport signals.

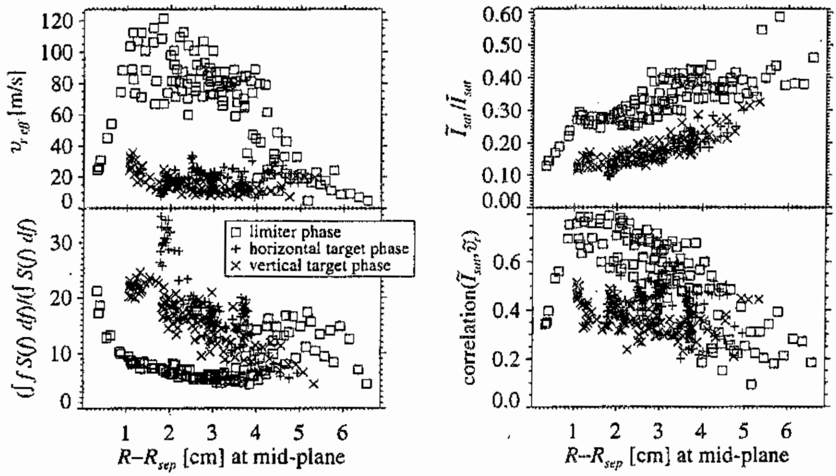

Figure 2. Radial profiles for limiter and divertor phases of the anomalous radial velocity, $\tilde{I}_s/I_s$, mean frequency spectra for floating potential fluctuations and the correlation between $\tilde{I}_s$ and $\tilde{v}_r$ signals.

3. Radial Particle Flux and its Comparison with Codes.

The derived anomalous particle fluxes have been used to estimate the anomalous outwards radial velocity, v_r = 10-20m/s, and, assuming a pure diffusive turbulent transport, the anomalous diffusion coefficient is $D_\perp$=0.15-0.3m^2/s, in horizontal divertor phases. There are two possibilities to obtain the experimental SOL decay length, of λ = 1 cm, with the 2-D EDGE2D/U-NIMBUS code simulations [1]. In the first case a $D_\perp$= 0.03 m^2/s and $\chi_\perp$= 0.625m^2/s were used, obtaining an outwards velocity of v_{diff} = 4m/s, in not good agreement with the experimental results. And in the second case the presence of an anomalous inward pinch [2] (v_{pinch} = 7.5 m/s) and a $D_\perp$ = 0.15m^2/s were assumed, resulting in a radial velocity of v_{diff} = 16m/s, comparable to v_r, and a λ = 1cm (figure 3), in good agreement with the experimental results.

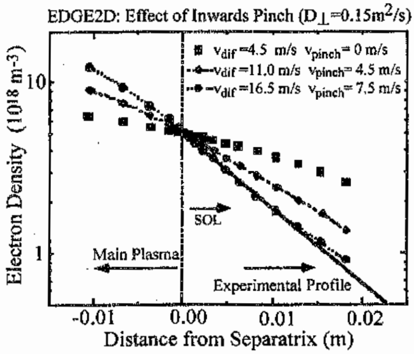

Figure 3. Outer mid-plane density profiles calculated by EDGE2D/NIMBUS code for different values of $D_\perp$ and an anomalous inward pinch term.

Future work will be directed towards comparing vertical and horizontal divertor results.

4. Differences between Divertor and Limiter Phases and the Radial Coherence

A notable change occurs in the characteristics of the turbulence between limiter and divertor phases, in ohmic discharges. The turbulent transport (figure 2) is larger in limiter phase than in X-point plasmas, due to larger fluctuation levels and to a higher correlation between density and poloidal electric field fluctuations. The anomalous radial velocity also shows differences between the two phases (see figure 2).

The level of radial coherence of the I_s fluctuations between the two groups of probes (separated 1.3 cm radially and 2.3 cm poloidally) is close to the statistical random noise, in the divertor phase (figure 4), which suggests that the radial correlation length of the turbulence is smaller than the typical dimensions of the SOL in those conditions. The pressure decay length in the shot shown is about 1.2 cm at the probe location.

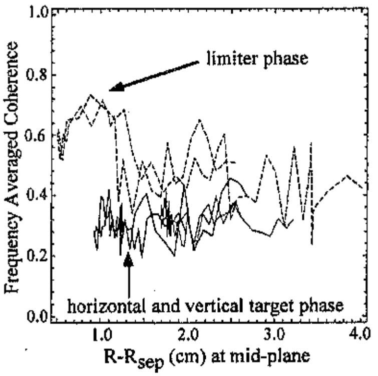

Figure 4. Frequency averaged coherence for $\tilde{I}_s$ signals between the two groups of probes versus the radial position and for the limiter and divertor phases.

However, a significant coherence is obtained in the limiter phases where the profiles are flatter and the SOL width (decay length 3.5 cm) is larger than in divertor cases.The frequency averaged radial coherence level between I_s signals increases as the probe is close to the separatrix position (figure 4). The feature in the coherence is located in the frequency range 0-40 kHz, and it is observed by the outermost tips before the innermost tips with a typical time delay of 30-40 μs. This could be explained by a poloidal velocity of the order of 1000 m/s in the ion diamagnetic direction, assuming structures in phase in the radial direction [3].

The coherence between the radially separated $\tilde{I}_s$ signals is always larger than for turbulent flux signals.

5. Double Peak Structure in Divertor Profiles

Measurements of broadband electrostatic fluctuations were also carried out in the JET Mk-I divertor plasmas [4] using a set of four Langmuir probes, two at the inner and the other two at the outer divertor, for high and low recycling conditions.

For low recycling regimes the radial profile of the relative fluctuation levels is almost constant in the SOL and increases in the private flux region [4].

In the evolution from low to high recycling regimes, by increasing the plasma density, a narrow peak in the ion saturation current appears near the separatrix creating a double peak structure [5] (figure 5). This peak grows further until it dominates the profile before detachment sets in. A significant reduction from earlier in the pulse, up to a factor of two, in the fluctuation level of ion saturation current (figure 6) is observed at the location of the peak nearest to the separatrix. This reduction has been measured in the I_s profiles at the outer divertor plates as well as at the inner.

Simulations with EDGE2D/U-NIMBUS are unable to reproduce this feature with a constant $D_\perp$ in the SOL plasmas and values similar to those used in section 3. Bohm diffusion can produce a strong peaking at high recycling but not the double peak structure. It suggests that this phenomenon is due to a local change in transport and not to a localisation of ionisation sources near the separatrix. Sheared electric fields appear to be co-located with this feature and may be related to the reduction in $\tilde{I}_s/I_s$. Work is in progress to clarify if by a reduction in transport over a similar region of the EDGE2D/U-NIMBUS computational domain it is possible to reproduce some of these features.

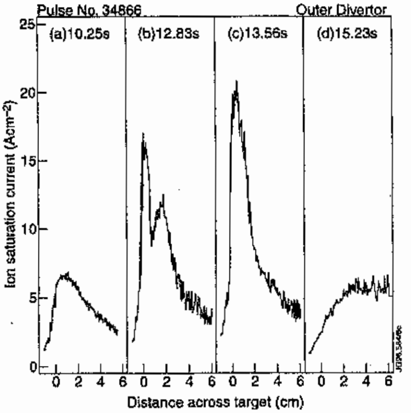

Figure 5.- Evolution of the I_s signal at the divertor plates going from low to high recycling conditions.

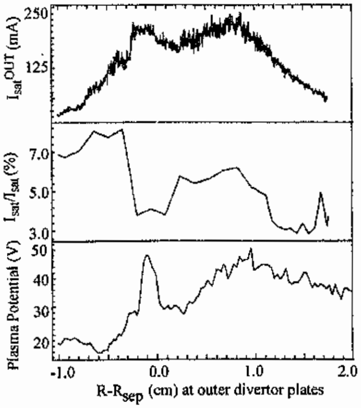

Figure 6.- Radial divertor profiles of I_s, $\tilde{I}_s/I_s$ and plasma potential (V_p) for high recycling plasmas.

6. Summary

- Turbulent particle transport and its radial correlation have been studied in the SOL plasmas of the JET Mk-II divertor by using a specially adapted movable Langmuir probe.
- The general properties of the fluctuations in the SOL plasmas exhibit the features similar to those observed in the SOL of other devices.
- Assuming a pure diffusive turbulent transport, an anomalous inward pinch is needed in EDGE2D/NIMBUS simulations in order to reproduce the profiles and the experimental value of $D_\perp$ and v_r.
- A significant radial coherence between the I_s fluctuations at the two radial positions has been observed with limiter operation but not for divertor operation. This coherence seems to be related to the plasma SOL width.
- The correlation between $\tilde{I}_s$ signals is larger than between turbulent flux signals.
- A reduction of the fluctuations near the separatrix position has been observed for high recycling plasma conditions. It suggests that this phenomenon is due to a local change in transport and not to a localisation of ionisation sources near the separatrix. This reduction coincides with strong radial electric fields. Further work is needed in the EDGE2D/NIMBUS computational domain to understand these features.

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