Electric Field Measurements during the H-mode in JET

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Introduction

Charge exchange emission in the edge region of JET has been used to measure impurity ion parameters. Ion temperatures are obtained directly from the Doppler broadening of spectral lines and plasma flows from their Doppler shifts. Two sets of viewing chords enable us to resolve the flow direction and speed. The space resolution of the diagnostic is limited to about 5 *cm* in the radial direction due to the angle of intersection of the viewing chords with the plasma flux surfaces. The zero order force balance equation is used to derive the radial electric field, E_r,

$$\frac{\nabla p_z}{n_z} = Ze\,(E_r + \mathbf{v}_z \times \mathbf{B}) \qquad (1)$$

assuming that the radial ion velocity is negligible. In this equation $\mathbf{v}_z$, n_z, p and Z are the ion velocity, density, pressure and charge, $\mathbf{B}$ is the magnetic field and e the electronic charge. The absolute value of the ion density gradient is not needed for the computation of ∇p_z, only the normalised gradient, $\nabla n_z/n_z$. This is taken to be equal to the normalised gradient of emission intensity which assumes that the neutral beam attenuation is negligible over the observation region. Emission from intrinsic carbon (n=8–7, 529 *nm*) and injected neon (n=11–10, 525 *nm*) has been used in these measurements. The readout system could operate at 0.5 *ms* but in general was limited by photon statistics to 10 *ms*.

Particle Transport

The time evolution of carbon emission intensity at four radii is shown in figure 1. The emission signals have all been normalised at 13.65 *s*, when the H-mode starts. Until the transition the density rises proportionally at all radii. After the H transition the outermost radii (4.09 and 4.13 *m*) show little increase, while the density at the innermost radii (4.03 and 4.06 *m*) continues to ramp up. The change in impurity behaviour indicates the presence of a particle transport barrier between about 4.06 and 4.09 *m*. This is consistent with other observations[1] where the impurity transport barrier was inferred from measurements of various ion stages of oxygen. Emission from inside the transport barrier is at least ten times brighter than that from outside. This change in intensity occurs within two channel spacings, 6 *cm*, but is limited by the diagnostic resolution. To establish the actual fall-off length we simulated the observations using a simple model profile. The model assumes a linear transition from high to low brightness with the width of the transition region and the brightness ratio as adjustable parameters. A good simulation of the observations is achieved with a brightness ratio of ten and a width of about 1 *cm*.

Ion Temperature

The ion temperature increases along each viewing chord as the H–mode evolves, although the profile maintains its shape. The ion temperature gradients are less than $8\,keV.m^{-1}$ therefore the contribution of the ion temperature gradient to the overall electric field in JET is small.

Measurements with the outer chords show that the ion temperature outside the separatrix can be a kilovolt or more. In view of the large ratio between the intensity of light from inside the separatrix to that from outside a question arises as to the sensitivity of the diagnostic to optical crosstalk between its observation chords. However the signals from the inner chords are slightly Doppler shifted due to the toroidal motion (see below) whereas those from the outer chords are not, demonstrating that the signals from the outer chords are not due crosstalk.

Velocity Measurements

The two sets of viewing chords view the midplane of JET from above and below. The difference in the Doppler shifts from the two sets of chords gives the poloidal component of the plasma velocity; the common-mode shifts give the toroidal component. The poloidal measurements yield an absolute value for the velocity while the toroidal measurements are ambiguous with respect to the common zero offset of all the chords. It is therefore assumed that the plasma is at rest, toroidally, at the start of the neutral heating pulse.

In none of the H–modès studied is there evidence of poloidal rotation. Figure 3 shows the results from several H–mode discharges with a range of separatrix positions. The error bars are estimated from the scatter in the fitted parameters over a period of about one second during the H–phase. The discharges were $2.8\,MA$, $2.9\,T$ with $10\,MW$ of neutral heating and mainly ELM free (selected for the good measured signal levels rather than exceptional plasma performance). The range of separatrix positions extends the scope of measurements obtained from any single shot and demonstrates the consistently low value of poloidal rotation present in these discharges. The figure includes the carbon intensity profile from three of the discharges, showing that the velocity measurements encompass the location of the particle transport barrier.

Since other experiments report finding poloidal rotation in only a thin layer we consider the effect of our viewing geometry on the results. Figure 3 includes a model velocity profile with a FWHM of $1\,cm$ and peak $15\,km.s^{-1}$ as reported in[2]. We simulate the effect of the integration of our lines of sight by averaging the velocity over the viewing volumes of each chord, with a suitable weight function. This function is computed from the intensity of the neutral beams at each point along the viewing chord, where each point corresponds to a different major radius. The resulting weight function is roughly gaussian with a full width of about $5\,cm$. The simulated poloidal rotation profile is a lower bound in that the thickness of the rotation profile taken is the lowest quoted in the literature. Furthermore, a slight improvement in the diagnostic's spatial resolution occurs at steeper gradients of the emission intensity, which have the effect of weighting the measurement towards the small major radius end of the resolution length (a more refined simulation would include this effect). The simulated profile is included in figure 3. The evidence from the simulation is that we have sufficient velocity resolution to be able to measure the poloidal rotation, if it were of the same character as seen on DIII-D and other machines.

The toroidal rotation increases with time during the development of the H-mode. The inner two chords (for the shot of figure 1) reach velocities of 55 $km.s^{-1}$ and the outer ones less than 38 $km.s^{-1}$.

Radial Electric Field

From the measurement of all the terms of equation 1 the radial electric field can be calculated. Figure 2 shows the separate contributions to E_r. The poloidal rotation contributes nothing and the ion temperature gradient little to the total. The total field is positive over most of the observation region due to the toroidal rotation profile. Where the steep ion density gradient occurs the overall field becomes negative. The exact magnitude and width of the region of negative electric field depends upon the details of the assumptions in the ion density profile shape simulations. However the presence of steep density gradients gives rise to a negative component to E_r which dominates that due to the toroidal rotation over a short distance. The net electric field, of order -30 $kV.m^{-1}$, is comparable to that deduced using similar techniques on other tokamaks during H-mode. This field strength profile is also consistent with the impurity transport parameters deduced from laser ablation experiments on JET[3].

Conclusions

The radial electric field in the edge region of JET H-mode plasmas has been derived using ion parameters measured with impurity charge exchange spectroscopy. In the H-modes studied there is no evidence of poloidal rotation, however the ion pressure gradient contributes to the force balance resulting in an overall negative electric field of -30 $kV.m^{-1}$ with width of order 1 *cm*. This field is comparable to that measured on other tokamaks and is consistent with the results of impurity transport experiments.

References

[1] A. Tanga *et al* Nuclear Fusion **27** 11 1877

[2] R. J. Groebner, et al., General Atomics Report, GA-A20272, Presented to the 13th International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Washington, October 1990

[3] R. Giannella, G. Van Oost, et al., these proceedings (see the discussion in section one, and references [2] and [3] therein.)

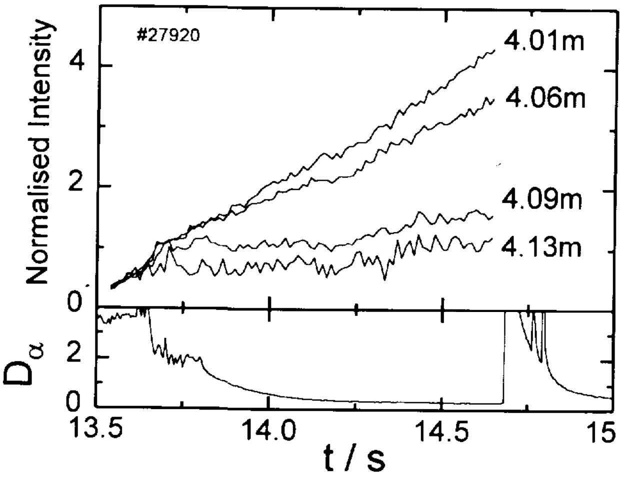

Figure 1: Plot of normalised impurity density, n_Z, versus time at the start of an H-mode. The nominal separatrix radius was 4.064 m. The D$_\alpha$ trace is also shown. n_Z is taken to be proportional to the total countrate in a line.

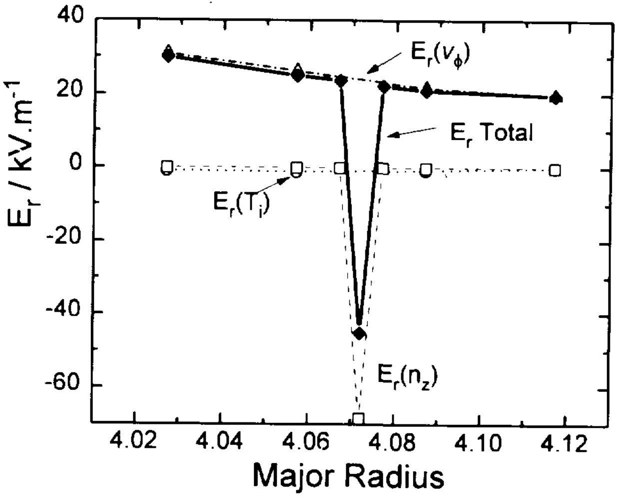

Figure 2: Computed E_r profile and its components from the radial force balance. $E_r(v_\phi)$ is the contribution to E_r from v_ϕ etcetera.

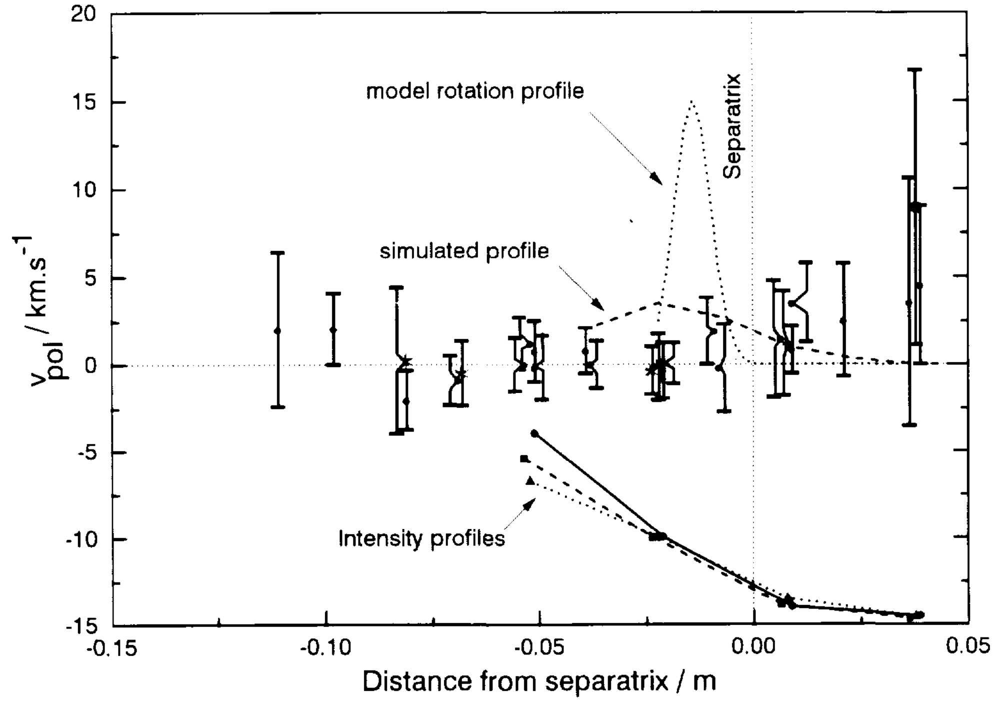

Figure 3: Plot of measured v_θ with distance from the separatrix. The error bars represent statistical errors, estimated from the time histories of the velocity signals. See the text for a description of the simulation curves. Emission curves at the bottom of the figure show the location of the particle transport barrier.