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Poloidal rotation velocity in JET advanced mode plasmas using charge exchange recombination spectroscopy

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1. Set-up of the charge exchange diagnostic and improvements to the spectral analysis

The Charge eXchange Recombination Spectroscopy (CXRS) diagnostic on JET used for impurity ion poloidal rotation velocity measurements (v_θ) consists of an edge plasma view with up-down symmetric lines of sight (LOS) mainly intended for studies of Edge Transport Barriers, and a more central view for studies of plasmas with an Internal Transport Barrier (ITB), on which this paper concentrates.

On a shot to shot basis six chords are chosen for the measurement, mostly in the mid-plane radial range R_{mid} = 3.30 m – 3.70 m (corresponding to r/a ~ 0.25 – 0.70). The LOS view from the top of the vessel down to the midplane and their intersection with the path of the heating beam defines their measurement volume. Optical fibres capture the photons from the plasma, and direct them to a 1.33 m Czerny-Turner spectrometer in the laboratory. The six 529.05 nm spectral lines are monitored simultaneously on a CCD camera. The spatial resolution of the LOS varies from 2 to 10 cm, depending on the number and type of neutral injectors that were used in the discharge and the magnetic geometry of the plasma. The spectra are recorded with a minimum exposure time of 50 ms.

The v_θ measurements have been improved in several ways [1]:

- Two independent techniques are used to provide an accurate line calibration. The first method uses a Perkin-Elmer type 303-306 samarium hollow cathode discharge lamp, with a SmI line at 528.291 nm close to the C VI line at 529.1 nm. The second method uses the Be II at 527.06 nm and C III at 530.47 nm in the plasma spectrum as two marker lines on either side of the C VI line. As such the dispersion relation can be checked on a shot to shot basis, giving an accurate Doppler shift.
- The contribution of the toroidal rotation velocity that is picked up by the viewing chords of the core poloidal CX diagnostic, has been determined in dedicated experiments. It appeared to be 15% smaller than the calculations that take into account the original design parameters of the diagnostic and magnetic geometry of individual shots. The resulting difference for the poloidal rotation velocity is about 5 km/s.

- The CX spectra are distorted by temperature effects, originating from the energy dependence of the CX reaction rate and from the gyro-orbit motion during the finite lifetime of the excited state of the C^{5+} ions after charge exchange. The apparent velocities and temperatures have been estimated for the poloidal viewing chords of the CX diagnostic, and a correction to the spectra has been applied.

As a result the carbon poloidal rotation velocity and temperature in the region R_{mid} = 3.30 m - 3.65 m are now made routinely available on JET.

2. Experimental poloidal rotation velocity in plasmas with an internal transport barrier

The improved measurement technique has been used to study poloidal rotation velocity profiles in JET plasmas with an Internal Transport Barrier (ITB). For the first time on JET significant changes in v_θ linked to ITBs have been identified [2]. An example is given in figure 1 for pulse no. 61324 (B_ϕ = 3.2 T and I_p = 3.0 MA), which develops an inner and outer ITB. Figure 1 (a) shows the temporal and spatial dynamics of the ITB through the contour plots of local dimensionless Larmor radius ρ^*_T [3], as well as the radial extent of the poloidal CX diagnostic with respect to the location of the region with strong T_i gradients. The experimental six-point-profile of v_θ is shown in figure 1 (b) for two time slices. The profile in red is taken before the barrier has moved in the viewing range of the diagnostic, a flat velocity profile is measured, and the rotation speed is very low (< 5 km/s, including the error bar). The profile in blue is taken at a later time, when the barrier is in the diagnostic's view. A strong poloidal rotation of up to 40 km/s is picked-up. The rotation is in the negative direction (i.e. ion diamagnetic direction) for the inner part of the profile and positive, but less strong (up to 10 km/s), for the two LOS crossing the outer ITB. The time intervals with increased poloidal rotation velocities correspond to intervals with a reduced level of turbulence, as confirmed by reflectometry measurements. Although the origin for the v_θ spin up has not yet been identified, it may be related to the ITB sustainment mechanisms, as the high velocities persist during the complete duration of the barrier.

3. Comparison to neoclassical predictions

In figure 2 the experimental v_θ profiles for the two time slices are compared to the neoclassical predictions. The plasma was simulated with the JETTO transport code in an interpretative way, i.e. using the experimental input profiles at different times during the run, and NCLASS was used for the neoclassical v_θ predictions. Prior to the formation of the ITB (figure 2 (a)) the profiles are flat and the rotation speed is of the order of a few km/s. The agreement is good, considering the intrinsic errors in both the measured profiles and the predictions: the intrinsic errors in the experimental temperature, density and Z_{eff} profiles for instance limit the accuracy of the NCLASS predictions. In figure 2 (b) the comparison is presented for a time slice during the ITB phase; the predictions for C^{6+} ions are only a few km/s whereas the measured velocities are a few tens of km/s, and are of the order of the predictions for the main plasma ions.

4. Discussion

A direct consequence of the high poloidal rotation velocity is that the $v_\theta B_\phi$ contribution to the radial electric field (E_r) in the barrier region becomes of the same order as the large $v_\phi B_\theta$ component from unbalanced NBI injection, suggesting a larger stabilising ω_{ExB} flow shear, than when the neoclassical predictions for v_θ are used. It was found that the strong flow shear exceeds the linear growth rate of the instable modes and helps to predict the exact time and location of the barrier formation in JET plasmas using the Weiland model in cases for which the model failed with the neoclassical v_θ [4].

A possible reason for the difference between NCLASS predictions and measurements is that certain terms are not included in NCLASS that affect the poloidal rotation: one of them is the friction force between the main and impurity ions. Possibly the impurity ions are dragged by the main ion flow to increase their velocity to the main ion speed. It could explain why the order of magnitude of the measured v_θ corresponds to the predicted rotation velocity for the main ions rather than for the carbon ions, at least this holds for the negative part of the profile from about 3.40 m up to 3.55 m, but does not explain the positive increase around $R_{mid} = 3.60 – 3.65$ m at the location of the outer ITB, nor does it explain why the more central region $R_{mid} < 3.40$ m seems to have even stronger rotation than the predictions for deuterium ions. Furthermore, the beam friction is not yet included in NCLASS, although an upgrade is in progress [5], which might influence the poloidal rotation profile. However, from the plasmas studied there does not appear to be a direct relationship between the beam power deposition profile and the dynamics of v_θ in the ITB region. It thus seems unlikely that the friction force between the fast ions from the beam and the bulk and impurity ions, could completely explain the discrepancy between measured and simulated poloidal velocity. In addition to neoclassical explanations, the role of turbulence also needs to be investigated. Simulations are ongoing to assess the possible poloidal flow driven by Reynolds stress. On the experimental field, the diagnostic capabilities have recently been extended with additional viewing chords that have a time resolution of the order of 5 ms, and a more central viewing geometry. As such the relationship between the v_θ excursions and ITBs can be investigated further, in a wide range of plasma parameters, and the question of causality between ITB formation and the v_θ excursions will be addressed.

References

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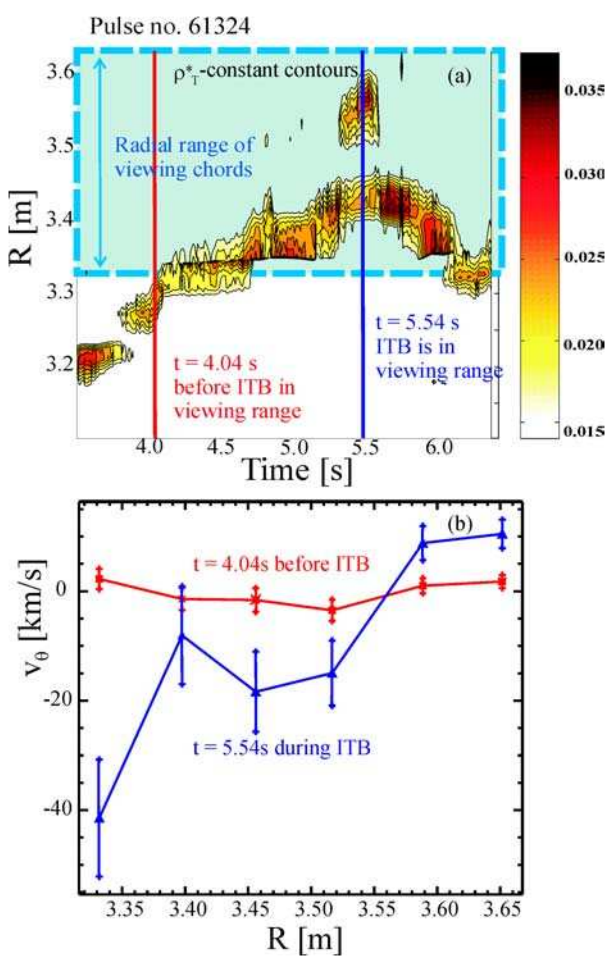

Figure 1: (a) Dynamics of the ITB and region covered by the v_θ diagnostic.
(b) v_θ profiles before and during the ITB.

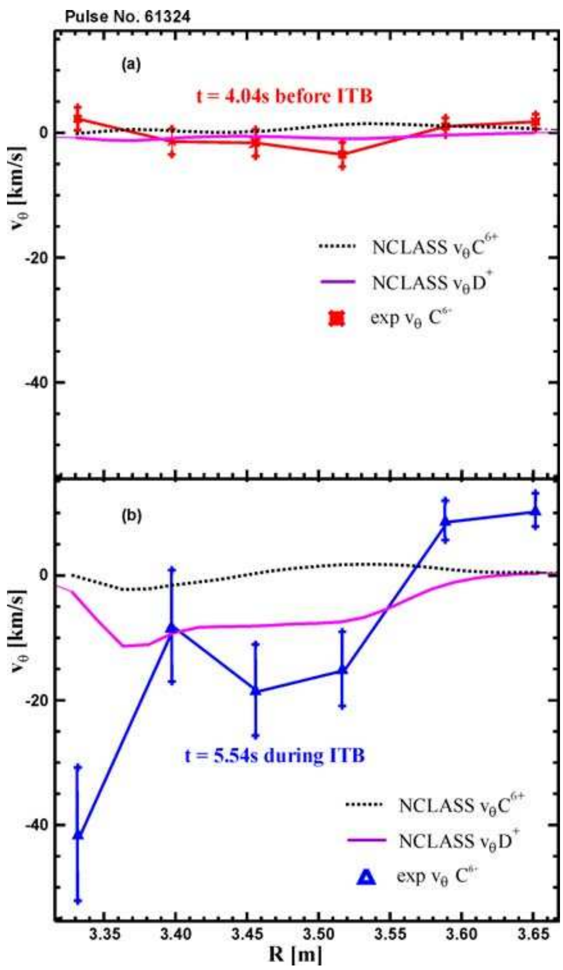

Figure 2: Comparison between measured v_θ and neoclassical predictions both for impurities and main ions,
(a) before and (b) during the ITB phase.