EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(01)02-98

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**See appendix of the paper by J.Pamela "Overview of recent JET results", Proceedings of the IAEA conference on Fusion Energy, Sorrento 2000*

Preprint of Paper to be submitted for publication in Proceedings of the
EPS Conference,
(Madeira, Portugal 18-22 June 2001)

INTRODUCTION

The measurement of the poloidal velocity of rotation (V_{pol}) in tokamaks is of interest for several reasons: the most important being that V_{pol} enters the formula for the radial electric field Er multiplied by the large toroidal magnetic field, which makes possible a non-negligible contribution to E_r as soon as V_{pol} increases above a relatively small value. On its side, through sheared E×B flow, E_r is thought to be fundamental for determining confinement.

In this work we present the spectroscopic diagnostic system that has recently been set up to measure core V_{pol} for intrinsic (carbon) or extrinsic (helium) impurities at JET. We will show the first results obtained when measuring V_{pol} in discharges where ITBs, ICRH or both are present, compare our results with neoclassical calculations performed for the same conditions, and find that the two results are, within the experimental errors, in reasonable agreement.

THE EXPERIMENTAL SETUP

A pictorial view is given in Fig.(1). A set of 16 lines of sight intercept the heating beam in octant four with a nearly perpendicular angle, on the low field side. The light is relayed via fibre optics to a 1.33m Czerny-Turner spectrometer coupled to a CCD detector, a system derived from a pre-existing edge CHRS diagnostic [1]. Coupling optics match fibre and spectrometer fnumbers in order to optimise light collection. The present set-up allows a maximum of six lines of sight to be monitored simultaneously in order to avoid overlapping of spectra on the CCD. The lines of sight can be chosen on a shot-byshot basis, ideally along the entire minor radius with a minimum radial fiber-to-fiber distance on the equatorial plane of about 0.1m. In practice, innermost lines (say, intercepting the equatorial plane at R < 3.2m) are unavailable because of the strong radiation collected from the divertor. Charge exchange (CX) lines from CVI at 529.1nm or from HeII at 468.6nm are monitored. Rotation velocity is deduced through the Doppler shift

$$\frac{\Delta\lambda}{\lambda} = -\frac{1}{c}(V_{pol}\cos\theta_{pol} + V_{tor}\cos\theta_{tor}) \qquad (1)$$

In (1) $\cos(\theta_{pol,\,tor})$ are the cosines of the angles between the lines of sight and the poloidal (toroidal) direction. The observation is not exactly done on a vertical plane thus, depending on the line of sight, $\cos(\theta_{pol}) \approx 0.96$, $\cos(\theta_{pol}) \approx 0.2 \div 0.3$. The sensitivity on the large V_{tor} with its associated errors represents one of the main concerns about the reliability of the measurements. The position of the unshifted CX wavelength is calibrated by using several known wavelengths from a Sm lamp and interpolating them with a linear dispersion law. Since the hardware was found to be liable to small movements, the calibration needs to be repeated routinely.

THE FITTING PROCEDURE AND ERROR EVALUATION

An example of spectrum fitting is shown in Fig.(2). The spectral line is reconstructed through a least squares fitting routine including: (a) the active CX line, (b) a passive CX line, (c) a background modelled using a second order polynomial, for a total of 9 free parameters. A number of tests have been carried out to evaluate the weight of the background light (passive component and continuum) on the final result. When present, notches in the beam emission have provided means to evaluate a background to be subtracted. However, in many circumstances, no appreciable differences have been found in evaluating the Doppler shift, respectively, with and without background subtraction; not surprisingly, the active component being usually more intense than the passive term.

The apparent velocity thus obtained is then corrected by finite-plasma-temperature atomic effects (in our case, the correction is usually less than five km/s) [2]. The toroidal velocity is independently measured by another spectrometer, on octant eight. An error propagation analysis shows that the dominant uncertainty is due to V_{tor}: while all other sources of error (statistical errors on collected photons, fitting errors, calibration error account collectively for an error of approximately ± 5km/s, ΔV_{tor} alone can contribute up to more than 20km/s in pulses with high toroidal rotation induced by beams. An additional error is introduced by mapping V_{tor} on the spatial positions where measurements of V_{pol} are carried out. Additionally, uncertainties on angles qtor, estimated of the order of few %, introduce errors proportional to V_{tor}.

RESULTS: ITB FORMATION

The standard paradigm is that transport barriers arise as a consequence of turbulence stabilization, when the shearing rate of the E×B flow exceeds the growth rate of turbulent modes. The electric field is usually supposed to be mainly radial, and is given by

$$E_r = V_{tor}^{\ i} B_{pol} - V_{pol}^{\ i} B_{tor} + \frac{1}{Z_i e n_i} \frac{dP_i}{dr} \tag{2}$$

with the subscript *i* that stands for a generic particle species. Increases in E_r are related to variations in toroidal rotation and/or pressure gradients. When it is not otherwise measured, poloidal velocity is usually estimated through neoclassical theory, which predicts small contributions in Eq. (2) [3]. Some recent researches show instead, in correspondence of enhanced confinement modes, sharp radially localized variations of V_{pol} that could affect the electric field profiles [4]. Figure (3) shows measured carbon V_{pol} together with that computed under the same plasma conditions using the neoclassical code [3] for the Pulse No: 53521 (main plasma parameters for this pulse are shown in Fig. 4). This pulse features, in particular, an ITB around t = 7s. The agreement is quite good, with possibly a bias in some of the chords (@3.34 and 3.41m) due to some yet unidentified systematic error. The spectra at R = 3.22m is especially disturbed by background emission, while the outermost one is probably affected by averaging effects, since we are in the region where gradients become rather high. Notice that experimental data are sampled every about 0.1s, while the numerical resolution time is of 0.18s, so the most rapidly varying features are likely to be missed by the simulation, notably the dip around 7s.

POLOIDAL ROTATION INDUCED BY RF

If highly sheared E×B flows are beneficial to confinement, an interesting opportunity is to induce them by external means. A number of recent theories suggest the possibility of inducing a controlled poloidal rotation in plasmas by using RF waves in the range of either ion or electron cyclotron frequency [5,6]. The idea behind ICRH drive is that the RF can induce a radial charge separation by preferentially driving resonant particles, thus generating a supplementary E_r. At the same time a radial current J_r develops to keep the quasineutrality of the plasma and thus imparts a $J_r \times B$ poloidal torque. Our results show that the value of V_{pol} is quite small for these pulses, but they have not yet been comforted by numerical simulations.

CONCLUSIONS.

The diagnostics implemented seems to be reliable, although relatively large errors prevent the study of fine structures. Measured poloidal velocities are of the order of a few tens of km/s in agreement with neoclassical predictions. Interesting phenomena occur at the onset of ITB's, however careful search for possible small systematic errors needs to be done before further exploitation of the results.

REFERENCES

[1]. N. Hawkes, N. Peakock, Rev. Sci. Instrum. **63**, 5164 (1992).

[2]. M. von Hellerman et al., Plasma Phys. Contr. Fusion **37**, 71 (1995).

[3]. F. Crisanti et al., *Analysis of E×B flow shearing rate in JET ITB discharges*, submitted to Nucl. Fus.

[4]. S. de Peña Hempel et al., 25th EPS Conf. on Contr. Fus. and Plasma Phys, vol. 22C, 484 (1998); R.E. Bell et al., Phys. Rev. Lett. **81**, 1429 (1998); C.L. Rettig et al., 26th EPS Conf. on Contr. Fus. and Plasma Phys, vol. 23J, 1221 (1999);

[5]. C.S. Chang et al., Phys. Plasmas **6**, 1969 (1999); C.S. Chang et al., *ibid.* **7**, 1089 (2000)

[6]. C. Liu et al., 26th EPS Conf. on Contr. Fus. and Plasma Phys., vol. 23J, 593 (1999).

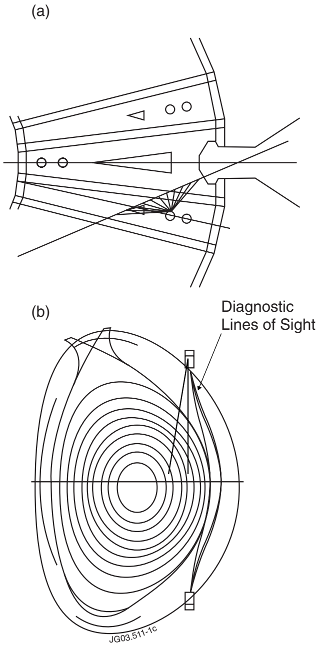

Figure 1: Experimental setup. Only upper chords are used, and only a few of them are shown here.

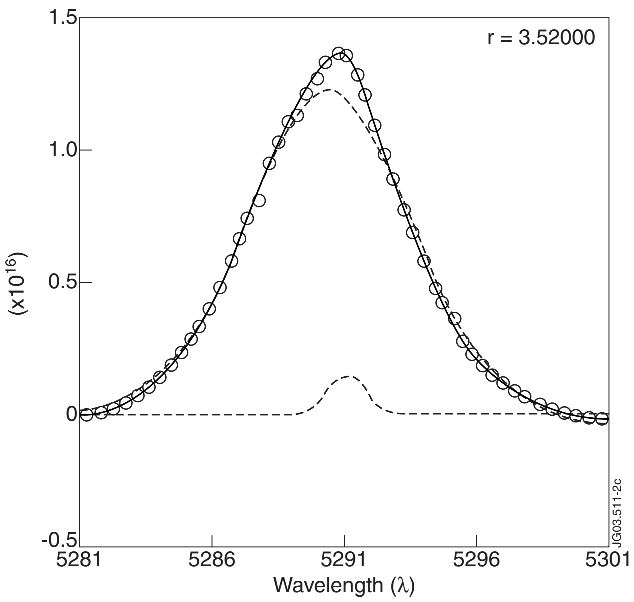

Figure 2: A sample of charge exchange spectrum: symbols, experimental spectrum (after removal of background); dashed lines, active and passive CX spectrum; solid line, total fitted spectrum.

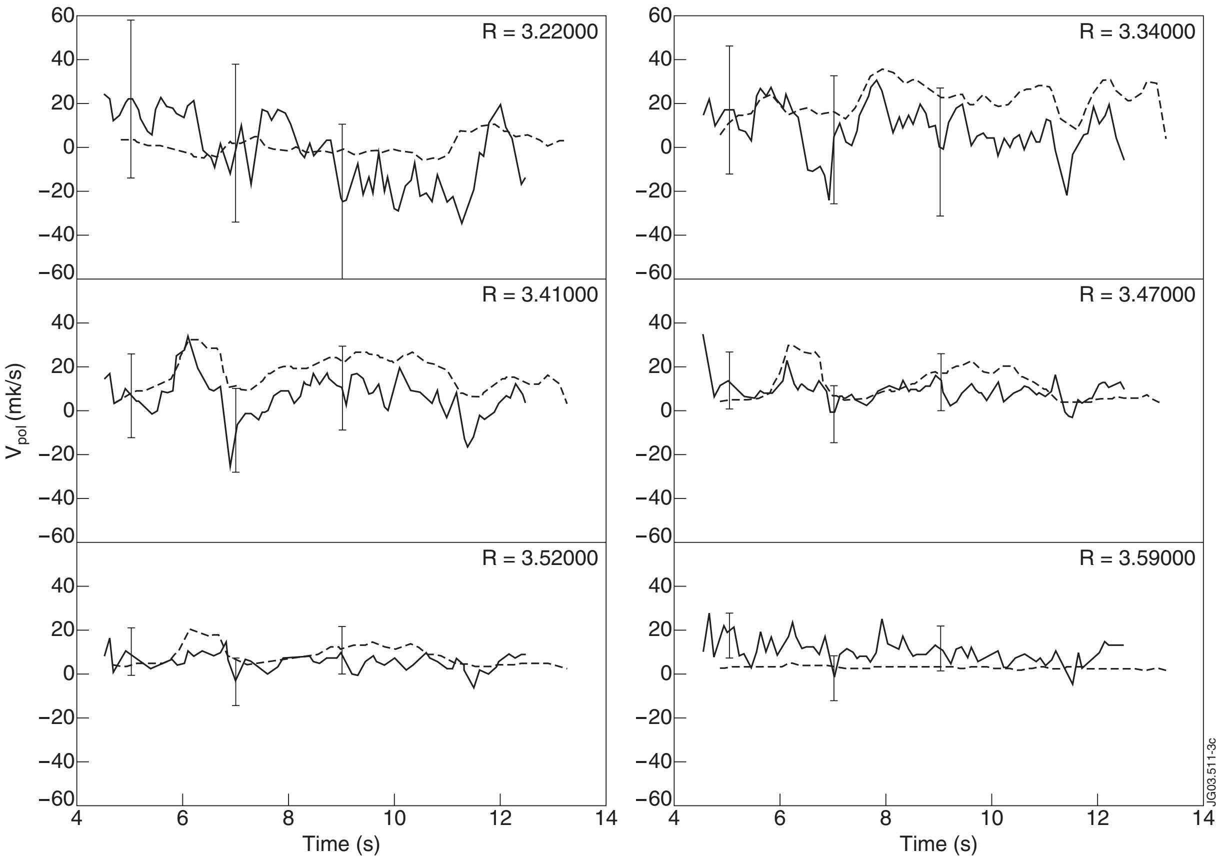

Figure 3: measured (solid line) and computed (dashed line) V_{pol} for Pulse No: 53521. Some error bars are also shown.

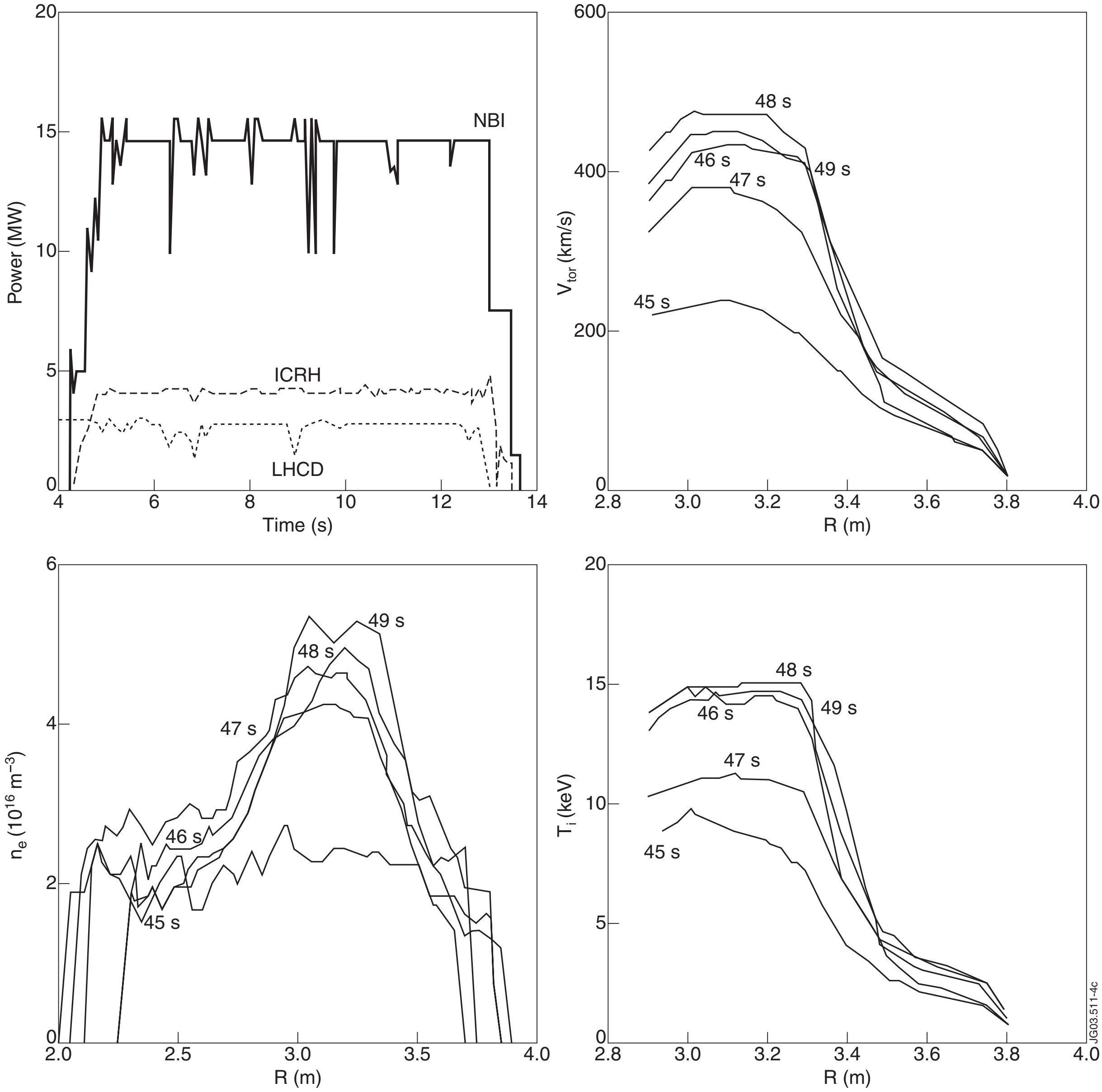

Figure 4: plasma waveforms for Pulse No: 53521: heating power; carbon toroidal velocity, electron density and carbon temperature between 5s and 9s.