CXRS Acquisition Optimisation for Rotation Studies of Fast Events on TCV *(Rotation studies in transport barriers on TCV)*

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Introduction

The study of momentum plasma transport mechanisms and the resulting plasma rotation has recently become intense. Together with the basic question of momentum conservation and distribution, rotation shear is thought to reduce the anomalous effects of turbulence and thus the threshold for entering into the H-mode high confinement regime or forming internal transport barriers (ITB).

In this paper we focus on the important upgrade recently undertaken by the TCV Charge eXchange Recombination Spectroscopy (CXRS) diagnostic and show its potential in the study of fast events (a few ms range) such as sawteeth (ST) crashes or the transport barriers formation. Some preliminary experiments aiming to assess the $E \times B$ shearing role on the electron transport and on an eITB formation/sustainment are also presented.

CXRS diagnostic on TCV

The CXRS diagnostic observes the CVI line (n=8→7, λ =529.1 nm), emitted when a CX reaction takes place between a C^{6+} ion in the plasma and a 50keV neutral H^0 beam, injected in bursts of 10-30 ms by a low power Diagnostic Neutral Beam Injector (DNBI) at the vessel midplane. Carbon is the main impurity in TCV (wall tile material) and is considered thermalised with the main ion species (D and/or H).

The CXRS diagnostic on TCV consists of three observation systems that cover the plasma core and edge [1]. A whole plasma minor diameter is covered by two toroidal systems (High Field Side and Low Field Side), each composed of a set of 40 horizontal lines of sight arranged in two paired arrays separated by 1.5 cm at the midplane neutral beam crossing. In addition, a third poloidal system intersects the neutral beam in the vertical direction in the LFS region. The diagnostic is thus optimised for plasmas vertically centered in the vacuum vessel. The collected light is spectroscopically analysed to deduce the temperature T_i, density n_c, toroidal v_ϕ and poloidal v_θ velocities of the carbon ions.

The TCV, low power DNB perturbs only slightly the plasma, therefore the carbon velocity may be interpreted as the intrinsic ion motion in the plasma, since the externally applied torque can be neglected. However, the $H^0(E_o)$ energy is still sufficient to traverse the whole plasma radius. In general, most devices have a high power NBI perturbing the rotation profiles dominated by this applied torque, therefore they generally use short, hopefully non-perturbing, pulses or passive spectroscopy of impurity atoms radiating in the plasma core. This important characteristic of the TCV's CXRS - DNBI system permits a much larger flexibility for the pulse timing and triggering but limits the intensity of the active signal detected by the cameras.

CXRS 2010-2011 upgrade

In order to improve the acquired signal quality and increase the CXRS exploitation range, the diagnostic has recently been equipped with two CCD cameras featuring on-chip gain (Andor ^{TM} iXon $^{EM+}$ DU897D-CSO-BV) resulting in improved sensitivity and time resolution. It enables measurements (512×20 frame transfer format) with integration times of 1.7 ms (instead of 12 ms before) and an improved Signal/Noise ratio by a factor of 8. The back illuminated e2v CCD97 detectors (e2v CCD57-10 before) have now a quantum efficiency up to 95 % (instead of 85 %). These cameras will allow the detection of faster events ($\sim$few ms) in scenarios where the beam is strongly attenuated and the active signal weaker or much more irregular (eITBs or density ramp in H-modes). This is true even at the low densities of typical eITB studies. The new cameras can also be better tuned in between shots, increasing the measurements quality. With the installation of these cameras, the entire CXRS acquisition process and data analysis required modification of the integration into the TCV plant control system.

Fast acquisition measures, optimisation and intelligent triggering

During the initial CXRS data acquisitions, some limitations in the cameras setup parameters were observed, in particular an amplification gain dependence on the CCD illumination. An accurate scan in the Electron Multiplying (EM) gain, preamplifier gain, exposure time, horizontal and vertical clock speed was performed to derive an optimal set up for the fast (t_{exp}=2-4 ms) and standard (t_{exp}=10-30 ms with a time resolution of 20-90 ms due to the DNBI duty cycle) acquisitions. The standard acquisition is usually used to study stationary plasma phases, whereas the rapid acquisition is used to investigate fast events occurring in plasmas such as sawteeth (ST) crashes or TB formations.

In addition, to better exploit the CXRS acquisitions intelligent triggering has been recently developed for TCV. A real-time (RT) trigger system based on a digital control system recently installed on TCV is used to monitor the evolution of the ST, measured using a soft X-ray detector. After every ST crash is detected, a sequence of regularly spaced triggers (Δt=2 ms) is generated and sent then to the CXRS system (Fig.1). This unique procedure has been used to investigate the momentum transport across ST events since the rotation profiles just before and after the ST crashes can be measured. A strong co-current torque was observed in the plasma core at the ST crash followed by a slower counter-current relaxation outside the inversion radius[2].

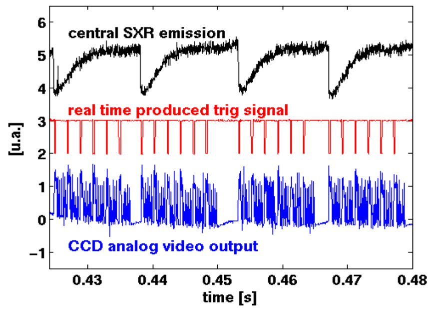

Fig. 1: RT- trigger on ST crashes

Recently, a RT ST trigger modulation that partially stabilises the ST was implemented [3] lengthening the ST period and simultaneously synchronising the CXRS timing. To date, the CXRS integration time was required to be synchronised with the DNBI time pulses (ramp up triggering) to acquire the active and passive spectra. A RT DNBI trigger is nearing completion for TCV, which will directly trigger the DNBI (and consequently the CXRS) on a detected fast event (ST crash, ELM,...) or set the CXRS acquisition to be asynchronous with the DNBI pulses (ramp down triggering). By setting the DNBI and CXRS acquisitions independently, it will be possible to overcome the problem of a minimum regular DNBI time pulse and to maximise the measurements set to investigate so hitherto unstudied scenarios resulting from limited signal strength.

Application on transport barriers studies and preliminary rotation profiles in eITBs

The CXRS and TCV's unique possibilities can now be used to study the fast events that occur in transport barriers. EITBs are formed using electron cyclotron heating and current drive (ECH/ECCD) to create hollow or flat current profiles, essential for their formation. On TCV a key ingredient for the eITBs formation and sustainment is the degree of reverse shear [4], and for other devices the rational q and/or the $E \times B$ shearing have a strong influence.

The effect of EC power on the barrier strength and rotation profiles has been examined by applying 730kW central ECH or counter-ECCD (giving a central eITB, [5]) and by comparison with a similar Ohmic plasma discharge. Preliminary results show that all three cases are characterized by a counter rotation profile ($v_\phi > 0$, Fig.2c). Moreover, when applying a central cnt-CD power a peaked counter current rotation is sustained in the core with rotation values approximately doubled compared with the ECH case [6]. As the ∇v_ϕ values for the cnt-CD and the Ohmic case are similar near the barrier edge (the highlighted regions in Fig.2c), the question then arises whether the transport could be the same for both cases thanks to these gradients.

The cnt-CD case, shows also a doubled central electron pressure, indicating a confinement improvement inside $\rho_\psi = 0.6$ with 6 keV on-axis (Fig.2a). From the p_e profiles (and gradients) the existence of a marked difference in the electron transport is deduced. Moreover, the $v_\phi B_\theta$ profiles, being the main contribution to $E_r \times B$, show the three regions corresponding to a negative (see Fig.2b: violet), zero (orange) and positive (pink) $E \times B$ shearing term. The zero $E \times B$ shearing region (around $\rho_\psi = 0.4$) corresponds to the position of the maximum ∇p_e. This preliminary result suggests that the $E \times B$ shearing is not expected to be the cause of the electron transport improvement. However, the increased v_ϕ profile for the eITB case could result from the improved confinement. Further analysis and experiments are required to be performed in

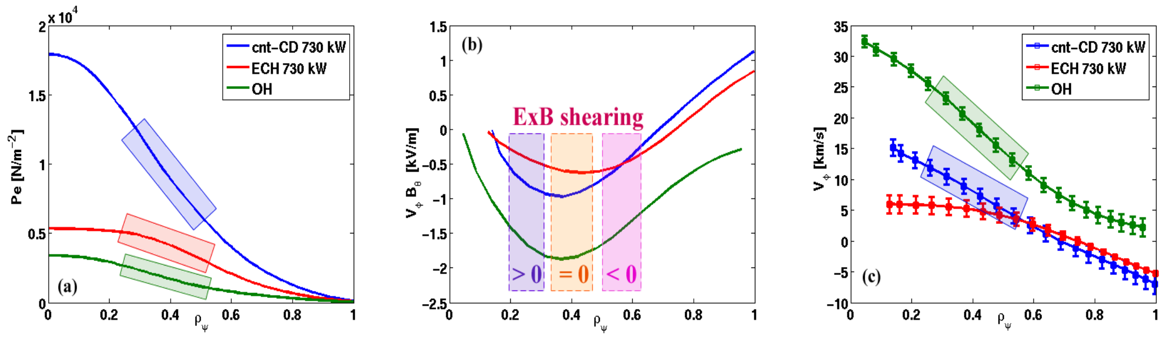

Fig. 2: (a) p_e, (b) $v_\phi B_\theta$, (c) v_ϕ profiles for the cnt-CD, ECH and OH cases

order to confirm this initial observation. For this purpose, a new eITB target at z=6 cm on TCV is being developed, by applying off-axis co-ECCD with central ECH to obtain a stronger and more off-axis barrier than the eITB case. The effect of ECH power and inductive current density perturbations [4] on the barrier strength and rotation profiles will then be examined using the present optimised diagnostic configuration. Stationary and pre-barrier formation ion parameter profiles may then be measured to assess the role of $E \times B$ shearing for eITBs in TCV.

Conclusion

TCV is now equipped with an unique CXRS system characterised by a high speed and wide acquisition flexibility, which can be exploited to investigate faster events (in the ms range) in TCV scenarios that feature transport barriers. Firsts measurements on a central eITB plasma suggest that the $E \times B$ shearing is not the cause of the formation of an eITB, but improved electron transport could lead to increased central v_ϕ.

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