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Fast Imaging Experiments of Edge Transport in the TJ-II Stellarator

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I. Introduction

In this paper, experimental results from the fast visible fast camera upgrade in TJ-II stellarator are presented. The use of the intensified camera has allowed fast plasma imaging with reduced external perturbation, studies about shear flow development and turbulent structures characterization. Interferometric filters have been used to determine the level of impurity ejection present during discharges, giving a quasi-direct measure of particle transport and confinement properties.

II. Experimental Setup

The TJ-II stellarator is a medium size machine currently under operation in CIEMAT, Madrid. Its main parameters are R=1.5 m., a= .22 m., B_T ~1T, $\iota(a)/2\pi$ ~1.6, max. central T_e ~1keV, max. central $n_e \sim 4\cdot10^{-19}$ m^{-3}. It has 600 kW of ECRH nominal power and about 1 MW NBI nominal power. Recycling processes in the vacuum vessel are enhanced by boronization and lithiation. Plasma-wall interaction is usually localised at the helical limiter, but can be partially changed when inserting the two mobile poloidal carbon limiters symmetrically spaced 180º. Fast camera observation is performed through 2 different observation ports, looking at one of the limiters. One of these ports is tangential, and allows the observation line of sight to be almost perpendicular to the poloidal symmetry plane of the limiter (with less than 5º error), thus parallel to local field lines. The other view port is located in the poloidal plane of the limiter (slightly over it) and provides a close radial view of it.

The fast camera is a Photron APX based in CMOS technology capable of taking up to 250 kHz sampling rate videos. The Hamamatsu C9548 intensifier unit (a two stage device with a first Gen II coupled to a Gen I tube), has a high-speed gated system capable of 100 kHz operation. With this intensifier signal level can be effectively increased up to two orders of magnitude. The camera is placed on an optical bench, some meters away from TJ-II to avoid magnetic interactions, with optical coupling realized via coherent fibre bundles and relay lenses. Narrow bandwidth interference filters (1 nm FWHM) can be placed before the objective in order to make spectroscopic visualisation of atomic lines. In that way specific emission lines are selected, thus discriminating the observed physical phenomena.

III. Perpendicular Dynamics: Quasi-periodic rotation

The use of the image intensifier allowed the camera to reach 100 kHz sampling rates with the limiter placed 20 mm away from the separatrix, thus working in turbulent relevant time scales (in the order of 10 μs). Both radial and tangential camera view positions have been employed to study ECRH plasmas.

From tangential position, line of sight is almost parallel to local magnetic field in the region over the limiter. Most received emission comes from the neutrals returning to the plasma after recycling, so images can be considered a narrow toroidal section of the plasma immediately over the limiter. Images show a bright area decaying radially towards the center of the plasma. However, when only fluctuations in the signal are considered, a group of structures (blobs) emerges moving within a radial stripe in the poloidal direction. These blobs could be the section of toroidal filaments poloidally rotating around the center of the plasma through its edge. There is much previous work on the study of this blobs in TJ-II [1],[2]. Besides, experiments conducted with probes [5] provide evidence of a radial electric field creating an ExB drift in this plasma region. As well, observations indicate a change in the sign of this electric field when a certain density (around 0.65 $x10^{19}$ m^{-3}) is surpassed. This change of perpendicular rotation can be seen in fast camera movies by the naked eye: at low densities, blobs rotation is anticlockwise, changing its sense after critical density is surpassed. In between both situations, an unstable regime prevails in which both rotations alternate. To quantify this apparent movement, signal levels of two poloidally separated points are correlated along the whole discharge. As figure 1 shows, both signals have a high degree of correlation with a short delay between them. This delay corresponds to the time a blob takes to travel between the sampling points, giving a direct measure of poloidal flux velocity. Furthermore, a clear direction change can be observed after the passage of the critical density (around 1042 ms), as well as a non defined region around it. The effect seems stronger in the right side of the figure due to the higher signal

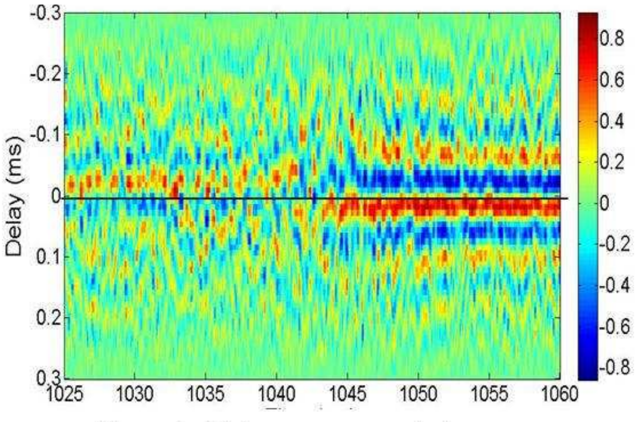

Figure 1: Blob passage correlation map

levels corresponding to higher densities. Measured velocities are around 3.5±2 km·s^{-1}, which fit measurements in [5]. It shows as well a regular horizontal pattern which suggests a quite constant rotation velocity: filaments are not only rotating at the same velocity, but they also show enough periodicity to allow correlation between them with repetition rates around 10 kHz, as a quasi-coherent mode.

IV. Poloidal Asymmetries in Particle Transport: role of ECRH and NBI heating

Spectroscopic two dimensional imaging using a lithium interference filter (centred at 670 nm) [3] allows the observation of plasma-wall interaction evolution as a function of plasma parameters and configuration. Lithium atomic emission is proportional to the lithium density and the electron density (with nearly no electron temperature dependency) and its interpretation is simpler than that of Hα emission. The neutral lithium density, at least in front of limiters, is due to plasma sputtering and therefore proportional to the plasma out-flux.

With the above mentioned experimental setup, several films were taken from the tangential port during an ECH and NBI operation day. Nominal powers were injected into the plasma, separated by some 40 ms. This generated a first ECH-like plasma reaching densities between 0.5-1x10^{19} m^{-3}, followed by a density ramp (after the start of neutral injection) surpassing 3x10^{19} m^{-3}. The optical stage was set to observe both the limiter and the vessel walls. The central solenoid (in the following, the hard core) acts as a natural toroidal limiter for the plasma when poloidal limiters are retired. Relation between the radial position of the limiter and the recycling role of both devices has already been studied in ECH phase [4]. Now, NBI and ECH phases comparison is possible, as well as a more detailed observation of the geometric distribution of the recycling processes, thanks to the bidimensional vision.

Sequences are taken at 17.5 kHz sampling rates for several limiter positions, with distances to the separatrix ranging from 5 to 20 mm. On them, two main interaction areas can be observed, corresponding to the limiter and the hardcore. Based on the results, two immediate conclusions can be stated,: First, interaction is greater in both areas during ECH phase, despite the lower density and suggesting an improved confinement in NBI phase. Second, there is a change in the “preferred” interaction area, going from a hard-core toroidally limited plasma to a poloidally locally limited one.

Averaged signals have been obtained representing the level of interaction in both regions for several limiter positions (5, 10 and 20 mm away from the separatrix). Limiter signal is up to a 50% greater (in the case with closer limiter) than hard core in NBI phase. As well, an increase in the ratio appears after NBI start in the 5 and 10 mm. discharges (20 mm. discharge can be considered as no limiter one here), following a corresponding lineal increase in the density. Other interesting feature of the sequence is the observation of oscilations in signal levels in both regions: during the whole film, emission (i.e. sputtering) is irregular and appears to be dominated by fluctuating processes. This suggests a relation with turbulent transport mechanisms. This fluctuation appears both in limiter and hardcore and seems to be reduced during the improved confinement NBI phase. Both signals have been correlated to determine the degree of relation between them. As figure 2 shows, there is small correlation in the ECH or early NBI phases (ms 1040), with a great increase in correlation corresponding with the confined density ramp (ms 1090 & 1115) which can be observed in the three limiter positions with little difference between them. Similar results are obtained when correlating local signals at different positions of the limiter area. During NBI phase, all these evidence support the idea of a well confined plasma with less particle transport dominated by large scale isotropic transport events, rather than by local, non isotropic ones.

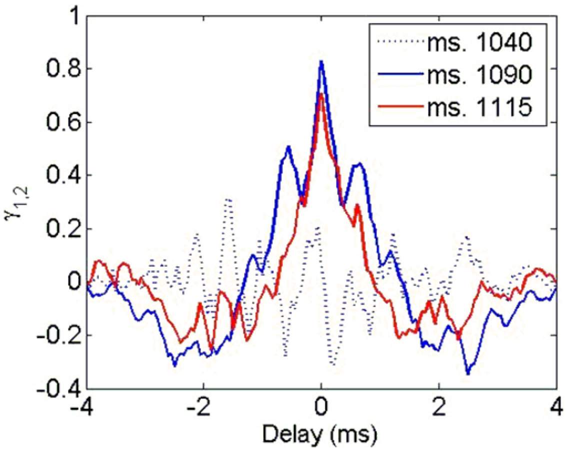

Figure 1: Transport events correlation between limiter and hard core regions

V. Conclusions

In conclusion, intensified fast visible cameras are a powerful tool in the investigation of turbulence, transport and dust generation and dynamics in fusion devices. TJ-II results have shown the observation of quasi-coherent turbulent structures propagating poloidally at the plasma edge and a change in the preferred plasma-wall interaction area and symmetry of transport events depending on plasma conditions (heating and density) have been monitored in the proximity of the poloidal limiter after lithium coating.

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