5. PARTICIPATION IN THE TJ-II PROGRAMME

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5.1. INTRODUCTION

The Portuguese participation in the TJ-II[1] programme has been mainly focused in three research areas:

- Microwave reflectometry;
- Edge plasma physics;
- Heavy ion beam diagnostic.

5.2. MICROWAVE REFLECTOMETRY[2]

5.2.1. Introduction

CFN has developed a fast frequency hopping reflectometer, operating in the Q-band (33-50 GHz), with wave propagation in X-mode. It can be tuned to any selected frequency, within a fraction of a ms, while keeping synchronized the local and radiofrequency oscillators, with the same stability of a fixed frequency system. This property enables to probe several plasma layers within a short time interval, to characterize the radial distribution of plasma turbulence.

In 2004 the hardware developed by CFN was delivered to Madrid and tested at CIEMAT. The reflectometer started to be routinely operated after the installation of vacuum windows and the development by CIEMAT of some control and acquisition software. Plasma physics studies based on the analysis of the experimental results have been initiated.

5.2.2. Description of the diagnostic

This reflectometer (Figure 5.1) incorporates: (i) a fast frequency synthesizer operating at 8-12.5 GHz multiplied into the millimeter-wave range 32-50 GHz; (ii) a harmonic mixer for heterodyne detection with sensitive phase and amplitude measurements; and (iii) low pass filters (not shown in Figure 5.1) to protect the system against the high RF power from the electron cyclotron heating system (f_{ECH}=53.2 GHz).

The system uses fundamental waveguide transmission line and separate antennas for launching and receiving the signals, viewing the plasma from the low field side. The antennas (Figure 5.2) are standard gain horn type with a 3dB beam width of about 20º and located in a toroidal position defined as φ = 85.3º where the plasma is not symmetric with respect to the equatorial plane of the device. To ensure an almost pure X-mode, 24º twists are included in the in-vessel transmission waveguides.

5.2.3 Experimental results

The reflectometer probes plasma densities from 0.3 to 1.5×10^{19} m^{-3}, almost the whole density range of the TJ-II plasmas heated by electron cyclotron waves (ECH). However, due to the shape of the ECH plasma density

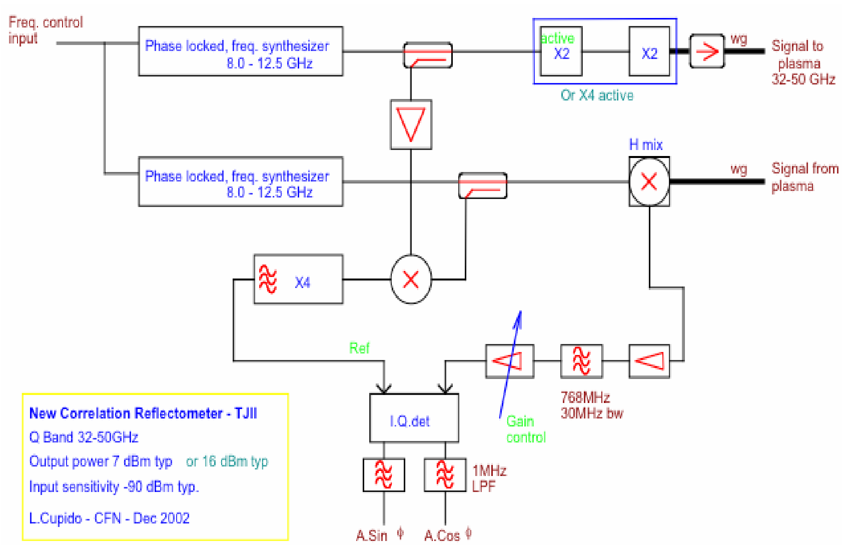

Figure 5.1 – Diagram of the fast hopping reflectometer installed in TJ-II

[1] TJ-II a stellarator of the Association EURATOM/CIEMAT
[2] Work carried out in collaboration with the TJ-II Team. Contact Person: J. Sanchez

profiles, they are flat (or even hollow) in the range ρ < 0.6, and due to the low radial gradient of the magnetic field, the radial range covered by the reflectometer is limited in most cases to ρ ≥ 0.6.

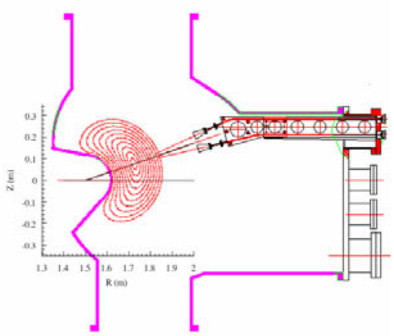

Figure 5.2 - Arrangement of the antennas and waveguides inside the vacuum vessel and magnetic surfaces of the standard magnetic configuration.

5.2.4. Plasma physics studies

It was previously found that above a critical plasma density, a perpendicular velocity shear layer develops spontaneously in the TJ-II plasma edge. Reflectometer measurements characterized the inversion in the perpendicular rotation velocity of the turbulence and its dependence on plasma conditions. Besides, reflectometry data indicate that a second velocity shear layer develops at inner radial locations and moves radially inwards when the plasma density increases beyond a critical value.

Numerical results obtained using a 2D full-wave code reproducing the experimental measurements (Figure 5.3) demonstrate the capability of the reflectometer to measure the velocity shear layer with a spatial resolution better than twice the probing wave-lengths in vacuum.

5.3 EDGE PLASMA PHYSICS[3]

5.3.1 Introduction

This research line included in 2004 studies on:

- Energy transfer between parallel flows and turbulence;
- Dynamical relation between parallel flows and instabilities;
- Transport and fluctuations during electrode biasing experiments,

5.3.2. Energy transfer between parallel flows and turbulence

Experiments in the TJ-II have shown radial variations in the cross correlation between parallel and radial velocity fluctuations (comparable to JET) near the LCFS. These gradients are due to the radial variations in the level of poloidal electric field fluctuations and in the cross-phase coherence.

The radial structure of $d<\tilde{v}_r\tilde{M}_{||}>/dr$ changes with the increase of the plasma density; in particular, strong gradients in $d<\tilde{v}_r\tilde{M}_{||}>/dr$ are developed at the radial location where perpendicular sheared flows and double gradient in the Mach number are developed above a critical density.

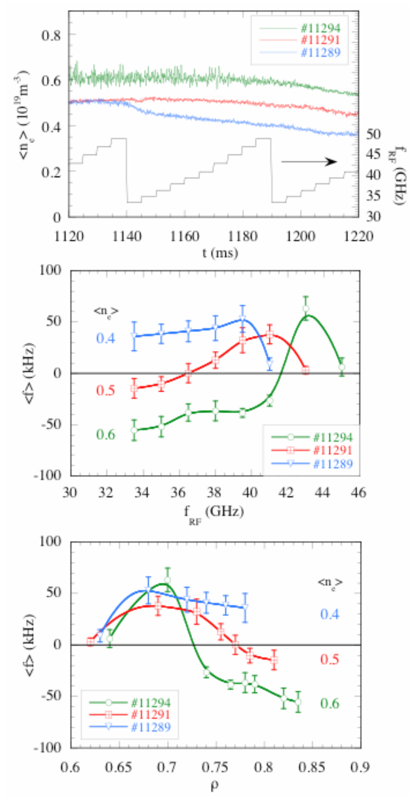

Figure 5.3 - (a) Time evolution of the line-averaged density for three discharges with densities below (open triangles), close (crossed squares) and above (open circles) the critical value ($<n_e>$ ≈ 0.5 $10^{19}m^{-3}$). The staircase variation of the reflectometer probing frequency is also shown. (b) Mean frequency of the complex amplitude spectra for the different probing frequencies in these three discharges and in a fourth discharge with higher line density ($<n_e>$ ≈ 0.9 $10^{19}m^{-3}$: full circles) and (c) the same data as a function of the cut-off radius.

From the gradient of the radial profile of the mean parallel flow and the radial-parallel component of Reynolds stress, the turbulence production (P) is given by:

$$P=\left\langle \tilde{v}_r\tilde{M}_{//}\right\rangle \partial M_{//}/\partial r \qquad (5.1)$$

This term combines the velocities cross-correlations $<\tilde{v}_r\tilde{M}_{||}>$ (momentum flux) with the mean velocity gradient ($\partial M_{||}/\partial r$) and gives a measure of the amount of energy per unit mass and unit time that is transferred between mean flow and fluctuations. As can be shown in Figure 5.4 two different signs are found in P, thus implying that the turbulence can act as an energy sink for the mean flow (viscosity) or energy source (pumping) near the shear layer. Figure 5.4 shows that the production term can be of the order of 500 s^{-1} in forward toroidal field. Experiments in TJ-II show production terms with the same order of magnitude as JET for high density plasmas. In low density plasmas the production term is reduced or inexistent.

[3] Work carried out in collaboration with the TJ-II Team. Contact Person: C. Hidalgo

The power per unit of mass necessary to pump the flow up to the velocity value experimentally measured in a turbulence characteristic time (τ_c) is given by: $W = E / \tau_c = M_{//}^2 / 2\tau_c$. Assuming τ_c in the range of a few turbulence correlation times it follows that W is of the order of 10^3 s^{-1}, which turns out to be comparable to the production term in this region (Figure 5.4). This result suggests that the mean flow generated by turbulent mechanisms is relevant.

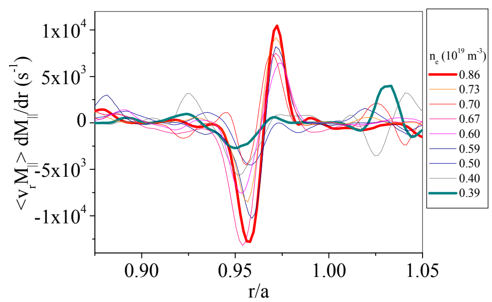

Figure 5.4 - Radial profile of production term in TJ-II

5.3.3. Dynamical relation between parallel flows and instabilities

Following studies previously performed taking advantage of the flexibility of the TJ-II configuration, the time evolution of parallel flows and edge instabilities (indicated by the H_α temporal variation) for configurations with reduced well in the edge have been studied (Figure 5.5). With the appearance of edge instabilities parallel flows are significantly modified, showing a coupling between edge transport and parallel flows. This result is consistent with recent experiments carried in the plasma boundary of JET tokamak.

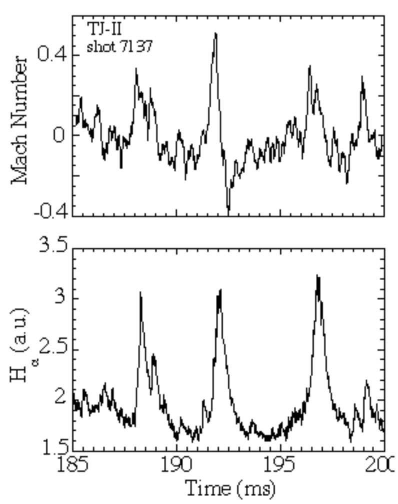

Figure 5.5 - Time evolution of parallel flows and edge instabilities in TJ-II

5.3.4. Transport and fluctuations during electrode biasing

A graphite electrode has been developed for biasing experiments on TJ-II and the first results have been obtained.

As biasing is applied, the biasing current amplitude increases rapidly for both polarities and the floating potential at the plasma edge is also modified in a rather short time scale (<50 μs) leading to a strong modification in the edge radial electric field in the region just inside the limiter. The plasma response is different at densities below and above the threshold value to trigger the spontaneous development of ExB sheared flows. At low densities, the edge plasma potential is fully controlled by external biasing. In this case, strong increase in plasma density and reduction in edge fluctuation level and H_α signals are observed during biasing (Figure 5.6). At higher densities edge plasma potential profiles are determined not only by external biasing but also by the electric fields spontaneous developed. Although an improvement in particle confinement is observed for both polarities, a larger increase is observed for negative electrode biasing.

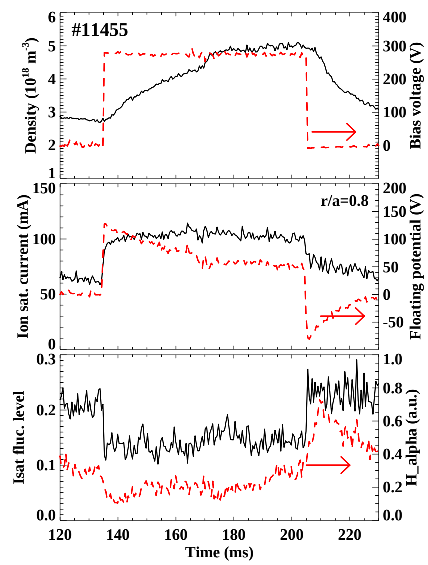

Figure 5.6 - Time evolution of the plasma density, biasing voltage, edge potential, ion saturation current, Isat level of fluctuations and H-alpha signal for a discharge with positive electrode bias.

5.4. HEAVY ION BEAM DIAGNOSTIC[4]

The work in this research line has been mainly focused on the improvement of the dedicated data acquisition system.

Calls for tenders for a new VME computer and a new trigger module have been made. The operating system has been converted from OS-9 to LINUX. The new VME computer has been tested. The operating software has been implemented and the VME drives have been compiled. Thirty-six transimpedance amplifiers have been commissioned and tested.

[4] Work carried out in collaboration with TJ-II and IPP-Kharkov Teams. Contact Person: C. Hidalgo