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Fluctuation measurements by reflectometry in the stellarator TJ-II

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Abstract

Reflectometry measurements using a broadband fast frequency hopping system have permitted the characterization of the velocity shear layer that develops spontaneously in the edge of TJ-II plasmas above a certain critical density. Simultaneously, a second velocity shear layer develops at inner radial locations, that moves radially inwards when the plasma density further increases. The interpretation of these experimental results has been crosschecked with results obtained using a 2-dim. full-wave code. Both experimental and numerical results demonstrate the capability of the reflectometer to measure the velocity shear layer with a good spatial resolution. Changes in the spectra shape linked to low order rational surfaces in the rotational transform profile are also reported. These results are interpreted in terms of a localized increase in the perpendicular velocity of the fluctuations.

Reflectometer description

The reflectometer is a broadband fast frequency hopping heterodyne system, designed for measuring plasma turbulence, that allows probing several plasma layers within short time interval during the discharge. A detailed description of the system can be found in [1]. The antennas are standard gain horn type with a 3dB beamwidth of about 20°. The antenna arrangement was designed to view the plasma perpendicularly to the cut-off layers, however a small misalignment may exist as it is seen in the measurements. The reflectometer (f: 33-50 GHz, X-mode) covers the density range from about 0.3 to 1.5 10^{19} m^{-3}, almost the whole density range of the TJ-II plasmas heated by ECH (B=1 T, f_{ECH}=53.2 GHz, $n_{cut-off}$=1.75 10^{19} m^{-3}). However, due to the flat density profiles of the ECH plasmas and to the low magnetic field gradient, the accessible radial range is limited to $\rho \geq 0.5 - 0.6$.

Characterization of perpendicular velocity shear layers

As it has been reported [2] a perpendicular velocity shear layer develops spontaneously in the plasma edge of TJ-II above a certain plasma density. To study this phenomenon a set of experiments has been done modulating the plasma density around the critical value. In these experiments the plasma is created and heated by ECH with a total power of 400 kW.

During the experiments the reflectometer is tuned to a low frequency (34 GHz) to probe a layer close to the Langmuir probe radial position ($\rho \geq 0.8$). The reversal in the perpendicular phase velocity measured by the Langmuir probes when the plasma density reaches the critical value is also seen in the reflectometer signal. Figure 1 shows the time evolution of the line density in a standard magnetic configuration discharge and the mean frequency of the complex amplitude ($Ae^{i\phi}$) spectra at $\rho \approx 0.8$. In this example, as the density increases from 0.4 to 0.6 10^{19} m^{-3}, the perpendicular phase velocity measured by Langmuir probes reverses from $+10^3$ to -10^3 m/s [3].

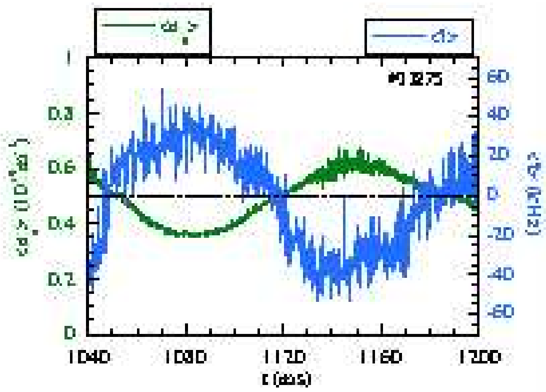

Figure 1. Plasma density and mean frequency of the reflectometer signal spectra.

The comparison of the reflectometer measurements with Langmuir probes results gives us information about the direction of the reflectometer misalignment. The misalignment in the antennas is such that negative/positive mean frequencies stand for rotation in the electron/ion diamagnetic direction (negative /positive E_r).

Experimentally, the behaviour of the turbulence rotation for inner radial locations has been studied changing the reflectometer probing frequency in a staircase mode during the discharges. For plasma densities below the critical value, the mean frequency of the reflectometer signal spectrum is positive independently on the probing frequency. When the plasma density is slightly above the critical value the reversal in the perpendicular velocity is only seen for the lowest probing frequencies while the mean frequency of the reflectometer signal spectrum stays positive for the high probing frequencies. In these conditions the radial position where the perpendicular velocity reverses, computed as the radial location where the asymmetry changes sign, is located at $\rho \approx 0.8$. Increasing the plasma density further, this velocity shear layer moves to inner radial locations. As an example figure 2 shows the mean frequency of the reflectometer signal spectrum as a function of the radial cut-off location for four discharges with line densities:

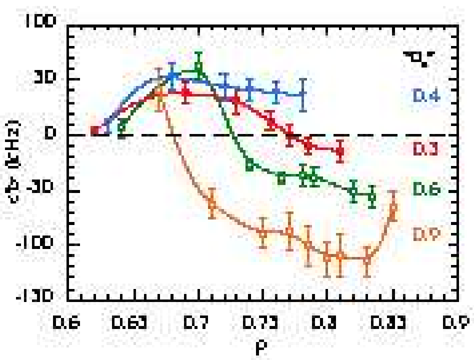

Figure 2: Mean frequency of the reflectometer spectra vs. cut-off radius in four discharges with increasing densities.

0.4, 0.5, 0.6 and 0.9 $10^{19}m^{-3}$. HIBP measurements show that the inversion in the perpendicular rotation measured with the reflectometer may be dominated by the radial electric field. These results draw attention to the capability of the reflectometer to measure the inversion of the perpendicular rotation of the turbulence in a rather narrow radial region. This observation has been analysed using a two-dimensional full-wave numerical code [4]. As it is explained in [5] the code works with propagation in x-mode and incorporates the antennas arrangement of the experimental system. Realistic plasma shape and magnetic field distribution are introduced in the code using the theoretical magnetic surfaces of TJ-II.

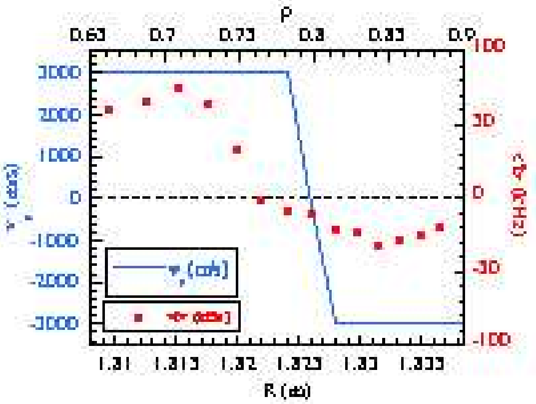

Figure 3: Perpendicular velocity and mean frequency of the simulated spectra as a function of the major and normalised radius.

First numerical simulations indicate that asymmetric spectra are obtained for a misalignment as small as two degrees. Considering this tilt angle, we have studied the behaviour of the reflectometer signals in plasmas with a velocity shear layer localized in a very narrow region. For this study we consider a perpendicular velocity v_p=–3000 m/s at the plasma edge that changes linearly to v_p=+3000 m/s within a narrow region δx and stays constant further inside. The reflectometer signals are simulated for different probing frequencies within the band 33-50 GHz. The result for δx=4 mm is displayed in figure 3. This figure shows the perpendicular rotation velocity and the mean frequency of the simulated complex amplitude spectra as a function of the major and normalised radius. These simulation results demonstrate the capability of the reflectometer to measure the velocity shear layer with a good spatial resolution, better than twice the vacuum probing wavelengths (λ_0: 0.7–0.8 cm).

Modification of the reflectometry signals spectra linked to rational surfaces

Modifications in the spectra have been observed in configurations having a low order rational surface in the rotational transform profile within the radial range covered by the reflectometer. An example is displayed in figure 4. The spectrum at the most internal radial location (ρ = 0.55) shows a coherent mode of about 10 kHz and the spectra modification appears for the adjacent probing frequencies (at ρ = 0.65 & 0.7). These results have been obtained in a magnetic configuration having the rational surface 3/2 close to ρ = 0.65. These measurements can be interpreted as a localized increased in the perpendicular rotation velocity of the fluctuations: due to the small misalignment of the antennas and to

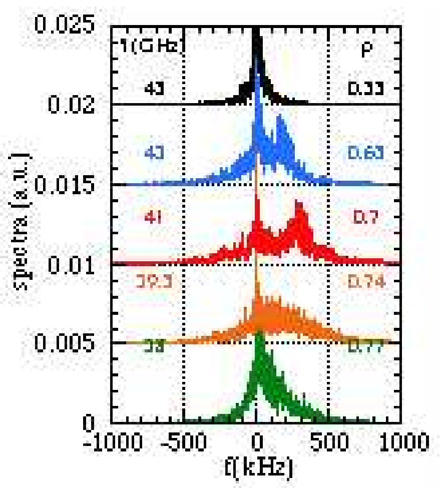

Figure 4: Spectra measured in a magnetic configuration with iota = 3/2 at ρ≈0.65 (in vacuum)

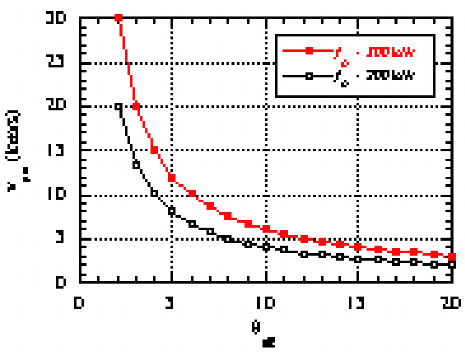

Figure 5: Perpendicular rotation velocity at different tilt angles for Doppler frequencies: 200 & 300 kHz and probing wavelength 7 mm.

the long probing wavelengths, the perpendicular velocity should be as high as 15-20 km/s to reproduce the experimental spectra (see figure 5). Similar spectra are measured in a magnetic configuration in which the rational surface 3/2 is introduced in the plasma by the induction of negative OH current. In this case, the spectra are modified in a narrow radial range, what could be related to the small size of the magnetic island due to the higher magnetic shear. The reported phenomenon could be explained if we consider that the magnetic island produce an enhancement in the electron diffusion higher than the ion diffusion and consequently the plasma reacts creating a positive radial electric field to preserve the ambipolarity. A similar phenomenon has been measured using the HIBP diagnostic during the formation of electron internal transport barriers triggered by low order rational surfaces [6]: the positive radial electric field increases in a factor of three in the central plasma region when the e-ITB forms.

Acknowledgments

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