Turbulence characteristics at the plasma edge in the limiter H-mode in TEXTOR.

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Introduction

The regime with the periphery transport barrier obtained recently in TEXTOR plasma [1] belongs to the classical limiter H-mode in tokamaks. Its extensive investigation in the connection with the application of external magnetic perturbations can open the possibility for the ELM mitigation. In this paper we present the results of density fluctuations study in the pedestal region of limiter H-mode in TEXTOR. The heterodyne O-mode correlation reflectometer operates in a frequency range of 26-37 GHz and covers the periphery region of a plasma column which is of most interest in the H-mode regime. The advanced five-horn antenna system (Figure 1) allows to investigate both a propagation and spectral-correlation properties of the plasma turbulence. The 4 receiving antennas are focused to the center of vessel and spaced poloidally so that the correlations can be performed for one of four distances $\Delta\theta$=0.025, 0.05, 0.075 or 0.1 radian, where θ is a poloidal angle. The system is equipped with sine-cosine detectors thus recoding separately amplitude and phase of the reflected wave. The acquisition time is 1 μs. In present measurements the midplane antenna system at the low field side was used.

Experimental results

The results discussed in this paper are obtained in series of successive shots. The plasma parameters are as follows: I_p=210kA, B_t=1.2T, $< n_e >\approx 2 \times 10^{19}$ m^{-3}, q(a)≈3. The auxiliary heating is provided by two tangential neutral beam injectors (NBI) in co- and counter-current direction at approximately equal power. In all discharges under consideration the L-H transition takes place at ≈120-150 ms after NBI heating starts. The edge localized mode (ELM) with the period of ≈2-3 ms is observed continuously after the transition to H-mode. The stored plasma energy increases by $10 \div 15\%$.

The time evolution of angular turbulence rotation (perpendicular to main magnetic field) and the cutoff position of the probing wave for two successive shots, with and without L-H transition, are shown in Figure 2. The L-H transition and the associated step in the poloidal rotation at the plasma edge occur 10-50 ms after switching on the counter-NBI and assumes the significant increases in the radial electric field. The rotation in the H-mode increases in the electron diamagnetic drift (edd) direction by ∼2.5 times compared to L-mode. One can not claim that the turbulence spin-up precedes the L-H transition on the base of presented data within time resolution of method.

Figure 3a shows the dynamics of the reflectometry spectrum before and after L-H transition. The D_α signal and the turbulence rotation are shown in Figure 3b. After L-H transition the spectrum shrinks and broadens intensively with the ELM frequency (see Fig. 3c and 4a). Figure 3c,d demonstrates the detailed phasing between turbulence spectrum, D_α and electron density at the periphery. The HCN interferometer chords at R≈2.05m and R≈2.15m corresponds to pedestal and SOL region. Following the spectral evolution of the turbulence one can divide the time scale into two stages for further analysis: "during ELMs" and "between ELMs" (actually H-mode). The first one starts ≈100–300μs before the jump of the D_α sig-
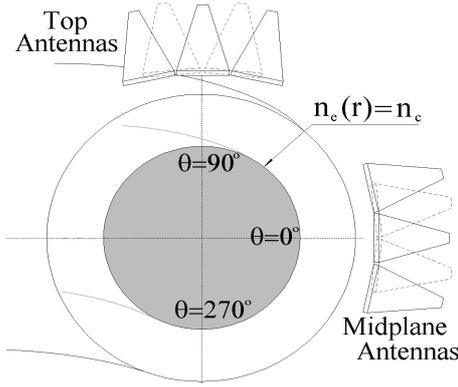
Figure 1: *Poloidal cross section with reflectometer antennae.*
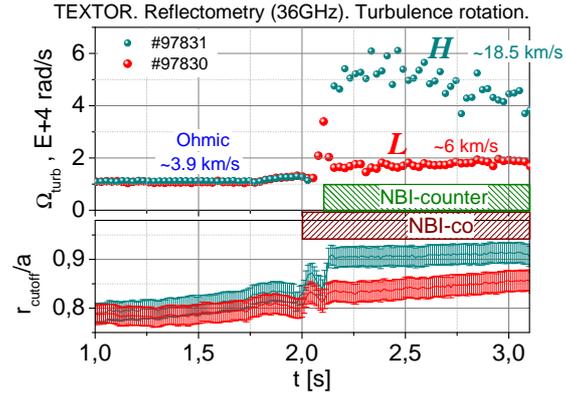

Figure 2: *Turbulence angular velocity and cutoff position evolution for two shots: with and without L-H transition.*

nal, at this moment the reflectometry spectrum is already broadened but not to the maximum and the buildup of pedestal is nearly saturated which is seen by n_e chords dynamics (see Figure 3c,d). During this stage the turbulence spectrum reaches its maximal broadening and the density pedestal deteriorates. The second stage starts with spectrum shrinking and density pedestal reconstruction and is characterized also by the minimal D_α level. The observed difference (Figure 4a) in these two plasma states implies the correlation between improved confinement in "between ELMs" stage and the suppression of fluctuations in the range of 150–500kHz (or in the $k_\perp$ range of 0.5–1.7 cm^{-1}) compared to "during ELMs" stage. From other hand, the interpretation of reflectometry data in terms of the density fluctuation level should be done with caution, because of a changing density gradient near the cutoff position in the pedestal region. Taking a modulation of 10-15% of the gradient and a simple evaluation of the relative turbulence level according to $\tilde{n}/\langle n \rangle \sim \langle \tilde{\phi} \rangle / \sqrt{L_n}$, where $\langle \tilde{\phi} \rangle$ and L_n are phase fluctuations and density scale-length, one can see that L_n can not compensate the variation in $\langle \tilde{\phi} \rangle$. Thus, one can claim a suppression of the higher frequencies turbulence during H-mode at the pedestal region. The high frequencies suppression after L-H transition was reported earlier from many tokamaks (see for example [2]).

Note, the spectra in Figure 4a differ not only quantitatively but also qualitatively. The presence of quasi-coherent (QC) mode (f≈105 kHz, m≈ 14) in "between ELMs" stage is a further argument for the improved confinement compared to "during ELMs" stage. The QC modes are high-m helical modes which can be excited in relatively good confined plasma near the high-m rational surfaces [3]. The instability which can excite QC modes can be different, but the wavelength of QC mode is connected with the driving instability. In the case under consideration the most possible candidate is some kind of resistive-ballooning instability. QC modes were observed in H-mode plasma also at C-MOD with the phase contrast imaging system and reflectometry [4] and recently at JFT-2M tokamak with reflectometry [5].

The narrow peak near 30 kHz in the "between ELMs" stage (Figure 4a,b) corresponds (assuming the velocity v≈18.5 km/s) to poloidal m-number ≈3.8. The low m-number implies some MHD mode, but it contradicts with the q(a)≈3. While the m-number is derived from angular rotation velocity as $m = 2 \cdot \pi \cdot f / \Omega$, it means that the velocity of this mode differs from turbulence rotation which is analyzed in the higher frequency range of 50-500 kHz.

In the phase "during ELMs" both QC and 30 kHz (possibly MHD) modes are practically absent in reflectometry spectra.

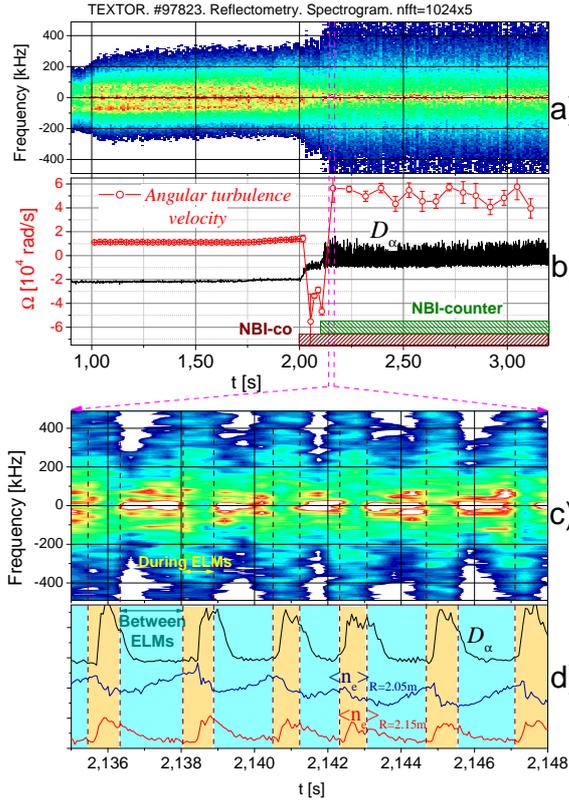The correlation analysis allows to study also the time characteristics of observed fluctua-

Figure 3: *Turbulence spectrum evolution (**a**) and time traces of the turbulence rotation and D_α signal (**b**). The detailed phasing between turbulence spectrum (**c**), D_α and periphery density behavior (**d**).*
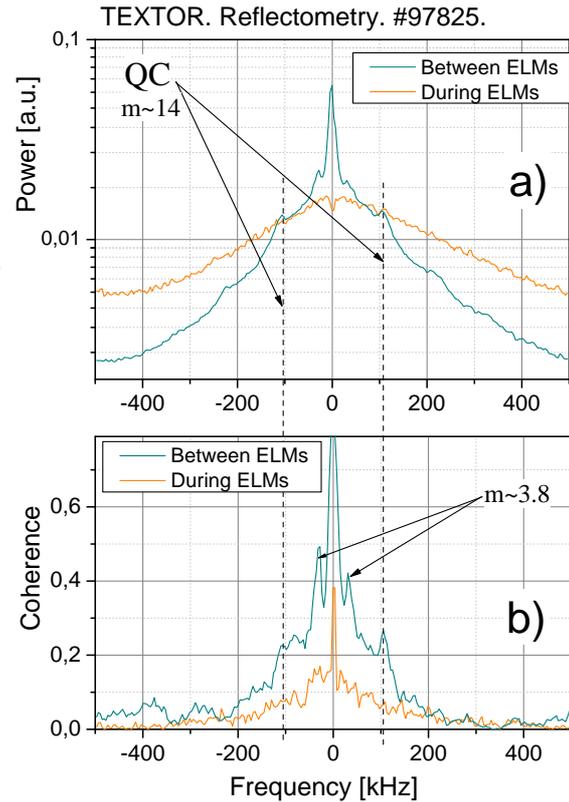
Figure 4: *Turbulence power spectra (**a**) and coherence (**b**) obtained between and during ELMs (conditional averaging over ≈1 s is used) show rather different turbulence properties.*

tions. Figure 4b shows the coherence spectra for two ploidally spaced antennas. Assuming nearly the same velocity of turbulence (as shown later), one can conclude that the decorrelation time of fluctuations in the range of $1 - 200$ kHz decreases in the "between ELMs" stage (H-mode) compared to "during ELMs" stage. This agrees well with the turbulence transport paradigm which implies the turbulent diffusion dependence on the decorrelation time as $\sim 1/\tau_{dc}$. The radial distribution of τ_{dc} "between" and "during" ELMs stages is presented in Figure 5. The difference at r/a=0.86 is about 2 times which is an additional indication of enhanced turbulent transport during ELMs. The data obtained in normal L-mode (NBI heated plasma with the same global parameters and without transport barrier) are given as a reference. With increasing radius this difference reduces to less than 20% at r/a≈0.98 which apparently characterizes more the specific region near LCFS than the H-mode itself.

Figure 6 presents the turbulence angular velocity measured in the normal L-mode and in ELMy H-mode. The Ohmic rotation level is given as a reference. After L-H transition the perpendicular turbulence rotation increases by 2.5–3 times reaching ≈17-19 km/s in the radial range r/a=0.86-0.98. Due to the limited probing frequency range we could not resolve the rotation shear which is observed in H-mode plasmas. Taking into account the accuracy of the rotation measurements, one can not to distinguish rotation "during ELMs" and "between ELMs" stage (H-mode). At several machines, however, the modulation of poloidal rotation by the ELMs was observed in [6]. Our inability to find the noticeable modulation can be explained by the fact that the speed-up phase is usually much longer (a few ms) than the
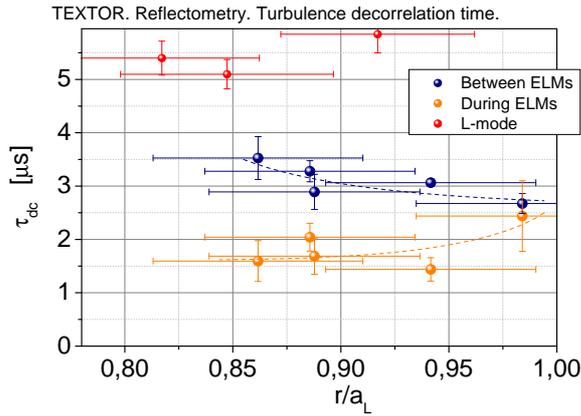
Figure 5: *The decorrelation time of density fluctuations averaged over $50 - -500$ kHz in "between ELMs" (H-mode) and "during ELMs".*
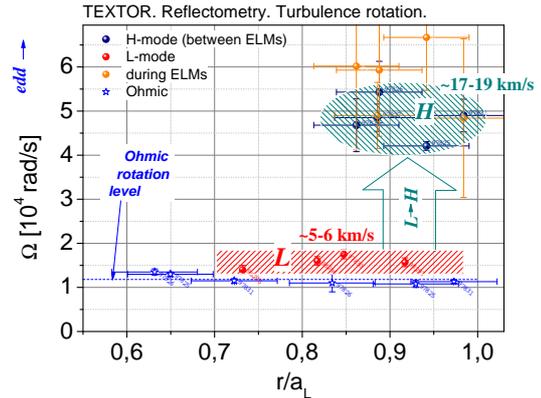

Figure 6: *Turbulence angular velocity measured in normal L-mode and in ELMy H-mode. Data for "between" and "during ELMs" stages are presented separately.*

recovery of rotation following the ELMs ($\approx$100 mks) [7]. In this sense the separation into "during ELMs" and "between ELMs" stages based mainly on the turbulence and pedestal evolution does not allow us to resolve probable fast changes in rotation velocity.

Summary

A variety of behavior in turbulence properties is seen near the H-mode transition. The observed $E \times B$ spin-up $\Delta v \approx$13–14km/s is a rate slower than is usually observed for L-H transition in the divertor tokamaks.

Three experimental observations of i) the suppression of turbulence in the range of 150–500kHz ($k_\perp$=0.5–1.7 cm^{-1}); ii) the increase of turbulence decorrelation time and iii) the appearance of QC modes in the "between ELMs" stage can indicate the strong correlation between turbulent transport, density pedestal evolution and ELM events in the pedestal region of H-mode plasma in TEXTOR.

References

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