# MEASUREMENTS OF TURBULENCE AND PLASMA PROPERTIES NEAR THE LAST CLOSE FLUX SURFACE WITH MULTI-PIN LANGMUIR PROBE AND CORRELATION REFLECTOMETRY IN T-10

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The main goals of the work were, firstly, to investigate in details the plasma parameters and turbulence in transition zone from SOL to the region with closed magnetic field lines and, secondly, to make direct comparison between turbulence characteristics measured with local Langmuir probe and non-local reflectometry diagnostics. Ohmically heated discharge with $I_p$ = 290 kA, $B_T$ = 2.42 T, $<n>_e = 3.8 \bullet 10^{19}$ $m^{-3}$ was studied. The plasma column were separated from the wall with circular limiter at r=33 cm. and the rail limiter at r = 30 cm. The measurements were made with movable multi-pin Langmuir probe, O-mode correlation reflectometer and stationary Langmuir probes allocated at the tip of rail limiter in the series of reproducible discharges[1]. The lowest reflectometry frequency 22 GHz ($n_{cr} = 0.6 \bullet 10^{19}$ $m^{-3}$), enables us to have the reflection layer close to the rail limiter at r = 30 cm. At the same time it was possible to insert the multi-pine Langmuir probe up to the radius of 28.5 cm. So we have the radial region, accessible for both diagnostics. The multi-pine Langmuir probe was equipped with 10 probes, separated in poloidal and radial directions. So it gives possibilities to measure simultaneously the main plasma parameters together with turbulence rotation and poloidal and radial correlation lengths. The probes data make possible to calculate plasma rotation from radial balance force equation for ions. So it arises a unique opportunity to compare plasma rotation with turbulence velocities, measured with the same Langmuir probes.

The radial profiles of plasma density, electron temperature, floating potential and calculated potential of plasma are shown in Fig. 1 a, b, c, d respectively. The density profile was reconstructed from mm-wave and infrared multichannel interferometers, amplitude modulation reflectometry and probes data. A steep density and temperature gradients are evident at the location of rail limiter (r = 30 cm). Plasma potential, presented in Fig. 1 d, was calculated from the floating potential and temperature in accordance with reference[2]. It has the maximum at r = 30 cm, providing significant velocity shearing rate $\omega_{E B}$. The change of the radial electric field sign may be caused by the enhanced parallel electron losses to the rail limiter. The value of $\omega_{E\ B}$ and increment $\gamma$ of resistive interchange instability are presented in Fig. 2d[3]. One can see that $\omega_{E\ B} > \gamma$ in narrow region near r = 30 cm and so the long wave turbulence can be suppressed which should result in the decrease of plasma transport. The MHD fluctuations near rational surface with q = 3 shown in Fig. 2e can explain flat density profile at r=31 cm. and facilitate steep density gradient formation at r = 30 cm.

The typical turbulence characteristics are shown in Fig. 3 and 4 measured with multi-pine Langmuir probes and reflectometry respectively. Both figure presents the results of poloidal correlation analysis in SOL (I), inside the velocity shear zone (II and at plasma edge (III). The poloidal correlations are made with two poloidally separated channels and include the fluctuation amplitude spectrum of the first channel (a), cross-phase (b) and coherency (c) spectra between two channels. The probes data in Fig. 3 clearly show in SOL (r = 30.5 cm) and in edge (r = 29 cm) regions the presence of maxima in amplitude spectra, which correspond to the fluctuations with wave-length about 10 cm. In difference very smooth spectrum, corresponding short wave-length broad band turbulence is typical for the velocity shear zone (r = 30 cm). The decrease of long wave component is also seen from Fig. 2g. This observation is supported by dramatic decrease of the radial correlation length from 2 to 0.3 cm in the velocity shear zone as seen in Fig. 2c. It is seen that poloidal correlation lengths, measured with probes and reflectometry also decrease in that zone. In contrast the relative turbulence amplitude doesn t vary (Fig. 2b). This is in agreement with the decrease of correlation length in H-modes, measured by reflectometry and suggest the importance of turbulence decorrelation due to the high shearing rate in formation of low transport zone[4]. It is important to mention that Low Frequencies (LF) are not moving at r = 29 cm in difference to quasi-coherent (QC) fluctuations. The velocity of plasma rotation, perpendicular to magnetic field lines is shown in Fig. 2 a with stars. It was calculated from radial force balance equation for deuterium, assuming that ion temperature is equal to the measured electron one[5]. The experimentally measured velocity of broad band in SOL practically coincides with plasma rotation. The turbulence simulation of SOL Quasi-Coherent (QC) fluctuations show that they rotate also together with plasma. The opposite situation is in the edge region. The calculated plasma velocity is near zero, while QC rotate in electron direction with the velocities up to $6{\bullet}10^{5}$ $cm^{-3}$ , while low frequencies have also zero rotation. These results point out that rotation of LF is near to plasma rotation, while QC additionally rotates in electron diamagnetic drift direction as should be the case for the electron drift waves. The reflectometry results presented in Fig.4 show high qualitative similarity of reflectometry and probes spectra. Figure 2 also demonstrate good quantitative agreement between both diagnostics. The LF fluctuations velocities measured with reflectometry in Fig. 2 a practically coincides with the probes data. The same is true for the core QC fluctuations.

Both diagnostics register a very special fluctuations around 20 kHz. These fluctuations looks very similar to the 25 kHz oscillations discovered with reflectometry near q = 2 position [6,7]. Figure 2f presents their amplitude radial profiles from probes and reflectometry. It is seen that they are located also near rational q = 3 position as evidenced by MHD fluctuations at 7 kHz in Fig. 2e. The radial profiles of both diagnostics demonstrate also good agreement, taken into account non-locality of reflectometry. Figure 5 demonstrate the results of poloidal correlation analysis of the probes saturated currents (top) floating potentials (bottom). Two features of this oscillations should be underlined. Firstly it is evident that representation of 20 kHz mode in potential spectra in a factor of 5 higher then in saturated current. Secondly these fluctuations has zero poloidal cross-phase shift. It means that they vary simultaneously on all magnetic surface. Taken into account high value of radial potential fluctuations one can suggest periodic fluctuation of poloidal velocity similar to proposed in theory for zonal flows [8].

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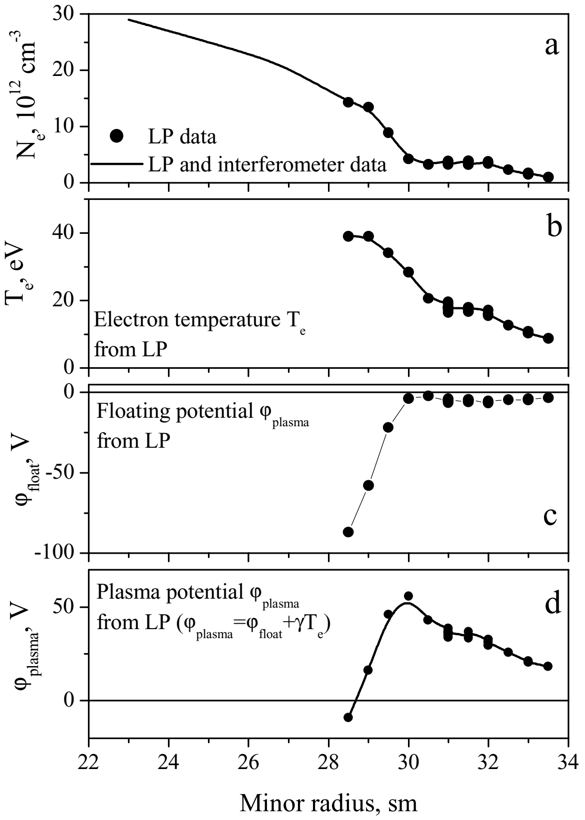


Figure 1.

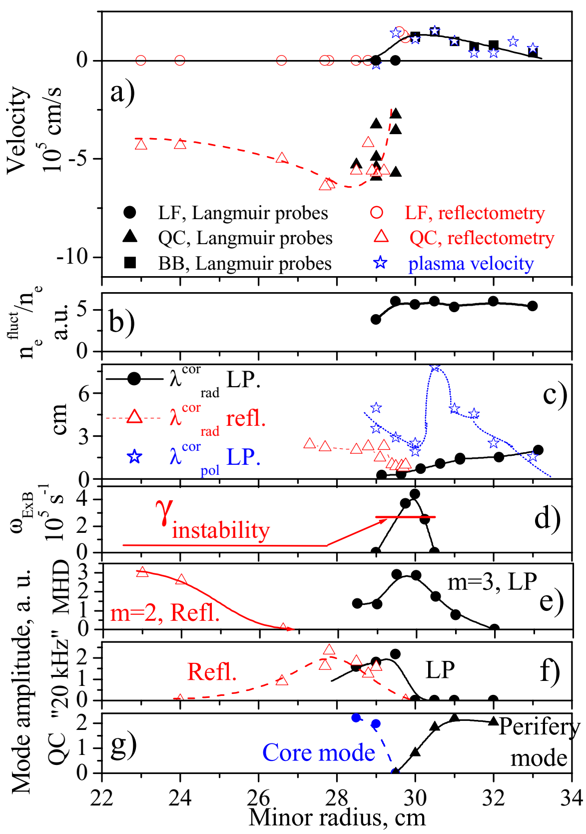


Figure 2.

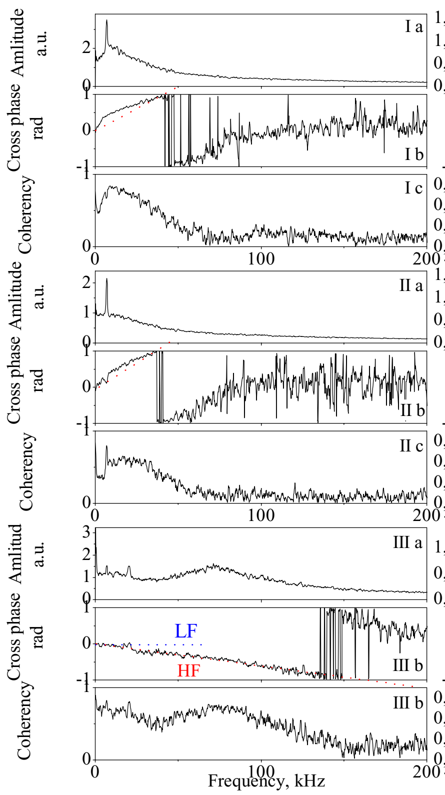


Figure 3.

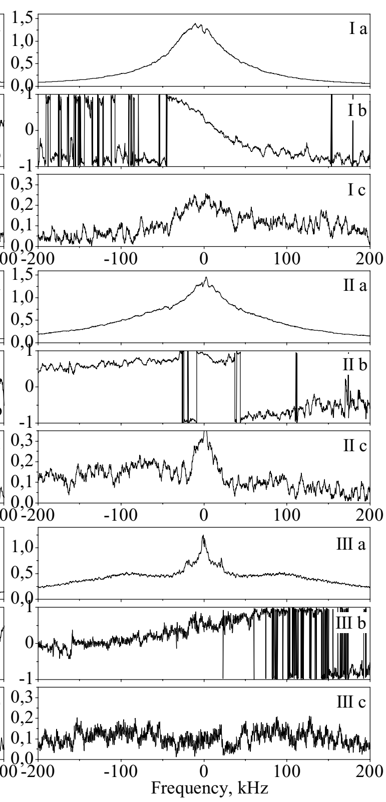


Figure 4.

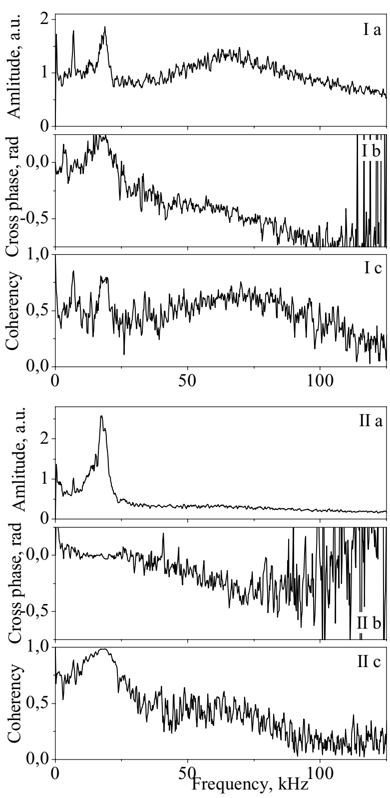


Figure 5.