Suppression of the particle fluctuation-induced fluxes and spectral analyses of the plasma oscillations with ITB and ETB formation at FT-2 experiment

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Registration of the poloidal and radial components of the electric field and density fluctuations at the same time during one discharge permits to measure the transport reduction mechanism of the radial and poloidal particle fluxes near LCFS and SOL [1, 2]. This paper present our observations and conclusions about development of the transport process at the plasma periphery of the small tokamak FT-2 during additional Lower Hybrid Heating (LHH), when external (ETB) transport barrier followed by Internal (ITB) transport barrier is observed [3, 4]. The experiment is concerned with plasma under $q = 6$ (R=0.55m, a_L=0.079m, $I_{pl} = 22$kA and $B_t = 2.2$T, $P_{LHH} = 90 \div 100$kW), where the effective LHH and improved confinement transition are realised [3].

The L-H transition with ETB has been observed after RF pulse end. Energy confinement time increases from $\tau_E(OH) = 0.8$ms up to $\tau_E(postLHH) = 2.8$ ms when LHH is switched off and L - H transition is observed [4]. The RF pulse ($\Delta t_{LH} = 5$ms) is applied at the 30th ms of a $\Delta t_{pl} = 50$ms plasma shot. During additional LHH the ITB is formed spontaneously a few ms after the RF pulse start. ITB formation could be explained by radial electric field E_r increase at LHH, which is supported by experimental data [3, 4]. Similar results were obtained by analysis of helium HeII (454.5 nm) and carbon CIII (464.5 nm) lines emission [5, 6]. In this case E_r is calculated by force balance equation analysis for impurity ions $v_\theta = \nabla_r P_{iz} / Z e n_{iz} B_\Phi - E_r / B_\Phi + v_\Phi B_\theta$. The impurity poloidal velocity v_θ is determined by Doppler shift of observed ion line emission. Effective LH heating and spontaneous ITB formation in neoclassical model has been explained through careful numerical Monte Carlo modelling [7].

As shown experimental data, L – H transition and ETB formation is associated with negative E_r rise near LCFS after LHH pulse [5, 6]. This abrupt E_r change is resulted mainly from the non monotonic $T_e(r)$ profile. During relaxation period decrease of the T_e take place by greater extent near inner region of the LCFS than in SOL. Such induced negative E_r after RF pulse gives fast rise to quasi-steady-state $\Gamma_0(t)$ drift fluxes with reversed direction structure which may inhibit transport across this flow. Large rise of grad(n_e) after LHH near LCFS with L-H transition is observed after the end of LH pulse for a long time – about 10ms [5, 6].

Experimental scenario and multielectrode Langmuir probe arrangement for measurement at Low (LFS, $\theta = 310^0$) and High (HFS, $\theta = 230^0$) Field Sides characteristic properties of the periphery plasma parameters are described in detail in [5, 6, 8]. The poloidal angle θ shows the probe position in respect to the equatorial outboard midplane in the direction of the electron diamagnetic drift. The plasma core was slightly shifted upward (at a $\cong$ 77 mm) for measurements by

probes in the deeper layers of the plasma core near LCFS and for some adjustment of the poloidal parameters symmetry. The probes can be moved step by step from limiter shadow and SOL (r ~ 80 – 76mm) up to LCFS region (r~76 – 74 mm). Observed suppression of the radial fluctuation induced flux $\Gamma_r^{\sim}(t) = C_{n(\sim)E(\sim)} c \langle n^{(\sim)2}(t) \rangle^{1/2} \langle E_\theta^{(\sim)2}(t) \rangle^{1/2}/B_\varphi$, could be ca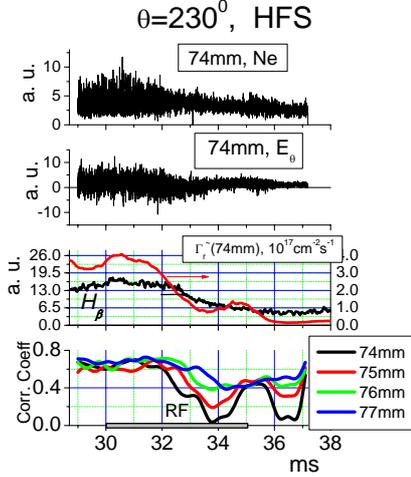used by damping of poloidal electric field $E_\theta^{\sim}$, density oscillations $N_e^{\sim}$ as well as by the reduction of the correlation coefficients $C_{n(\sim)E(\sim)}$ [1, 2, 8]. Fig. 1 illustrates the time history changes of these fluctuation parameters at plasma periphery for LCFS region $r = 74mm$ at HFS $(\theta = 230^0)$. The correlation coefficient $C_{n(\sim)E(\sim)}$ is depicted for a few probe positions, $r = 74\text{-}77mm$. These data show a gradual decreases of the fluctuation parameters $E_\theta^{\sim}$, $N_e^{\sim}$, $C_{n(\sim)E(\sim)}$ as well as $\Gamma_r^{\sim}(t)$ on the plasma edge when ITB forms on the medium radii $(r = 4\text{-}5cm, \ t \sim 32ms)$. Radial fluctuation induced flux $\Gamma_r^{\sim}$ at the periphery decreases concurrently with H_β radiation decrease. Suppression of radial fluctuation induced transport at plasma column periphery, starting from ITB formation at 32 ms, defines the mechanism of L - H transition after LHH pulse end [5].

Fig, 1

The time history changes of the plasma periphery parameters at HFS.

The internal plasma core processes affect the density and poloidal electric field fluctuations intensity in farther peripheral regions (i.e. in the vicinity of LCFS and SOL) practically immediately. Such non-local effect of fluctuation suppression could be connected with formation of peripheral vortexes and streamers [9, 10], comparatively large-scale structures with radial scale dimension of 2 - 3 cm. This could explains, how ITB formation can be detected by probes on far plasma periphery.
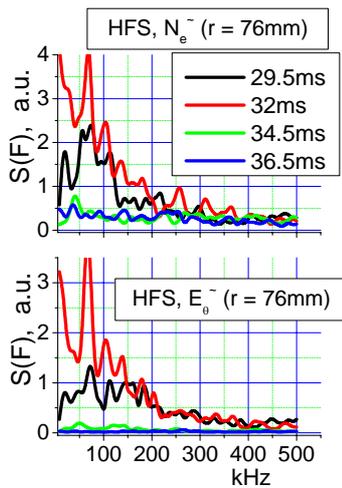
Instabilities of different types develop in non-equilibrium edge tokamak plasma conditions. Broad band spectra of low-coupled oscillations appeared far from the excitation threshold for each instability, that is, plasma passes to turbulent state with large numbers of degrees of freedom. Existence of long-living large-scale structures could essentially modify energy and particle transport in the edge plasma region.

To determine the type of the instability responsible for anomalous transport the spectral analysis is necessary. Fig. 2 presents spectral data for poloidal electric field $E_\theta^{\sim}$ and density $N_e^{\sim}$ oscillations at frequency range (0 - 500 kHz) observed by probe near LCFS on the HFS. The probe is located at r=76mm. The Figure depicts

Fig. 2

Spectral data for poloidal electric field $E_\theta^{\sim}$ and density $N_e^{\sim}$ oscillations near LCFS on the HFS

abrupt fluctuation spectra suppression after t = 32ms, when ITB forms. For 0-500 kHz frequency band there are the following set of the typical plasma modes: ion gradient mode (ITG), drift trapped electron modes (DTEM) and balloon resistive interchangeable mode (BRI) [11]. Accordingly to
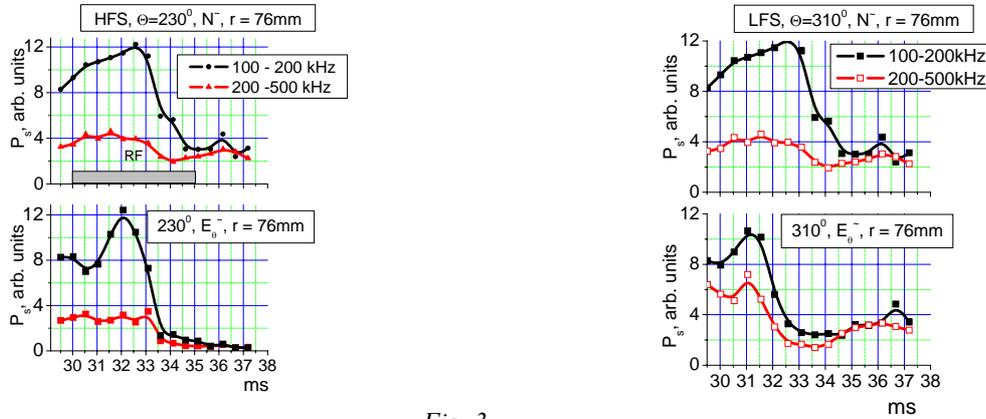

Fig. 3
Time evolution of the power spectra in the chosen frequency bands for both LFH and HFS probe locations.

increment estimations for these modes [11] and similar experimental observations [10], the ITG mode can be instable in the range $\Delta f = 50 - 200$ kHz, DTEM mode can be observed in frequency band 300 - 500 kHz, and BRI for frequency <100 kHz. The frequency range <100 kHz with contribution of the MHD modes needs separate examination. To estimate the drift modes changes only, two frequency bands (higher than 100 kHz) were chosen. First of them is "lower-frequency" one (100 - 200 kHz) related, apparently, with ITG mode and second one is "higher-frequency" (200 - 500kHz) which is close to DTEM mode. Time evolution of the power spectra in these frequency bands is presented in the Fig. 3, which reveals the suppression of $E_{\theta}^{\tilde{}}$ and density $N_e^{\tilde{}}$ fluctuations for both LFS and HFS probe locations. Effectively drift instability $E_{\theta}^{\tilde{}}$ and $N_e^{\tilde{}}$ suppression is observed in "lower-frequency" band for both field sides. At the same time only $E_{\theta}^{\tilde{}}$ on HFS is suppressed dramatically for both lower and higher frequency band. It should be stressed again, that sharp decrease of the power spectra for $E_{\theta}^{\tilde{}}$ and $N_e^{\tilde{}}$ are triggered once when ITB is formed.

The considerable attention in experimental researches of the edge plasma's characteristics is given by statistical analysis of fluctuation properties. Such investigations are important for the construction of the appropriate theoretical model of the turbulence and anomalous transport. In the theory of plasma turbulence it is assumed that the statistical properties of fluctuating processes are close to the properties of Gauss's random process [12]. Although there are observations of the edge plasma on the many fusions devises, that the time realizations of density and potential have "burst" structures, i.e. they contain the fast density spikes and holes. That's why the probability distribution function (PDF) of the fluctuations may be far from Gauss's PDF [13, 14]. In this situation there are some special procedures developed for the analysis of experimental results, in particular, there is an idea for interpretation of the experimental PDF of the fluctuation induced radial flux at the plasma edge like a number of same normal (Gaussian) distribution of amplitudes of turbulent fluxes with help of EM – algorithm [13]. The PDF of the described intermittent transport is a good characteristic to describe the dynamics of these large transport events. The Fig 4 illustrates how change of PDFs of

fluctuation induces flux oscillations measured near of the LCFS on HFS and LFS. One can see that HFS PDFs have more clear positive non-Gaussian long lag tail, which is the signature of long-range
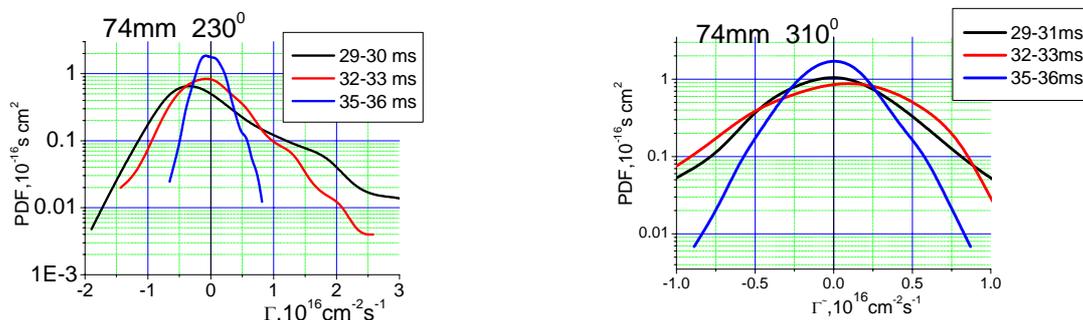

Fig. 4

Change of the PDF of fluctuation induces flux oscillations measured near of the LCFS on HFS and LFS. Here (29-31ms) is label of the time samples of amplitudes of fluctuating flux for OH, (32 – 33ms) is label of the time samples of amplitude after ITB and (35 – 36ms) – after L-H formation.

correlation transport events. After ITB formation this tile decreases and after $L – H$ transition the PDF transforms to the symmetric PDF. The LFS PDF has a lag tail smaller than at HFS, but also undergoes transformation to the symmetric PDF after $L – H$ transition. This statistical and spectral data give additional evidence that ITB formation fundamentally affects on micro-instabilities intermittent transport and spectra changes at the periphery and stimulate the $L – H$ transition after LHH [3-5]. Presented results could be useful in further researches of instabilities at the plasma periphery, and study of anomalous high energy and particle transport in plasma.

So, characteristic properties of microturbulence suppression at discharge periphery was obtained. The following is noteworthy, that effective LHH and following internal transport barrier formation predetermine observed $L – H$ transition.

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