Low-frequency fluctuations of diverted plasma flow and their relation to edge fluctuations in the Uragan-3M torsatron

BELETSKII Aleksej A., GRIGOR'EVA Lyudmila I., SOROKOVOY Eduard L., CHECHKIN Viktor V., SOROKOVOY Yegor L., VOLKOV Yevgenij D., BURCHENKO Pavel Ya., KULAGA Anatolij Ye., TSYBENKO Sergej A., LOZIN Aleksej V., SLAVNYJ Aleksandr S.

Institute of Plasma Physics, National Science Center

"Kharkov Institute of Physics and Technology", Kharkov, Ukraine

Abstract. In the l=3/m=9 U-3M torsatron with a natural open helical divertor and a plasma produced and heated by RF fields, joint studies of low frequency (5-100 kHz) density (ion saturation current) fluctuations have been carried out at the plasma boundary (SOL) and in the diverted plasma flow (DPF). The knowledge of relation between fluctuation processes at the boundary and in the divertor region is important as the former are known to induce the anomalous transport, while the level of density fluctuations in some DPF can attain more than 20% of the equilibrium component. The spectral characteristics of DPF fluctuations are compared with those of the fluctuations in the SOL, and two characteristic frequency ranges are revealed. Modifications of spectral characteristics due to spontaneous transition to an improved confinement mode are investigated too.

Keywords: plasma confinement, H-transition, anomalous transport, fluctuations, divertor, power spectrum

1. Introduction

Low-frequency density and potential fluctuations in the edge plasma resulting in the anomalous transport are a subject of research in plasma confinement physics for a long period [1-3]. Changes in fluctuation behavior are a good indicator of transition to improved confinement modes. In particular, investigations of spontaneous transition to an improved confinement state (hereinafter, transition) in the U-3M torsatron reveal a distinct decrease of the fluctuation level and radial turbulent particle flux with transition near the plasma boundary [4,5]. Naturally, processes near the plasma boundary should be tightly related to processes in the diverted plasma flow (DPF). In particular, it is of interest to study these relations on the basis of joint measurements of fluctuation spectral characteristics at the edge and in the DPF.

2. Experimental conditions and measurement techniques

In the U-3M torsatron (l = 3, m = 9, R_o = 1m, $\bar{a} \approx$ 0.12 m, $\iota(\bar{a}) \approx 0.3$) the whole magnetic system is enclosed into a 5 m diameter vacuum chamber, so that an open natural helical divertor is realized. The toroidal magnetic field, $B_\phi = 0.7$ T, is produced by the helical coils only, the ion toroidal drift $\boldsymbol{B}\times\nabla\boldsymbol{B}$ is directed upward (Fig. 1). A "currentless" plasma is produced and heated by RF fields ($\omega \approx \omega_{ci}$). The RF power irradiated by the antenna is ≲200 kW in the 30-50 ms pulse. The working gas (hydrogen) is admitted continuously into the vacuum chamber at the pressure of ~10^{-5} Torr.

To study low-frequency density (ion saturation current) fluctuations (hereinafter, fluctuations), plane Langmuir probe arrays in DPF [6] and a movable four-tip Langmuir probe array in SOL [4] are used. The dispositions of divertor probe (DP) arrays in two half field period-separated ($\Delta\phi = 20^0$) symmetric poloidal cross-sections AA and DD and of the movable probe (MP) array in the cross-section VG ($\Delta\phi = 52.5^0$ from AA) are shown in Fig.1.1. As a recording facility, a 12 bit ADC with 1.6 μs sampling rate/channel was used.

To obtain spectral characteristics of the fluctuations, methods described in [7] were used.

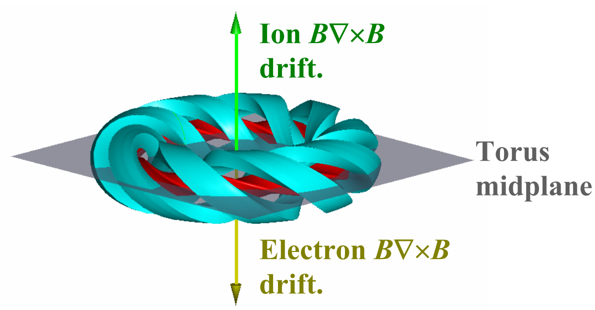

Fig.1. Electron and ion $\boldsymbol{B}\times\nabla\boldsymbol{B}$ drift directions.

Author's e-mail: beletskii@ipp.kharkov.ua

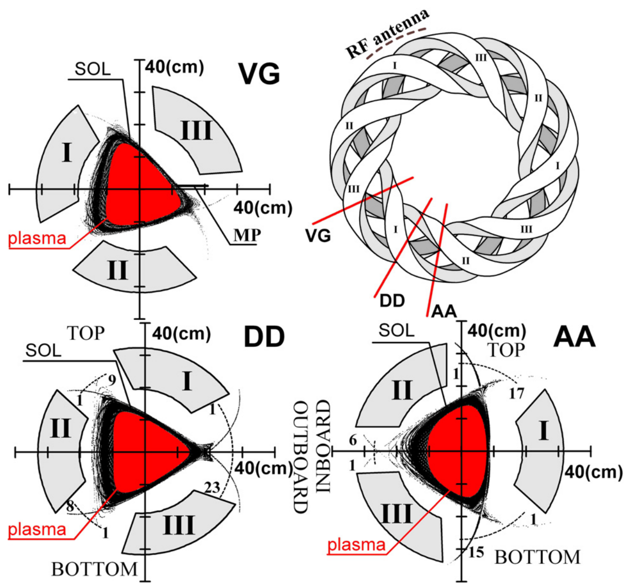

Fig.1.1. Disposition of divertor probe arrays 1-17, 1-15, etc. (cross-sections AA and DD) and movable probe array (cross-section VG, segment MP) relative to helical coils I,II,III and calculated edge structure of field lines. Positions of 4 MP tips are shown in the inset to VG.

3. Spectral characteristics of fluctuations in SOL and DPF

As an example, power spectra of fluctuations in the DPF maxima in two divertor magnetic channels (legs) symmetric about the torus midplane in the cross-section DD (top and bottom spacings) are presented in Fig. 2. The evolution of fluctuation power is traced within 4.8 ms, that is equal to 3000 ADC counts (Fig. 2a,b).

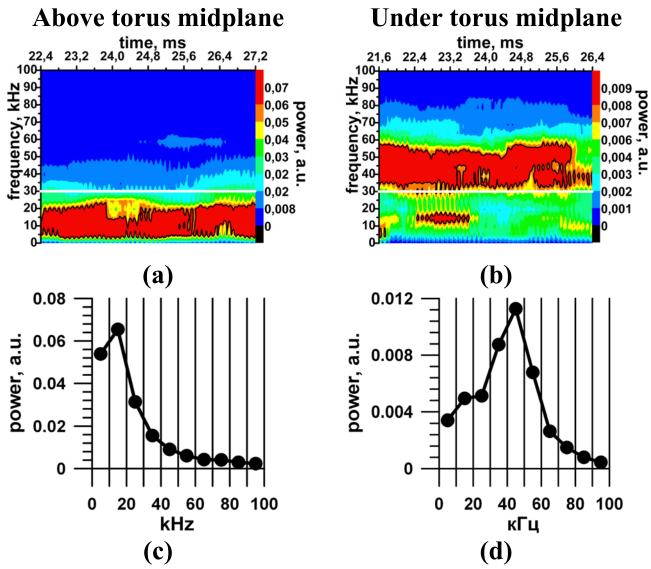

Fig.2. Time evolution of fluctuation power spectra (a,b) and corresponding time-averaged spectra (c,d) in the top (a,c) and bottom (b,d) spacings of the cross-section DD.

Corresponding power spectra averaged over this time period are shown in Fig. 2c,d. In combination with the data from the top and bottom spacings of the cross-section AA, a conclusion can be made, that there are two frequency ranges where the maximum fluctuation power is observed, namely, one with frequencies less than 30 kHz (over the torus midplane) and one with frequencies exceeding 30 kHz (under the midplane).

It is known [6] that the spatial DPF distributions in U-3M exhibit a strong vertical (up-down) asymmetry with the larger ambipolar flow and the non-ambipolar flow with an excess of ions always outflowing with the ion $\boldsymbol{B}\times\nabla \boldsymbol{B}$ drift (upward, in our case). At the same time, the electrons dominate in the non-ambipolar flow outflowing downward [6]. It is naturally to suppose that the observed vertical asymmetry in spectral characteristics of the fluctuations is in some way related to the DPF vertical asymmetry, and the fluctuations with frequencies < 30 kHz are connected with the fast ion loss that is responsible for the DPF asymmetry [6].

Studies of spectral characteristics of the fluctuations near LCMS depending on the radial distance also reveal two frequency ranges with maximum spectral power as in the DPF case. The results are shown in Fig. 3. With the MP moving toward a smaller radius, the maximal fluctuation power gradually shifts from a frequency range >30 kHz (Fig. 3b,d: r = 12.0 cm) to a range <30 kHz (Fig.3a,c: r=10.4 cm).

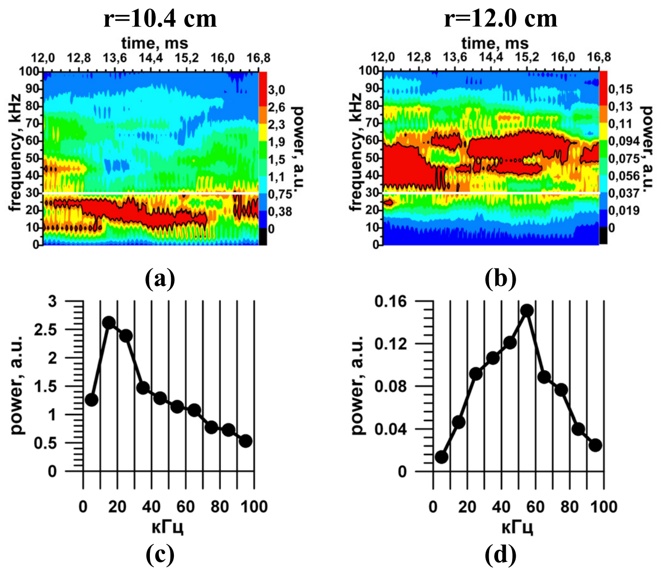

Fig.3. Time evolution of fluctuation power spectra (a,b) and corresponding time-averaged spectra (c,d) in close vicinity to LCMS, (a) and (c), MP position r=10.4 cm; and more distantly, (b) and (d), r=12,0 cm.

In addition to power spectra, cross-coherence spectra for fluctuations in SOL at different distances from the LCMS, on the one hand, and fluctuations in different

DPF, on the other hand, are also investigated. The coherence spectra between fluctuations detected in the bottom spacing of the DD cross-section in the DPF maximum (DP #1) and fluctuations in SOL for two MP positions, r=12.0 cm and r=10.6 cm, are shown in Fig. 4. In the case r=12.0 cm, the maximal coherence up to ~ 0.8 in the frequency range 40 – 60 kHz is observed. As it has been already shown above, the maximum fluctuation power, recorded in SOL (Fig. 3b,d) and in the DPF under the torus midplane (Fig. 2b,d) belongs to the same frequency range. The coherence gradually decreases with the MP displacing toward the LCMS.

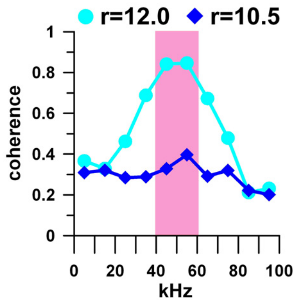

Fig.4. Cross-coherence spectra for fluctuations in the divertor region (DD, bottom, probe #1, see fig.1) and SOL (movable probe at r=12.0 cm and r=10.6 cm).

The large coherence apparently can be explained as follows. A bundle of magnetic field lines after crossing the MP tip at the radius r=12.0 cm due to the rotational transform enters the divertor region and falls on the DP #1 in the bottom spacing of the DD cross-section [8]. On the other hand, field lines located closer to the LCMS (e.g., r=10.6 cm) can make a many-fold pass round the torus before deviating to the divertor region. Therefore, fluctuations in these SOL layers should be less correlated with fluctuations in DPF.

The fact that the highest fluctuation power in the DPF on the electron $\boldsymbol{B}\times\nabla\boldsymbol{B}$ drift side and the maximum coherence are observed in the same frequency range is an evidence in favor of a common nature of the fluctuations in SOL at r=12 cm and in the DPF under the midplane.

Thus, two layers can be generally marked out in the SOL. More distantly from the LCMS, the development of fluctuation processes is connected with the electron loss – an electron escape to the divertor region on the electron $\boldsymbol{B}\times\nabla\boldsymbol{B}$ drift side, while in the layer closer to the LCMS the excitation of the fluctuations is related to the ion loss. It would be natural to relate the electron loss in the outer layer to a higher field line stochastization in this layer.

4. Changes in spectral characteristics with H-mode transition

Like some other plasma parameters, spectral characteristics of the fluctuations change during the transition. Typical fluctuation power spectra taken before and after the transition in DPF maxima in the top and bottom spacings of the AA and DD cross-sections and in the inboard spacing of the cross-section AA are shown in Fig. 5.

In the cross-section AA the fluctuation power decreases above the torus midplane and increases below

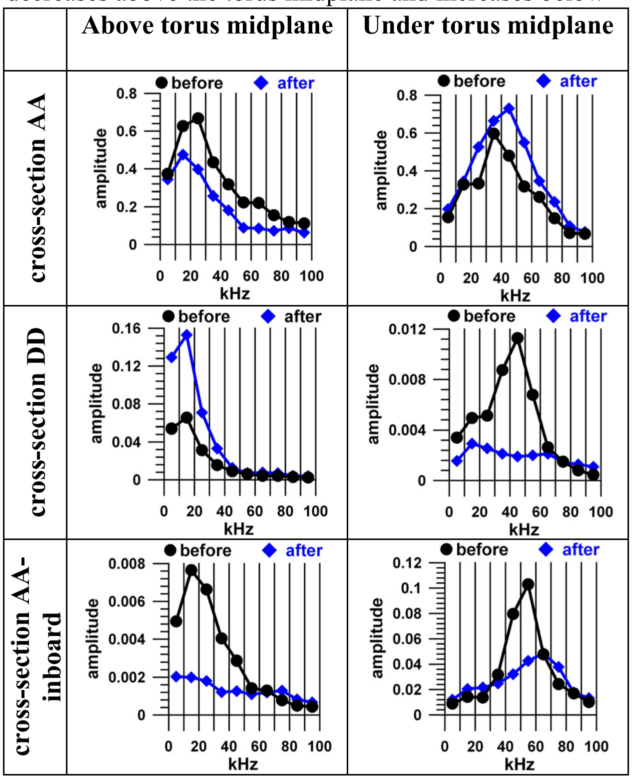

Fig.5. Power spectra before and after the H-mode transition in two symmetric poloidal cross-sections AA and DD.

the midplane after the transition. In the inboard spacing the fluctuation power decreases both above and below the midplane.

In the DD cross-section the power spectra change in the opposite way with transition: the fluctuation power increases above the torus midplane and decreases under it. The same tendency is also observed in the outboard spacing of the cross-section DD.

Taking into account that fluctuations with frequencies lower than 30 kHz (higher than 30 kHz) are presumably related to ion (electron) transport processes, the dynamics of particle loss during the transition could be described in the following way, basing on fluctuation spectral characteristics. In the cross-section AA an insignificant reduction of ion loss is observed (a slight decrease of ion outflow to the DPF above the midplane). At the same time, the electron loss insignificantly increases (a slight increase of electron outflow in the DPF under the midplane). In the inboard spacing of the AA cross-section, both the ion and electron loss are significantly reduced. In the cross-section DD a considerable reduction of electron loss (a sharp drop of electron outflow to the DPF under the torus midplane) and a considerable rise of ion loss (a sharp increase of ion outflow to the DPF) above the torus midplane occur with transition.

As a whole, these results are in a good agreement with those of studies of H-transition effects on equilibrium characteristics of DPF (in particular, on fast ion outflow to the DPF) in U-3M [9].

5. Summary

As a result of investigations of DPF fluctuations and comparison of their spectral characteristics in two symmetric poloidal cross-sections with those in SOL in the U-3M torsatron, the following conclusions can be made.

(i) A new manifestation of the DPF vertical asymmetry is observed, viz., a difference in the form of power and coherence spectra in symmetric divertor channels over and under the torus midplane.

(ii) As a result of search of correlation between fluctuations in SOL and DPF, their spectral characteristics and juxtaposing of these data with the distributions of non-ambipolar DPF [6], two layers of SOL are defined. The SOL layer with electron predominance is localized more distantly from the LCMS; the other layer with ion predominance is localized closer to the LCMS.

(iii) Basing on corresponding spectral characteristics, it is shown, that the DPF on the ion $\boldsymbol{B}\times\nabla\boldsymbol{B}$ drift side is formed predominantly by particles outflowing from the SOL layer nearest to the LCMS; on the electron drift side the DPF is formed predominantly by particles escaping from more distant layers of the SOL.

(iv) Changes occurring in spectral characteristics of the fluctuations during the H-mode transition confirm the character of electron and ion loss dynamics, associated with transition.

References

[1] M. Endler *et al.,* Journal of Nuclear Materials*,* 1999, **266-269**, 84-90 (1999).

[2] A. J. Wootton *et al*., Phys. Fluids B*,* **2**, 2879-2903 (1990).

[3] H. Y. Tsui *et al.*, Phys. Fluids B **5** 2491-2497 (1993).

[4] E. L. Sorokovoy *et al.,* Problems of Atomic Science and Technology, Series "Plasma Physics" No. 10*,* p. 21 (2005).

[5] V. V. Chechkin *et al*., Plasma Phys. Control. Fusion **48**, A 241 (2006).

[6] V. V. Chechkin *et al.* Nucl. Fusion **42** 192 (2002).

[7] E. J. Powers, Nucl. Fusion **14** 749 (1974).

[8] Sorokovoy *et al.* Problems of Atomic Science and Technology, Series: Plasma Physics No 1 p. 60 (1999).

[9] Chechkin V.V. *et al*., (2007) (This conference).