CHARACTERISTICS OF EDGE PLASMA TURBULENCE IN SPONTANEOUS CHANGE OF CONFINEMENT MODE IN THE URAGAN-3M TORSATRON

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It is shown that in the Uragan-3M torsatron under conditions of spontaneous change of confinement mode caused by formation of an internal transport barrier, a layer with the $E\times B$ velocity shear appears at the boundary of confinement region. Appreciable changes of the edge microturbulence characteristics and turbulence-induced particle flux in the vicinity of this layer evidence a formation of the edge transport barrier as well.

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1. INTRODUCTION

In the Uragan-3M (U-3M) torsatron with an open helical divertor (l = 3, m = 9, R_o = 1 м, $\bar{a}$ ≈ 0,12 м, B_ϕ = 0,7 T, $\iota(\bar{a})/2\pi$ ≈ 0,3) a spontaneous transition to an improved confinement state (below – "transition") is observed under conditions of plasma production and heating by RF fields in the $\omega \le \omega_{ci}$ range of frequencies [1,2]. This transition is related to an internal transport barrier (ITB) formation in the layer near the τ = 1/4 rational magnetic surface [2], this having been confirmed by the form of electron density and temperature profiles as well as the existence of an $E\times B$ velocity shear in the layer considered.

It has been demonstrated in [3] that the transition is accompanied by substantial changes in the diverted plasma flow (DPF) magnitude. At the initial phase of these changes being essentially non-steady-state, a reduction of all the PDF components in the spacings between the helical coils is observed, this being an evidence of plasma confinement improvement. The initial phase is terminated by an enhanced escape of thermal and suprathermal ions from the confinement volume, that is accompanied by a rise of some DPF components, thus indicating a certain degradation of confinement.

It is shown in the presented paper that parallel with the ITB formation a layer with the $E\times B$ velocity shear is also formed at the plasma boundary in U-3M. In the vicinity of this layer substantial changes of the electrostatic microturbulence and assotiated radial particle flux are observed, that indicate an edge transport barrier (ETB) also to be formed.

2. EXPERIMENTAL CONDITIONS

The investigations were carried out in a hydrogen plasma with the line-averaged electron density $\bar{n}_e \sim 10^{18}$ m^{-3} and electron temperature $T_e(0) \approx 500$ eV. To study the low-frequency (1-300 kHz) electrostatic turbulence in the edge plasma, an array of 4 movable probes was used. The molybdenum ϕ = 0.5 mm/l = 3 mm probe tips 1, 2, 3, 4 were arranged in the angles of a square 3 mm on side (see inset in Fig. 1) and orientated with the major radius. The ion saturation current (ISC) fluctuations, $\tilde{I}_s$, were recorded by the probes 1 and 2. Also, the probe 2 measured equilibrium components of ISC, I_s, and floating potential (FP), V_f, and was used for VI-characteristic measurements. The probes 3 and 4 measured the FP fluctuations, $\tilde{V}_f$. As a recording facility, a 12 bit ADC with 1.6 μs sampling rate/channel was used.

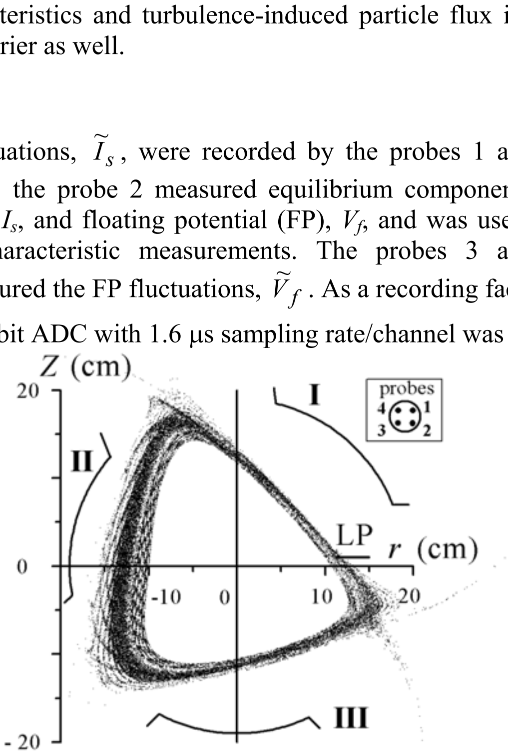

Fig. 1. Relative lay-out of helical coils I, II, III and calculated edge structure of field lines in the poloidal cross-section where measurements are made.The range of probe array LP displacement is indicated by a bold straight segment

3. DYNAMICS OF EDGE DENSITY AND POTENTIAL PROFILES DURING THE TRANSITION

In Fig. 2 edge radial profiles are presented of (a) electron density (in relative units), (b) floating potential, V_f, and (c) electron temperature, T_e, measured at t_1 = 20 ms (before the start of transition) and t_2 = 45 ms (after transition). As follows from Fig. 2, the transition is accompanied by a small broadening ($\Delta r \sim 1$ mm) of the plasma column (Fig. 2(a) and by a more distinct change of the FP profile, $V_f(r)$, (Fig. 2(b)). As according to Fig. 2(c), the electron temperature does not change significantly with r at the plasma boundary, the radial profile of the plasma potential, $V_p(r)$, should have qualitatively the same form as $V_f(r)$. Then it follows from this form that a layer with a radial electric field shear

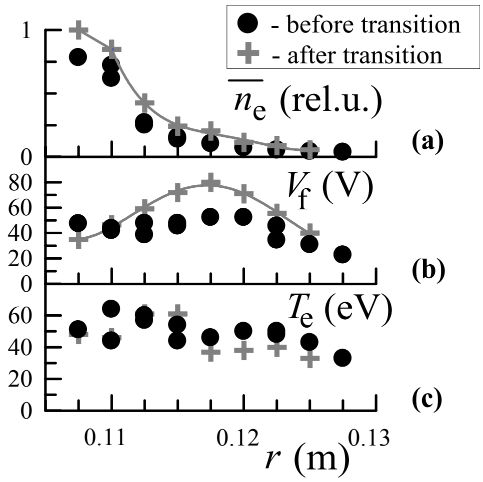

Fig. 2

occurs at the plasma boundary during the transition (E_r is directed inward at $r < 11.75$ cm and outward at $r > 11.75$ cm). Hence, the velocity of plasma poloidal rotation $E \times B$ reverses its direction in this layer. As it has been shown recently [4], the ExB velocity shear seriously affects the edge turbulence, resulting in a quenching of the fluctuations, their de-correlation and a reduction of the radial turbulent flux of particles and heat.

4. CHANGES OF EDGE TURBULENCE CHARACTERISTICS DURING THE TRANSITION

The time evolution of the ISC fluctuations $\tilde{I}_s$ in the vicinity of the $E \times B$ velocity shear layer (r = 11 cm) during the transition is shown in Fig. 3(b) together with the density $\overline{n}_e$ (Fig. 3(a)). Also, in Fig. 3(b) shown is in the $\tilde{I}_s(t)$ background the time behavior of the corresponding r.m.s. value, $<\tilde{I}_s>_t$, averaged over the 200 μs interval. It is seen that the intensity of plasma density (ISC) fluctuations is appreciably reduced with the transition.

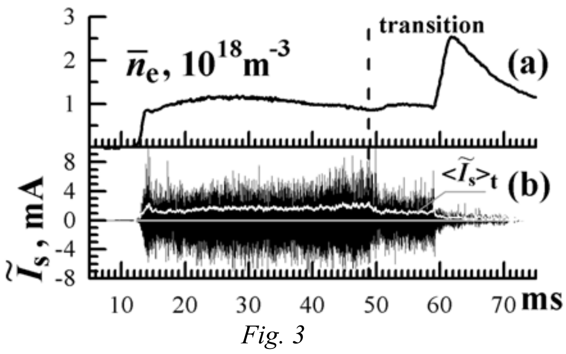

Fig. 3

As a result of a more detailed analysis, the process of transition can be divided into three phases. A fragment of the $<\tilde{I}_s>_t$ time evolution in the vicinity of the transition (r = 11 cm) is shown at the top of Fig. 4. The state preceding the transition is denoted as I. The initial phase of the transition consists of two separate phases, A and B, lasting for ~ 1-2 ms, while the third phase, C, persists till the end of RF pulse. Below, in the left column of Fig. 4, shown are the normalized power spectra of the ISC fluctuations in the preceding state and three phases of the

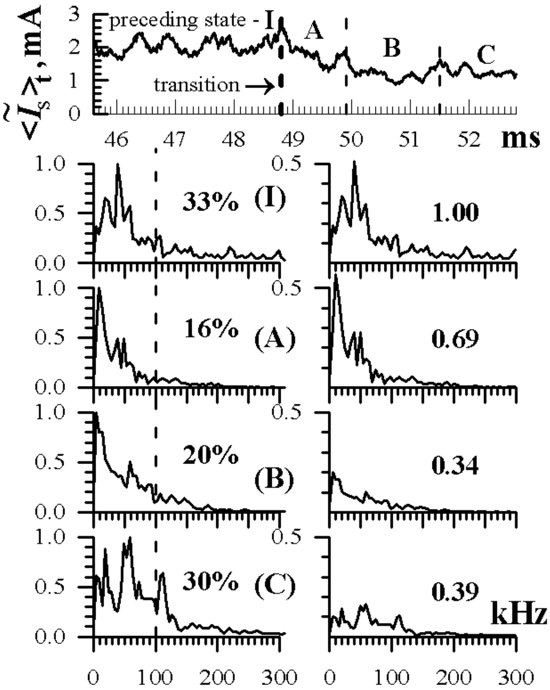

Fig. 4

transition. The percentages indicate the power fraction contained in the f > 100 kHz frequency region. The corresponding non-normalized spectra are in the right column, where the numbers indicate the total (i.e., over the entire frequency diapason) power for each phase relative to that in the preceding state (I). It follows from Fig. 4 that a considerable reduction of the total fluctuation power arises at the phase A with a simultaneous reduction of the high-frequency (f > 100 kHz) power fraction. A further reduction of the fluctuation power is observed at the phase B with some redistribution of the total power over the entire frequency region and a rise of power fraction in the high-frequency part of the spectrum. At last, at the phase C, where some deterioration of the confinement occurs, a small rise of both the total power and its high-frequency fraction takes place. The time behavior of the FP fluctuations is qualitatively the same.

In Fig. 5 shown are (a) the phase spectrum between FP fluctuations recorded by the probes 3 and 4, and (b) the coherence spectrum between the density and potential fluctuations ($\tilde{I}_s$, probe 2; $\tilde{V}_f$, probe 3) at the state I and at the phase C. The values of the poloidal phase velocity of the fluctuations at r = 11 cm are 5.4×10^5 cm/s before the transition, 8.4×10^5 cm/s at the phase A and 7×10^5 cm/s at the phase C. It is impossible to determine the phase velocity at the phase B as there is no linear section in the cross-coherence spectrum. This is possibly caused by a strong de-correlation of the fluctuations at this phase of the transition.

Together with (a) the density $\overline{n}_e$, Fig. 6 shows (b) the time evolution of the function

$$\tilde{G}(t) = \tilde{I}_s(t)[\tilde{V}_{f4}(t) - \tilde{V}_{f3}(t)]$$

that is proportional to the radial turbulent particle flux, $\tilde{\Gamma}_T = \tilde{n}\tilde{E}_\theta / B_\phi$, [5]. The 200 μs interval-averaged turbulent flux is presented in white. Below (Fig. 6(c)), a section of the averaged turbulent flux is shown in the vicinity of

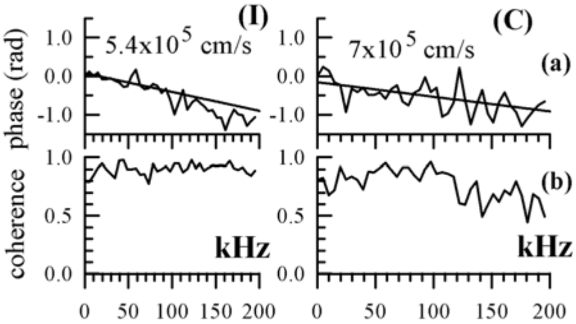

Fig. 5

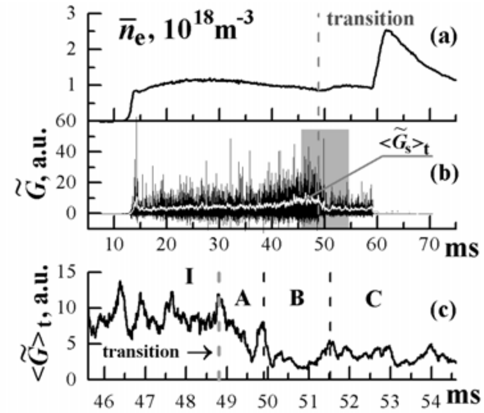

Fig. 6

transition (shaded in Fig. 6(b)). It is seen that an appreciable reduction of the flux takes place simultaneously with the reduction of the fluctuation level (cf., Fig. 4). The maximum reduction of the flux is 3.3 at the phase (B) and 2.2 at the phase (C) as compared with the preceding state (I).

Like some other tokamaks and stellarators, an intermittency is inherent to the turbulent flux of particles in the U-3M torsatron. This intermittency is displayed as strong short-time separate bursts, whose amplitude can multiply exceed the average flux level [5]. The burst amplitude decreases with transition similar to the average level of the turbulent flux. However, the fraction of flux transported in the bursts does not change substantially before and after the transition.

5. SUMMARY

In the U-3M torsatron under RF plasma production and heating conditions, a spontaneous change of the confinement state due to the ITB formation is also accompanied by an ETB formation in the layer of stochastisized field lines. The indications of ETB formation are:

- appearance (or rise) of the radial electric field shear near the plasma boundary;
- reduction of the level of plasma density and potential fluctuations;
- reduction of the high frequency fraction (f>100 kHz) in the power spectra of the fluctuations (at least at the A and B phases);
- reduction of the coherence between density and potential fluctuations in the high frequency region;
- more than two-fold reduction of the radial turbulent particle flux near the plasma boundary.

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ХАРАКТЕРИСТИКИ ТУРБУЛЕНТНОСТИ КРАЕВОЙ ПЛАЗМЫ ПРИ СПОНТАННОМ ИЗМЕНЕНИИ РЕЖИМА УДЕРЖАНИЯ В ТОРСАТРОНЕ «УРАГАН-3М»

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В торсатроне У-3М при изменении режима удержания плазмы, вызванном образованием внутреннего транспортного барьера, вблизи границы плазмы появляется слой с широм скорости $E\times B$. Соответствующие изменения характеристик мелко-масштабной турбулентности в окрестности этого слоя и вызванного турбулентностью радиального потока частиц, свидетельствуют об образовании также и краевого транспортного барьера.

ХАРАКТЕРИСТИКИ ТУРБУЛЕНТНОСТІ КРАЙОВОЇ ПЛАЗМИ ПРИ СПОНТАННІЙ ЗМІНІ РЕЖИМУ УТРИМАННЯ В ТОРСАТРОНІ «УРАГАН-3М»

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В торсатроні У-3М при зміні режиму утримання, викликаній створенням внутрішнього транспортного бар'єра, біля границі плазми виникає шар з шіром швидкості $E\times B$. Відповідні зміни характеристик дрібномасштабної турбулентності поблизу цього шару та викликаного турбулентністю радіального потоку частинок свідчать про створення також і крайового транспортного бар'єра.