ITB FORMATION DINAMICS IN THE URAGAN-3M TORSATRON INFERRED FROM MICROWAVE REFLECTOMETRY

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PACS: 52.55.Hc; 52.70.Gw

Phenomena of internal transport barrier (ITB) formation have been observed in tokamaks and stellarators for different types of configurations (limiter/divertor) and heating scenarios (OH+ECH, NBI) [1, 2].

In the Uragan-3M torsatron the ITB formation was recently observed during plasma production/heating by RF power absorption [3]. Experiments on RF plasma production were performed at magnetic field B_0 =0.7 T and for centered magnetic configuration. Frame type antenna was powered on frequency f~8.8 MHz (P= 200 KW) corresponding to excitation of ion cyclotron waves.

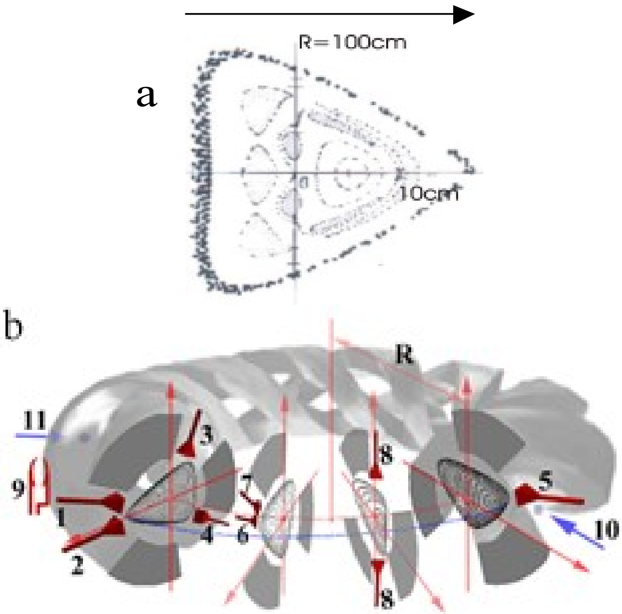

Fig.1
a: Magnetic surfaces and magnetic islands chains in the standard configuration of Uragan-3M torsatron.
b: Setup of microwave diagnostics in the Uragan-3M torsatron. 1-7 – reflectometer, 8 – interferometer λ=2mm, 9 – Fabri-Perot resonator, 10,11 – RF antennas K1 and K2.

In these experiments magnetic configuration of l=3 torsatron with open helical divertor Uragan-3M is characterized by the outward shift (≈ 5cm) of magnetic axis and existence of magnetic islands chains near the rational (ι=1/4 and 1/5) surfaces (Fig.1a).

Transition to improved confinement (characterized by increase of plasma energy measured by saddle-type ψ-loop, electron (ECE) and ion (NPA) temperature and electron density (interferometer λ=2mm)) was observed at comparatively low density ($\overline{n}_e$ =1.10^{12} cm^{-3}) and above certain RF power [3].

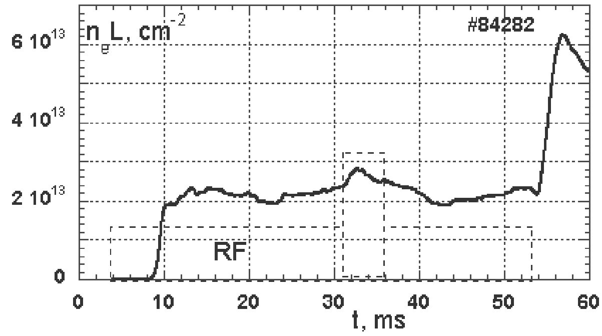

Fig.2 Plasma density evolution in regimes with ITB formation.

This work was aimed to study of transition to ITB dynamics namely plasma density and poloidal rotation velocity profiles in the vicinity of island chain and density fluctuations prior and during onset of new plasma state.

This information was obtained from the multifrequency microwave reflectometry: conventional – for electron density profile and density fluctuation (frequency and wave number spectra) measurements and correlation (radial, poloidal and toroidal) – for plasma rotation (poloidal and toroidal) velocity studies. U-3M microwave reflectometry setup and methods were described earlier [4]. For toroidal plasma rotation observation we put 2 microwave antennas in other, toroidally displaced locations. We also used data of single channel 2 mm interferometer – for line-averaged electron density measurements and 8 mm Fabri-Perot resonator – for diverted plasma density measurements (Fig.1b.).

For radial profile studies of rather low density plasma ($n_e(0)$= 2.10^{12} cm^{-3}) O-mode 10 GHz and lower X-mode 20÷30 GHz probing were used. At magnetic field of 0.7 T this allowed to observe X-mode microwave reflection from plasma layers with electron density in the range 0.1÷3.8 10^{12} cm^{-3}.

The radial position of reflecting layer r_{ref} was determined from relation:

$$\mathbf{r_{ref} = r_c + r_s}$$

here r_c is the distance of reflecting layer from magnetic axis defined from relations:

$$\frac{n_c}{\overline{n}(m+1)} = \left[1 - \frac{r_c}{a}\right]^m ; \; n_c = n_{cr}(1 - \frac{f_{ce}}{f}) ;$$

where $m = \frac{n_c - \overline{n}}{\overline{n}}$ for maximal frequency that was reflected.

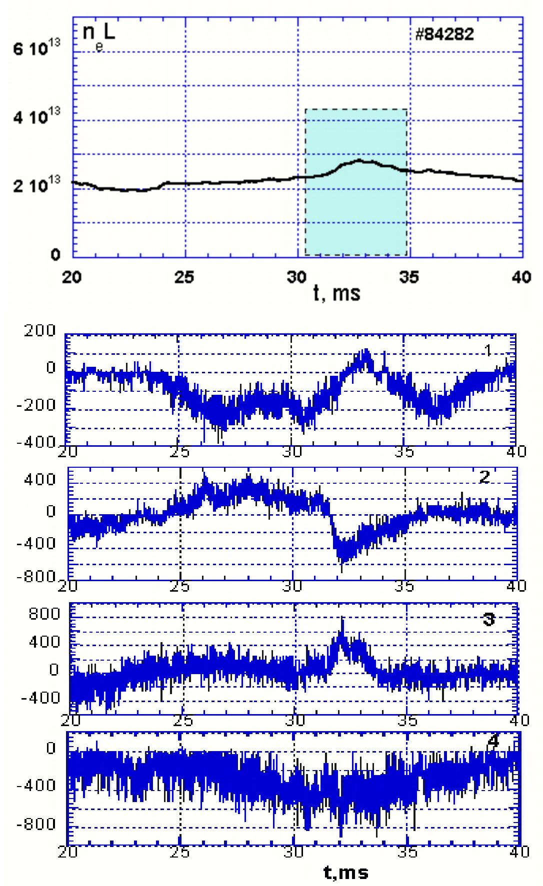

Fig.3. Time behavior of signals of 2 mm interferometer and reflectometers at different probing frequencies of X-waves (1- f=26 GHz n_e=2.1·10^{12} cm^{-3}, 2- f=25 GHz n_e=1.65·10^{12} cm^{-3}, 3- f=23 GHz n_e=1·10^{12} cm^{-3}, 4- f=21 GHz n_e=0.36·10^{12} cm^{-3}).

Value of r_s was determined from a reflected wave phase shift. X-mode reflecting layer position error was estimated according to [5] and is in the range of 1.3÷0.4 cm for *f* in the range of 21÷26 GHz.

The onset of transition to ITB was manifested in a rapid change of reflected X-mode amplitude and phase (Fig.3) that corresponded to the density profile widening [6]. A 30% increase of line-averaged plasma density was observed also (Fig. 2, Fig.3-upper).

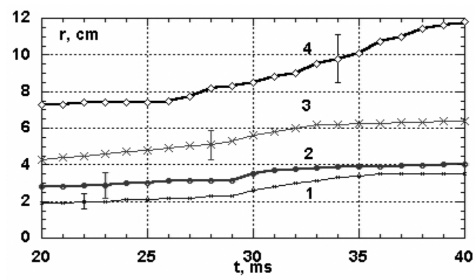

Fig.4. Reflecting layer position time evolution (1- n_e=2,1·$10^{12}$$cm^{-3}$;2-1,3 ·$10^{12}$$cm^{-3}$; 3 -0,6·$10^{12}$$cm^{-3}$;4- 0,36·$10^{12}$$cm^{-3}$)

Density profile studies showed a slow evolution of reflected layer radius (Fig.4) corresponding to widening of density profile with a small decrease of the central density (Fig.5).

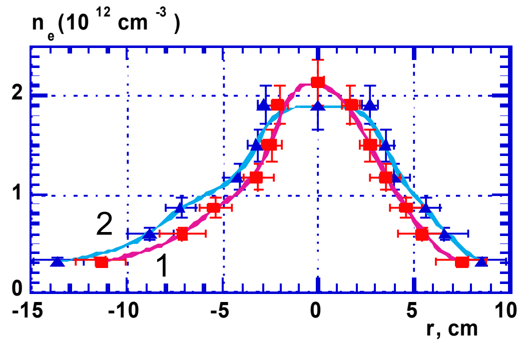

Fig.5. The radial profiles of electron density prior to (1) and during of (2) ITB period.

The most striking effect of transition was observed in the radial profile of poloidal rotation velocity (Fig.6).

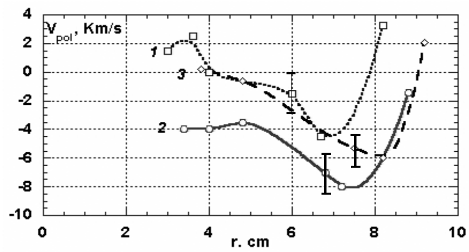

Fig. 6. Radial profiles of poloidal rotation velocity 1- prior, 2-during, 3-after period of transition into ITB regime.

Prior to (1) and after of (3) the transition period an inner plasma half-radius rotates in the direction corresponding to the “electron root”; at outer half-radius direction of rotation corresponds to the “ion root”. During the transition phase (2) the poloidal rotation velocity at inner half-radius is larger by a factor of 2 than before and after transition phase. Large velocity shear was always observed at $r/a \geq 0.8$. In contrast to poloidal rotation the toroidal rotation velocity didn’t show a noticeable radial shear (Fig.7).

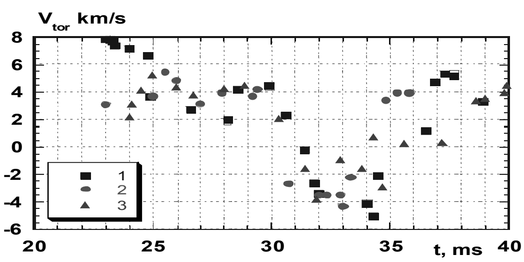

Fig.7 The time evolution of toroidal rotation of plasma layers with different density (1-2·$10^{12}$$cm^{3}$,2-1,3·$10^{12}$ cm^{-3}, 3-0,65·10^{12} cm^{-3}).

Taking into account-measured values of poloidal and toroidal velocities and poloidal and toroidal magnetic fields (B_t=0.7T, B_θ~0.15-0.2T) the ratio of the electric field components connected with plasma rotation is $\frac{V_\phi B_\theta}{V_\theta B_\phi} \approx 0.1$ during the ITB.

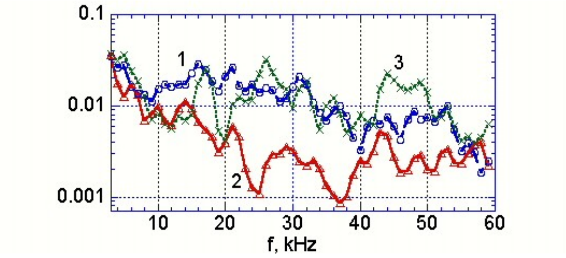

Fig.8. Spectra of reflectometer signal fluctuations (1-before transition, 2-during transition, 3 – after transition)

During transition phase spectrum of reflected signals transformed: in one with strong suppression of the part in the range of 20-40KHz (Fig. 8).

Spectrum averaged amplitude of density fluctuations $\tilde{n}/n$ also slightly decreased (Fig.9).

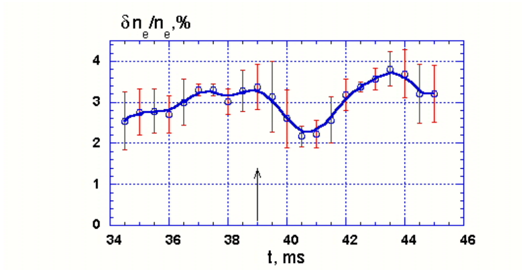

Fig. 9. Density fluctuation level evolution during the transition in ITB regime (n_e~10^{12} cm^{-3}, r_{int}~9 cm, r_{ext}~5 cm).

Measurements of density ratio in divertor and in trap confirm the improvement of particles confinement during the ITB regime (Fig. 10).

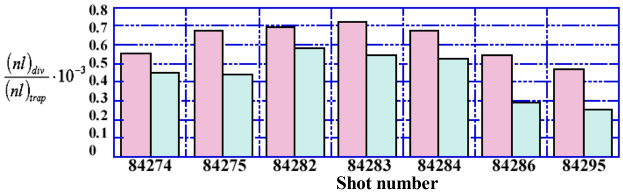

Fig.10 Ratios of integral plasma density in divertor and in trap before (left bars) and during (right bars) of ITB.

Analysis of reflectometry data showed that the phenomenon of ITB formation is marginal: it appears spontaneously for rather low density and high electron temperature plasma.

However the strong change of poloidal rotation velocity profile and fluctuation spectrum allows to think that plasma transits in another state. The lower plasma density and larger RF power results in longer period of this state existence (Δt= 3-7 ms). More data are necessary for better understanding of this phenomenon. The study of it will be the topic of future studies.

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