EVOLUTION OF PLASMA DENSITY, ITS FLUCTUATIONS AND E×B ROTATION AFTER CARBON INJECTION IN THE URAGAN-3M TORSATRON

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1. INTRODUCTION

Carbon impurity diffusion in the Uragan-3M (U-3M) torsatron with open helical divertor (l=3, m=9, R_0=1 m, a ≅0.12 m) has been studied previously [1]. In these experiments carbon atoms were injected in RF produced plasma by laser ablation of solid carbon target put inside of vacuum chamber. Injected atom number could be changed in the range 10^{16} -6.10^{17} atoms by changing laser pulse energy. It was observed that plasma time response on carbon injection depended strongly on injected atoms amount (Fig.1): with evolution time corresponding to impurity diffusion (Δt≈5 ms) – at low carbon amount (a) and one corresponding to plasma diffusion (Δt≈20 ms) – at larger carbon amount (b). Impurity diffusion was studied at low injected carbon amount. Plasma response on impurity injection depended also on plasma density.

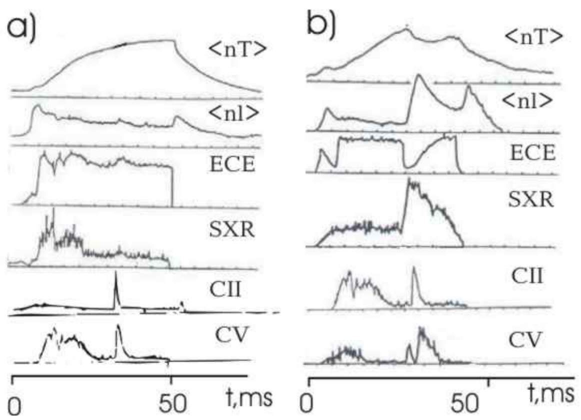

Fig.1 Plasma parameter behavior during carbon injection at $n_e(0) = 8 \cdot 10^{12} cm^{-3}$ *[a) - F_L=3 J/cm^{-2}, b) F_L = 15 J/cm^{-2}].*

Studies of dependence of ionized carbon impurity lines on carbon atom influx showed nonlinear dependence of ratio CV/CII lines intensity on CII intensity that was interpreted as result of change of screening efficiency of divertor layer plasma due to it radiative cooling. In this report we present results of studies of plasma density evolution at injected carbon amount corresponding to case b) of Fig.1 (F_L = 10÷15 J/cm^{-2}) at different values of plasma density.

2. EXPERIMENT

Hydrogen plasma in the U-3M torsatron was produced and heated by RF power absorption at $\omega \approx \omega_{ci}$ at constant gas flow-in. Frame type antenna [2] was used for RF power (up to 200 KW) excitation of antenna.

In these experiments most data were obtained by using 4-channel microwave homodyne reflectometer (Fig.2) with plasma probing by both O- and X- modes [3]. Line-integrated density $< n_e l >$ was measured by 2-mm interferometer, electron temperature – by ECE and ion temperature – by NPA.

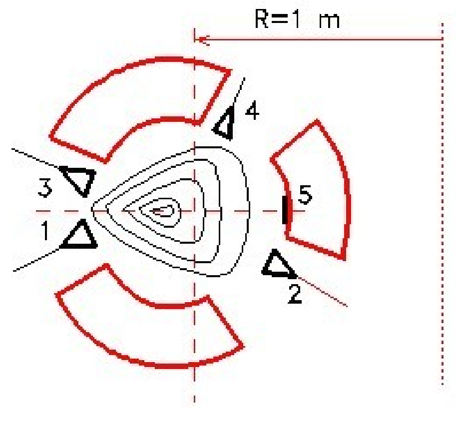

Fig.2. Reflectometer antenna setup at "U-3M": 1- outboard antenna (X-mode), 2- inboard antenna (O-mode), 3- outboard antenna (O-mode), 4- vertical antenna (O-mode), 5- carbon target in other poloidal crossection).

Typical behavior of plasma density in discharges with high electron density is shown on Fig.3 a. Injection of ≈1% of carbon atoms resulted in rather strong and nontrivial change of density behavior (Fig.3 b): the fast (≈0.5 ms) drop down of n_e by ≈ 15%, fast (≈1 ms) increase it up to almost the same value and second decrease of n_e with establishing of a new quasistationary state.

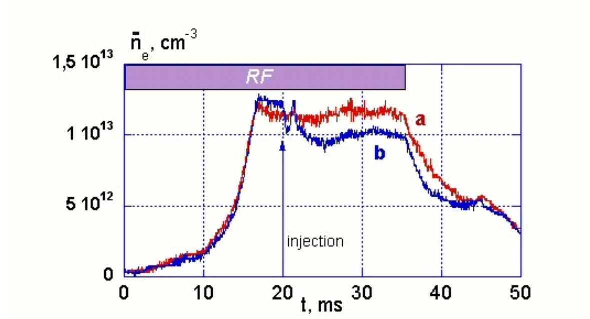

Fig.3. Time behavior of line-integrated plasma density in U-3M (a – without, b- with C injection).

Analysis of reflected signals (Fig.4), corresponding reflection from different plasma radiuses showed some outward movement of outside plasma layer (n_{cr}=1.7·10^{12} cm^{-3}) during this fast drop-down and up phase (Figs.3b, 6a).

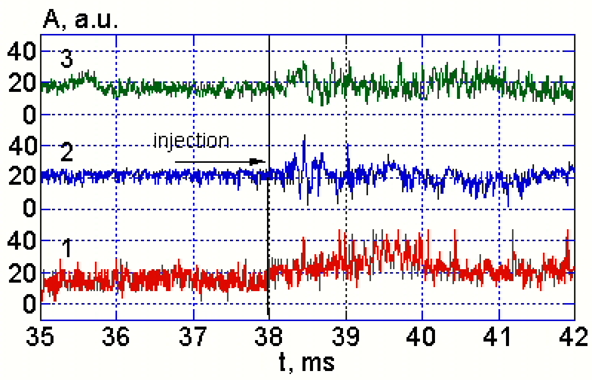

Fig.4 Reflected wave amplitude before and during injection : (1)- outboard probing (N_{cr}=1,7.10^{12} cm^{-3}), 2) and 3) inboard and outboard probing (N_{cr}=4.10^{12} cm^{-3})

Simultaneous 4 line-of-views probing of plasma by O-mode with the same frequency allowed studying the spectral properties and correlation between fluctuations in different poloidal locations. Some conclusions from these studies:

1) impurity injection results in change of spectrum of fluctuations – with increase its part below ≈ 20 KHz and decrease the part above 20 KHz (Fig.5);

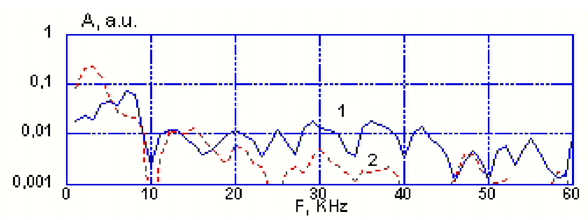

Fig.5. Density fluctuation spectra (1- prior to , 2 – during injection).

2) during this fast change phase radial correlation length is changing too (Fig.6b);

3) poloidal rotation velocity of studied plasma layers decreased and changed direction (Fig.6c).

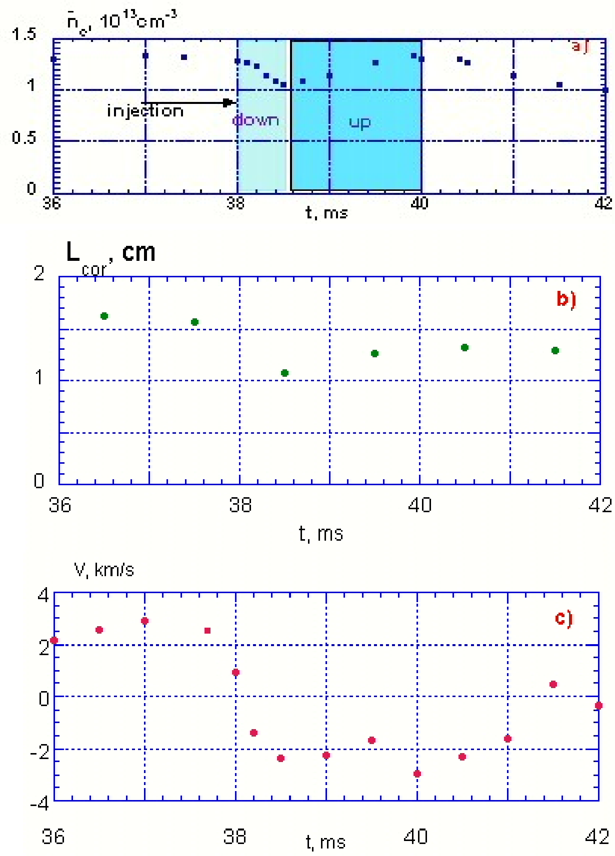

Fig.6. Time behavior of plasma parameters with carbon injection at 38 ms (a- line-integrated plasma density, b- correlation length betwin two radial plasma layers, c- velocity of poloidal rotation

If the hydrogen pressure was decreasing, the density build up was slower and resulting density was lower. An example of such discharges is shown in Fig.7-1. At this specific base pressure (≈ 5.10^{-6} tor) electron line-averaged density reaches value of $2{,}5 \cdot 10^{12}$ cm^{-3} at the moment of RF turn off but then increase up $4 \cdot 10^{12}$ cm^{-3} and then slowly decays. This is behavior similar to one shown on Fig.1. Injection of 2.10^{16} C atoms triggered faster density build resulted in a higher density (Fig.7-2).

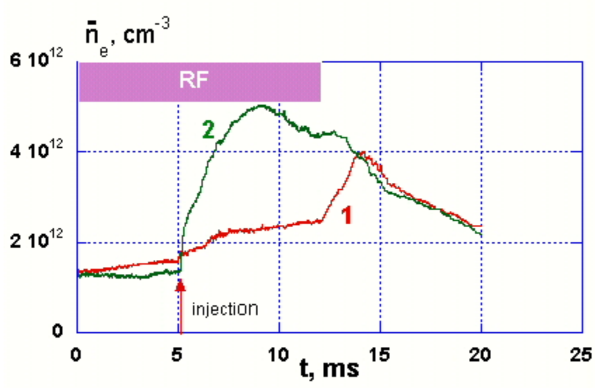

Fig.7. Time behavior of line-integrated plasma density in U-3M (1 – without, 2- with C injection).

3. DISCUSSION

To understand observed phenomena during impurity injection in U-3M torsatron, one must take into account 2 distinct peculiarities of experiment: 1) strong dependence of RF power deposition profile on electron density [2] and 2) existence of scrape-off plasma layer (SOL) at confined plasma border. Plasma density behavior in discharge is result of concurrent processes - gas ionization and particle diffusion. In simplest form for averaged electron density analysis one can use an equation

$$dn_e/dt = \Gamma - n_e/\tau_n, \qquad (1)$$

where Γ is source term describing ionization of hydrogen atoms going into plasma and second term is describing electron diffusion characterized by particle confinement time τ_n.

For cylindrical geometry

$$\Gamma = \frac{2 n_a v_a}{a}$$

where n_a and v_a – density and velocity of H atoms at plasma border *a.* In magnetic configuration of torsatron with divertor the atom flux on confined plasma border *a* is partly absorbed by SOL. The value of this flux can be described as

$$\Gamma(a) = A \cdot \Gamma(b)$$

where $\Gamma(a)$ - hydrogen flux at plasma boundary, $\Gamma(b)$ - the one at the SOL boundary *b,* A= $\exp\left(-\frac{S_i(T_e) \cdot \int_b^a n_e(x)dx}{v_a}\right)$ - attenuation factor of SOL ($S_i(T_e)$ - hydrogen ionization rate coefficient).

Carbon atom injection can result in increase of electron density in divertor layer ($\int_b^a n_e(x)dx$), in decrease of $S_i(T_e)$ due to radiation cooling thus giving decrease and increase of atom density at plasma border. Fast change of poloidal rotation may reflect change of diffusion process thus influencing the second term (τ_n) in eq.1. This change may be a result of RF power deposition profile due to change of electron density profile at plasma edge during impurity injection.

These considerations are used here to show that the full picture of electron density perturbation influence on particle balance in torsatron with divertor and RF power deposition is very complicated and needs more thorough studies. This is the topic of our further studies.

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