Study of the particle escape from the plasma center after on-axis ECRH switching on in the T-10 tokamak

N.V. Kasyanova, V.F. Andreev, E.P. Gorbunov, V.Yu. Kitaeva, T.B. Myalton, D.S. Sergeev, N.N. Timchenko, V.V. Chistyakov

NRC "Kurchatov Institute", Moscow, Russia

1. Introduction

The experiments carried out in different tokamaks [1, 2] and stellarators [3, 4] have shown that after on-axis ECRH switching on the additional particle escape from the heating zone to the periphery appeared, so called "density pump out" effect. Study of the density evolution at ECR heating is important for the future reactor ITER in which the main heat contribution by α-particles will be in the central part of the plasma.

In this work the results of the experimental study of the additional particle escape from plasma center after on-axis ECRH switching on in the T-10 tokamak (major radius R=1.5 m, minor radius a=0.3 m) are presented [5-6]. To reconstruct particle diffusivity and pinch velocity the inverse problem is formulated for the transient process after ECRH switching on. The numerical analysis of the experimental data allows us to find the value of the particle escape from plasma center as a function of the average density and ECRH power.

2. The experimental results

Two series of the experiments were carried out with different fixed values of on-axis ECRH power and the same plasma current. Line average plasma density was varied from shot to shot. The first series was carried out under following conditions: ECRH power P_{EC}~1.1 MW, plasma current I_p=180 kA, range of the average density variation $<n_e>=1.4\text{-}3.3\cdot10^{19}$ m^{-3}. The second series was carried out at fixed ECRH power P_{EC}~0.55 MW, plasma current I_p=180 kA. The average density was varied in the range of $<n_e>=1.4\text{-}3.3\cdot10^{19}$ m^{-3}. The plasma density was measured by microwave and laser interferometers (12-13 channels).

Fig. 1 shows the time evolution of the central line average density for shots with different average density at ECRH power P_{EC}~1.1 MW. One can see that the central line average density decreases immediately after on-axis ECRH switching on and the density change depends on the average density. Fig. 2 presents the dependence of the maximum change of the central line average density on the average density at different values of ECRH power P_{EC}~1.1MW and P_{EC}~0.55 MW. The experiments show that the particle escape from plasma center increases with the growth of the average density till certain critical value $<n_e^{cr}>$

and then it decreases. At ECRH power P_{EC}~1.1 MW the critical value of the average density is $< n_e^{cr} >$~2.6x10^{19} m^{-3} and at ECRH power P_{EC}~0.55 MW the critical value of the average density is $< n_e^{cr} >$~2.1x10^{19} m^{-3}.

3. Inverse problem

To reconstruct the transport coefficients (additional particle flux) from the experimental data the following procedure was used. Let us write the equation for a local density n with unknown particle diffusivity D_n, pinch velocity v_p and particle source S:

$$\frac{\partial n}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\, D_n \frac{\partial n}{\partial r}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(r\, n\, v_p \right) + S \qquad (1)$$

with appropriate initial and boundary conditions:

$$\frac{\partial n}{\partial r}(r=0,t) = 0,\ n(r=1,t) = N_0,\ \ n(r,t=t_S) = N^S(r),\ 0<r<1,\ 0<t<t_0 \qquad (2)$$

Suppose we know experimental values of the local density $n^{\exp}(r,t)$ in N radial points and M time points. The inverse problem is stated as follow. It is necessary to find the particle diffusivity D_n, the pinch velocity v_p and the particle source S so that the solution of equation (1)-(2) provides minimum of the discrepancy functional:

$$J = \frac{1}{2}\sum_{k=1}^{M}\sum_{i=1}^{N}\gamma_i\left[n(r_i,t_k) - n^{\exp}(r_i,t_k)\right]^2 \Big/ \sum_{k=1}^{M}\sum_{i=1}^{N}\gamma_i\left[n^{\exp}(r_i,t_k)\right]^2 \qquad (3)$$

The solution of the inverse problem is based on the parameterization of the unknown functions. Let us expend the required functions in a polynomial basis:

$$D_n(r) = \sum_{j=1}^{M_D} D_j \cdot \varphi_j^D(r),\ \ v_p(r) = \sum_{j=1}^{M_V} v_j \cdot \varphi_j^V(r),\ \ S(r) = c_s \sum_{j=1}^{M_S} S_j \cdot \varphi_j^S(r),$$

where $\varphi_j^D, \varphi_j^V, \varphi_j^S = \{1, r, r^2, r^3, \ldots\}$ are polynomials and D_j, v_j, c_S are unknown expansion coefficients found from minimization of the discrepancy functional (3).

4. Analysis of the experimental data

Fig. 3a – Fig. 3b present results of the analysis of the experimental data for shot #62416 (ECRH power P_{EC}~1.1 MW, average density $<n_e>$=2.0x10^{19} m^{-3}). Fig 3a shows the particle diffusivity in the stationary ohmic stage (red curve) and in the transient process after on-axis ECRH switching on (blue curve). Analogously Fig. 3b presents the pinch velocity in the ohmic stage (red curve) and in the transient process (blue curve).

The results of the inverse problem solution show that after ECRH switching on the particle diffusivity in the plasma center increases approximately by a factor of five at ECRH power

P_{EC}~1.1 MW and weakly grows at ECRH power P_{EC}~0.55 MW. The pinch velocity variation is approximately the same in both cases.

In Fig. 4 are presented the diffusive (Fig. 4a) and convective (Fig. 4b) particle fluxes for shot #62416 (ECRH power P_{EC}~1.1 MW, average density $<n_e>=2.0x10^{19}$ m^{-3}). Analysis of the experimental data shows that after on-axis ECRH switching on both additional diffusive flux and additional convective flux from plasma center to the periphery arise. The additional convective flux is approximately independent on the ECRH power. The additional diffusive flux increases with ECRH power growth. Note that at ECRH power P_{EC}~1.1 MW particle escape from plasma center is generally due to the additional diffusive flux, at ECRH power P_{EC}~0.55 MW particle escape is generally due to the additional convective flux.

5. Conclusions

The experimental results show that the particle escape from plasma center after on-axis ECRH switching on first increases with the growth of the average density and then it decreases starting from a certain critical value of the average density $< n_e^{cr} >$. The critical value of the average density $< n_e^{cr} >$ depends on the ECRH power. Analysis of the experimental data shows that after on-axis ECRH switching on the additional diffusive and convective fluxes from plasma center to the periphery arise. At ECRH power P_{EC}~1.1 MW the particle escape is due to the additional diffusive flux and at ECRH P_{EC}~0.55 MW it is due to the additional convective flux.

This work was supported by Rosatom (State Contract № H.4x.44.90.13.1101 of 13.05.2013)

References

[1] TFR Group, Nucl. Fusion **25** (1985) 1011

[2] Erckmann V and Gasparino U, Plasma Phys. Control. Fusion **36 (**1994) 1869

[3] Renner H. et al., Plasma Phys. Control. Fusion **31** (1989) 1579

[4] Stroth, U., et al., Phys. Rev. Lett. **82** (1999) 928

[5] N.V. Kasyanova et al., Proc. 39-th EPS/ICPP Conf. on Plasma Physics, 2012, ECA, vol.36F, P1.078

[6] N.V. Kasyanova et al., Problems of Atomic Science and Technology. Ser. Thermonuclear fusion, 2012, issue 4, p. 71-79

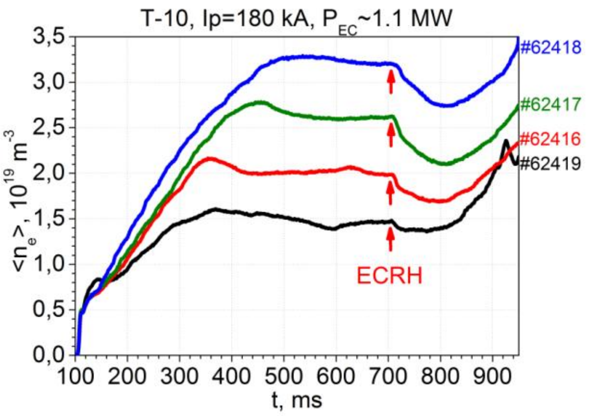

Fig. 1 Time evolution of the central line average density at ECRH power P_{EC}=1.1 MW.

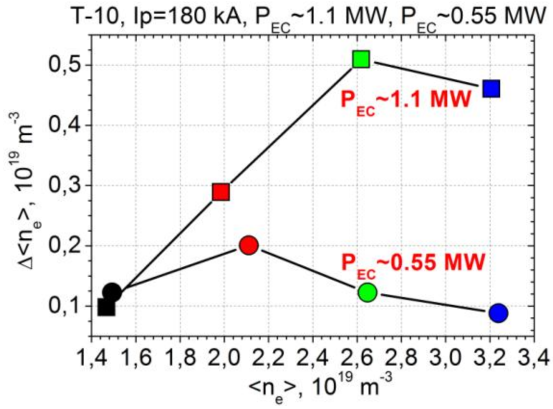

Fig. 2 Dependency of the maximum change of the central line average density on the average density at two values of the ECRH power.

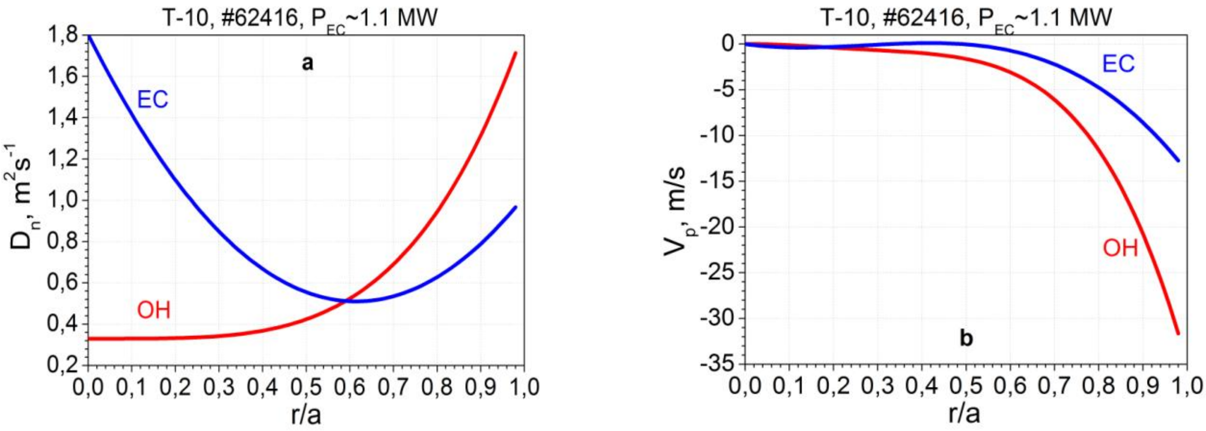

Fig. 3 Particle diffusivity (a) and pinch velocity (b) before on-axis ECRH switching on (red curve) and after on-axis ECRH switching on (blue curve) at heating power P_{EC}~1.1 MW.

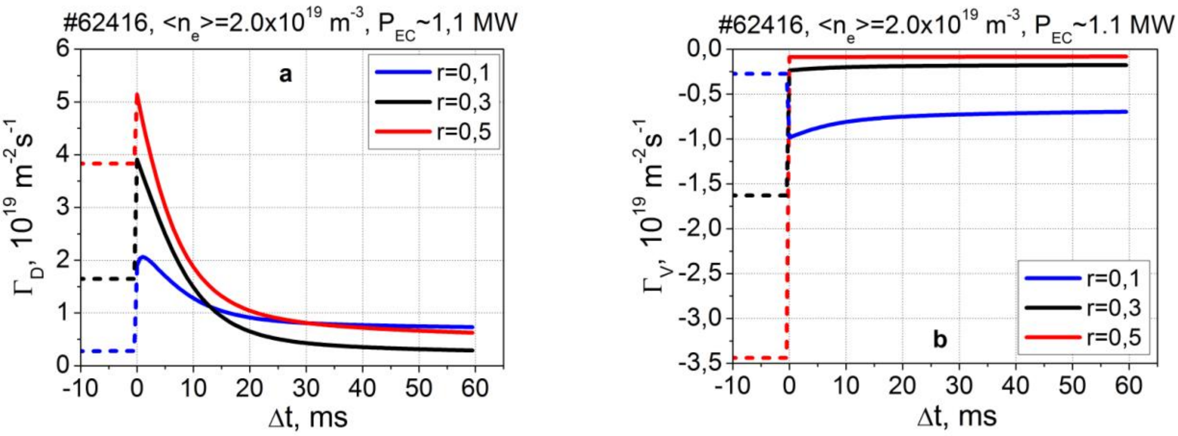

Fig. 4 Diffusive (a) and convective (b) fluxes in ohmic stage (dashed curve) and after on-axis ECRH switching on (solid curve) at heating power P_{EC}=1.1 MW for different non-dimensional plasma radii.