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Modelling of Improved Core Confinement on FT-2 Tokamak

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1. Introduction

In experiments on FT-2 tokamak (R=55 cm, a =8 cm, I_{pl} =22 kA, B_T=2.2 T, P_{HF}=100 kW, f=920 MHz) formation of an Improved Core Confinement (ICC) [1] at effective low hybrid heating (LHH) was observed. As a result of effective LHH absorption the ion temperature T_i starts to grow from the moment of additional heating switching on. Besides, sharp growth of an electron temperature (T_e) and density (n_e) in the plasma core starts 1-2 ms after HF pulse switching on. On T_e and n_e profiles obtained by Tomson scattering diagnostics [2] a region with large spatial gradients is formed at r = 3 cm and r = 6 cm respectively. This fact corresponds to formation of two transport barriers. Coefficient of effective electron heat conductivity in the core region decreases approximately by factor 8-10, achieving its neoclassical value. Transition into ICC regime is proved out by conserving (or some rising) T_e and n_e on the post heating stage. To explain ICC we assume that effective central heating of ions (from 100 eV to 300 eV) changes radial electric field (E_r) profile and, as consequence, shear of poloidal rotation $\omega_{\vec{E}\times\vec{B}}$. This process may be a key factor causing suppression of anomalous transport.

Experimental check of this hypothesis is one of the important tasks of plasma experiments. It is necessary to note, that the mechanism of suppression of turbulent transport by shear of poloidal plasma rotation, explaining transition into a mode of the improved confinement, was explored earlier and confirmed experimentally on large machines [3,4] where formation ICC was produced by additional heating by neutral beams (NBI) or HF heating (IBW). Analysis of experiments requires numerical simulation using self-consistent code, where transport coefficients depend on shear of poloidal rotation. Such simulations by means of BATRAC code for FT-2 are presented below.

Numerical simulation demonstrated that central heating of ions may initiate suppression of turbulent particle and heat fluxes and to formation of an Internal Transport Barrier [5].

2. Theoretical background

In the transport self-consistent code BATRAC transport equations are solved:

$$\frac{\partial n}{\partial t}-\frac{1}{r}\frac{\partial}{\partial r}\left[rD(\omega_S)\frac{\partial n}{\partial r}-V(\omega_S)n\right]=S \tag{1}$$

$$\frac{3}{2}n\left(\frac{\partial T_{e,i}}{\partial t}+\frac{\vec{\Gamma}}{n}\vec{\nabla}T_{e,i}\right)+nT_{e,i}\vec{\nabla}\frac{\vec{\Gamma}}{n}-\frac{1}{r}\frac{\partial}{\partial r}\left[r\frac{3}{2}n\chi(\omega_S)\frac{\partial T_{e,i}}{\partial r}\right]=Q_{e,i} \tag{2}$$

$$\frac{\partial B_\vartheta}{\partial t}=\frac{\partial}{\partial r}\left[\frac{c^2}{4\pi\sigma_{\parallel}r}\frac{\partial}{\partial r}(rB_\vartheta)\right] \tag{3}$$

Here $\sigma_{\parallel}$ is neoclassical parallel conductivity. Anomalous transport coefficients are supposed to be functions on ω_s [4]:

$$\omega_s = \frac{RB_\vartheta}{B}\frac{\partial}{\partial r}\left(\frac{E_r}{RB_\vartheta}\right) \tag{4}$$

Due to the anomalous viscosity the toroidal plasma rotation is neglected. Radial electric field in equation (4) is defined by following expression [5]:

$$E_r = E_r^{(STAND)} - \frac{2.3en\sqrt{\varepsilon}E_\phi}{(1+\nu_e^*\varepsilon^{3/2})(1+\nu_e^{*1/3}+\nu_e^*)\sigma_\perp^{apprax}B_\vartheta} \tag{5}$$

here $E_r^{(STAND)} = \frac{T_i}{e}[\frac{d\ln n}{dr}+(1-k)\frac{d\ln T_i}{dr}] + B_\vartheta \bar{u}_\phi$, $\sigma_\perp^{apprax} = \frac{\sigma_\perp^b}{1+\nu_i^*}$,

$\nu_i^* = \frac{qR\nu_i}{\sqrt{2T_i/m_i}\,\varepsilon^{3/2}}$, $\sigma_\perp^b = \frac{3}{2}\frac{\sqrt{\varepsilon}m_i n\nu_i}{B_\vartheta^2}$

Particle and heat sources profiles are taken from the experiments (similar to [6]) and are shown in Figs. 1-2.

3. Discussion

It is widely recognized that internal transport barrier formation is initiated by reducing the transport coefficients which depend on electric field shear. The threshold values ω_s were chosen to better fit the experimental data ($\omega_{s1} = 1.2\cdot 10^5 s^{-1}$ and $\omega_{s2} = 2.5\cdot 10^5 s^{-1}$ respectively).

As has been shown in the simulation, triple increase of ion temperature during first millisecond of LHH governs other changes of plasma parameters. Indeed, the following phenomena have been observed in the numerical experiments:

(i) Considerable drop of diffusion coefficient in the core during LHH heating. In Fig. 3 the diffusion coefficient for three moments is shown: for ohmic heating (29.5 ms), 1.5 ms after the beginning of additional heating (31 ms), 3 - 3.5 ms after the beginning of additional heating (33 ms).

(ii) Substantial change of the radial electric field profile. This fact is illustrated by Fig. 4 where the transformation of E_r profile for three moments (29.5, 31, 33 ms accordingly) is shown.

(iii) The central density rises substantially due to the increase of the particle confinement. Plasma density profiles n_e for 3 moments (29.5, 31, 33 ms) are illustrated by Fig.5.

(iv) Sharp rise of the central electron and ion temperature and peaked profiles followed by electron and ion temperature profile broadening at the end of RF pulse. In Figs. 6-7 the profiles and temporal behaviour of the electron and ion temperature are displayed for three moments (for 29.5, 31, 33 ms accordingly).

As a result, we can conclude that transport barriers have formed on n_e, T_e profiles on 3 and 5 cm, accordingly.

4.Summary

Improved core confinement (ICC) regime of FT-2 tokamak was simulated by BATRAC transport code [1]. Transport coefficients were assumed to be the functions of shear of ExB poloidal drift, while evolution of the electric field profile was addressed consistently with transports equations. Radial electric field was obtained from the equation, where both ion and electron parallel neoclassical viscosities were taken into account. The latter is a key issue for the transition to the ICC regime. Modeling yields dynamics of the transition to ICC regime including the formation of Internal Transport Barrier on the density and temperature profiles for FT-2. Triggering of the ICC transition is caused by auxiliary Low Hybrid Heating. Particle source and RF heating source are determined by the experimental data. The rise of the density, electron and ion temperatures obtained in numerical simulations fits experimental measurements. In general, the model appears to be consistent with many features of ICC transition during LH heating observed on FT-2 tokamak [2].

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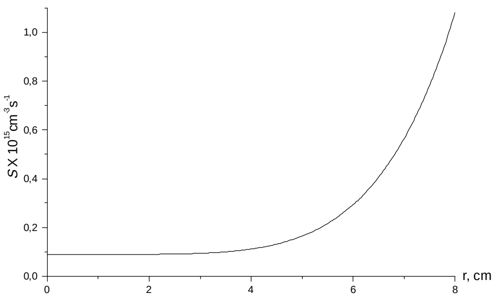

Fig.1 Particle source profile

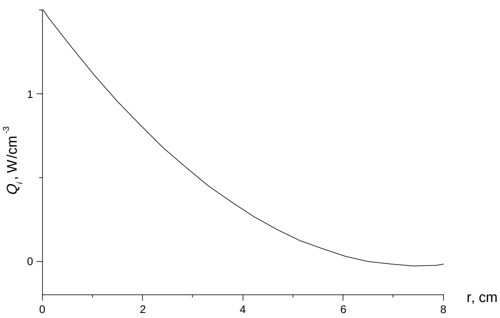

Fig.2 Heat source profile

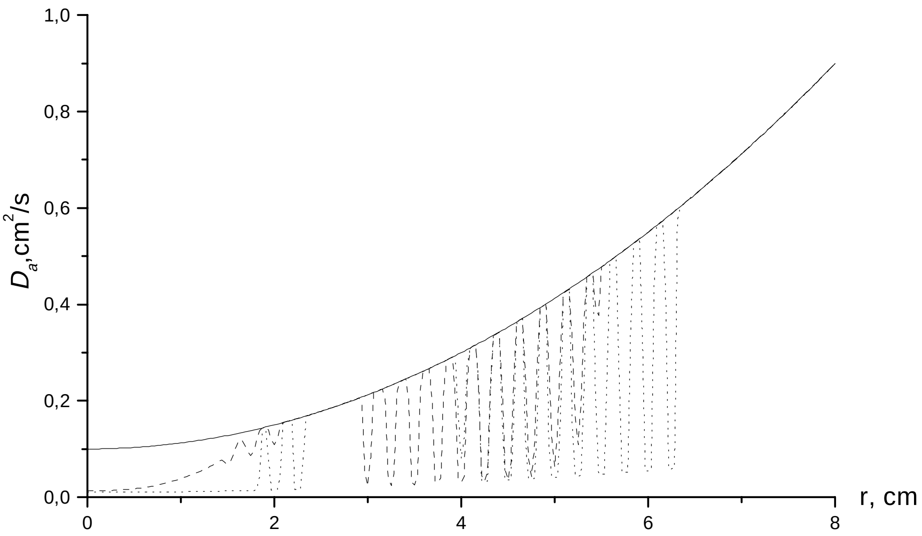

Fig.3 Anomalous diffusion coefficient (solid-29.5 ms, dashed-31 ms, dotted-33ms)

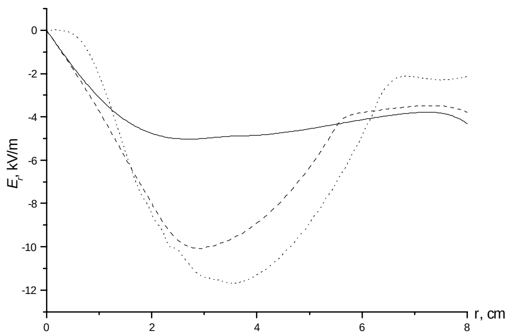

Fig.4 Radial electric field (solid-29.5 ms, dashed-31 ms, dotted-33ms)

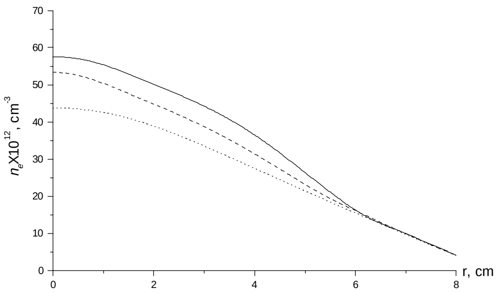

Fig.5 Density evolution (solid-29.5 ms, dashed-31 ms, dotted-33ms)

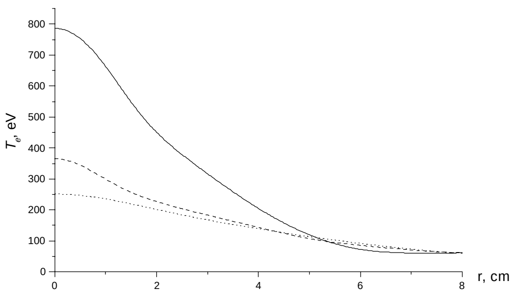

Fig.6 Electron tempetrature (solid-29.5 ms, dashed-31 ms, dotted -33ms)

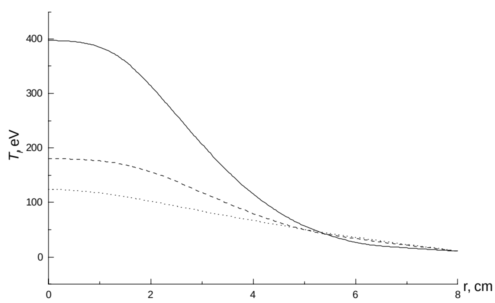

Fig.7 Ion tempetrature (solid-29.5 ms, dashed-31 ms, dotted-33ms)