Plasma diffusion modeling in T-10 periodic gas-puff experiment

A.V. Danilov, Yu.N. Dnestrovskij, V.A. Vershkov, M.A. Borisov, S.V. Cherkasov, A.Yu. Dnestrovskij and S.E. Lysenko

National Research Centre 'Kurchatov Institute', Institute of Tokamak Physics, 123182 Kurchatov Sq. 1, Moscow, Russian Federation

Peaked density profile providing enhanced neutron yield and reactor performance may be suggested in low-collisionality ITER plasma on the basis of recent research [1,2]. This underlines the importance of particle transport study in fusion plasma. The experiments with periodic gas-puff have proved to be a powerful tool for plasma diffusion investigation [3]. The new series of T-10 experiments were carried out in 2011-2012 in Ohmic discharges with $B_T = 2.4$ T, current $I_p = 200$ kA and densities $\bar{n}_e = 1.7$, 2.5 and 3.5×10^{19} m^{-3}, and for $\bar{n}_e = 2.5\times10^{19}$ m^{-3} with $I_p = 130$, 200 and 300 kA [4]. Periodic D_2 puff was made though piezoelectric valve in the stationary stage of the discharge with modulation periods of $T = 60$ and 90 ms. In the experiments, the chord distribution of the density perturbations amplitudes and phases were measured with multichannel interferometry. The amplitude and phase of modulation for each interferometer chord were obtained as the amplitude and phase of the Fourier harmonic of the modulation frequency, as described in [3]. The modulation of chord density signal was clearly seen over the whole plasma cross section (Figure 1).

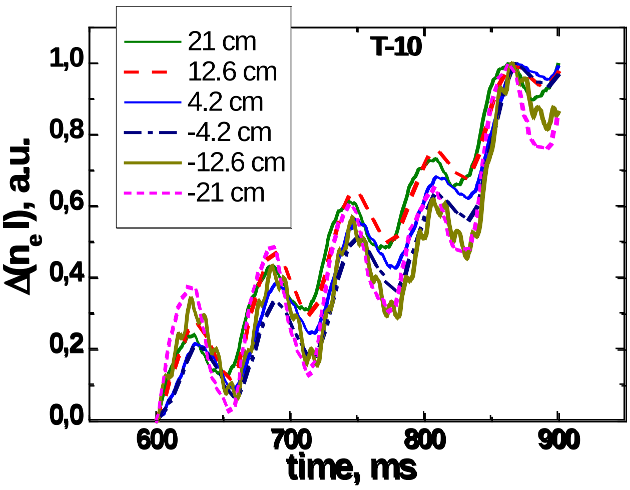

Figure 1. The modulation of plasma chord density in the gas puff experiment (interferometer signals).

The simulation of plasma density disturbances propagation was performed with the ASTRA code. The first attempt was made with constant in time diffusion coefficient and pinch velocity. The particle flux was presented in the usual form:

$$\Gamma = -\left(D\, {}^{\partial n}/_{\partial r} + rVn\right) \qquad (1)$$

with

$$D(r) = D_0(1 + C\rho^2), \quad V(r) = V_0(1 + C\rho^2), \qquad (2)$$

where $\rho = r/r_{lim}$, r is current radius value and r_{lim} is the limiter radius. In the stationary case the flux Γ vanished in the plasma core and the density profile was described by only one parameter $D/V = D_0/V_0$. The values of D_0 and V_0 could be taken separately from the solution of the stationary problem with known total wall neutrals influx. If this quantity is not available, the value of D_0 remains free in a wide enough range. The parameter D_0/V_0 was varied for the best stationary density profile fitting, and the optimal value was found to be $-D_0/V_0 = 0.06\ m^2$. After that the parameter C value was adopted in the range $0 < C < 10$ to meet observed density perturbations amplitudes and phases. The simulation results are presented in Figure 2. Calculated values were normalized by the experimental value at the radius r = 20 cm. One can mention that inside this radius the observed density perturbations can be reasonably described by the model (1), (2), while it fails at the plasma periphery. The best fit was obtained with C=5.

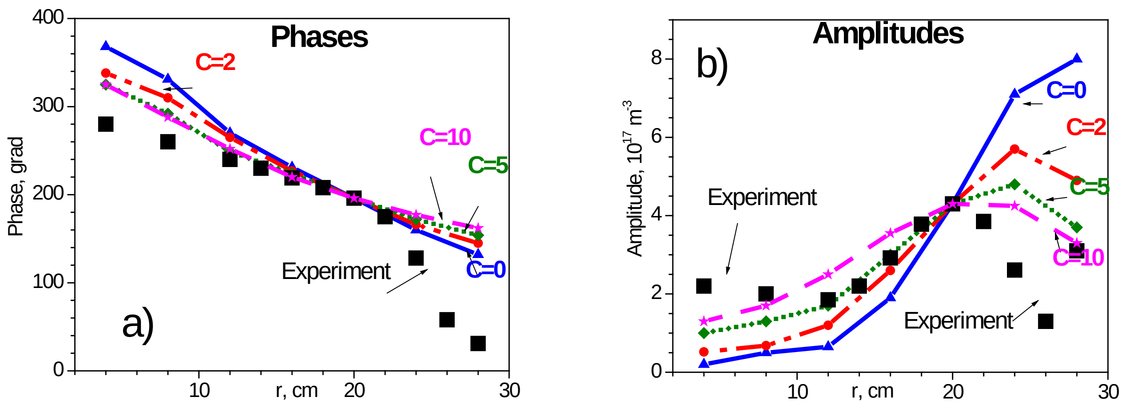

Figure 2. ASTRA simulation of gas puff experiments with the model (2); T=60 ms. a) Phase shifts radial profiles. b) Amplitudes radial profiles. Black squares – experimental data; Lines with corresponding C values - modeling results. Calculated values are normalized by the experimental value at the radius r = 20 cm.

In order to describe the high phase shifts at the plasma edge a more complex model with periodic time variation of pinch velocity was employed:

$$D(r) = D_0(1 + C\rho^2), \quad V(r) = V_0(1 + C\rho^2)\{1 + B\sin[{}^{2\pi t}/_{T} + C_1(1-\rho)]\}. \qquad (3)$$

With D_0=0.4 m^2/s and C=5 fixed, two parameters B and C_1 remain free in the model. The calculation results for several sets of parameters values are presented in Figure 3.

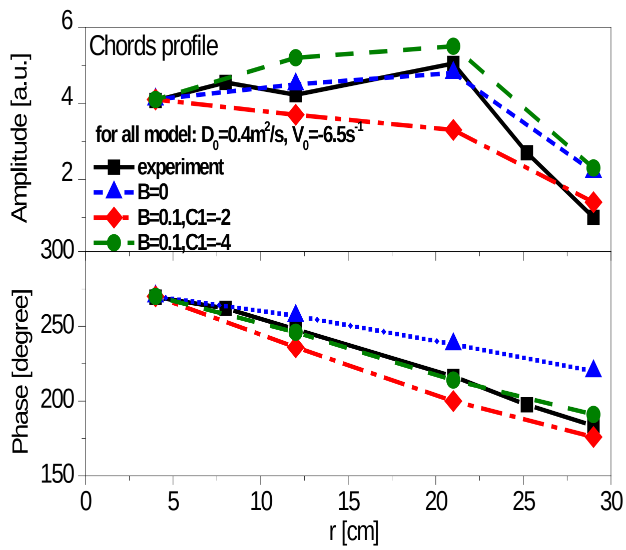

Figure 3. Results of gas puff experiments modeling with time-varied pinch velocity.

The necessity of the pinch velocity time variation may be in connection with the variation of the edge temperature due to periodic plasma cooling in gas puffing, evident from significant modulation of the loop voltage. The edge temperature modulation provides one more possibility of recent experimental results interpretation connected with the Canonical Profile Transport Model [5]. In the framework of this model the particle flux has the form

$$\Gamma = -d_0 n\left({p_e'}/{p_e} - {p_c'}/{p_c} \right) - d_1 n', \tag{4}$$

where n is the plasma density, $p_e = nT_e$ is the electron pressure, p_c is the canonical pressure profile. The canonical profile and the coefficients d_0 and d_1 are also known from [5], and as $d_0 >> d_1$, the second term in (4) is unessential in our problem. The first term in (4) can be represented in the form

$$\Gamma_0 = -\left[d_0 n' + d_0 n\left({T_e'}/{T_e} - {p_c'}/{p_c} \right) \right]. \tag{5}$$

Here the first term describes the diffusion and the second one – the convection. The convection term depends on the electron temperature profile, defined by the energy balance equation. The term proportional to the electron temperature gradient is usually considered as “thermodiffusion”.

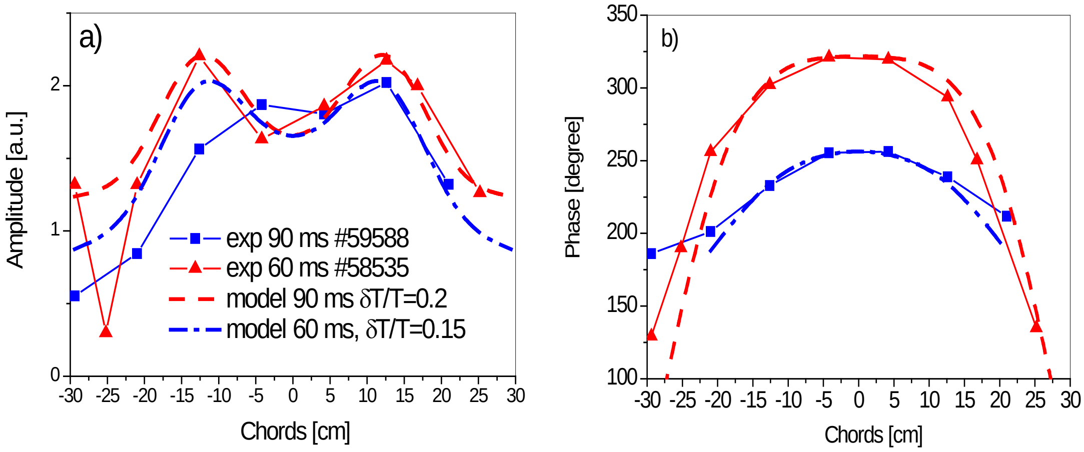

Figure 4. Relative chord densities modulation amplitudes (a) and phase shifts (b) profiles for two modulation periods T=60 and 90 ms. Points are measurements, dashed and dash-dotted curves present CPTM modeling results with different edge temperature modulations δT/T.

The gas puff was simulated with ASTRA code by 1% modulation of wall cold neutrals influx, and anti-phased modulation of edge electron temperature (the background edge electron temperature is T(a) = 30 eV), and modulation of density edge values of the same phase as of neutrals influx. The runs reveal strong dependencies of simulated modulation amplitudes and phases on the ratio of temperature and density edge disturbances. Namely, amplitudes and phases agree with experiment, when the relative value of the edge temperature modulation is about twice the density one. The amplitudes of the loop voltage modulation obtained in modeling with the edge temperature modulation values under consideration met those measured. The results of modeling are presented in Figure 4.

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