Improvement of plasma confinement due to ion and electron heating at the edge of tokamak.

Shurygin R.V., Mavrin A.A.
RRC “Kurchatov Institute”, Moscow, Russian Federation

The behavior of turbulent fluxes in the vicinity of the resonant point $m/n = q(x_{res})$ in the plane plasma layer (x,y) near tokamak wall is studied numerically. Four-field $\{\phi, n, p_e, p_i\}$ approximation for two-fluid nonlinear MHD equations is used. Numerical simulation was based on the system of equations for vorticity, density, ion and electron pressures:

$$\frac{\partial W}{\partial t} + \mathbf{V_E}\cdot\nabla W = \frac{B\omega_{ci}}{c}\nabla_{\|}J_{\|} - \omega_{ci}\frac{2\nabla B}{B}\cdot\mathbf{b}\times\nabla(p_e + p_i) + \mu_{\perp}\Delta_{\perp}W, \tag{1}$$

$$\frac{\partial n}{\partial t} + \mathbf{V_E}\cdot\nabla n = \frac{\nabla_{\|}J_{\|}}{e} + \mathbf{Q}\cdot(\nabla p_e - en\nabla\phi) + D_{\perp}\Delta_{\perp}n, \tag{2}$$

$$\frac{3}{2}\left(\frac{\partial p_e}{\partial t} + \mathbf{V_E}\cdot\nabla p_e\right) = \frac{5p_e\nabla_{\|}J_{\|}}{2en} - \frac{5}{2}\mathbf{Q}\cdot[p_e(e\nabla\phi) - \nabla(p_eT_e)] - W_{ei} - \nabla\mathbf{q_e} + S_e(x), \tag{3}$$

$$\frac{3}{2}\left(\frac{\partial p_i}{\partial t} + \mathbf{V_E}\cdot\nabla p_i\right) = \frac{5p_i\nabla_{\|}J_{\|}}{2en} - \frac{5}{2}\mathbf{Q}\cdot\left[p_i\left(e\nabla\phi - \frac{\nabla(p_e + p_i)}{n}\right) + \nabla(p_iT_i)\right] + W_{ei} - \nabla\mathbf{q_i} + S_i(x), \tag{4}$$

$$\eta J_{\|} = -\nabla_{\|}\phi + \frac{\nabla_{\|}p_e}{en}, \tag{5}$$

$$W = \nabla_{\perp}(en\nabla_{\perp}\phi + \nabla_{\perp}p_i), \quad \mathbf{Q} = \frac{2c}{e}\frac{\mathbf{b}\times\nabla B}{B}, \tag{6}$$

$$\mathbf{q_j} = -\chi_{\perp j}\nabla_{\perp}p_j - \chi_{\| j}\nabla_{\|}p_j, \quad \mathrm{j = e,i}, \quad \mathrm{W_{ei}} = 3\frac{m_e}{m_i}\nu_{ei}(p_e - p_i),$$

$$\mathbf{V_E} = \frac{c[\mathbf{B}\times\nabla\phi]}{B^2}, \quad \Delta_{\perp} = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}, \quad \nabla_{\|} = \frac{\mathbf{B}}{B}\cdot\nabla.$$

Here, $\mathbf{B} = B_0(1 - \frac{x}{R_0})\mathbf{e_z}$, where B_0 =const is the toroidal tokamak magnetic field, R_0 is the major radius of the torus, $x=r/a$, r is the radial coordinate and a is the minor radius. The rest of the notations in Eqs. (1)–(6) is as follows: $n(x,y,t)$ is the density; $p_{e,i}(x,y,t)$ are the ion and electron pressures; $\phi(x,y,t)$ is the electrostatic potential, which describes oscillations of the electric field.

Note that to calculate the electrostatic potential we use the equation for generalized vorticity, which includes both the electric drift and the ion diamagnetic drift.

$S_{e,i}$ are auxiliary heating power injected in the electron or in the ion component. The values $S_{e,i}(x)$ have been imposed as

$$S_{e,i} = q_{0e,i} \exp\{-[(x-0.2)/0.2]^4\}$$

Computations were carried out over the region 0<x<1 for parameters close of the DIII-D tokamak: R_0=170cm, a=67cm, B_0=2T, q=4. The width of plane layer is d=3cm.

The simulation was aimed to reveal the dependence of the turbulent particle flux on power heating injected in to ions and electrons inside the edge plasma layer.

In Fig.1 the dependence of the turbulent particle flux on the ion heating parameter q_{0i} is demonstrated. Our simulation shows that the increase of q_{0i} reduces the turbulent flux of particles flux and of the heat for both ions and electrons. The resulting effect looks like L-H transition.

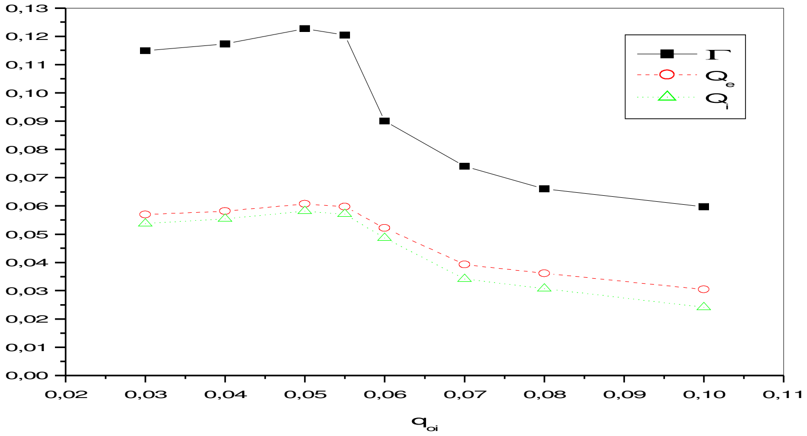

FIG.1. The dependence of the turbulent flux of particles on the ion heating parameter q_{0i}.

Such a behavior of the fluxes is found to result from the known stabilizing effect of the shear ExB drift velocity,

$$V_E(x) = \frac{cE(x)}{B} = -U_{oy}(x) + \frac{1}{en}\frac{\partial p_i}{\partial x},$$

which rises under the ion heating through an increase of the ion diamagnetic velocity.

The equation for the ion pressure, p_{0i}, can easily be obtained by averaging Eq. (4) over y and by supplementing the right-hand sides of the resulting equations with the necessary dissipative and source terms:

$$\frac{\partial p_{0i}}{\partial t} = -\frac{\partial Q_i}{\partial x} + S_i(x) + \chi_{oi}\frac{\partial^2 p_{0i}}{\partial x^2},$$

where $Q_i = <p_i V_x>$ - turbulent ion heat flux.

It is obviously that at $x=0$ area an increase or a decrease of p_{0i} depends on the sign of the derivative of ion flux Q_i. In some cases, $\partial Q_i(0)/\partial x$ can change its sign with the increase of q_{0i}. Our simulation shows such change of the sign when got changes from $q_{0i}=0.06$ to $q_{0i}=0.07$ (see Fig.2).

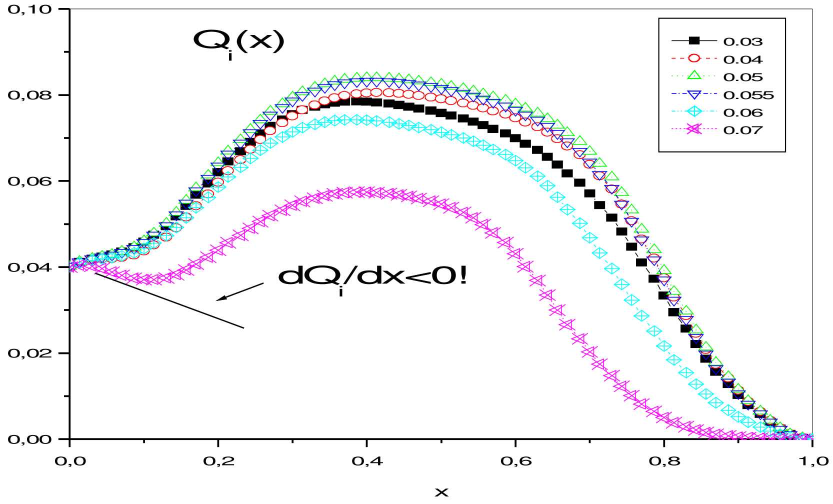

FIG.2. The radial dependence of the turbulent flux of the ion heat on the ion heating parameter q_{0i}.

The value of derivative $\partial Q_i(0)/\partial x$ becomes negative. It implies on occurrence of the additional heating and of increase of p_{0i} due to turbulent ion heat flux. In this case, the positive feedback is produced:

$$S_i + \Delta S_i \to p_{0i} + \Delta p_{0i} \to V_{ExB} + \Delta V_{ExB} \to \phi - \Delta \phi \to [\frac{\partial Q_i(0)}{\partial x} > 0 \to \frac{\partial Q_i(0)}{\partial x} < 0] \to p_{0i} + \Delta p_{0i} \to V_{ExB} + \Delta V_{ExB} \to \phi - \Delta \phi \to \cdots$$

One could say that fluxes sharply decrease with an increase of heating, and the event a L-H transition appears. The simulations show that the mentioned positive feedback takes place only for plasma parameters in very narrow range.

The similar effect of the transition to the improved confinement was found in the numerical calculations for the case with electron power injected into plasma edge (see Fig.3). It can be explained by two different mechanisms, which can result in suppression of the fluctuations. The first one is an increase of the longitudinal current $V_{\parallel e} \sim J_{\parallel} \sim \sigma \sim T_e^{3/2}$ due to the increase of the electron temperature. As a consequence, the dissipation power increases, and turbulent particle flux reduces. From the other hand, the electron heating results in the increase of the ion temperature due to Column collisions. In its turn, the growing ion pressure generates the enhanced *ExB* drift velocity, which provides an extra reduction of the turbulent flux. The analysis show, that the first effect is more important. The power injection with $q_{0e,i}$ ~0.1 in the certain plasma component (both electrons and ions) results in the rising of the temperature of the component up to 160-170eV.

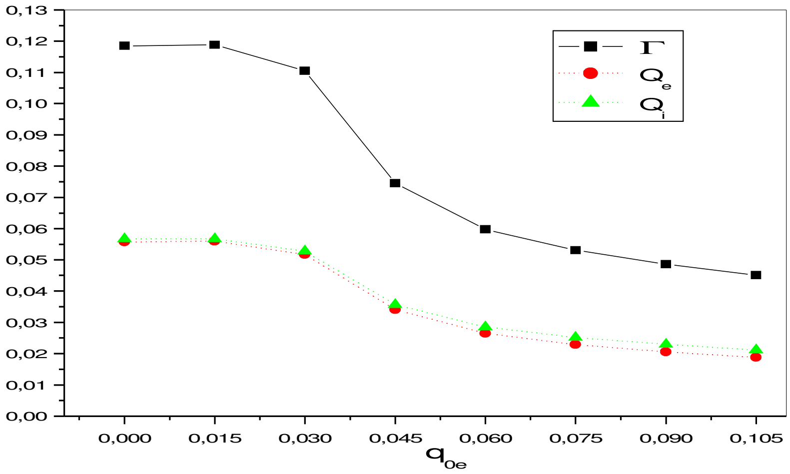

FIG.3. The dependence of the turbulent flux of particles on the electron heating parameter q_{0e}.

The simulation was aimed to reveal the dependence of the turbulent particle flux on power heating injected in to ions and electrons inside the edge plasma layer. Our simulation shows that the additional power heating injected in to ions result in improvement of confinement due to the known stabilizing effect of the shear *E*x*B* drift velocity. The resulting effect looks like L-H transition. Also our simulation shows that the additional power heating injected in to electrons result in improvement of confinement, but due to an increase of the longitudinal current $V_{||e}$~$J_{||}$~σ~$T_e^{3/2}$ due to the increase of the electron temperature. As a consequence, the dissipation power increases, and turbulent particle flux reduces.

References

1. *Zeiler A., Drake J.F., Rogers B.* // Phys.Plasmas.1997.V.4.P.2134.
2. *Simakov A.N., Catto P. J.* // Phys.Plasmas.2003.V.10.P.4744.
3. *Voitsekhovitch I., Garbet X., Benkadda S., Beyer P., Figarella C.* // Phys.Plasmas. 2002. V.9. P.4671.