# CONVECTIVE AND DIFFUSIVE TRANSPORT IN TOKAMAKS WITH HIGH PLASMA PRESSURE.

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The estimation of particle transport coefficient both around magnetic axes (convective zone) and in diffusive one (far from magnetic axes) for any finite plasma pressure up to its maximal value from equilibrium point of view was found.

As rule all calculations were fulfilled for spherical tokamak with aspect ratio A=1.5 and $B_j / B_0 = 1$ where $B_j$ is plasma current magnetic field value and $B_0$ is the value of toroidal magnetic field in housing centre without plasma.

The analysis of the papers [1-3] shows that for equilibrium calculations even for maximal plasma pressure in tokamak with circular superconductive housing with acceptable precision it is possible to use model description of magnetic surfaces

$$\frac{\Psi}{aRB_j} = \psi(\varepsilon,\theta) = \frac{r^2}{a^2} + \varepsilon\eta\cos\theta(\frac{r^2}{a^2} - 1) = \frac{r^2}{a^2} + \varepsilon\left(\beta_j + \frac{1}{4}\right)\cos\theta(\frac{r^2}{a^2} - 1) = \mathrm{const} \qquad (1)$$

where $\Psi$ is poloidal magnetic flux, r is distance from the housing center, $\theta$ is poloidal angle, $\varepsilon = \frac{r}{R} = \frac{r}{a}\frac{1}{A} = \frac{x}{A}$ is inverse aspect ratio, a and R are tokamak minor and major radii, $\beta_j = 8\pi < p > / B_j^2$, $< p >$ is the average pressure inside a.

The diffusion coefficient in tokamaks with different aspect ratio and different plasma pressure we will estimate on the surfaces with the same normalized plasma pressure $< P >= \frac{P}{P_{max}} = \mathrm{const}$. In this model maximal from equilibrium point of view plasma pressure is equal to $\beta_j^{cr} = A - \frac{1}{4}$. Taking into account (1) it is possible to calculate radial distribution of the magnetic field module.

$$b(x,y) = \frac{B(x,y)}{B_0} = b(r,\theta) \qquad (2)$$

where

$$b(x,y) = \frac{1}{h}\sqrt{1 - \left(\frac{B_j}{B_0}\right)^2 \varphi(\beta_j, x, y)} \qquad (3)$$

$h = 1 + x / A$ , and

$$\varphi = \left[2\left(\beta_j - 1\right) + \frac{\eta x}{A}\right]\left(1 + \frac{\eta x}{A}\right)\left(1 - \left(\frac{r}{a}\right)^2\right) - \left(\frac{r}{a}\right)^2\left(1 + \frac{\eta x}{a}\right)^2 - \frac{1}{4}\left(\frac{\eta x}{A}\right)^2\left(1 - \left(\frac{r}{a}\right)^2\right)^2 .$$

This distribution depends on three parameters namely $\beta_j$, $B_j/B_0$ and A. As example in Fig.1 one can see the radial distribution of the magnetic field module in the equatorial plane (y=0) for the three values of $\beta_j$ namely for $\beta_j = 0.05$ (curve 1), $\beta_j = 1$ (curve 2) and $\beta_j = 1.25$ (curve 3). Curve 2 corresponds to the boundary between paramagnetic and diamagnetic plasmas. Fig.2a presents the poloidal cross-sections of magnetic flux surfaces $\Psi(x,y) = \mathrm{const}$ (solid lines) and magnetic field module $\left|b(x,0)\right| = \left|\frac{B(x,0)}{B_0}\right| = \mathrm{const}$ (dash line) for $\beta_j = 0.05$ and in Fig.2b the same data are presented only for $\beta_j = 1.25$. From these figures one can see that when plasma pressure rise up to $\beta_j = 1.25$ the biggest part of surfaces $\left|b(x,0)\right| = \mathrm{const}$ in the region occupied by plasma becomes closed (Fig.2b). It is evident that in plasma with the biggest pressure transport will be suppressed in comparison with plasma with small pressure when lines $\left|b(x,0)\right| = \mathrm{const}$ crossed the housing (Fig.2a). Here 1 is magnetic axes and 2 is minimum of magnetic field module.

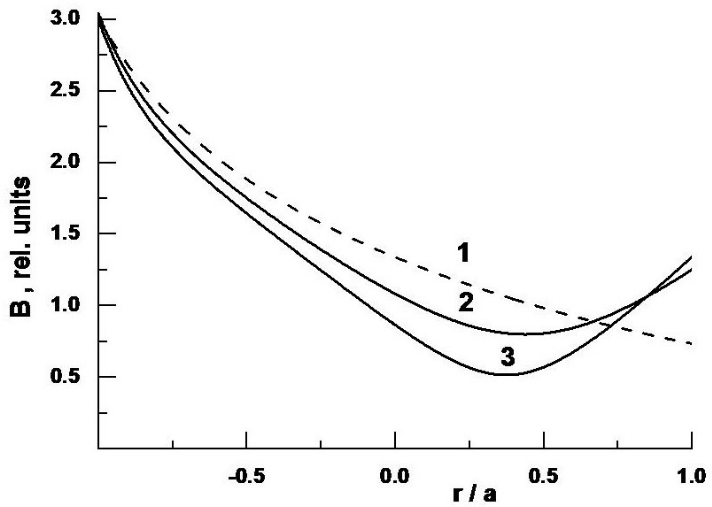

Fig.1

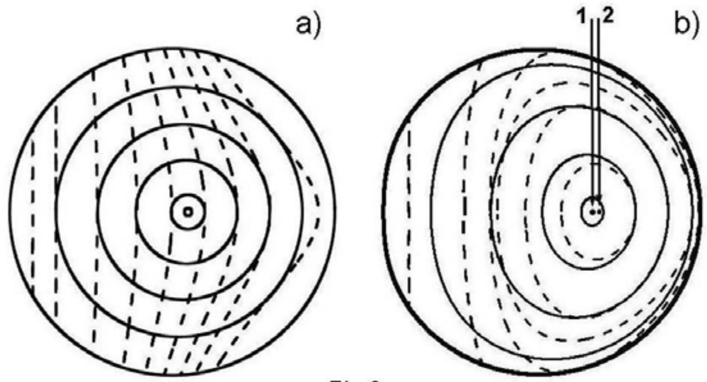

Fig.2

For quantitative calculations of transport coefficient let us use random-walk estimation

$$D = \sum_{\sigma_s}\left(\nu_{eff}^{tr} f_{tr}^{\pm}\left(\Delta x_{tr}^{\pm}\right)^2 + \nu_{eff}^{u} f_{u}^{\pm}\left(\Delta x_{u}^{\pm}\right)^2\right) \quad (4)$$

here *tr* marks the trapped and *u* marks the untrapped particles, $<\Delta x>$ is average excursion of a particle from magnetic surface, $\nu_{eff} = \nu / f^2$ is effective collision frequency [5]. In (4) $\nu_{eff}$ is the frequency at which the steps of random walk are taken and $<\Delta x>$ is the step size. The values $<\Delta x>$ we will find from the drift particle orbit equation and amount of trapped particles will be fond from equation $f_t = \sqrt{1 - B_{min} / B_{max}}$ [5] where $B_{min}$ and $B_{max}$ are the magnetic field minimum and maximum on the particle orbit.

For comparison of the coefficient of transverse particle transport it is convenient to introduce "topological" diffusive coefficient $\chi$ on the surface :

$$< D >= \frac{D_\beta}{D_1} = \left(\frac{n_\beta}{n_1}\right)^{1+\alpha} \left(\frac{\beta_1}{\beta}\right)^{\alpha} \chi\left(P, \beta/\beta_1\right) \tag{5}$$

Where index 1 is connected to plasma with $\beta_j = 0.05$, and index $\beta$ is connected to plasma with pressure $\beta_j$. Exponent $\alpha$ is equal to 5/6 for convective zone (around magnetic axes) and is equal to 1/2 in diffusive zone. In Fig.3 one can see the dependence of $\chi$ on $\beta_j$ for different values of <P> (0.9- curve 1, 0.71 - curve 2, 0.414 - curve 3 and 0.115 - curve 4). From this Figure is understood that when the plasma pressure rise the "topological" diffusive coefficient $\chi$ decrease on all distances from the magnetic axes but the most intensive this effect can be seen in the middle between axes and periphery of plasma column (<P> ~ 0.4-0.7 – curves 2-3).

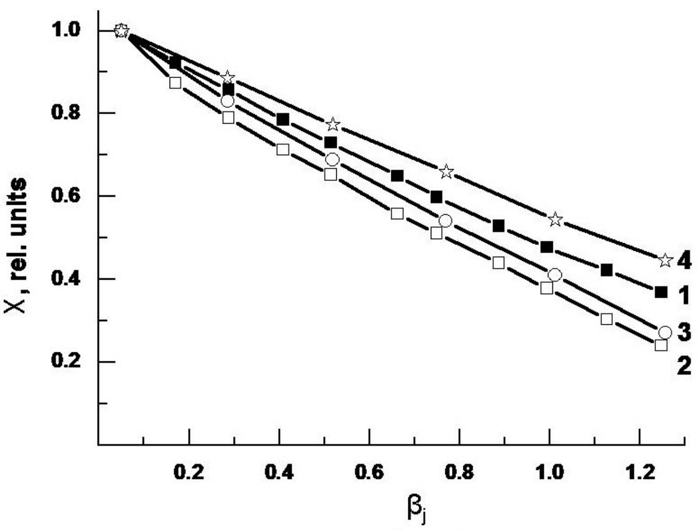


Fig.3

In the convective zone the behavior of $\chi$ is more exotic. So starting from the magnetic axes this coefficient falls up to the boundary of this zone, at the boundary its jumps up to its maximal value and after that slowly decreases up to plasma boundary. The sizes of convective zones are $\Delta r / a \approx 0.04$ at $\beta_j = 0.05$ and $\Delta r / a \approx 0.1$ at $\beta_j = 1.25$.

The practical interest has the effect of plasma pressure on transport coefficient under different aspect ratio A. Tree tokamaks with aspect ratio equal to A=1.5 ($B_j / B_0 = 1$,

$\beta_j = 1.25$), A=2.25 ($B_j / B_0 = 2/3, \beta_j = 2$) and A=3 ($B_j / B_0 = 1/2, \beta_j = 2.75$) were examined. Result of calculations of coefficient $\chi$ dependence on plasma pressure $\beta_j$ on the surface <P>=0.71 are given in Fig.4. In Fig.3 it was shown (curve 2) that on this surface transport suppression is maximal. From Fig.4 it is possible to conclude that when the plasma pressure is maximal in spherical tokamak (A=1.5) $\chi$ decreases in 5 times, in tokamak with A=2.25 its decreases in 2.3 times and in tokamak with A=3 $\chi$ decreases in 1.5 times only. Dash curves in Figure are described by expression

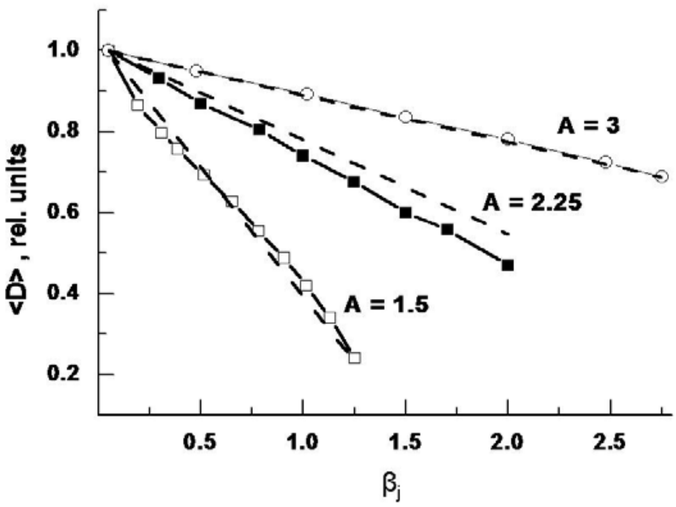

*Fig.4*

$$\chi(\rho_j = 0.02) = 1 - \frac{1.3}{A^{1.3}} \frac{\beta_j}{A - 0.25} \qquad (6)$$

CONCLUSION

In this study it was shown (eq.(5)) that transport coefficient <D> is much smaller than "topological" coefficient $\chi$ for high pressure plasmas. Really if plasma pressure varies from $\beta_j$ = 0.05 up to $\beta_j$ = 1.25 only with help of temperature changing <D> drops additionally in 5 times.

The numerical and experimental investigations of transport in tokamaks near the maximal plasma pressures give possibility to optimize the steady state tokamak-reactor operation.


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