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Radial Electric Field in Toroidal Systems and a Thermoelectric Field of Plasma

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1. Introduction. According to researches [1], on the basis of the received experimental distributions of only key parameters of plasma – $T_e(\rho)$, $T_i(\rho)$ and $Z_{eff}(\rho)$ it is possible to receive spatial distribution of potential of thermoelectric field (TEF), namely, $\varphi_r(\rho) = \alpha(Z_{eff}(\rho), T_e(\rho), T_i(\rho))\cdot T_e(\rho)$, where α – functional of the above-stated profiles and $E_r(\rho) = -\nabla\varphi_r(\rho)$. This electric field (EF) is caused by the taking into account of effect of some dynamic descreening of the conventional static (Debye) shielding of the charged particles in non-uniform plasma at the account of their movement and distinction in masses. The nature of this EF is formed on micro-scales, and it is shown in macro-scales. The basis such TEF is attractive because it is calculated from the first principles [1a, 1c]. From practical point of view the calculation of such EF allows: a) to estimate: (i) of a thin structure of an electric potential / field of plasma and distribution of speeds (toroidal / poloidal) rotation of plasma in toroidal plasma systems; (ii) of a thin structure of a shear speeds of rotation plasma near to an internal / external barrier and characteristics of collision plasmas; b) to compare the calculated distributions of these speeds with experimentally measured in order to define their conformity to the equation of balance of forces and to determine parameters of "tail" of particles distribution of plasma which can be shown as by-product of additional heating.

2. Thermoelectric coefficient a. It agrees [1a, 1c] thermoelectric coefficient of this TEF $\alpha = (2/e\pi^{1/2})[G_i(Z_{eff}(\rho)T_e(\rho)/T_i(\rho)) - G_e]$. For equilibrium plasma $G_e = 0.345$ and $\varphi_r(\rho) = 0$ at U = 1.93. Therefore, if distributions $T_e(\rho)$ and $T_i(\rho)$ are known, that in a point, where $\varphi_r(\rho) = 0$ the value of Z_{eff} is determined. If it is known also distribution $Z_{eff}(\rho)$ that distributions of potential and EF are unequivocally determined.

3. Components of velocity of rotation in a stable state

In tokamak at a stationary stage of development of the discharge the process of ionization occurs on border of a plasma shell. At presence radial components of EF in a magnetic field (MF) in tokamak the particles of plasma are drifting in crossed E and H fields. If radial moving of elementary volumes of plasma would not be, then components of drift velocity of plasma on the given radius would unequivocally be defined by values of **E** and **H** in the given point. However, as a result of dynamic processes in plasma the ions of peripheral plasma can change their radial coordinate in during time. At such moving a particles transfer their moments along radius. The component of this moment directed across MF very quickly fades because of the big viscosity of movement on this direction.

Therefore the poloidal velocity of rotation of plasma in zero approximation (if there is no brought external mechanical moment) at a steady state will be always determined by the poloidal component of researched drift velocity. Thus, the distribution of value of poloidal velocity of plasma rotation is a differential characteristic of EF. The toroidal component of velocity of plasma rotation is an integrated characteristic of EF because it is mean value at detour on small radius and a toroidal component of the moment of quantity of movement sum up due to of small values of viscosity along direction of MF. So, in this case it is possible to write down a calculated formulas of definition of toroidal velocity and a poloidal rotations: $V_t \sim cE_rB_p/B^2 \pm (2\,|\varphi|eZ_i/m_i)^{1/2}(B_p/B)$; $V_p \sim cE_rB_t/B^2$. As the first member of the first formula is small in comparison with the second it can be neglected and then it is possible to write down: $V_t \sim \pm (2\,|\varphi|eZ_i/m_i)^{1/2}(B_p/B)$. Here the change of a sign is determined by the moment of transition of function of potential through a zero. The initial sign of a toroidal projection is determined by the vector product [**EB**].

4. DIII-D . For acknowledgement of applicability of these formulas we shall take advantage of the published data with DIII-D on which experiment on reception of the "H-mode" regime by means of central ECH and ohm heating was carried out. [2]. Radial distributions of temperature and density are submitted on a fig. 1a and 1b, accordingly, for both cases. Letters "E" and "O" in indexes correspond to case ECH and ohmic heating, accordingly.

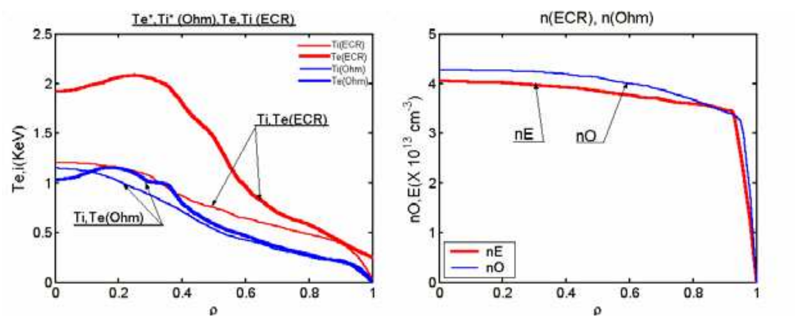

Fig. 1a, 1b. Radial distributions Te, Ti and n in regimes with "H-mode" regimes for cases of initiation of transitions at ECH and ohmic heating.

For definition of poloidal components of MF we shall take advantage of the Spitzer conductivity formula and parameters of the installation. The calculated values of thermoelectric potential and field are submitted on a fig. 2a and 2b, accordingly.

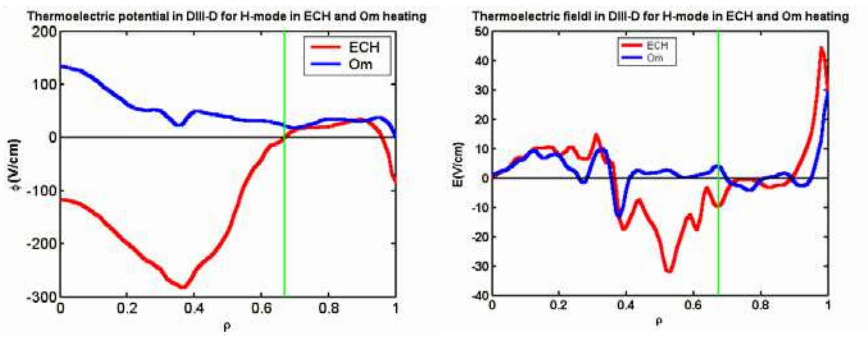

Fig. 2a, 2b. Radial distributions φ, and E_r in "H-modes" regimes for cases of initiation transitions by means of ECH and ohmic heating.

Corresponding distributions of angular velocity of toroidal rotation – Ω_t at "H – mode" regimes in DIII-D for various values Z_{eff} are resulted on fig. 3a and 3b.

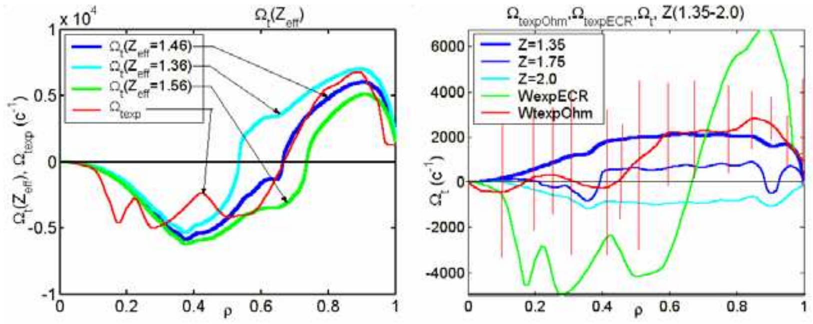

Fig. 3a, 3b. Radial distributions of rotation of plasma on DIII-D in "H-modes" regimes for cases initiation of transitions by means of **a**) ECH and **b**) ohmic heating.

The analysis of set of the received calculated data allows to draw some conclusions. (i). The radial distributions of EF can appear very sensitive in respect of value Z_{eff}. (see fig. 3). (ii) Both ways of initiation of transition of the discharge in the "H - mode" regime give almost conterminous radial profiles of plasma density, not looking on absolute distinction of Te profiles, the calculated profile of electric potential and EF. But it appears, the EF on periphery of a cord in both cases have value ~ 10 V/cm that prevents from penetration of ions of an impurity inside of a cord, and also promotes intensification of plasma rotation in this area and to emission of ions of an impurity from a cord. Atoms of hydrogen penetrate into plasma as atomic hydrogen with half energy of dissociation deuterium molecules, i.e. about 2.25 eV. It leads atoms of deuterium to ionization inside from a maximum of this peripheral EF of a cord. Thus, it creates distributed divertor on border of the tokamak cord.

5. Stellarator CHS. The similar analysis has been carried out and on the published data of stellarator CHS [3] where accuracy of performance of the equation of balance and a degree of coincidence of distributions EF received by different diagnostic methods and in different experimental conditions was checked. The radial distributions EF, received in the given experiment and from calculations for two moments of time (t_1=90 мс and t_2=110 мс) are submitted on fig. 4a and 4b, accordingly. The plasma in installation was supported due to a neutral beam and an ECH. By the moment t_2 the ECH is switched off and a new stationary regime is established.

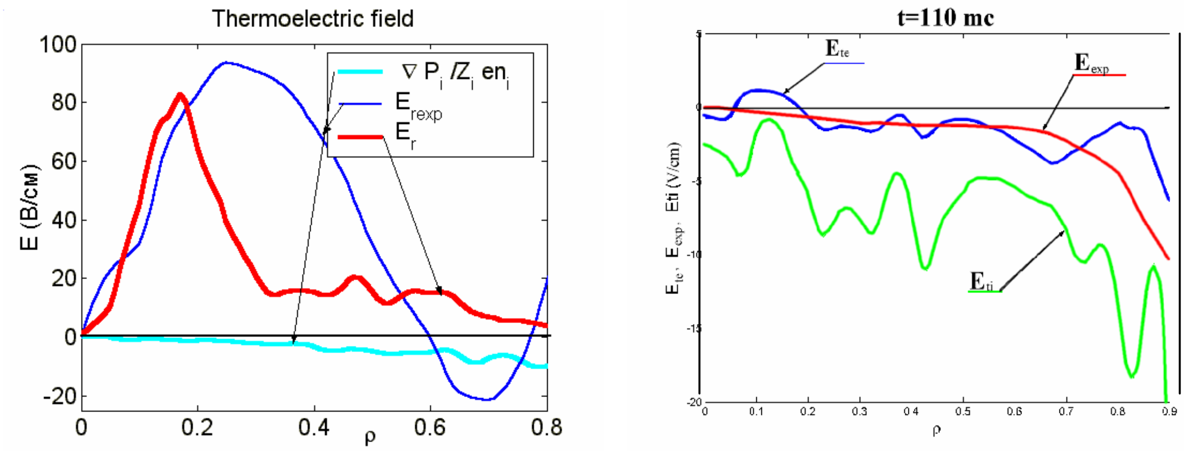

Fig. 4a, 4b. **a**) Radial distribution of EF which was been received in experiment, Eexp, its calculated value, Er, and also value of $\nabla P_i/Z_i e n_i$ at the moment of time t_1=90 mc. **b**) t_2=110 mc, ECH it is switched off and the new stable state was established. In this figure distributions of a calculated E_r, its an experimental distribution, E_{exp}, and EF which defines poloidal velocity of rotation on neoclassic ($Vp = kc\nabla T_i/eB_t$), $E_{ti} = k\ \nabla T_i/eB_t$ are shown.

At t_1 E_r and E_{exp} essentially differ, but it is caused by the brought additional moment (AM) of plasma rotation. AM is shown because of displacement ECH concerning the centre of plasma and due to of appearance of radial velocity of ions directed outside in operative range ECH (at $\rho \sim 0.35$). The difference curve can to give some estimation of an operative range of this AM. From here it is possible to define velocity of a leaving of ions outside. The second figure shows good conformity of experiment and calculation, and also an essential divergence between experimental value of EF and what is determined by the T_i, giving poloidal velocity of plasma rotation according to of the neo-classic, $V_p = kc\ T_i/eB_t$.

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