Influence of the Magnetic Shear and MHD Processes on Confinement Properties of T-10 Reversed Shear Plasmas.

N.A. Kirneva, A.A. Borschegovskiy, V.V. Chistyakov, Yu.V. Esipchuk, E.P.Gorbunov, D.A. Kislov, S.V. Krylov, I.I. Orlovskiy, Yu.D. Pavlov, G.N. Ploskirev, I.N. Roy, A.V. Sushkov, E.V. Trukhina, V.M. Trukhin and the T-10 team

RRC"Kurchatov Institute", Moscow, Russia

Investigation of the magnetic shear influence on electron energy confinement is carried out on T-10 tokamak in regimes with electron cyclotron heating/ current drive (ECRH/ECCD) with P_{ECRH} up to 1÷1.5 MW. Early application of the ECRH power during plasma current ramp-up is used in T-10 to increase current penetration time and to form configuration with reversed shear q(r) profile [2]. Typical discharge with ECRH preheating discharge is presented in Fig. 1,a in comparison with L-mode shot with similar plasma parameters and P_{ECRH}. L-mode shot has the monotonous q(r) profile, q=1 sawteeth are pronounced. Comparison of temperature profiles and effective values of electron heat conductivity (obtained from an interpretative transport analysis) in L-mode and in discharge with ECRH preheating demonstrates obvious signs of electron Internal Transport Barrier (eITB) formation in the latter case. As is shown in [2] eITB is formed during current ramp-up when q_{min}>3 (t~0.035 s after I_p start-up). Development of long scale MHD instabilities observed during further q(r) profile evolution leads to the transient ITB deterioration. Complete electron ITB destruction correlates with m/n=1/1 mode development in the core when q_{min} ~1 appears ($t \geq t_2$, see Fig. 1,a).

This paper represents analysis of drift turbulence stability and predictive modeling of T-10 shots with eITB to analyze mechanism of transport barrier formation and role of the q(r) profile and in particular magnetic shear in this process.

Drift turbulence analysis has been performed for L-mode and eITB shots using linear electrostatic Code KINEZERO [3]. Experimental electron temperature and density profiles have been used, ion temperature profiles have been obtained from the ASTRA Transport Code [4] with assumption of $\chi_i = 2.3\chi_i^{neo}$ which is usually valid for the T-10 L-mode in a whole range of plasma densities. Plasma current (and q(r)) profile has been modeled in assumption of neoclassical conductivity, peculiarity of q(r) dynamics were additionally controlled by MHD events observed in the case with ECRH preheating (see [2] for more details of q(r) determination). Figure 2,a represents a family of q(r) and T_e(r) profiles that has been used in the KINEZERO calculations. Comparison has been done between reversed shear case and L-mode discharge. Results of the calculations of drift turbulence increments are shown in Figure 2,b.

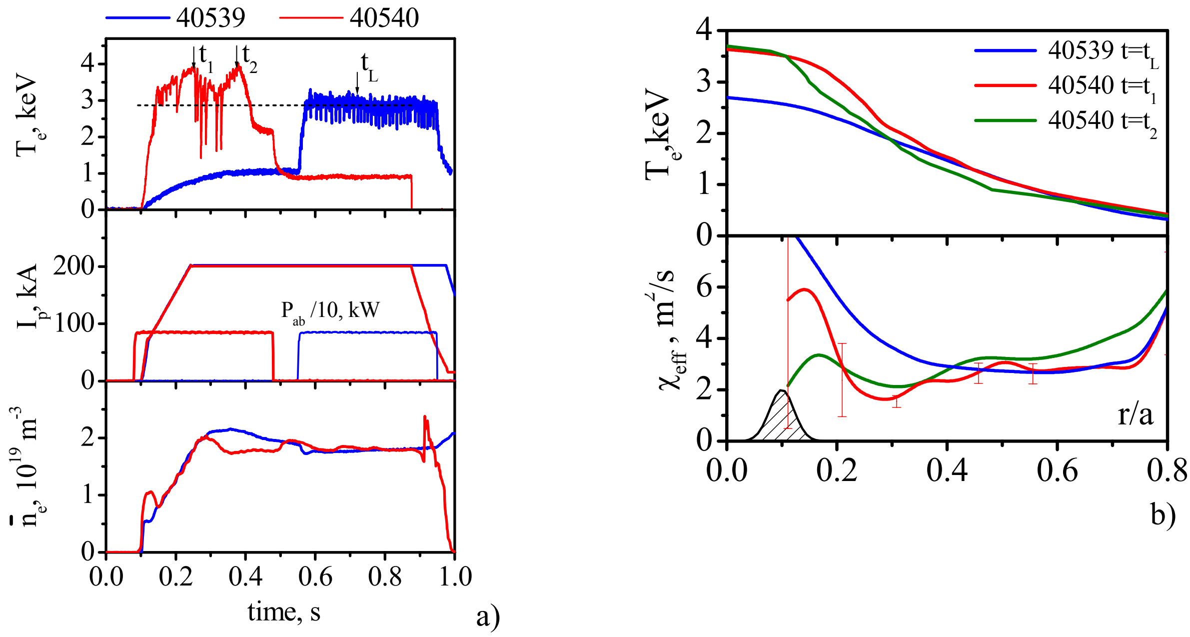

Fig. 1 *(a) Typical scenario of discharge with eITB formation (40540) in comparison with L-mode shot with similar parameters (40539); (b) temperature profiles and effective values of electron thermal conductivity taken at the time slices marked on fig. 1(a).*

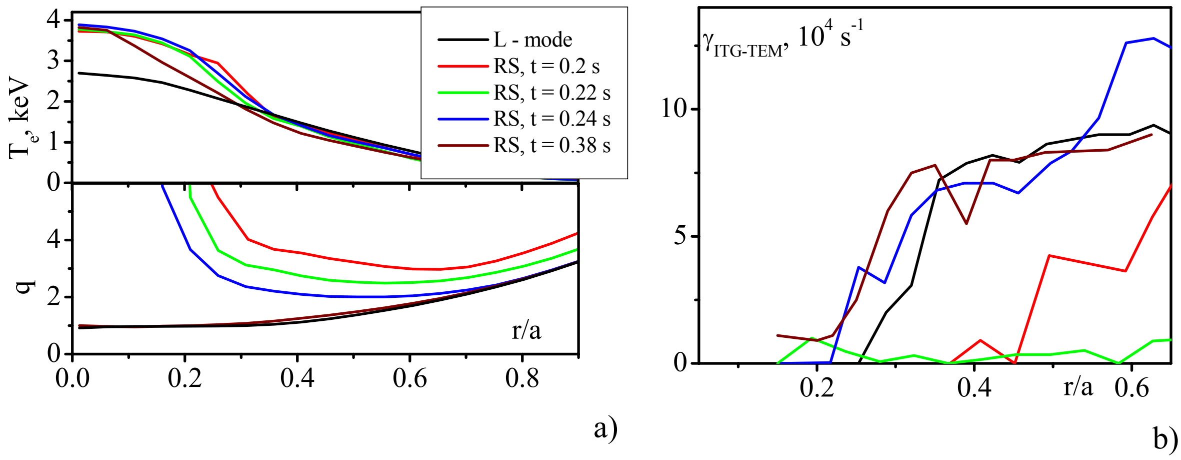

Fig. 2 *Temperature and q(r) profiles for time slices used in KINEZERO calculations (a); Increments of long wavelength turbulence obtained from KINEZERO calculations (b).*

In accordance with the KINEZERO results short wavelength turbulence (ETG mode) is predicted to be stable in a whole range of investigated parameters. Long wavelength turbulence is stable (or marginally stable) inside of r/a = 0. 35 (that is position of eITB foot) during the initial stage of discharge until q_{min}~2 (t = 0.24 s). Further evolution of plasma parameters leads to the development of long wavelength turbulence (mainly ITG mode). Analysis of this results and set of test calculations showed that the ITG mode suppression predicted by KINEZERO can be explained as a stabilizing effect of q(r) profile reversal, which includes negative magnetic shear and increase of α parameter ($\alpha=-q^2\cdot\beta R\cdot grad(P)/P$) due to the increase of the central q value rather than effect of pressure gradient. It should be mentioned that in agreement with the KINEZERO predictions the ITG mode becomes unstable at the time instant corresponding to $q_{min}\sim2$ achievement and its increment becomes close to the L-mode value. However eITB still exists at this time instant as it is seen from Figures 1(b) and 2(a). Test calculations have been made to analyze this surprising discrepancy between code prediction and experimental observation. q(r) profile has been varied so that the negative magnetic shear value inside of the $r=r(q_{min})$ has been increased (in absolute value) up to the value peculiar for the q profile at t=0.2 s ($t=t(q_{min}=3)$). ITG mode appeared to be stable for this test q(r) profile. At the same time variation of the α parameter without changes of the magnetic shear value did not lead to sufficient changes of the turbulence characteristics. It allows us to propose that the negative magnetic shear is the very important ingredient in eITB formation in T-10 conditions. Contradiction mentioned above can be explained by the accuracy of q(r) profile determination, however existence of additional mechanism responsible for eITB formation in T-10 conditions can not be completely excluded.

Transport analysis of the discharge with eITB was carried out using empirical mixed Bohm/gyro-Bohm transport model similar to that presented in [5]. The decrease of the anomalous electron heat transport inside of the $s\leq0$ region and increase of the heat transport losses due to the magnetic island growth have been added into the model to describe electron temperature behavior in discharges with reversed shear q(r) profile and continuous current profile evolution. Moreover, simple model of internal reconnections has been implemented into the transport model to take into account effect of MHD events observed after $t=t_1$ on the q(r) profile evolution (see Fig. 1(a)). Results of the modeling of electron temperature dynamics are presented on Fig. 3 together with the experimentally observed behavior of $T_e(0)$. Modelling of the discharge dynamics qualitatively agrees with the experimental observation. It is seen that the decrease of the transport inside of the $s\leq0$ region is the important factor to adjust calculated dynamics of electron temperature with experimental one. Transport analysis shows that Bohm-like term dominates in electron heat transport in regime discussed here. Relative role of the neo-Alcator term increases with the decrease of q_{min}. Contribution of gyro-Bohm transport is negligibly low (Fig. 4).

Basing on the results presented here it can be concluded that the q(r) profile reversal including negative shear and increase of α value (due to the central q increase) plays the key role in eITB formation in T-10 RS discharges rather than stabilizing mechanism due to the pressure gradient. However, as it was mentioned above possible existence of additional mechanism of ITB formation can not be completely excluded. This is the question for further investigation.

Acknowledgement. Authors would like to thank C. Bourdelle for the help in analysis of KINEZERO results and helpful discussions. We would like to thank also S.V. Neudatchin, S.V. Tsaun and A.N. Chudnovskiy for the useful discussions. This work was made under the financial support of Russian Ministry of Education and Science (grants MK-3246.2005.2, NSh-2264.2006.2; contracts 02.452.11.7069, 02.445.11.7471) and Federal Agency on Atomic Energy (contracts 6.05.19.19.06.856 and 1.05.19.19.06.533).

[1] Litaudon X., Plasma Phys. Control. Fusion 48 (2006) A1
[2] Kirneva N.A. et al Plasma Phys. Control. Fusion 47 (2005) 1787
[3] Bourdelle C. et al, Nucl. Fus. 42 (2002) 892
[4] Pereverzev G.V. et al, Kurchatov Institute Report IAE-5358/6
[5] Tala T.J.J. et al Plasma Phys. Control. Fusion 44 (2002) 1181

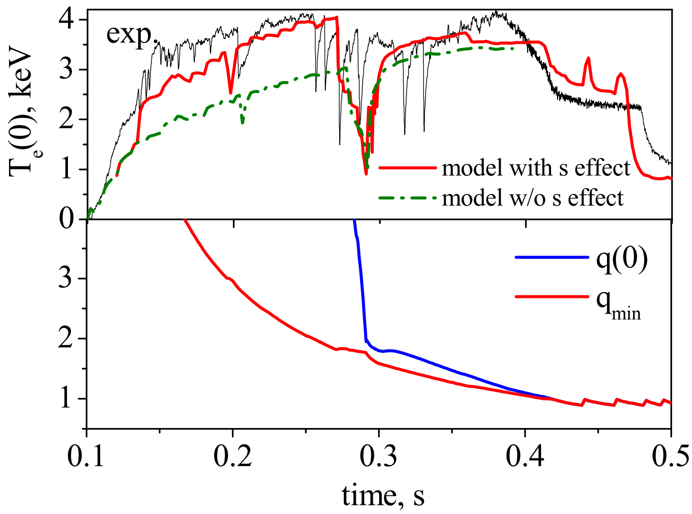

Fig. 3 *$T_e(0)$ temporal evolution e obtained from the modeling in comparison with the experimental result. Modeling results without taking into account of magnetic shear effect are also shown (upper plot); calculated dynamics of central and minimum values of safety factor q (bottom plot).*

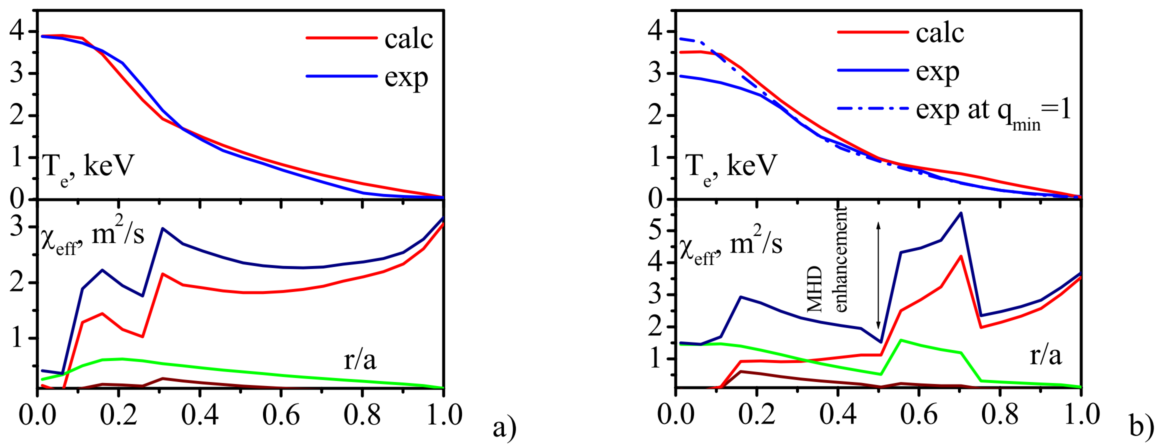

Fig. 4 *Results of the modeling of temperature profiles at $t=t(q_{min}=2)$ (a) and $t=t(q_{min}=1)$ (b) in comparison with the experimental results. Electron thermal conductivity (dark blue curve) is also shown together with the impact of Bohm (red), gyro-Bohm (dark red curve) and neoclassical (green) terms.*