

# THE NON-LOCAL TRANSPORT EFFECT STUDY IN FAST CURRENT RAMP UP EXPERIMENT AT THE FT-2 TOKAMAK

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Some facts of the plasma cooling or heating with non-thermal diffusion velocities are well known. Such phenomena have been observed in the pellet injection experiments, fast current ramp up, during sawtooth and ELM activity [1; 2, 3]. Various types of the model as model of canonical electron temperature profiles and the marginal-stability-based models have been discussed in [3] to explain the non-local effects. The most comprehensive and general self-organized-criticality (SOC-type) model explains the electron temperature fast changes through the propagation of fluctuation increasing inward from the edge their piling up and producing an  $\mathbf{E} \times \mathbf{B}$  flow-shear-induced thermal barrier at about the half radius. In that models the level of fluctuation at one place depends on sources of instabilities located elsewhere. However, there is not comprehensive experimental evidence of any equilibrium potential or fluctuation changes at the half radius and formation of a thermal barrier.

In the fast current ramp up (CRU) experiments in FT-2 tokamak ( $a = 8$  cm,  $R = 55$  cm,  $B_T = 2.2$  T,  $I_p = 22$  kA and CRU pulse duration about 3 ms with  $\Delta t_{CRU} = 0.5$  ms from 22 kA up to 30 kA) the same features of the high velocity propagation of the impact have been observed. In the Fig. 1 and 2 the temporal changes during CRU of the  $T_e(r)$  and  $n_e(r)$  measured

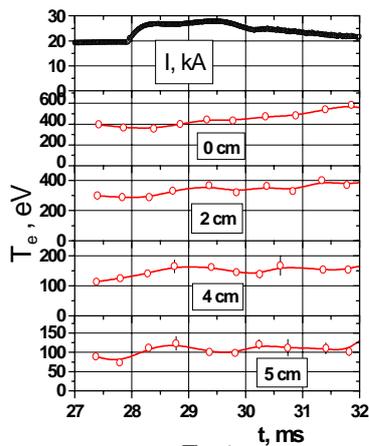


Fig. 1

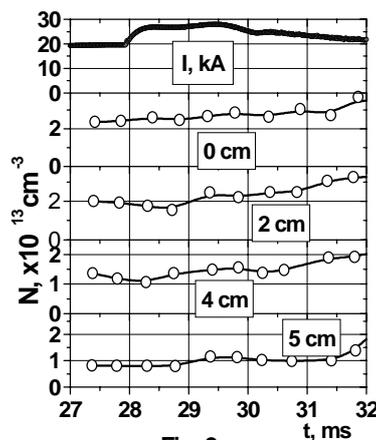


Fig. 2

by Thomson scattering diagnostics are shown for  $r = 0$  cm, 2 cm, 4 cm and 5 cm. The same fast electron core temperature increase for higher densities ( $n(0) = 3.5 \cdot 10^{13} \text{ cm}^{-3}$  and  $4.5 \cdot 10^{13} \text{ cm}^{-3}$ ) was observed by SXR measurements also. One can see in Fig. 1, that rise of the electron temperature are in phase and realize during first

ms at all radii. Evolution of the electron and ion temperature profiles measured by CX analyzer are presented in the Fig.3. One can see that the ion temperature increases more

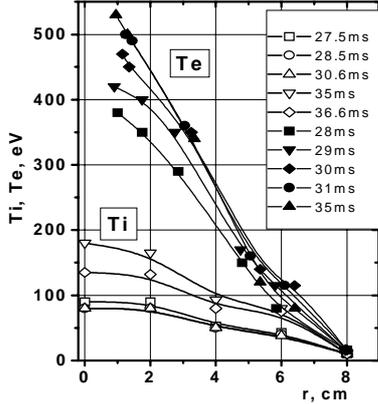


Fig. 3

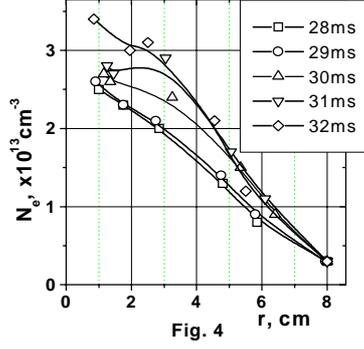


Fig. 4

slower similar to density change shown in Fig.4. As to diffusive *local* transport changes the heat impact can propagate in the elapsed time  $\Delta t$  after the perturbation with velocity  $\sim \sqrt{\chi \cdot \Delta t}$ . According to the experimental data the increase of  $T_e$  in the center could be only after  $\Delta t_\chi \cong 10$  ms. The

calculations by ASTRA code shown in Fig.5 demonstrate the sharp decrease of the central thermoconductivity  $\chi_e$  during the first millisecond followed by decrease of  $\chi_e$  at all plasma cross section.

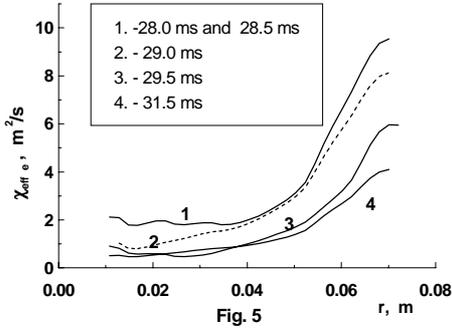


Fig. 5

On the other hand, the calculated skin time for the FT-2 experimental plasma parameters was  $t_{\text{skin}} \cong 3$ ms and it would be naturally to await for delay of the central electron temperature and density response only through  $\Delta t > 3$ ms from beginning of the CRU at least. So,  $t_{\text{response}} (\cong 1\text{ms}) < t_{\text{skin}} < t_\chi$ . The explanation of such non-local effect can be connected with suppression of the microturbulence. We have experimental evidence of such processes.

The behavior of small-scale plasma turbulence (0.01 - 1cm) was studied on the FT-2 tokamak by the method of collective scattering of CO<sub>2</sub> -laser radiation at small angles [4, 5]. The Figure 6 compares the time dependence of the relative value of the power spectra  $\langle P_s(F) \rangle / (\langle n_e \rangle)^2$ , averaged in the band of frequencies F from 100 to 800 kHz, for an stationary phase of ohmic discharge and for a discharge with a current increase of  $\Delta I_p$ . The power is normalized to the square mid-chord plasma density  $(\langle n_e \rangle)^2$  in order to eliminate from consideration the

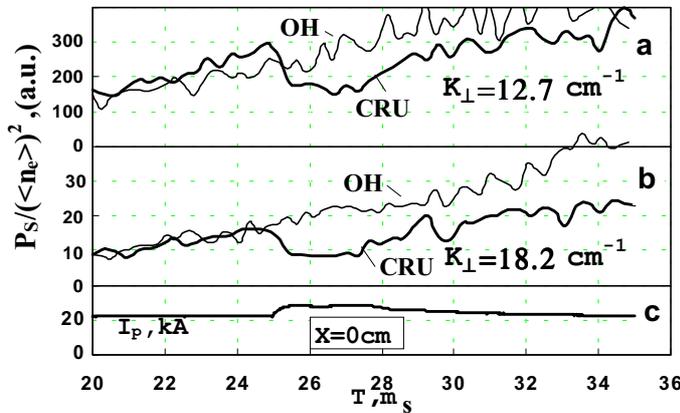


Fig. 6

increase of  $P_s$  because the increase of  $\langle n_e \rangle$  always observed during a current rise. The data for the two wave numbers  $K_\perp$  obtained by central probing ( $X = 0$  cm) are represented in the same arbitrary units. It can be seen that switching on additional current immediately reduces the fluctuation level. It is noteworthy that a low turbulence level was maintained for a long time after the flat part of the

additional current pulse ended. Shifting the scattering volume along the major radius of the tokamak, it was possible to estimate indirectly the spatial region in which the microturbulence was suppressed. In this case measurements showed that suppression of the fluctuation covered the central region of the discharge ( $r < 5\text{cm}$ ).

The indirect data on the position of the zone in which microturbulence was suppressed were obtained from spectral measurements of scattered radiation. As shown in [4], just after CRU the fluctuations are suppressed in broad frequency band, which is evidently shifted towards upper region with  $k_{\perp}$  increasing. The frequency band of suppression becomes to be narrowed in 3 ms after the CRU start. The suppression after current pulse switching off as a hysteresis effect is correlated with the improvement of the particle and ion temperature confinement [5]. One can assume, that each F - component processed as a Doppler frequency shift is related to the scattering from plasma radial layer where plasma poloidal velocity  $V_{\theta} = 2\pi F / k_{\perp}$ . In this assumption the suppression appears in the vast radial interval with poloidal velocity being from  $5 \cdot 10^4 \text{ cm/sec}$  to  $2 \cdot 10^5 \text{ cm/sec}$ . In the course of time this velocity interval is narrowed to value near of  $10^5 \text{ cm/sec}$ .

The assumption that the decrease of the turbulence level is associated with rapid reconstruction of the rotational shear seems more likely due to the fact that the fluctuations are immediately suppressed over a wide frequency region,. Such reconstruction can be expected because the rate of the Ware pinching varies when a strongly inhomogeneous longitudinal electric field appears in the plasma. A suggested candidate for such a mechanism is the radial current generation caused by the motion of the banana particles in a non-uniform toroidal electric field [6]. For our calculation we used the model proposed in [7] where the fact was taken into account, that the Ware drifts of ions and electrons are not automatically equal to each other. It is well-known that in the banana regime the toroidal electric field results in the ambipolar Ware drift of the charged particles, but when the collisionality parameters of

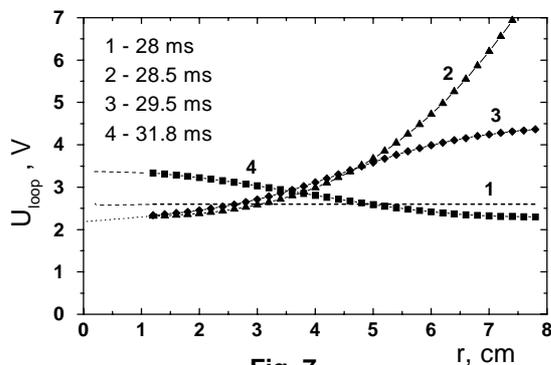


Fig. 7

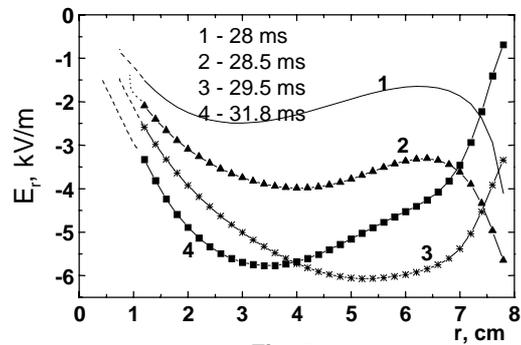


Fig. 8

electrons and ions differ significantly (as typical for ohmic heating (OH) regime of FT-2 tokamak,  $v_e^* \sim 1$  and  $v_i^* \sim 10$ ), the ion Ware drift is suppressed and radial current is generated. Such current is to be balanced by the radial

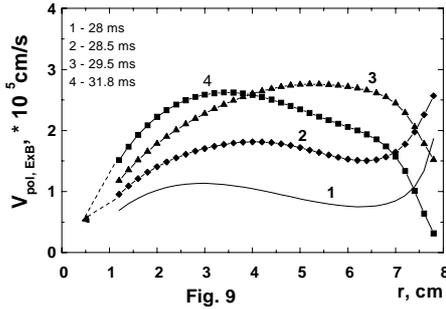


Fig. 9

current associated with the neoclassical parallel viscosity of ions. This effect leads to some radial electric field additional to the neoclassical electric field  $E_r^{neo}$  and increase of the poloidal rotation shear especially in moment CRU, when  $E_{||} = U_{loop}/2\pi R$  is relatively larger. For our calculation we used  $U_{loop}$  obtained by ASTRA code and shown in Fig. 7 for different moments of CRU experiment. Following to the eq.(5) from [7] we can rewrite  $E_r$  as:

$$E_r = \frac{23 \cdot c \cdot e \cdot \sqrt{\epsilon} \cdot n \cdot E_{||}}{B_p \cdot \sigma_{\perp}} \left[ \frac{I}{I + \nu_i^{*1/3} + \nu_i^*} - \frac{I}{I + \nu_e^{*1/3} + \nu_e^*} \right] + E_r^{neo}, \text{ (where } \sigma_{\perp} \text{ is taken from [7])}$$

The radial electric field  $E_r$ , poloidal rotation velocity  $V_{pol(ExB)}$  and shear  $\omega_{ExB}$  are shown in Fig. 7, 8 and 9. It is worth to note, that increase of the poloidal rotation and shear begins in 0.5 ms from CRU start at middle radius and conserves such higher level in the central core during long period of plasma current relaxation. So, the non local - effect observed during CRU experiment can be connected with suppression of the microturbulence by shear of the poloidal velocity at middle radii. The origin of such process lies in the reconstruction of  $E_r$  by the pinch Ware mechanism at inhomogeneous longitudinal  $E_{||}$ . The role of the distinction of ions and electrons collisionality parameters for modeling of the  $E_r$  is emphasized.

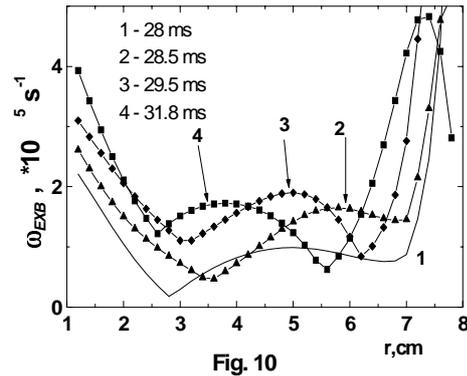


Fig. 10

### Acknowledgements

The authors would like to thank Professor V. Rozhansky for encouragement of this work. The research described in this publication was possible partly by INTAS-RFBR 95 -1351, RFBR 97-02-18119, RFBR 97-02-18084 and RFBR 98-02-18346 Grants.

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