PLASMA CONFINEMENT AND MHD STABILITY IN THE EXPERIMENTS WITH CURRENT PROFILE MODIFICATIONS PRODUCED BY ECCD IN T-10 TOKAMAK

Sushkov A.V., Razumova K.A., Gorshkov A.V., Kislov D.A., Kislov A.Ya., Kirneva N.A., Martynov A.A., Pavlov Yu.D., Sannikov V.V., Savrukhin P.V. and Sokolov M.M.

RRC "Kurchatov Institute", Moscow, Russian Federation

Electron Cyclotron Current Drive (ECCD) allows to modify current density profile j(r) on the T-10 tokamak. Both Co and Counter direction of ECCD with respect to Ohmic plasma current was studied. Creation of the reversed shear configuration in the central part of plasma was possible. In this case safety factor q(r) should have minimum value out of plasma center. MHD stability and plasma confinement under different q_{min} value has been investigated in this experiment.

It is well known that usually in the case of q_{min} <1 the sawtooth relaxations exist in plasma. The additional ECR heating or ECCD can modify the sawtooth shape. Saturated or "humpback" sawteeth can be observed under on axis Counter ECCD with q_{min}<1 [1,2]. In the case of a "humpback" sawteeth central electron temperature $T_e(0)$ increases before the internal crash. Then after the crash $T_e(0)$ rapidly restores, indicating very good confinement at this moment, that deteriorates after a short time. $T_e(0)$ slowly decreases to the initial value, Fig. 1. For investigation of this process all available methods of T_e measurements were used. ECE channels have spatial resolution 4 cm and time resolution 100 μs. Thomson scattering system has spatial resolution 1.5 cm and 8 pulses per shot with the time interval $\Delta t \geq$ 1msec. SXR pulse amplitude height analysis method, (SXRpha) permits to register 16 time windows with duration $\Delta t \geq$ 2ms (more then 10 shots were used for good statistic). In addition SXR pinhole camera data (spatial resolution 1 cm, time resolution $\Delta t \geq 10$μs) have been used.

"Humpback" of sawtooth may be interpreted as a temporal improvement of plasma confinement: intensity of D_α decreases; β_p increases, Figs.1,2. In some regimes the similar behavior of $I_{SXR}(t)$ and $T_e(t)$ was observed, but in many cases I_{SXR} do not increase before the crash contrary to behavior of ECE waveform. We analyzed SXR spectra (I_{SXRpha}) in short time windows during "humpback" sawtooth in other to understand the reason of this difference, Fig. 3. There are no significant changes in SXR spectra during all the phenomenon. SXRpha method give the same $T_e(0,t)$ as other methods, but the SXR intensity, which was measured as a count rate at zero photon energy (if we extend the temperature slope to this energy) has another time behavior, shown in Fig. 3. As $I_{SXRpha} \propto n_e^2 Z_{eff}/\sqrt{T_e}$ and $I_{SXR} \propto n_e^2 Z_{eff} T_e$, one can suspect that modification of $n_e(r)$ or $Z_{eff}(r)$ may take place during the humpback.

The "humpback" sawteeth was observed not only with $q_{min} \leq 1$ but also with $q_{min} \leq 2$. Besides that, sometimes in operating regimes with $1<q_{min}<2$ oscillations of central electron temperature without internal disruptions were observed (like "hills" in TCV terminology). Fig. 4 demonstrates oscillations of T_{ECE} (ΔT_e >20%), D_α and ($\beta_p + l_i$) during this stage.

Internal disruptions due to m=3/2 or m=2 mode development were observed with $1<q_{min}<2$ with Counter ECCD (Fig. 5). When q_{min} passes the rational value (q_{min}= 1.5 and 2) central electron temperature increases abruptly. The m=2/n=1 or m=3/n=2 modes have been observed by SXR pinhole cameras before the temperature increases. No MHD activity has been detected by SXR pinhole cameras, ECE and Mirnov coils in shots with abrupt changes with off axis Co ECCD. An example of q(r) profiles calculated by ASTRA and TORAY codes [3,4] for Co and Counter ECCD is shown on Fig. 6.

The dynamics of $I_{SXR}(r)$, measured by SXR pinhole camera for "humpbacks", and stationary T_e increase are presented in Fig. 7. In order to make effects more pronounced the averaged value of $I_{SXR}(t_1)$ before the event was subtracted from $I_{SXR}(t)$ and normalized by $I_{SXR}(t_1)$ for each chord. One can see that the profile changes start at the radius in the vicinity of rational surface. I_{SXR} increases in this region. Simultaneously inside and outside of this region I_{SXR} decrease occurs. The $T_e(0)$ increases later. The I_{SXR} profile dynamics may be interpreted as local changes of transport coefficients near the rational surfaces. Local changes of transport coefficients with different ECRH power deposition were also observed in the experiments on RTP tokamak [5].

Summary

The similar effects in on axis Counter ECCD and off axis Co ECCD experiments were observed in spite of quite different q(r) profiles and existing of negative shear in the first case and weak shear in the second case. The same "humpback" and "hill" phenomena were observed in T-10 with ECCD and in TCV experiments with ECR heating [2]. Abrupt changes of Isxr(r) profiles dependent on q(r) profile modifications produced by ECCD have been observed in the experiments. This effect is suggested to be described by local changes of transport coefficients.

Acknowledgements

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References

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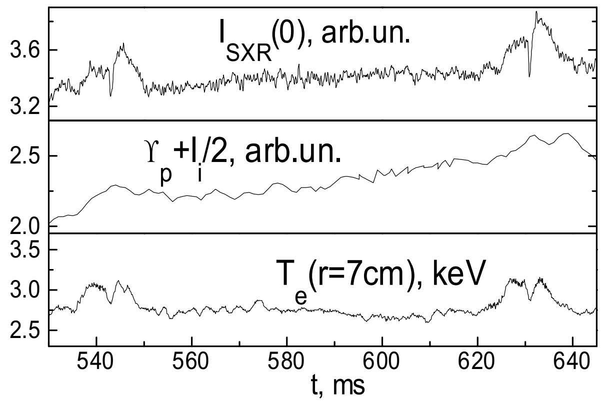

Fig. 1a. “Humpback” sawteeth #61865, I_p = 200 kA, B_t = 2.4 T, n_e = $1.2\cdot10^{19}$ m^{-3} Counter CD, P_{EC} = 0.5 MW.

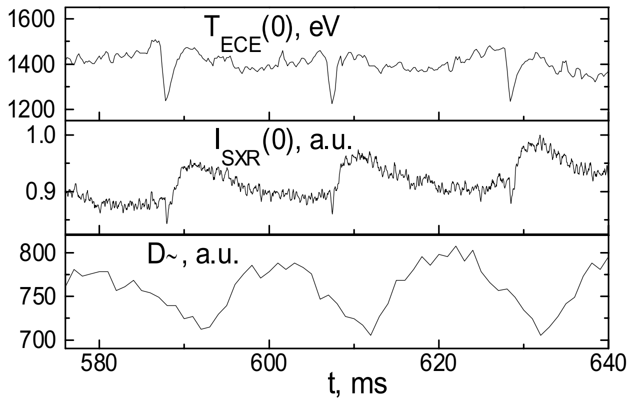

Fig. 1b. “Humpback” sawteeth. Shape of ECE trace differs from the shape of the I_{SXR} trace.

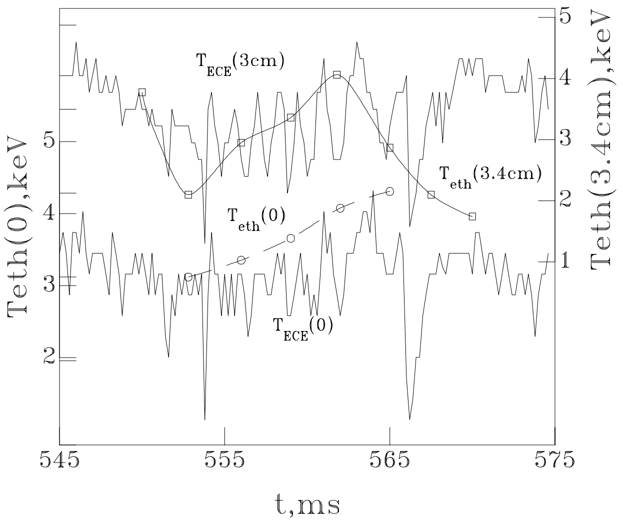

Fig. 2a. Time evolution of T_e during “humpback” sawtooth measured by Thomson scattering and ECE diagnostic at two radii.

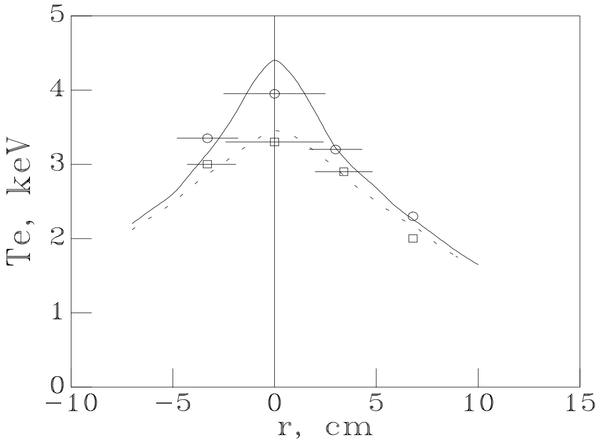

Fig. 2b. Thomson scattering T_e-profiles (solid and dashed lines) and T_e-profiles from ECE diagnostic (open symbols) before the crash and between the “humpback” sawteeth.

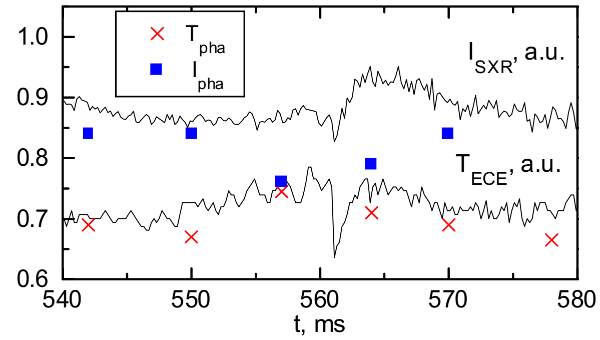

Fig. 3. Time evolution of T_e during "humpback" sawtooth from SXR spectra slope the values. $I_{pha(E=0)} \propto n_e^2 Z_{eff}$. $I_{SXR}(t)$ and $T_{ECE}(t)$ also are shown.

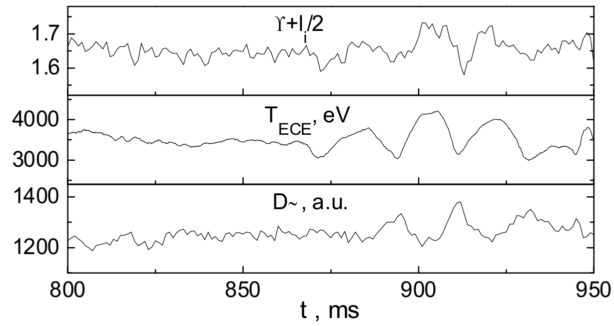

Fig. 4. Giant hills (25% of T_e) with on axis Counter ECCD, P_{EC} = 0.84 MW

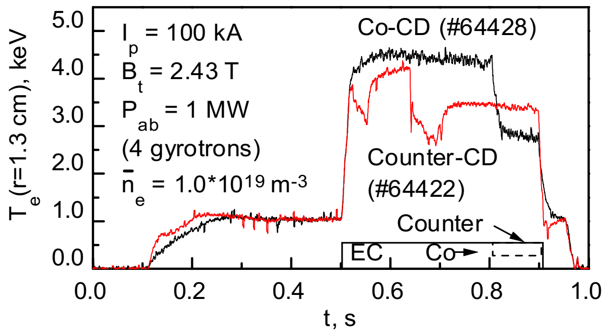

Fig. 5. $T_{eECE}(0)$ time evolution when q_{min} passes 1.5 and 2 with on axis Counter ECCD

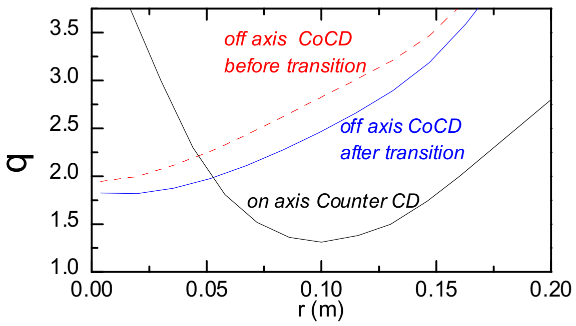

Fig. 6. $q(r)$ profiles calculated by ASTRA + TORAY codes.

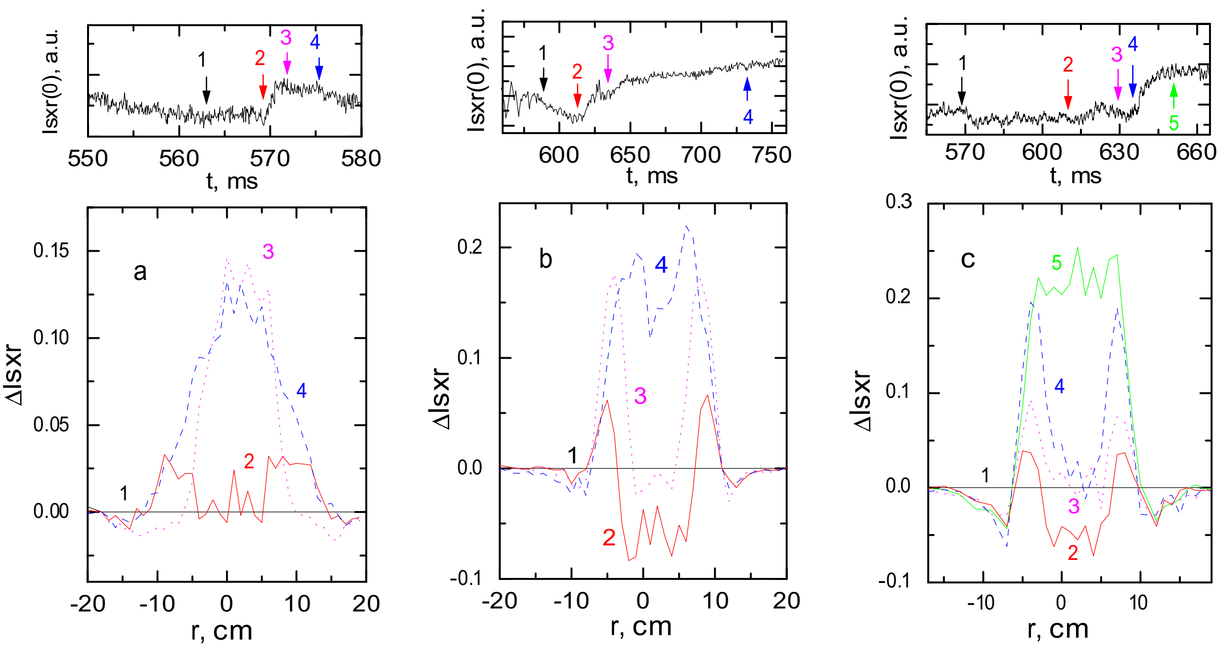

Fig. 7. Relative change of radial profiles of SXR intensity integrated chords: a) for "humpback" sawtooth, b) for T_e increase with on axis Counter ECCD , c) for T_e increase with off axis Co ECCD. Arrows on the time traces of $I_{SXR}(0)$ corresponds to ΔI_{SXR} profiles 1-4.