The variation of the radial and poloidal coherency after middle-amplitude sawteeth crashes in T-10 regimes with central ECRH

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Introduction.

Small scale turbulence widely treated as one of the causes of abnormal transport genesis. The variation of the turbulence amplitude at T-10 is correlated with the variations of the particle flow mainly [1]. The enhanced heat transport with quick reduction along the time was observed during "ballistic" stage and typical enhanced heat pulse propagation (HPP) during diffusive stage of the pulse propagation induced by sawteeth crash [2-4] in L-mode. Also, there is turbulence amplitude grow accompanying HPP [5]. The scope of this report is the study of the correlation of heat flux perturbation with the amplitude behavior and variation of poloidal and radial coherences of small-scale density perturbations.

Experimental setup.

Measurements were held in scenario with slightly off-axis ECR heating (1.2 MW) in the $\rho \sim 0.25$ to observe sawteeth of the greater scale. Experiment was made with $I_p = 250$ kA, $B_T = 2.45$ T and $n_e = 2.3 \cdot 10^{19}$ m^{-3}. ECE diagnostics provided temperature data and electron density profiles were provided by 15 channels interferometer. Sawtooth oscillations were studied during ECRH in the time interval with steady electron density and temperature.

Variations of small-scale density fluctuations were analyzed using a correlation reflectometer based on voltage-controlled oscillators and mixers with suppression of the intermediate and side bands. The measurements were made from the LFS, using antennas located on the poloidal coordinate -60 ° with respect to the equatorial plane. The change in the observation radius was achieved by changing the frequency of the probing radiation in a series of reproducing pulses. The high stability of the generators and the ability to accurately set the frequencies of the probing signal provide data with a low level of phase noise of the reflectometer and the ability to accurately determine the reflection radii.

For statistical data analysis it is necessary to select a large number of averaging windows. This was achieved by selecting sawtooth oscillations according to the following criteria: a sharp front of temperature drop should be observed in the central part of the cord, there should be no disturbances associated with the excitation of the mode m / n = 1/1, there should be no secondary crashes and irregularities on sawtooth far from the area of mixing. Such sawtooth oscillations were averaged inside a 10-ms window centered at the moment of crash in the central region of the cord, as shown in Figure 1.

Experimental data analysis.

The analysis of HPP is performed from analytical or numerical solutions of the simplified equation $3/2\, n\partial(\delta T_e)/\partial t = -div(n{\chi_e}^{HP}\nabla\delta T_e)$. The equation is applicable for analysis in a limited space-time interval with │δne/ne│<<│δTe/Te│,│δTe/Te│<< │grad(δTe)/grad(Te)│, when the dependence of heat sources and transfer coefficients by density and temperature can be neglected. The dependence χ_e ($\nabla T_e/T_e$) in the case of exceeding $\nabla T_e/T_e critical$ suggested in [2,9] leads to $\chi_e^{HP} = \chi_e + \nabla T_e(\partial\chi_e/\partial\nabla T_e)$ when ${\chi_e}^{HP} >> \chi_e$ [2], what was observed in experiments with HPP caused by sawteeth crashes at T-10 and TFTR. The model of critical gradients predicts (under P_{ECRH} >> P_{OH} like in our case) $\chi_e \propto \sqrt{T_e}|(\nabla T_e/T_e)/(\nabla T_e/T_e)_{crit} - 1|,.(\nabla T_e/T_e)_{OH} \approx (\nabla T_e/T_e)_{crit}$. [9] Hence, for the relative perturbation of the χ_e is possible to estimate as $\delta\chi_e/\chi_e \approx 1.5\,\delta(\nabla T_e/T_e)/(\nabla T/T) + \delta T_e/2T_e$ (2). It is also possible to estimate the speed of heat pulse propagation using experimental data from the evolution of δTe(r,t) [6,7]. For this purpose, a numerical solution of equation (1) with zero or experimental initial conditions and with experimental boundary conditions is applied. Two phases of HPP were observed outside the inversion radius of sawtooth oscillations. The rapid non-diffusion outward HPP occurs within 0.3 ms after the crash characterized by very high values ${\chi_e}^{HP} > 10\ m^2/s$. This value exceeds the average values of the heat conductivity coefficient by an order of magnitude (calculated approximate values: ${\chi_e}^{PB}$ (r/a=0.5) = 1.0 m^2/s, ${\chi_e}^{PB}$ (r/a=0.6) =1.4 m^2/s. Analysis of HPP using Te(r,t) decay within time interval (the length was taken individually in each case) shifted by 0.4–0.5 ms away from the time of sawteeth crash gives ${\chi_e}^{HP}$ = 2-3 m^2/s (averaged inside 0.4 <r/a <0.7). The data from HFS and LFS was analyzed separately.

Using the reflectometry data allows one to observe the perturbation amplitude spectra, the spectra of radial and poloidal correlations, and also calculate the perturbation of the plasma electron density from the spectral density in the one-dimensional approximation [8]. After the MHD phase of the internal crash, a fast grow of the amplitude of density fluctuations is observed, with an increasing time delay as it approaches the outer part of the plasma column. The delay time corresponds to the arrival time of the heat wave at the advancing radius. The average turbulence level is higher at the edge of plasma, but the relative fluctuation level grows at different radial positions after sawtooth crash doesn't show any unambiguous relation. Also, at the inner reflection radii the short increase of radial correlation can be observed, but there is no similar effect clearly detected at the poloidal correlation spectra nor at the spectra from the external reflection points. This can be explained by the high average turbulence level at the periphery and mainly broad band spectra domination, that requires more data to analyze coherency parameters.

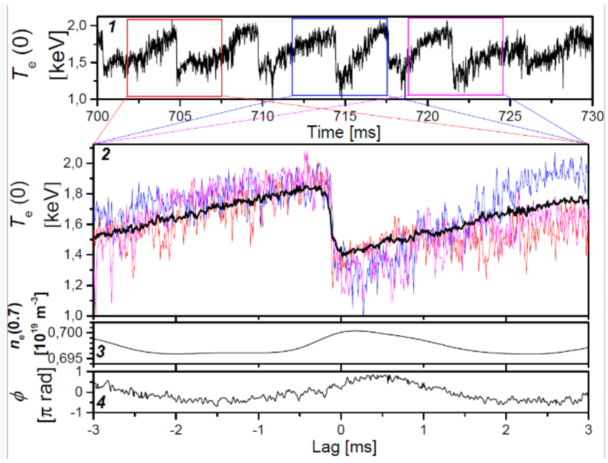

Figure 1 – Sawtooth oscillation selection and data averaging process. One can see low electron density level change.

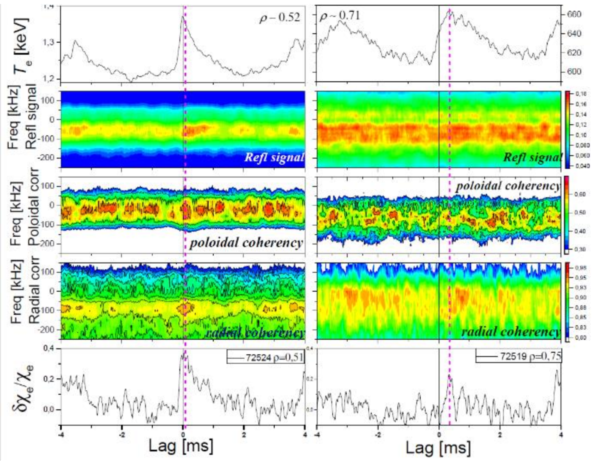

Figure 2 – From top to bottom: electron temperature, turbulence spectra, poloidal and radial correlation spectra, relative heat transfer coefficient.

Conclusion.

As a result of the work carried out on the T-10 tokamak, the variation of turbulence parameters was measured for the first time in the process of sawtooth oscillations in the region from 0.6 to 0.9 normalized radius in scenario with slightly off-axis ECRH and compared with the parameters of heat transfer in different phases of the heat pulse. The analysis of HPP after sawtooth oscillations showed the presence of a non-diffusion “ballistic” phase of heat pulse propagation with $\chi_e^{HP} > 10$ m^2/s for ~ 300 μs after MHD crash and a “slow diffusive” phase with χ_e^{HP}=2-3 m^2/s. These obtained values substantially exceed the values of the heat conductivity coefficient obtained from the heat balance $\chi_e^{PB} \approx 1.0 - 1.4$ m^2/s) without contradicting the critical gradient model. An analysis of the dynamics of the behavior of small-scale turbulences has shown that a fast grow in the amplitude of perturbations after an internal crash is observed in the internal regions. This growth is accompanied by an increase in the radial coherence of the perturbations. Variations of turbulence parameters at the periphery of the plasma column are significantly smaller and correspond to the moment of arrival of the heat wave at the observation radius and also have a more diffusive character in comparison with the observed processes in the inner part of the cord. The moment of an increase in the amplitude of turbulence correlates with an increase in the relative value of the local thermal conductivity coefficient calculated from experimental data according critical gradient model [9]. The work was supported by ROSATOM corporation.

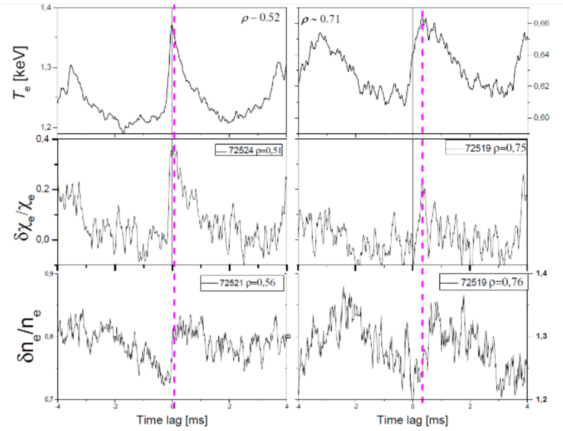

Figure 3 – Comparison of electron temperature(top), relative heat transfer coefficient(middle) and relative turbulence amplitude (bottom) evolution during sawtooth crash.

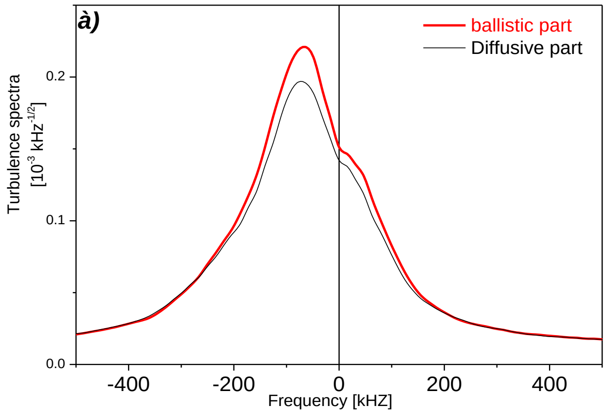

Figure 4 – Turbulence spectra during ballistic phase (0-0.3 ms from sawtooth crash) and diffusive part (over 0.4 ms after sawtooth crash.

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