

INVESTIGATION OF ROLE OF SUPERTHERMAL ELECTRONS IN PLASMA DYNAMICS UNDER ECH ON TOKAMAK T-10 AT REGIMES WITH INSTABILITIES ON $q = 3$

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The investigations of dynamics of superthermal electrons at OH discharges ($B_z \sim 2,5$ kGs, $n_e \sim 1 \div 2 \times 10^{13}$ cm⁻³, $I_z \sim 230 \div 330$ kA, $q_L \sim 3$) and under oblique ECH ($P_{ECH} \sim 700$ kW, $f = 140$ GHz, heating on 2nd resonance, input angle 69°) were made on tokamak T-10. Spectra analysis of plasma emission on 1st ECR ($f = 40 - 90$ GHz, O-mode), on 2nd ECR ($f = 100 - 170$ GHz, X-mode), in range of magnetised Langmuir oscillations (0.1 - 18 GHz), in SXR-range (2 - 50 keV) and HXR-range (100 - 2000 keV) were fulfilled. Simultaneous ECE measurements on 1st and 2nd harmonics got possibility besides the evaluation of total energy of upthermal electron components to determine a relation of them perpendicular and longitudinal energy. Essential longitudinal anisotropy in electron energy distributions is kept practically full time of discharge current. It is possible to choose two kind of fast electrons on them space location. The first are born at the initial stage of discharge and are distributed through full cross-section of plasma column. The energy spectrum is essentially soft as far as a growing of Langmuir range fluctuations under plasma pinching by primary current of accelerated electrons. The hard electron component ($E > 100$ keV) goes practically to zero level at the first act of ELM-like instability. Relative part of upthermal electrons in total local density rises typically to plasma periphery. Analysis of ECE and SXR dynamics shows that energy quench inside column during instabilities on $q = 3$ is determined largely by loss of energy in upthermal component. The depth of

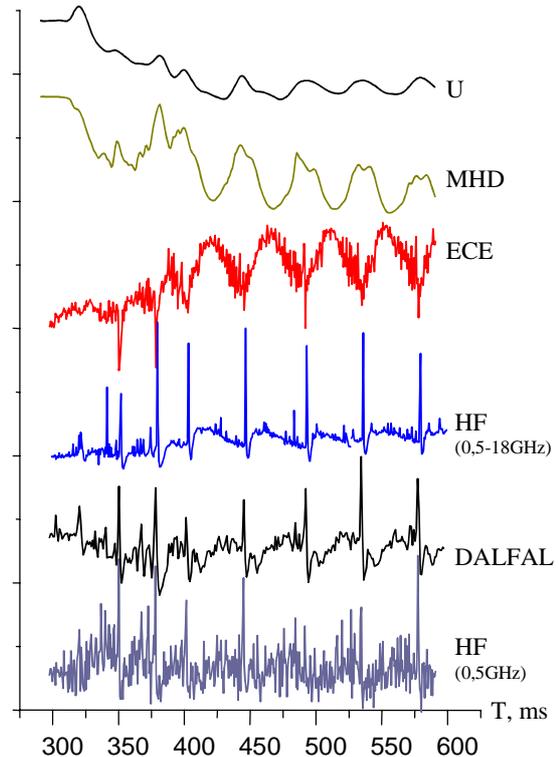


Fig. 1. Correlation of plasma parameters at regime with ELM-like instabilities on $q = 3$.

ECE modulation in the plasma centre does not exceed 20%, while in the periphery it can reach 70%. Electrons of HXR-range do not appear under ECH as rule. Distributed in space electron group produces apparently a periodical pinching of current channel, rise of electric field on the front of pinch-wave, excitation of plasma oscillations up to unstable them amplification under critical value of electric field [1]. Time evolution of some plasma characteristics is shown on Fig. 1.

Another electron group (it was discovered by second low frequency maximum in spectrum of 1st ECE) appears on the edge of plasma column (very likely next to limiter) under energy saturation of the central plasma area. According to set of sign, this component is mainly result of the longitudinal momentum transport by the potential plasma waves. It can exist also up to the end of discharge decreasing at the acts of instabilities and increasing many times under ECH of the internal regions. ECE intensity of this group is reduced with a rise of plasma density and evidently depends essentially on the vacuum cleaning of limiter and chamber. At discharges of another kind, the localised electron beam was registered for average plasma density up to $3 \times 10^{13} \text{cm}^{-3}$ [2]. At that case, the moment of slow decrease of its ECE to neglected small level corresponded usually to development of disruptive instability. Under ECH, ECE intensity of the periphery superthermal electron flux rises essentially (Fig. 2b) and then more then higher input EC power. ECE intensity of boundary beam enhances

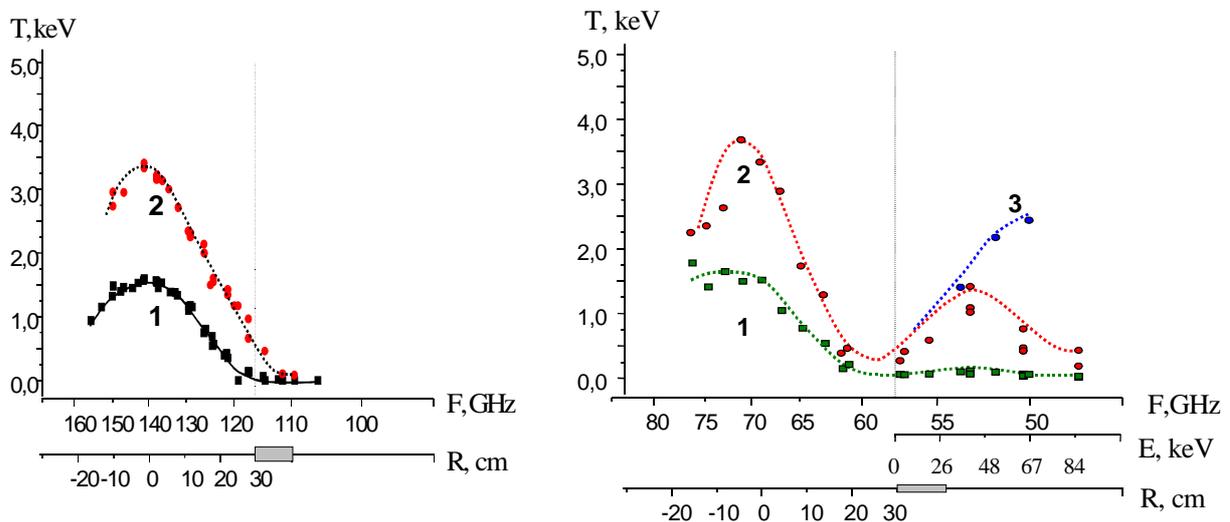


Fig. 2. ECE spectra at phase of quasistationary total plasma current on 1st (b) and 2nd (a) resonance. 1 - OH stage, 2 - on-axis ECH ($B_z = 25$ kGs), 3 - off-axis ECH ($B_z = 28$ kGs). Space scales were marked in supposition of “thermal” emission nature. Energy scale corresponds to the local supposition of beam next to limiter (30 cm). $I = 270$ kA, $n_e = 1.1 \times 10^{13} \text{cm}^{-3}$.

on a shift of absorption zone to the areas of lower or higher magnetic field. Analysis of 2nd ECE (Fig. 2a) shows that transverse energy of distributed upthermal electron flux in the external plasma region can reach 0.5 - 0.7 keV on longitudinal energy 15 - 20 keV. Characteristic total energy of the edge beam depending on time and way of creation can be 30 - 70 keV with perpendicular energy no more then several hundreds keV. Radiation temperature of corresponding emission surpasses tens times that just before ECH and is comparing with central electron temperature under ECH.

An effective generation of the edge electron beam can not be explained by direct absorption of input EC power (resonance conditions are not satisfied) or by stationary increase of electric field in the plasma periphery and, as at OH stage too, is the result of the non-local (wave) transport.

Analysis of spectrum of Langmuir fluctuations (Fig. 3) and its dynamics at OH stage and under ECH gives possibility to believe that those oscillations are driving force of the transport phenomena including the development of kinetic instabilities of electron component and, as consequence, global instabilities. Actually, those oscillations and superthermal electrons, which are responsible on them excitation, can be observed full discharge time essentially non-linear increasing with the current ramp up to critical level. Spectrum of oscillations is transformed in certain manner remarkably earlier the moment of quench. It saturates in range of spectral maximum, decreases in high frequency part and increases on low frequencies. Just before instability on $q = 3$ (also on $q = 1$ and 2), this spectral overpumping occurs exponentially in time forming as rule sharp maximum in the vicinity of the low frequency spectral boundary. Set of peculiarities of spectrum and its dynamics shows on the possibility of existence in plasma at the same time several space modes of the potential oscillations connected with details of the magnetic field structure ($q = 1,2,3$) [3].

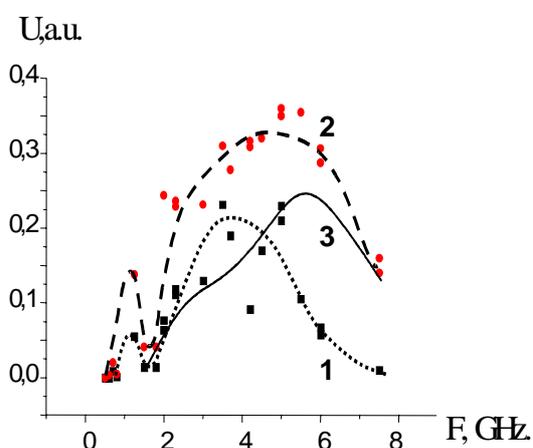


Fig. 3. Spectra of plasma oscillations: 1 - OH regime, 2 - ECH, 3 - difference between curves 1 and 2. Mode corresponding to excitation of oscillations inside $q = 1$ is distinguish in low frequency range. Main part of spectral energy apparently is stipulated for mode which excites inside zones $q = 2$ or 3.

Certain conformity between spectrum of plasma oscillations and energy spectrum of fast electrons was discovered. The intensity of oscillations increases significantly in high frequency range of spectrum. A behaviour of intensity in this range including many details correlates with confidence with ECE dynamics of the edge superthermal electron component. In particular, synchronous modulation of the boundary ECE is observed on excitation of sawtooth oscillations on $q = 1$ in the plasma centre: slow increase together with electron temperature inside $q = 1$, exponential enhancement on energy saturation in the centre with fast rise of low frequency fluctuations and, finally, slow decrease corresponding to cooling phase of zone outside $q = 1$ (Fig. 4).

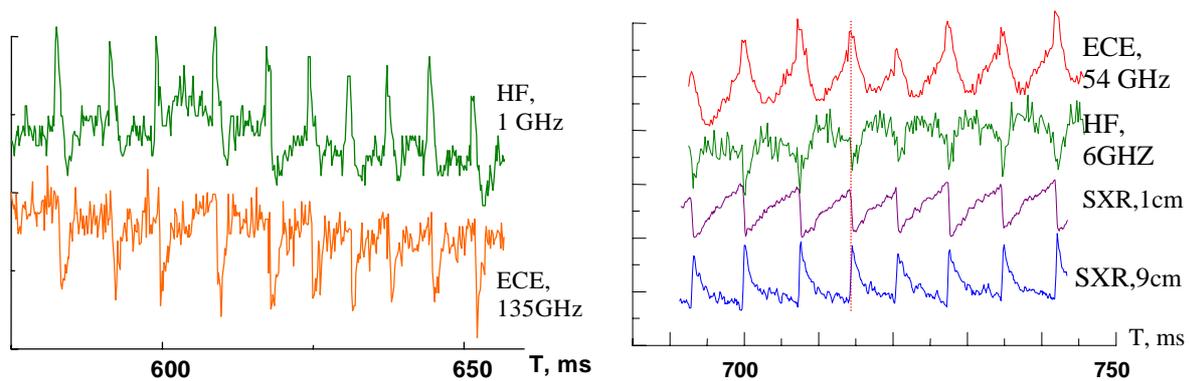


Fig. 4. Correlation of low (left) and high (right) frequency plasma fluctuation, 2nd (left) and boundary 1st (right) ECE and SXR-signals at regime with excitation of sawtooth oscillations on $q = 1$ and suppression of ELM-like instability by ECH.

The forming of the edge superthermal electron flux by the potential waves through transport of longitudinal electron momentum can be the physical ground of so called regimes with “improved confinement”. According to rough evaluation the current carrying by superthermal boundary electron flux can reach 10% from total value. Certain correlation in dynamics of ECE, plasma noises and atomic spectral lines allows to think an essential role of atomic processes in limiter area for excitation and stabilisation of ELM-like ($q = 3$) instabilities.

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