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Modulating phenomena in T-10 tokamak plasma under EC heating

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The analysis of the forced macroscopic plasma oscillations under slightly modulated ECH power (10 -15%) is presented. The measuring complex of EC emission on first (O-mode) and second (X-mode) resonance [1] was used as main diagnostics. It gives possibility to register besides temperature profiles also the characteristics of upper thermal electron flux up to ~ 300 keV.

Two kind of amplitude-frequency modulation of electron energy are evolved. First is developed under central heating (~ 1 MW, 140 GHz, direct lunch) in regimes with sow-tooth oscillations (fig. 1). The forced oscillations with deep up to 40% can exist in total plasma volume. As rule, the even harmonics of modulated frequency (1.8 kHz) widened by cross-modulation with current density oscillations (from source of poloidal field) are developed in plasma. The modulation maximum is being in the plasma centre. Tree space zones corresponding to modes m/n = 1/1, 3/2 и 2/1 are divided. All oscillations in high field side are phase-coherent. All oscillations in low field side have constant for this regimes time shift 90 mcs relatively to oscillations in low field side. This shift does not depend on frequency of forced oscillations and is parameter (half of period) of natural plasma oscillations. It equals also to duration of the temperature drop under internal disruption and the accompanying high spike of plasma oscillations. Modes 1 and 2 have identical negative shift. Mode 3/2 has positive one. Spectrum of volume oscillations is shown in fig. 2.

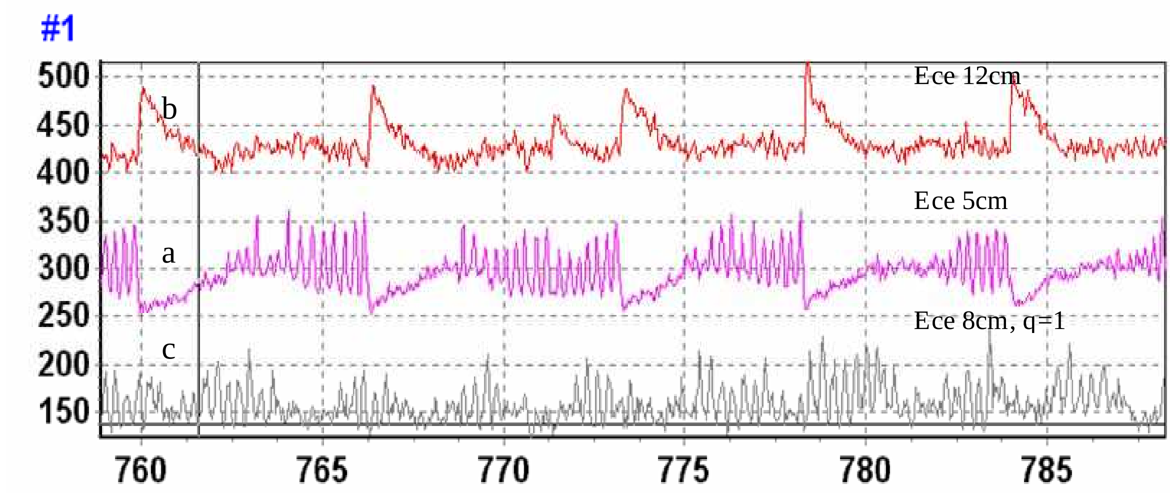

Fig.1. EC signals in positive (a), negative (b) phase of saw-tooth and from q=1 zone (c).

Second kind of modulation is developed as the localized in space oscillations together with first one under additional switch-on of gyrotron 129 GHz (0.4 MW) that heats the vicinity of q = 1 zone. Quasi-monochromatic modulation on even monochromatic harmonics of 1.6 kHz with satellites on power supply excitation frequencies (± 300, 600… Hz) is observed at once in several zones q = 1, 2. 3. Some times new q = 1 zone around plasma centre can developed. Spectra for such case are shown in fig. 3.

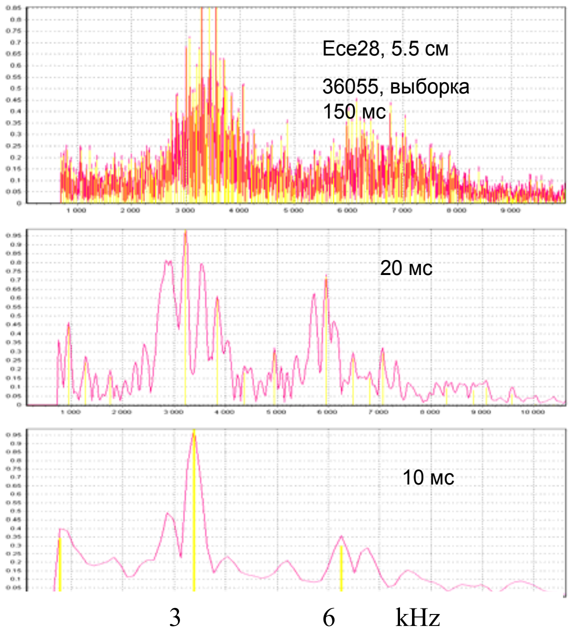

Fig.2. Spectra of volume oscillations.

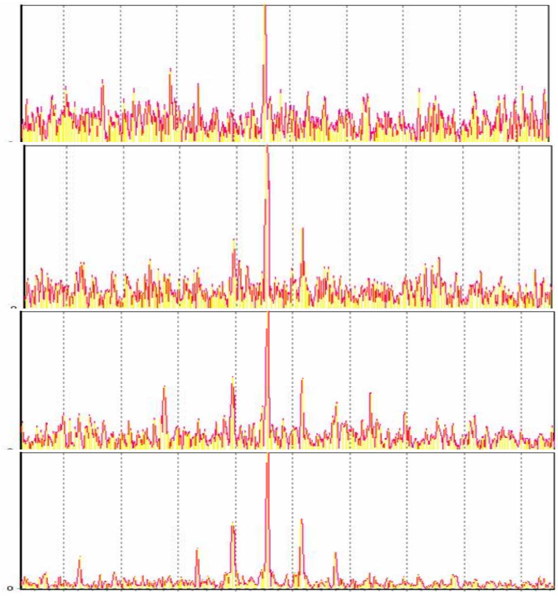

Fig.3. Spectra of localized oscillations.

It was determined that the fluxes of runaway electrons of high energy are present permanently on rational magnetic surfaces (fig. 4). They relax periodically that gives possibility to find them space positions with high accuracy. Relativistic frequency shift of receiving emission (O-mode) gives an evaluation of total electron energy. The ratio of spectrum power in O- and X-mode shows that electrons pitch-angles are small.

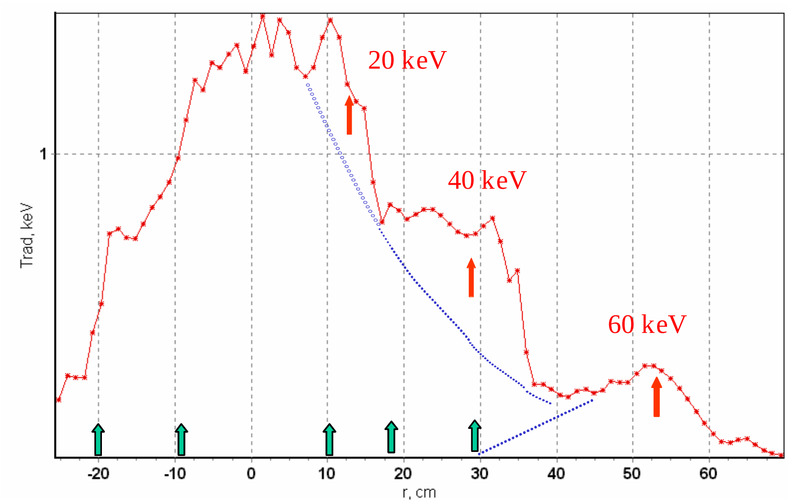

Fig.4. The peculiarities no monotonous spectrum shows to the location of runaway electron fluxes.

They increase sharp under relaxations of flux.

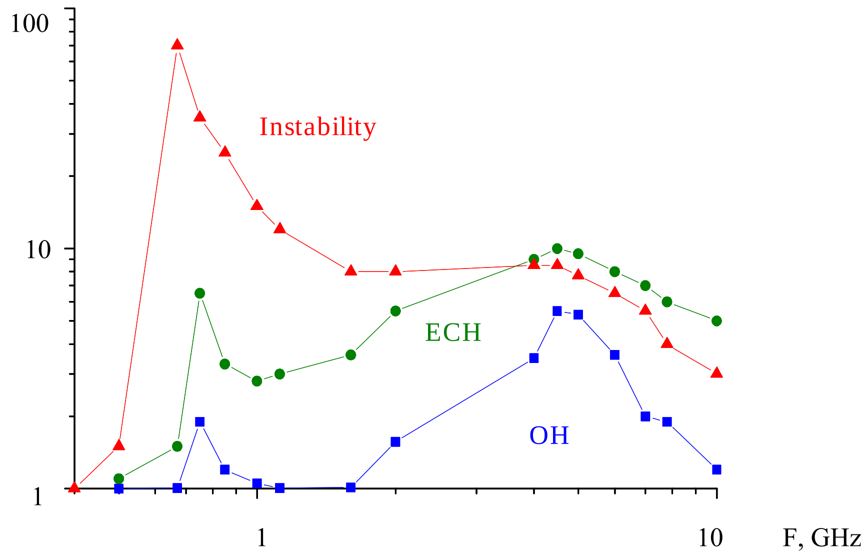

Fig.5. Spectra of the potential plasma oscillations.

Fig. 5 shows the spectra of potential plasma oscillations in OH and ECH stages and in the moment of internal disruption development. It can see that the energy pumps over in spectrum to low frequency boundary (ω_{pi}). In stable phase, waves of space charge move inside small angles to the magnetic field direction. Under instability, they move practically across it. The boundary frequency corresponds to the wave generation of electron local flux in q = 1 zone [2]. Strong correlation between ECE dynamics from central and periphery areas and potential plasma oscillations shows to essential role of last in transport of longitudinal electron momentum and in plasma self-organization.

The analysis of temperature profile dynamics in discharges with different effective charge of plasma shows that the rate of current pinch depends essentially on the beginning value of electric field. Fig. 6 illustrates the temp of the maximum movement to the plasma center. Effective charge changes from a to c no more than two times. Pinch velocity under this increases more than one order of value and flux of runaway electrons – two order of value. An evaluation of electric field pulsing in acts of modulation by periodical generation of high energy electrons gives ~ 1 V/cm.

The natural frequency of volume oscillations was determined as ~ 6 kHz (fig. 7). It develops in moment of gyrotrons switch-on, under stop of synchronization by external source and under periodical generation of high energy electrons. This value corresponds to the above-mentioned characteristics of oscillations.

The complex of experimental data can not be explained in limits of known hydrodynamic models. Scenario of process grounded on plasma properties which was discovered in T-10 experiments is suggested. The ground of process is the no linear pinch-waves (“zero-mode”) that are summarized with particles movement along magnetic force

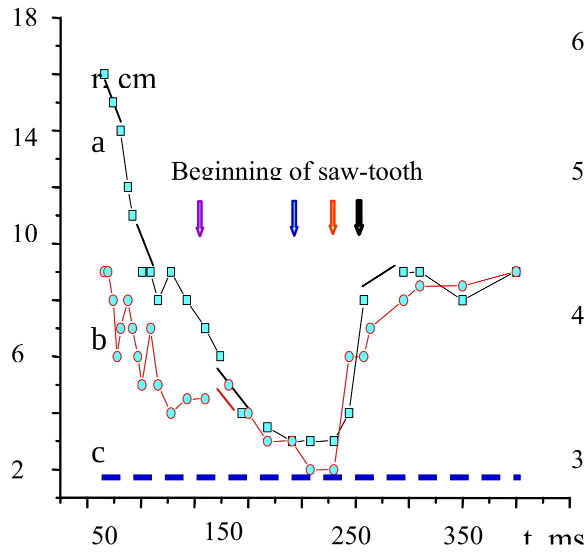

Fig.6. Rise of pinch velocity with effective charge of plasma.

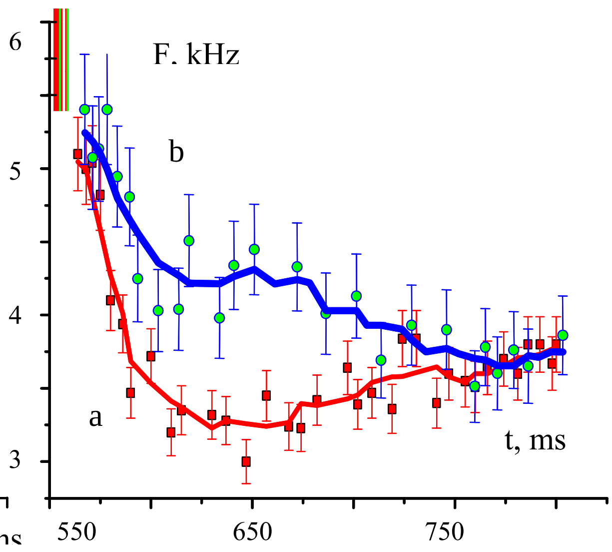

Fig.7. Frequency change of volume oscillations with q=1 zone heating (a) and without it (b).

lines (here – mode m/n = 1/1). Under pumping of the current channel (normal pinch-effect), longitudinal electric field increases, generation of “fast” electrons rises and, correspondingly, the local current density is being higher. This process has positive feedback. Electrons in them movements to the plasma centre outstrip ions. Corresponding electric field creates the plasma rotation in certain toroidal (poloidal) direction.

Rise of superthermal electron flux leads to multiplication of the potential plasma waves and, as result, to the rise of effective current resistivity. When electric field is being higher than critical value [3], current density decreases, plasma drifts outside (opposite pinch-effect), sine of radial electric field changes. Direction of the movement changes also. Frequency of precession can be doubled under ECH. Necessary amplitude of radial electric field ~ ± 50 V/cm can be real. Mutual interaction of local runaway electron fluxes through the plasma waves provides certain synchronization in time and zone like activity in space for current and energy of plasma.

1. V.I.Poznyak, e. a., Proc. of the 30th EPS Conference, S-Petersburg, 2003;
2. V.I.Poznyak, e. a., Proc. of the Intern. Workshop “Strong microwaves in plasmas”, 1997, v.1, p.
3. Poznyak V.I. e. a., Proc. in 15th Intern. Conf. on Plasma Phys. And Contr. Fusion, Seville, 1994, v.2, p. 169; Proc. of the Ninth Workshop on ECE and ECH, Borrego Springs, California, 1995, World Scientific, p. 137.