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Influence of Lower Hybrid heating on poloidal plasma rotation and small-scale turbulence in FT-2 tokamak

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Inhomogeneous plasma rotation, according to the present day understanding, can play a substantial role in energy confinement in toroidal plasmas, suppressing drift micro turbulence and thus reducing anomalous heat and particle fluxes.

In this paper the temporal variation of the poloidal plasma rotation and small-scale turbulence are studied under the incidence of RF heating power in Lower Hybrid (LH) frequency range. The experiment is performed at research FT-2 tokamak (R_0 = 55 cm, a = 8 cm, $B_T \approx (1.7 \div 2.2)$ T, $I_p \approx (19 \div 37)$ kA, $n_e(0) \approx (0.5 \div 5)\cdot 10^{13}$ cm^{-3}, $T_e(0) \approx 500$ eV), where the RF power up to $P_{RF} \approx 120$ kW at frequency $f_{RF} = 918$ MHz is launched into the plasma by a two-waveguide grill. The plasma poloidal rotation profile is measured using recently found enhanced Doppler frequency shift effect of the highly localized microwave back scattering (BS) in the Upper Hybrid Resonance (UHR) [1], as well as by Doppler reflectometry.

The UHR BS or enhanced scattering (ES) [2] utilizes for local diagnostics of small-scale plasma fluctuations the growth of wave vector and electric field of the probing extraordinary wave in the UHR, where condition $f_i^2 = f_{ce}^2(R) + f_{pe}^2(r)$ is fulfilled for the probing frequency f_i (R and r are tokamak major and minor radii, correspondingly). The scattering cross section of the UHR BS experiences very sharp maximum at the fluctuation wave number $q_{conv} \equiv 2(2\pi f_i/c)\sqrt{c/V_{Te}}$, which corresponds to BS of the probing wave in its linear conversion point [2]. According to [3], in toroidal devices, where the UHR and magnetic surfaces do not coincide due to dependence of magnetic field on the major radius R, the large probing wave vector, perpendicular to the UHR surface, at the off equatorial plane incidence has a finite projection onto the poloidal direction. This projection is given by relation $k_\theta = k_{\theta 0} - \frac{q_{conv}}{2} \frac{\vec{e}_\theta \vec{e}_R f_{ce}^2}{R\left|\vec{\nabla}(f_{pe}^2 + f_{ce}^2)\right|}\Bigg|_{UHR}$, where $k_{\theta 0}$ gives the probing extraordinary mode

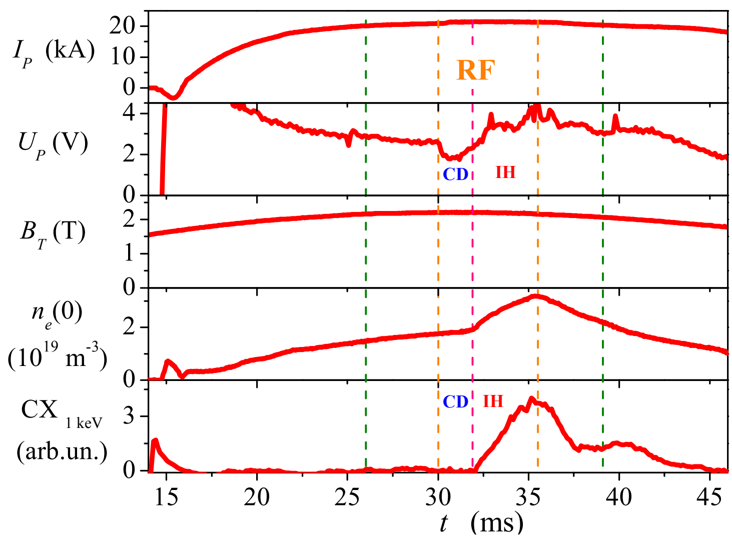

Fig.1. *Discharge wave forms.*

poloidal wave number out of the UHR zone, $\vec{e}_\theta$ and $\vec{e}_R$ are unit vectors in poloidal and major radius directions. This projection, which can be much larger than the poloidal component of wave vector at the antenna, leads to substantial enhancement of the Doppler frequency shift of the microwave BS by fluctuations moving with poloidal plasma flow, which is given by $f_D = 2k_\theta V_\theta$, where V_θ is the fluctuation poloidal velocity.

In the present paper a specific regime of LH heating at densities $2{\cdot}10^{13} < n_e(0) < 3{\cdot}10^{13}$ cm^{-3}, at which the LHCD and electron heating terminates and wave – ion interaction and ion heating starts, was investigated. The wave forms of the discharge are shown in Fig. 1. As it is seen there, just at the onset of RF pulse at t = 30 ms an evident decrease is observable in the loop voltage signal indicating the LHCD effect. This effect is accompanied by the plasma density growth, leading to the LHCD termination at $t \approx 31.8$ ms. Soon after that, at $t \approx 32$ ms, the steep increase of fast ion population at energy in 1 keV range is observed in the discharge by the charge exchange diagnostic, indicating transition to the LH Ion Heating (LHIH) regime. Under these conditions excitation of small scale component of plasma turbulence was observed at FT-2 tokamak by CO_2 [4] and UHR scattering diagnostics [5]. Here we study the reasons and consequences of this effect. The temporal evolution of the UHR BS spectrum at probing frequency f_i = 62 GHz during the RF pulse is

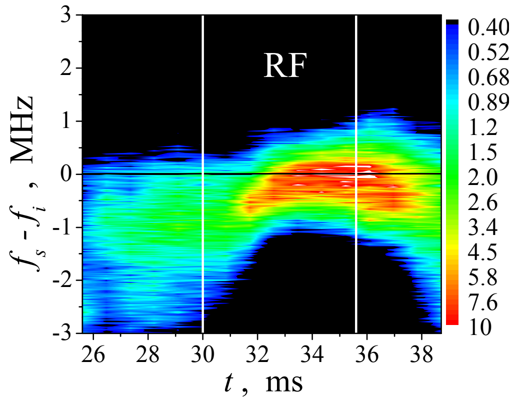

Fig.2. *ES spectrum evolution* (62 GHz).

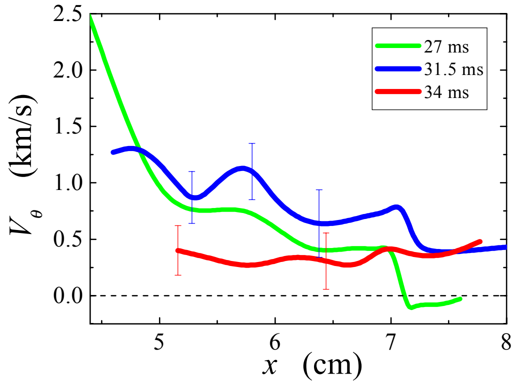

Fig.3. *ES poloidal velocity profiles.*

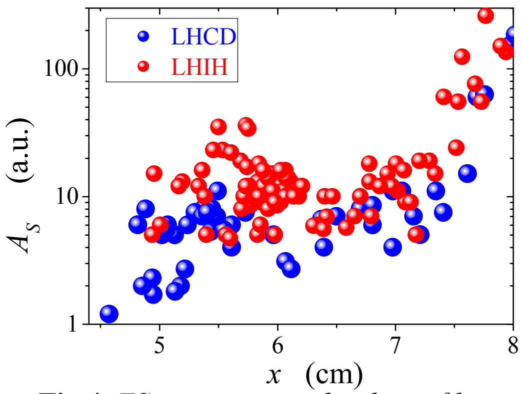

Fig.4. *ES spectrum amplitude profile.*

shown in Fig. 2. As it seen at 30 ms < t < 31.8 ms, the BS spectrum remains similar to that observed in ohmic heating. The fast reduction of the Doppler frequency shift and the spectrum narrowing starts simultaneously with the fast neutral flux growth. This evolution of the BS spectrum is accompanied by steep increase of its amplitude. The relaxation of the BS spectrum to that, observed in the ohmic discharge, starts just after the RF power switch off. The poloidal velocity profiles ($x = R\text{-}R_0$), determined from the Doppler frequency shift of the UHR BS spectra are shown in Fig. 3 for three typical moments. Before the RF pulse the velocity profile is typical for the low current regime, as measured by this technique. The velocity monotonically decreases when approaching the plasma edge and change sign in the vicinity of LCFS (green curve in Fig. 3). At the LHCD phase the velocity increases slightly, however its shear remains unchanged during the first millisecond after RF power onset (blue). The dramatic variation of the velocity profile is observed only after transition to the LHIH regime at $t > 32$ ms. As the result, at $t = 34$ ms poloidal velocity is substantially reduced and its profile in the edge region becomes flat (red). It is important to note that the flattening of the rotation profile and related decrease of the poloidal velocity shear results in strong growth of the BS signal, proportional to the level of small scale density fluctuations, as it is shown by dependences of BS signal on the UHR position, plotted by blue and red points in Fig. 4 for the LHCD and LHIH phases of RF pulse correspondingly. Similar observations were made also by the O-mode Doppler reflectometry with low field side oblique probing at 15° with respect to LCFS. Suppression of poloidal rotation was measured by this diagnostic during the RF pulse, which resulted in decrease of the velocity shear at the plasma edge, by the end

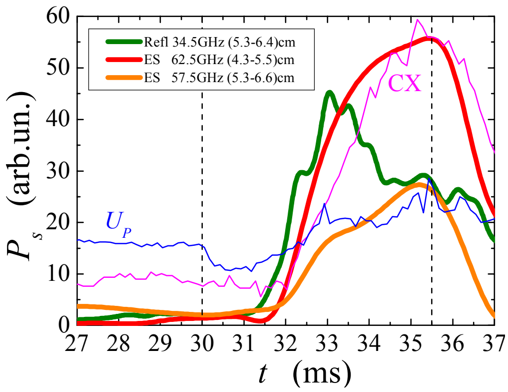

Fig.5. *Scattered power evolution.*

of the RF pulse. The level of the Doppler reflectometry signal at the plasma edge also experienced substantial growth at the transition from the LHCD regime to the LHIH, as it is shown in Fig. 5 for Doppler reflectometry probing frequency 34.5 GHz (green curve). This growth is only partly associated with the outer shift of the cut off layer and indicates the growth of long scale

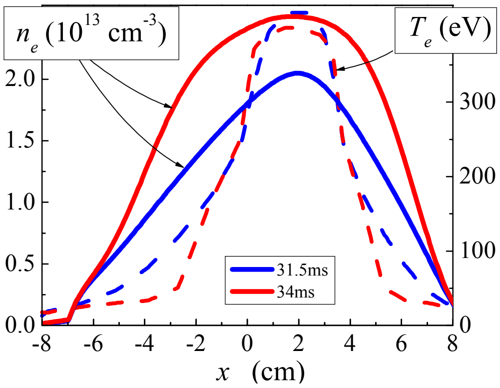

Fig.6. *Electron density and temperature.*

component of tokamak micro turbulence. The dependences of the UHR BS signal at probing frequencies 62.5 GHz (red) and 57.5 GHz (orange) are shown in Fig. 5 for comparison. The drastic increase of the turbulence level initiated by the rotation shear suppression is accompanied by substantial cooling of the electron component at the plasma periphery, which occurs at the background of growing density (see Fig. 6).

The typical feature of the plasma rotation at the very edge (out of the LCFS), observed by the UHR BS technique at RF power onset, was quick change of velocity direction. This effect well pronounced in all regimes of interaction and at different grill antenna phasing is illustrated by Fig. 7 in which the temporal variation of the BS spectrum is shown.

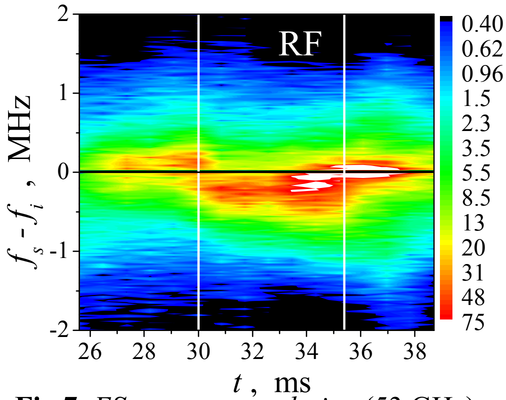

Fig.7. *ES spectrum evolution* (53 GHz).

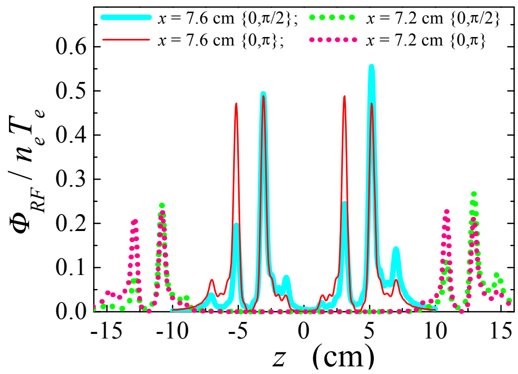

Fig.8. *Normalized ponderomotive potential.*

The possible explanation of this robust effect taking place in the vicinity of the LH grill, which is situated in the UHR BS diagnostics cross section, is based on the improvement of electron confinement along magnetic field due to their trapping by the ponderomotive potential $\Phi_{RF} = \frac{f_{pe}^2}{f_{RF}^2} \frac{\tilde{E}_z^2}{16\pi}$ produced by two LH wave resonance cones (where $\tilde{E}_z$ is the toroidal component of RF field). The distribution of this potential along the field line is shown in Fig. 8 for different grill phasing at two minor radii. At $P_{RF} \approx 88$ kW and $T_e \approx 10$ eV it appears to be comparable to plasma pressure.

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1. A.B. Altukhov et al., 30 EPS Conf. on Controll. Fusion and Plasma Phys. ECA **27A** (2003), p-4.170pd.
2. K.M. Novik and A.D. Piliya, Plasma Phys. Controll. Fusion **35**, 357 (1994).
3. D.G. Bulyiginskiy, A.D. Gurchenko, E.Z. Gusakov et al., Phys. Plasmas **8**, 2224 (2001).
4. V.N. Budnikov et al., 23 EPS Conf. on Controll. Fusion and Plasma Phys. ECA **20C** (1996), P.855.
5. V.N. Budnikov et al., Plasma Phys. Rep. **24**, 233 (1998).