RADIAL ELECTRIC FIELD EFFECTS IN EXPERIMENTS AT FT-2 TOKAMAK

S.I. Lashkul, V.N. Budnikov, V.V. Dyachenko, L.A. Esipov, E. Z. Gusakov, E.R. Its, M. Yu. Kantor, D.V. Kouprienko, A.Yu. Popov, S.V.Shatalin[†], E.O. Vekshina[†]

A.F Ioffe Physico-Technical Institute, 194021, St.Petersburg, RUSSIA
[†] Technical University, St.Petersburg, RUSSIA

Experiments in the FT-2 tokamak (I_{pl} = 22 kA, B_t = 2.2T, R=0.55m, r=0.08m) had demonstrated effective lower hybrid (LH) plasma heating related both to the direct RF power absorption and plasma transport suppression [1]. In respect to the plasma-wave interaction, the experiments had shown that one can provide the transition from the parametric decay to the linear LH resonance wave absorption mechanism at the same launched RF power.

The present paper describes experimentally observed transport barrier formation initialised by the LH heating for various plasma experimental scenarios. A model for the internal (ITB) and external (ETB) transport barrier formation is discussed. It is shown that the key factor for the improved central confinement and the L-H transition is the additional radial electric field generated as a result of high central ion heating.

Experimental observations.

The RF power (920 MHz, 100 kW) was launched into the plasma with a two-waveguide grill, utilising the 180° waveguide phasing [1]. The comparative study of plasma confinement for two typical RF heating scenarios was performed in the experiment. In the first of them, labelled below as (a), the central ion absorption of RF power was achieved, which lead to a pronounced ion heating from 100 eV to 300 eV localised at the discharge axis (Fig.1). In the second scenario, characterized by a slightly higher central plasma density, exceeding the LH resonance value, the power deposition region was shifted from the axis, which resulted in a broader ion temperature profile and smaller ion heating effect from 100 eV to 200 eV (Fig. 2).

Figures 1 - 3 demonstrate the behaviour of main plasma parameters for both cases. In Fig.1 one can see that while the ion temperature rise starts just after the RF pulse is on, the beginning of central electron heating is delayed by 1.5 ms. Furthermore, as it is seen in Fig.3, where the variation of the central plasma parameters for (a) and (b) scenarios is shown correspondingly by straight and dotted lines, the increase of T_e(r = 2cm) from 400 eV up to 650 eV during LHH is followed by a further growth up to 700 eV in the post heating stage. This fact clearly indicates that not only the RF power absorption, but improved core confinement (ICC) is as well responsible for the electron heating in this scenario. In the alternative case (b), the central electron temperature rises only slightly during the RF pulse and quickly decreases after its end. (See Fig.2, where the ion temperature (i), electron temperature and density (ii) profile evolution is shown.). It should be underlined that the well pronounced steepening of the electron temperature profile is observed in Fig.1 in the post heating stage for the (a) case, which could be accounted for an internal transport barrier formation.

As it is seen in Figs.1, 2, the ion temperature and density transport barriers formed during LHH probably exist at radii r = 5cm÷7cm for both cases (a) and (b). These suppositions were confirmed recently by new visible spectroscopy diagnostic. The diagnostic consists of high resolution Czerny-Turner spectrometer and a piezo valve puffing additionally helium via the bottom port. The spectral line HeII(468.54nm) profile was detected shot by shot by the photo-multiplier tube. The measurements of spectral line profile of ionised helium provides local values of T_i and poloidal rotation v_θ. The Doppler broadening $\Delta\lambda_D$ of the observed line is proportional to the ion temperature T_i(eV) where as the Doppler shift $\Delta\lambda = \lambda_0(v_\theta / c) \cos\theta$ of the spectral lines is a direct measure of the He^+ ion poloidal velocity v_θ. The measured change in $v_\theta = \nabla_r P_{iz} / Zen_{iz}B - E_r / B$ can be related to a change of E_r or variation of the diamagnetic drift of the helium ions. The preliminary analysis of the line profile measurements show that the poloidal velocity change in FT-2 can be understood in terms of a radial electric field variation in the edge plasma region [3]. The evolution of ion temperature for different radii is shown in Fig. 4. As it is seen, the ion temperature T_{iCX}(r=6cm) measured by CX analyser at r=6cm, and by spectrometer at r = 7cm and 8cm decreases during first 1.5 ms after the RF is on, which is typical for the formation of outer region of transport barrier.

Additional experimental evidence in favour of particle transport decrease after the LHH pulse was provided by the array of three movable multi electrode Langmuir probes positioned near the last closed magnetic surface (LCMS), which allowed the measurements of the evolution of local electron temperature, plasma density, spatial potential, electric field, as well as quasi-stationary and fluctuation-induced ExB drift flux densities practically at any poloidal angle. Fluctuations of local plasma parameters in the wide range of frequencies (10-500 kHz) and local values of fluctuation-induced particle flux were measured [4]. The measurements of integral radial flux Γ_r at r=8 cm shows that, after the RF heating is switched off, the transition to H-mode takes place, accompanied by a reduction of this flux by nearly a half of its ohmic value. The quasi-stationary radial electric field (E_r) profiles at several poloidal angles at the outer perimeter of the torus were measured using smoothed radial profiles of the electron temperature and floating potential measured by Langmuir probes. The transition to the external transport barrier (ETB) is shown to be accompanied by the appearance of a significant non-uniformity in E_r (in both poloidal angle and radius). The Langmuir probe measurements also demonstrate a sharp increase of the density gradient near the LCMS for poloidal angle of 30 degree (at the outer perimeter of the torus) [4]. This is direct experimental evidence of the transport barrier formation and significant non-uniformity in E_r.

Unfortunately the direct observations of the turbulence induced transport or at least of the turbulence spectra behaviour were only possible in the above experiments in the limiter shadow. The situation will be improved in the coming campaign, when the unique set of microwave scattering diagnostics will be installed on FT-2. The set consists of the upper hybrid resonance correlative scattering diagnostics, providing spatially and wave number resolved measurements of small scale turbulence density component and Doppler fluctuation reflectometry, utilising the oblique incidence of the probing microwave and providing data on the longer turbulence scales.

Discussion.

To explain ICC for electron component in scenario (a) we assume that effective central heating of ions (from 100 eV to 300 eV) and formation of the picked temperature profile change the radial electric field E_r spatial distribution and, as a consequence, leads to the enhancement of the shear of the poloidal rotation ω_{ExB} and suppression of drift wave turbulence. The spatial distribution of the poloidal rotation shear, given by expression

$$\omega_{ExB} = \left| \frac{B_\theta R}{2\pi B_\phi} \frac{d}{dr}\left(\frac{E_r}{B_\theta R}\right) \right|$$

,where E_r was calculated using the modified neoclassical expression [5] from the experimental temperature and density profiles. The value of toroidal electric field, which enters the expression in [5], was determined with a help of the ASTRA code. The corresponding dependencies are shown for scenario (a) in Fig. 5 for moments just before the RF pulse (curve 1) and after the ion temperature pike formation (curve 2). The curve 3 there is showing the shear distribution for the case (b). As it is seen there, unlike the case (b), the shear for (a) case possesses a maximum value of about 10^5 s^{-1} in the core region (r~ 3cm) at 1.5 ms after the pulse start. The ASTRA code simulation carried out for the (a) case shows that the electron thermal diffusivity χ_e at the same time decreases distinctly at the middle radii and remains at low level for a long time in the post heating stage [1]. This conclusion is in agreement with BATRAC transport code simulation [2], where the dramatic dependence of transport coefficients on ω_{ExB} has been demonstrated for the FT-2 (a) scenario.

It should be noted that for both regimes a huge rise of ω_{ExB} is predicted at the discharge periphery, at r = 6~8cm, just after the RF pulse is on (see Fig. 5). This process may be a key factor causing suppression of anomalous transport in the plasma edge in both scenarios. An increase of the plasma poloidal (E_rxB-) rotation shear is supposed to be responsible for the internal transport barrier formation (ITB) in the region r=5~8cm.

Conclusions.

A possibility of controlling the transport processes in the tokamak plasma with Lower Hybrid Heating (LHH) has been demonstrated. It is shown that the key factor for the improved central confinement and L-H transition is an additional radial electric field generated by high central ion heating which stimulates the growth of central electron temperature (1.5 ms after the RF switch on). An increase of the plasma poloidal E_r x B rotation shear apparently leads to the internal improved confinement (r < 5cm) for electrons, and to an internal transport barrier formation for particles and ion thermal energy at r = 5 ~ 7 cm. The ETB formation is due to a strongly non-uniform E_r after the LHH pulse switching.

The study was performed with the support of the Ministry of General and Professional Education of Russian Federation (TOO-7.4-2797) and the Russian Basic Research Foundation Grants 00-02-16927, 01-02-17926 and 01-02-06141.

References

[1] Lashkul S.I et al. Plasma Physics and Controlled Fusion .42 (2000), A169 - A174
[2] S.P. Voskoboinikov et al. Technical Physics Letters, 2000, 26, 19, (2000)39-45
[3] S.I. Lashkul et al, Proc. 2nd EPS Conf. on RF Heating and CD, Brussels, 1998, p.161
[4] S.V.Shatalin et al. Budapest, 27-th EPS Conf on Cont. Fus. and Plasma Physics, 2000, pp. 740 – 743
[5] V.A. Rozhansky et al, Plasma Physics Reports, V.27.N4, 2001, p219-224

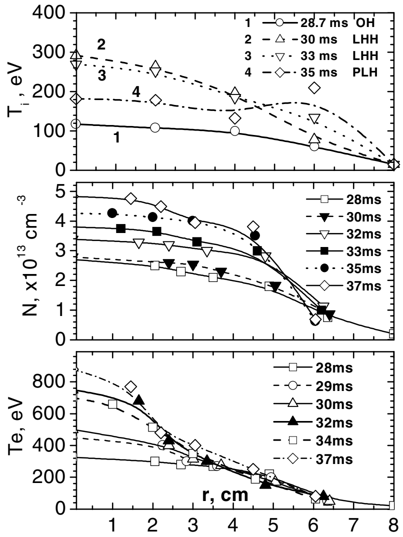

Fig. 1
The behaviour of main plasma parameters for the central ion absorption of RF power

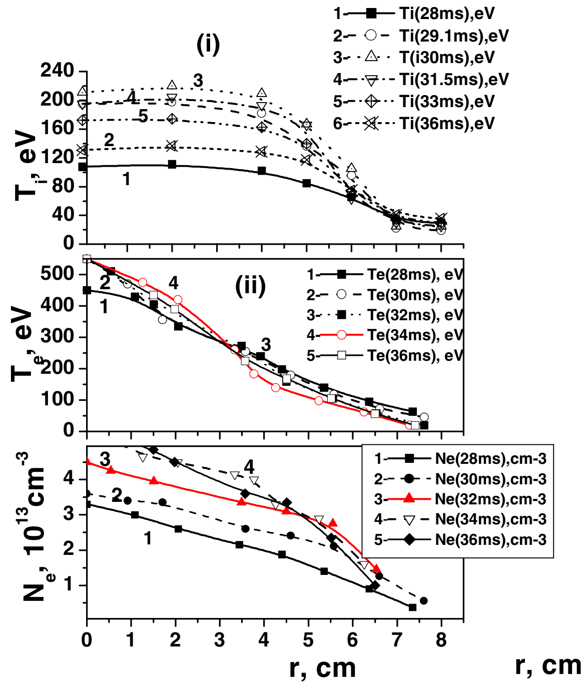

Fig. 2
The behavior of main plasma parameters for the second's scenario, when ion absorption of RF power was shifted from the axis.

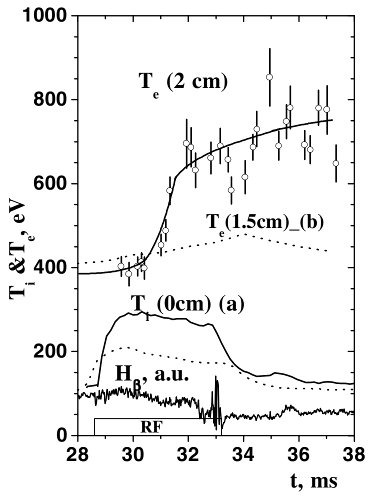

Fig. 3
The variation of the central plasma parameters for (a) and, (b) scenarios

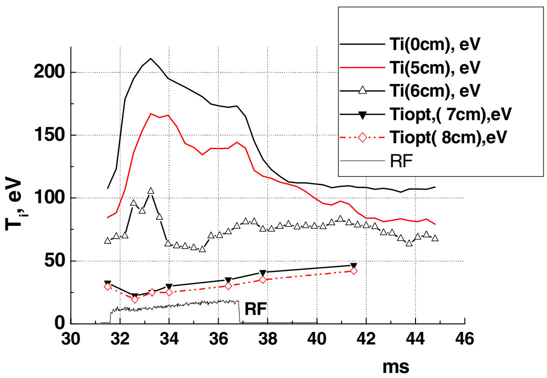

Fig. 4

The evolution of ion temperature for different radii

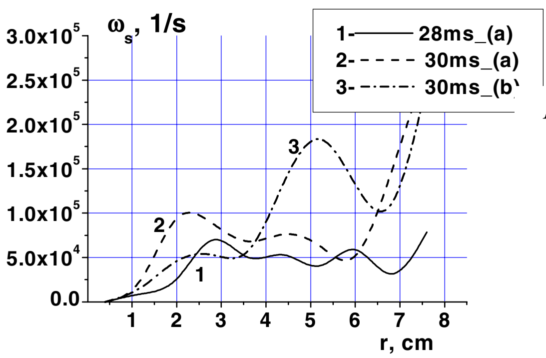

Fig. 5 The spatial distribution of the poloidal rotation shear. The corresponding dependencies are shown for scenario (a) for moments just before the RF pulse (curve 1) and after the ion temperature pick formation (curve 2). The curve 3 there is showing the shear distribution for the case (b).