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ECRH effect on the electric potential in toroidal plasmas
(Overview of recent T-10 tokamak and TJ-II stellarator results)

A.V. Melnikov[1,2], C. Hidalgo[3], L.I. Krupnik[4], E. Ascasibar[3], A. Cappa[3], A.A. Chmyga[4], G.N. Deshko[4], M.A. Drabinskij[1,5], L.G. Eliseev[1], P.O. Khabanov[1,5], S.M. Khrebtov[4], N.K. Kharchev[1], A.D. Komarov[4], A.S. Kozachek[4], S.E. Lysenko[1], J.L. dePablos[3], V.N. Zenin[1], A.I. Zhezhera[4]

[1]National Research Centre 'Kurchatov Institute', Moscow, Russia, Melnikov_AV@nrcki.ru
[2]National Research Nuclear University MEPhI, Moscow, Russia
[3]Fusion National Laboratory, CIEMAT, Madrid, Spain
[4]Institute of Plasma Physics, KIPT, Kharkov, Ukraine
[5] Moscow Institute of Physics and Technology, Dolgoprudny, Russia

Electric field E or electric potential φ plays a key role in the transport and turbulence processes in toroidal plasmas by both mean and oscillatory components. It is believed that mean radial E_r suppresses the turbulence eddies via $E\times B$ shearing mechanism, while oscillatory E_r (zonal flows and Geodesic Acoustic Modes, GAM) provides the mechanism of turbulence self-regulation [1].

ECRH/ECCD is a powerful tool to affect and to study hot plasmas confined in closed magnetic traps, aiming for both basic plasma physics and thermonuclear fusion research [2].

Various aspects of the ECRH (using from one to three gyrotrons, operated in second-harmonic X-mode with on- and off-axis power deposition) effect on the static and oscillatory component of plasma potential were studied in two machines of similar size by Heavy Ion Beam Probing (HIBP), which is a unique diagnostics for core plasma potential, operating now on the T-10 tokamak (R=1.5m, a=0.3m, B=2.4T, P_{ECRH} = 0.4-2.4MW, f_{ECRH}=129, 144GHz) and TJ-II stellarator ($<R>$=1.5m, $<a>$=0.3m, B=1T, P_{ECRH} = 0.3-0.6MW, f_{ECRH}= 53.2GHz) [3]. Fine-focused (<1cm) and intense (150μA) Cs^+ or Tl^+ beams with energy up to 300 keV, equipped with advanced control systems provide measurements in wide density interval n_e=(0.3–5)$\times10^{19}$m^{-3} in wide range of magnetic configurations in Ohmic and ECRH plasmas on T-10 and ECRH and NBI heated plasmas on TJ-II [4].

For any sign (positive or negative) and value of the mean electric potential of target plasmas, auxiliary ECRH pushes the potential evolution towards positive direction. So, the extra potential Δφ is always positive; it increases from 100V up to 400V with P_{ECRH}. The increase of P_{ECRH} raises the plasma electron temperature T_e, that causes the raise of the electric potential, see figs.1 and 2.

Contrary, Δφ decreases with plasma density raise. Plasma poloidal rotation, independently measured by HIBP with poloidal cross-phase of density perturbations, evolves accordingly [5].

Plasma potential profile evolution in the regimes with T_e and n_e changes is consistent with Neoclassical expectations [6].

Broadband electrostatic oscillations (up to 200 kHz) are strongly excited by ECRH in low-density plasmas of TJ-II, while for high-density plasmas, obtained in T-10 the effect found is opposite [6]. It was found in T-10 that the GAM frequency f_{GAM}

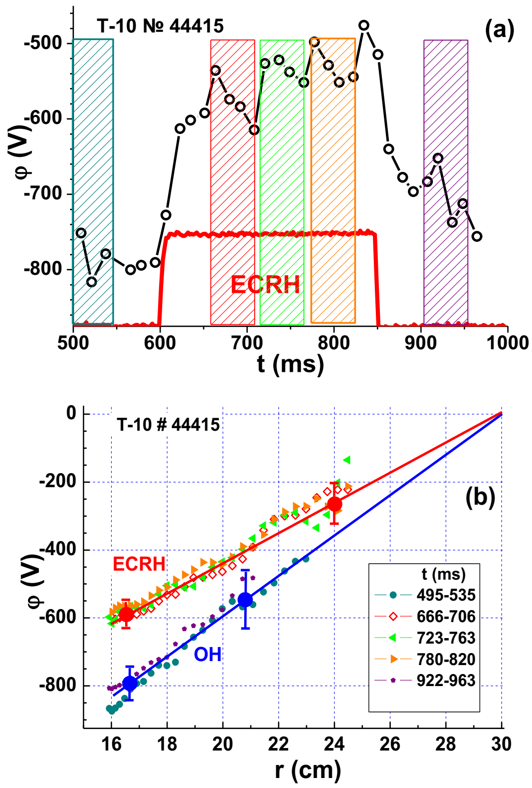

Fig. 1. Plasma potential time evolution at ρ=0.55 during an ECRH pulse (a) in ohmic (OH) discharge of the T-10 tokamak (r=16cm corresponds to ρ=0.55); Δφ (ρ=0.55)=200V. Hatched color ribbons denote the times for the profile measurements, shown in (b). The estimated error bars are in red for ECRH and in blue for OH.

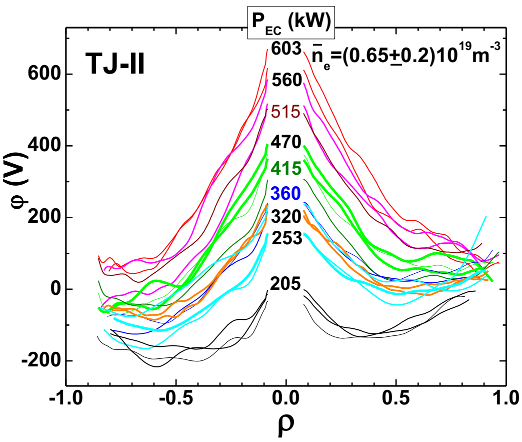

Fig. 2. Plasma potential profile dependence on P_{ECRH} in nearly on-axis ECR heating experiments in the TJ-II stellarator. Profiles are measured from Low Field Side (LFS) to High Field Side (HFS) several times during one shot.

increases with ECRH in accordance to the theoretically expected dependence on the electron temperature for the turbulence driven $f_{GAM} \sim T_e^{1/2}$ [7]. Figure 3 shows the overall T_e dependence of f_{GAM} on T_e, that was obtained in a wide range of tokamak regimes with ohmic and auxiliary ECR heating. The results show a consistency of the experimental data with the theoretical prediction for GAM, excited at r=21cm (ρ=0.7), over the whole operational limit of the machine, in which T_e varied by a factor of 4.

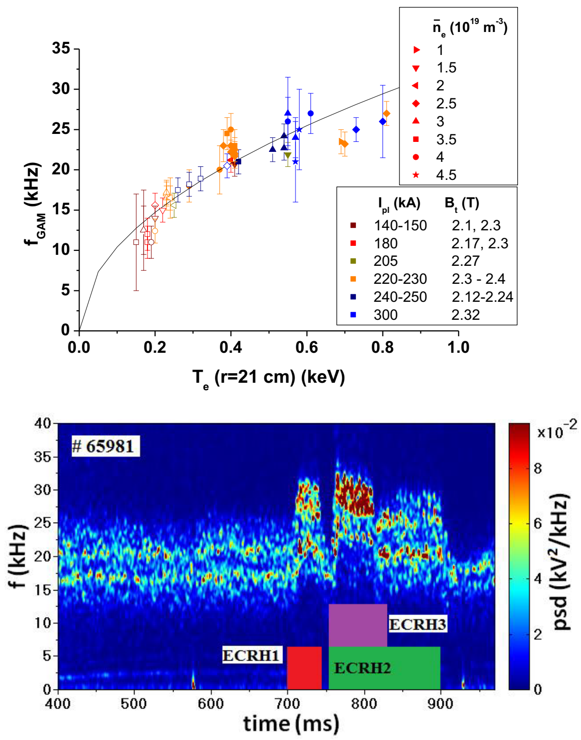

Fig. 3. ECRH effect on the GAM, as studied in the T-10 tokamak by HIBP. Upper figure: f_{GAM} dependence on T_e on OH (open symbols) and ECRH (closed symbols) discharges. Lower figure: power spectrogram of the plasma potential shows f_{GAM} time evolution in the shot with auxiliary ECRH pulses. Port-through power $P_{ECRH1} \sim$ 0.65MW, $P_{ECRH2} \sim$ 0.85MW, $P_{ECRH3} \sim$ 0.55MW. GAM is accompanied by a higher frequency satellite.

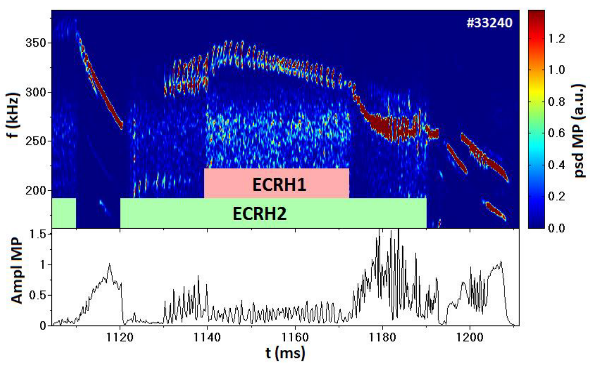

Fig. 4. ECRH effect on the NBI-indiced AE. Upper figure: power spectrogram of the Mirnov coil, presenting the transition of AE from steady frequency form in NBI phase (no ECRH) to chirping form due to ECRH/CD (ECRH2-on). An application of the second gyrotron (ECRH1) causes the suppression of the mode amplitude, as shown in lower figure.

The NBI-excited Alfven Eigenmodes (AEs) are affected strongly by ECRH: the steady frequency AEs transform to the chirping modes with frequencies up to 400 kHz [8]. A further increase of the P_{ECRH} from 0.3MW (one gyrotron on) to 0.6MW (two gyrotrons on) causes a mitigation of the AE intensity, as presented in figure 4.

In the low-density plasmas of TJ-II strong ECRH produces supra-thermal (ST) electrons, exciting electrostatic ST-modes [9].

Dual HIBP in TJ-II, consisting of two identical HIBPs located ¼ torus apart, provides measurements of stable long-range potential correlations (LRC), resembling spatially localized low-frequency zonal flows (<30 kHz) in the core of ECRH plasmas [10]. Unless LRC are also observed in the NBI-heated plasma in some conditions, their intensity in the ECRH plasma is much stronger.

Finally, various aspects of the ECRH effect on the plasma mean electric potential, broadband electrostatic turbulence, including turbulent particle flux and plasma turbulence rotation, and quasicoherent modes, including GAMs, AEs, ST-modes, will be summarized.

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