Heavy Ion Beam Probe investigations of plasma potential in ECRH and NBI in the TJ-II stellarator

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Direct measurements of electric potential and its fluctuations are of a primary importance in magnetic confinement systems [1]. The Heavy Ion Beam Probe (HIBP) diagnostic is used in TJ-II stellarator with helical axis ($<R>$ = 1.5 m, $<a>$ = 0.22 m, B_0 = 1.0 T) to study directly the plasma electric potential profiles with spatial (up to 1cm) and temporal (up to 2 μs) resolution. The singly charged heavy ions Cs $^+$ with energies up to 135 keV are used to probe the plasma column from the edge to the core. Both ECRH and NBI heated plasmas (P_{ECRH}= 200 - 400kW, P_{NBI} = 200 - 400kW, E_{NBI} = 30 kV) were studied. The NBI experiments were done with target ECRH plasma. The typical parameters were: T_e (0) ~ 1 keV, T_i ~ 80 eV, $\overline{n_e}$ ~ (0.5 - 1)×10^{19} m^{-3} and the energy confinement time τ_E ~ 3 - 4 ms [2].

Different combinations of gas puffing, ECH heating and wall conditioning scenarios have been explored aiming for the optimization of power deposition and density control in NBI plasmas. The density control in NBI discharges has proven to be difficult so far. Figure 1 shows the temporal evolution of plasma density, radiated power losses, ion temperature, stored energy, H$_\alpha$ monitors and soft-X rays. The density increases monotonically along with temperature decay until a radiation collapse occurs (Fig. 2.). Note that ECRH cut-off takes place at the local density n_e = 1.7×10^{19} m^{-3}. Plasmas created by off-axis ECH and with ECH maintained during the NBI phase, together with wall conditioning, are promising. In this way, the NBI discharges with the density control (up to 130 ms) have been obtained.

Low-density ECRH ($\overline{n_e}$ = 0.5-1.1×10^{19} m^{-3}) plasmas in TJ-II are characterised by the core positive potential of order of 500 – 1000 V and positive electric fields up to 50 V/cm [3]. Figure 3 shows the line-average density evolution, while Fig. 4 shows the plasma potential profile evolution. The presented profiles resembles the plasma potential patterns found during NBI experiments on the stellarator-torsatron CHS [1] from the positive "Bell" to the negative "Well" with intermediate "Mexican hat".

NBI plasmas are characterized by the negative electric potential in the whole plasma column and the negative radial electric fields in the range of 10 – 40 V/cm, (Fig. 4). The density rise during the NBI phase is accompanied by the decay of the core plasma potential. When the density attains the level of $\overline{n}_e \approx 2.0 \times 10^{19}$ m^{-3}, the potential stops its lowering and remains almost constant (Fig. 5). The evolution of plasma potential in one shot shows the clear link between the potential and density, but not with the method of heating, ECRH or NBI (Fig. 6). The potential profile evolves smoothly from positive to negative values passing through the zero average potential (Fig. 7).

It was reported [4] that the existence of the edge sheared flow in TJ-II requires a minimum plasma density in ECRH plasmas. Near (below) this threshold density, the level of edge turbulent transport, as well as the turbulent kinetic energy, increases significantly at the plasma edge. Langmuir probe measurements in ECRH plasmas revealed the negative E_r formation at the edge (0.85 < ρ <1), when $\overline{n}_e > 0.5 \times 10^{19}$ m^{-3}. The upgrading of the HIBP signal dynamic range allows reliable radial profiles to be obtained from the plasma center to close to the edge (0.1<ρ<0.9), where they can be overlapped with Langmuir probes data. Figure 8 shows an example of the potential profile evolution obtained in a single shot. This data shows that the origin of the negative potential is at the plasma edge; the negative well then spreads across the whole plasma radius, when the density increases. Note that both diagnostics, i.e. the HIBP and edge probes show the same critical value for the negative potential formation, $n_{cr} \sim 0.5 \times 10^{19}$ m^{-3}. Furthermore, the HIBP data shows that the negative E_r increases as the density rises above this critical value.

Conclusions

The recent study of ECE&NBI regimes in TJ-II shows:

1. The evidence of positive electric potential up to + 1300V in the low-density ECRH plasma.

2. The evidence of negative electric potential up to – 600 V in the whole NBI heated plasma column for the first time in heliac configuration.

3. Proof of the potential patterns found in CHS torsatron, for heliac configuration.

4. The density/potential link: the higher the density, the lower the plasma potential at the core and at the edge.

5. Transition from the positive potential to the negative starts at the edge when the line-averaged density exceeds a threshold value.

Acknowledgements

References

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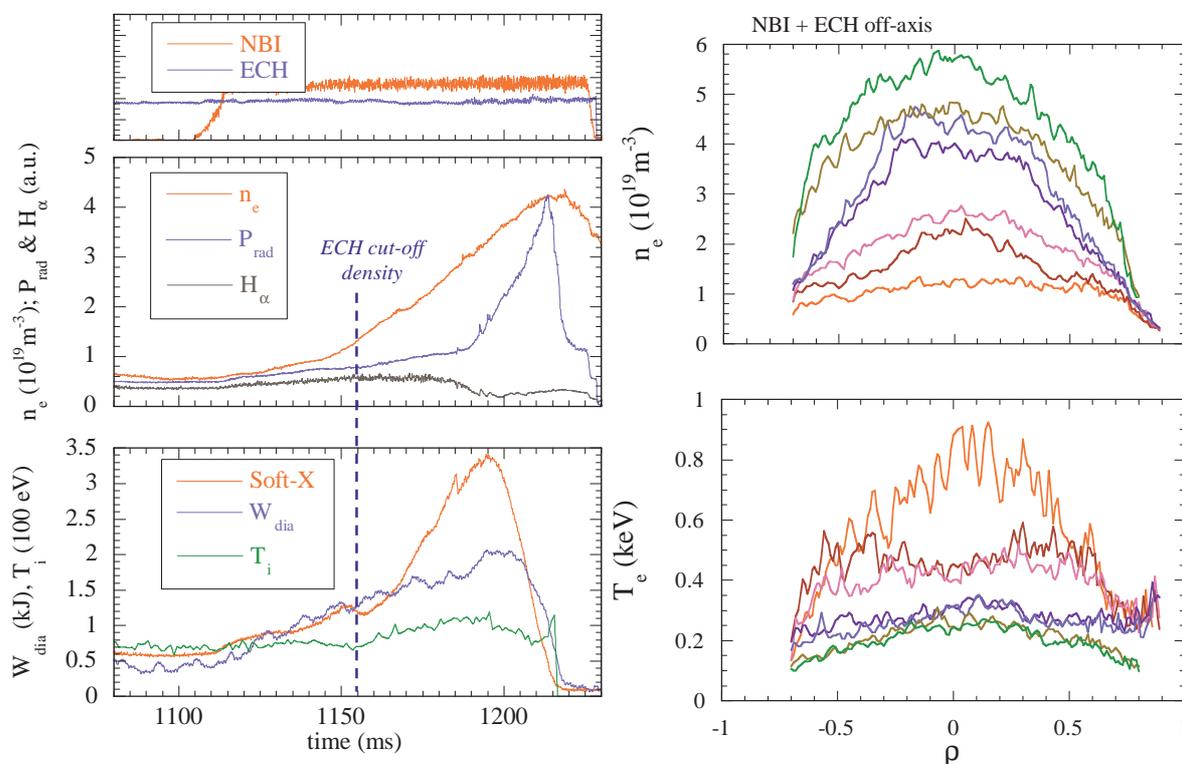[4] M.A. PEDROSA et al., *Plasma Phys. Control. Fusion* **47**, 777 (2005)

Fig. 1. The temporal evolution of a non-steady state ECRH plus NBI discharge, where the density increases up to radiation collapse. The signals shown are: ECRH and NBI monitors, line-averaged electron density $\overline{n_e}$, radiated loss P_{rad}, H_α emission, stored energy W_{dia}, soft X-ray and central ion temperature T_i.

Fig. 2. The electron density and temperature profiles evolution in the non-steady state off-axis ECRH plus NBI plasmas, measured by the Thomson scattering diagnostic for series of reproducible shots in the standard magnetic configuration (100_44_64) with $\iota(a)/2\pi \approx 1.6$. Corresponding curves are shown with the same colors.
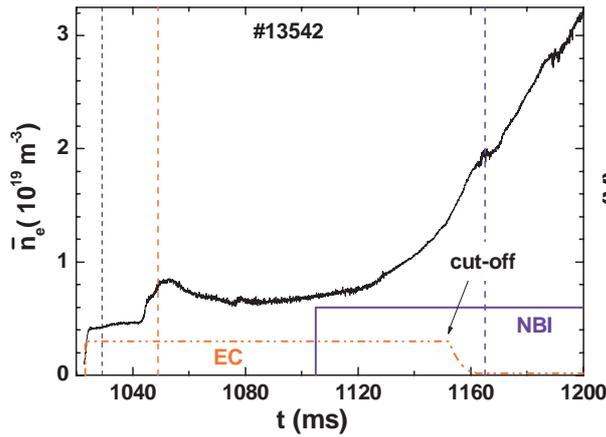
Fig. 3. The temporal evolution of the density in a non-steady ECRH and NBI shot. The vertical lines show the time instants of potential profiles measurements shown in Fig.4.
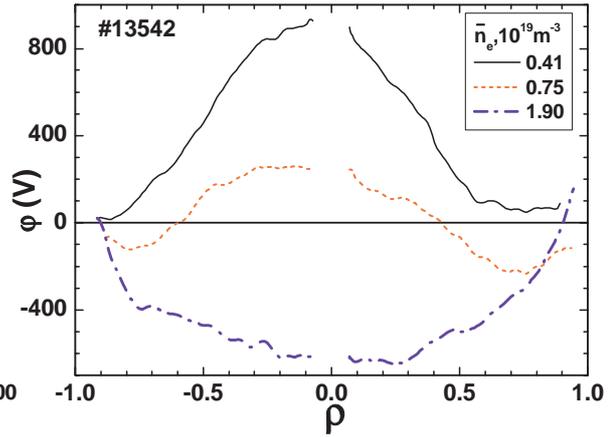

Fig. 4. Temporal evolution of the potential profile. In the ECRH phase the potential is positive, in NBI phase the potential is negative.
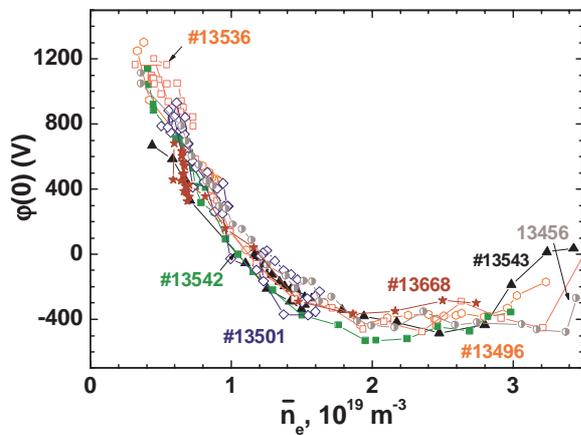

Fig. 5. The dependence of the central potential on the line-averaged electron density for several ECRH/NBI discharges.
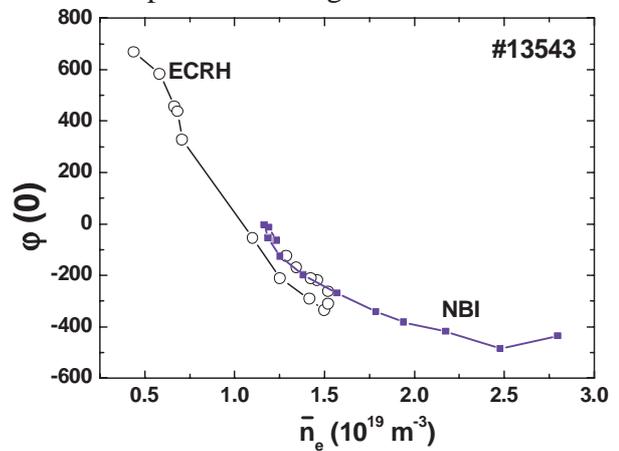

Fig. 6. The dependence of the central potential on the line-averaged electron density for a single ECRH/NBI discharge. The potential is unambiguously linked with density.
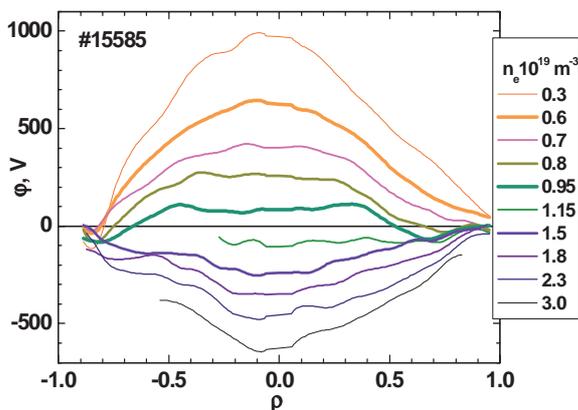

Fig. 7. The potential profile evolves smoothly from positive to negative values passing through the zero average potential.
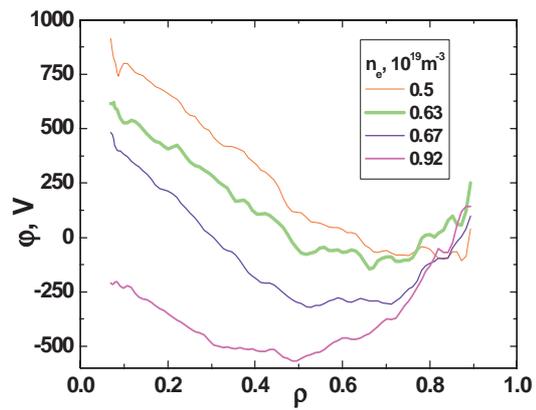

Fig. 8. The evolution of the potential profile with density in the ECRH plasma. When the density exceeds $n_{cr} = 0.5 \times 10^{19}$ m^{-3}, a negative electric field is formed near the edge.