NEW CAPABILITIES OF PLASMA POTENTIAL AND DENSITY MEASUREMENTS USING A DUAL HEAVY ION BEAM PROBING (HIBP) DIAGNOSTIC IN THE TJ-II STELLARATOR

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The unique capabilities of the dual HIBP system allow the investigation of multi-scale mechanisms to be expanded from the plasma edge to the plasma core in the TJ-II stellarator. Experiments with combined NBI and ECRH heating have shown direct experimental evidence of the influence of ECRH on turbulent mechanisms, increasing the level of fluctuation, on the amplitude of Long-Range-Correlations (LRC) as proxy of Zonal Flows (ZFs) for potential fluctuations but not for density and poloidal magnetic fluctuations and on neoclassical radial electric fields. Whereas ECRH influences the level of fluctuations in a wide range of plasma densities, ECRH induced reversal of the neoclassical radial electric field has been observed only in low-density plasmas. The TJ-II unique experimental capabilities would allow validation of nonlinear saturation of turbulence simulations (e.g. TEM), including quantitative assessments of discrepancies (e.g. level of fluctuations, correlation lengths and interplay with ZFs) between theoretical and experimental results.

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INTRODUCTION

The measurements with dual HIBP system will allow us to obtain the important information on the spatial structure of ZFs in helical device TJ-II. The dual HIBP experiment can give chance to see the correlation between fluctuations registered in different poloidal and toroidal locations practically in the whole plasma volume: on the same field line, on the same magnetic surface or on different magnetic surfaces at different points, disposed toroidally and/or poloidally. The dual HIBP system containing both HIBP-1 and HIBP-2 is aimed for the following physical tasks: 1) toroidal long-range correlations via simultaneous measurements by HIBP-1 and HIBP-2; 2) poloidal long-range correlations via simultaneous measurements by two energy analyzers in HIBP-2; 3) poloidal short-range correlations via simultaneous measurements in the set of slits by each of two energy analyzers in HIBP-2.

In the present paper we have investigated the influence of ECRH on neoclassical (radial electric fields), anomalous (fluctuation levels) and zonal flows mechanisms in the TJ-II stellarator.

1. EXPERIMENTAL SETUP

TJ-II stellarator is a four-period flexible low magnetic shear Heliac with major radius of 1.5 m, minor radius of about 0.22 m and magnetic field of 1 T. TJ-II plasmas studied here were heated by Electron Cyclotron Resonance Heating (ECRH) (2 x 300 kW gyrotrons, at 53.2 GHz, 2-nd harmonic, X-mode polarisation) and Neutral Beam Injection (NBI) (2 x 500 kW, port-through power at 33 kV). Central electron temperature and plasma density up to 1 keV and 1.7 x 10^{19} m^{-3} are achieved in ECRH plasmas, whereas in NBI sustained regimes core plasma densities and electron temperatures in the range (0.5…2) x $10^{19}m^{-3}$ and 400 eV respectively were investigated.

The TJ-II vacuum vessel is divided into four sectors that are marked in Fig. 1 as Sector A, B, C and D, corresponding to its four-fold toroidal symmetry. Each Sector is divided into 8 regions. The results reported in the paper were obtained using a unique experimental set-up in operation of the TJ-II stellarator that includes two HIBP systems (see Figs. 1, 2). The dual HIBP system [1] was used to study the temporal and spatial evolution of density and plasma potential profiles, fluctuation levels and Long-Range-Correlations (LRC) as proxy of zonal flows (ZFs) in the whole plasma cross-section.

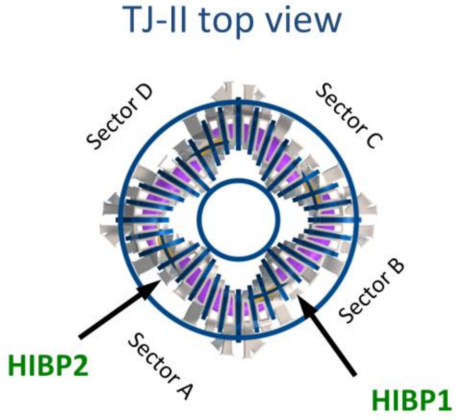

Fig. 1. Schematic view of TJ-II showing the locations of dual HIBP system

A 20-channel stainless steel split plate was used as ion beam detector in HIBP-2, while 8-channel detector is in operation in HIBP-1 at the moment [2]. The unique possibilities of the dual HIBP system allow us to expand the investigation of multi-scale mechanisms from the plasma edge, using the dual Langmuir probe system, to the plasma core.

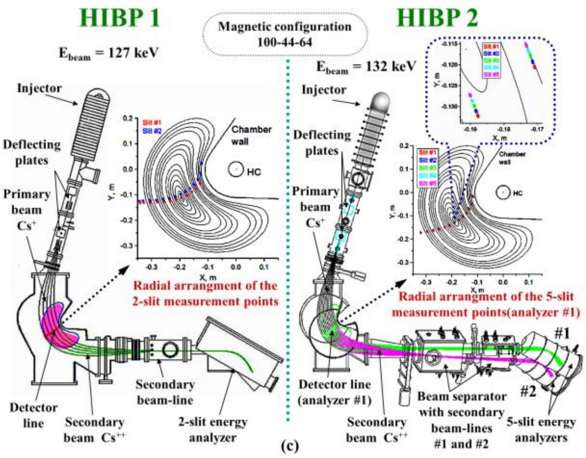

Fig. 2. The dual HIBP system

2. EXPERIMENTAL RESULTS

2.1. INFLUENCE OF ECRH ON RADIAL ELECTRIC FIELDS AND PLASMA PROFILES

Fig. 3 shows the time evolution of plasma parameters in on-axis ECRH / NBI heated plasmas and the corresponding radial profile of plasma potential. In low density plasmas ($n \approx 0.6 \text{ x } 10^{19}\ \mathrm{m^{-3}}$) according to neoclassical predictions there appears a transition from negative (ion root of the ambipolarity equation) to positive (electron root) radial electric field (Er), once ECRH is turned on [3, 4]. So far the reversal in E_r induced by ECRH has been observed at low density plasmas (see Fig. 2, #39894) but not in high density $> 1 \text{ x } 10^{19}\ \mathrm{m^{-3}}$ regimes (see Fig. 2, #40187).

As ECRH is added to the discharge at plasma densities below the ECRH density cut-off ($\approx 1.7 \text{ x } 10^{19}\ \mathrm{m^{-3}}$), a pronounce increase of electron temperature can be observed with central electron temperature reaching values up to 1 keV (see Fig. 3). It should be noted that the influence of long-scale length (neoclassical) radial electric field components on zonal flow-like structures has been recently reported in the TJ-II stellarator. The E_rxB shearing rate corresponding to the short scale length structures of the radial electric field may be sufficient to regulate turbulence. It is interesting that direct observation of fine scale structures in radial electric fields have been also reported in the JET tokamak to be consistent with stationary zonal flows.

2.2. INFLUENCE OF ECRH ON FLUCTUATION LEVEL

The influence of ECRH heating on the profile of total current fluctuation levels is illustrated in Fig. 4. In these studies the HIBP-1 system was in the radial scanning mode covering the whole TJ-II plasma cross-section (from low to high field side). The level of density plasma fluctuations significantly increased from the deep core (rho ≈ 0) up to the edge (rho ≈ 0.8) in ECRH phase.

The growth of the fluctuations level is due to the amplification of broad-band fluctuations in the 1…300 kHz range. It is empirically correlated with the peaking in the electron temperature profile while keeping plasma density roughly constant in the ion root

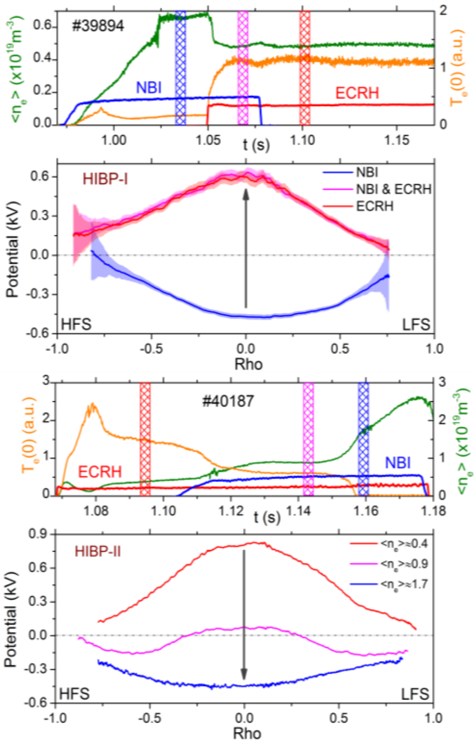

Fig. 3. Time evolution of plasma density and electron temperatures with combined ECRH / NBI regimes and corresponding plasma potential profiles in the TJ-II stellarator. The plasma potential reverses from negative values to positive values in low density plasma (#39894) but not at high density (#40187) regimes with combined ECRH and NBI heating. ECRH was on axis for shot #39894 and off-axis for shot #40187

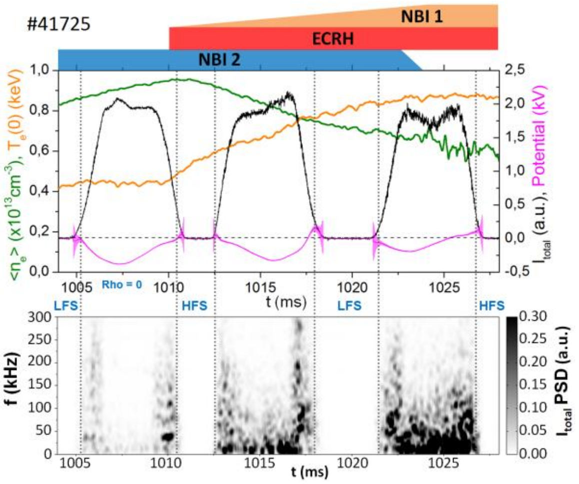

Fig. 4. Influence of ECRH on density fluctuation profiles (shot # 41725) measured with the HIBP-I system in the scanning mode

(negative radial electric field) regime. Thus, electron temperature driven instabilities (e.g. TEM) as well as ECRH induced kinetic effects can explain the observed influence of ECRH on TJ-II fluctuation levels.

It is worth noting that previous experiments in the AUG tokamak have shown that the influence of ECRH power on the turbulence level is only observed in the regions that are close to the ECRH deposition location. However, in the TJ-II stellarator the influence of ECRH on the level of fluctuations is observed in the whole plasma cross-section, as shown in Fig. 4.

2.3. INFLUENCE OF ECRH ON LRC

The amplitude of Long-Range-Correlations (LRC) increases for potential fluctuations but not for density and poloidal magnetic fluctuations as shown in Fig. 5. Furthermore, LRC of plasma potentials dominate in the low frequencies (< 20 kHz) with cross-phase near zero value, which is consistent with previous LRC studies using edge probes.

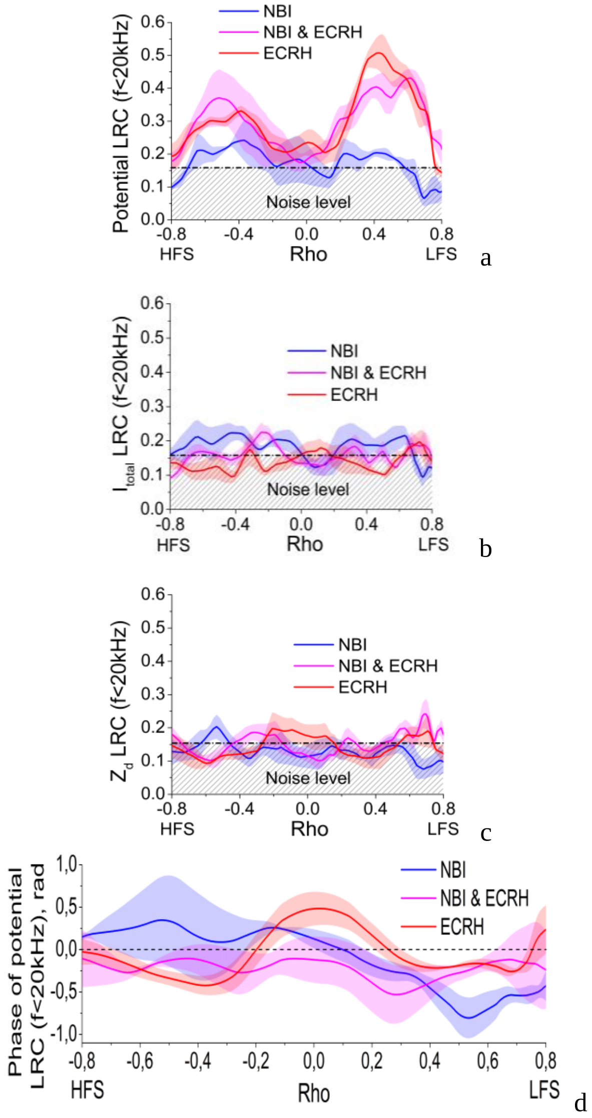

Fig. 5. Long-Range-Correlations at f<20 kHz measured with HIBP-1 in the scanning mode and HIBP-2 at point rho=-0.63 (shot #39894) for plasma potential (a), secondary ions (density) (b) and toroidal shift (poloidal magnetic fluctuations)(c), the phase of potential LRC at f < 20 kHz(d)

These results are consistent with the development of ZF structures that are amplified by ECRH. It should be noted that previous experiments in the TJ-II plasma edge region have shown that as plasma density increases, and ECRH-heated plasmas ($n < 10^{19}$ m^{-3}) give way to pure NBI-heated plasmas ($n > 10^{19}$ m^{-3}), the amplitude of LRC (characterized by the dual Langmuir probe system) increases. An experimental programme is in progress to compare the influence of ECRH on fluctuation level and LRC characterized by the dual HIBP (core and edge regions) by Langmuir probe systems in the edge region of the TJ-II stellarator.

CONCLUSIONS

Dual HIBP diagnostic is the unique tool for direct measurements of potential, density and poloidal magnetic field Long Range Correlations. Experiments in plasmas with combined NBI and ECR heating in the TJ-II stellarator have demonstrated possible influence of ECRH on turbulent mechanisms, which increase both the level of broadband fluctuations and the amplitude of LRC, as well as neoclassical radial electric fields. The TJ-II unique experimental capabilities would allow validation of data obtained by different numerical codes for turbulence simulations. Such codes evaluate quantitative assessments of discrepancies (e.g. level of fluctuations, correlation lengths and interplay with Zonal Flows) between theoretical and experimental results [5]. The additional experiments are planned to investigate the distribution of LRC in different plasma heating scenarios.

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НОВЫЕ ВОЗМОЖНОСТИ ИЗМЕРЕНИЯ ПЛОТНОСТИ И ПОТЕНЦИАЛА ПЛАЗМЫ ПРИ ИСПОЛЬЗОВАНИИ ДВОЙНОГО ДИАГНОСТИЧЕСКОГО КОМПЛЕКСА НА ПУЧКАХ ТЯЖЁЛЫХ ИОНОВ (ЗПТИ) НА СТЕЛЛАРАТОРЕ TJ-II

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Уникальные возможности двойной системы ЗПТИ позволяют расширить исследование влияния мульти-масштабных механизмов удержания от границы до центра плазмы в стеллараторе TJ-II. Эксперименты с комбинированным нагревом нейтральным пучком и электронно-циклотронным резонансом (ЭЦР) показали прямое экспериментальное доказательство влияния ЭЦР на турбулентные механизмы, приводящие к увеличению уровня флуктуаций, амплитуды дальних корреляций (как показатель зональных течений) для колебаний потенциала, неоклассического радиального электрического поля, но не для колебаний плотности плазмы и полоидального магнитного поля. В то время как ЭЦР влияет на уровень флуктуаций в достаточно широком диапазоне плотностей плазмы, индуцированный ЭЦР-переворот неоклассического радиального электрического поля наблюдается только для плазмы с низкой плотностью. Уникальные экспериментальные возможности TJ-II позволили бы проверку численного моделирования нелинейного насыщения турбулентности (например, ТЕМ), включая количественные оценки в расхождении (например, амплитуды колебаний, длины корреляции и их взаимодействие с зональными потоками) между теоретическими и экспериментальными результатами.

НОВІ МОЖЛИВОСТІ ВИМІРЮВАННЯ ГУСТИНИ ТА ПОТЕНЦІАЛУ ПЛАЗМИ ПРИ ВИКОРИСТАННІ ПОДВІЙНОГО ДІАГНОСТИЧНОГО КОМПЛЕКСУ НА ПУЧКАХ ВАЖКИХ ІОНІВ (ЗПВІ) НА СТЕЛАРАТОРІ TJ-II

О.І. Жежера, О.О. Чмига, Г.М. Дешко, Л.Г. Елісєєв, К. Ідальго, О.Д. Комаров, О.С. Козачок, Л.І. Крупнік, О.В. Мельніков, Х.Л. де Паблос, С.В. Перфілов та команда TJ-II

Унікальні можливості подвійної системи ЗПВІ дозволяють розширити дослідження впливу багато-масштабних механізмів утримання з периферії до центру плазми в стелараторі TJ-II. Експерименти з комбінованим нагрівом нейтральним пучком і електронно-циклотронним резонансом (ЕЦР) показали пряме експериментальне підтвердження впливу ЕЦР на турбулентні механізми, що приводять до збільшення рівня флуктуацій, амплітуди далеких кореляцій (як показник зональних течій) для коливань потенціалу, неокласичного радіального електричного поля, але не для коливань густини плазми і полоідального магнітного поля. У той час як ЕЦР впливає на рівень флуктуацій в досить широкому діапазоні густини плазми, індукований ЕЦР-переворот неокласичного радіального електричного поля спостерігається тільки для плазми з низькою густиною. Унікальні експериментальні можливості TJ-II дозволили б перевірку чисельного моделювання нелінійного насичення турбулентності (наприклад, ТЕМ), включаючи кількісні оцінки в розходженні (наприклад, амплітуди коливань, довжини кореляції і їх взаємодія з зональними потоками) між теоретичними і експериментальними результатами.