A DUAL HEAVY ION BEAM PROBE DIAGNOSTIC ON THE TJ-II STELLARATOR

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The aim of the report is to show the development of HIBP diagnostics on the TJ-II stellarator and, as a result, the expansion of the range of plasma parameters measurements. The first Heavy Ion Beam Probe (HIBP-1) diagnostic is being used on TJ-II stellarator since 2000. It has been shown significant progress in the measurements of plasma profiles and oscillations. The second HIBP-2 system was installed on TJ-II in 2012. Dual HIBP system, consisting of two identical HIBP-1 and HIBP-2 located ¼ torus apart, provides the measurement of the long-range correlations of plasma parameters in the full plasma column. Low noise high gain (10^7 V/A) preamplifiers with 1 MHz bandwidth sampling is used. They allow to study broadband turbulence and quasi-coherent modes like geodesic acoustic modes, Alfven eigenmodes, suprathermal electron induced modes, etc. New capabilities of the dual HIBP diagnostic in plasma potential and density investigations were demonstrated on TJ-II stellarator in the measurements of the correlation between fluctuations in different poloidal and toroidal locations: on the same field line, on the same magnetic surface or on different magnetic surfaces at different points, separated toroidally and/or poloidally.

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INTRODUCTION

The first plasma in TJ-II stellarator was produced in 1997. The locations of main diagnostics and parameters are shown in Fig. 1 and Table 1.

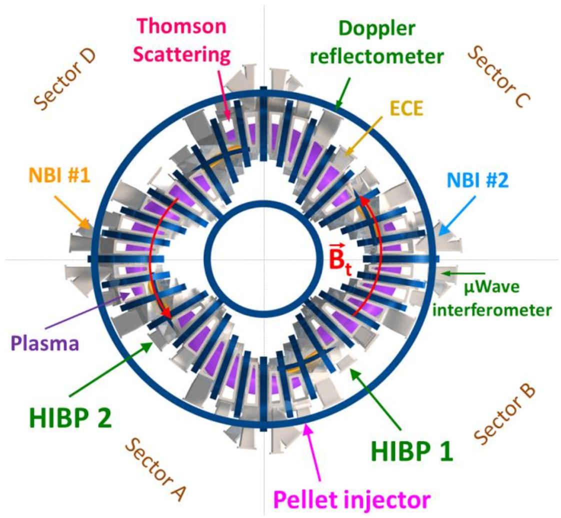

Fig. 1. Schematic view of TJ-II stellarator with the locations of dual HIBP diagnostic

HIBP-1 diagnostic was installed in 2000 [1, 2] and had the following parameters: injector primary cesium ion current 30…60 μA, energy analyzer – 1 slit/4 collectors, amplifier frequency bandwidth 125 kHz.

The initial HIBP-2 parameters (2012 year) were: injector primary ion current 50…100 μA, energy analyzer 5 slit/20 collectors, preamplifier frequency bandwidth 500 kHz [3].

Both HIBP-1 and HIBP-2 of dual HIBP operate in the similar cross-section of TJ-II vacuum chamber, located 90 degrees toroidally apart (see Fig. 1). Distance between measurement points of the diagnostics in toroidal direction is 2...3 m. The main HIBP parameters are shown in Table 2 for injectors and Table 3 for analyzers.

HIBP-2 diagnostic differs from HIBP-1. It has 2 energy analyzers contrasting to one analyzer in HIBP-1 [4].

Each analyzer of HIBP-2 has 5 entrance slits (20 channels of simultaneous measurements), HIBP-1 has 2 entrance slits (8 channels).

Table 1

Main parameters of the stellarator TJ-II

Parameter	Value	Unit
Major radius, R_0	1.5	m
Minor radius, a	‹ 0.22	m
Plasma volume, V	1	m^3
Field periods	4	–
TF coils	32	–
Numbers of ports	104	–
Rotational transform, $l/2\pi$	0.9…2.5	–
Magnetic field on axis, B_0	~1	T
ECRH heating power, P_{ECRH}	‹ 600	kW
NBI heating power, P_{NBI}	‹ 1	MW
Density, n_e	‹ 6	10^{19} m^{-3}
Pulse length	‹ 300	ms

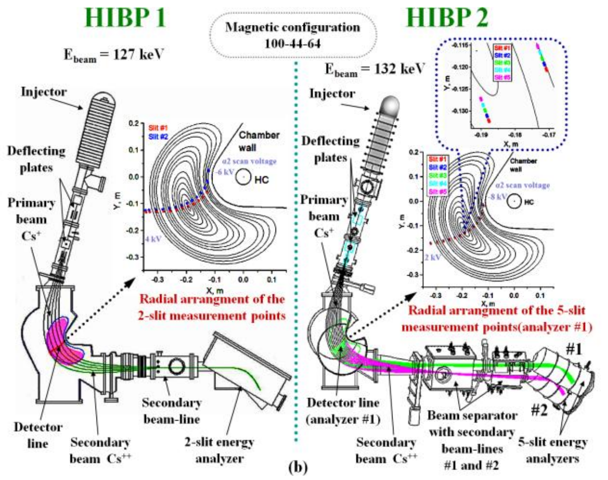

Fig. 2. Schematic of Dual HIBP and measurement points position (radial scan) in plasma with the standard TJ-II magnetic configuration

Table 2

Parameters of injectors: primary ion current $\boldsymbol{I_{pc}}$*, Faraday cup diameter internal* $\boldsymbol{Ø_{FC}}$*, distance between deflecting plates* $\boldsymbol{l_{DP}}$

Injector	I_{pc}, μA	$Ø_{FC}$, mm	l_{DP}, mm
HIBP-1	30…200	26	25
HIBP-2	30…350	50	35

Table 3

Parameters of analyzers

Analyzer	№ analyzers	Slits/ channels	Amplifier location	U_{beam}/U_{an}, kV
HIBP-1	1	2/8	external	127/23.55
HIBP-2	2	2·5/20	internal	132/22.65

1. HIBP DIAGNOSTICS OPTIMIZATION

The large-scale modernization of dual HIBP diagnostic was recently completed. Modernization was carried out in the following areas:

– injectors – upgrade of the emitter block design and, emitter manufacturing technology;

– energy analyzers – installation of two entrance slits (8 measurement channels) on HIBP-1, adjustment of analyzer 2 on HIBP-2 (5 slits, 20 channels), upgrade of amplifiers for HIBP-1 and HIBP-2 analyzers (1 MHz bandwidth and 10^7 V/A gain);

– software – upgrade of the program for monitoring and controlling parameters of dual HIBP.

This modernization allows to simplify the control and monitoring of the system parameters, increase the life-time of the solid-state cesium thermo-ionic emitter. Increase in the primary ion current (up to 200 μA for HIBP-1 and up to 350 μA for HIBP-2) allows to improve the signal-to-noise ratio at the periphery and at the center of the plasma (at a density up to $3 \cdot 10^{19}$ m^{-3}).

2. EXPERIMENTAL RESULTS

HIBP-1 and HIBP-2 (Fig. 2) may operate separately or jointly (simultaneously). Simultaneous operation of both HIBPs is aimed to study the long-range correlation (LRC) of the oscillations of the core plasma electrostatic potential, density and poloidal magnetic field, and so directed to the study of Alfvén eigenmodes (AE) and zonal flows in toroidal plasmas.

2.1. LONG-RANGE PLASMA POTENTIAL CORRELATION

Long-range plasma potential correlations present a fingerprint of the plasma behavior during the development of edge shear flows and the key role of electric fields to amplify them.

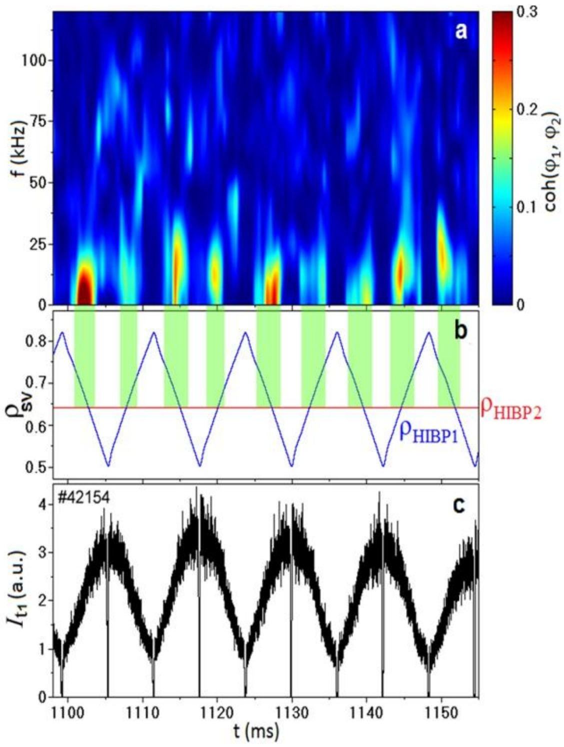

Fig. 3. Spectrogram of the coherence between potential signals, Phi1 detected by HIBP-1 and Phi2 detected by HIBP-2. Bursts of coherency between potentials at the coincidence of SV radial positions for both beams evidence to LRCs of potential, localized at the certain radius (a); HIBP-1 scans over the Low-field-side of the plasma cross section, HIBP-2 in the fixed position (b); variation of total beam current (plasma density) during radial scan (c)

Results (Figs. 3-5)show the presence of the long-range correlations in potential fluctuations, which are amplified by the development of radial electric fields during ECRH, whereas there is no correlation between ion saturation current signals [5, 6].

2.2. ALFVEN EIGENMODES ($\boldsymbol{f_{AE}}$ ~ 100…300 kHz)

Spatial distribution of AEs was studied by dual HIBP in the plasma core [7, 8]. Spectrogram of the coherence between potential signals is shown on Fig. 6.

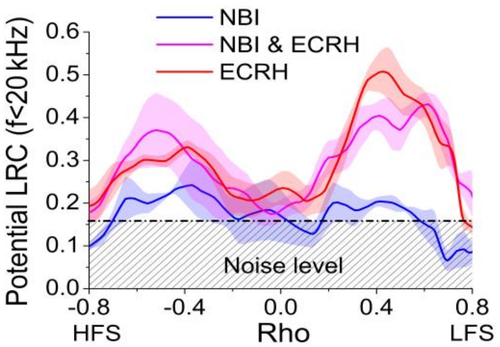

Fig. 4. LRCs in the plasma potential averaged over 0<f< 20 kHz measured with HIBP-1 in the scanning mode and HIBP-2 at the fixed point rho=-0.63 (shot #39894) are significantly increase when ECRH is applied

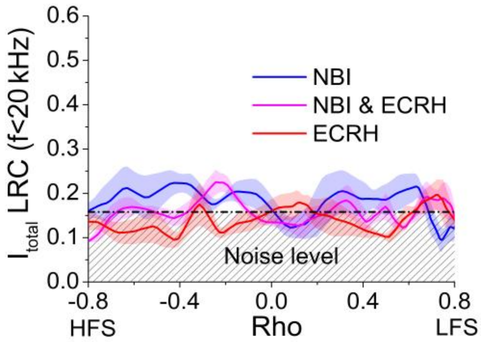

Fig. 5. LRCs averaged over 0<f< 20 kHz in the secondary beam total current (which is proportional to the plasma density) are in the order of the noise level in all heating scenarios

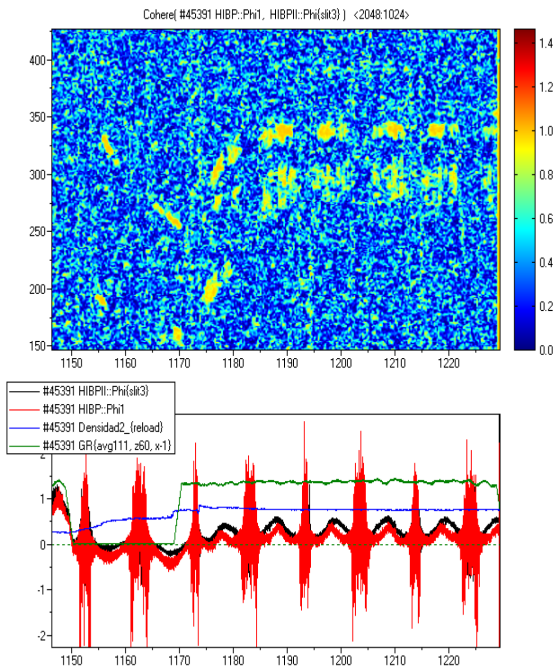

Fig. 6. Spectrogram of the coherence between potential signals, Phi1 detected by HIBP-1 and Phi2 detected by HIBP-2, both scan over the plasma cross section (a). Plasma potentials during NBI and NBI+ECRH (b)

2.2. INFLUENCE OF PELLETS ON PLASMA POTENTIAL AND FLUCTUATION LEVELS

The influence of pellets on core plasma turbulence and plasma profiles has been recently investigated using the dual HIBP. Experiments (Fig. 7) show the change in plasma potential (transition from ion to electron root of the ambipolarity equation) [9, 10]. Density fluctuations is strongly reduced in a short time scale (1 ms), followed by an increase along the evolution of plasma density and the recovery of the electron temperature [11].

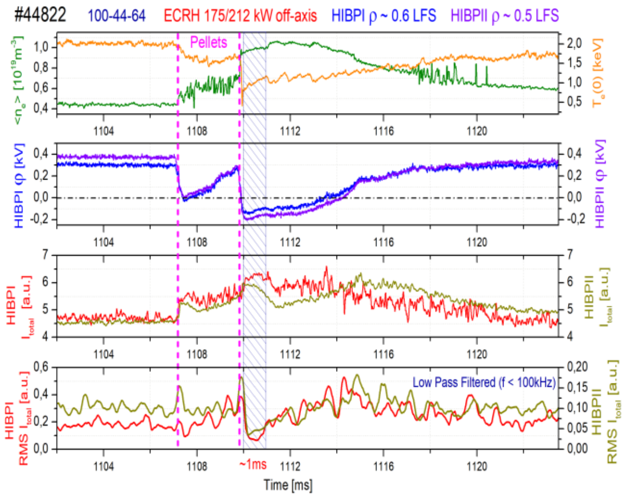

Fig. 7. Influence of pellets on plasma potential and fluctuation levels

CONCLUSIONS

HIBP is a unique diagnostic to study directly plasma electric potential and turbulence characteristics in toroidal plasmas. The dual HIBP diagnostic is the next level of development of this diagnostic, which allows to measure long-range correlations in plasma potential and density, toroidal and poloidal structure of plasma turbulence and instability modes in the core and edge plasmas. Development of this diagnostic on TJ-II stellarator opens unique possibilities in this field, which is the most interesting and fast growing branch of both fundamental and applied physics of the magnetically confined plasma [12]. At present, dual HIBP is involved in all pilot physical programs of TJ-II: Zonal Flow, L-H transitions, ELMs characteristics, Alfven modes, MHD-activity, pellets experiment, etc. Next steps of optimization will be an upgrade of the HIBP-1 primary beam-line to increase ion current to the level of the HIBP-2, installation of focusing power supplies on dual HIBP diagnostic to optimize the focusing process of the primary ion beams, modify the HIBP-1 analyzer – 5 slits/20 channels.

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ДВОЙНАЯ ДИАГНОСТИКА ЗОНДИРОВАНИЯ ПЛАЗМЫ ПУЧКОМ ТЯЖЕЛЫХ ИОНОВ НА СТЕЛЛАРАТОРЕ TJ-II

А.А. Чмыга, E. Ascasibar, J. Barcala, М.А. Драбинский, Л.Г. Елисеев, C. Hidalgo, П.О. Хабанов, С.М. Хребтов, А.Д. Комаров, А.С. Козачек, Л.И. Крупник, С.Е. Лысенко, А.В. Мельников, A. Molinero, J.L. de Pablos, С.В. Перфилов, В.Н. Зенин и TJ-II группа

На стеллараторе TJ-II создана двойная система зондирования плазмы пучком тяжелых ионов (ЗППТИ). Система состоит из двух идентичных комплексов, расположенных на расстоянии ¼ тора. Первый диагностический комплекс начал действовать в 2000 году. Второй комплекс был установлен в 2012 году. Использование усилителей детекторных сигналов с низким уровнем шума (10^7 В/А) и полосой пропускания 1 МГц позволяет изучать широкополосную турбулентность и квазикогерентные моды, такие как геодезические акустические моды; альфвеновские собственные моды; моды, индуцированные надтепловыми электронами и т. д. Новые возможности двойной системы были продемонстрированы при измерениях дальних корреляций между флуктуациями, измеренными в различных полоидальних и тороидальных положениях: на одной или на разных магнитных поверхностях, в различных точках, смещенных тороидально и/или полоидально.

ПОДВІЙНА ДІАГНОСТИКА ЗОНДУВАННЯ ПЛАЗМИ ПУЧКОМ ВАЖКИХ ІОНІВ НА СТЕЛАРАТОРІ TJ-II

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На стелараторі TJ-II створена подвійна система зондування плазми пучком важких іонів (ЗППВІ). Система складається з двох ідентичних комплексів, розташованих на відстані ¼ тора. Перший діагностичний комплекс почав діяти в 2000 році. Другий комплекс був встановлений в 2012 році. Використання підсилювачів детекторних сигналів з низьким рівнем шуму (10^7 В/А) з пропускною здатністю 1 МГц дозволяє вивчати широкосмугову турбулентність та квазікогерентні режими, такі як геодезичні акустичні моди; альфвенівські моди; супертермальні моди, які збурюються швидкими електронами, тощо. Нові можливості подвійної системи були продемонстровані при вимірюваннях далеких кореляцій між флуктуаціями в різних полоїдальних та тороїдальних місцях: на одній лінії магнітного поля, на одній або на різних магнітних поверхнях у різних точках, розташованих тороїдально та/або полоїдально.