PLASMA DIAGNOSTICS

FEATURES OF HIBP DIAGNOSTICS APPLICATION TO STELLARATOR-LIKE DEVICES

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Features of heavy ion beam probe application to stellarator-like devices have been connected with specific stellarator characteristics: zero (negligible) plasma current, relatively high poloidal and stray magnetic fields, toroidal asymmetry of magnetic surfaces and various operational regimes connected with different magnetic configurations. This paper shows how to decrease the errors in HIBP measurements due to these disadvantages. Absence of the plasma current in stellarator-like devices gives possibility to make secondary ion beam energy analyzer calibration *in situ* in each plasma shot. This advantage improves accuracy of plasma potential measurements by HIBP diagnostic on TJ-II stellarator.

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INTRODUCTION

The absence of plasma current in the stellarator devices leads to the uniformity of the probing beams trajectories during plasma discharge and without it in the same confinement magnetic fields. This feature may be used for analyzer calibration *in situ* in each shot just after plasma pulse during magnetic field flattop. The improved HIBP experiment, applied in TJ-II, based on this calibration.

Relatively high poloidal and stray magnetic fields, toroidal asymmetry and different magnetic configurations result in 3D nature of the probing beam trajectories; toroidal beam focusing and toroidal displacement of sample volumes. These features were taken into account in optimization of HIBP diagnostics geometry and HIBP experiments on the TJ-II stellarator.

1. HIBP MEASUREMENTS DIFFICULTIES

Typical displacement of secondary ion beam toroidal coordinate in TJ-II is about half of meter. This displacement leads to difficulties of beam passing through stellarator-like devices. Magnetic fields are focusing the probing beam trajectories. There are as poloidal so toroidal beam focusing in tokamaks and stellarators. Strong focusing of toroidal beam projections – toroidal focusing exists only in devices with high poloidal magnetic field. It limits the probing beam passing conditions to analyzer through secondary beam-line.

By variations of toroidal injection angle beam with fixed injection energy and poloidal injection angle go out stellarator port (dark area) and must pass into detector aperture. Due to toroidal focusing with strong threshold in Z coordinate not all detector positions can be used. Detector with Z_d position bigger then Z_{thr} cannot measure probing particles. Z_{thr} coordinate changes with energy/poloidal angle. So in real experiments with strong toroidal focusing it must be used movable in toroidal direction detector.

Fig.1 demonstrates the experimental detector lines in TJ-II with different toroidal positions of detector (Zd). In radial profile mode of HIBP implementation location of measurement point (so-called sample volume) is movedthrough plasma bulk along detector line. Changing of the poloidal injection angle controls position of sample volume. Conditions of toroidal focusing link directly with poloidal injection angle. It leads to limitation of detector line length when detector toroidal coordinate (Z_d) bigger then threshold one (shots 9044, 9062, 9079). Limitation was avoided when detector was shifted up to –2 cm (shot 9298) from secondary beam-line center.

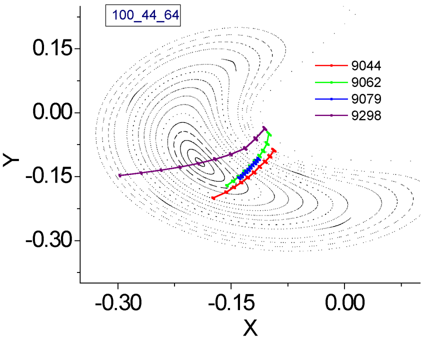

Fig.1. Detector lines obtained in different toroidal position of detector Z_d=0,1,2,-2

2. IMPROVED EXPERIMENTAL MANUAL OF THE PLASMA POTENTIAL PROCESSING

Traditionally plasma potential φ for HIBP diagnostics was calculated by formula [1, 2]:

$$\varphi=2(G+\delta i\,F)U_a-U_b$$

where G and F are gain and dynamic functions of electrostatic energy analyzer, U_a and U_b are analyzer and injector voltages respectively, δi is normalized difference of currents calculated by: $\delta i=\dfrac{(i_1-i_2)}{(i_1+i_2)}$ where i_1 and i_2 are beam currents on the upper and lower analyzer collector plates.

In general, there is a set of errors in plasma potential processing. Firstly, gain analyzer function strongly depends on entrance angles and toroidal beam position. In real plasma experiments some uncertainties exist in values of these parameters. Secondly, plasma loading and partial beam cutting in vacuum vessel and beam- lines also lead to errors in potential measurement. In time evolution mode of HIBP potential measurements this erroneous result in absolute value of plasma potential. But in potential profile mode they lead to shape distortion of relative potential profiles.

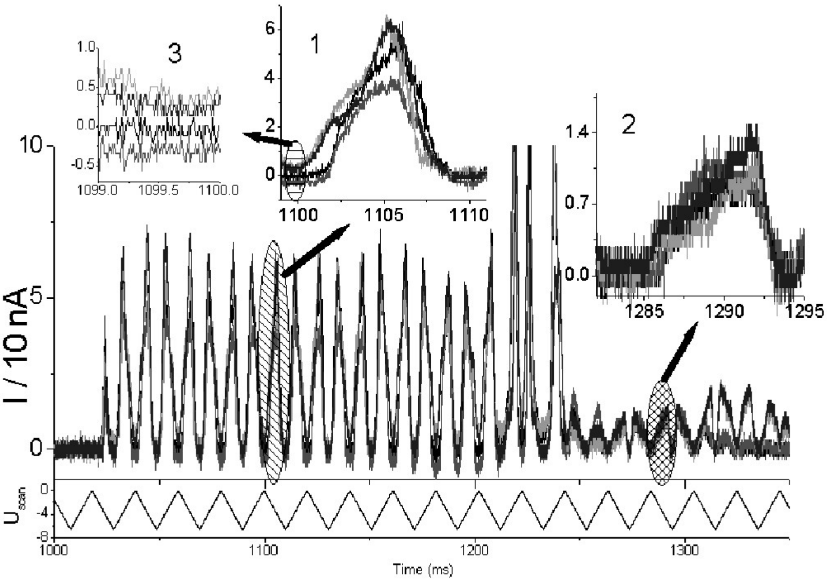

Fig.2. Current signals from four splitting detector plates of energy analyzer during one TJ-II pulse

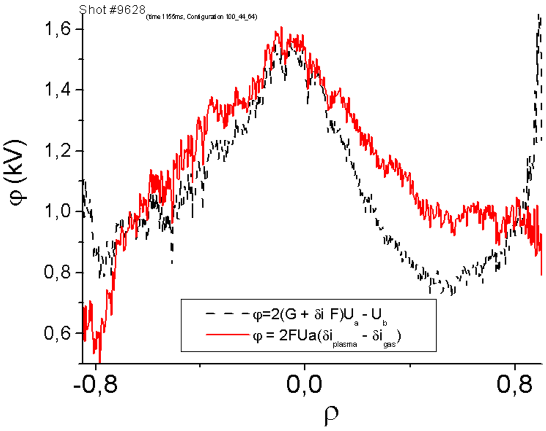

Fig.3. Radial profiles of plasma potential

Shot # 9527, configuration 59_85_62

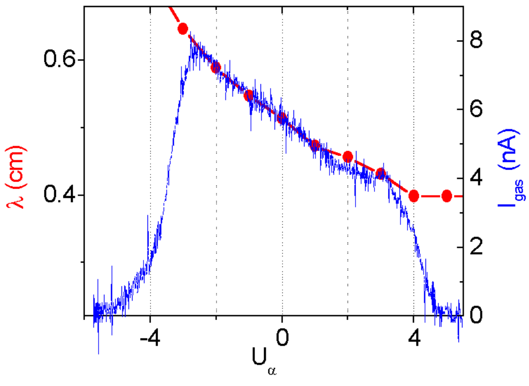

Fig.4 Total beam current versus poloidal sweeping voltage in gas target and calculated length of sample volume

In stellarators without plasma current mentioned above errors in plasma and in gas target are the same in potential processing. It is possible to take into account these errors by gas target calibration *in situ*. Errors from beam entrance angels and beam position are present in traditional formula as additive values. In the case of small beam cutting (i_1, i_2 >>j_1, j_2, where j_1, j_2 loosed on the walls part of beam currents) errors in measured normalized difference of currents may be presented as additive value:

$$\delta i' = \frac{(i_1 - j_1) - (i_2 - j_2)}{(i_1 - j_1) + (i_2 - j_2)} | \text{¿}$$

$$i_1 >> j_1$$

$$i_2 >> j_2$$

$$\underset{\text{¿}}{\text{¿}}\text{¿¿¿¿¿¿}\,\delta i + \frac{j_2 - j_1}{i_1 + i_2}\,\text{¿}$$

where δi –current difference without beam cutting.

In this case it is possible to use corrected expression:

$$\varphi_{cor} = \varphi_{plasma} - \varphi_{gas} = 2\ FU_a(\delta i_{plasma} - \delta i_{gas})$$

where δi_{plasma} and δi_{gas} - values obtained on plasma and gas target accordingly.

Fig.2 demonstrates the secondary beam currents on four splitting detector plates during one TJ-II pulse. HIBP diagnostic was worked in space mode of measurements. Sample volume location moved along radius through plasma bulk. Sweeping voltage controlled the entrance angle. Sample volume crossed plasma balk many times during one shot. To apply this proposed *in situ* calibration addition helium gas puff was used after plasma shot during magnetic field flattop. In the time interval from 1050 to 1220 ms HIBP measured signals from plasma. In part 1 and 2 (Fig.2) beam currents obtained in one scan time in plasma and gas target accordingly are presented. Part 3 demonstrate plasma loading signals. These data are taking into account in plasma potential processing.

Described above manual in the plasma potential processing was used in TJ-II stellarator. Fig.3 shows two radial plasma potential profiles obtained by traditional experimental processing (dotted) and developed for TJ-II (fat).

It is seen strong difference of profiles due to same errors described above.

3. IMPROVED EXPERIMENTAL MANUAL OF DENSITY PROFILE PROCESSING

Intensity of total beam current with neglect beam attenuation (rather small n_e) given in [2]: $I_{total} \sim n_e \sigma_{eff} \lambda$ where n_e – plasma electron density, σ_{eff} – effective ionization cross section of the primary ions (constant in plasma bulk), λ - sample volume length. In space profile mode of HIBP measurements sample volume length is a function of the measurement position due to radial dependence on poloidal beam focusing. For measurement of the electron density radial profile it is necessary to normalize the total current profile to $\lambda(\rho)$ one. It is possible to calculate this function $\lambda(\rho)$ and also it is possible to measure it directly. In stellarators (zero plasma current) trajectories of probing beams in plasma and gas targets are uniform, so dependence of $\lambda(\rho)$ is also uniform. Radial profile of total beam current in gas target depends only on $\lambda(\rho)$ because gas density and σ_{eff} are constants. It is possible to normalize the electron density profile by function $\lambda(\rho)$. Fig.4 shows comparison of measured total beam current in gas target and calculated $\lambda(\rho)$ profile. Area of poloidal swiping voltages from –3 kV to 2.5 kV corresponds to normalized radius from –1 to 1. Beam current and sample volume length are proportional. In stellarators devices magnetic surfaces are not symmetric, and it is necessary to take into account density of magnetic surfaces along detector line. Proposed above manual of density profile processing takes into account only geometric problems of sample volume. Real measurements must be link with calculations.

CONCLUSIONS

There are some disadvantages of the HIBP diagnostics implementation in stellarator-like devices. Some of them have been analyzed in this article. To decrease the errors in HIBP measurements due to these disadvantages it is necessary to elaborate the HIBP geometry optimization. Development and installation of beam control systems in HIBP equipments are useful in plasma parameters processing.

Absence of the plasma current in stellarator-like devices gives a possibility to make analyzer calibration *in situ* in each plasma shot. This advantage improves accuracy of plasma potential measurements by HIBP diagnostics.

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REFERENCES

1. T.S. Green, G.A. Proca. A parallel plate electrostatic energy analyzer // *Rev. Sci. Instr*. 1970, v. 41, N10, p.1409-1414.
2. T.P. Crowley. Rensselaer Heavy Ion Beam Probe Diagnostic Methods and Techniques// *IEEE Trans. Plasma Sci.* August, 1994, v. 22, N 4, p.291-309
3. I.S. Nedzelskiy, A. Malaquias, B. Goncalves, C.A.F.Varandas, J.A.C. Cabral, N.B. Dreval, S.M.Khrebtov, A.D. Komarov, A.L. Kozachok, L.I. Krupnik // *Review of Scientific Instruments.* 2003, v.74, Issue 3, p.1850-1852
4. I.S. Bondarenko, A.A. Chmyga, N.B. Dreval, S.M.Khrebtov, A.D. Komarov, A.S. Kozachek, L.I. Krupnik, P. Coelho, M. Cunha, B. Goncalves, A. Malaquias, I.S. Nedzelskiy, C.A.F. Varandas, C. Hidalgo, I. Garcia-Cortes, A.V. Melnikov // *Rev. Sci. Instr.* January, 2001, v. 72, N 1, p.583-585.

ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ HIBP ДИАГНОСТИКИ ДЛЯ УСТАНОВОК СТЕЛЛАРАТОРНОГО ТИПА

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Возможности применения диагностики плазмы с помощью пучка тяжелых ионов в установках стеллараторного типа связаны со специфическими характеристиками стеллараторов: практически нулевой ток плазмы, относительно высокие значения полоидальных и рассеянных магнитных полей, тороидальная ассиметрия магнитных поверхностей; и различными режимами работы с разными магнитными конфигурациями. Показано, как можно снизить уровень ошибок HIBP измерений, вызванных этими неблагоприятными условиями. Отсутствие тока плазмы в установках стеллаторного типа дает возможность проводить калибровку анализатора энергий вторичного пучка ионов непосредственно в каждом плазменном разряде. Это позволяет увеличить точность измерения потенциала плазмы с помощью пучка тяжелых ионов на стеллараторе TJ-II.

МОЖЛИВОСТІ ЗАСТОСУВАННЯ HIBP ДІАГНОСТИКИ ДЛЯ ПРИСТРОЇВ СТЕЛЛАРАТОРНОГО ТИПУ

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Можливості застосування діагностики плазми за допомогою пучка важких іонів у пристроях стеллараторного типу зв’язані зі специфічними характеристиками стеллараторів: практично нульовий струм плазми, відносно високі значення полоідальних і розсіяних магнітних полів, тороідальна асиметрія магнітних поверхонь; і різними режимами роботи з різними магнітними конфігураціями. Показано, як можна знизити рівень похибок HIBP вимірювань, зв’язаних з цими несприятливими умовами. Відсутність струму плазми у пристроях стеллараторного типу дає можливість проводити калібровку аналізатора енергій вторинного пучка іонів у кожному плазмовому розряді. Це дозволяє збільшити точність вимірювань потенціалу плазми за допомогою пучка важких іонів на стеллараторі TJ-II.