HEAVY ION BEAM PROBE DESIGN STUDY FOR TCABR

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The Heavy Ion Beam Probe (HIBP) diagnostic is known as a unique tool for the direct plasma electric potential measurements. It gives also information on plasma density, temperature and current profile. The method is based on the injection of single charged ion beam into the plasma and the registration of the double charged particles born due to collisions with the plasma electrons. The area of the ionization in plasma is the sample volume of the plasma potential measurements. The position and the size of the sample volume are determined by the calculation of the trajectories of the probing particles. Three schemes have been analysed: Cs^+, Tl^+ ion and neutral injection for TCABR parameters: B_0 = 1.5 T, I_{pl} = 135 kA. The calculations show that ion probing allows getting radial profiles of TCABR plasma parameters with the injection angle fast scan system. In all cases of ion beam injection we must use a curved beam line for ion beam transportation from last α – steering plates towards upper port. The primary ion beam injector must be situated out of high magnetic field area and its length is about 1.5m. The energy range (less than 100 keV for Cs^+, or Tl^+) allows using compact and cheap ion gun equipment.
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1. INTODUCTION

The Heavy Ion Beam Probe (HIBP) diagnostic is known as unique tool for direct plasma electric potential measurements [1]. It gives information on plasma density, thermonuclear and current profile also. The method is based on the injection of a single charged ion beam into the plasma and the registration of double charged particles born due to collisions with plasma electron. The area of the ionization in plasma is the sample volume of plasma potential measurement. The position and the size of the sample volume are determined by the calculation of trajectories of probing particles [2].

The especial concern introduces application of this method for analysis of mechanisms of transport processes,
instabilities and fluctuations in plasma at usage of different methods of adding heating. The TCABR tokamak was designed to study Alfven wave heating of plasma [3]. HIBP diagnostic is the extremely powerful tool for this.

The applied equipment for a variety of magnetic confinement devices (tokamaks, stellarators, bumpy torii, tandem mirrors) has common features but differ in beam energies and ion beams. The geometry of the confining magnetic field and the size of confinement device determines the energy requirements of the ion beam used for any HIBP application.

HIBP design study for TCABR is described.

2. CALCULATION

TCABR is middle size tokamak (see Fig. 1,2). The rectangular stainless-steel vacuum chamber (500 mm x 450 mm) is located inside 18 toroidal field coils (outer size - 1900 mm x 1050 mm, inner size - 1300 mm x 700 mm). Parameters of tokamak TCABR for design study are as follows: plasma current I_{pl} = 135 kA, toroidal field B_t = 1.07 T, major radius of vacuum vessel R = 603 mm, plasma radius a_{pl} = 180 mm, diameter of entrance and exit ports d = 63 mm.

It is necessary to agree basic performances of the diagnostic equipment with parameters of the unit for definition of possibility of using of a HIBP method for the given installation.

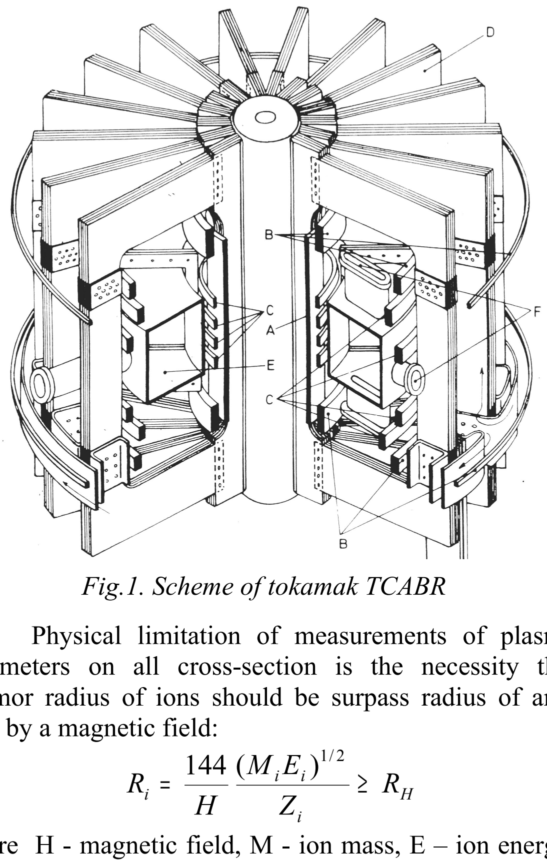

Fig.1. Scheme of tokamak TCABR

Physical limitation of measurements of plasma parameters on all cross-section is the necessity that Larmor radius of ions should be surpass radius of area held by a magnetic field:

$$R_i = \frac{144}{H}\frac{(M_i E_i)^{1/2}}{Z_i} \geq R_H \qquad (1)$$

where H - magnetic field, M - ion mass, E – ion energy, Z – ion charge. From this condition it is possible to make an estimation of a tolerance range of variation by main specifications of the diagnostic equipment (energy and a kind of particles):

$$E_i \geq \left(\frac{R_H H}{144}\right)^2 \frac{Z_i^2}{M_i} \qquad (2)$$

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According to this the minimum of energy of a probing beam of ions Tl^+ is about 50 keV.

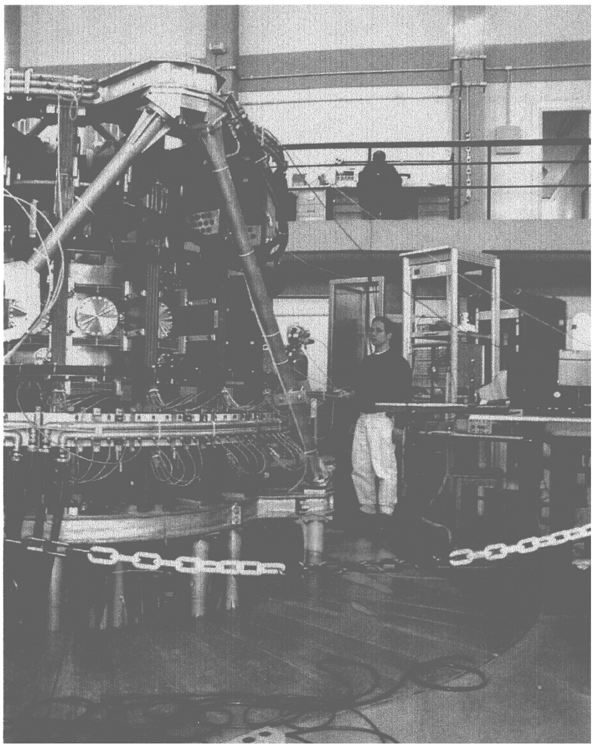

Fig.2. Photo of tokamak TCABR

Besides, there are geometrical limitations, which are determined by a design of vacuum chamber (arrangement of entrance and exit ports), arrangement of magnetic coils, bearings and established diagnostic equipment. It narrows down the size of investigated area in plasma.

Determination a position and size of studied area of plasma in the installation it is possible by an extremely computational way.

System of equations of particles motion in electromagnetic field was solved by a Runge-Kutta method for calculation of trajectories of primary and secondary beams [4].

The changes of energy in range 55-105 кeV and injection angle in range 65-76° allow make measurements of parameters of plasma on all cross-section of a plasma column (see Fig.3).

3. DESIGN

Traditional composition of heavy ion beam diagnostic system consists of two main parts: an injector of primary ion beam and analyzing device of secondary ion beam.

Injector provides formation of primary ion beam with parameters we need in local volume of plasma – conditions for beam focusing, level of intensity, necessary energy range, kind of particles, density of ion current. It consists two main parts too – emitter-extractor unit and shaping-focusing system [5].

Analyzing device provides a measurement of parameters of secondary ion energy. It possible use two type of electrostatic energy analyzers – electrostatic grid analyzer and parallel plate analyzer. The first type has compactness, the simplicity of design and a wide range of measured energies but possesses a difficulty to obtain a high energy resolution more then $\nabla E/E \sim 10^{-4}$. We propose a 30° Proca-Green electrostatic energy analyzer likes used on TJ-1 tokamak [6].

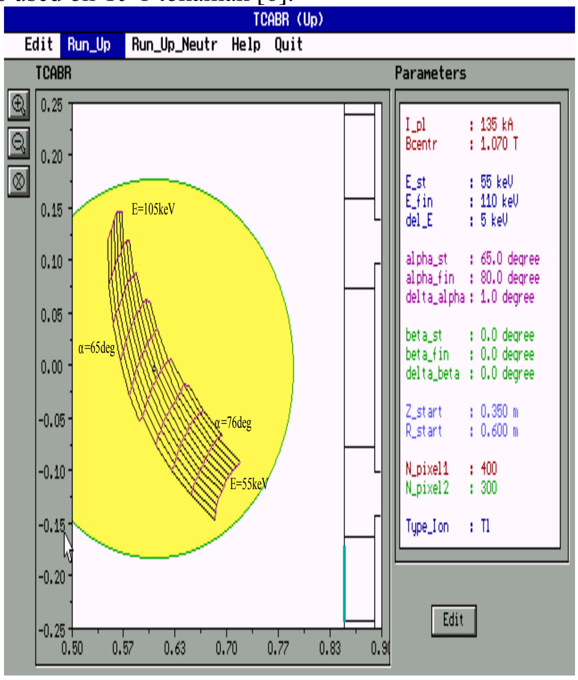

Fig.3Detector grid for ranges of energies of primary beam ion 55-105 keV and injection angles 65-76°

The HIBP TCABR general view is shown in Fig.4.

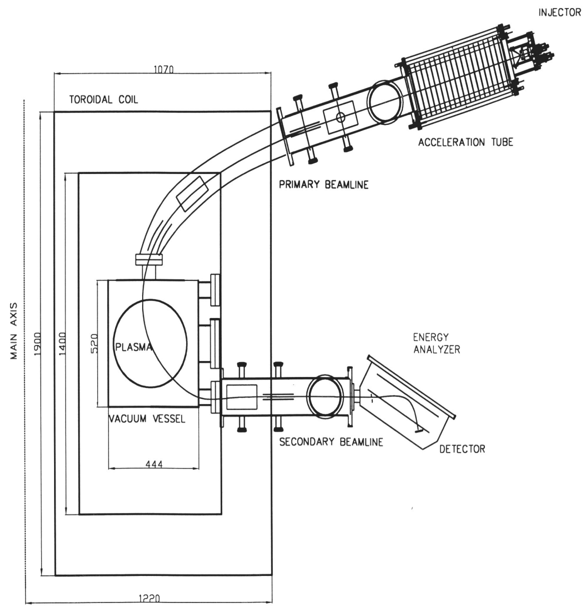

Fig.4 HIBP TCABR general view

Injectors emitter-extractor unit includes Tl^+ or Cs^+ solid-state thermoionic emitter with heating filament, pierce and extractor electrodes. Shaping-focusing system consists three-electrode lens, 18 section accelerating tube with high voltage resistive divider, high voltage power supply system.

Primary beam line has the port for vacuum pump. Primary steering plate used to correct the position of the beam in center of the beam line. Primary sweep plates are used to control an enter angel of primary beam to plasma.

Faraday cup and wire detectors monitor of beam intensity and profile before it will be injected to plasma. The secondary beam line attached to exit port also contains sweep system. The purpose these plates are to collimate the secondary beam entering the analyzer.

TCABR isn't comfortable for HIBP diagnostic. It has very large empty magnetic field volume with comparison to the plasma volume. Therefore we must use a curved beam line for ion beam transportation from last $\alpha-$ steering plates towards upper port. The primary ion beam injector must be situated out of large magnetic field area and its length is about 1.5m (see Fig.4).

One of the exotic cases is using of neutral Cs beam injection with the injection angle near vertical axis. The detector line of equal angle 86^0 from horizontal plane connects the edge and the centre of plasma column if the neutral beam energies are in the range 30 – 80 keV. The energy range (less than 100 keV for Cs^+, or Tl^+) leads to using compact and cheap ion gun equipment.

4. CONCLUSION

HIBP design study for TCABR described in this article. The geometry of the confining magnetic field and the size of confinement device determine the energy requirements of the ion beam used for any HIBP application. It is possible to use HIBP diagnostic for measurement of plasma potential during Alfven wave heating.

The TCABR-HIBP will consist of a 120 keV accelerator. An injector can employs two types of ion species such as Tl^+ and Cs^+. A 30° Proca-Green electrostatic energy analyzer will be used for determination of the secondary ion energy.

Construction of tokamak needs use of special units and methods to provide of transportation primary ion beam to plasma.

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REFERENCES

1. F.C.Jobes and R.L.Hickok. A direct measurement of plasma space potential// *Nucl.Fusion*. vol.10, 1970, p.195-197.
2. L.I.Krupnik, A.V.Melnikov, L.G.Zimeleva, and N.V.Samokhvalov. Optimization of the Heavy ion beam probing experimental conditions// *I.V.Kurchatov Atomic Energy Institute, Preprint*.4517/7. Moscow, 1987.
3. R M O Galvao, V Bellintani Jr, R D Bengtson et al. Alfven wave heating and runaway discharges maintained by the avalanche effect in TCABR// *Plasma Phys. Contr. Fusion*. 43, 2001, A299.
4. V.E.Bykov, L.I.Krupnik, A.V.Melnikov et al. Calculation of trajectories of heavy ion probe beams in stellarator type instulations “URAGAN-2”, “URAGAN-3” and “URAGAN-2M”// *Preprint KhIPT 88-9, Kharkov, KhIPT AS UkSSR*, 1988.
5. I.S.Bondarenko, A.A.Chmyga, N.B.Dreval et al. Heavy Ion Beam Injectors for the Plasma Potential and Electron Temperature Measurements.// *Problems of Atomic Science and Technology. Series: Plasma Physics.* 6(6), 2000, p.181.
6. I.S.Bondarenko, S.M.Khrebtov, L.I.Krupnik et al. Heavy ion beam probe diagnostics on TJ-1 tokamak and the measurements of the plasma potential and density profiles.// *Rev Sci.Instrum*. 68(1), January, 1997.

ВИВЧЕННЯ КОНСТРУКТИВНОГО РІШЕННЯ СИСТЕМИ ЗОНДУВАННЯ ПЛАЗМИ ПУЧКОМ ВАЖКИХ ІОНІВ ДЛЯ TCABR

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Система зондування плазми пучком важких іонів відома як унікальний інструмент для прямих вимірювань потенціалу плазми. Вона також дозволяє одержувати інформацію про густину плазми, температуру і профіль току. Метод заснований на інжекції пучка однозарядних іонів у плазму та реєстрації двозарядних часток, утворених у результаті зіткнень з електронами плазми. Область іонізації у плазмі визначає елементарний об’єм, у якому здійснюється вимірювання потенціалу плазми. Положення і розмір елементарного об’єму визначається за допомогою розрахунків траєкторій зондуючих часток. Проаналізовано три варіанти: інжекція іонів Cs^+, Tl^+ та нейтральних атомів для параметрів TCABR: B_0 = 1.5 Т, I_{pl} = 135 кА. Розрахунки показують можливість одержання профілів параметрів плазми TCABR за допомогою системи швидкого сканування по кутам інжекції іонного пучка. У всіх випадках інжекції іонного пучка необхідно застосування вигнутого іонопроводу для транспортування іонного пучка від вихідних відхиляючих $\alpha-$ пластин до порту токамака. Інжектор первинного іонного пучка повинен бути розташований поза областю сильного магнітного поля , а його довжина буде біля 1,5 м. Енергія іонного пучка (біля 100 кеВ для Cs^+ або Tl^+) дозволяє застосувати компактний и дешевий іонний інжектор.

ИЗУЧЕНИЕ КОНСТРУКТИВНОГО РЕШЕНИЯ СИСТЕМЫ ЗОНДИРОВАНИЯ ПЛАЗМЫ ПУЧКОМ ТЯЖЕЛЫХ ИОНОВ ДЛЯ TCABR

Л.И. Крупник, Г.Н. Дешко, А.А. Чмыга, Н.Б. Древаль, С.М. Хребтов, А.Д. Комаров, А.С. Козачек, Р.М.О. Гальвао, Ю.К. Кузнецов

Система зондирования плазмы пучком тяжелых ионов известна как уникальный инструмент для прямых измерений потенциала плазмы. Она так же позволяет получать информацию о плотности плазмы, температуре и профиле тока. Метод основан на инжекции пучка однозарядных ионов в плазму и регистрации двухзарядных частиц, образующихся в результате столкновений с электронами плазмы. Область ионизации в плазме определяет элементарный объем, в котором происходит измерение потенциала плазмы. Положение и размер элементарного объема определяются с помощью расчета траекторий зондирующих частиц. Проанализировано три варианта: инжекция ионов Cs^+, Tl^+ и нейтральных атомов для параметров TCABR: B_0 = 1.5 T, I_{pl} = 135 kA. Расчеты показывают возможность получения профилей параметров плазмы TCABR с помощью системы быстрого сканирования по углу инжекции ионного пучка. Во

всех случаях инжекции ионного пучка необходимо использование изогнутого ионопровода для транспортировки ионного пучка от выходных отклоняющих ̰ пластин до порта токамака. Инжектор первичного ионного пучка должен быть расположен вне области сильного магнитного поля , а его длина составит около 1,5 м. Энергия ионного пучка (около 100 кэВ для Cs^{+} или Tl^{+}) позволяет использовать компактный и дешевый ионный инжектор.