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 $\alpha$ − 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. INTRODUCTION

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 Alfvén 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 $B_1 = 1.07$ 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.

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:

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

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):

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

Fig.1. Scheme of tokamak TCABR
According to this the minimum of energy of a probing beam of ions Tl⁺ is about 50 keV.

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 keV 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 \( \Delta E/E \sim 10^{-4} \). We propose a 30° Proca-Green electrostatic energy analyzer likes used on TJ-1 tokamak [6].

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

![Fig.2. Photo of tokamak TCABR](image)

![Fig.3. Detector grid for ranges of energies of primary beam ion 55-105 keV and injection angles 65-76°](image)

![Fig.4. HIBP TCABR general view](image)
ВИЧУВАННЯ КОНСТРУКТИВНОГО РІШЕННЯ СИСТЕМИ ЗОНДУВАННЯ ПЛАЗМИ ПУЧКОМ ВАЖКИХ ІОНІВ ДЛЯ TCABR

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Система зондирования плазмы пучком важких іонів відома як унікальний інструмент для прямих вимірювань потенціалу плазми. Вона також дозволяє отримувати інформацію про густину плазми, температуру і профіль току. Метод заснований на інджекції пучка однозарядних іонів у плазму та ретракції двозарядних часток, утворених у результаті зіткнень з електронами плазми. Область інжекції в плазмі визначає елементарний об’єм, у якому здійснюється вимірювання потенціалу плазми. Положення і розмір елементарного об’єму визначаються за допомогою зрештої траекторій ізотопів плазми.

Точки інтерпретації плазми HIBP diagnostic for measurement of plasma potential during Alfvén wave heating. The method is based on the injection of a 120 keV accelerator. An injector can employ 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.

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 Alfvén wave heating. The TCABR-HIBP will consist of a 120 keV accelerator. An injector can employ 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.

REFERENCES


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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.