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Potential profile measurements on compact helical system (CHS) using a 200 keV heavy ion beam probe

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Abstract

A 200 keV heavy ion beam probe system has been prepared to measure potential profiles in the compact helical system. Probing beam trajectory is successfully controlled by a secondary beam sweep system to keep the injection angle of the secondary beam constant during the radial scan. As a result, it was observed that the potential profile changes after the neutral beam heating is applied on electron cyclotron heated plasmas. © 1997 Elsevier Science S.A.

1. Introduction

A concept of a active trajectory control [1] method was incorporated into a 200 keV heavy ion beam probing (HIBP) on a compact helical system (CHS). Introduction of an additional sweeper in front of an energy analyzer gives us the following three advantages: (1) reducing a potential measurement error caused by uncertainty of beam injection angle into the energy analyzer; (2) making the observation region wider; (3) keeping the energy analyzer away from location where the magnetic field disturbs the beam energy determination. In this article, we describe the HIBP system using the newly proposed idea, and recent results of potential profile measurements.

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2. Experimental set-up

The CHS is a heliotron/torsatron device the major and average minor radii of which are 1.0 m and 0.15 m, respectively. The CHS has a pair of helical winding coils, and four pairs of poloidal coils for controlling the magnetic field axis and the configuration. The CHS has 45° and 180° rotational symmetries in toroidal and poloidal directions, respectively. Magnetic field configurations of the CHS are denoted by magnetic axis location.

The primary beam of a HIBP is injected from a top port, and the secondary beam comes from the horizontal port which is separated from the top port by 22.5° in a toroidal direction. A 30° parallel plate energy analyzer is used to measure the secondary beam energy [2,3]. The beam energy

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can be determined by the beam position on a split plate detector, which is indicated by secondary current difference between top and bottom plates, that is, $\xi = (i_{top} - i_{bot})/(i_{top} + i_{bot})$. The parameter ξ is related to space potential as

$$\phi = 2V_P[F(\theta, \psi)\,\xi + G(\theta, \psi)] - V_A = \psi_0 + \phi_{offset} \quad (1)$$

where $\phi_0 = 2V_P F\xi$, $\phi_{offset} = 2V_P G - V_A$, and θ and ψ represent the injection angles on-axis, and off-axis respectively, of the analyzer and V_P and V_A are the parallel plate voltage and accelerator voltage, respectively. Calibration of our analyzer before installation gave $F(\theta, \psi) \simeq 1.5 \times 10^{-2}$, $G(\theta, \psi) \sim 4.9$ when $\theta = 30°$, $\psi = 0°$ [2].

An octupole deflector is chosen to control secondary beam trajectories since the deflector has a large opening to obtain secondary beams of which the angle and position at the entrance are widely distributed. The voltage combination for two octupoles (primary and secondary sides) is calculated in advance to satisfy the condition that entrance angle and position of secondary beam is constant at the energy analyzer slit. A digital analog converter is used to control the high voltage amplifiers whose outputs are applied on each plate of octupoles.

We inject primary beams into target magnetic field configurations filled with helium gas for the trajectory calibration. The detected secondary beam generated in the gas ionization process should have the same energy as the primary, therefore, the normalized potential parameter ξ indicates undesirable displacement in the injection angle. We have confirmed that normalized potential ξ can be kept constant during radial scans for the configurations with the magnetic axis of both 92.1 and 94.9 cm. Thus, the normalized potential signal ξ from plasmas represents the plasma space potential.

3. Experimental results

The HIBP was performed on a plasma whose magnetic axis and field strength are 92.1 cm and 0.89 T with neutral beam injection (NBI). The observation points with the 70.4 keV cesium beam are shown in Fig. 1; the observation points range from the upper edge to the lower edge in the plasma. The plasma was started up with electron cyclotron heating (ECH), then the NBI was applied at $t = 30$ ms. Fig. 2(a) indicates the time evolution of NBI deposition power, stored energy and electron density. The electron density is 1×10^{13} cm^{-3} at the NBI phase whose deposition power is 180 kW, and the average electron temperature was estimated to be about 250 eV from stored energy ($\simeq 450$ J).

Fig. 2(b) shows the time evolution of the normalized potential ξ, together with the secondary beam intensity, and the averaged radius of observation points. In this case, it took about 8 ms to measure the potential distribution from an upper edge to a lower edge. During the start-up phase from $t = 20–30$ ms, the potential at the plasma center is negative, then the normalized potential at the plasma center turns to positive in the transient phase from $t = 30–40$ ms. In the steady NBI heated plasma from $t = 45–65$ ms, the plasma potential is negative, which is consistent with results using charge exchange spectroscopic measurements [4]. It is also observed that an initial hollow profile of the total secondary inten-

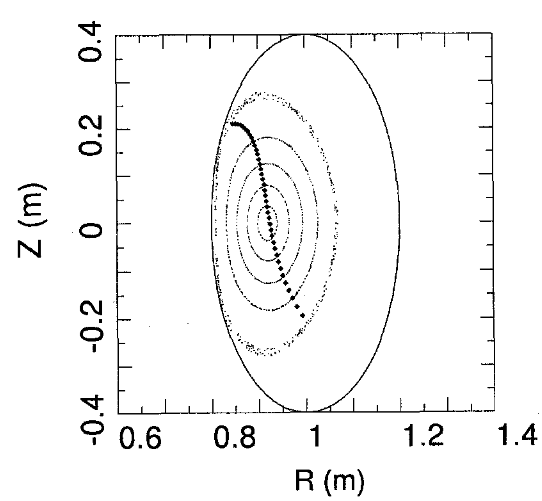

Fig. 1. Observation points for the 92.1 cm configuration. The open circles indicate the projected points of the observation points onto the magnetic flux surface by tracing magnetic field line. The observation points are distributed in a toroidal direction.

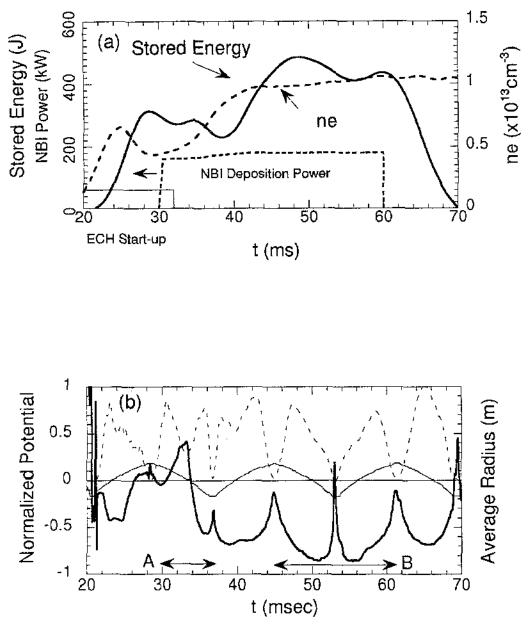

Fig. 2. (a) Time evolution of the stored energy and the electron density, together with the neutral beam deposition power. (b) Time evolution of the normalized potential signal (solid line), average radius of the observation point (thin solid line), and total secondary intensity (dashed line). Neutral beam injection is applied at $t = 30$ ms.

sity changes to a profile without a hollow. This should be caused by a change of the density profile supposed to be hollow when the electron density is lower.

4. Discussion and summary

In Fig. 2 we show the time evolution of normalized potential since we have not measured the function $G(\theta, \psi)$ with sufficient precision to estimate the offset value ϕ_{offset}; a percentage error of the function $G(\theta, \psi)$ results in $\phi_{\text{offset}} \simeq 600$ V for the present 70 keV beam. However, the potential $\phi_0 = 2V_P F(\theta, \psi)\ \xi$ in Eq. (1) can be estimated within an error of several percent. Fig. 3 shows the potential distribution ϕ_0 as a function of the plasma averaged radius for the transient phase (region A in Fig. 2(b)) and the NBI phase (region B in Fig. 2): we use $V_P = 14.4$ kV, $F(30°, 0°) = 0.015$. The negative averaged radius $\langle r \rangle$ means

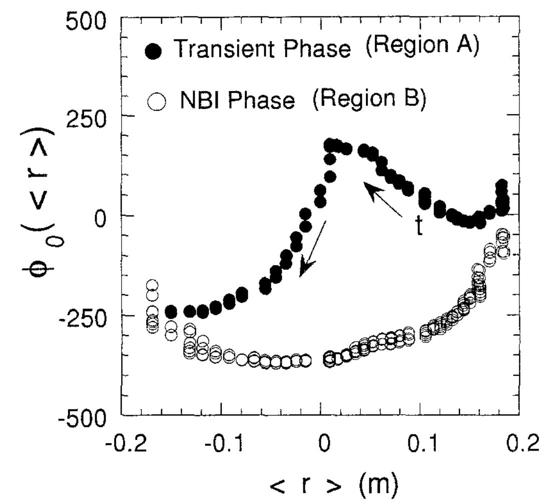

Fig. 3. Potential distributions of transient phase from ECH to NBI plasma, and a steady NBI plasma. The offset of the potential remains uncertain.

the ionization position is located below the magnetic axis in a vertical direction. By assuming the potential at the plasma edge is zero, we estimate $|\phi_{\text{offset}}| < 100$ V. The difference between the potential of the transient and NBI phases is clear in the figure.

In summary, we have obtained a potential distribution for the CHS plasma, using an active trajectory control method. The change of potential distribution is observed in a transient phase from ECH to NBI plasmas.

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