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# 2 Dimensional Potential Measurement by HIBP in the Large Helical Device
LHDにおけるHIBPによる電位の二次元構造の計測


Akihiro Shimizu, Takeshi Ido, Masaya Kurachi[1], Ryohei Makiho[1], Masaki Nishiura[2], Shinji Kato, Masayuki Yokoyama, LHD experiment group
清水昭博, 井戸毅, 倉地正也[1], 牧野良平[1], 西浦正樹[2], 加藤眞治, 横山雅之, LHD実験グループ

*National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan*
*[1)]Graduate School of Engineering, Nagoya University, Furo, Chikusa, Nagoya 464-8603, Japan*
*[2)]Graduate School of Frontier Sciences, The University of Tokyo, Kashiwa, Chiba 277-8561, Japan*
核融合科学研究所 〒509-5292 岐阜県土岐市下石町322-6
[1]名古屋大学工学研究科 〒509-5292 名古屋市千種区不老町
[2]東京大学新領域 〒277-8561 千葉県柏市柏の葉



Two-dimensional potential profiles were measured with a heavy ion beam probe (HIBP) in the Large Helical Device (LHD). To measure the two-dimensional potential profile with the HIBP, the probe beam energy is required to be changed. However, it is not easy because the beam transport line of LHD-HIBP system is long (~20 m) and we need much time to adjust the beam orbit in this transport line. To reduce the beam adjustment time, an automatic beam adjustment system has been developed. By applying this system to our LHD-HIBP control system, the beam adjustment time is dramatically reduced, and two-dimensional potential profiles can be successfully measured in LHD.


## 1. Introduction

The structure of radial electric field, $E_r$, is an important parameter to consider the confinement physics of torus plasmas, because the $E_r$ is correlated to plasma flow through $E \times B$ flow. Many theoretical and simulation researches show that turbulence in the torus plasma caused by micro instability is suppressed by the shear flow and the confinement property is improved [1]. Experimental results that support the theory were obtained as good confinement discharges, such as the H-mode and the internal transport barrier (ITB) [2-3]. On the other hand, the flow influences magnetic island structure, so it is also important to study island formation physics. Two dimensional potential measurements is very helpful to investigate those physics, therefore we developed a 2D potential measurement method with a heavy ion beam probe (HIBP) in the large helical device (LHD).

HIBP [4] is a very powerful diagnostic tool, because it can directly measure the plasma potential in the high temperature plasma with good time and spatial resolutions, without perturbing the plasma. Typically, the observation region of HIBP is controlled by varying the probe beam incident angle on the condition of the fixed beam energy, and one dimensional potential profile is obtained. If the probe beam energy is also changed, two-dimensional potential profile can be obtained.

In LHD, the HIBP system has a very long beam transport line (~20 m) and we have many deflectors and lenses on this line to adjust the beam trajectory along the line [5]. When the probe beam energy is changed, many deflector voltages must be controlled appropriately to transport the beam in this long beam transport line. To reduce the required time for this adjustment, an automatic adjustment system was developed and applied to our HIBP system. By using this system, the beam trajectory on the beam transport can be adjusted in a short time (~3 min.). In the experiment, the probe beam energy was changed shot to shot, and a two-dimensional potential profile was successfully measured.

## 2. Heavy Ion Beam Probe on LHD

The magnetic field strength of LHD is strong (~3 T) and the minor radius of plasma is about 0.6 m, the maximum probe beam energy reaches 6 MeV. This high energy probe beam is generated by the tandem accelerator. The tandem accelerator is located on the second floor of the basement of the LHD building. The probe beam is transported from this floor to the LHD along the very long beam transport line. A schematic view of LHD HIBP system is shown in Fig.1. Many electro deflectors and quadrupole lenses are equipped in the beam transport line to adjust the beam trajectory. The beam incident angle to LHD is varied by the 8-pole electrostatic deflector located at the injection port. At the ejection port, we have another 8-pole electrostatic deflector and adjust the beam direction to a suitable angle to the energy analyzer. In Fig.2, observation points of HIBP in the plasma are shown. Although the actual observation points are arranged three-dimensionally, this figure shows a projection of the observation points on the horizontally elongated cross section for simplicity. On the condition of the fixed probe beam energy, a one-dimensional potential (along a line of corresponding beam energy in Fig.2), is measured by changing incident/eject beam angles. When the probe beam energy is changed, we can measure other one-dimensional profiles on other observation lines, therefore a two-dimensional potential profile can be obtained by changing the beam energy shot to shot.

## 3. Automatic Beam Adjustment System

When the probe beam energy is changed, many power sources of deflectors and lenses in the beam transport lines must be adjusted. To do this automatically, a PC-based automatic beam adjustment system was developed. The beam positions in the transport line are measured with beam profile monitors (BPMs) The signal from BPMs are acquired through the ADC, and the displacements of the beam position are calculated. The required deflector voltage to shift the beam position to the center of beam transport line is calculated in the PC, and the calculated voltage are applied to deflector high voltage power sources through CAMAC DAC modules. After that, the probe beam positions are measured with BPMs again, and the next optimization loop is repeated. Using the automatic beam adjustment system, the required time to optimize the beam can be dramatically reduced from several tens minutes to 3 minutes.

## 4. Experimental Results

Using the automatic beam adjustment system, the probe beam energy is changed shot to shot, and the two-dimensional potential profile is measured in the LHD. The plasma is produced and sustained by neutral beam injection (NBI) heating, and an auxiliary heating of electron cyclotron heating (ECH) is applied. The line averaged electron density is $0.4 \times 10^{19}$ m$^{-3}$ and the central electron temperature is 4 keV. In Fig. 3, the obtained potential profile is shown with magnetic surfaces. Since the actual observation points are arranged in three-dimensional space, the projection on the horizontally elongated cross section is shown for simplicity. The two-dimensional equilibrium potential profile was successfully measured. In the future, the two-dimensional structure of potential fluctuation will be measured by this system.

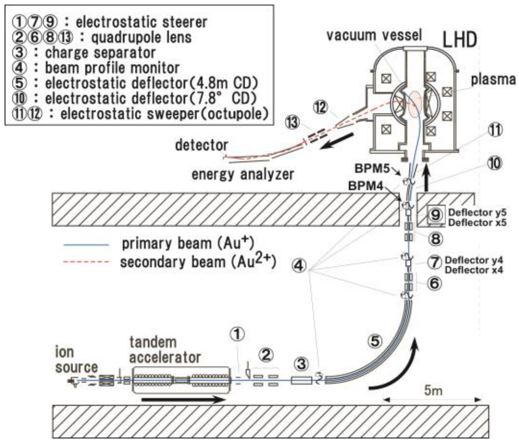


Fig. 1. Schematic view of LHD HIBP system

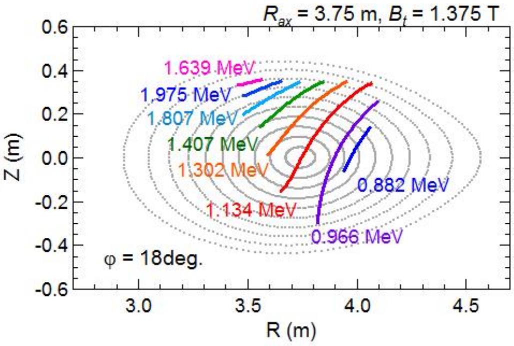


Fig. 2. Observation points with HIBP

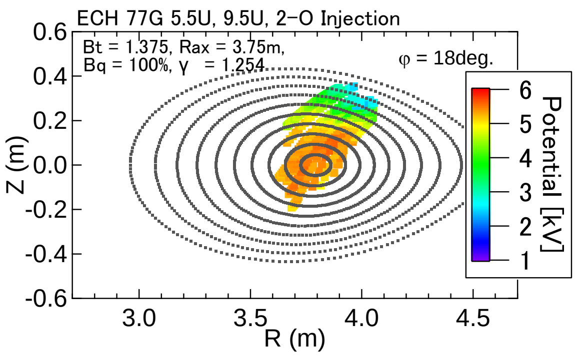


Fig. 3. Two-dimensional potential profile measured with HIBP

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