§15. The Trial Measurement of Density Profile with Heavy Ion Beam Probe System in CHS

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Density profile measurement is essential to investigate plasma properties, such as particle transport and pressure driven MHD instability. Usually Thomson scattering and interferometer are used to measure the density profile. Heavy Ion Beam Probe (HIBP) system can also give information of density profile, with higher repetition rate than Thomson scattering. In addition, the method allows density profile estimation with quite high spatial resolution; in principle, the observable position can be continuous.
by sweeping heavy ion beam, more channels than in interferometer are achieved, which may lead to fine structure measurement of density profile related to island.

In HIBP diagnostics in CHS, primary beam, Cs^+, is injected into plasma. Secondary beam, Cs^{2+}, which is produced by electron impact collision in plasma, is detected with split plates in the energy analyzer. The intensity of secondary beam is written as,

$$I_s = I_0 n_e \bar{\sigma} \exp(-\beta_1 - \beta_2)\delta\ell_s / v_B \,.$$

Here, I_0 is current density of injected heavy ion beam, n_e is electron density, $\bar{\sigma}$ is an averaged cross section for ionized process Cs^+ to Cs^{2+}, $\delta\ell_s$ is a sample volume, v_b is velocity of beam ion, β_1 and β_2 are beam attenuation along primary and secondary beam orbits, respectively, which are written as,

$$\beta_1 = \int n_e \bar{\sigma} d\ell_1 \,,\quad \beta_2 = \int n_e \bar{\sigma} d\ell_2 \,.$$

ℓ_1, ℓ_2 are path lengths of primary and secondary beam. Current density of injected beam, I_0, strongly depends on the condition of cesium ion source, therefore we develop the reconstruction method independent of the beam intensity [1]. For simplicity, three assumptions are applied. 1) Line averaged density is known with interferometer. 2) Density is a flux surface function. 3) Temperature profile is known as a function of normalized minor radius. We define N^- as,

$$N^- = \frac{1}{2}\left(\frac{1}{Is}\frac{\partial I_s}{\partial \rho}(\rho) - \frac{1}{Is}\frac{\partial I_s}{\partial \rho}(-\rho)\right).$$

In order to obtain a density profile, the following equation should be solved,

$$\frac{1}{n_e}\frac{\partial n_e}{\partial \rho} = N^- - \frac{1}{\bar{\sigma}}\frac{\partial \bar{\sigma}}{\partial \rho} \quad A_1^- \quad A_2^- \,.$$

Here,

$$A_1^- = \frac{1}{2}\left[\frac{\partial \beta_1}{\partial \rho}(\rho) - \frac{\partial \beta_1}{\partial \rho}(-\rho)\right],\quad A_2^- = \frac{1}{2}\left[\frac{\partial \beta_2}{\partial \rho}(\rho) - \frac{\partial \beta_2}{\partial \rho}(-\rho)\right].$$

This equation can be solved numerically using iteration procedure as follows. In the first estimation, the attenuation of beam is neglected, namely A_1^- and A_2^- is assumed 0. Then initial density profile is calculated from,

$$n_e(\rho) = n_e(0)\exp\left[\int_0^\rho \left(N^- - \frac{1}{\bar{\sigma}}\frac{\partial \bar{\sigma}}{\partial \rho}\right) d\rho\right].$$

By using this density profile, the beam attenuation of the first order, A_1^- and A_2^-, can be calculated. The second estimation can be performed including the attenuation terms, A_1^- and A_2^- using the following formula (with $i = 1$),

$$n_e^{i\ 1}(\rho) = n_e(0)\exp\left[\int_0^\rho \left(N^- - \frac{1}{\bar{\sigma}}\frac{\partial \bar{\sigma}}{\partial \rho} \quad A_1^{-,i} \quad A_2^{-,i}\right) d\rho\right].$$

Then the same procedures are repeated. The i-th order terms of A_1^-, A_2^- give the higher order estimation of density profile. The process is continued for a convergent criterion to be satisfied, $|n_e^{i+1} - n_e^i| < \varepsilon$, where ε is a given small value.

Fig.1 shows profiles of secondary beam I_s for the plasma sustained with a) ECH or b) NBI. By applying the method described above, the density profiles are obtained as is shown in Fig.2. Density profile from Thomson scattering is also shown for comparison. The profile from HIBP shows good agreement with Thomson scattering, while in the edge region density from HIBP is less than that of Thomson scattering. Possible reasons of this discrepancy are i) Lotz's empirical formula does not give a good approximation in low temperature regime, or ii) neutral particle in the plasma edge may contribute to ionization process of the primary beam.

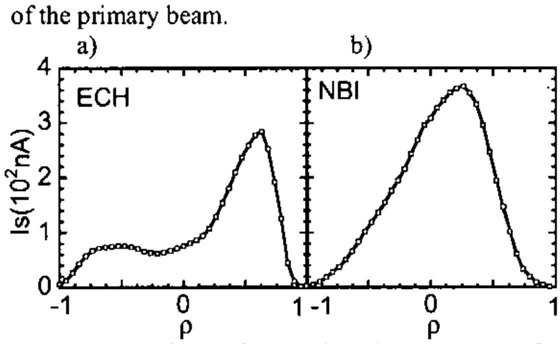

Fig.1 a) Profiles of secondary beam current from ECH plasma and b) from NBI plasma

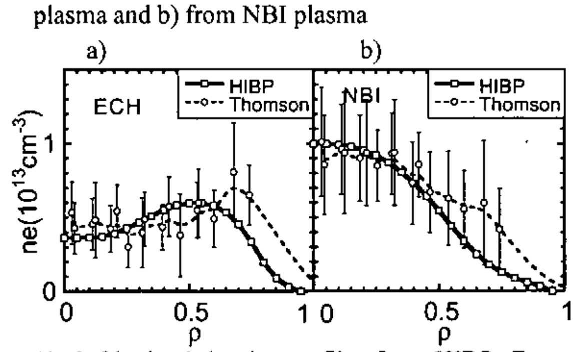

Fig.2 Obtained density profiles from HIBP. For comparison, the profile measured with Thomson scattering is shown. a) ECH and b) NBI plasma.

[1] A. Fujisawa, M. Kitazawa, A. Shimizu, S. Ohshima, H. Iguchi, Rev. Sci. Instrum.74 (2003) 3335.