§15. The Density Profile Measurement with Heavy Ion Beam Probe System on CHS

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Diagnostics to measure the density profile is indispensable to study the particle transport. In CHS, phenomena such as MHD instability and bifurcation are often accompanied by the change in the density profile. Therefore it is important to measure the density profile with high temporal resolution to make clear the physical mechanism of these phenomena. Conventionally, Thomson-scattering and FIR are used to measure the density profile. Heavy Ion Beam Probe (HIBP) also has the possibility to be a powerful tool to measure it. In CHS, by sweeping the probing beam fast, density profile is obtained with relatively fast temporal resolution (~4 ms).

In HIBP diagnostics, the intensity of secondary beam detected at the detector is roughly proportional to electron density of plasma at the ionization position. However, the beam current decays on the beam path by collisions, so we must take this effect (so called "the path integral effect") into account to obtain the accurate density profile from HIBP diagnostics. The intensity of secondary beam current is expressed as, $I_s = I_0 n_e \langle\sigma_{12} v_e\rangle \exp(-\beta_1-\beta_2)\, \delta\ell_S / v_B$. Here, I_s: secondary beam current, I_0: injected beam current, $\langle\sigma_{12} v_e\rangle$: the ionization rate averaged by the Maxwell velocity distribution, n_e: electron density at the ionization point, $\delta\ell_S$: sample volume size, v_B: the velocity of beam. The coefficient β_1 (β_2) is the attenuation factor of beam on primary (secondary) beam path, and is expressed as $\int n_e \langle\sigma_{12} v_e\rangle / v_B \, d\ell_1$ ($\int n_e \langle\sigma_{23} v_e\rangle / v_B \, d\ell_2$). Here, $\langle\sigma_{23} v_B\rangle$ is the ionization rate of double charged ions to triple or higher charged state. The injected beam current I_0 is not easy to measure accurately, so we develop a method to obtain n_e profile without the information of I_0 itself [1]. In this method, the following equation should be solved:

$$-\frac{1}{n_e(\rho)}\frac{\partial n_e}{\partial \rho}(\rho) = -N^-(\rho) + \frac{1}{\langle\sigma_{12} v_e\rangle(\rho)}\frac{\partial \langle\sigma_{12} v_e\rangle}{\partial \rho}(\rho) - \frac{1}{2}\left[\frac{\partial \beta_1}{\partial \rho}(\rho) - \frac{\partial \beta_1}{\partial \rho}(-\rho) + \frac{\partial \beta_2}{\partial \rho}(\rho) - \frac{\partial \beta_2}{\partial \rho}(-\rho)\right] \quad (1).$$

Here, $N^-(\rho) = \left[\frac{1}{I_s(\rho)}\frac{\partial I_s}{\partial \rho}(\rho) - \frac{1}{I_s(-\rho)}\frac{\partial I_s}{\partial \rho}(-\rho)\right]$ and ρ is the normalized minor radius at the ionization points.

Because β_1 and β_2 include path integral of n_e, Eq. (1) is an integral equation of n_e. According to the paper [1], the Eq.(1) can be solved numerically by the iterative calculation. In this method, the path integral effect can be reduced because in the Eq.(1) $\partial\beta_1/\partial\rho\,(\rho) \sim \partial\beta_1/\partial\rho(-\rho)$ and $\partial\beta_2/\partial\rho\,(\rho) \sim \partial\beta_2/\partial\rho(-\rho)$ so the sum of terms in the rectangular bracket of Eq.(1) becomes small. In Fig.1, the first, the second and the third terms in R.H.S of Eq.(1) at the last iteration are shown as a function of ρ. The third term (sum of β' terms) is small and has only small effect on n_e profile.

In the Fig.2, the temporal evolution of density profile measured with HIBP is shown. Up to 100 ms, plasma is sustained by ECRH, and after 100ms, it is sustained by NBI. We can see the hollow profile for ECR heated plasma and the parabolic profile for NB heated plasma. We will use this method to study the particle transport in phenomena such as bifurcation, radiation collapse etc.

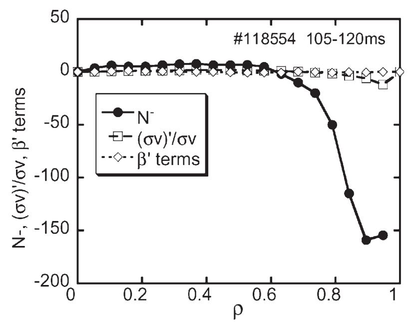

Fig.1. Terms in Eq.1 as a function of ρ

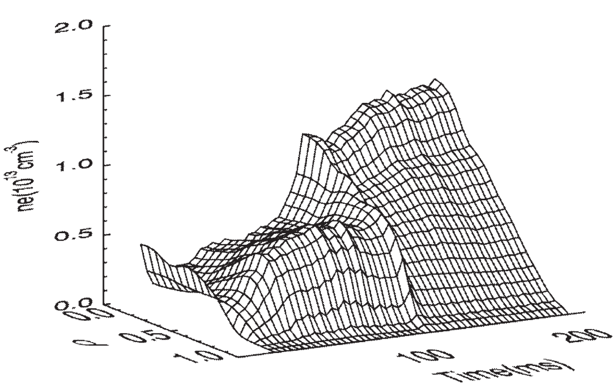

Fig.2. Temporal evolution of density profile measured with HIBP. Up to 100 ms, plasma is sustained by ECRH , after 100 ms it is sustained by NBI.

Reference
1) A. Fujisawa, et al., Rev. Sci. Instrum. **74**, (2003) 3335