§16. Simultaneous Measurements of Density and Potential Fluctuation with Heavy Ion Beam Probe in CHS

Nakano, H., Fujisawa, A., Shimizu, A., Ohshima, S., Minami, T., Yoshimura, Y., Okamura, S., Matsuoka, K.

In CHS, the Heavy Ion Beam Probe (HIBP) has been used to measure mainly the potential profile, its dynamics and density fluctuations with a high temporal (~μs) and spatial resolution (~mm). In order to obtain understanding of plasma transport, we have developed an intense ion source to fully utilize the capabilities of the HIBP, that is, simultaneous measurements of density and potential fluctuations.

The measurements of density and potential fluctuations with HIBP in CHS were performed in the magnetic configuration with field strength of 0.88 T at the center of vacuum chamber. In the present experiments, a 53 GHz gyrotron was used to sustain the hydrogen plasma in which average density is $\sim 0.6\times10^{19}\mathrm{m}^{-3}$ and electron temperature at the center of plasma is ~2.5keV.

Figure 1 shows examples of fluctuation power spectra of density and potential at $\rho \sim 0.68$. The potential fluctuation is normalized with the electron temperature ($T_e \sim 170$ eV) measured with the Thomson scattering measurement. The HIBP data are acquired with a sampling time of 2 μs. Here, a fluctuation spectrum is calculated using the Fast Fourier Transform (FFT) method for data of ~1 ms (that is 512 data points). The spectra shown in the figures are the average of the ones obtained from ten sequential periods.The noise levels (gray lines) are estimated from the noise of the current–voltage converter.Both spectra show broadband (or turbulence) characteristics. The power density decreases monotonically in the higher frequency range from ~70 kHz, and becomes close to the noise level above ~200 kHz. The amplitude of density fluctuation appears larger than that of the normalized potential. The fluctuation levels of these examples are 4.1% and 2.7% for density and normalized potential, respectively. The level of fluctuation amplitude is evaluated by taking square root of the power density integrated from 10 kHz to 250 kHz without noise.

Fluctuation spectra for the density and the normalized potential have been obtained for a quite wide range of plasma radius with spatial resolution of 2.5 mm in the ECR-heated plasma that has a line-averaged density of $\sim 0.6\times10^{19}\mathrm{m}^{-3}$. Figure 2 shows the radial profiles of fluctuation level for density and normalized potential in the region of $\rho < \sim 0.95$. The fluctuation signals outside $\rho \sim 0.95$ are below the noise level in our measurements. The solid line in Fig. 2 is the fitting curve with the assumed form $\alpha+\exp[(\rho-\rho_0)/\beta]$. Both fluctuation levels show a rapid increase in the plasma periphery of $\rho > \sim 0.85$. In the region of $\rho < \sim 0.85$, the fluctuation level of normalized potential is stationarily ~0.8% and the Boltzmann relationship should be satisfied in this region; the levels of density fluctuation are ~2.2%.

The density (or detected beam) fluctuation, which is contaminated with the density fluctuation along the beam orbits, cannot reflect purely local density fluctuations. If the electron temperature fluctuation, which may have a large contribution in the plasma edge, is neglected, the fluctuation power is reduced into the following formula,

$$\left(\frac{\delta I_\mathrm{d}}{I_\mathrm{d}}\right)^2 \sim \left(\frac{\delta n_\mathrm{e}}{n_\mathrm{e}}\right)^2 + \int\left(\frac{\delta n_\mathrm{e}}{n_\mathrm{e}}\right)^2\left(n_\mathrm{e}\frac{\langle\sigma_1 v_\mathrm{e}\rangle}{v_\mathrm{b}}\right)^2 \mathrm{d}l_1 + \int\left(\frac{\delta n_\mathrm{e}}{n_\mathrm{e}}\right)^2\left(n_\mathrm{e}\frac{\langle\sigma_2 v_\mathrm{e}\rangle}{v_\mathrm{b}}\right)^2 \mathrm{d}l_2$$

under the simplest assumption that the correlation of density fluctuations is infinitesimally short. The power of local density fluctuations can be obtained by solving above integral equation, when the ionization cross-sections on the orbits are known. The ionization cross-sections can be estimated using the Lotz 's empirical formula. The solution can be found after iterations with the profile of detected beam intensity as the initial solution.

Figure 3 shows an estimated profile of density fluctuation levels together with the fitting curve of the beam fluctuation profile in Fig. 2. Here, we assumed that ionization rates are $\sigma \sim \sigma_{12}^{\mathrm{Lotz}}$ and $\sigma \sim \sigma_{23}^{\mathrm{Lotz}}$, and that density profile is $n_e = 5.0\times10^{18}((1-\rho^4)^2+0.2)\ \mathrm{m}^{-3}$. The same electron temperature profile used for the normalized potential fluctuation is assumed. The real beam trajectory of the CHS HIBP is used for this calculation. The result indicates that the profile can be significantly modified in the inner region of plasma, and that the level can be ~0.5%.

At present, we try to obtain purely local density spectra using the above reconstruntion method on the measured spectra.

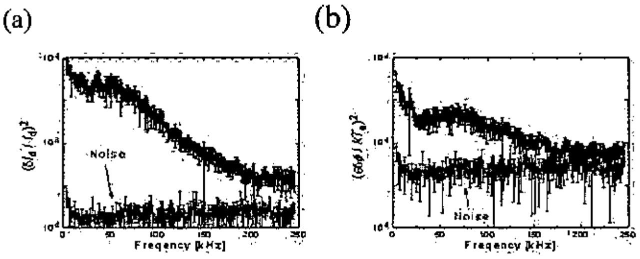

Fig. 1. Examples of density and potential spectra and noise ones(gray line) at ρ=0.68. (a) The density fluctuation spectrum. (b) The normalized potential fluctuation spectrum.

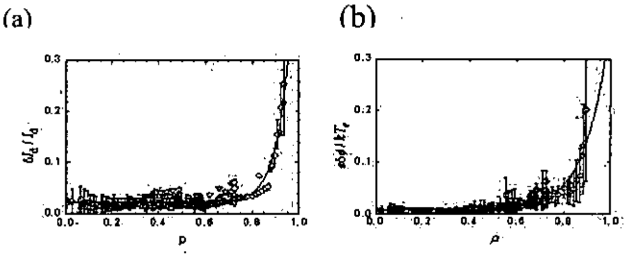

Fig. 2. The radial profile of density fluctuation amplitudes (precisely the detected beam fluctuation amplitude) (a) and potential fluctuations normalized by electron temperature (b). The solid line is a fitting curve to the data.

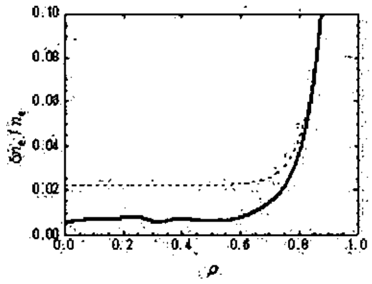

Fig. 3. The solid and dashed lines show the radial profiles of the estimated amplitude of local density fluctuation and measured amplitude of detected beam fluctuation , respectively. The amplitude of detected beam fluctuation is the same as the fitting function in Fig. 2(a).