§1. Magnetic Field Fluctuation Measurements Using Heavy Ion Beam Probe in CHS

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Heavy ion beam probe (HIBP) has the capability, in principle, to simultaneously measure density, potential and magnetic field fluctuations. However, the capability to measure the magnetic field fluctuations has not been utilized except limited cases, for example, in TEXT tokamak [1]. This is because an axi-symmetric configuration provides an advantageous circumstance where the toroidal beam displacement can be directly related with the local vector potential. However, the magnetic field measurement should be possible even in a configuration without any axi-symmetry. In CHS, the capability of the HIBP has been developed and succeeded in measuring the magnetic field fluctuations of the plasma interior [3].

In the HIBP measurement, the magnetic field fluctuations at the observation point can be connected to the fluctuations of toroidal beam displacement in the energy analyzer. The CHS HIBP is equipped with a multiple detection system to measure the toroidal displacement of the beam coming from adjacent observation points simultaneously. The fluctuation of the difference between the beam displacements on the neighboring detectors is connected to the magnetic field fluctuations in the following simple form, as

$$\Delta\tilde{\phi}_{\rm D} = G(\xi_{\rm obs})\tilde{\omega}_\phi\Delta\xi + 2\int_{\xi_{\rm obs}}^{\xi_{\rm det}} \frac{1}{\rho^2}\frac{\partial\tilde{\pi}}{\partial\eta}(\xi)\Delta\eta(\xi)d\xi_s, \quad (1)$$

where $\tilde{\omega}_\phi = \tilde{\Omega}_\phi/R_L B v_B$ and $\Omega_\phi = rF_\phi = r(\vec{v}_B\times\vec{B})_\phi$ with F_ϕ, R_L, B and v_B being the magnetic force toward the toroidal direction, the Lamor radius of beam, the magnetic field strength, and the beam velocity, respectively. The other two parameters, $\Delta\xi$ and G, are the normalized distance between the two observation points and a geometrical factor determined by the beam trajectory, respectively. The second term indicates the path integrated fluctuations along the secondary beam orbits [2]. It is shown that the second term can be neglected if the inverse aspect ratio a/R is sufficiently small. In such case, the toroidal displacement should mainly reflect the local magnetic field fluctuations.

Figure 1 shows the result of an actual measurement of magnetic field fluctuations carried out in CHS. The discharges of the target are sustained with magnetic field strength of $B = 0.88$ T and with electron cyclotron resonance (ECR) heating at 200 kW. The electron density and central temperature of the plasma are approximately are $n_e \sim 5\times10^{12}\mathrm{cm}^{-3}$ and ~ 1 keV, respectively. In the measurement the observed position of $r = 12$ cm (or $\rho = r_{\rm obs}/a \sim 2/3$) was chosen since the signal-to-noise ratio is maximum in this plasma condition. The spectrum shown in Fig. 1 is obtained using Fast Fourier Transformation (FFT) as an average for ~ 70 windows, each of which consists of $2^{12}(\sim 8$ ms) data providing frequency resolution of 0.12 kHz; the data is digitized with 0.5 MHz sampling rate, hence, the corresponding Nyquist frequency is 250 kHz.

In order to evaluate the absolute value of magnetic field fluctuations, the conversion factor α_c is calculated, which is defined as $\tilde{B}_\perp = \alpha_c\Delta\tilde{\phi}_D$ where $\alpha_c = G^{-1}(R_L/\Delta x)(R_L/R_{obs})(v_b/v_\parallel)B$, where $\tilde{B}_\perp$ and $v_\parallel$ are the magnetic field component perpendicular to both toroidal and beam directions and the beam velocity perpendicular to toroidal direction, respectively. A trajectory calculation gives the necessary parameters to evaluate the conversion coefficient, $\alpha_c = 6.92\times10^5$ (Gauss/rad). The calculation also shows that the observation points are aligned almost in radial direction. Hence, the measured magnetic field is poloidal component in the experimental condition.

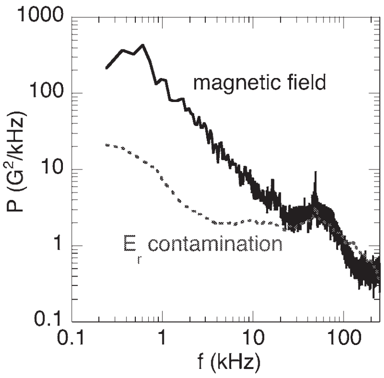

Fig. 1: Examples of magnetic field fluctuation measurements using an HIBP in CHS. A spectrum of magnetic field fluctuation. The spectrum is considered to contain local magnetic field fluctuation, path integral magnetic field fluctuation, and the local radial electric field fluctuation. The solid and dashed lines represent the abovementioned total fluctuations and the expected contamination due to local radial electric field fluctuation.

In summary, the multi-channel HIBP was used to measure the magnetic field fluctuation in the ECR-heated CHS plasma. The present results could be the first observation of local magnetic field fluctuations in a high temperature core of magnetically confined plasmas.

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2) A. Shimizu, A. Fujisawa, S. Ohshima, H. Nakano, Rev. Sci. Intrum. **76** 043504 (2005).

3) A. Fujisawa, A. Shimizu, H. Nakano, S. Ohshima, Plasma Phys. Control. Fusion **49** 845 (2007).