§ 8. Scenario of Magnetic Field Fluctuation Measurement with Heavy Ion Beam Probe

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Heavy Ion Beam Probe (HIBP) is a powerful diagnostic tool to measure the temporal evolution and profile of potential, density, and magnetic field in an interior of plasma. The principle of this diagnostics is as follows. A beam of Cs^+ is injected to plasma, and by an electron impact this Cs^+ is ionized to Cs^{2+} in the plasma. At an energy analyzer located on outside of plasma, the beam energy, intensity, and displacement of beam position in the toroidal direction are measured. By the change of beam energy, plasma potential is estimated directly. Beam intensity includes information of density. Information of magnetic field is obtained from the displacement of beam position.

Magnetic field measurement in CHS with HIBP is difficult because of its 3-D magnetic field configuration. Obtained information from HIBP is only displacement of beam position at the energy analyzer, and it is not easy to find how the displacement corresponds to variation in the magnetic field. An effect of path integral also makes the interpretation more complicated. However, it is possible to estimate the unfavorable effect of path integral when only fluctuation phenomenon is interested. In order to investigate a basic perspective of relation between the beam displacement and magnetic field fluctuation, a numerical calculation has been performed in an axisymmetric magnetic field, *i.e.* tokamak. In the axisymmetric field, a canonical momentum in the toroidal direction, namely the angular momentum, is conserved. This momentum can be written in cylindrical coordinates as, $P_\phi = mR^2\dot{\phi} + qRA_\phi$. Here, ϕ is the toroidal angle, R the major radius, m the mass of a beam ion, q the charge, and A_ϕ the toroidal component of vector potential. By using the conservation of this momentum, beam displacement δ in the toroidal direction at the energy analyzer can be expressed as follows,

$$\delta = \alpha R_s \tilde{A}_{\phi s} \int_{l1}^{l2} \frac{1}{R^2} dl - \alpha \int_0^{l1} \frac{\tilde{A}_\phi}{R} dl - 2\alpha \int_{l1}^{l2} \frac{\tilde{A}_\phi}{R} dl \cdot \qquad (1)$$

α is qR_d/mv, v is the velocity of beam ion. Subscript s means that the quantity is at an ionized point of beam, $Cs^+ \rightarrow Cs^{2+}$, and d means that at the energy analyzer. The integral is done along a beam path, and l_1 is the path length from the injection point to an ionized point, l_2 is from the ionized point to the energy analyzer. The first term includes local information of fluctuation, and the second and the third terms correspond to path integral effects of fluctuation from primary (Cs^+) and secondary beam (Cs^{2+}) path. Since in the real experimental measurements the square of δ is analyzed, the correlation terms must be considered. The correlation terms are assumed as follows,

$$< \tilde{A}_i \tilde{A}_j >= P_{i,j}\gamma_{i,j}\Theta_{i,j} = \exp(-(r_i - r_c)/0.05^2) \cdot \exp(-(r_j - r_c)/0.05^2)$$
$$\cdot \exp\left(\left(\mathbf{r}_i - \mathbf{r}_j\right)^2 / l_c^2\right) \cdot \cos\left(m\left(\theta_i - \theta_j\right)\right) \cdot \cos\left(2\pi\left(r_i - r_j\right)/\lambda_r\right) \qquad (2)$$

< > means the ensemble average. $P_{i,j}$ is the product of amplitude of fluctuation, $\gamma_{i,j}$ the correlation of fluctuation between two points, and $\Theta_{i,j}$ the difference in phase. r is the minor radius, r_c the radial position for maximum amplitude of fluctuation. $\mathbf{r}_i$ and $\mathbf{r}_j$ are position vectors, l_c the correlation length, θ_i, θ_j poloidal angles, m the poloidal mode number, and λ_r the radial wavelength.

Beam orbits used in the calculation are shown in Fig.1. Shape of poloidal cross section is a circle for simplicity. Calculation results for this geometry are shown in Fig.2. The assumed condition is as follows: $m = 2$, $l_c = 0.1$ m, and $\lambda_r = 0.1$ m. Solid lines are assumed profiles of fluctuation amplitude. r_c is 0.02, 0.1, 0.17 m for Case A, B, and C (r=0.2 m corresponds to outermost magnetic surface). Dotted lines are fluctuation amplitudes detected by HIBP. The radial positions for the maximums are not changed, however due to the path integral effects, the maximum values of detected amplitudes become smaller than assumed ones. The dependence of position of energy analyzer on the signal distortion is also investigated. If the analyzer is located farther from plasma the path integral effects become less, and the local information of fluctuation becomes more dominant in the detected signal. Detailed calculation is now in progress.

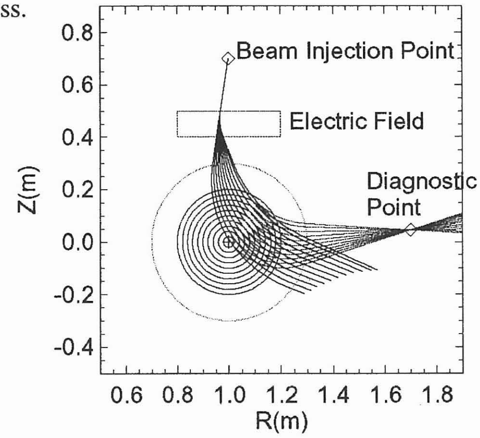

Fig.1 Assumed orbits of heavy ion beam.

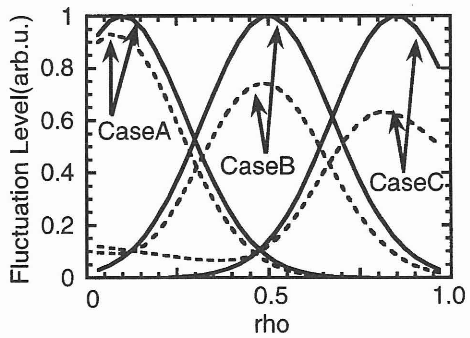

Fig.2 Simulation results of magnetic field fluctuation measurements. Solid lines are assumed profiles of amplitudes of fluctuations, and dotted lines are detected ones with HIBP.