§13. Heavy Ion Beam Probe Measurement in Turbulence Diagnostic Simulator

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The development of experimental diagnostics in fusion plasmas enables to obtain high spatial and temporal resolution measurements of fluctuations [1]. In order to verify the observation of fluctuations within the required resolutions, it is helpful to use simulation data as a test field for the measurements. The turbulence diagnostic simulator is combination of fluid turbulence codes and numerical diagnostic modules to simulate experimental measurements of plasma turbulence [2]. The spatio-temporal data analyses as same in experiments can be made on the simulation data.

We have been developing several numerical diagnostic modules, one of which is described here. The heavy ion beam probe (HIBP) is a powerful diagnostic in plasma experiments [3], and we carry out numerical HIBP measurements on 3-D simulation data of turbulence in toroidal plasmas to find out how detected signals are influenced by finite spatial resolutions and fluctuations along the trajectories of the probe beam.

In order to provide turbulence data, a three-field (stream function, vector potential and pressure) reduced MHD model was extended to calculate the drift-interchange turbulence in large aspect ratio helical plasmas with a circular cross-section [2]. The averaging method with the stellarator expansion [4] is applied. Equations are solved in the toroidal coordinates with the spectral expansion in the poloidal and toroidal directions. The nonlinear simulations with a fixed pressure source are carried out. The parameters for the simulation are described in Ref. 2). Spatio-temporal data of turbulent fields are generated by this global simulation. Modes with low poloidal and toroidal mode numbers are excited in the linear growing phase, and saturation is obtained with energy exchanges between various modes by nonlinear couplings. Figure 1 (a) shows the snapshot of the contours of the electrostatic potential.

Time series of 3-D data from numerical simulations are analyzed with the numerical diagnostic modules. For HIBP measurement, heavy ions are injected into the plasma, and the ions that are ionized from charge +1 to +2 in the plasma are detected as shown in Fig. 1 (a). The difference between the particle energy of the injected ions and the detected secondary ions corresponds to the potential at the ionization point. The trajectory of the ion changes in accordance with the ionization point, so the ionization point can be identified. The intensity of the detected beam is affected by the ratio of ionization in the sample volume and the attenuation along the trajectory [5]. If the density is low, the beam intensity can be assumed to obey the density at the ionization point. The HIBP module simulates this mechanism. The energy of the detected ion and the beam intensity are the outputs of the measurement, which are translated into the plasma potential and the electron density. Considering a finite beam width and a finite detector size,

the detector catches ions from not a single ionization point but some region, so averaging over the ionization region (sample volume) gives the HIBP signals taking account of the spatial resolutions of the measurement.

The numerical HIBP measurement is carried out on the fluctuation fields. The radial profiles are calculated using a snapshot data. The HIBP signal is given by averaging over the sample volume, which screens the fine structures within the sample volume. The comparison between the numerical measurements and the corresponding local values indicates that the calculated values agree well in the case when the typical length of the fluctuations is not smaller than the size of the sample volume.

The data set includes time series, so time evolutions of quantities can be obtained. The ion trajectories are fluctuated with the temporal variation of the perturbed field, so the observation point and the size of the sample volume changes accordingly. The deviation of the observation point is 5 % at most, and the size of the sample volume is around 8 % of the minor radius in this case. Therefore, the potential and density fluctuations have the deviation of more than 10 % from the values on a fixed point in the sample volume. Figure 1 (b) shows the comparison between the potential calculated with the HIBP measurement and that at the fixed point. The characteristic oscillation can be identified with the numerical HIBP signal, so the selected beam width and detector size are small enough to study the fluctuations.

The observation point can be selected by adjusting the condition of the probe beam, and data at any multiple points are available. Correlation analyses can be carried out using the numerical HIBP signals, and show existence of a radially broad mode. In this way, the fluctuation analysis shows that the numerical measurement is useful to obtain the results that can be compared with experiments.
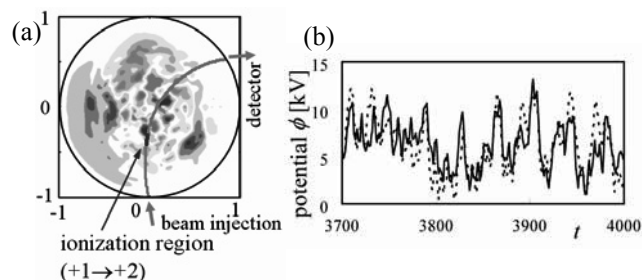

Fig.1: (a) Contours of the electrostatic potential fluctuation on the poloidal cross-section. An example of the HIBP beam trajectory with the ionization region is also shown. (b) Time evolutions of the electrostatic potential with the numerical HIBP measurement (solid line) and the local value at the fixed point in the sample volume (dashed line). This is the case with the beam width of 1cm and the detector size of 3cm.

1) Fujisawa, A.: Nucl. Fusion **49** (2009) 013001.
2) Kasuya, N. et al.: Plasma Sci. Technol. **13** (2011) 326..
3) Fujisawa, A. et al.: Phys. Rev. Lett. **93** (2004) 165002.
4) Wakatani, M.: *Stellarator and Heliotron Devices* (Oxford University Press, Oxford 1998).
5) Nakano, H. et al.: Rev. Sci. Instrum. **78** (2007) 063502.