§3. Measurement of Spatial Structures of Density Fluctuations using a Microwave Frequency Comb Reflectometer

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Nonlinear process in multi-scale turbulence is one of the keys in plasma transport, and dynamical changes of the mean and fluctuation profiles must be measured with high spatio-temporal resolutions for the identification. In this research, development of a new experimental diagnostic for detailed fluctuation measurements is promoted with the integration of theoretical, simulation and experimental approaches. For that purpose, a reflectometer using microwave frequency comb has been developed [1]. Turbulence Diagnostic Simulator (TDS) [2], which is an assembly of simulation codes for numerical diagnostics in magnetically confined plasmas, is used as the platform of the development. This is the last year of the research planned for three years, and the technique has been developed in a basic experimental device to be applied to a LHD experiment. Analysis methods were also studied to identify nonlinear processes in turbulent plasmas.

An experimental system for comb reflectometry has been developed on the PANTA device in Kyushu University to confirm its efficiency [3]. The comb signal with the frequency range of 12 - 27 GHz and the frequency interval of 0.5 GHz is injected and reflected in the plasma, which enables simultaneous monitoring at more than 30 distinct spatial locations. The signals are directly transferred to the digital storage oscilloscope (DSO), so the waveforms of the incident and reflected signals are detected with high temporal resolution. The measurement using the comb reflectometer has been started from the last year, and two kinds of improvement have been achieved in this year on analysis method and comparison with a simulation.

The conditional averaging method can reduce random noise from the observed signals. The detected signals by the DSO can be treated as a series of pulse (the full width at half maximum of the envelope is 0.07 ns and the repetition period is 2 ns). Averaging a large number of pulses with temporal adjustment using the incident signal as the reference, the characteristic wave form of the reflected signal is obtained. By setting a series of time windows, the time evolution of the density perturbation is obtained with resolution of 0.1 [μsec]. Figure 1 shows the frequency spectrum of the density fluctuation. The results are consistent with that obtained by an electrostatic probe.

Although monitoring at several spatial locations is possible by the system in PANTA, there is ambiguity to determine the phase difference between neighboring channels due to fringe jump. It is necessary to carry out a numerical simulation of the diagnostic for reconstruction of the density profile. The module of the ray tracing of the RF wave in the integrated simulation code TASK [4] is used. Calculation of the ray to give the reflection point and the phase delay to give comparison with output signals is carried out with a given background density profile [3]. Figure 2 shows examples of calculations to show the dependence on different profiles. From these calculations, the fringe jumps between neighboring channels can be estimated, and the reconstruction of the density profile is carried out from the experimental observation.

The method is applied to the LHD experiments. The system has been developed to observe fluctuations at 36 distinct spatial locations in the last campaign, and a data analysis gives detailed structures, which makes possible to discuss the relation between the flow shear and fine structure of fluctuations [5]. The measurement also shows the spatial structure of a MHD mode near the edge of the plasma [6]. Simulations of experimental diagnostics in actual 3-D magnetic configurations are important for the validation, so data analysis modules are developed for simulations with the LHD magnetic configurations [7].

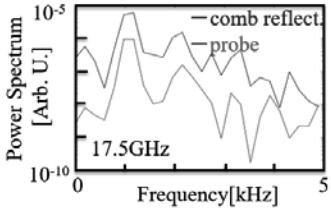

Fig.1: Power spectrum of the density fluctuation obtained by using the comb reflectometer in PANTA (red). The spectrum by the electrostatic probe is also shown (blue).

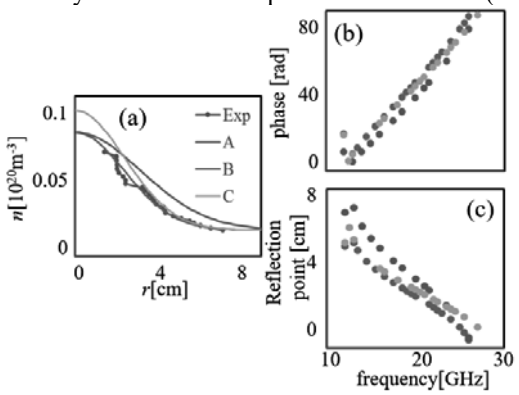

Fig.2: (a) density profiles A - C used in the simulations. The violet circles represent the density profile estimated from the PANTA experiment. Comb reflectometer simulation result of (b) the phase delays and (c) the reflection points with the density profiles A - C.

1) Inagaki, S. et al.: Plasma Fusion Res. **8** (2013) 1201171.
2) Kasuya, N. et al.: Plasma Sci. Tech. **13** (2011) 326.
3) Mizokami, T.: Master Thesis, Kyushu Univ. (2016).
4) Fukuyama, A.: http://bpsi.nucleng.kyoto-u.ac.jp/task/.
5) Inagaki, S. et al.: APTWG 2015, Dalian, China (2015) DI1.
6) Soga, R. et al.: J. Instrum. **11** (2016) C02009.
7) Kasuya, N. et al.: JPS annual meeting, Sendai (2016) 21pAE-5.