# §12. Research of Plasma Turbulence, Turbulent Transport and Experimental Methods

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Transport study of the turbulent toroidal plasma has progressed in the recent decade. Transport phenomena that are difficult to understand under the existing paradigm for turbulent transport have been successively observed (e.g. non-local edge-core coupling and internal diffusion barrier formation in LHD). In recent days, new trends in plasma turbulence study have resulted from the integration of 1) non-linear statistical turbulence theory, 2) multi-scale simulation and 3) experiments in small devices. The aim of such study is a formulation of research based on the experimental observation of nonlinear processes of plasma turbulence. This research aims at establishing a basis of turbulence transport study by improving a linkage between theory and experiment in the Linear Mirror Device Upgrade (LMD-U) at Kyushu University. Developement of advanced methods for experimental data analysis is also in scope of our research. Results obtained from the transport study on LHD and knowledge from our turbulence study will be integrated into the generic physics foundation of high-temperature toroidal plasmas.

The theory for multi-scale coupling in turbulence is developed and radial eigenmodes of geodesic acoustic modes (GAMs) with discrete eigenfrequencies in toroidal plasmas are analysed [1]. The eigenmode has a wavelength of the order of $\rho_i^{2/3} L_T^{1/3}$, where $\rho_i$ is the ion gyro-radius and $L_T$ is the temperature gradient scale length, and has its highest peak near the radius where the eigenfrequency coincides with the local GAM frequency, which is defined as

$$\omega_G = \frac{v_{th,i}}{R}\sqrt{\frac{7+4\tau_e}{4}+\frac{23+16\tau_e+4\tau_e^2}{2(7+4\tau_e)q^2}}, \qquad (1)$$

where $v_{th,i}$ is the ion thermal velocity, $\tau_e = T_e/T_i$ and $q$ is the safety factor. Based on this result, a new kind of plasma diagnostics, GAM spectroscopy, is proposed. Observing the radial position of the highest peak of the eigenmode provides a method to measure the local ion sound velocity. The ion composition can be determined from the local ion sound velocity, densities and temperatures.

In toroidal plasmas, the most common methods to measure fluctuations are those for density fluctuations such as conventional reflectometry. However, it is difficult to detect GAMs by simply using the density fluctuation diagnostics because the density fluctuation component is small. The amplitude of turbulent density fluctuations is modulated by GAMs through the parametric modulational instability. Multi-channel reflectometry is capable of measuring the GAMs structure. This new analysis method is applied to a reflectometry signal from LHD. Typical results are shown in this annual report (Inagaki S., "Envelope analysis of density fluctuation in edge-core coupled plasmas") [2].

Drift wave excitation experiments were performed in the LMD-U. A cylindrical plasma with a diameter of approximately 10cm and an axial length of 3.74m is produced by the helicon wave system (with a wave frequency of 7MHz and a power of 3kW) and radially confined in the linear magnetic configuration (the magnetic field is 900G). Neutral gas (Ar) is injected by a mass flow controller. Typical electron temperature and density are 3eV and $1\times10^{19}\mathrm{m}^{-3}$, respectively. Advanced diagnostic tools, such as multi-channel probes and Reynolds stress probes, have been developed to realize local measurements with high resolution and accuracy in LMD-U [3,4]. Advanced analysis tools for nonlinear phenomena, such as bicoherence and wavelets, have also been exploited with massive data processing systems [5,6].

In spite of the importance of temperature fluctuation on the turbulent transport, there has been no observation of the temperature fluctuation. A new method to measure temperature fluctuation, thus, is proposed. Electron temperature is usually determined from the voltage-current curve (V-I curve) of the Langmuir probe. The V-I curve is obtained with a sweeping probe bias voltage. The V-I curve varies over time due to fluctuations (mainly potential fluctuations). Thus, the conditional averaging, which uses the potential fluctuation as reference, allows us to estimate the time-varying V-I curve, i.e. time-varying electron temperature coincident with the potential fluctuation. A preliminary result is obtained in LMD-U. Electron temperatures obtained from the time-varying V-I curves tend to be smaller than those obtained from the time-averaged V-I curves. To observe ion temperature fluctuations in LMD-U, a multi-grid energy analyzer has been designed and assembled.

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