論文の内容の要旨

論文題目　**A study of temporal and spatial structure of edge turbulence in the TST-2 spherical tokamak**

（　**TST-2 球状トカマク装置における周辺部乱流の時空間構造の研究**　）

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In fusion plasma research, the study of anomalous transport by turbulence is important for controlling the transport and plasma operation.　In magnetically confined plasmas, various types of fluctuations are induced due to plasma instabilities. These fluctuations cause anomalous transport flux, and the plasma confinement is deteriorated as a result. In conventional tokamak plasmas, these transports are thought to be caused mainly by drift waves driven by pressure and temperature gradients, and the contribution of magnetic fluctuations is believed to be negligible. A spherical tokamak (ST) can confine high pressure plasma with a relatively weak magnetic field strength and is very attractive as a fusion reactor from an economic point of view. However, magnetic fluctuations could be large in ST plasmas, where the high pressure, the weak magnetic field strength (i.e. the low safety factor) and the large plasma current may enhance magnetic fluctuations through instabilities. Therefore, understanding not only the drift wave like fluctuations but also the magnetic fluctuations and their effects on plasma turbulence is important.

In this thesis, the temporal and spatial structures of the edge turbulence in TST-2 ST plasmas are measured by using Langmuir probes and magnetic pickup coils. TST-2 has a short inter-discharge time, which is necessary to obtain a large number of data sets and to perform ensemble averaging in order to reveal the structure of the plasma turbulence and higher order non-linear processes associated with the plasma turbulence.

It was found that the observed fluctuations can be classified into two types: (i) the MHD type fluctuation characterized by a global structure and low frequencies (< 20 kHz), and (ii) the drift wave like fluctuations characterized by a smaller spatial scale and higher frequencies (> 20 kHz). The discharges in TST-2 are characterized by a large MHD type fluctuation.

The relative fluctuation level is $\tilde{B}_r/B_t = 10^{-2}$ inside the last closed flux surface (LCFS), and the level is much higher than those in conventional tokamaks.

The electrostatic particle flux is dominated by the MHD fluctuation component. However, the fluctuation in the frequency range < 20 kHz is mainly an ideal MHD mode, and it does not induce transport. This fact suggests that resistive modes and/or other non-MHD modes which induce transport are mixed with the ideal MHD mode. The total flux is $\Gamma_r = 5 \times 10^{20}$ m^{-2}s^{-1}. The estimated radial diffusion coefficient is $D_r = 10$ m^{2}s^{-1}.

The correlation length of the MHD fluctuation along a field line is about 5 m, and the Rechester-Rosenbluth type diffusion coefficient is estimated as $D_{st} = 10$ m^{2}s^{-1}.

The high coherence of floating potential fluctuations $\tilde{V}_\mathrm{f}$s along the field line up to 100 kHz leads to the possibility that the fluctuations are frozen to the magnetic field line and oscillate with the MHD fluctuation. In order to clarify the possibility, the spatial structure of fluctuations is reconstructed by tracing the trajectory of the field lines. The profile of the coherence at 50 kHz shows decay lengths of $\delta R = 30$ mm and $\delta Z = 12$ mm. The inverses of these values agree roughly with the local wavenumber spectral width $\sigma_k = 0.05$ mm^{-1}. This agreement implies that the fluctuations are frozen to a field line.

We have experimentally revealed the detailed temporal and spatial structure of the edge turbulence in ST plasmas for the first time. In the time domain, the turbulence can be classified into slow MHD fluctuations and fast drift wave type fluctuations. The former has large amplitudes and its effect on transport is significant. In the perpendicular directions, the drift wave type fluctuations are frozen to the slow MHD fluctuations. The structures in the parallel direction (i.e. the parallel wavenumber and the parallel correlation length) were measured for the first time inside the LCFS in tokamaks. The revealed structures imply that the turbulence in STs are complicated and we should take into account the 3D effect in future ST research.

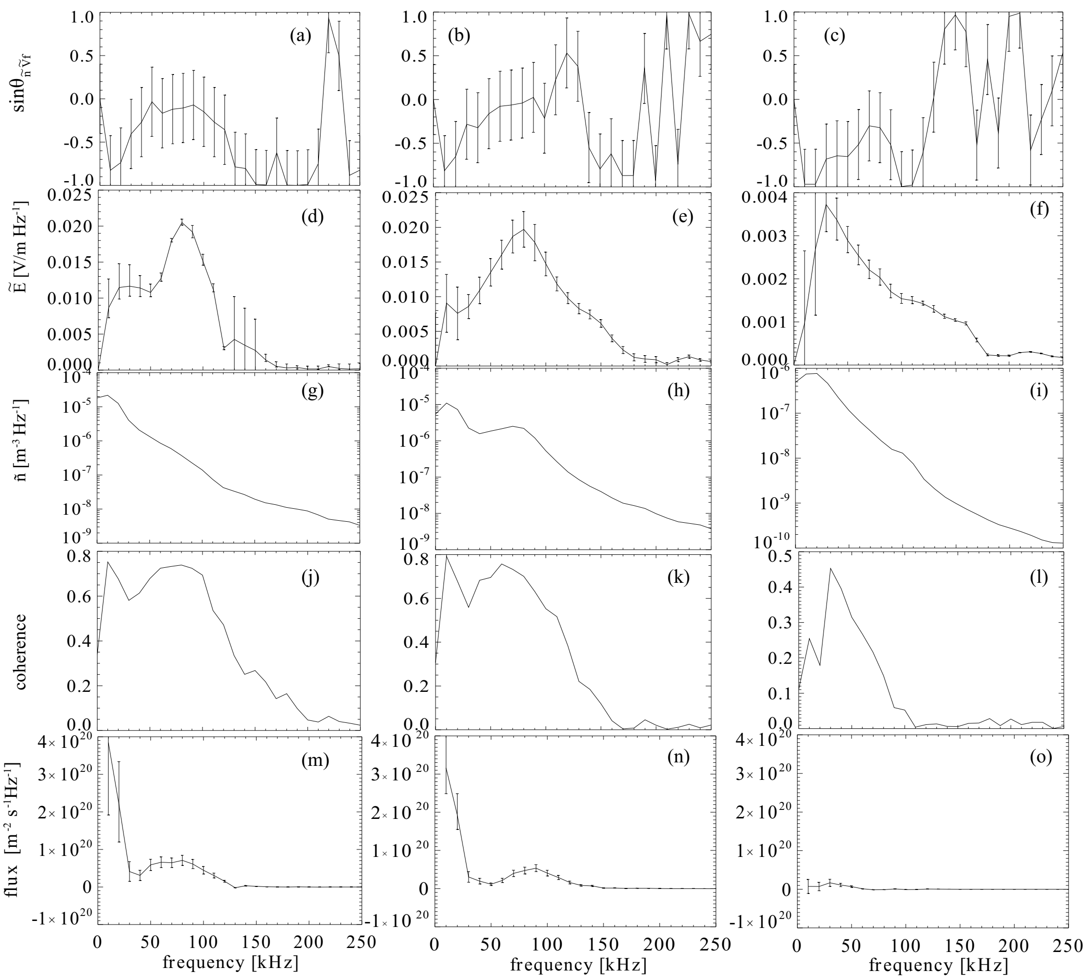

Figure 1：Frequency dependence of $\sin(\theta_{nE})$ (a), (b), (c), $|\tilde{E}|$ (d), (e), (f), $|\tilde{n}|$ (g), (h), (i), coherence between $\tilde{E}$ and $\tilde{n}$ (j), (k), (l) and particle flux (m), (n), (o) at R=560 mm (left), R=580 mm (middle) and R=650 mm (right). Error bars are derived from standard deviations of each value in multiple shots.

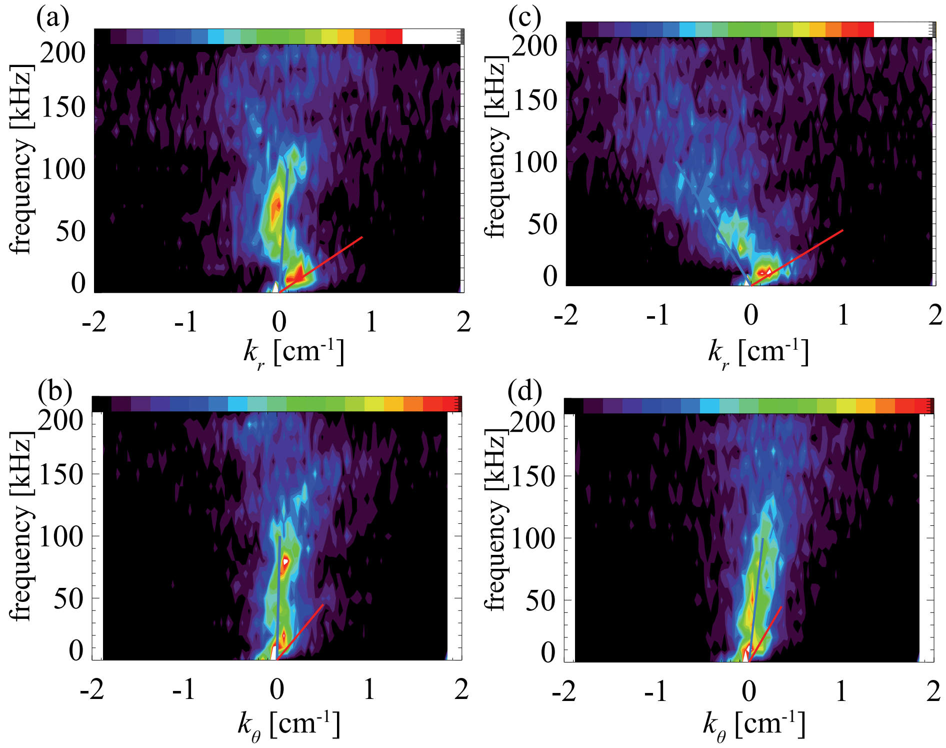

Figure 2：Wavenumber spectrum of k_r (a) and k_θ (b) at R=560 mm and k_r (c) and k_θ (d) at R=600 mm. These are derived from V_f s of the composite probe system. A clear difference between the dispersion relations up to 20 kHz and that above 20 kHz can be seen.

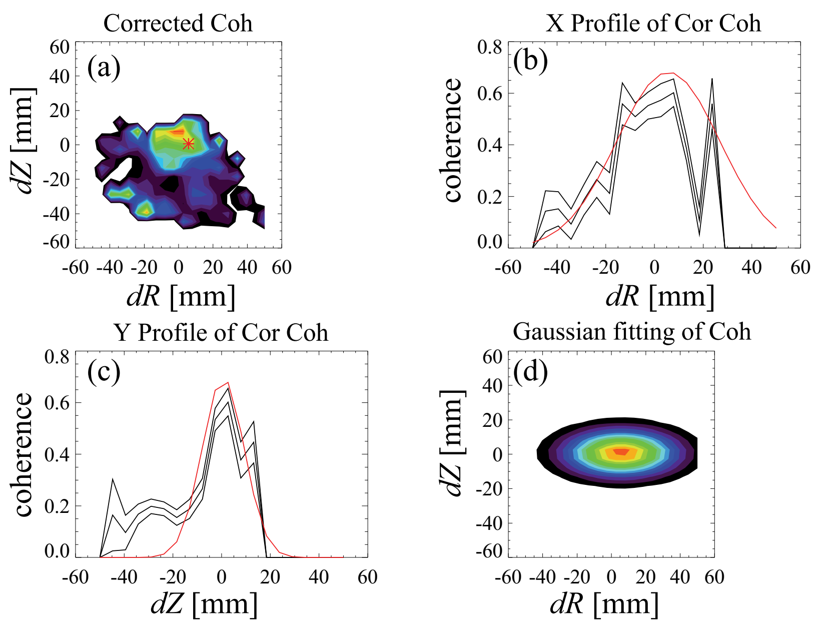

Figure 3： 2D-map (in $R-Z$ plane) of the coherence of V_f s at 50 kHz (a), and cutaways along dR (b) and dZ (c) with Gaussian fitting curves (red). The 2D-map of the Gaussian fitting curve (d) is also shown. 1/e width of the gaussian is δR = 30 mm and δZ = 12 mm.