Edge density fluctuation patterns measured by two-dimensional beam emission spectroscopy on the KSTAR tokamak

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Introduction

In tokamak plasma, density fluctuation patterns at the edge region near the pedestal have close relation with performance of H-mode and its behaviours such as edge localized modes (ELMs). It could be suppressed or enhanced during transition between varying operation modes and shows different response according to the spectral band. Beam emission spectroscopy (BES) is commonly used diagnostics to measure the density fluctuation. A BES system can measure the electron density from light intensity of Doppler-shifted line emission of neutral beam and its fast measurement speed up to several MHz enables fluctuation study on electron density. A two-dimensional measurement is also available by using a detector array and corresponding optics. A two-dimensional distribution and its flow of density fluctuation can be studied via correlation analysis between detectors. A trial BES system based on direct imaging avalanche photo diode (APD) camera has been installed for Korea Superconducting Tokamak Advanced Research (KSTAR) and density fluctuation patterns at the edge region have been measured during several types of H-mode control experiments[1]. Since the test was focused on checking the environment of KSTAR, the trial system consists of simple optics that leads low optical throughput and high background leakage. All system worked properly and the measured photon flux was reasonable as expected from the simulation. Although the simple optics deteriorated the performance of the trial system, some interesting characteristics of KSTAR plasma, especially related with H-mode discharge, have been measured. In this paper, we will describe prominent features of the edge density fluctuation on the KSTAR tokamak measured by two-dimensional trial BES system.

Specifications of the KSTAR BES System

The KSTAR BES system measures the fluorescence of a heating deuteron beam. The beam is injected in tangential co-current direction. The light collection optics was placed at 45 degree away in toroidal angle from the observation point via long-narrow diagnostics port. Inside the port, a 2 m diagnostics cassette was installed. Series of optics transmit the light to the APD camera placed at the outer end of the port for reducing the effect of magnetic field and high-energy radiation. The light is directly imaged onto a 4 x 8 channels APD detector array (Hamamatsu S8550). All 32 channels are simultaneously digitized in 12-bit at 2 MHz and the data are transferred to a server after 10 second measurements. The camera has similar specifications with the MAST BES camera[2]. One more visible camera was installed to calibrate the observation position by sharing common view with the APD camera. The distant between centers of adjacent measurement points on the observing poloidal plane was 1.3-1.5 cm. Accordingly, the measurement area was 6 cm x 12 cm in poloidal and radial direction, respectively. The measurements were focused on the edge region near pedestal. Despite the limitation of the trial system such as high background noise and low optical throughput, some prominent features have been detected through correlation studies between two-dimensional detectors on the KSTAR plasma.

Spectral Correlation Analysis

Fast measurements speed of 2 MHz enables high-frequency fluctuation analysis. Fluctuation of the measured photon intensity can be analysed by spectral auto-power calculation. The auto-power spectrum showed $f^{-\alpha}$ type spectra and α was ~2 on the edge of KSTAR plasma. The power spectrum can be obtained by comparison between adjacent detectors. This cross-power spectrum showed similar spectra with the auto-power spectra except much lower

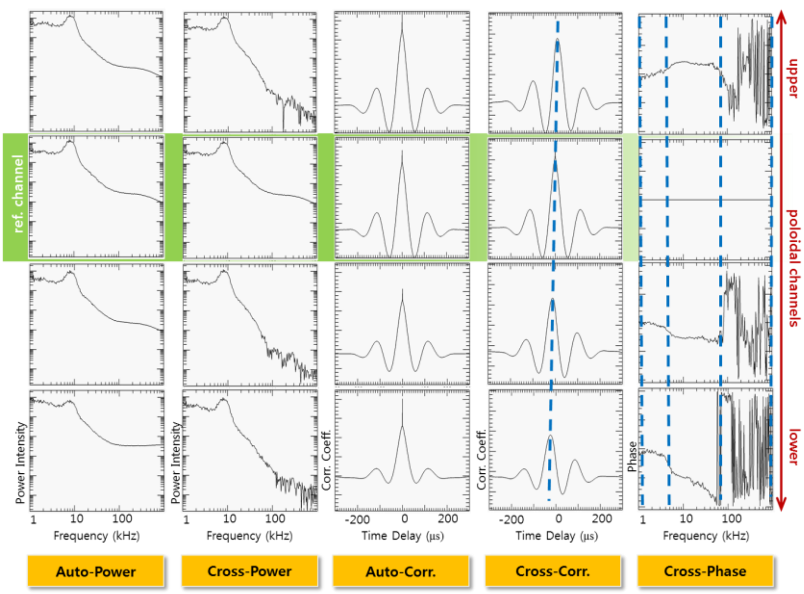

Fig. 1 Several fluctuation spectrum analyses using correlation between poloidal channel. Fluctuation structure of plasma density and its movements can be studies by these analyses.

power over 100 kHz. This implies that the spectral power over 100 kHz comes from non-plasma related source, such as a quantum noise of detector. A spectral cross-phase also can be calculated by time-delay method. This method enables to detect a movement of plasma structure. If the plasma rotates poloidally then the cross-phase between poloidally adjacent detectors will be linearly proportional to the distance between detectors. In the KSTAR plasma, most of the poloidal rotation was detected within the frequency range of 10-50 kHz. The rotation speed was ~1 km/sec. Over 100 kHz, the cross-phases were random values that mean two signals are uncorrelated. The cross-phases of low frequency range under 10 kHz were near zero. This can happen when the poloidal rotation speed is zero, or the poloidal mode number is zero so the rotation is not detectable via the fluctuation of local density. High background signal that is not localized also can be a reason of the zero cross-phase.

GAM-like Spectral Peak

On the edge density fluctuation pattern of the KSTAR plasma, one of the prominent features was a broad spectral peak near 10 kHz. This peak appeared on both of the density fluctuation spectrum and the poloidal cross-phase spectrum. Some characteristics relate the peak with the geodesic acoustic mode (GAM)[3]. The peak has frequency of 10 - 20 kHz and spatially localized inside the pedestal. The frequency showed similar trend with electron temperature and sometimes its peak was split. No magnetohydrodynamics activities in this frequency range were detected on the Mirnov coil signal during that time. The peak did not comes from the background noise because it was disappeared when the beam off. The peak on the density fluctuation spectrum only appeared after L-H transition, which is not match with the GAM characteristics. However, the peak appeared before transition on the cross-phase spectrum and its rotation direction is reversed. The reason is not clear now and it needs further investigation.

Quasi-Coherent Mode

Quasi-coherent (QC) mode is a broad peak in the range of 30 - 100 kHz[4] - much higher than GAM frequency. The QC structure also was detected on the fluctuation spectrum and the cross-phase spectrum. This structure was radially localized in the width of 2 cm near separatix. The QC mode was accompanied with sawtooth-like signal on the H-alpha and the electron temperature during L-mode. Electromagnetic fluctuation also was occurred in the frequency of 1-3 kHz and its harmonics. The QC mode is a signature of the enhanced D-alpha H-mode, but in this case, there was no sign of the confinement improvement.

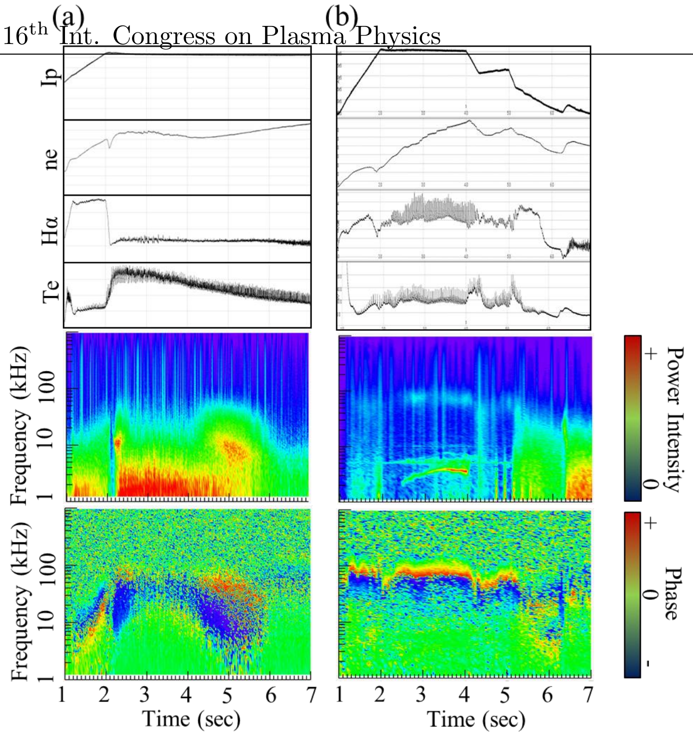

Fig. 2 Edge density fluctuation patterns on the KSTAR tokamak. (a) GAM-like peak near 10 kHz. (b) Quasi-coherent mode near 100 kHz. The upper one is a density fluctuation spectrogram and the lower one is a cross-phase spectrogram.

Summary and Future Work

The GAM-like and the quasi-coherent fluctuations were detected on the KSTAR edge plasma using trial BES system. An explanation is limited but it suggests possibilities of investigation on the localized fluctuation and its movements using the fully developed KSTAR BES system. The measurements and scaling of GAM frequency is planned on this year. The KSTAR already has an electron cyclotron emission imaging (ECEI) system and other fluctuation imaging systems are planned on different toroidal angles. It will be great opportunities to study three dimensional edge physics using simultaneous measurements with multiple fluctuation imaging systems including this BES system.

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