J. Plasma Fusion Res. SERIES, Vol. 6 (2004) 449–452

Edge Transport Barrier in CHS Measured Using Beam Emission Spectroscopy

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(Received: 12 December 2003 / Accepted: 7 May 2004)

Abstract

An edge particle transport barrier was observed as a transition phenomenon characterized by the rapid decrease of the H_α signal and the increase of line-averaged density in the neutral beam heated plasma in the compact helical system (CHS) when the heating power exceeds a certain threshold. A beam emission spectroscopy (BES) measurement showed a rapid increase of local plasma density near the plasma edge accompanied by coherent-like density fluctuations around 5 kHz.

Keywords:

BES, density fluctuation, edge transport barrier, H-mode, CHS

1. Introduction

The formation of an edge transport barrier (ETB) at the H-mode transition [1] plays a very important role in achiving a high performance plasmas confinement. Several phenomena that suggest a correlation between the formation of ETB and the fluctuation of plasma parameters have been observed, including the enhancement of specific MHD instabilities such as the edge localized mode (ELM) [2] and edge harmonic oscillation (EHO) [3], and the suppression of turbulence near the plasma edge with steepened gradients of temperature and density. Therefore, it is important to understand the relationship between the formation of ETB and fluctuations of plasma parameters.

Recently, a transition phenomenon characterized by a rapid decrease of the H_α intensity signal was observed in the neutral beam heated plasma in the compact helical system (CHS) when the heating power exceeded a certain threshold. The increase of line-averaged density and the increase of the local edge density measured by means of YAG-Thomson scattering at the transition have been reported [4], which suggests a formation of ETB.

We have applied beam emission spectroscopy (BES) for the measurement of the local density variations or perturbations with high time resolution. The BES, which has been proposed to measure long wavelength plasma density fluctuations, detects emissions from the collisionally excited neutral beam atoms (denoted as "beam emission") [5]. Since the observable region is the intersection of beam line and sightline for each fiber channel, local values and their correlations are available. Provided the beam attenuation is negligible, then the beam emission intensity can be regarded as a function of the plasma density.

In this paper we report an initial study of a transition phenomenon in CHS by using the BES measurement.

2. Experimental setup

Figure 1 is a schematic drawing of BES systems in CHS.

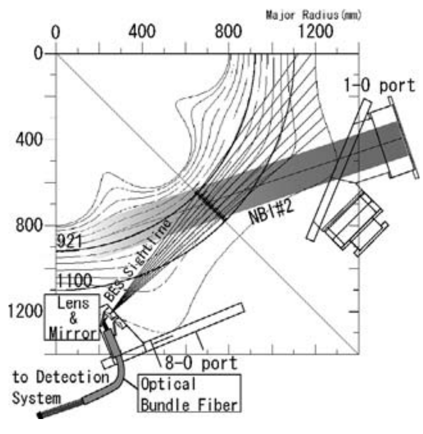

Fig. 1 Schematic of the BES system on the CHS device.

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Spatial channels of BES consist of 8 optical fibers with object lenses which focus on the position along minor radius of CHS. The observation regions for channels 1 and 8 are close to the center and edge, respectively. One system for the hydrogen neutral beam injection (NBI) heating with the acceleration voltage of about 28 keV is used for the probe beam for BES. The H_α wavelength in the beam emission is Doppler-shifted to 651.9 to 652.4 nm for the observation angle of 23° to 34° with respect to the beam line, so that it can easily be separated from H_α emission from bulk plasmas (656.28 nm). Narrow band interference filters, whose transmission wavelength can be controlled by the filter holder temperature, are used to select the Doppler-shifted emissions, which are detected using avalanche photo-diode detectors (APD) combined with a 100-kHz low-pass filter.

3. Experimental results

3.1 Temporal evolutions of the intensity of BES signals

A typical temporal evolution of the beam emission intensity for the discharge with transition is shown in Fig. 2 together with that of H_α intensity. Plasma was initiated by electron cyclotron heating (ECH). It was further heated by an NBI (#2) with the port-through power of 620 kW from 43 to 143 msec, and then another neutral beam (#1) with the port-through power of 670 kW was superposed from 83 to 113 msec. The standard magnetic field configuration in CHS was adopted in which the vacuum magnetic axis position R_{ax} was 92.1 cm from the torus center and the toroidal magnetic field strength at the magnetic axis B_{ax} was 0.95 T. The BES signal is observed during the period in which the probe beam, the first NBI (#2), applies.

For the near-edge region (CH8, R = 110.3 cm, normalized radius r/a~1.02 with a spatial resolution, width of the sightline, about 1.6 cm), as seen in Fig. 2, the intensity rises at t = 85 msec and decreases at t = 113 msec, which coincides with the transition and back transition observed in the H_α signals, respectively. The normalized radius r/a is defined by the magnetic flux surfaces calculated based on the three-dimensional equilibrium code VMEC for $\beta = 0$ %. The signal in the edge region can be considered to correspond to the temporal evolution of the local plasma density because the beam attenuation is negligible near the plasma edge. This rapid increase in the signal is observed only in CH7 (r/a~0.91) and CH8, which indicates the formation of the particle transport barrier in the edge region.

It should be noted that a slight decrease of the signal inside CH6 (r/a~0.77) before the transition is caused by the moderate change of the density profile and is independent of the occurrence of the transition. Thereafter, the signal decreases rapidly at the transition. Near the plasma center (CH1, r/a~0.23), the signal at 100 msec (after the transition) has decreased by approximately 35 % compared with that at 80 msec (before the transition). This rapid decrease can be caused either by the enhanced beam attenuation due to the edge density building-up, by the decrease in the core density, or by both of them. Since the enhancement of the beam attenuation estimated from the YAG-Thomson density profile measurements is from 10 to 20 percent, there is a possibility that the core density decreases at the transition. However, the errors in the YAG-Thomson measurements in the edge region are largely due to the low density and temperature. More detailed evaluation is required to confirm this.

3.2 Density fluctuations during barrier formation

The left-hand side of Fig. 3 shows the contour plot of the fluctuation power spectrum in the beam emission signals

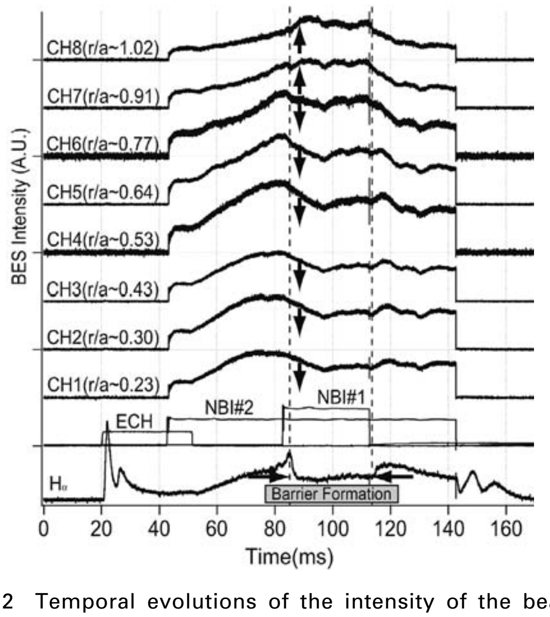

Fig. 2 Temporal evolutions of the intensity of the beam emission.

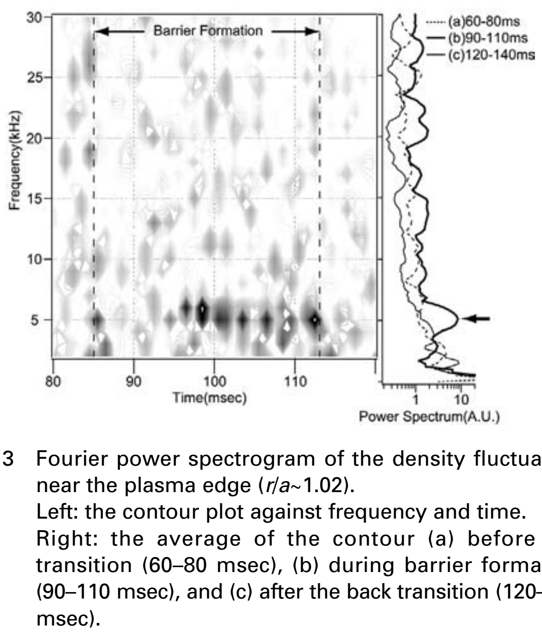

Fig. 3 Fourier power spectrogram of the density fluctuation near the plasma edge (r/a~1.02).
Left: the contour plot against frequency and time.
Right: the average of the contour (a) before the transition (60–80 msec), (b) during barrier formation (90–110 msec), and (c) after the back transition (120–140 msec).

at r/a~1.02 as a function of time and frequency obtained through a fast Fourier transform (FFT) analysis over every 1 msec. The Fourier spectra averaged (a) from 60 to 80 msec (before the transition), (b) from 90 to 110 msec (during barrier formation), and (c) from 120 to 140 msec (after the back transition) are shown on the right-hand side. The spectral energy before transition is concentrated in the low-frequency region and monotonically decreases with frequency. However, coherent-like fluctuations around 5 kHz were observed intermittently only during the barrier-formation phase.

Figure 4 shows the temporal evolution of the fluctuation level of the BES intensity averaged over 4–7 kHz for (a) CH1 (r/a~0.23) and (b) CH8 as the amplitude values obtained from an FFT analysis over every 250 μsec starting from the time indicated in the context. The signal at 91.25 msec for CH1 (indicated by a filled arrow) can be considered to correspond to the density fluctuation of interest, which exists in the observable region of CH1. On the other hand, in both CH1 and CH8 the signals are detected at 98.25 msec and 101.25 msec (indicated by open arrows). The signals in CH8 correspond to the density fluctuation near the plasma edge. However, the signals in CH1 that appears with those in CH8 can be caused by the density fluctuation in the region of CH1 and the beam density fluctuation. In order to distinguish these phenomena, we investigated the phase and the level of fluctuations.

Phase shift between measurement channels: When the perturbation originates in the edge region, it may affect the beam density in the downstream of the beam line. In this case, it is expected that the phase of fluctuations in this frequency changes the sign between the outer channel and the inner one. The reason is that the increase in the edge density leads to the increase in the beam attenuation, which results in the decrease in the inner beam density. The raw signals around (a) from 98.25 to 98.5 msec and (b) from 101.25 to 101.5 msec are expanded as shown in Fig. 5. The phase of this perturbation changes the sign both between CH6 and CH7 as shown in Fig. 5(a) and between CH7 and CH8 as shown in Fig. 5(b). One might conclude that the signal in the inner region consists of the information in the edge density fluctuation.

Estimation of the beam density fluctuation level for the inner region: We estimated the perturbations in the downstream signal, which arises in response to that in the upstream events, based on the following model.

(1) The density profile measured by the YAG-Thomson scattering is used, although there are ambiguities in the low-density edge region as described previously.
(2) The density change near the edge is from 2 to 4 percent, which corresponds to the amplitude of coherent fluctuation of 5 kHz near the edge measured by BES, as shown in Fig. 4(b).
(3) The region where density is fluctuating is $r/a > 0.9$, which corresponds to the width where the outer two BES channels are observing.

The intensity fluctuation component expected from the downstream beam density fluctuation is approximately from 0.1 to 0.2 percent of the central density, which is considerably lower than the detector root mean square noise level of 1 %. Nevertheless, if the fluctuations are coherent in the low frequency range and their mean values vary, they are reflected in a trend of the signals. Indeed, the fluctuation level observed in the central channel is about 1 to 1.5 percent (Fig. 4(a)), so it is difficult to distinguish the density fluctuation from beam fluctuation in the inner region.

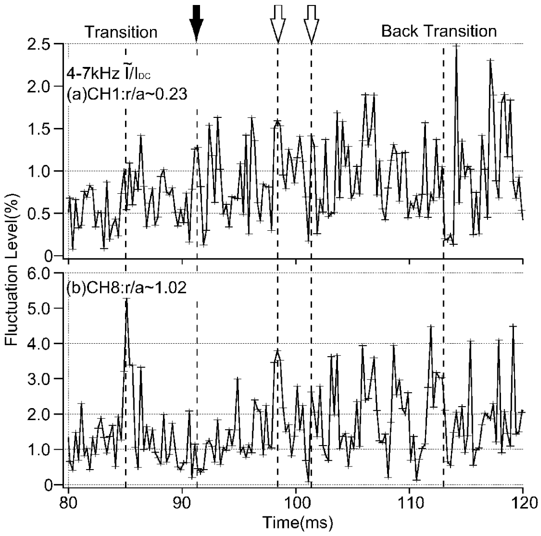

Fig. 4 Temporal evolution of the fluctuation level of the BES intensity averaged over 4–7 kHz for (a) CH1 (r/a~0.23) and (b) CH8 (r/a~1.02).

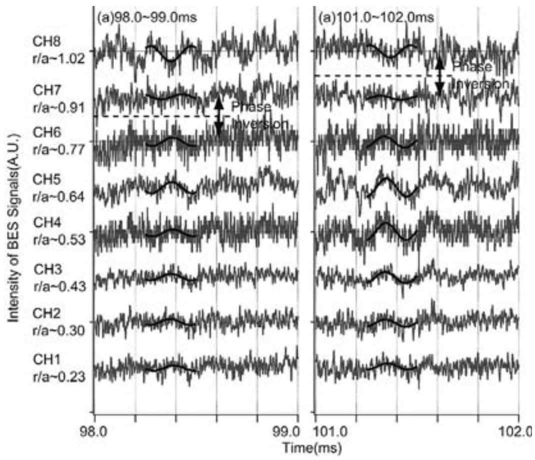

Fig. 5 Enlarged view of BES signals around (a) from 98.25 to 98.5 and (b) from101.25 to 101.5 msec. Solid bold lines are fitting curves (5-kHz sine).

4. Discussion

As described in Section 3.2, coherent-like fluctuations of BES signals around 5 kHz were observed intermittently while the barrier was formed. They had a radially inversed phase due to the downstream beam density fluctuation caused by the edge density fluctuation and/or due to the density fluctuation that had a radially inversed phase. The sawtooth oscillation can be regarded as an example of the phenomenon with the radial phase inversion of plasma parameter fluctuation because it is characterized by the phase inversion of temperature oscillation [6]. In CHS, the density fluctuation around 5 kHz associated with the sawtooth oscillation has been observed near the edge with electric probes [7]. To clarify the mechanisms of phase inversion of density fluctuations, the correlations between these phenomena and our observations should be examined.

We suspect that this fluctuation is related to the transition phenomenon; presumably it is enhanced by the increase in the local density or pressure gradient near the last closed flux surface (LCFS) accompanied by the transition. The coherent oscillations related to the density or pressure gradient have been reported in both Tokamaks [3,8,9] and Helicals [10,11], although the detailed mechanisms and identifications are still under investigation. We are also analyzing the characteristics of this oscillation.

5. Summary

We applied a BES measurement in CHS and studied the transition phenomenon characterized by the rapid decrease of the H_α signal and the increase of line-averaged density observed in the neutral beam heated plasma. We observed the following:

(1) The local plasma density near the plasma edge increases rapidly at the transition, which suggests the formation of ETB.

(2) A coherent-like density fluctuation around 5 kHz is enhanced intermittently while the barrier is formed.

The characteristics of this fluctuation, such as the relationship between the increase in the local density or pressure gradient near the LCFS and the enhancement of the fluctuation, should be investigated.

Acknowledgement

One of the authors (T.O.) was partly supported thorough the 21st Century COE Program, "Mechanical Systems Innovation," by the Ministry of Education, Culture, Sports, Science and Technology.

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