# Study of Nonlinear Behavior of Low-Frequency MHD Mode Caused by Transition of Radial Electric Field in LHD[*)]

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The response of low-frequency magnetic fluctuations in a transition of radial electric field ($E_r$) is investigated in the edge region of LHD plasmas. Consequently, the amplitude of a magnetic fluctuation with $f \simeq 2$ - $5$ kHz is suddenly enhanced at the transition timing of $E_r$, and then disappeared after the transition of $E_r$. Furthermore, it is found that the amplitude of $H_\alpha$ signals is enhanced, corresponding to the abrupt diminishing of the magnetic fluctuation with $f \simeq 2$ - $5$ kHz.

Keywords: MHD mode, magnetic fluctuation, density fluctuation, radial electric field, LHD

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## 1. Introduction

Understanding and controlling plasma transport is a critical challenge for improving plasma confinement [1–3]. The plasma fluctuations have been considered as a primary origin of the plasma transport. The recent progress in the study of the mesoscale structures informs us that they are nonlinearly generated by microscale fluctuations [4–6]. The magneto-hydrodynamics (MHD) modes are also found to interact with microscale fluctuations [7]. Although the study of turbulent transport is in progress, the transient transport events are still under question. These facts indicate that identification of all the possible fluctuations and these nonlinear behaviors in confined plasmas remain urgent issues [8].

Recently, the transition of the edge radial electric field ($E_r$) in the Large Helical Device (LHD) plasmas [9] occurred by increasing the neutral beam injection (NBI) power. Furthermore, the study of the response of the fluctuations in the transition of $E_r$ will help to understand the plasma fluctuations driven transport. This paper reports the results of the experiment to study the response of the low-frequency magnetic fluctuations in the transition of $E_r$ by increasing the NBI power in the 17th campaign of the LHD plasmas.

## 2. Experiment

The LHD has a major radius $R$ of 3.6 m, an averaged radius of 0.6 m, and a magnetic field strength on the axis $B_{ax}$ of 2.75 T. The plasma is produced initially by electron cyclotron heating (ECH) with hydrogen gas and sustained with two perpendicular NBI powers. In addition, the charge exchange spectroscopy (CXS) system has

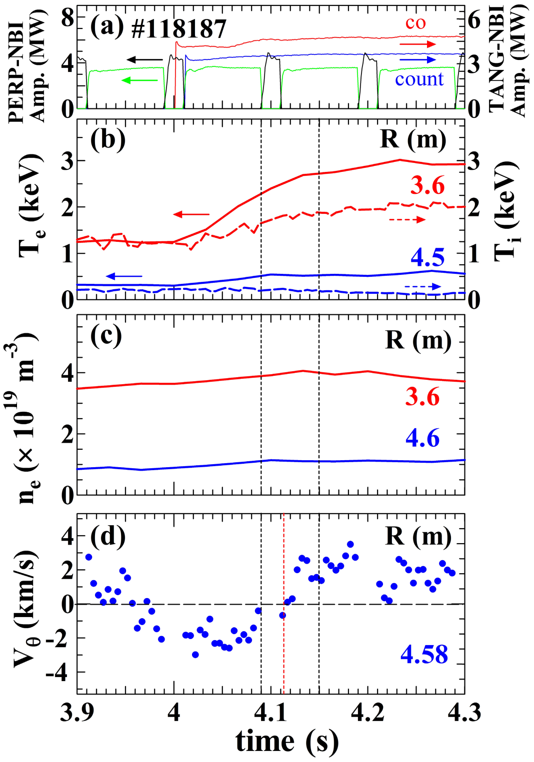

Fig. 1 Time evolution of (a) the NBI powers, (b) the electron temperature ($T_e$) and ion temperatures ($T_i$), (c) the electron density ($n_e$), and (d) the poloidal rotation velocity ($V_\theta$) in the LHD.

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been used to measure the profile of ion temperature ($T_i$) and plasma poloidal rotation velocity ($V_\theta$) [10]. Figure 1 presents the typical time evolution of the plasma parameters in the discharge. The two tangential NBI in the codirection with a power of ~4.0 MW and in the counterdirection with a power of ~3.0 MW start at 4.0 s. A large jump of the central $T_e$ ($R \simeq 3.6$ m) is observed at $t \simeq 4.1$ s (transition timing), and the central $n_e$ start to decrease at $t > 4.1$ s. Furthermore, the poloidal rotation velocity starts to change from negative to positive value at the transition timing. Usually, the poloidal rotation velocity corresponds to the $E_r$, since the contribution of the toroidal rotation velocity to the $E_r$ is much smaller than that of the poloidal rotation velocity [11]. Therefore, it is confirmed that the transition from negative $E_r$ to positive $E_r$ can be controlled by the increasing the NBI power experiment in the edge plasma region.

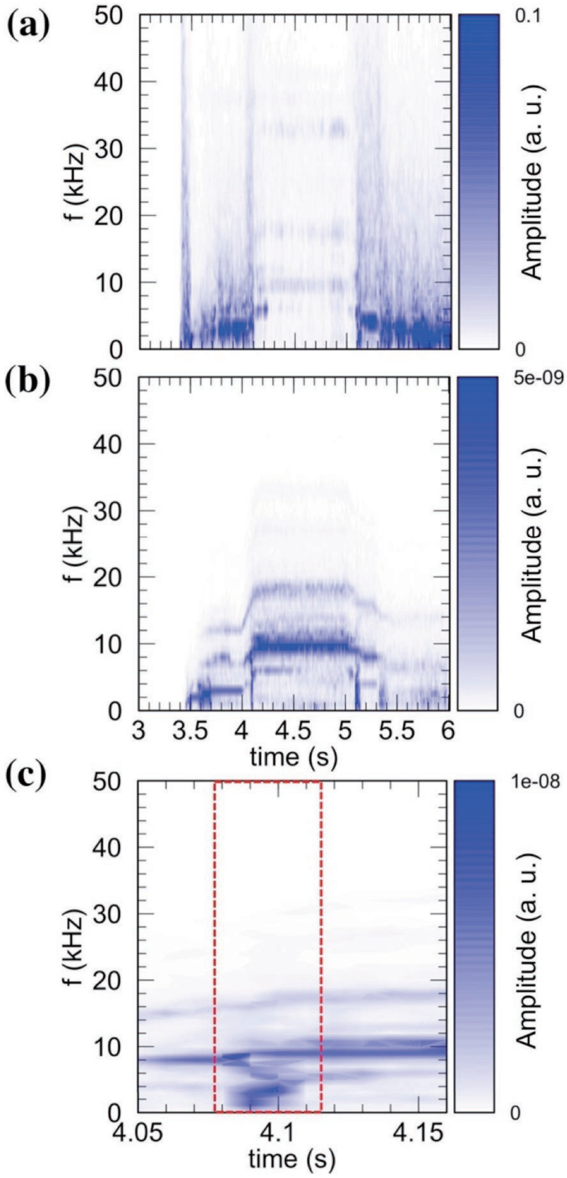

Fig. 2 Temporal evolutions of power spectrum of (a) the density fluctuations and (b) magnetic fluctuations at the edge plasma region ($R \simeq 4.6$ m), and (c) the specific spectrum of the magnetic fluctuationsat $t \simeq 4.1$ s as a function of frequency.

## 3. Results and Discussion

The density fluctuations are obtained with a microwave reflectometer in the edge plasma region. The low frequency fluctuations ($f < 20$ kHz) are suddenly reduced at the transition timing, as shown in Fig. 2 (a). On the other hand, the low frequency of magnetic fluctuations is enhanced at the transition timing, which are obtained with a magnetic probe, as shown in Fig. 2 (b). Interestingly, the magnetic fluctuation with $f \simeq 2$ - $5$ kHz is suddenly enhanced at the transition timing (show the dotted red line), as shown in Fig. 2 (c). The increasing time of the amplitude of magnetic fluctuation with $f \simeq 2$ - $5$ kHz (~20 ms) is faster than the value of macroscopic parameters (~100 ms) during the transition of $E_r$. In addition, the edge harmonic oscillation (EHO) mode is significantly observed at 4.1 s < $t$ < 5.1 s. It is reported that the EHO mode enhances the plasma transport through the edge without significantly increasing the thermal transport [12]. In order to fully understand the MHD mode driven plasma transport phenomena in the transition of edge $E_r$ plasma [13], it is necessary to identify the magnetic fluctuation with $f \simeq 2$ - $5$ kHz.

Figure 3 (a) demonstrates the auto-power spectrum of magnetic fluctuation at the transition timing, and the peak of fluctuations with $f \simeq 2$ - $5$ kHz are clearly observed. The cross-coherence spectrum between the density and mag-

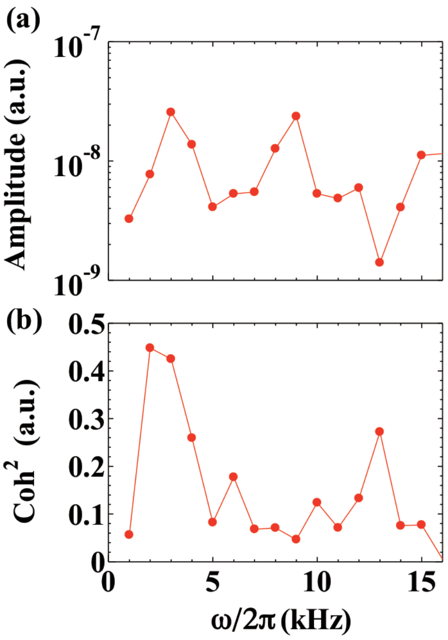

Fig. 3 (a) Auto-power spectrum of magnetic fluctuations, and (b) cross-coherence spectrum between density and magnetic fluctuations at $t \simeq 4.1$ s.

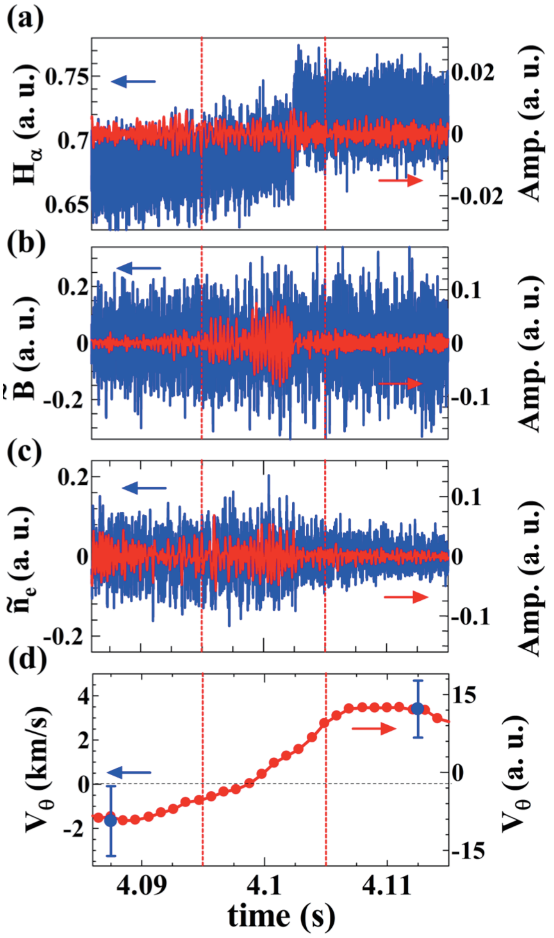

Fig. 4 Time evolutions of (a) the $H_\alpha$ signal, (b) the magnetic fluctuations, (c) the density fluctuations, and (d) the poloidal flow signalsfrom the CXS (blue marks) and the reflectometer (red marks) at the transition timing. The red lines indicate the fluctuations in the frequency band 2 - 5 kHz.

netic fluctuations is shown in Fig. 3 (b), and the fluctuation with $f \simeq 2$ - 5 kHz also has a significant level. This implies that the magnetic fluctuation with $f \simeq 2$ - 5 kHz has strong relation with the density fluctuation in the edge plasma region.

Furthermore, we investigated the relation between the magnetic fluctuation with $f \simeq 2$ - 5 kHz and the $H_\alpha$ signal. Figure 4 shows the time evolution of (a) the $H_\alpha$ signal, (b) the magnetic fluctuations, (c) the density fluctuations, and (d) the poloidal flow signals at $t \simeq 4.1$ s. The red solid lines indicate the fluctuations in the frequency band 2 - 5 kHz. It is confirmed that the amplitude of the $H_\alpha$ signal is suddenly enhanced, corresponding to the abrupt diminishing of magnetic fluctuation with $f \simeq 2$ - 5 kHz, as shown in Fig. 4 (a). Furthermore, the poloidal rotation velocity is estimated by the CXS signals (blue marks), and the high time-resolution of the poloidal flow signal is obtained by the reflectometer (red marks) in the edge plasma, as shown in Fig. 4 (d). The signals from the reflectometer have a significant change, which is caused by the transition of the $E_r$.

## 4. Summary

We have observed the amplitude of the magnetic fluctuation with $f \simeq 2$ - 5 kHz is suddenly enhanced when a transition of the radial electric field ($E_r$) occurs in the edge plasma region. In addition, it is found that the amplitude of the $H_\alpha$ signal is enhanced, corresponding to the abrupt diminishing of magnetic fluctuation with $f \simeq 2$ - 5 kHz. It is not clear whether this mode trigger the $E_r$ transition. Further experiment is necessary to investigate the causal relationship between this MHD mode and $E_r$ transition.

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