Spontaneous transition improving particle confinement in high-beta plasmas of Large Helical Device

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Introduction

The spontaneous transition phenomenon of the confinement is an important physics to explorer the fusion reactor. In tokamaks, as an example of the transition, the H-mode, where the plasma stored energy is significantly increased with the pedestal formation in the plasma edge, is widely known [1]. On the other hand, for stellarators, the spontaneous transition like the tokamak H-mode is also observed in many experiments [2]. At the spontaneous transition, signals of Hα or Dα clearly dropped and the plasma stored energy increased. Electron temperature and density increased moderately and the radial electric field is formed in the plasma edge. However, for stellarators, generally only the particle transport is improved. Therefore, the clear formation of the pedestal in the plasma edge was not observed. For tokamaks, the confinement was improved by the orders, but, for stellarators, the confinement improvement is moderately improved by the factor comparing with the tokamak.

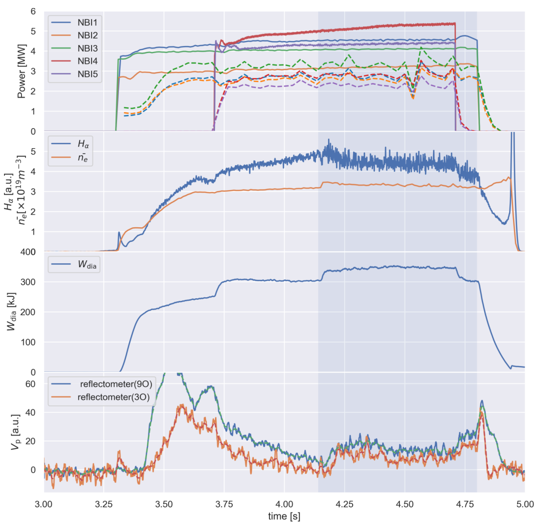

Figure 1: A summary of the typical L-H transition (176854). From the top panel, the input power (bold lines) and absorbed power (dashed line), the line averaged density and Hα, the plasma stored energy, and the poloidal velocity are shown respectively. The blue color window indicates the H-mode phase.

The Large Helical Device (LHD) is an L=2 and M=10 superconducting Heliotron device in

Japan. In the LHD experiment, the spontaneous transition from L- to H-mode was frequently observed [3]. However, the L-H transition was mainly studied for the outward shifted vacuum magnetic axis. For an outward shifted vacuum magnetic axis of R_{ax}=3.9m, since the edge rotational transform is unity and the edge magnetic field structure is stochastic, the rational number of the plasma edge might be a key to happen the L-H transition. Recently, in the high-beta plasma experiment of the LHD, the spontaneous transition phenomenon was frequently observed, too [4]. The high-beta experiment is performed in the inward shifted vacuum magnetic axis.

In this study, the L-H transition in the high-beta experiment of LHD is studied. In next section, the L-H transition phenomena observed in the high-beta experiment is discussed. In particular, the improving particle confinement is studied. In third section, the density fluctuation is studied. Finally, this study is summarized.

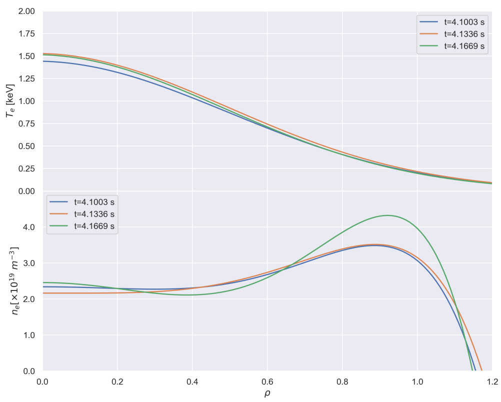

Figure 2: Radial profiles of the electron temperature, and density are shown as the function of the normalized minor radius, ρ.

L-H transition in high-beta plasma

In figure 1, a shot summary of the typical L-H transition in the LHD high-beta plasma is shown. From the top panel, the input power (bold lines) and absorbed power (dashed line), the line averaged density and Hα, the plasma stored energy, and the poloidal velocity are shown respectively. This discharged was conducted for an inward shifted configuration of R_{ax} = 3.56 m. In this configuration, some rational surfaces of m/n = 6/10, 5/10, 4/10 appear in the plasma edge. The L-H transition happened at t = 4.147 s. The blue color windows indicates the H-mode phase. At the timing of the L-H transition, in the second panel, Hα signal sharply drops, and then the line averaged density sharply increases simultaneously. Also, in the third panel, the plasma stored energy increases. In the forth panel, the poloidal velocity measured at different toroidal locations are shown, and the poloidal velocity sensitively responds to the confinement change at the L-H transition.

In figure 2, radial profiles of the electron temperature, and density are shown as the function of the normalized minor radius, ρ. Electron temperature profiles are almost identical before and after the L-H transition, but electron density profiles change significantly before and after the L-H transition. The electron density on the shoulder of the hollow shape profile increases after the L-H transition. These profile changes suggest that the H-mode in the high-beta plasma improves the particle confinement.

To understand this characteristics, the particle transport is considered by the density fluctuation measurements. In figure 3, Amplitude and Spectrogram of the density fluctuations measured by 2D PCI are shown at a time window of t = 4 - 4.5 s. For comparisons, Hα, the line averaged density, and plasma stored energy are also shown. For the amplitude of the density fluctuation, three cases for 3-30kHz, 30-150kHz, and 150-490kHz are shown respectively. After the L-H transition, the low frequency amplitude for 3-30kHz decreases, and the medium frequency amplitude for 30-150kHz increases but it decreases quickly. On the other hand, the high frequency amplitude increases after the L-H transition. For Spectrogram, these changes are more obvious. Before the L-H transition, the amplitude of the density fluctuation for the low frequency mode is dominant. However, at the L-H transition, the frequency of the fluctuation clearly changes, and spreads into the high frequency. An interesting point is that the frequency range of the fluctuation spreads into roughly 300kHz, but the amplitude itself decreases in the all range of the frequency. Especially, in later phase of the H-mode, the amplitude for $f \sim$ 100kHz disappears. From this observations, we can speculate one hypothesis, that is, the fluctuation before the L-H transition is dominant by the low frequency mode but after the L-H transition the high frequency mode by the turbulence is dominant. This hypothesis also supports the limitation of further increasing the density and stored energy.

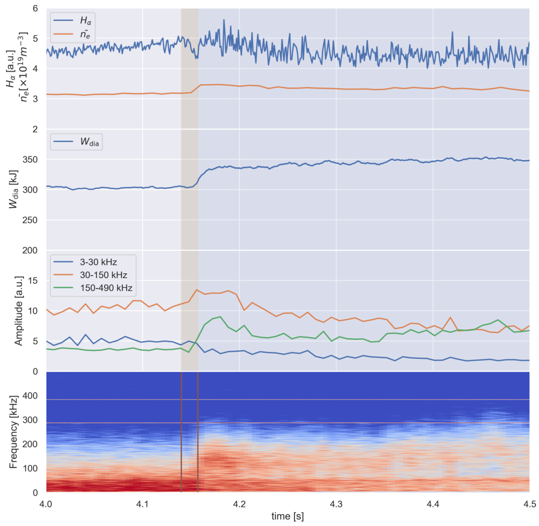

Figure 3: Amplitude and Spectrogram of the density fluctuations measured by 2D PCI are shown at a time window of t = 4 - 4.5 s. For comparisons, Hα, the line averaged density, and plasma stored energy are also shown.

This L-H transition happens in the high-beta plasma. Therefore, the turbulence in the high frequency range may be driven by the MHD activities. To understand the interlink of the MHD and turbulence, the density fluctuation in the low frequency range is studied. Figure 4 shows Spectrograms of the magnetic probe and line-integrated density measured by CO2 interferometer, and Coherence of the magnetic probe and the interferometer. For a reference, Hα signal and line averaged density also show. Before the L-H transition, for the magnetic probe, a mode of $f \sim$ 5kHz dominantly appears. However, after the L-H transition, many modes appears for $f \sim 3-10$ kHz. These mode are driven by the steep pressure gradient by the improved particle confinement in the plasma edge. On the other hand, Spectrogram of the CO2 interferometer is not clear. The week coherent mode appears at $f \sim$ 5kHz after the L-H transition. To see the coherent structure of the mode, the coherent of the magnetic probe and density fluctuation is calculated. After the L-H transition, the clear coherent structure appears at $f \sim$ 5kHz.

The radial structure of the coherent mode is studied. The density fluctuation at f = 5234.375Hz, where the coherence of the magnetic probe and density fluctuation is most strong, is appeared. The coherent mode is localized in the plasma edge. From the magnetic probe analysis, m/n = 2/1 or 3/2 modes are enhanced in the range. Therefore, the localized mode of the density fluctuation might be driven by those MHD modes. Also, those MHD modes drive the high frequency turbulence.

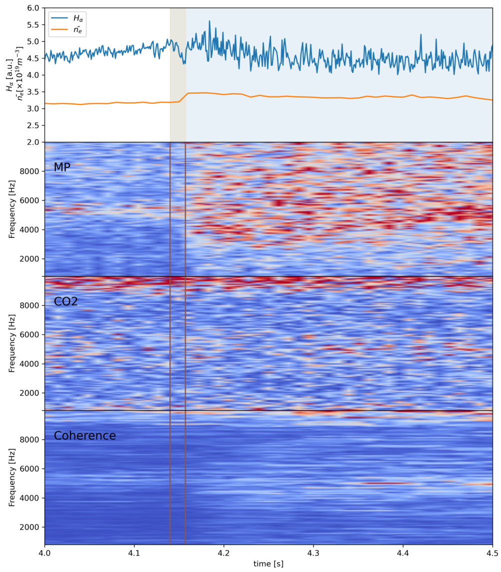

Figure 4: Spectrograms of the magnetic probe and line-integrated density measured by CO2 interferometer, and Coherence of the magnetic probe and the interferometer. For a reference, Hα signal and line averaged density also are shown.

Summary

In this study, the L-H transition observed in the high-beta plasma experiment of the LHD is discussed. At the L-H transition, the electron temperature profile does not change, but the electron density profile changes significantly. However, the improved particle confinement is limited quickly after the L-H transition. To understand the mechanism improving the particle confinement, the density fluctuation is studied by the interferometer. After the L-H transition, the low frequency amplitude for 3-30kHz decreases, and the medium frequency amplitude for 30-150kHz increases but it decreases quickly. On the other hand, the high frequency amplitude increases after the L-H transition.

References

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