§13. Long-Pulse Plasma Discharge Using a Positive-NB Injector

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The LHD is equipped with three negative-ion-based NB injectors and one positive-ion-based NB injector. In the positive-NBI low-energy hydrogen beams of 40 keV are injected perpendicularly while high-energy beams of 180keV are injected tangentially in the negative-NBIs. Although the negative-NBIs, which started their operation in 1998, were designed to achieve high-nτT plasmas, electron heating is dominant due to their high injection energy. Since the low-energy beams dominantly heat the ions, the positive-NBI was constructed and operational in 2005 to realize high-T_i hydrogen plasmas. The positive-NBI is reliably operated, and the injection power reaches 7MW for short pulse operation, exceeding the designed value of 6MW. The ion temperature is successfully increased by the ion heating with the positive-NBI, and 5.6 keV of T_i was obtained in a hydrogen plasma [1].

LHD has superior characteristics for steady-state operation in principle, compared with tokamaks. Therefore, plasmas should basically be sustained as long as the plasma heating lasts. To demonstrate the ability of steady-state operation in LHD, long-pulse heating experiments were carried out with the negative-NBIs, and the plasma was sustained by the NBI alone for 128s with an injection power of 0.2MW using one negative ion source [2]. In the 12th LHD experimental campaign, we tried long-pulse plasma sustainment with the positive-NBI.

Although the positive-NBI is designed as high-power and short-pulse (<10s) operational system, we have modified the power supplies to extend the injection duration to several tens of seconds with a reduced injection power. Since the positive-NBI has four ion sources, sequential injection utilizing four positive ion sources has been tested in order to realize a long-pulse injection for longer than 1min. Each ion source was adjusted so as to inject 25keV-500kW for 30sec. Consequently, continuous injection of 500kW could be possible if the plasma is not collapsed.

Figure 1 shows the time evolutions of the long-pulse plasma sustained by the positive-NB injection and the ECRH. The ECRH utilizes two 77GHz gyrotrons and one 84GHz gyrotron. In this long-pulse plasma discharge, the 84GHz microwave is injected continuously for 82s with a power of 100kW. One 77GHz microwave is repeatedly and intermittently injected for 10s at a duty factor of around 0.7 with a power of 200kW, and the other starts the injection at t=33s and is continuously injected for 60s with a power of 350kW. In the case of only the positive-NBI heating, the plasma density is gradually increased and leads to radiative collapse. That is probably because the electron heating rate is not large with the low-energy NB heating and the positive-NBI brings hydrogen gas in the NBI vacuum vessel through the injection port. By adding the ECRH the rate of increase in the density is suppressed, and the extent of the suppression is dependent on the ECRH power. As shown in Fig. 1, the electron density is gradually increased with time for the first 33sec, and, in turn, starts to decrease at t=33sec due to the addition of 77GHz ECRH with a relatively high power of 350kW. It is observed that the density rise is suppressed during simultaneous apply of high-power 77GHz-ECRH of 550kW with two gyrotrons. Finally, the plasma is radiatively collapsed at t=93sec when the ECRH stops. In this shot, three positive ion sources are injected for 30s by turns, and the fourth ion source has just started the injection at nearly the same timing as the plasma collapse. In the positive-NBI heating, the ions are mainly heated and the particles are much supplied, compared with the negative-NBI heating. Thus, the electron heating by the ECRH is required for sustaining the long-pulse positive-NBI heated plasma. From the above results it is expected that relatively high-density plasmas are sustained for several minutes by combination of the positive-NBI with the sequential injection using four positive ion sources and the continuous ECRH.

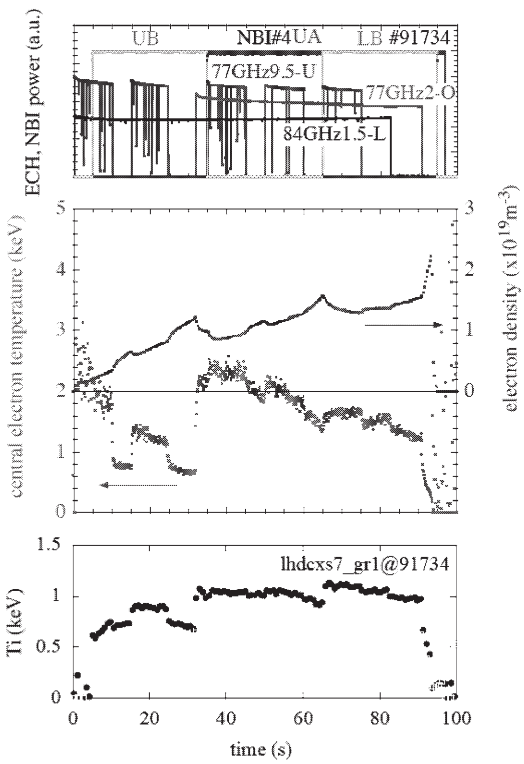

Fig. 1. Time evolutions of a long-pulse plasma sustained by the positive-NB injection superposed occasionally with the ECRH. In the positive-NB injection, sequential injection is carried out with four ion sources.

[1] K. Nagaoka, et al., in this annual report.
[2] Y. Takeiri, et al., Nucl. Fusion **46** (2006) S199.