Neutral Beam Injectors

K. Nagaoka, K. Tsumori, K. Ikeda, H. Nakano, M. Kisaki, Y. Fujiwara, H. Nuga, M. Osakabe, T. Kondo, M. Sato, M. Shibuya, H. Sekigushi, S. Komada, T. Kamiya,

e-mail: nagaoka@nifs.ac.jp

1. Objective

Neutral beam injection (NBI) is the most powerful tool for plasma heating on LHD [1]. The plasma breakdown is also available due to NBI, which provides a variety of plasma operation such as a magnetic configuration without electron cyclotron resonance [2].

2. Appratus

2.1. Configuration of NBIs

Three NBIs (NBI#1,#2,#3) inject the beam tangentially and produced mainly passing fast ions circulating in the clockwise direction for NBI#2 and counter clockwise direction for NBI#1 and #3. Two NBIs (#4 and #5) provide perpendicular beam injection to the magnetic field. The detailed port arrangement of NBI is shown in Figure 1.

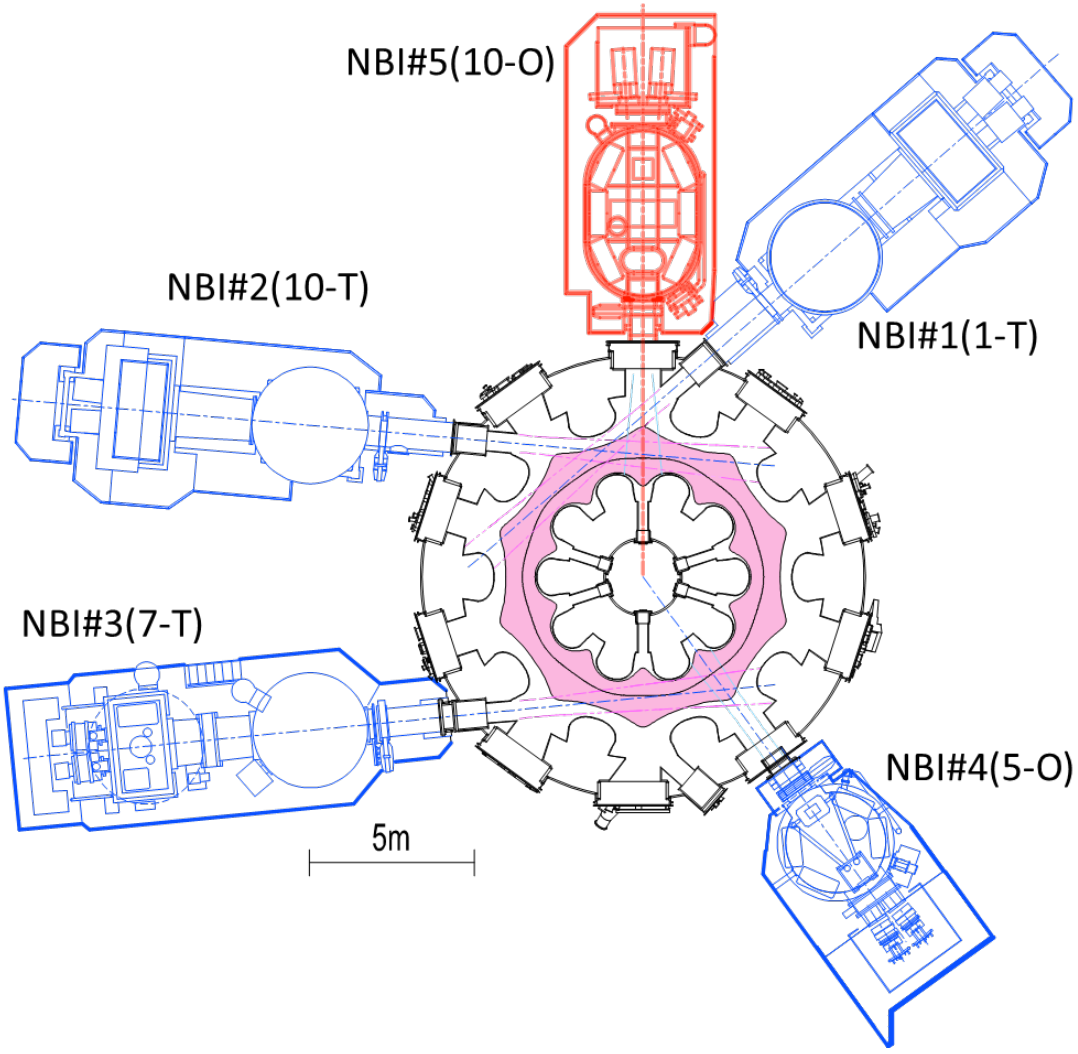

Fig. 1. Top view of LHD and arrangement of NBIs. .

2.2. Typical parameters of beam operation

Three negative-ion-based neutral beam injectors (NBI#1,#2,#3) [3] and two positive-ion-based beam injectors (NBI#4,#5). Deuterium beam injection is operational from 19th experimental campaign of LHD. However, hydrogen beams are also required for the initial phase and closing phase of this campaign. In order to produce good plasmas in a variety of conditions, negative-NBI will be kept the condition optimized for hydrogen beam operation, while positive-NBI will be optimized for deuterium beam operation. The typical port-through power is summarized in the Table 1.

# NBI	IS type	Power for H	Energy for H	Power for D	Energy for D
NBI#1	negative	6 MW	190 keV	3 MW	180 keV
NBI#2	negative	5 MW	180 keV	3 MW	180 keV
NBI#3	negative	5 MW	180 keV	3 MW	180 keV
NBI#4	positive	6 MW	40 keV	9 MW	60 keV
NBI#5	positive	6 MW	40 keV	9 MW	80 keV

Table 1. Typical parameters of NBI injection in the case of short pulse operation with duration of 1 - 2 sec.

3. Beam injection pattern

The beam operation pattern is controlled by following parameters,

- Start time (3.0 -7.0 sec)
- Beam duration (0.5 - 2.0 sec)
- Power modulation duty (optional)

The waveform of NBI injection pattern can be produced by the LHD portal web server (http://kaiseki-dev3.lhd.nifs.ac.jp/rails/op_pattern/op_pattern). The beam modulation (ON/OFF) is available for NBI#4 and #5. The minimum of beam off time is 20 msec and the maximum pulse number during one discharge of LHD is 20. Please complete to input the beam operation pattern in the LHD portal server until the day before the experiment, then the data is shared with the beam operators. The beam modulation of NBI#1,#2 and #3 is optionally available. If you request such optional beam operation, please contact to NBI operation managers, K. Nagaoka (ext.2177) one week before the experiment.

4. How to see NBI data

4.1. summary sheet

The NBI waveform can be seen in the main monitor just after the plasma discharge. The PDF file of summary sheet is available from LHD portal server.

4.2 Kaiseki-data server

The time evolution of detailed beam operation such as the beam energy, beam power, on time ,,, can be obtained from Kaiski-data server. The list of data related to NBI operation is summarized in Table 2.

file_name	name_data	unit	explanation of the data: all data is given as a function of time
nbpwr_tot_temporal	Pport-through_t-nb-all	MW	Total port-through power of tangentally injected beam (NBI#1,#2,#3)
	Pport-through_r-nb-all	MW	Total port-through power of perpendicularly injected beam (NBI#4,#5)
	Energy_NB1	keV	Energy of beam ions of NBI#1
	Port-Through_NB1	MW	Port-through power of NBI#1
	Energy_NB2	keV	Energy of beam ions of NBI#2
	Port-Through_NB2	MW	Port-through power of NBI#2
	Energy_NB3	keV	Energy of beam ions of NBI#3
	Port-Through_NB3	MW	Port-through power of NBI#3
	Energy_NB4	keV	Energy of beam ions of NBI#4
	Port-Through_NB4	MW	Port-through power of NBI#4
	Energy_NB5	keV	Energy of beam ions of NBI#5
	Port-Through_NB5	MW	Port-through power of NBI#5
nb1pwr	Ebeam_nb1	keV	Energy of beam ions of NBI#1
	Pport-through_nb1	kW	Port-through power of NBI#1
	Pdeposit_nb1	kW	Deposited beam#1 power into plasma (Pportthrogh - Psinethrough)
nb2pwr	Ebeam_nb2	keV	Energy of beam ions of NBI#2
	Pport-through_nb2	kW	Port-through power of NBI#2
	Pdeposit_nb2	kW	Deposited beam#2 power into plasma (Pportthrogh - Psinethrough)
nb3pwr	Ebeam_nb3	keV	Energy of beam ions of NBI#3
	Pport-through_nb3	kW	Port-through power of NBI#3
	Pdeposit_nb3	kW	Deposited beam#2 power into plasma (Pportthrogh - Psinethrough)
nb1pwr_temporal	Ebeam_nb1	keV	Energy of beam ions of NBI#1
	Pport-though[MW]	MW	Port-through power of NBI#1
	Ion-statusA		0: no operation of ion source 1A, 1:beam acceleration
	Ion-statusB		0: no operation of ion source 1B, 1:beam acceleration
nb2pwr_temporal	Ebeam_nb2	keV	Energy of beam ions of NBI#2
	Pport-through_nb2	MW	Port-through power of NBI#2
	Ion-stsA_nb2		0: no operation of ion source 2A, 1:beam acceleration

	Ion-stsB_nb2		0: no operation of ion source 2B, 1:beam acceleration
nb3pwr_temporal	Ebeam_nb3	keV	Energy of beam ions of NBI#3
	Pport-through_nb3	MW	Port-through power of NBI#3
	Ion-stsA_nb3		0: no operation of ion source 3A, 1:beam acceleration
	Ion-stsB_nb3		0: no operation of ion source 3B, 1:beam acceleration
nb4apwr_temporal	Ebeam_nb4a	keV	Energy of beam ions of NBI#4a
	Pport-through_nb4a	MW	Port-through power of NBI#4a
	Ion-stsU_nb4a		0: no operation of ion source 4UA, 1:beam acceleration
	Ion-stsL_nb4a		0: no operation of ion source 4LA, 1:beam acceleration
nb4bpwr_temporal	Ebeam_nb4b	keV	Energy of beam ions of NBI#4b
	Pport-through_nb4b	MW	Port-through power of NBI#4b
	Ion-stsU_nb4b		0: no operation of ion source 4UB, 1:beam acceleration
	Ion-stsL_nb4b		0: no operation of ion source 4LB, 1:beam acceleration
nb5apwr_temporal	Ebeam_nb5a	keV	Energy of beam ions of NBI#5a
	Pport-through_nb5a	MW	Port-through power of NBI#5a
	Ion-stsU_nb5a		0: no operation of ion source 5UA, 1:beam acceleration
	Ion-stsL_nb5a		0: no operation of ion source 5LA, 1:beam acceleration
nb5bpwr_temporal	Ebeam_nb5b	keV	Energy of beam ions of NBI#5b
	Pport-through_nb5b	MW	Port-through power of NBI#5b
	Ion-stsU_nb5b		0: no operation of ion source 5UB, 1:beam acceleration
	Ion-stsL_nb5b		0: no operation of ion source 5LB, 1:beam acceleration

Table 2. List of NBI data available in Kaiseki-data server. The temporal data is available just after the shot, however, nbi1,2,3_pwr are a few days after the shot.

5. Remarks

In general, negative-ion-based NBIs need commissioning to provide high power and stable beam injection. Please attention the schedule of NBI operation, which is announced before every campaign of LHD experiment. If you need CXS diagnostic for getting ion temperature profile, rotation profile, carbon density profile, etc., the beam modulation of NBI#4 and/or #5 is necessary. When you plan to use MSE diagnostic, please inform to NBI operation managers (K.T. and K.N.) before fix the experiment schedule, because optional beam operation is necessary to get current profile measurement.

References

[1] Y. Takeiri, et al., Fusion Science and Technology 58 (2010) 482.

[2] O. Kaneko, et al., Fusion Science and Technology 58 (2010) 497.

[3] K. Tsumori, et al., Fusion Science and Technology 58 (2010) 489.