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# The Progress of NBI heating experiment on HL-2A

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## 1. Introduction

In 2008 NBI experiment campaign, one of the two beamlines around HL-2A is operated successfully and the deuterium atomic beam with power of 0.7 MW at its energy of 36 keV has been injected into the torus. The NBI experiment is performed in range of plasma density $(0.5 -2.5)\times10^{19}$ $m^{-3}$, plasma current 100-200 kA and toroidal magnetic field 1.0-2.0 T. HL-2A tokamak with double null diverter has the major radius of 1.65 m and minor radius of 0.40 m.

The H-mode discharge has been observed using NBI and ECRH on HL-2A. The central ion temperature of 2.7 keV has been obtained with the line-average density of $1.5\times10^{19}$ $m^{-3}$ and neutral beam power of 0.6MW at beam energy of 35 keV. Stored energy is double and plasma density is increased from $1.95\times10^{19}$ $m^{-3}$ to $3.5\times10^{19}$ $m^{-3}$ after NBI is turned on at plasma current of 160 kA. The fishbone instability and giant sawteeth are easily excited during NBI.

## 2. NBI and ECRH System

The NBI system with total beam power of 4 MW at the beam energy of 45-55 keV is being built on HL-2A [1]. It is composed of 2 beamlines in which four bucket ion sources are equipped in each. Injection port with dimension of about 39cm×33cm is about 5.33 m away from the ion sources. Each beamline is located at opposite side of the torus in tangential direction injection. Before the ion source is operated in the beamline around the torus, ion beam current of 20 A at energy of 40 keV with the duration of 0.1 s for each ion source has been reached on an ion source platform.

The beam characteristics of each ion source are investigated in the ion source platform [2]. The e-fold divergence of a beam is measured with Faraday cup array located 3.26 m downstream from the ion source, as shown in figure 1. The minimum beam divergence of $1.06^0$ at extracted current of 13 A can be attained at high voltage of 34.8 kV. In figure 1, one can find that the beam divergence is very sensitive to high voltage to be applied the accelerator if ion beam current is invariant. A colorimeter with water cooling pipes is located at near the injection port, downstream from these ion sources to measure the total beam power profile, as shown in figure 2. At the beam energy of 35 keV for 4 ion sources sustaining ~0.4 s with beam current of ~14 A for each source, total NBI power is about 0.7MW.

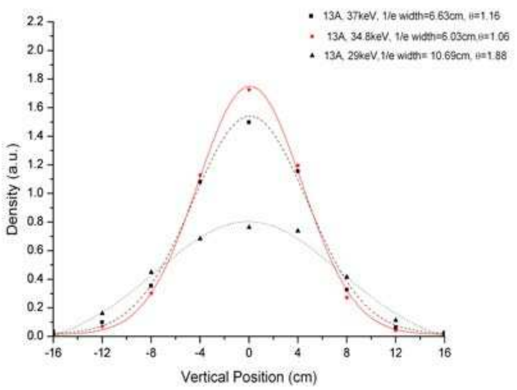


Fig.1 Beam profile with different high voltages at extracted current of 13 A

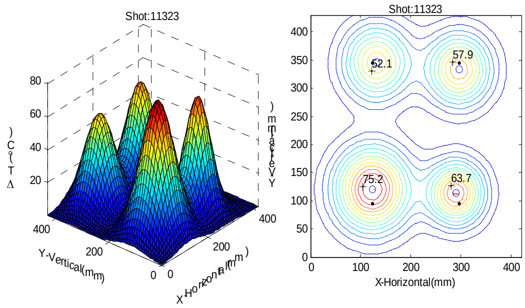


Fig.2 Beam power profile measured with thermal couple array near the injection port

To investigate the fractions of beam species, $H_\alpha$ Doppler shift spectroscopy located at the drift duct is applied for measuring the components of the neutral beam. The fractions of beam species are investigated for a wide range of beam current, as shown in figure 3. The fractions of $H_1^+$ increases with the acceleration

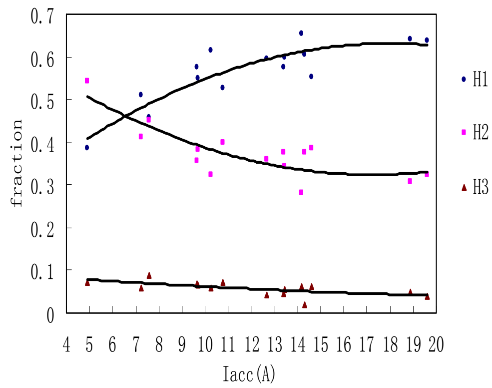


Fig.3 The beam species fractions versus the beam current voltage.

current ($I_{acc}$), which reaches ~65% at the $I_{acc}$ = 15 A.

The ECRH system is operated at the frequency of 68 GHz (2 MW, 1 s), coupling to the O-mode wave or $2^{nd}$ harmonics of X-mode from the low field side. The wave sources of the system consist of four gyrotrons, each has a power of 500 kW.

### 3. H-mode discharge by NBI and ECRH

Figure 4 shows the first H-mode discharge using the NBI power of 0.7 MW and ECRH power of ~0.9 MW, plasma current of 160 kA, plasma density of $1.5\times10^{19}$ $m^{-3}$ and toroidal magnetic field of about 1.3 T. The L-H mode transition occurs after 120 ms from NBI injection and 20 ms from ECRH injection. The H-mode returns to L-mode and then ELM disappears after the NBI is turned off for 20 ms even if ECRH is remained. The storage energy increases about 70% during H-mode and plasma density dramatically rises too.

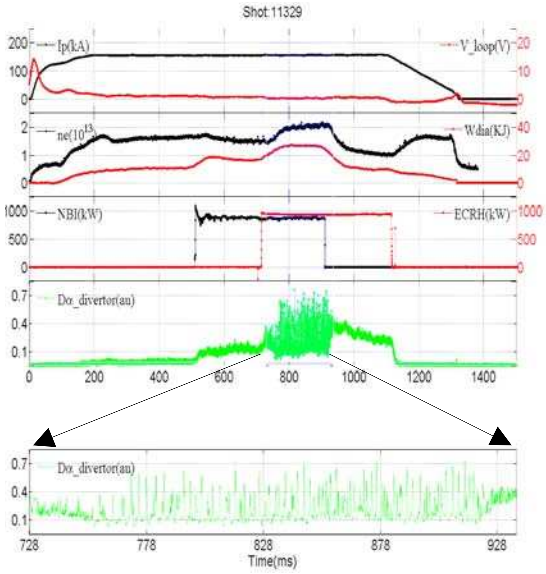


Fig.4. The first H-mode discharge in HL-2A with NBI power of 0.7 MW and ECRH of 0.9 MW

### 4. Fishbone instability excited by NBI

Fishbone instability can be driven by purely energetic electrons (ECRH) or ions (NBI). Electron fishbone instability was discussed in last IAEA conference [3]. Typical ion fishbone activity driven by NBI is also observed in HL-2A, as shown in Fig. 5, which has the mode oscillation frequency

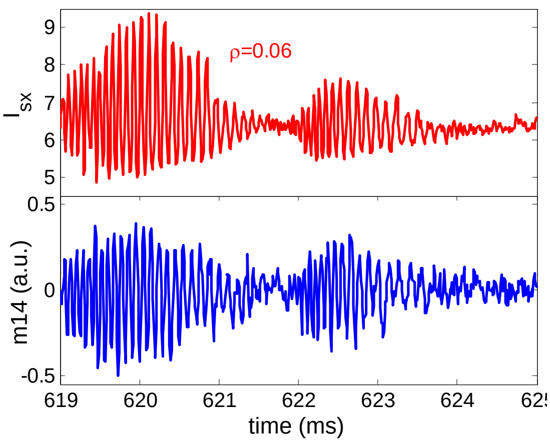


Fig.5 Fishbone activity driven by NBI

less than 25 kHz.

## 4. Summary

One of two neutral beam injections has been operated successfully on the HL-2A and its neutral beam power of about 0.7 MW has been injected into the torus. The beam characteristics have been investigated in an ion source platform. The beam has the divergence of about $1.06^0$ and $H_1^0$ fraction of about 65%. Under the NBI power of 0.7 MW, the H-mode discharge has been achieved in HL-2A. The ion fishbone and giant sawteeth were observed too using the NBI heating. We shall continuously improve the power supply system and build a new beamline located at the opposite side of this torus in future.

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