# Recent progress on the 1MW-NBI system on HL-2A Tokamak

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Neutral beam injection is one of the most effective way to heat the magnetic confinement nuclear fusion plasma. On HL-2A Tokamak, the 1MW-NBI system, composed of 4 arc discharge circular bucket ion sources, has been run successively for years. The H-mode discharges at different operation parameters were carried out on HL-2A Tokamak by combining neutral beam injection and electron resonance heating [1]. For further understanding the inner physics of ion source extraction and maximizing the beam power of ion source, the following studies were carried through in the 1MW-NBI beamline on HL-2A Tokamak.

## 1 The neutral beam ion source

The ion sources of NBI system on HL-2A Tokamak are circular bucket ion sources with magnetic multi-pole line-cusp [2-4]. A sketch map of the 1MW-NBI system installed on HL-2A Tokamak is shown in Fig.1. The parameters of the beamline and the neutral beam ion sources are given separately in Tab.1 and Tab.2.

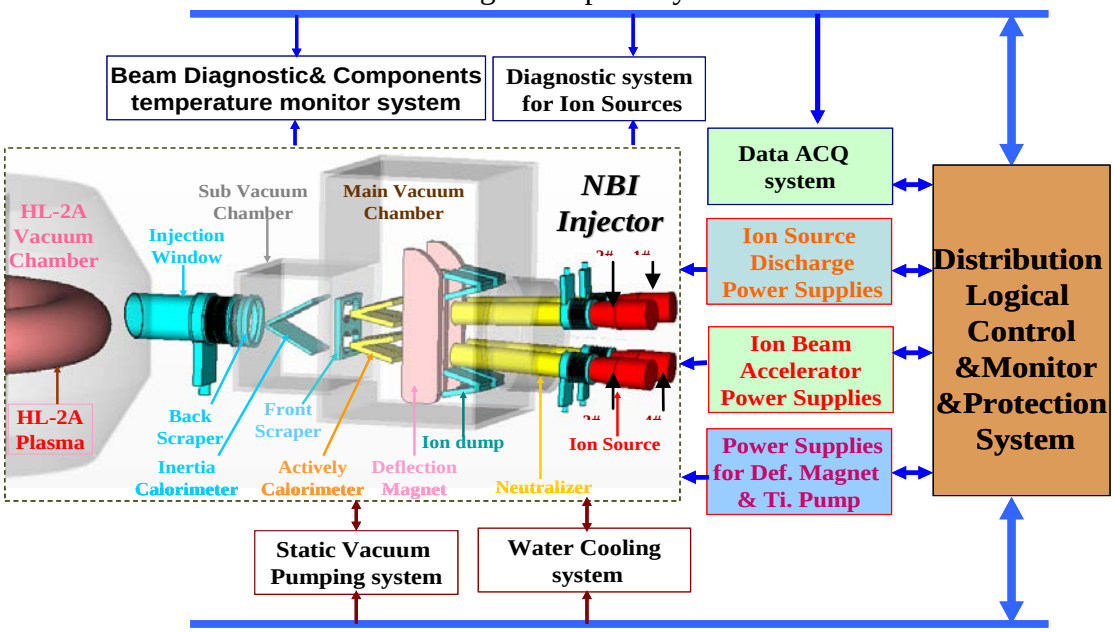


Fig. 1 Sketch map of 1MW-NBI system on HL-2A Tokamak

## 2 The analysis of deceleration voltage and deceleration current of Ion source

Keeping the arc discharge conditions and the acceleration voltage the same, and scanning the deceleration voltage, from -2.2kV~-0.4kV, in the ion source extraction experiments, the appropriate value of the deceleration voltage was obtained. The extraction current changing vs. deceleration voltage divided by acceleration voltage was shown in Fig.2. It can be seen that .when the ratio of deceleration voltage divided by acceleration voltage is less than 2.5%, the measured acceleration current increases sharply; and when this ratio is larger than 2.5%, the measured acceleration current

almost keeps constant. From this, it can be obtained that during the extraction experiment, the deceleration voltage ought to set no less than 2.5% of the acceleration voltage.

By separately fixing the arc discharge currents at 300A, 350A, 380A and 400A, the discharge pressure was scanned. Then the dependence of the ratio of deceleration current to the acceleration current on the discharge pressure was obtained, as it is shown in Fig.3. It was found that, with the same discharge gas pressure, the deceleration current increases with the arc current, while the ratio of deceleration current to the acceleration current are almost the same, as it is shown in Fig.3. After a carefully analysis on the formation process of the deceleration current with appropriate perveance, the main part of the deceleration current is considered to be formed in the ionization process of the neutral molecules existing among the grids by colliding with the extracted ion beam particles. With a simple particle collision ionization model, with the ionization cross section shown in Tab.3, the variation of ratio of the deceleration current to the acceleration current vs. the discharge pressure is plotted in Fig.3. It is found that the simulation calculation result matches the experimental results well.

Tab.1 Parameters of beamline

| | |
|---|---|
| Beam energy | 45keV |
| Ion beam current | 24A |
| Pulse length of beam | 1s |
| Number of ion sources | 4 |
| Injection angle | 58° |
| Operation gas | $H_2$&$D_2$ |
| Vacuum system | Ti-pump |
| Ion source | Arc |
| Neutralization efficiency | 70% |
| Deflection angle of Residence ion-beam | 180° |

Tab.2 The Neutral beam injection ion source

| | |
|---|---|
| Size of discharge chamber | Diameter: 26cm; Depth: 24cm; |
| Cathode filaments | Φ×L=1.5×150mm; |
| Cusps magnats | 36 lists, 21.8cm in length, 0.6cm in width, 1cm thick. |
| Extraction grids | Φ17.4cm; Transparency: 49%; |
| Holes in girds | Φ0.69cm; 313 holes; |

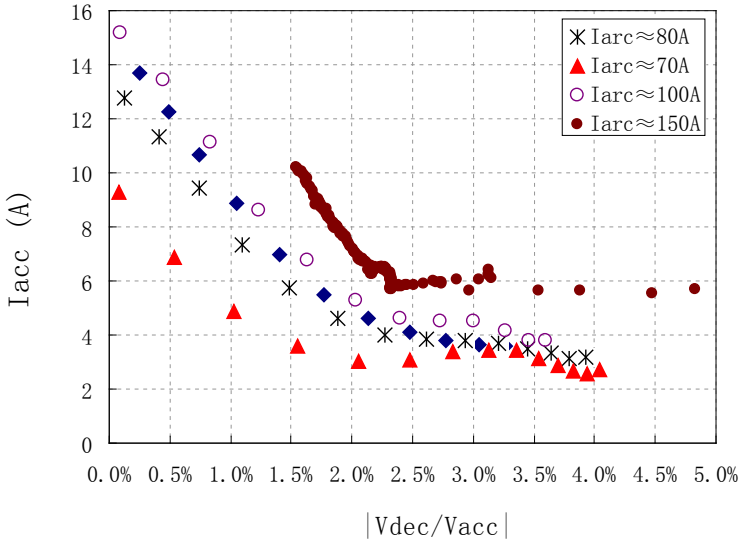


Fig. 2 the variation of acceleration current vs. the ratio of deceleration voltage to acceleration voltage

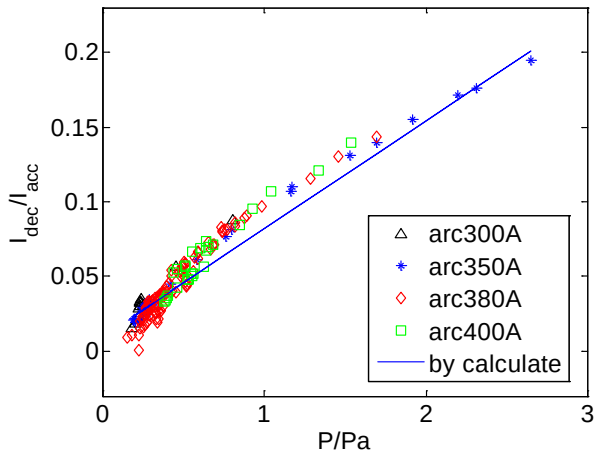


Fig. 3 the dependence of the ratio of deceleration current to the acceleration current on the discharge gas pressure

Tab.3 The cross section of H2+and H+ production by H+ colliding with H2

| Particle Energy/keV | Cross section/$cm^2$ | |
|---|---|---|
| | $H^+ + H_2 \rightarrow H_2^+$ | $H^+ + H_2 \rightarrow H^+$ |
| 5.0 E 00 | 8.1 E −16 | 4.0 E −17 |
| 1.0 E 01 | 8.0 E −16 | 9.3 E −17 |
| 2.0 E 01 | 6.2 E −16 | 1.2 E −16 |
| 3.0 E 01 | 4.8 E −16 | 8.7 E −17 |
| 4.0 E 01 | 3.8 E −16 | 6.3 E −17 |
| 5.0 E 01 | 3.4 E −16 | 4.4 E −17 |

## 3 The effect on neutralization efficiency by complementary gas puff

With the complementary gas puff successfully operated in the neutralizer, the neutralization efficiency increased obviously, as it is shown in Fig. 4. It can be seen that the neutralization efficiency was increased about 10% on average with using complementary gas puff in neutralizer.

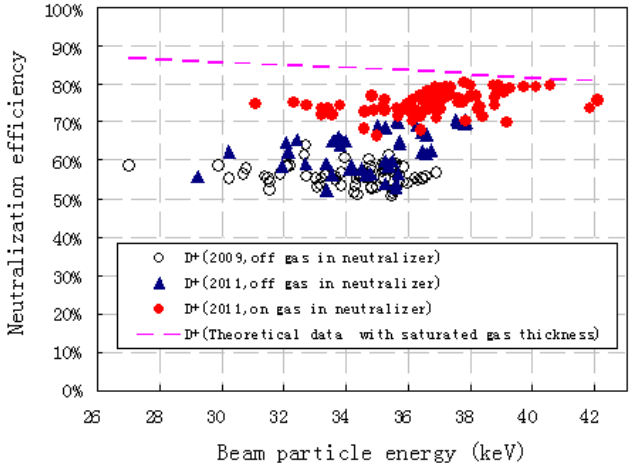


Fig. 4 the neutralization efficiency vs. the beam particle energy with the complementary gas puff on and off

## 4 Progress of ion beam current of single source and NBI power of the 1MW-NBI system

During the single ion source extraction experiments, the extraction current exceeded 20A with Deuterium as the discharge gas, and that exceeded 22A for Hydrogen gas. One of the typical curves is shown in Fig.5. And the corresponding extracted electrical power exceeds 1MW.

The neutral beam injection power into HL-2A Tokamak was increased year by year, as is shown in Fig.6. It can be seen that in 2012 the total injection power into plasma exceeded 1MW.

## 5 Conclusion

Through physical studies on bucket ion sources and engineering improvement on 1MW-NBI injector, the NBI power increased year by year. Finally, the high confinement H-mode discharges have been achieved on HL-2A Tokamak with only neutral beam injection heating, as it is shown in Fig.7, and the NBI power exceeded 1MW.

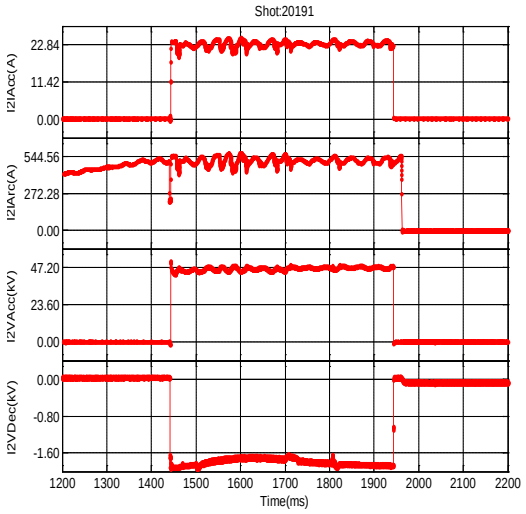


Fig.5 typical curves during the ion source extraction experiments

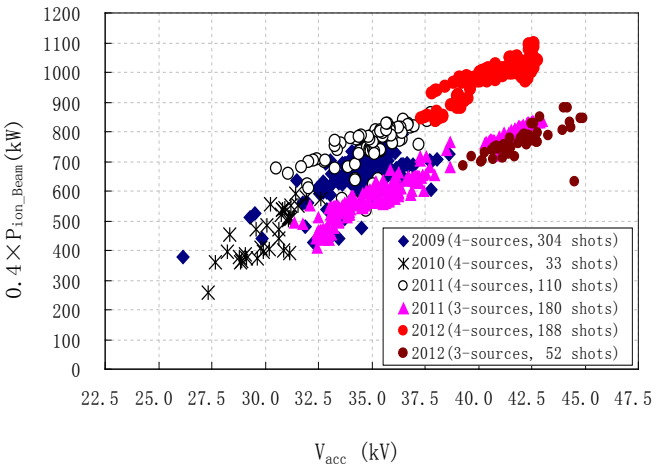


Fig. 6 Progress of NBI power into the plasma of HL-2A

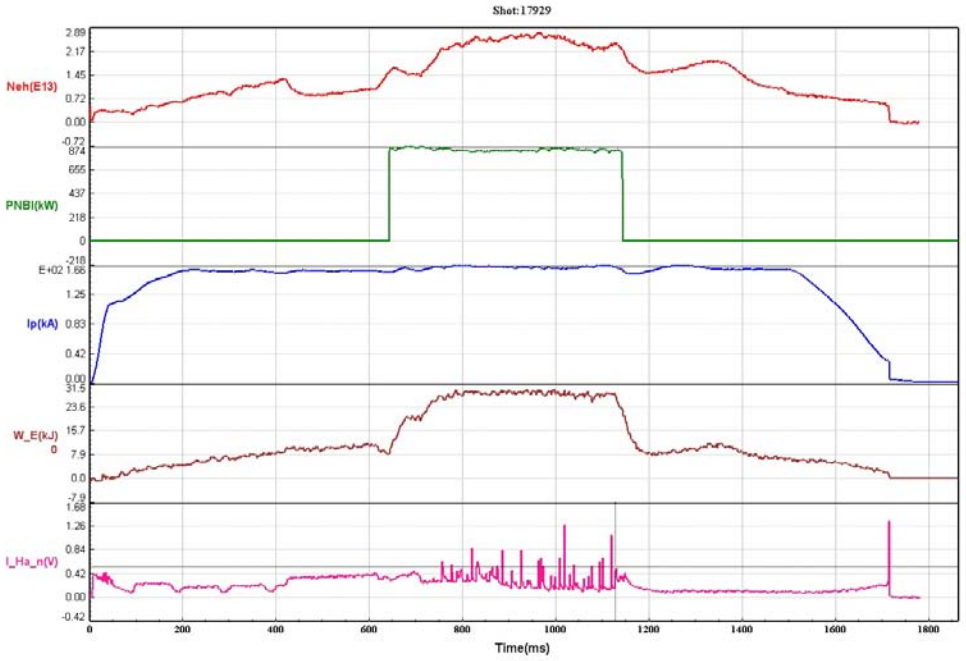


Fig. 7 one of the typical shot of H-mode discharge on HL-2A Tokamak with only NBI heating

## Reference

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