Extension of high power deuterium operation of negative ion based neutral beam injector in LHD

Katsunori Ikeda and LHD-NBI team

National Institute for Fusion Science (NIFS), JAPAN

18th International Conference on Ion sources 2019 Lanzhou, China
Contents

• **Introduction**
  • NBI for Large Helical device, and previous result and issues
  • Idea for reduction of co-extracted electron current

• **Improvement for injection beam power**
  • Update for beam accelerator
  • Operation results
  • Reduction of electron current and thermal load on a grid

• **Summary**
Introduction -- LHD and NB injectors --

--- Deuterium operation was initiated in 2017---

2 x **P-NBI** (Positive ion based)

- **Optimized D operation**
  - 60 keV – 9 MW (BL4)
  - 80 keV – 9 MW (BL5)

3 x **N-NBI** (Negative ion based)

- **Optimized H operation** (BL1, BL2, BL3)
  - 180 keV – 5 MW (H)/ beam line
- Only operation gas change to D
  - 180 keV – < 2.5 MW (D)

at 1st Deuterium operation
Performance and Issues for NNBI

$3 \times \text{N-NBI}$ (Negative ion based)

- Optimized Hydrogen (BL1, BL2, BL3)
  - 180 keV, 5 MW (H) / beam line
- Only operation gas change to D
  - 180 keV, < 2.5 MW (D)

- Injection power decrease below half.
  - Decrease of negative ion current
- Increasing electron current / ion current ratio
  - Increase of electron current
  - $\rightarrow$ thermal load of the extraction grid
Performance and Issues

3 x N-NBI (Negative ion based)

- Optimized Hydrogen (BL1, BL2, BL3)
  180 keV, 5 MW (H)/ beam line
- Only operation gas change to D
  180 keV, < 2.5 MW (D)

- Injection power decrease below half.
  = Decrease of negative ion current
- Increasing electron current / ion current ratio
  = Increase of electron current
  -> thermal load of the extraction grid

High power beam operation was limited by co-extracted electron current in high-power discharge

1st D operation in 2017

Scope of development in LHD-NNBI

• **Increase of injection beam power** without increase of beam energy
  
  => increase $D^-$ current

• **Decrease of $I_e/I_D^-$** in high power beam operation using high power arc discharge

  From the result of small negative ion source in the testbed …
Idea of electron reduction by previous results

Electrons are shielded by EDM field

Negative- ion rich plasma produced inside of EDM robe

Distribution of extracted negative ions with beam


Idea of electron reduction by previous results

Electrons are suppressed by EDM field

Negative- ion rich plasma produced inside of EDM robe

Distribution of extracted negative ions

Expansion of negative ion rich area => co-extracted electrons will be decrease


Update for beam accelerator and results of 2$^{\text{nd}}$ deuterium operation
Modification of Accelerator

Potential
-180 kV  Plasma Grid (PG)
-170 kV  Extraction Grid (EG)
-170 kV  Steering Grid (SG)
0 V  Grounded Grid (GG)

770 apertures
8 mm (2017)
New configuration of short ext. gap
12% up
Increase B on PG surface

Electron Deflection Magnet (EDM)
(1) Inside EDM field
Bending co-extracted electrons
=> EG (thermal)

(2) Outside EDM field
Important role for electron shielding in the vicinity of PG and maintaining negative ion rich plasma
Reduction of $I_e/I_{D^-}$ current ratio

$\frac{I_e}{I_{D^-}} : 0.38 \Rightarrow 0.28$  
(@ 180kW/source)

$\frac{I_e}{I_{D^-}} \sim$ maintaining 0.31 in high power

25% decrease in $I_e/I_{D^-}$

- Co-extracted electron current decreases well by strong EDM field in D operation.
- Electron-ion current ratio is as low as that in H operation.
Increase of $D^-$ current

- Negative ion current is not saturated by high arc discharge power
- Efficiency of arc discharge power is the same

$\Rightarrow$ Update to increase negative ion current will be needed
Reduction of thermal load on the accelerator

No damage in the EG and GG

40% reduction for EG thermal load

20% reduction for GG thermal load
# Operation summary in 2018

**Total injection power**: 6.3 MW $\Rightarrow$ 7.0 MW $\Rightarrow$ 8-9 MW

### BL1
- **2018**: Hydrogen optimization (6MW by H)
  - Large co-extracted electron current in D
- **2019**: Update PG and PG-EG 6.5 mm to decrease co-extracted electron in D operation

### BL2
- **2018**: Aperture type GG $\Rightarrow$ Slot type GG
  - Increase injection power but $I_e/I_D$ is still large.
- **2019**: Update PG-EG 7mm same as BL3

### BL3
- **2018**: PG-EG 7mm is well performed 2.9MW beam injection and $I_e/I_D \sim 0.31$ using high power arc discharge
- **2019**: New magnetic filter position will be tested

---

**Testbed**: Progressive accelerator design will be tested

---

**Deuterium**

**Injection power**

<table>
<thead>
<tr>
<th>Beam line number</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**$I_e/I_D$**

<table>
<thead>
<tr>
<th>Beam line number</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Summary

• Performance of negative-ion source for LHD-NNBI is improved by small change in the beam accelerator. (PG-EG : 8mm => 7mm)

• D⁻ current is improved : 46A => 55.4A (j = 233 A/m²).
  \( I_e/I_{D^-} \) current ratio is improved : 0.38 => 0.28 in the same arc power condition, which is maintained 0.31 at maximum D⁻ current. Thermal load on the beam accelerator large decreased (60% in EG).

• Injection beam power is improved : 2.3 MW => 2.9 MW in BL3. Total injection power also increased 6.3 MW => 7.0 MW by 3 beam lines.