Long pulse and high power density H⁻ ion beam accelerations for ITER
- Achievement for 60 s acceleration of 1 MeV beam in QST-


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Neutral Beam system for ITER

In fusion reactors, high power and high energy neutral beam (NB) system is required for plasma heating and current drive.

Overview of the ITER NB system

- High power negative ion accelerator is required for ITER.
- QST has been carrying out R&Ds for the ITER accelerator.
The prototype accelerator for the development is relevant to the 5 stage Multi-Aperture and Multi-Grid (MAMuG) accelerator of the reference design for ITER.
Previous R&Ds for high power and long pulse beam

Direct interception by beam deflection:
Beam deflections by magnetic field (due to electron suppression magnet and filter magnet) were compensated with aperture offset in ESG.

High temperature around magnet in EXG:
Arrangement of cooling channel and magnet in EXG was modified.

Poor voltage holding capability:
Voltage holding was improved by extending each gap length in the accelerator.

As the results of these developments, beam acceleration of 683 keV, 100 A/m² was achieved for 60 s which was power supply limit in 2014.
Remaining issues to achieve 1 MeV, 60 s

Pulse length was extended to 60 s but energy and current density were lower than the ITER requirements.

Key issue:
- Degradation of negative ion surface production efficiency for long pulse operation due to the non-optimized range of the PG temperature
- Off perveance against the ITER beam of 1 MeV, 200 A/m²
Stable negative ion surface production on the plasma grid

Negative ion surface production is largely affected by Cs coverage on the PG

Optimum PG temperature for high negative ion production: **230~280 °C**

But PG temperature exceeded this optimum range for 60 s operation at 60 % of arc discharge power for 1 MeV.
In order to suppress PG temperature rise for high discharge power, PG was modified to have large heat capacitance.

Original PG

Modified PG

Thickness: 2 mm ⇒ 6 mm
Shape: Flat ⇒ Taper

This modification increases heat capacitance by 2.5 times.

By the modification, PG temperature was kept in the optimum range at high discharge power of 27 kW required for 1 MeV beam acceleration.
⇒ The stable negative ion production was maintained for 60 s.
⇒ For further pulse extension, temperature controllable grid is under examination.
Off perveance of 1 MeV 200 A/m²

Current density at previous long pulse operation was 8% lower compared to Perveance curve of 1 MeV, 200 A/m².

The cause of this off perveance was examined.
To reduce the voltage drop, protection resistor at -1MV potential was reduced from 63 kΩ to 36 kΩ and the number of beamlet was reduced from 15 to 9.

These countermeasures suppressed drop of acceleration voltage from 13% to 4%.

For high current beam acceleration,
- Maximum drain current (Iacc): ~ 400 mA
- Substantial voltage of 1st gap: 13% ↓
  - From 200 kV → 175 kV at 1MV
- Electric field in the 1st gap weaken
- Off perveance
  - Low extraction voltage to match electric field in 1st gap
Negative ion current density increased 20% from 125 A/m² to 150 A/m² at 800 kV for higher extraction voltage.

High current density beam over 200 A/m² at 1 MeV was accelerated after the modification.
Acceleration grid heat load has decreased by the countermeasure.

- Total grid heat load has decreased to 9% at 1 MeV beam acceleration.
- This grid heat load is enough low for long pulse acceleration.
High power density beam acceleration of 0.97 MeV, 190 A/m² (0.26A) has been achieved for 60 s (which was power supply limit).

Stable beam acceleration without no breakdowns has been achieved for 60 s.

This is the first long pulse acceleration of ITER class power density beam.
Summary

• For the ITER NB accelerator, development of high power density and long pulse accelerator has been carried out with the MeV accelerator.
• The temperature of the PG with 6 mm in thickness has been tuned to be optimum range for the negative ion production for 60 s which was a limitation of the power supply.
• The beam optics has been adjusted to realize a stable acceleration of the negative ion beam at high current density equivalent to the ITER design value.
• Acceleration of 0.97 MeV, 190 A/m² for 60 s has been achieved for the first time in the world.

This result significantly proceeds the realization of the ITER NB system.
Thank you for your attention!