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Development and Future Plan of the negative hydrogen ion sources for NBI at SWIP

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ABSTRACT

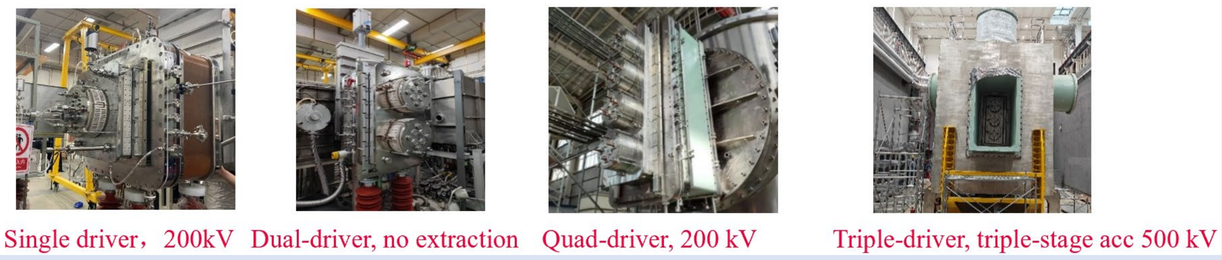
- A radio-frequency negative ion source with an extraction area of 0.32 × 0.4 m² has been developed.
- The source operates without the need for a start filament. The design parameters are achieved, though not simultaneously.
- Building on the development of the single-driver source, a three-driver, three-stage acceleration ion source has been developed and is currently in operation.

INTRODUCTION

- Neutralization efficiency of NNBI can stay above 60 % when beam energy is larger than 150 keV.
- The NNBI facility at SWIP, formally started construction in 2017 and planned to be completed in 2025. The aim of the facility is to explore and master the key technologies of NNBI for future fusion reactor. The aim of the facility is to attain a hydrogen neutral beam with the particle energy of 500 keV, current density of 300 A/m², and pulse duration of > 100 s.
- The facility mainly contains two test stands: test stand I focuses on the negative ion source technology researches, and test stand II is the full-function prototype for the neutral beam injector.

SOURCE DESIGN AND TEST STAND I

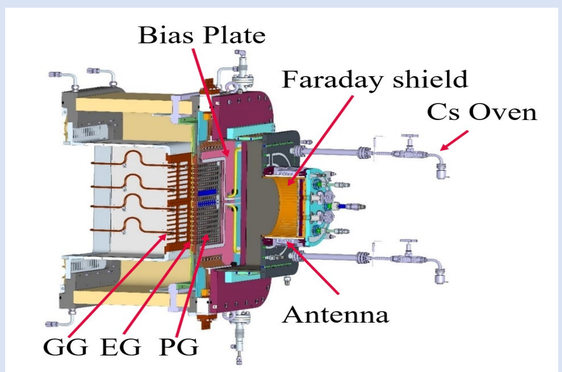
- Test stand I is developed for test of single-driver and dual-driver source.
- RF power supply: 2 MHz, 80 kW
- Extraction power supply: 10 kV/60 A
- Acceleration power supply 1: 200 kV/5A
- Acceleration power supply 2: 110 kV/50 A (PSM)
- Isolation transformer: 200 kV
- Plasma diagnostics: Langmuir Probe, Optical emission spectroscopy, Cavity ring-down spectroscopy
- Beam diagnostics: W-wire dump, Mo plate dump, beam profile measured by infrared camera.

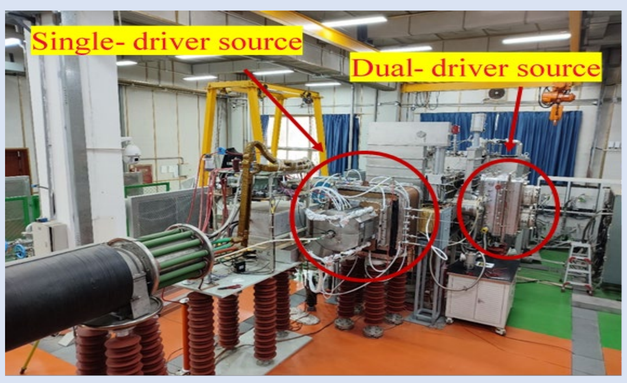


Roadmap of negative ion sources

Primary parameters of the ion sources

	Single-driver	Dual-driver	Quad-driver	Triple-driver
RF power	80 kW, 2 MHz	80 kW×2, 2MHz	80 kW×4, 2MHz	80 kW×3, 2MHz
Driver dimensions	Φ28 cm, 14 cm（height）	Φ28 cm, 14 cm（height）	Φ28 cm, 14 cm（height）	Φ28 cm, 14 cm（height）
Expansion chamber	60 (l) ×50(w) ×25(d) cm³	100 (l) ×50(w) ×25(d) cm³	180 (l) ×50(w) ×25(d) cm³	148 (l) ×50(w) ×25(d) cm³
PG apertures	Φ14 mm, 17×8×2	Φ14 mm, 17×4×6	Φ14 mm, 17×11×2+17×13×3	Φ14 mm, 12×16×3
Extraction voltage	10 kV	-	10 kV	10kV
Acceleration voltage	110 kV/200 kV	-	200 kV	500 kV

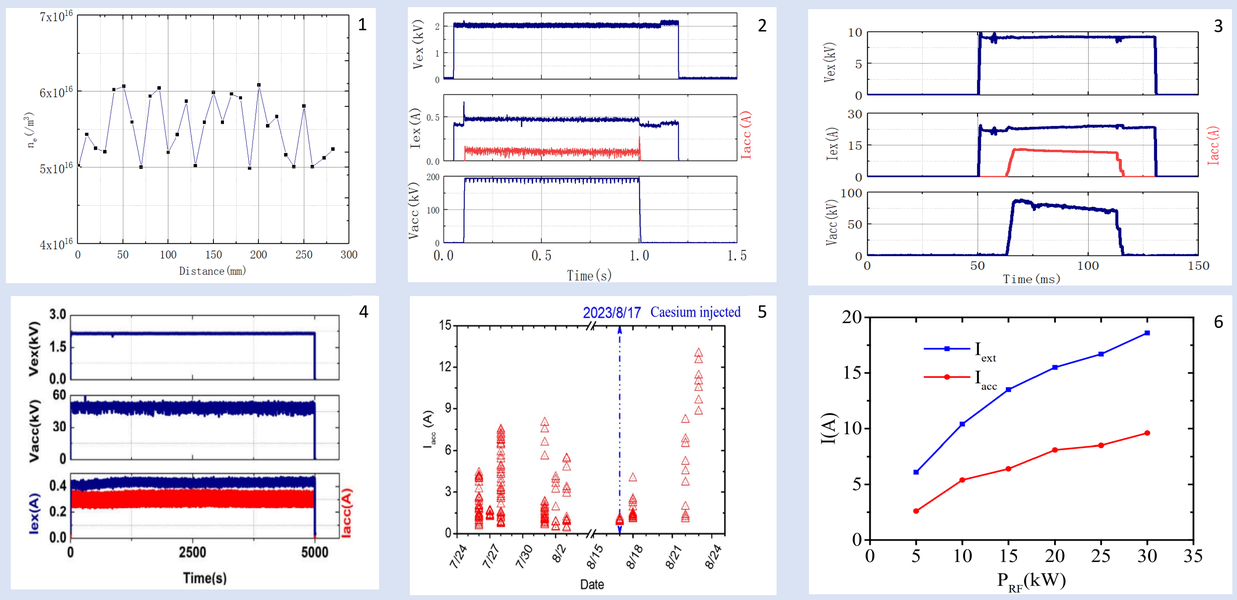




Single driver source and test stand I

EXPERIMENTAL RESULTS

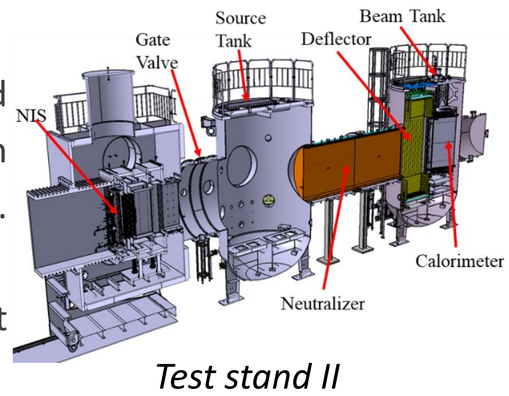
- At an RF power of 35 kW, the extracted negative hydrogen beam parameters are 13 A at 100 keV for 0.1 s, with a corresponding beam current density of 317 A/m².
- For long-pulse operation, the beam parameters are 50 keV at 0.25 A for 5000 s.
- For high beam energy operation, the parameters are 198 keV at 0.15 A for 3 s.
- The design parameters have not yet been achieved simultaneously due to limitations in the ion source test stand, which currently lacks a dedicated calorimeter.
- As a result, the beam energy impacting the back plate of the vacuum chamber must be kept within limits, and the electrode transparency is too high to withstand long-pulse, high-power beams simultaneously.



Typical Beam characteristics: 1.homogeneity, 2. high beam energy, 3. high beam current, 4.long pulse, 5. I_{acc} statistical, 6. I_{acc} and I_{ext} vs RF power

FUTURE PLAN

- First beam in 2024, at RF power of 8 kW, 0.4 A/40 keV/200 s negative hydrogen ion beam has been extracted.
- Although no higher beam energy and current was achieved, the first operation was closed to upgrade the test stand, e.g. assembling the large cryopumps.
- The aim parameters of the next experiment campaign is 200 kV, 10 A, 100s.



Test stand II

CONCLUSION

- The single driver radio-frequency negative ion source with an extraction area of 0.32 × 0.4 m² has been developed and tested on test stand I. The source operates without the need for a start filament. Currently, the maximum beam current, beam energy, and beam duration achieved are 13 A, 198 keV, and 5000 s. The design parameters are achieved, though not simultaneously.
- The triple driver source has been developed and tested at test stand II. Currently, 0.4 A/40 keV/200 s negative hydrogen ion beam has been extracted.

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