Research activities of RF based negative ion source in the ASIPP

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Outline

- Background
- Introduction of RF source test facility
- Research activities of RF N-beam source
  - RF plasma discharge
  - Negative ion beam extraction
- Summary and future plan
MFE development pathway in CHINA

4 steps

CFETR

ITER

EAST

HL-2M

J-TEXT

1 GW, Power Plant Validation

One goal: FE

Phase I: Q = 10, 400 s, 500 MW, Hybrid burning plasma

Phase II: Q = 5, 3000 s, 350 MW, steady-state burning plasma

II: DEMO validation, Q > 10, CW, 1 GW, > 50 dpa
I: Q = 1 - 5, steady state, TBR > 1, > 200 MW, < 10 dpa

Advance PFC, steady-state advanced operation

Advanced divertor, high power H&CD, diagnostics

Disruption mitigation, basic plasma

2015 2020 2025 2030 2035 2040 2045 2050 2055 2060
CRAFT Project

Comprehensive Research fAcity for Fusion Technology (CRAFT)
National big science facility (2019.9-2025.5)
CRAFT NNBI system

Key technology

- Negative ions generation
- Negative beam acceleration
- HVPS and transmission
- High speed cryopump
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The matching network on test facility

\[ \begin{align*}
C_2 &= 2.65 \text{nF} \pm 0.5 \text{nF} \\
C_1 &= 1.1 \text{nF} \sim 5 \text{nF}
\end{align*} \]
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Design of RF plasma source

- **Faraday shield**
  - ID = 200mm
  - Height = 140mm
  - Thickness = 4 mm

- **Size of insulator**
  - ID = 210mm
  - Height = 156mm
  - Thickness = 8 mm

- **Expansion area**
  - Length = 650mm, height = 260mm, depth = 240 mm
R&D of RF driver

- Heat loading on FS is around 50% of total
- FS is very different to manufacture (by vacuum brazing)
- Active cooling FS with three pipes was developed

Temperature analysis

Stress and thermal displacement analysis
Single driver ion source

Picture of RF ion source

Position of movable probe
Plasma parameters measurement (w/o cusp mag.)

- **0.5 Pa @ 20 cm**
  - RF power vs. Electron density
  - Electron temperature vs. RF power

- **30 kW @ 20 cm**
  - Pressure vs. Electron density
  - Electron temperature vs. Pressure
Plasma parameters with space distribution

30kW @ 0.5 Pa W/O cusp magnet

Electron density (m$^{-3}$)

Electron temperature (eV)

Position (cm)

Electron density (m$^{-3}$)

Electron temperature (eV)

Position (cm)
Long pulse operation (47kW@1000s)

Waveform of plasma discharge (1000s)

80 kW RF discharge with 60s duration

Temperature rise of cooling water for each components
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Design of negative ion accelerator

- 2 segments, \(5 \times 6\) beamlets for each, aperture separation 22mm and 20mm
- Center of electron suppression magnetic field \(\sim 500\)G
- Electron Suppression Magnet: \(5\text{mm} \times 5.5\text{mm}\) (cross section), SmCo, 1 T

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Development of negative ion accelerator

Plasma Generator

- $V_b$ (<10 V)
- $V_{ext}$ (Max=12 kV)
- $V_{acc}$ (Max=50 kV)
Magnetic filter on negative beam source

- 4×2 permanent magnets (Sm$_2$Co$_{17}$) installed 55mm before PG
- Magnetic intensity is 1T
- $\int |B_x|dz$ between 1.2 mTm-1.35 mTm
Magnetic filter on negative beam source

- The electron temperature decreased from 5.5eV to 1 eV with magnetic filter.
- The magnetic filter effects on electron density can be neglected.
- The results were good for the negative beam source.
Negative ion extraction exp.

- Plasma grid current: $I_{PG}$
- Extraction grid current: $I_{EG}$
- Ground grid current: $I_{GG}$
- Faraday plate current: $I_{FS}$
Negative ion extraction W/O Cs

- The source pressure keeps 0.33 Pa
- Negative ion density realized 10 A/m² (20kW)
- The ratio of electron to negative ion is around 25

EG and GG current as a function of RF power

Faraday cup current and GG current as a function of RF power
Cs dispenser for negative ion production

R&D of Cs dispenser to enhance the H- yield

- Temperature of plasms chamber was actively controlled around 45 degree
- Temperature of PG was heated by RF plasma between 100 to 180 degree

Cs dispenser installed on the beam source
Diagnosis of negative ion

After Cs feeding

W/O Cs feeding

After Cs feeding

Intensity of 852nm line of Cs

Measurement of H- density with CRDS

OES measurement points

Density H [m^3] vs. Time [s]

Picture of CRDS system
Day by day conditioning

sixteen days conditioning with Cs

RF power: 40 kW
Source pressure: 0.6 Pa
Conditioning results of negative ion extraction

Extracted ion density vary with RF power

Extracted ion density with different extraction voltage
Long pulse negative ion extraction

Ten holes were left because of weak pump speed.

- RF power: 46 kW
- Extracted ion density: 153 A/m²
- Ratio of electron to H⁻: 0.3
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Summary

- High power negative ion based RF ion source was designed in ASIPP for CRAFT NNBI system
- A RF ion source test facility was developed for the performance testing at the first phase
- A negative source with singer driver and three layers grids was developed
- Long pulse plasma discharge of 1000s was achieved on with RF power of 47 kW (60s with 80 kW)
- The negative ion production and extraction was tested with Cs feeding
- Long pulse of 105 s beam extraction with density of 153 A/m² was achieved (the ratio of electron to ion was 0.3)
RF beam source test facility upgrade (Oct. 2020)

- RF P.S.: 100kW @ 1MHz
- Extractor P.S.: -16kV@20A
- Acc. P.S.: -50kV@50A (Oct. 2020)

- TC/WFC
- Langmuir Probe
- Microwave interferometer
- OES & CRDS
Future plan

- Characteristic study of negative ion production and extraction（Cs feeding, PG temperature control, beam optics …）
- Long pulse negative ion production and extraction with large size
- Increase source size (two drives, large extraction grid)
- …

ITER-like Faraday shield

Manufactured large size PG, EG and GG
Thanks for your attention!