Operation of RF ion source in CSNS

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- China Spallation Neutron Source (CSNS) introduction
- RF H-source description
- First beam production without cesium
- Conclusion and future improvements
Linac parameter:
Ion source: Penning surface ion source.
Energy before/after RFQ: 50keV/3MeV
Energy before/after DTL: 3MeV/80MeV
RF cavity frequency: 324 MHz
Repetition rate: 25Hz
Pulse length: 500 μs
Goal of upgrade: 300 MeV after SC-cavity

RCS parameter:
Circumference: 228 m
Repetition rate: 25 Hz
Energy on target: 1.6 GeV/proton
Target material: Tungsten
Average power on target: 100kW
Goal of upgrade: 500 kW
CSNS introduction

Where we are?

- 2009-05, Before ground breaking
- 2012-06, Construction began
- 2017-08, First 1.6 GeV beam on target
The front end of the CSNS LINAC contains an ion source, an LEBT beam transportation, a chopper and an RFQ accelerator.

The remained beam after chopper: 50%~60%
Acceptance of RFQ: $0.2\pi\text{mm}\text{mrad}$

For the 500 kW upgrading, at least 50 mA H- beam from ion source is required.
The ion source

**Ion source in service**

A clone of ISIS ion source

- Maximum current: 50~60 mA,
- Width: 500 us,
- Repetition rate: 25 Hz,
- Life time: 4~6 weeks
- RMS Emittance: \(\sim 0.8 \pi \text{ mm mrad}\)
- 25 mA within RFQ’s acceptance

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**Ion source under development**

- Silicon nitride plasma chamber
- Indirect water cooling
- 1500 Watt power allowed
- Thread teeth separated, epoxy sealed antenna
- Spark-gap ignitor
First beam produced.

The test bench of the RF ion source.
In December of 2018, first H- ion beam was extracted. At 18kW RF power and 10kV extracting voltage, 16 mA beam on Faraday cup was obtained.

After weeks of optimization, we got 32 mA beam on Faraday cup.

RF power 36kW  
Extractor pulse width: 450 μs  
Repetition rate: 25 Hz  
HV acceleration: 39 kV  
Extractor voltage: 10kV  
Extractor current: above 1.5A

We have to measure the percentage of electron in the beam, so we switched to helium.
Check the content of electrons

We make sure that pure helium is injected to the chamber by spectrum analyze.

Then we measure the Faraday cup current and the extractor current, the ratio of the two value is about 0.7%.

According to this we roughly estimate roughly 30~40% of the extracted beam is electron!

Solution: Cesium injection and re-design the extractor.
Heat load test

H2 flow rate: 18sccm,
Pulse width: 600us,
Repetition: 25Hz
Cooling water inlet: 26.5 degree
Heat load test

A straight line is used to fit the experimental data. If the fit curve is extrapolated to 1500W, T_mid is around 78 degree.

Thermal simulation of the chamber@ 1500W, suppose a 4π-homogenous radiation of the plasma. Maximum temperature of the outer surface of chamber is 81 degree.
RF power coupling

A typical RF power coupling circuit

\[ Z = \frac{n^2 X_S^2 R - i n^2 X_S \{ n^2 R^2 + (X_L - X_T) [n^2 (X_L - X_T) - X_S] \} }{n^4 R^2 + [n^2 (X_L - X_T) - X_S]^2} \]

When completely matched,

\[ \begin{align*}
\frac{n^2 X_S^2 R}{n^4 R^2 + [n^2 (X_L - X_T) - X_S]^2} &= 50 \\
n^2 R^2 + (X_L - X_T) [n^2 (X_L - X_T) - X_S] &= 0
\end{align*} \]

When \( n^2 R \approx 50 \), Then \( C_s \approx 0 \)
Maximum power of solid-state amplifier: 80kW

For initial test we used a 7:1 transformer, and found it does not fit the impedance of the plasma $R_p$. But it helps us to estimate the value of $R_p$.

We changed to a 5:1 transformer, the reflection of RF power is less than 3% at 37.4 kW input power, which is acceptable.
We use two ways to estimate the impedance of the plasma,

1. From the percentage of the reflected RF power under matched condition. This is measured with double-directional coupler.

2. Direct way: \( R_p = R - R_{ant} = \frac{8P_p}{I_{pp}^2} - R_{ant} \), Here \( R_{ant} = 0.35\Omega \)

The impedance of the plasma increase with RF power. It stabilized around 2.4 Ohm when RF power goes above 20kW.

Detailed study will be carried out to study the influence of RF power, frequency, and gas flow rate to the plasma.
Main Concern:
1. Sputtering of cathode element, which may causes the contamination of the plasma chamber.
2. Electron depletion, which may causes self-extinguish.
Simple ignitor of long lifetime

Sputter-rate of metals by H3+ ion at different energies.

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<th>E</th>
<th>Ti(47.9)</th>
<th>Cu(63.54)</th>
<th>Zr(91.22)</th>
<th>Mo(95.94)</th>
<th>Hf(178.49)</th>
<th>Ta(180.95)</th>
<th>Pt(195.08)</th>
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<td>0.025</td>
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Hafnium and Tantalum have lower work function. They can easily produce seed electron for the ignition.

We tested the Hf cathode for more than one week, there is no evidence of self-extinguish.
Improved pepper-pot emittance meter

A typical pepper-pot emittance meter, beam distribution information is lost.

Small faraday cup with hole in the bottom, the hole has same diameter as hole in the plate.

Normalize the photon intensity signal to the faraday cup signal.
The RF H- source in CSNS starts to produce H- beam.
Si3N4 is proved to be a good choice for high power RF source.
The impedance of the plasma is preliminary measured, detailed study will be carried out in the future.
The electrons are not totally eliminated in the extracted beam, the extractor should be optimized.
To produce 50 mA H- beam, cesium injection is in preparation.
Thanks for your attention!