Commissioning results of the 18GHz Superconducting Source for Ions - SUSI


National Superconducting Cyclotron Laboratory

Michigan State University, East Lansing, MI 48824, USA
• Motivations to build SUSI

• SUSI Design and Construction

• Magnet Tests and Quenches

• Commissioning Results:
  \( ^{40}\text{Ar} \): \( \text{Ar}^{11+} \) and \( \text{Ar}^{14+} \)
  \( ^{129}\text{Xe} \): \( \text{Xe}^{20+} \) and \( \text{Xe}^{27+} \)
  \( ^{209}\text{Bi} \): \( \text{Bi}^{28+} \) and \( \text{Bi}^{33} \)

• Beam Transport
Rare isotope production by fast-beam fragmentation and in-flight separation

Forefront US user facility for rare isotope research and education in nuclear science, astro-nuclear physics and accelerator physics

→ Fast, stopped, and re-accelerated beams
**Coupled Cyclotron Facility - CCF**

**K 500 Injection**

<table>
<thead>
<tr>
<th>Ion</th>
<th>Charge State</th>
<th>Current (euA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{18}$O</td>
<td>3+</td>
<td>35</td>
</tr>
<tr>
<td>$^{40}$Ar</td>
<td>7+</td>
<td>40</td>
</tr>
<tr>
<td>$^{58}$Ni</td>
<td>11+</td>
<td>8</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>12+</td>
<td>5</td>
</tr>
<tr>
<td>$^{78}$Kr</td>
<td>14+</td>
<td>15</td>
</tr>
<tr>
<td>$^{48}$Ca</td>
<td>8+</td>
<td>10</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>21+</td>
<td>11</td>
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</tbody>
</table>

**ECR** → $^{48}$Ca $^8+$ → **K500** → $^{48}$Ca $^8+$ → **K1200** → $^{48}$Ca $^{20+}$ → **Target**

5 keV/u → 12 MeV/u → 140 MeV/u
Evolution of CCF Beam Intensities

CCF Peak Extracted beam Current [pnA]

- O16
- Ar40
- Ca48
- Ni58
- Kr78
- Xe124

Time:
- 2004Q3
- 2004Q4
- 2005Q1
- 2005Q2
- 2005Q3
- 2005Q4
- 2006Q1
- 2006Q2
- 2006Q3

Intensities:
- 929 W
- 958 W
- 1911 W
- 1710 W
NSCL Goal: Improve Primary Beam Power from CCF

- Improve ion beam intensity from Ion sources
- Improve beam matching into K500
- Minimize beam losses on deflectors
- Improve stripper foil lifetime

R&D effort:

- SuSI (3rd Generation Ion sources)
- Artemis-B
- Beam collimation
- Electrostatic focusing below ECR
- Beam chopper
SUSI Design and Construction
• **3rd Generation ion source with High B mode**
  \[ B_{\text{inj}} = 2.6 \, \text{T}, \quad B_{\text{ext}} = 1.5 \, \text{T} \text{ axial field} \]
  \[ B_r = 1.5 \, \text{T} \text{ radial field} \]

• **Fully Superconducting Coils**

  • Operating frequency:
    18GHz (2kW) + 14.5 GHz (2kW)

  • Plasma chamber diameter:
    100.8 mm (aluminum)

• Extraction voltage: up to 27kV (Cyclotron)

• Bias Disk

• 500l/s injection + 2000 l/s TP
SuSI – Specific features

- “Flexible field”
  - the relative distance between the resonant zone and plasma electrode can be varied
  - the distance between the two magnetic maxima can be varied
  - the “depth” of the magnetic minimum can be varied
  - the position of the magnetic profile can be shifted

- Injection Assembly (Baffle) can be moved (i.e Plasma chamber volume can be changed)
- Biased disk position can be adjusted (relative to the baffle)
<table>
<thead>
<tr>
<th>Task Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coils winding completed</td>
<td>September 2005</td>
</tr>
<tr>
<td>Tested and trained Individuals coils</td>
<td>November 2005</td>
</tr>
<tr>
<td>Coil assembly (Hexapole + Solenoids)</td>
<td>early 2006</td>
</tr>
<tr>
<td>Coil assembly testing (Helium Dewar)</td>
<td>February 2006</td>
</tr>
<tr>
<td>Cryostat completed</td>
<td>September 2006</td>
</tr>
<tr>
<td>Yoke is installed</td>
<td>December 2006</td>
</tr>
<tr>
<td>Source is complete and moved to development Lab</td>
<td>January 2007</td>
</tr>
<tr>
<td>First Plasma Ignited</td>
<td>March 2007</td>
</tr>
<tr>
<td>Quenches problems and commissioning</td>
<td></td>
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</tbody>
</table>
Magnets Tests and Quenches
Coils were taken to currents above what their maximum operating currents would be.

- 2 small solenoids taken to 445 A, 1 large to 485 A, no quenches
- Sextupoles trained to 720 A requiring 5-7 quenches, initial quench varied from 300A – 500A, all sextupole coils tested

**Design values for 18GHz:** 210A small(extraction) solenoids; 290A Large Solenoid(Injection); 370A (Hexapole)
1st dewar test had sextupole on 1 600A power supply and 2 outer solenoids in series on another a 400 A power supply.

– Sextupole assembly trained from 250A to 567 A with 10 quenches. Then taken to 550 A and back to 0 without quench.

– Solenoids taken to 400 A after 1 quench at 365 A. Bruker supply blew a capacitor shortly thereafter. It was replaced with another Alpha.

– Sextupole again taken to 550 A alone without quench.
Trying to ramp up the field of the Solenoid and of the sextupole in sequence always resulted in a quench (While ramping)

- Solenoids energized first:
  - Solenoids at 400 A → Sextupole quenches around 100 A.
  - Solenoids at 120 A → Sextupole quenches around 260 A
  - Solenoids below 100A → Sextupole goes to 500 A (no quench)

- Sextupole energized first, each done multiple times.
  - Sextupole at 400 A → Quenches when solenoids reached about 150 A
  - Sextupole at 350 A → Quenches when solenoids reached about 180 A

Shunt voltages monitored on scope to see where quench initiated. Sextupole shown to be quenching first even though the solenoids are being ramped.
• Ramp rates did not influence behavior

• Training sextupole alone higher with quenches at 600, 621, and 653 A did not improve behavior.

Improve lead restraint in dewar did not improve behavior

• Solenoids and sextupole *energized evenly together* gave best results.
  – Reached 240 A each on first try.
  – Trained to 390 A each in 3 quenches.
  – Ramped to 390 A each, then increased sextupole only to quench at 409 A.

Finally:
• It was possible to ramp solenoids to 390A and then take the sextupole up to 585 A
The coil system was found to quench after having reached the desired field values.

Coils system now within ion source cryostat

Red – 14.5 GHz fields
Blue – 18 GHz fields
Green – 24 GHz fields

- Quench (all systems)
Δ - ramped down (all systems)
• The last Quench after the source had reach the field values was observed on November 2\textsuperscript{nd} 2007! (Field had been up for 8mn)

• The source was run for more than 250 Hours since August without any Quenches

• 4 out 6 Solenoids were used over a wide range of currents (Mid1 and 2, Extraction1 and 2. Also the Hexapole can be adjusted over a wide range (~100A) without any problem.

• A Magnetic field equivalent to run a 24GHz microwave was run for 24h and then ramp down without quench!
Commissioning Results with SUSI

$^{40}\text{Ar}$: $\text{Ar}^{11+}$ and $\text{Ar}^{14+}$

$^{129}\text{Xe}$: $\text{Xe}^{20+}$ and $\text{Xe}^{27+}$

$^{209}\text{Bi}$: $\text{Bi}^{28+}$ and $\text{Bi}^{33+}$
Commissioning Results from SUSI: $^{40}\text{Ar}$

- $\text{Ar}^{10+}$
- $\text{Ar}^{9+}$
- $\text{Ar}^{8+}$
- $\text{Ar}^{11+}$
- $\text{Ar}^{12+}$
- $\text{O}^{3+}$
- $\text{O}^{2+}$

$\text{Ar}^{11+}$: 550 euA
$\text{Pw} = 1.5\text{kW (18GHz)}$
$\text{Pw} = 300\text{W (14.5GHz)}$

$\text{Ar}^{14+}$: 145 euA
Commissioning Results from SUSI: $^{129}\text{Xe}$

$^{129}\text{Xe}$: optimized on $\text{Xe}^{27+}$: 180 euA
1.8 kW 18 GHz
500 W 14.5 GHz

$^{129}\text{Xe}$: optimized on $\text{Xe}^{20+}$: 335 euA
1.7 kW 18 GHz
300 W 14.5 GHz
Commissioning Results from SUSI \(^{209}\text{Bi}\)

Distribution optimized on \(\text{Bi}^{28+} \sim 150\text{euA}\)

1.4kW (18GHz) + 300W (14.5GHz)
Commissioning Results from SUSI :^{209}\text{Bi}

Distribution optimized on Bi^{31+}

1.7kW (18GHz) + 300W (14.5GHz)

About 20euA Bi^{36+} and 65euA of Bi^{33+}
Plastic insulation issue

While using the source at higher power (1kW), the HV insulation acrylic tube failed.

Caused by X-rays triggered by too high sextupole setting?
Beam Transport
• Accel-Decel system

• Adjustable puller position

• Beamline following the ion source can be biased up to –20kV
NSCL Allison Emittance scanner (2D)

Beam

Slits: $S_1 = S_2 = 60 \text{ mm} \times 0.5 \text{ mm}$

$g = 12 \text{ mm} ; D = 7.5 \text{ cm} ;$

$\Delta x_{\text{int}} = s = 0.5 \text{ mm}$

$\Delta x'_{\text{int}} = +/- s/D = +/- 6.7 \text{ mrad}$

$x'_{\text{Max}} = 2g/D \cong 300 \text{ mrad}$
Emittance measurement after ion source

- Allison ES positioned right after extraction cube (X and Y)

25mm Gap

- Changing extraction field (Solenoid) or BD did not impact ES distribution

55mm Gap
• Test with a “pencil beam” and a steering magnet

SUSI Bending Magnet Test
1\textsuperscript{st} case: Argon beam 1.5 mA total extracted current. Source at 24 kV

2\textsuperscript{nd} case: Argon beam 4 mA total extracted current. Source at 24 kV
1st case: Argon beam 1.5mA total extracted current

- Transmission about 85% without bias and reach about 95% with –20 kV on the beam line.
2\textsuperscript{nd} case: Argon beam 4 mA total extracted current.

- Measured transmission goes from 68% at 24kV to 83% at 45 kev/q energy
- Total extracted current went up 0.5 mA to reach 4.5 with the beam line biased
- Current in F-Cup went up from 400 euA to 500euA
- RMS emittance improved with the biased beam line
Conclusion I

- Good intensity have been demonstrated for Argon, Xenon and Bismuth

- Transmission with No focusing element/ biased beamline was measured to be 83% with a 4mA beam. There seems to be some merit to bias the beam line

- More metallic beams will be produced soon: Calcium, Nickel and Uranium

- Systematic study of flexible field to improve extracted intensities and emittance

- Current limits to avoid quenches

- Potential upgrade by removing the 14GHz transmitter and replacing it with a 18GHz klystron to add more power (SECRAL)
• SUSI will likely be moved to Operation and connected to the CCF during the coming FY

• Beam dynamics simulations to determine the best transport scheme including method to properly collimate the beam emittance

• A new Set of coils have been made and all material and parts to build a new coils assembly have been purchased. Pending decision to allocate resources to assemble this 2nd set.