Recent Performance of the SNS H⁻ Ion Source and Low-Energy Beam Transport System

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Abstract

• Recent measurements of the H- beam current show that SNS is injecting about 55 mA into the RFQ compared to ~45 mA in 2010. Since 2010, the H- beam exiting the RFQ dropped from ~40 mA to ~34 mA, which is still sufficient for 1 MW of beam power. The RF team is in the process of retuning the RFQ to restore the apparently degraded transmission. The level of success in restoring the ~40 mA RFQ output current, desired for 1.4 MW beam power, will be discussed in Chiba.
To minimize the impact of the RFQ degradation, the service cycle of the best performing source was extended to 6 weeks. No degradation was noticed besides the electron dump voltage starting to fluctuate towards the end of some service cycles. The problem is being investigated to further extend the source service cycles.

• In addition we will report on several efforts to increase the performance of our H-sources as well as to decrease the performance variations from source to source and from service cycle to service cycle.
After a 2012 thermal failure of the test electrostatic low-energy beam transport system, it was reengineered to double its heat sinking and equipped with a thermocouple that monitors the temperature of the ground electrode between the two Einzel lenses. The recorded data show that emissions from the source at high voltage dominate the heat load. Emissions from the partly Cs covered first lens cause the temperature to peak many hours after starting up. On rare occasions the temperature can also peak due to corona discharges between one of the lenses and the center ground.
It is all about producing more H- ions more reliably!
The Spallation Neutron Source smashes a pulsed, 1 MW proton beam on to a Hg target to produce approximately $2 \times 10^{17}$ neutrons 60 times per second!
Since fall of 2009 SNS is running near 1 MW, 800 kW most of 2011 due to budget, 850 kW from fall 2012 through summer of 2013 due to target issues!

1 MW requires ~50 mA of H⁻ for 0.88 ms at 60 Hz for up to 6 weeks.
The SNS Baseline Ion Source and LEBT

- LBNL developed the SNS H\(^-\) ion source, a cesium-enhanced, multicusp ion source.
- Typically 300 W from a 600-W, 13-MHz amplifier generates a continuous low-power plasma.
- The high current beam pulses are generated by superimposing 50-60 kW from a pulsed 80-kW, 2-MHz amplifier.

- The two-lens, electro-static LEBT is 12-cm long. Lens-2 is split into four quadrants to steer, chop, and blank the beam.
- The compactness of the LEBT constrains beam characterizations in front of the RFQ. The beam current is measured after emerging from the RFQ, which equals the LINAC beam current.

We have produced >9 kC or >2.5 A\cdot h of H\(^-\) ions without any maintenance!
The Ion Source and LEBT availability have reached ~99.5%!
The MEBT beam current degraded from ~40 mA in 2010 to about 32 mA in 2012!

<table>
<thead>
<tr>
<th>Production Run (CY)</th>
<th>Duty cycle %</th>
<th>Pulse length ms</th>
<th>mA required</th>
<th>mA in MEBT</th>
<th>RF [kW]</th>
<th>tilt deg</th>
<th>Random Antenna Failures</th>
<th>%Availability</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-1</td>
<td>0.2</td>
<td>~.1</td>
<td>20</td>
<td>28-20</td>
<td>~70</td>
<td>3</td>
<td>0</td>
<td>99.9</td>
<td>1 ion source, 1 cesiation, raise collar temp</td>
</tr>
<tr>
<td>2006-2</td>
<td>0.8</td>
<td>~0.4</td>
<td>20</td>
<td>30-16</td>
<td>~70</td>
<td>3</td>
<td>0</td>
<td>99.98</td>
<td>1 ion source, 1 cesiation + 24h @115°C</td>
</tr>
<tr>
<td>2007-1</td>
<td>1.8</td>
<td>~0.5</td>
<td>20</td>
<td>20-10</td>
<td>60-80</td>
<td>3</td>
<td>1*(37)</td>
<td>70.6</td>
<td>Arcing LEBT; punctured antenna* after 37 days, start 2-week source cycles</td>
</tr>
<tr>
<td>2007-2</td>
<td>3.0</td>
<td>~0.6</td>
<td>25</td>
<td>25-30</td>
<td>35-50</td>
<td>3</td>
<td>0</td>
<td>97.2</td>
<td>Modified lens-2; e-target failures; tune for long pulses</td>
</tr>
<tr>
<td>2007-3</td>
<td>3.6</td>
<td>~0.6</td>
<td>25</td>
<td>25-30</td>
<td>uncal</td>
<td>3</td>
<td>0</td>
<td>99.65</td>
<td>modified Cs collar (Mo converter)</td>
</tr>
<tr>
<td>2008-1</td>
<td>4.0</td>
<td>0.69</td>
<td>32</td>
<td>20-37</td>
<td>48-55</td>
<td>3</td>
<td>1 (6)</td>
<td>94.9</td>
<td>Restore matching network; new tube; Beam on LEBT gate valve</td>
</tr>
<tr>
<td>2008-2</td>
<td>4.0</td>
<td>0.69</td>
<td>32</td>
<td>20-37</td>
<td>48-55</td>
<td>3</td>
<td>1 (9)</td>
<td>99.22</td>
<td>Start 3-week source cycles; Ramp up e-dump &amp; collar temperature</td>
</tr>
<tr>
<td>2009-1</td>
<td>5.0</td>
<td>0.8</td>
<td>35</td>
<td>25-30</td>
<td>~50</td>
<td>3</td>
<td>2ExAn + 1 (8)</td>
<td>97.52</td>
<td>Start &quot;Perfect Tune&quot;; use external antenna* source for 1st 8 weeks; start 7.2% conditioning</td>
</tr>
<tr>
<td>2009-2</td>
<td>5.1</td>
<td>0.85</td>
<td>38</td>
<td>20-37</td>
<td>~55</td>
<td>0</td>
<td>1 (1)</td>
<td>98.84</td>
<td>Start replacing LEBT, slim extractor; start 4-week cycles; 2 MHz degrades; plasma outages at end</td>
</tr>
<tr>
<td>2010-1</td>
<td>5.4</td>
<td>0.9</td>
<td>38</td>
<td>39-30</td>
<td>~60</td>
<td>0</td>
<td>1*(11) +1 (4)+1 (0)</td>
<td>96.80</td>
<td>Repair and tune-up RF; punctured antenna* to beam back in ~6 hours; lens-1 &amp; e-dump breakdowns;</td>
</tr>
<tr>
<td>2010-2</td>
<td>5.4</td>
<td>0.9</td>
<td>38</td>
<td>46-36</td>
<td>&lt;55</td>
<td>0</td>
<td>2 (10) +1 (3) +2 (0)</td>
<td>~98.5</td>
<td>Replace 1.6 μH with two 1 μH inductors; start 2 MHz on ground</td>
</tr>
<tr>
<td>2011-1</td>
<td>5.4</td>
<td>0.9</td>
<td>38</td>
<td>38-30</td>
<td>~60</td>
<td>1.5</td>
<td>1 (22) +1 (6) +1 (2)</td>
<td>98.2</td>
<td>Double LEBT pumping; start frequency hopping; source leaks by electric arc &amp; by plasma heating; start 6% conditioning</td>
</tr>
<tr>
<td>2011-2</td>
<td>4.4</td>
<td>0.73</td>
<td>38</td>
<td>38-30</td>
<td>~55</td>
<td>0</td>
<td>1*(&gt;5) 1 (9)</td>
<td>98.7</td>
<td>*start of run; contamination of #2 &amp; 4; 6 week #3 run; start rigorous antenna selection &amp; Dc% conditioning</td>
</tr>
<tr>
<td>2012-1</td>
<td>5.3</td>
<td>0.88</td>
<td>38</td>
<td>38/34</td>
<td>~60</td>
<td>3</td>
<td>0</td>
<td>99.3</td>
<td>6/2 week cycles with source 3&amp;4</td>
</tr>
<tr>
<td>2012-2</td>
<td>5.3</td>
<td>0.88</td>
<td>38</td>
<td>38/34</td>
<td>~60</td>
<td>3</td>
<td>0</td>
<td>99.7</td>
<td>6/2 week cycles with source 3&amp;4</td>
</tr>
<tr>
<td>2013-1</td>
<td>5.3</td>
<td>0.88</td>
<td>30-34</td>
<td>30-35</td>
<td>~60</td>
<td>0/1.5</td>
<td>1 (11)</td>
<td>99.3*</td>
<td>5.3 week run with #4; *until 4-26-13</td>
</tr>
</tbody>
</table>

*lifetime of failed antenna

Comments:
- 1 ion source, 1 cesiation, raise collar temp
- Arcing LEBT; punctured antenna* after 37 days, start 2-week source cycles
- Modified lens-2; e-target failures; tune for long pulses
- modified Cs collar (Mo converter)
- Restore matching network; new tube; Beam on LEBT gate valve
- Start 3-week source cycles; Ramp up e-dump & collar temperature
- Start "Perfect Tune"; use external antenna* source for 1st 8 weeks; start 7.2% conditioning
- Start replacing LEBT, slim extractor; start 4-week cycles; 2 MHz degrades; plasma outages at end
- Repair and tune-up RF; punctured antenna* to beam back in ~6 hours; lens-1 & e-dump breakdowns;
- Replace 1.6 μH with two 1 μH inductors; start 2 MHz on ground
- Double LEBT pumping; start frequency hopping; source leaks by electric arc & by plasma heating; start 6% conditioning
- *start of run; contamination of #2 & 4; 6 week #3 run; start rigorous antenna selection & Dc% conditioning
- 6/2 week cycles with source 3&4
- 6/2 week cycles with source 3&4
- start to measure LEBT & converter temperature
- 5.3 week run with #4; *until 4-26-13
2007 - 2009: changes implemented to increase beam current

~2010: peak performance with significant scatter in source performances

Since 2011 a degradation became apparent. Measured after the RFQ:

- #3 made easily 38 mA but dropped to 36 mA after increasing RF
- #4 which made 38 mA dropped to 34 mA after increasing RF
- #2 which made 35 mA dropped to 32 mA after increasing RF

To identify the root cause, in 2012 the production sources were tested with a LEBT on the test stand!
On the test stand, sources 3, 4, 2 make ~70, ~55, ~50 mA!
Where is the Beam?

- Test stand shows sources 2-4 to produce 50-70 mA
- However, only 32-36 mA reach the MEBT
- Where are the 18-34 mA lost? (~100 W)

- No beam current monitor in the LEBT
- But RFQ entrance aperture electrically isolated; stops ~70% of chopped beam
- Beam chopped in 4 diagonal directions

Steerers can drive 1 or 2 chopped beamlets completely on RFQ entrance aperture!
The maximum deflection: $2 \times 2.3 \text{kV} + 3 \text{kV}$

- Using maximum chopping and steering deflection drives centered beams completely on the chopper target!
- The lens-2 field repels secondary electrons $<0.015 \text{ mm}$ above the surface! They are fully suppressed!

The RFQ input current can be measured!
- Full symbols are well tuned and aligned sources, mostly for production!
- Increasing RF power to increase H- current, increases beam emittance, which lowers RFQ transmission.
- The RFQ transmission degraded compared to 2010
- Trying to compensate, more H- beam was made!
RFQ Field Measurements

- 2009 field is an average of the four quadrants
- Low power measurement in Nov 2012 show fields changed significantly
- Confirmed with high power measurements in May 2013

RFQ was retuned in June 2012!
Measured RFQ Transmissions

- Full symbols are well tuned and aligned sources, mostly for production!

RFQ transmission is up 10% absolute or 15% relative to 2012!
It is all about producing more H- ions more reliably!
LEBT issues

- Apparently source #3 overheated the LEBT center ground on the test stand, causing it to buckle excessively, snapping screws and insulators.

- Non uniform heating creates non-uniform local expansion stresses!

- LEBT failures cause ~1 day downtime!

- The mounts were reengineered to double their heat sinking.

- A thermo couple was added to understand the issues and reduce the likelihood of future failures!
The LEBT center ground can reach up to 130 C. It appears to be heated by:
1. 65 kV particles from the source
2. lens-1 discharges, especially after cesiation
3. occasional corona discharges from lens-2
P.S. Model calculations show no LEBT losses

Excessive LEBT temperatures can be avoided by lowering the beam current through detuning the RF!
**Lens-2 Discharges**

- March 6, 2013: the LEBT temperature rapidly increases for ~15 minutes, caused by a rare corona discharge.
- Within minutes the discharge grew to 0.5 mA, and after 15 minutes it started to decay, first rapidly and after reaching ~0.1 mA slowly over many hours.
- The LEBT was heated with up to 25 W, causing the LEBT temperature to raise ~30°C.
- This happened 16 days after a source installation during routine neutron production without apparent trigger event and without any effort to quench the discharge, as nobody had a clue.
- The lens-2 drawings called for a 0.063” radius, but it is typically only ~0.03”.
- We have increased the radius in LEBT #3 to 0.12”, ~1/2 the lens-2 thickness.
- This should reduce the likelihood of such corona discharges.
As seen with other RF H\textsuperscript{-} sources, the e-dump current grows with time.

- When the e-dump current exceeds some current, the voltage starts to fluctuate.
- Fluctuations can be reduced by lowering the voltage, which lowers the beam.
- It appears that the initial electron peak current destabilizes the voltage control.

**Better control of the e-dump voltage should enable 8-week source cycles!**
Summary and Conclusions

- The SNS ion sources routinely deliver ~50 mA H\textsuperscript{-} beam to the RFQ.
- The SNS RFQ transmission degraded, but partly recovered.
- Having resolved target issues, SNS is resuming 1 MW operations.
- SNS plans to ramp the power up to 1.4 MW over the next few years.
- Adding a thermocouple to the LEBT center-ground provides crucial information on the physics of electrostatic LEBTs.
- In addition, the thermocouple allows for risk management.
- The SNS electrostatic LEBT had 100% availability since 2010.
- We are in the process of understanding and improving the e-dump stability.
- This should allow for extending the source service cycle.

Thank you for your attention!
Cs’13
A Mini-Workshop on Controlling Cs
Saturday, September 14, 2013
9:00- 17:00
In Makuhari Techno Garden
Near JR Kaihin Makuhari Station
(in walking distance from Makuhari Messe)

Preliminary Program:
• O. Midttun, CERN: Cs oven conditioning and calibration
• A. Ueno, J-PARC: Cs quantity to optimize $H^-$ brightness at J-PARC
• M. Stockli, ORNL: Cs puzzles with the SNS $H^-$ source
• S. Laurie, ISIS: Cs handling on ISIS Penning
• Y. Belchenko, BINP: Long life Cs system for CW SPS
• R. Friedl, Augsburg U.: Reducing open issues on Cs dynamics
• A. Kojima, JAEA: Cs recycling in JT-60 long pulse operation
• And many Discussions!
• Chaired by W. Kraus (MPI), Y. Tsumori (NIFS), M. Stockli (ORNL)

Room-capacity limited participation; very few spaces remaining;
no-fee registration required; see Martin Stockli at ICIS’13