RAMPING UP THE SNS BEAM CURRENT WITH THE LBNL BASELINE H⁻ SOURCE

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Abstract

Over the last two years the Spallation Neutron Source (SNS) has ramped up the repetition rate, pulse length, and the beam current to reach 540 kW, which has challenged many subsystems including the H- source designed and built by Lawrence Berkeley National Laboratory (LBNL). This paper discusses the major modifications of the H^- source implemented to consistently and routinely output the beam current required by the SNS beam power ramp up plan. At this time, 32 mA LINAC beam current are routinely produced, which meets the requirement for 690 kW planned for end of 2008. In June 2008, a 14-day production run used 37 mA, which is close to the 38 mA required for 1.44 MW. A medium energy beam transport (MEBT) beam current of 46 mA was demonstrated on September 2, 2008.

INTRODUCTION

LBNL designed and built the SNS baseline H^- source, a mulicusp RF ion source [1]. Typically 250 W from a 600 W 13.56 MHz generator are matched into a 2.5 turn antenna loop inside the plasma chamber where it generates continuous, low-power hydrogen plasma. An additional 6%-duty-factor, 80-kW 2 MHz supply superimposes 40-70 kW for ≤1.23 ms at 60 Hz to boost the plasma density for beam production. As shown in Fig. 1, a transverse ~300 G filter field cools the plasma, which drifts towards the outlet aperture. The Cesium collar contains less than 30 mg of Cs in Cs_2CrO_4 cartridges [2]. Most of the negative ions form when bouncing from the Cs collar outlet aperture that is next to the source outlet.

A 1.6-kG dipole field, peaking 7 mm outside the source outlet, steers the co-extracted electrons toward one side of the e-dump, which is kept between +2 and +7 kV with respect to the -65 kV source potential. A fraction of the electrons impacts on the e-dump, while the other fraction ends on the extractor, where they generate thermal and radiation problems, especially when the extractor uses some of its +20 kV potential.

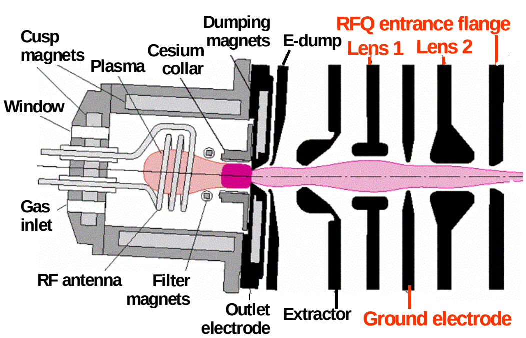

Figure 1: Schematic of the SNS H- source and LEBT.

Table 1: Duty factor, pulse length, unchopped MEBT beam current requirement and achievements, and the source and LEBT availability for neutron production runs. Run numbers reflect the calendar year.

Production Run	Duty fator	Pulse length	mA required	mA in MEBT	%Avail ability
Run 2006-1		~.1 ms	20	20-28	99.9
Run 2006-2	0.2	~.25ms	20	14-30	99.98
Run 2007-1	0.8	~0.4ms	20	10-20	70.6
Run 2007-2	1.8	~0.5ms	20	11-20	97.2
Run 2007-3	3.0	~0.6ms	25	25-30	99.65
Run 2008-1	3.6	~0.6ms	25/30	25-37	94.9
Run 2008-2	4.0	0.67ms	32	32-35	

The extractor accelerates the beam into the 12-cm long, two-lens electrostatic low-energy beam transport (LEBT), which focuses the beam into the radio frequency quadrupole (RFQ). The compactness of the LEBT prohibits any characterization of the beam before it is accelerated to 2.5 MeV by the RFQ. The first beam current measurement is obtained from the first MEBT beam current monitor near the exit of the RFQ (BCM02).

This paper discusses the failures and successes in meeting MEBT beam current requirements as outlined in the SNS power ramp up plan [3] and listed in Table 1.

LOW POWER PERFORMANCE

At the beginning of the SNS beam power ramp up, the short pulse length allowed the H^- source to exceed the required 20 mA as seen in Fig. 2a. When the pulse length was increased to ~0.25 ms for the 2nd 2006 run, the source was at times unable to match the 20 mA requirement as seen in Fig. 2b.

Short beam pulses (<<0.2 ms) yield high beam currents when the matching network is matched without plasma. When the pulse length of short pulses is extended, a significant reduction in beam current is found, as seen in Fig. 3.

Long pulses yield the highest beam current when the matching network is tuned with the presence of plasma,

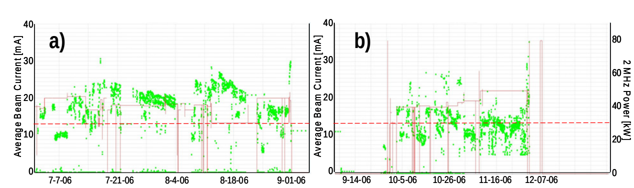

Figure 2: Requested 2 MHz peak power (solid line) and average chopped MEBT beam current (dots) compared with the required 13 mA (dashed line) for 2006.

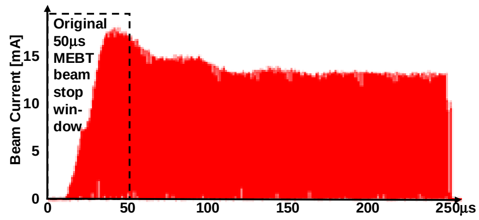

Figure 3: A 0.25 ms beam pulse optimized at 0.05 ms.

typically >0.2 ms after the start of the pulse. This, however, produces slow beam rise times, which often exhibit significant jitter. Or worse, sometimes the high-power plasma fails to ignite causing missing beam pulses. Mitigating efforts include compromise tunes, raising the 13 MHz and/or the 2 MHz RF power, and raising the H_2 flow. Raising the H_2 flow, however, reduced the beam current. Figure 4 shows this learning curve that yielded 20 mA beam current with maxed out 80 kW RF at the end of run 2007-2. There was no knob left that could meet the 25 mA required for the following run, starting 6 weeks later.

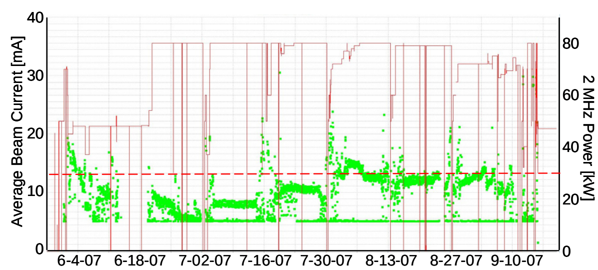

Figure 4: The learning curve of run 2007-2.

LEARNING EFFECTIVE CESIATIONS

To reduce the risk of Cs induced arcing in the ultra compact LEBT and the nearby RFQ, LBNL implemented Cs cartridges [2], which contain Cs_2CrO_4 and St101, a getter made of 16% Al and 84% Zr. When heated to temperatures above 550 °C, the Cs_2CrO_4 reacts with the getter, releasing Cs while forming Cr_2O_3, Al_2O_3, and ZrO_2 [4]. The cartridges are contained in tight slots in the Cs collar that surrounds the ion source outlet. It can be cooled or heated to ~400°C with compressed air. The compressed air is shut off and the high-power plasma duty factor is adjusted to achieve and control the higher temperature required for releasing Cs.

Keeping the collar as cold as possible before cesiating at 550 °C for 30 minutes [5] yielded inconsistent results despite standardizing the conditioning and cesiation procedures: Very often, the cesiation process had to be repeated, and while the initial beam current could be quite high, it would decay in a matter of days (at low duty factor) or hours (at high duty factor) to much more modest levels as it can be seen in Figs. 2 and 4.

Being challenged to deliver 25 mA for run 2007-3, these problems were overcome with new methods that were deduced from a detailed study of manuals, records and new observations. All newly refurbished sources are evacuated and regularly vented with dry air and reevacuated to lower their water content. When needed the source is vented with dry air and quickly installed into the LEBT vessel that was vented with dry nitrogen. After evacuation, the Cs cartridges are being heated to ~100 °C before their temperature is ramped up to 350 °C over the last ~hour before cesiation. This degassing of the Cs cartridges seems to have eliminated the need for repeated cesiations. Apparently the degassed getter can more rapidly react with the Cs_2CrO_4 to release Cs.

While the Cs cartridges are degassed, the RF plasma is rapidly ramped up to a 6% duty factor with 50 kW of 2 MHz, where the source is conditioned for at least two hours. This appears to have eliminated the persistence problem. The likely cause is that Cs sputters easily from surfaces covered with water and other residues, while the Cs bonds well to clean metal surfaces.

Using the new methods, a single cesition of 30 minutes at 550 °C normally produces a performance level very close to the optimal performance, which is the best performance that can be achieved with any kind of subsequent cesiation(s) applied to its configuration.

MODIFICATIONS TO REDUCE PERFORMANCE VARIATIONS

Despite standardizing all source dimensions, materials, refurbishments, preparations, and operations, significant, but apparently random variations were found from source to source. Being challenged to routinely produce 25 mA for run 2007-3 three significant problems were identified and mitigated.

Inadequate e-dump high voltage standoffs frequently arced and occasionally shorten out, which lowered temporarily or permanently the beam output. To improve the stability needed for the accelerator, the e-dump was often run near 2 kV, far below the optimal value. Newly designed standoffs appear to be arc-free.

Being heated, the cesium collar mounting legs would buckle, moving the collar by 1-3 mm either towards the ion source outlet aperture, which increases the beam current, or backward, which reduces the beam current. A new design yields a reduced, and consistently forward pushing force. This problem may explain source #2 to require ~50 kW for 25 mA in 11-07, while requiring only 35 kW for 25 mA in 12-07, as seen in Fig 5.

The Cs cartridges are 1.8 mm shorter than their slots, which allows for the Cs to be preferentially delivered either to the plasma chamber or to the Cs collar outlet

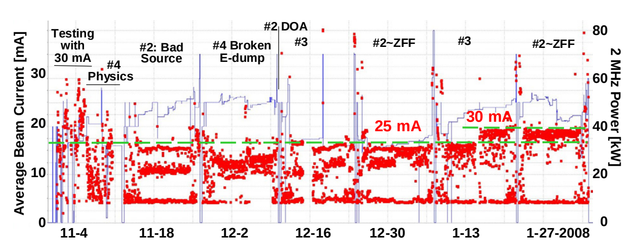

Figure 5: Measured (dots) and required (dashed line) average beam current with RF power (solid line) for run 2007-3.

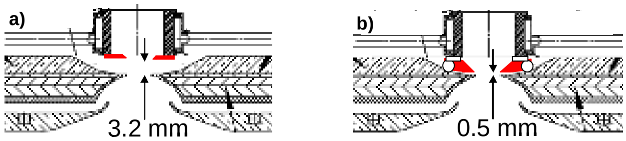

Figure 6: Original (a) and modified (b) Cs collar outlet.

aperture depending on the last tilt angle before the source was installed. Compression springs were installed to consistently deliver most of the Cs to the Cs collar outlet aperture.

MODIFICATION INCREASING THE BEAM CURRENT

Being challenged to make 25 mA for run 2007-3, it was discovered that the 1-mm-thick, SS Cesium collar outlet aperture was 3.2 mm from the source outlet aperture, as shown in Fig. 6a. This was much more than the previously reported 1 mm gap [6] and the desired minimal gap [7]. Thirteen configurations tested within 6 weeks lead to a 4-mm-thick, Cs collar outlet aperture, which is tapered at 40°, made from Mo, and centered with ceramic balls, which maintain a distance of ~0.5 mm to the source outlet aperture, as shown in Fig. 6b.

When implemented for run 2007-3, this modification delivered more MEBT beam current than the integrated Cs collar [6] and the elemental Cs collar [8], both of which were tested between run 2007-2 and 2007-3.

The new Mo Cs collar outlet aperture and the associated learning curve have roughly doubled the MEBT beam current. It enabled routine production runs with MEBT beam currents in excess of 32 mA, including the two-week production run with 37 mA seen in Fig. 7. 38 mA MEBT beam current is sufficient for 1.44 MW.

It also allowed for a demonstration of 46 mA at 60 Hz and 0.65 ms seen in Fig. 8. This record current was demonstrated with a single cesiation during the source startup, then over 7 days of 32 mA production, followed by a retune and ramp up of the Cs-collar temperature and the 2 MHz power.

Typically the operators increase the power of the 2 MHz amplifier when the beam power or current appears to decrease. Accordingly a measure of the requested 2 MHz power allows for an estimate of the beam decay rate. The 3% increase for the recent 3 week production period seen in Fig. 9, is currently the best estimate for the beam decay rate after a single cesiation.

The major concerns with the modified LBNL H- source are the antenna defects found in ~30% of sources after a 2

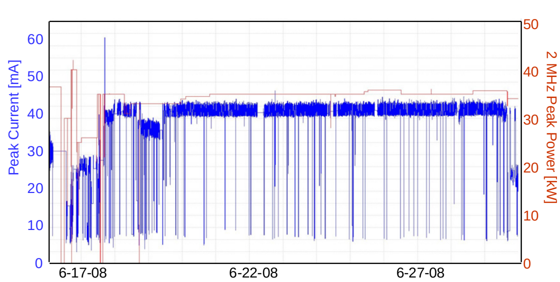

Figure 7: Two week production run with 37 mA.

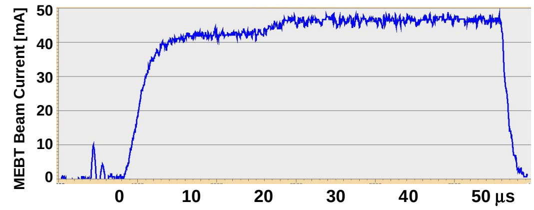

Figure 8: The 50-μs slice sampled by the RFQ 350 μs into the 650-μs 60-Hz pulses shows 46 mA.

or 3-week production period during 2008. Therefore we plan to use the external antenna source [9] in combination with the modified LBNL Cs collar for run 2009-1. This combination promises similarly high beam currents with a lower risk for antenna failures.

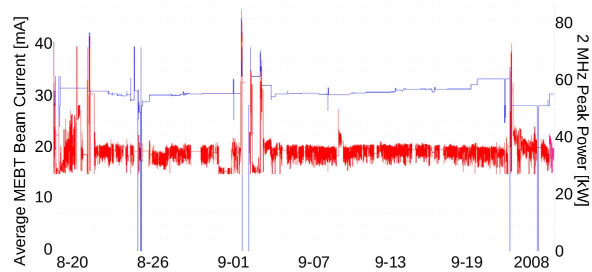

Figure 9: September 08 3-week run with ~32 mA MEBT beam current required a ~3% increase in RF power.

ACKNOWLEDGEMENTS

The successful commissioning and beam power ramp up of the SNS baseline ion source would not have been possible without LBNL delivering a first-class Frontend on a very tight schedule. After implementing a series of modifications, at 4% duty factor the ion source appears to meet all important specifications, including the 3-week lifetime. The work at Oak Ridge National Laboratory, which is managed by UT-Battelle, LLC, was performed under contract DE-AC05-00OR2275 for the US Department of Energy.

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