ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPMO42

RESULTS FROM THE NEW TITANIUM WIRED HARP AT THE SPALLATION NEUTRON SOURCE*

W. Blokland†, A. Aleksandrov, B. Cathey, W. Willis
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Abstract

A new harp has been installed in the Ring To Target Beam line (RTBT) section of Spallation Neutron Source. The harp is made of two planes with 32 titanium 50-micron wide wires each plane. The narrow, low-Z wires versus the 100-micron tungsten wires of the original harp, are to minimize the beam scattering. This harp will be both a backup and a complement to the existing harp further downstream. The newly created data-acquisition system is also suitable to replace the existing's harp data-acquisition system, now over 20 years old. We show the use of a cRIO platform as a cost-effective way to process many channels and sample the beam profile at the full 60 Hz beam repetition rate. We also describe the performance of the titanium wires. A passive analog board is used to lengthen the signals to allow sampling at ≤10 kS/s/ch. The data is acquired by the FPGA, passed on to the real-time OS, LabVIEW RT, and through the SNS EPICS Channel Access server presented to the control room.

INTRODUCTION

The original RTBT Harp is used to qualify the beam on the target and has been in operation for over 20 years. It was meant to be retractable but because of an early actuator failure it has remained in the beam, operating without major problems. It is in a location that is hard to access and highly radioactive. A failure would require downtime. To handle this failure, we have implemented a backup Harp. This new harp, further upstream, is accessible and replaceable. It is called Harp25 for its location relative to a quadrupole, while the old harp is called Harp30.

The Harp25 differs from the Harp30 in its unshielded location; therefore, the primary design consideration was to reduce proton scattering in the harp wire material. This was achieved by minimizing the amount of material in the beam path and by using materials with as low a Z (atomic number) as possible. The Harp30 consists of 5 parallel frames sandwiched together: horizontal signal wires, diagonal signal wires, vertical signal wires and two bias planes in between made of the same 100 µm tungsten wire. To reduce the amount of material, we eliminated the diagonal signal wires and the two bias planes. The bias is provided using a solid plate below the signal wires frames as shown in Fig. 1.

The signal wire frames are arranged in triangular configuration to allow the bias field to reach both planes' wires. The angle between the planes is determined by the ID of the vacuum chamber vertical leg as shown in Fig. 1. Our experience with the Harp30 has shown that tungsten wires are durable. However, since we aimed to reduce activation due to scattering, we sought a material with a lower Z. Although carbon or SiC monofilament would be ideal, their maximum available size is 30 µm, and the wire fragility makes assembling a multiwire harp challenging. Therefore, based on our prior positive experience with the SNS laser emittance harp, we decided to use 50 µm titanium wire for the prototype.

MECHANICAL DESIGN

The harp was designed to have two identical planes, with one mounted so that the wires are horizontal and the other with the wires mounted vertical. The two planes are mounted to a frame that sets them at a 15-degree angle from vertical. The 32 wires in each plane are 50 µm diameter titanium (99.8 % pure) and are spaced 4 mm apart. The wires are tensioned individually using spring-loaded copper collets in a Macor block on one end. The wires are clamped to a Garolite block using copper leads that are held in place by swivel head set screws. The copper leads extend from the block to make it easy to solder on signal wires. There is an electrically isolated bias plate under the two planes that can have up to 250 V bias voltage. The entire Harp head is mounted to a repurposed wire scanner actuator with an eight-inch stroke. This allows the Harp to be retracted completely out of the beam pipe and to be fully inserted for making measurements. The harp head and vacuum chamber are shown in Fig. 1.

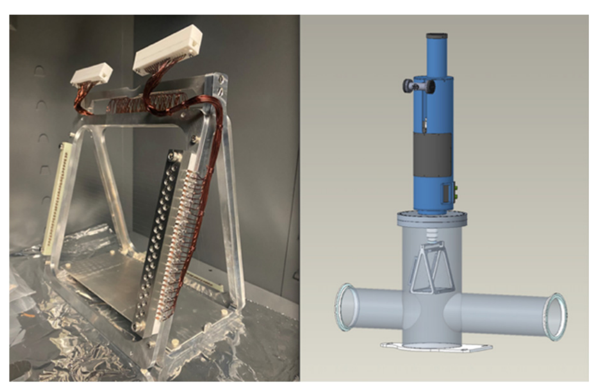

Figure 1: The harp head and vacuum chamber.

DATA ACQUISITION

The harp has custom analog boards, see [1], to reshape the short pulse coming from the wires to a longer pulse to match the bandwidth of the digitizers. The system is implemented in cRIO hardware. It has:

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.
† blokland@ornl.gov

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPMO42

- Digitizers: 8x NI-9202 10kS/s/Ch, 24-bit
- CPU: cRIO-9035 with FPGA
- Digital IO: NI- 9402
- SNS Timing Board

This new system is much smaller and occupies on only 4U of rack space versus the 18U required for the old system, see Fig. 2. The electronics is also much simpler than the original Harp data-acquisition hardware which it will also replace. We have 8×16 channels so that the system can also be used for the 3 planes Harp30. The cost estimate for the complete system including the custom analog boards is about \$30 k.

Figure 2: The installed harp hardware.

SOFTWARE

The software uses National Instruments' LabVIEW Realtime and LabVIEW FPGA. The FPGA code acquires data from the digitizers and sends it to the real-time program to analyze and present the results to the EPICS control system. The SNS Timing card provides the RTDL (Real-Time Data Link) and EVNT (Event Clock) to the FPGA for decoding. This gives us the trigger and information such as total beam charge. This data is tagged to the acquired waveforms.

The software runs at the full beam rep rate of 60 Hz and now allows us to present averaged profiles at 1 Hz. The noise is very minor at production intensities, and the averaging is not needed but useful at lower intensities. The analysis performs curve fitting such as a gaussian or super-gaussian function or a combination of the two to better fit with certain ring injection painting schemas.

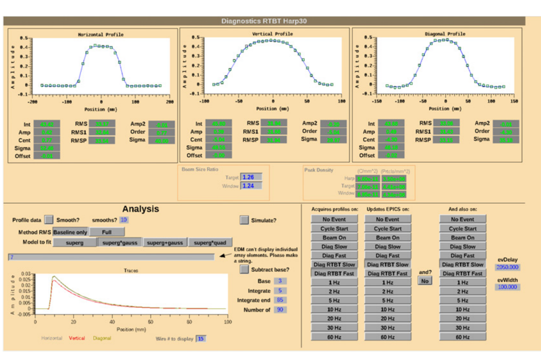

Figure 3: The operator Interface.

An example of the operator interface is shown in Fig. 3. This figure shows three profiles as with this picture the system was hooked up to Harp30, but the Harp25 interface is identical. Operators can change the events on which to trigger and set conversion coefficients to project peak density calculations at the Harp to the downstream Target and Proton Beam Window. These numbers are used to verify beam size stays within allowed values. On the bottom left you can see the waveforms for each wire. Visualizing this makes it much easier to time in the data-acquisition versus the old single sample-and-hold acquisition.

RESULTS

We are especially interested in the performance of the titanium wires to test it suitability in terms of signal, scattering, and longevity for accelerator applications.

Secondary Emission Yield

Figure 4 shows the sensitivity, the sum of the vertical profile, per μC of beam as a function of MWHr of beam on the target. All beam to the target also passes through the new harp as it was inserted during this time. It shows that the signal on the wires initially diminishes but then remains mostly flat. You can also see small peaks in the signal. These occurs after beam is off for more than approximately 10 seconds. Most spikes are filtered out from Fig. 4 to show a cleaner curve, while Fig. 5 shows a closeup to the increased sensitivity right after a beam trip. The sensitivity temporarily is a few percent higher, we surmise this is due to the wire cooling off during the trip.

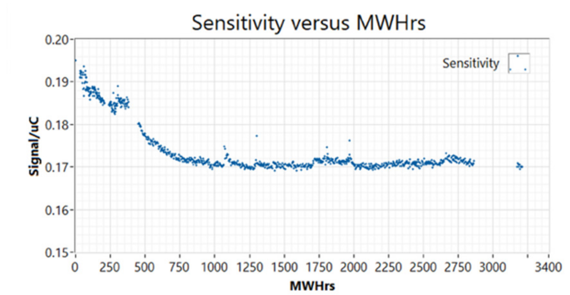

Figure 4: Wire sensitivity versus MWHrs.

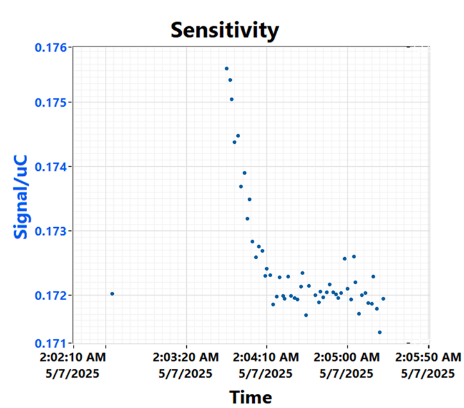

Figure 5: Wire sensitivity after a beam trip.

We ran simulations to calculate the expected value of the Secondary Emission Yield (SEY). These were done using the stopping power equation [2], with the density effect parameters for titanium from [3]. Finally, we used the yield equation and parameters from [4]. For simplification, we

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPMO42

assumed a "square" wire with a width of pi/4 the actual diameter. This follows the same technique used previously at SNS for simulating wire scanners as detailed in [5]. This gave a yield of 3 %. Given the assumptions for the parameters in [4], this is only an order of magnitude approximation.

We can also estimate the SEY from the measurements by comparing the intercepted charge by the wires with the charge measured. Raw data from the harp was archived over the run from October 2024 to May 2025. While the wire is round, we assume that the SEY is the same along the wire width. Because we didn't have a direct measurement using an oscilloscope but measured through the analog boards, we used a circuit simulator Multisim by National Instruments to convert the measured integrated voltage of the acquired waveform to the wire charge. The circuit simulator was used to design the analog boards and has previously shown to be accurate within a few percent of measurements. Given that we know the beam charge, wire spacing, wire width, and profile, we can estimate the SEY from the measured data, see [1] for the calculation. The estimate for the measured SEY from the vertical profile (horizontally spanned wires) is from around 5.4 % to 4.8 % from 11/14/24 to 02/25/25. This is within a factor of two of the calculated value and we regard this as reasonably close. We will do direct measurements in the future.

The conversion from the integrated voltage to beam charge allows us to calculate the SEY for each wire at different dates. Figure 6 shows the profile in the beginning of the production run (blue) and near the end (red) about 3000 MWHrs apart or 2.5 months. The figure shows a clear reduction in the horizontal profile amplitude while during these times the total beam charge was the same.

To see if the individual wires age differently, we divide a later obtained profile by an earlier profile. The ratio shows the approx. 10 % difference in the center, and perhaps a little less near the edges of the profile. However, we can't be certain if those wires have less sensitivity as the actual beam width could have changed. In the future, we will do a pencil beam scan to see if the different wires have different sensitivities.

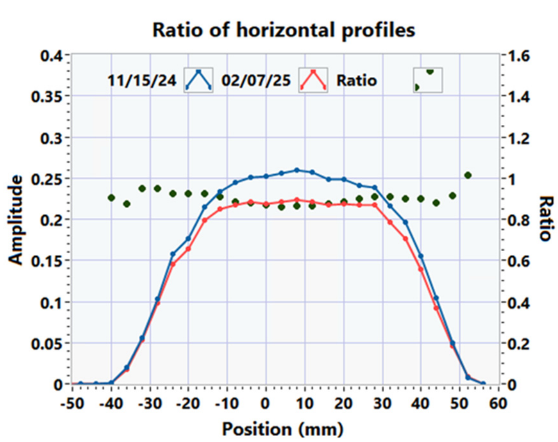

Figure 6: Ratio of horizontal profiles.

Longevity

During the run the horizontal profile showed wire failures, in the end three wires were broken. The harp had been activated to about 2 R/hr at 1 cm from the middle wires. Most radiation was estimated to be due to Beryllium-7. Many wires, especially those in the middle of the beam, were not longer taunt and their collets were no longer compressed. We show the exposed harp with elongated wires in Fig. 7.

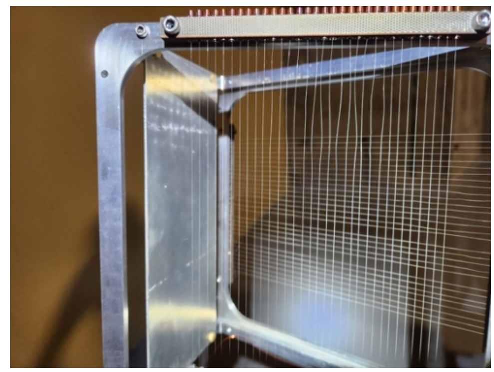

Figure 7: The harp after the production run.

CONCLUSION

The first Harp25 prototype demonstrated that the chosen approach is effective, providing continuous beam measurements at 60 Hz for a typical run duration. While the titanium wires generally performed well during the run, we are concerned about high residual activation and the mechanical hardening of the wire material.

FUTURE

For the next prototype iteration, we plan to switch to carbon or SiC monofilament wire while maintaining the same geometry and overall design as the initial prototype. We also plan additional SEY measurements to further detail its trend over time.

ACKNOWLEDGEMENTS

The authors wish to thank Syd Murray III, Drew Perkins, and Andy Webster for their help with the harp planning, assembly and installation as well as checkup after exposure.

This manuscript has been authored by UT-Battelle, LLC, under Contract DE-AC05-00OR22725 with the US Department of Energy (DOE). This research used resources at the SNS, a DOE Office of Science User Facility operated by the ORNL. The US government retains and the publisher, by accepting the article for publication, acknowledges that the US government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for US government purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan).

ISBN: 978-3-95450-262-2 ISSN: 2673-5350 doi: 10.18429/JACoW-IBIC2025-TUPMO42

REFERENCES

[1] W. Blokland, “High Beam Intensity Harp Studies and Developments at SNS”, in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 17-20. doi:10.18429/JACoW-IPAC2015-MOAB1

[2] R. L. Workman *et al.* (Particle Data Group), “Review of Particle Physics”, *Prog. Theor. Exp. Phys.*, vol. 2022, p. 083C01, Aug. 2022. doi:10.1093/ptep/ptac097

[3] R. M. Sternheimer, “Density Effect for the Ionization Loss of Charged Particle”, *Phys. Rev.*, vol. 145, no. 1, pp. 247–250, May 1966. doi:10.1103/PhysRev.145.247

[4] E. J. Sternglass, "Theory of Secondary Electron Emission by High-Speed Ions," *Phys. Rev.*, vol. 108, no. 1, pp. 1-12, Oct. 1957. doi: 10.1103/PhysRev.108.1

[5] M. Plum, W. Christensen, R. Meyer, and C. Rose, “SNS LINAC Wire Scanner System: Signal Levels and Accuracy”, in *Proc. LINAC’02*, Gyeongju, Korea, Aug. 2002, paper MO458, pp. 172–174.