HIGH BEAM INTENSITY HARP STUDIES AND DEVELOPMENTS AT SNS*

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Abstract

The Spallation Neutron Source (SNS) Harp consists of 30 wires for each of the horizontal, vertical, and diagonal planes. The purpose of the harp is to measure the position, profile, and peak density of the high intensity beam coming out of the accumulator ring and going onto the spallation target. The data-acquisition hardware is now over ten years old and many of the electronics parts are obsolete. Occasionally, the electronics must be rebooted to reset the sample-and-hold circuits. To evaluate options for a new system, the signals from the harp were studied. This paper will describe these studies’ results, the design, and initial results of the new and simpler data-acquisition system.

INTRODUCTION

The harp was built as a removable instrument to measure the horizontal, vertical, and diagonal position and profile of an up to 1.4 MW, 1 GeV proton beam 10 meters in front of the target, using thirty 100 μm tungsten wires per plane, see Fig. 1 and [1,2].

Initially, the harp was only to be inserted during tune-up, but the mechanism to insert and retract the harp was not strong enough and the harp is now left inserted at all times, allowing us to monitor the beam profile during full power production runs. The data-acquisition system consists of low-pass filters, amplifiers, and two sample-and-hold circuits per wire to integrate the charge intercepted by the wires to help define the requirements for a new data-acquisition system.

The data-acquisition electronics, designed and implemented by LANL, is now well over 10 years old and occasionally locks up and requires a manual reset. Many of the electronic parts are now obsolete and a redesign would be required to replace the electronics. Another issue is that the signal strength during production beam intensity saturates the sample-and-hold circuits. To avoid this saturation, we sample later, well into the signal decay to minimize the signal distortion.

STUDIES

To study the harp system and determine the requirements for a new data-acquisition system, we made the harp signal available for studies. An interconnect was placed between the diagonal plane cable from the harp and the electronics to allow us to temporarily disconnect a single wire from the electronics and route the signal to a scope for studies.

Wire Signal Strength

The first study was to determine the amount of charge intercepted by the wires to help define the requirements for a new data-acquisition system. The instant current created by the proton beam charges up the long cable from the harp to the upstairs service building, while a 1 MOhm resistor discharges the charge as shown in Fig. 2.

By fitting the discharge curve, we can approximate the total charge received, the peak voltage, and the capacitance of the cable. In this particular case, 2.5 μC beam, the measured charge was 177 pC, with a peak voltage 7.3 mV, giving a cable capacitance of C=Q/V=177pC/7.3 mV or about 24 nF. Given the beam pulse duration of 670 ns and assuming a flat-top longitudinal profile, the instantaneous current is 0.26 mA.

We extrapolate the maximum expected voltage and current for the full intensity beam of 21 μC to be around 60 mV and 2.2 mA.

Figure 1: Harp actuator and profiles.

Figure 2: Wire charge measurement.

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Secondary Electron Emission Coefficient

We obtain the Secondary Electron eMission (SEM) coefficient or the charge per proton by dividing the measured charge with the proton beam charge passing through the wire.

The proton beam charge passing through a wire $i$, $Q_b$ is calculated as the ratio of the profile area at the intercepting wire and total profile area multiplied by the beam charge:

$$Q_p = \frac{V_i \cdot W_{\text{wire}}}{\sum_{k=1}^{N} V_k \cdot W_{\text{spacing}}} \cdot Q_b$$

with $V_i$ the voltage at wire $i$, $W_{\text{wire}}$ the width of the wire, $W_{\text{spacing}}$ the spacing of the wires, and $Q_b$ the charge of the whole beam pulse, and $N$ the number of wires.

To derive the charge passing through a particular wire while this wire is disconnected from the existing harp data-acquisition system, we fitted the profile of the remaining wires to a double super-Gaussian function to reconstruct the voltage at the disconnected wire. The beam charge, $Q_b$, is a measurement from the RTBT current monitor.

The secondary emission coefficient was calculated to be 0.07. This compares to a calculated value of 0.15, using a simulation based on the Sternglass theory, [5]. The accuracy of the measurement is estimated to be around 20%, while the simulation and model accuracy is estimated to be within a factor of four.

Uniformity Scan

The harp wires have endured over 25 GWh of proton beam to date. The question is whether this led to a change in the SEM coefficient across a wire. To study this, we sent a single turn of beam, its RMS width narrower than the harp wire spacing, to the harp. The results are shown in Fig. 3.

![Uniformity scans results.](image)

In simulations, the filter reduced the maximum error in the charge integration from over 5% to 0.5%. Note that this filter also significantly reduces the peak voltage measured.

A prototype analog board implementing the filters and interfacing between the harp cable and the cRIO modules was created and is shown with the cRIO data-acquisition in Fig. 5.

The current digitizer multiplexes between the channels, and this can cause crosstalk between the channels. We

Figure 4: Analog circuit and measured signal.

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measured 0.5% to 1% crosstalk, sufficiently low for our purposes but we plan to do a comparison with a simultaneous sampling module.

Figure 5: The prototype data-acquisition system.

Figure 5 shows the cRIO data-acquisition system on the top and the analog board on the bottom. The cRIO runs LabVIEW Real-Time and can process every beam pulse at 60 Hz to provide an averaged profile each second. The system is much more compact than the existing system which occupies half of a full-size rack. The system includes SNS Timing decoder functions implemented on the cRIO’s FPGA with timing signals routed through a custom board. The digitizer signal routing uses non-referenced single-ended termination using a single reference for noise suppression on all channels.

Initial Results

We have tested the prototype system by hooking its analog interface board up directly to the harp cable and measuring the profiles for different beam intensities on the diagonal and horizontal planes. This does take the signal away from the existing system and to get its profiles, the same intensities were repeated at a later time. The results are shown in Fig. 6. The top graph shows the diagonal profiles obtained with the existing system, green, and the prototype system in red. The bottom graph shows the horizontal profile.

The estimated RMS fitted widths are within 3%. The peak parts do not quite match as closely as we had expected, and we will have to do further studies to investigate, in particular, by quickly switching between the two systems without any modifications to the beam setup parameters.

The observant reader might have noticed the slope in the tails for the diagonal profiles and the signal going negative. This has been observed for high intensities of beam but is in the noise for lower intensities. With the prototype system, we can now see a trace of the signals, as shown in Fig. 7. It shows the signal, blue, for wire 16 in the middle of the beam, and a negative trace, red, for wire 25 in the tail of the beam. We suspect that the bias voltages are not high enough to suppress emitted electrons from being absorbed, leading to a negative voltage on a nearby wire.

Figure 7: Negative going trace.

The low intensity results are shown in Fig. 8. The left side shows the profile obtained with 20 turns injected into the ring or about 320 nC, and on the right, a trace of a single turn of beam of about 18 nC hitting a single wire.

Figure 8: Low intensity profile and trace of a single turn beam.

DISCUSSION

The prototype results are encouraging: it can see single turn beam, well below the requirements, and see high intensity beam without saturation. The signal-to-noise can be further improved by switching to full differential mode, but this will require doubling the number of filters.

We plan to keep repeating the SEM coefficient study and uniformity scans to improve these measurements, but also to see if the results change with exposure of the wires to the beam.

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REFERENCES


