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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 circuitry. 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].

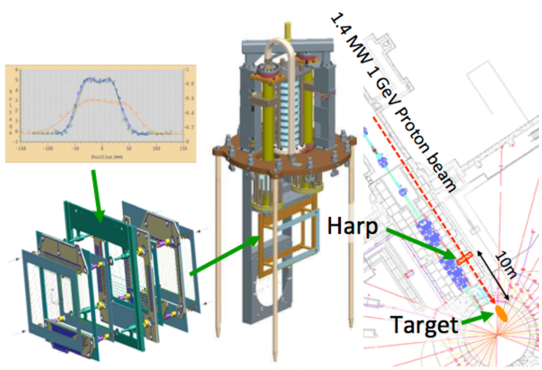

Figure 1: Harp actuator and profiles.

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 and to integrate the baseline charge, followed by digitizer boards, see [3]. The analysis uses a single or double super-Gaussian function fit to derive the position and RMS width of the beam, see [4].

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.

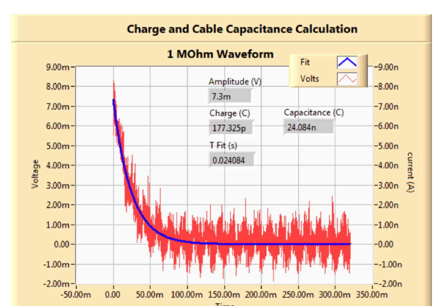

Figure 2: Wire charge measurement.

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 flattop 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.

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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_p, is calculated as the ratio of the profile area at the intercepting wire and total profile area multiplied by the beam charge:

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

with V_i the voltage at wire *i*, W_{wire} the width of the wire, $W_{spacing}$ 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.

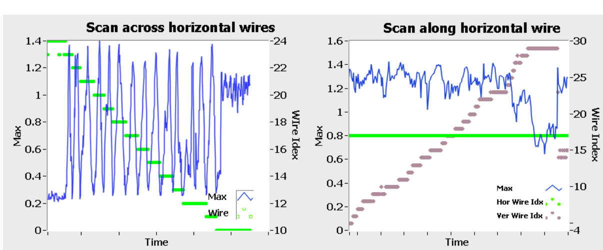

Figure 3: Uniformity scans results.

The left plot shows the maximum signal intensity, blue, on each horizontal profile wire (vertically oriented) as the beam is manually steered across the wires shown by the wire index, green. The peaks show a variation of 10%. The right plot shows signal, blue, on the horizontal profile wire, green, as beam is steered along it. The index of the vertical profile wire that is intercepting the beam is show by the purple dots. This shows a variation of around 10% in the peak value per vertical wire index. At the right side, we see a reduction in the signal, this could be due to beam loss as at this point as we steer the beam well outside its normal path. Otherwise, the numbers indicate that the SEM is stable within 10%. We plan to redo the uniformity scan by automating the steering of the beam and using smaller position steps to increase its accuracy.

DESIGN

The main requirement for the harp is to provide profiles for tune-up and monitoring during production, both of which are high intensity measurements. For low intensity, we need to be able to measure 1/50 of full beam intensity as that is where there is enough beam to create a wide enough profile at the harp. Also desired is about a 1:100 dynamic range within each profile, which gives us a total dynamic range of about 1:5000 for the digitizer. There is no fast beam abort requirement and no requirement to acquire at the full beam rep rate at 60 Hz; 1 Hz is fast enough.

Implementation

The high number of channels drove the previous design decisions to use custom electronics with sample-and-holds to reduce the cost of the overall system. The Diagnostics Group at SNS no longer has resources to design and build such boards. We decided to build a prototype data-acquisition system based on the cRIO platform from National Instruments around the 9205 module that provides 16 differential channels for $800. The total cost, including the CPU and SNS Timing adapter card, is $10k. Simulations, using Multisim, show that we must keep the termination under 100 kOhms to prevent charge build-up at 60 Hz beam repetition rate.

The specifications of the digitizer, 16 channels of 16-bits at 200 mV and up to 15 kS/ch/s, allow us to use passive termination, but only if we low-pass the signal, in particular the ramp-up of the signal during the 670 ns beam pulse duration. This passive circuit is shown in Fig. 4 along with the simulated (Multisim), blue, and measured signal, red.

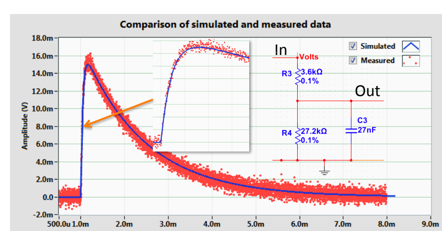

Figure 4: Analog circuit and measured signal.

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

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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.

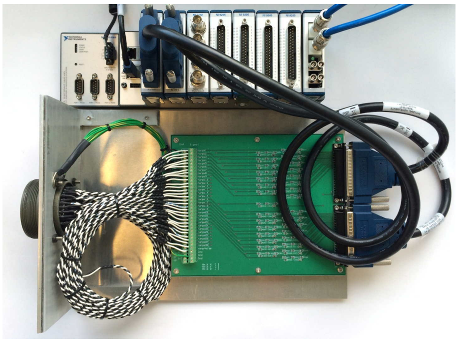

Figure 5: The prototype data-acquisition system.

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.

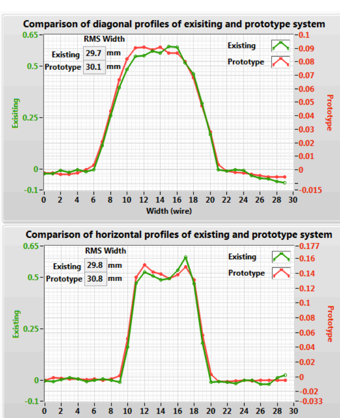

Figure 6: Profiles for a 5.7 uC proton beam.

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.

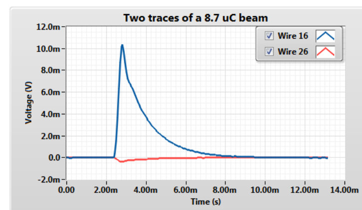

Figure 7: Negative going trace.

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.

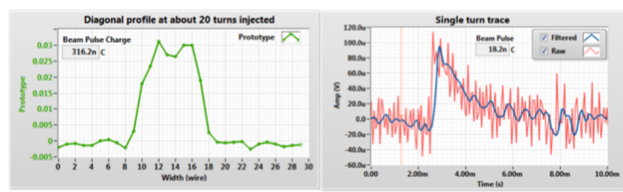

Figure 8: Low intensity profile and trace of a single turn beam.

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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