HALO MEASUREMENTS OF THE EXTRACTED BEAM AT THE LOS ALAMOS PROTON STORAGE RING*

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Abstract

The spatial beam density distribution beyond 2.5 to 3 standard deviations of the beam center is an important property for undertanding the relatively small fractional losses of high intensity beams at the Los Alamos Proton Storage Ring (PSR) and transport lines to the neutron production target. This part of the distribution (sometimes referred to as beam halo) is not well determined by the LANSCE-standard wire scanner system nor is it yet reliably predicted by the simulation codes. To significantly improve the experimental determination of the beam halo, an improved wire scanner has been developed, tested and installed in the extraction line. To enhance the signal-to-noise ratio, an amplifier consisting of a wide dynamic-range, integrating amplifier, sample-and-hold circuit, log amplifier and line driver is located near the beam line [1]. Offset errors at the input of the amplifiers are actively cancelled and timing gates are derived from a single input pulse. We will describe the prototype instrument, discuss our encouraging test results and report our experience with the instrument in the PSR extraction line.

INTRODUCTION

Efforts are underway to increase the extracted beam from the Los Alamos Proton Storage Ring (PSR) from the present 5 to 6 μC/pulse (100 to 120 μA) beam. However, losses in the extraction line increase non-linearly with increasing beam currents, and at ~8 to 10 μC/pulse, appear to be the limiting factor. To study the beam loss mechanisms, it is important to be certain of beam location and size in the extraction beam line. Data from the LANSCE-standard wire scanner (WS) measurements show that the core of the beam fits nicely inside the 5-inch-diameter pipe at the test location, but the present wire scanner system provides little data on possible beam "halos". The standard wire scanner amplifier is located in instrumentation racks more than a hundred feet from the beam line. The overall profile resolution of this wire scanner measurement is limited to three orders of magnitude. The new amplifier design has extended profile feature-resolution across six orders of magnitude.

DESIGN CONSIDERATIONS

The extracted beam from the PSR is a triangle-shaped, ~270 nsec pulse with a dynamic range of nanocoulombs to 10 μC charge per pulse at up to 20 Hz pulse rate. The 4-mil, biased, silicon-carbide wire has a secondary emission coefficient of approximately 2%. Peak secondary emission currents from the wire range from a few micro amps to 10 milliamps corresponding to a peak (integrated) charge on the wire of a fraction of 1 pC to 2 nC. The environment in PSR is such that a terminated cable located at a normal diagnostics station shows approximately 1 mV_{rms} noise.

The wide dynamic range of the WS signal coupled with the inherent noise environment of PSR suggests that some part of the necessary signal processing should be accomplished near the scanner. We have chosen to measure the average beam profile by integrating the WS signal. The effective capacitance of the measurement includes wire capacitance of ~150 pF and other miscellaneous capacitance for a total of 220 pF. Locating the integrator near the beam line has the added advantage, in addition to the minimization of the effect of the previously noted cable pickup noise, of increasing the S/N ratio as compared to long cable runs. The improved S/N characteristics acquired as a result of amplifier location are purchased at the expense of increased exposure of the electronics to radiation fields. The use of linear amplification to achieve five orders of magnitude in signal resolution translates to a tenth of a millivolt in ten volts and implies use of a 16-bit D/A converter. Both of these implications are challenging to implement, particularly given the above-noted PSR noise environment. As an alternative solution, we have chosen to process the integrated signal using a transimpedance logarithmic converter. The log amplifier allows the use of standard 12-bit A/D converters for signal processing with a single bit corresponding to 2.5 mV of signal. For simplicity, the integrator, the S/H and the log amplifier are also located near the near the beam line on a single printed circuit board. Three gain selections are available, implemented by the discrete selection of the integrating capacitance with a gain of 1 defined, in this report, as the selection of the largest integrating capacitance. Noise suppression is enhanced in the measurement by minimizing the integration time, limiting circuit bandwidth, background subtraction, and auto zeroing techniques. A description of the amplifier will follow the presentation of measurements.

BEAM MEASUREMENTS

The capability of the WS and amplifier response was tested over a range of extracted currents. Figure 1 shows the profiles of two scans of a 3.6-μC beam with amplifier gains of 1 and 10 using the new wire scanner amplifier.

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(For consistency in this report, data with a gain of 1, 10 and 100 are shown respectively in red, blue and green.) The semi-log plot shows log-amplifier input current as a function of scanner position in mm. A scan consists of seventy-five samples taken across the beam line with each sample an average of four beam pulses. The baseline noise scans (no extracted beam) for these two gain settings are also shown in the figure. Amplifier saturation is evident in the figure for the gain at 10. The choice of gains for the two scans was deliberately chosen to demonstrate the maximum output of the amplifier and also to allow comparison of the linearity of the amplifier over the same range of currents for two gains settings. The log amplifier has an internal intercept current of 100 pA, but a 1 nA offset current has been generated in the circuitry and sets the minimum measured signal current.

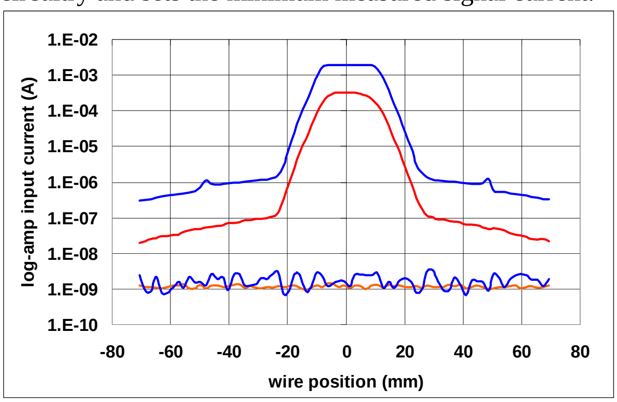

Figure 1: Profiles of a 3.6 μC beam taken with gains of 1 (red trace) and 10 (blue trace) are shown in the chart. Baseline scans without extracted beam were also taken at these gains to demonstrate amplifier noise characteristics.

A "halo" is apparent on the beam more than three orders of magnitude below the peak. The nature of this "halo" has not yet been determined. The wire is biased at –500 V for all of the reported data. Future efforts to increase the bias to greater than -5 kV will be made to explore the nature of this "halo."

It is apparent that the combined core of the beam and its "halo" do not represent a Gaussian distribution. Nonetheless, a Gaussian fit of the gain=1 data can be made and is shown as the solid blue line in Figure 2. The variance of the function is 49.26. The red crosses in the figure mark the measured data. While the nature of the "halo" and its profile are not presently known, it can be reasonably assumed to also have a normal distribution. A fitting function consisting of the sum of two normal functions was generated; function f_A (σ_A=7.016) primarily describes the core of the beam, and function f_B (σ_B=40.733), represents the contribution of the wings of the beam. Function f_A is very similar to the original normal function discussed previously, differing only in a slight change in the value of the deviation. The result of the addition of functions f_A and f_B is shown as the solid black trace in Figure 2.

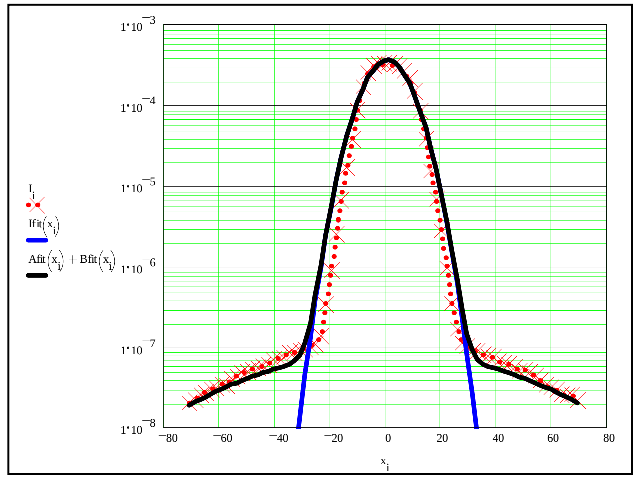

Figure 2: A normal function shown in solid blue has been fit to the data (red x's). A sum of two normal functions is shown in solid black. The x-axis is scaled as scanner position in mm's and the y-axis is log-amp input current in Amps.

The mid range of the amplifier can be demonstrated by reducing the extracted beam an order of magnitude and taking two scans with amplifier gains of 10 and 100. The results are shown in Figure 3 along with "no beam" scans at the same gains.

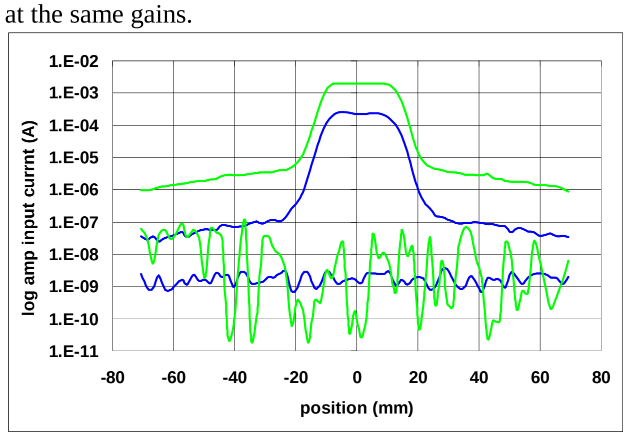

Figure 3: Profiles of a 0.36 μC beam taken with gains of 10 (blue trace) and 100 (green trace) are shown in the chart. Baseline scans, scans with no extracted beam, were also taken at these gains to characterize measurement noise.

At gain=10, the amplifier is again saturated at peak signal levels. The noise limit of the circuit is readily apparent when the gain is set to 100. Peak noise currents are two orders of magnitude above the offset current baseline for this gain. The increased noise is a function of the increased bandwidth at the higher gain.

Finally a scan of a 2 nC "single shot" beam, produced by accumulating beam in the PSR for a single turn followed by normal extraction timing, is shown in Figure 4. The plot shows some evidence of the beam being hollow. The wings of the beam, if they exist at this extraction current, are obscured by the noise.

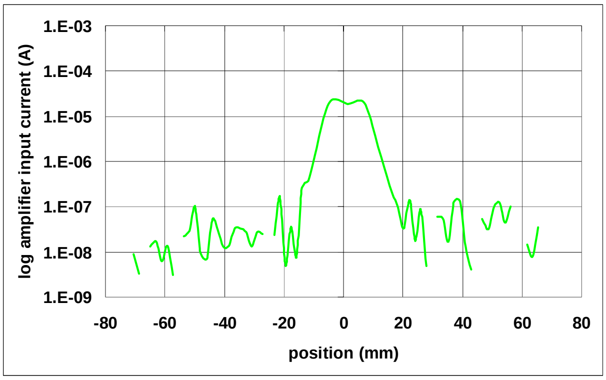

Figure 4: Profile of a “single shot” beam taken with gain of 100. Increased averaging of the samples will likely aide in the ability to resolve “halo” at low beam currents.

AMPLIFIER DISCUSSION

A block diagram of the amplifier is shown in Figure 5. The 1st-stage consists of an integrator with relay-selectable capacitors of 10 pF, 100 pF and 1000 pF generating the three gains referred to as 100, 10 and 1. The integrator and its buffer amplifier are actively reset by a low-bandwidth feedback loop. The feedback loop bandwidth is also relay-selected along with the gain to maintain a consistent control for the three gain settings.

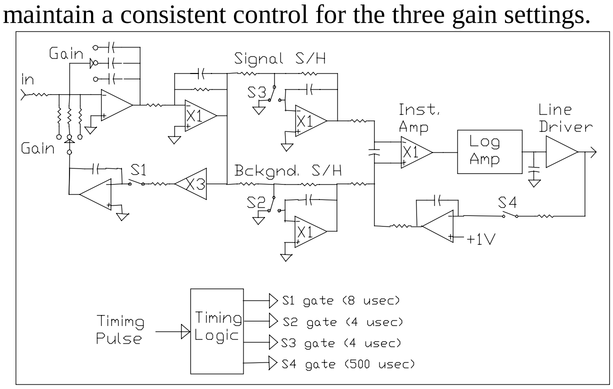

Figure 5: Block diagram of the amplifier.

In addition to providing auto-zero cancellation of the integrator’s input offset current and voltage and cancellation of bias supply leakage currents through the coupling capacitor, the feedback loop allows suppression of low-frequency noise components such as 60 Hz pickup. The auto-zero function is removed by switch S1 during a 10 μsec window around the beam time, and the feedback loop amplifier maintains the last correction voltage just prior to the integrating period.

Two sampling amplifiers acquire data during the integrating period using switches S2 and S3. The “background” sample occurs early in the window before the beam arrives and the “signal” sample occurs shortly after the beam appears. The relative timing between the switch gates is reasonably insensitive to adjustment error. The sampled signals are acquired on a holding capacitor at the input to an instrumentation amplifier. The instrumentation amplifier drives the transimpedance logarithmic amplifier, an Analog Devices AD8304, followed by a line driver. The bandwidth of the log amp varies as a function of input current from 10 kHz to 10 MHz. A low pass filter at the output of the log amplifier reduces the overall bandwidth to 1 kHz.

The linearity of the log amplifier is challenged at high and low input currents. The AD8304 requires a current source as an input driver to attain the manufacturers promised 160 dB (100 pA to 10 mA) range and log conformance less than 0.1 dB from 1 nA to 1 mA. The original design was implemented with a current source at the input to the log amp, but circuit issues and unexpected time constraints forced the removal of the current driver and resulted in measurement inaccuracy for currents somewhat less than 100 nA during beam line operations. The specific nature of the measurement inaccuracy, an effect of increasing dynamic input impedance of the log amp as input current falls, is well understood and has been corrected in the latest version of this circuit. Measured data as reported in this document has been corrected using a calibration curve generated in a careful test at the bench.

A second active feedback loop is used around the combination of the instrumentation amplifier, the log amp and the line driver. The dominant pole of the feedback loop is fixed at 1.59 Hz. Switch S4 removes the loop control during the log settling and A/D converter sample acquisition time. A one-volt source in the feedback loop is used to set the 1 nA offset current to the log amp.

Timing for the four switches is provided by a single master timer pulse with individual switches driven by pulses derived from the master timer pulse and fixed in time by on-board circuits.

SUMMARY

To significantly improve the experimental determination of the beam halo in the extracted beam from the Los Alamos Proton Storage Ring, an improved wire scanner has been developed, tested and installed in the extraction line. To enhance the signal-to-noise ratio, an amplifier consisting of a wide dynamic-range, integrating amplifier, sample-and-hold circuit, log amplifier and line driver is located near the beam line. Errors at the input of the amplifiers are actively cancelled and timing gates are derived from a single input pulse.

REFERENCES

[1] A. Browman, memo reports on wire scanner design to R. Macek, 7/8/2001 (macek72) and 9/19/2001 (macek75) available on the web at http://lansce2-serv.atdiv.lanl.gov/browman/CY2001.