

SNS LINAC WIRE SCANNER SYSTEM: SIGNAL LEVELS AND ACCURACY

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Abstract

The linac wire scanner system for the Spallation Neutron Source (SNS) at Oak Ridge, TN, USA, calls for 5 units in the medium energy beam transport (MEBT), 5 in the drift tube linac (DTL), and 10 in the coupled cavity linac (CCL). In this paper we present expected signal levels and an analysis of the error in the beam size measurement as functions of wire position and electrical signal errors.

1 OVERVIEW

In the Spallation Neutron Source (SNS) facility, H^- beams will be accelerated to 2.5 MeV in an RFQ, to 87 MeV in a drift tube linac (DTL), to 186 MeV in a coupled cavity linac (CCL), and finally to 1000 MeV in a superconducting linac (SCL). The 60 Hz, 1-ms, 36 mA peak current beam pulses are chopped into 690-ns long segments with a 1 μ s period to give an average current of 1.4 mA and an average beam power of 1.4 MW.

The wire scanner actuators in the SNS linac are based on custom-designed linear actuators from Huntington Mechanical Laboratories, Inc. Three carbon wires, 32 microns in diameter, are mounted to each wire scanner fork to measure the beam profile in three different planes. The wires are offset from one another so that no more than one wire at a time is within ± 2 rms of the beam center.

2 SIGNAL LEVELS

When an H^- beam strikes a wire the signal induced on the wire can be modeled by considering the H^- particle as a single particle entering the wire, whereupon it fragments into two electrons and a proton. Any electrons or protons that stop in the wire or exit the wire should be considered separately. The signal will thus comprise several sources: 1) the secondary electron emission (SEM) caused by the H^- particle entering the wire, 2) any electrons or protons that stop in the wire, and 3) SEM caused by any electrons or protons exiting the wire.

A well-known theory from Sternglass [1] describes the secondary emission yield as

$$Y = \frac{P d_s}{E_*} \frac{dE}{dx},$$

where Y is the secondary yield, P is the probability of an electron escaping, d_s is the average depth from which secondaries arise, E_* is the average kinetic energy lost by the incoming particle per ionization produced in the target, and dE/dx is the stopping power of the target.

Values suggested by Sternglass are $P \approx 0.5$, $d_s \approx 1$ nm, and $E_* \approx 25$ eV. For a round wire the number of particles intercepted by the wire is calculated from the wire diameter, but the SEM signal is calculated from the wire circumference.

The wire scanner signal computation therefore reduces to calculating stopping powers and ranges for H^- particles, protons and electrons. The H^- stopping power is the same as the proton stopping power for the very thin layer within the entering surface. It can be estimated from the Bethe-Bloch equation [2], and the proton range can be estimated by numerically integrating this equation. The electron range and stopping power can be estimated using Feather's rule [3] suitably modified [4] for materials other than aluminum. The Bethe-Bloch equation and Feather's Rule predict precise ranges for the electron and proton, but in reality there is straggling and scattering that leads to imprecision.

To further simplify our task we assume the wire of diameter D has a uniform thickness given by the average thickness $t = \pi D/4$. We've written a simple computer program [5] to compute and add up the various signal contributions. A sample plot of the calculated signal strength as a function of beam energy for the case of a 0.032 mm diameter carbon wire in the center of 26 mA, 0.2 cm rms beam is shown in Fig. 1. Results for other beam currents and sizes can be scaled from these values.

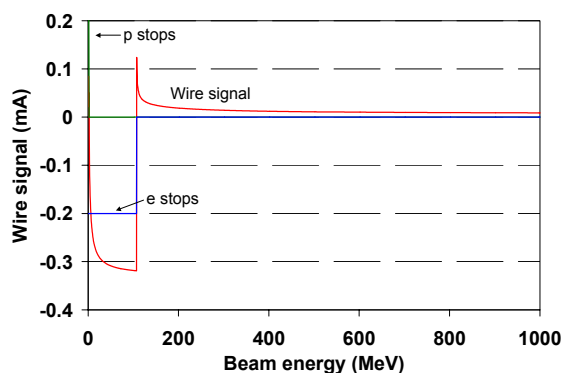


Fig. 1. Plot of calculated wire signal vs. beam energy for a 0.032 mm dia. carbon wire. The red line is the wire scanner signal in units of mA. The blue line, when non-zero, indicates that electrons are stopping in the wire (in this case for energies less than about 108 MeV). The green line, when non-zero, indicates that protons are stopping in the wire (in this case for energies less than about 1.5 MeV).

We've tested [5] this model of signal generation for wires in H^- , H^0 , and H^+ beams by comparing model predictions to observations made at the Los Alamos Neutron Scattering Center (LANSCE) and other facilities. The model agrees quite well for absolute measurements made with H^+ beams and relative measurements made with H^- , H^0 , and H^+ beams.

SEM coefficients have been observed [6] to change by up to 50% as target materials are exposed to beams. The values predicted by the computer program should therefore be given at least a $\pm 50\%$ error bar just for the degradation effect. Additional error sources are the approximations that the wire has a uniform thickness, and that the H^- , proton and electron ranges are precise. These latter effects will tend to smooth out the sharp peaks in the plots of signal strength as a function of beam energy. Caution should be used when employing results in these regions.

3 ACCURACY OF BEAM SIZE MEASUREMENT

The error on a beam size measurement, when measured with a wire scanner, depends [7] on several parameters: 1) the error in positioning the wire, 2) the absolute error on the signal amplitude measurement, 3) the relative error on the signal amplitude measurement, 4) the number of positions used for the scan, and 5) the beam jitter. The error also depends on the data analysis method, e.g., if a fitting function is used or if the width is directly computed from the data, as in an rms measurement. In most real-life situations it is best to fit the data with a function, such as a Gaussian, that accurately describes the data.

First we simulate a wire scan by sampling a simulated 40,000 particle, 1.80 mm rms beam [8] with a variable number of equally spaced wire positions between ± 1 cm. Typical rms beam sizes in the linac range from 0.05 to 0.25 cm. The signal, y_i , for each wire position is assigned to be all the particles within ± 0.01 cm of the wire center. An error is assigned to each y value, $\varepsilon_{y_i} = [(eabs)^2 + (erel \cdot y_i)^2]^{1/2}$, where $eabs$ is the absolute error (e.g. electronic noise), and $erel$ is the relative error (e.g. non-linearity in an amplifier circuit).

The wire position error δx is folded into the overall error ε_i by computing $\varepsilon_x = f' \delta x$, where f' is the derivative of the fitting function, and then $\varepsilon_i = \sqrt{\varepsilon_x^2 + \varepsilon_{y_i}^2}$.

We define the error in the fitted width to be $abs[(true\ width) - (fitted\ width)] + (error\ in\ fitted\ width)$, where $true\ width$ is the rms beam size of 1.80 mm, and abs denotes the absolute value function. The PAW [9] script then steps through the above procedure for a range of numbers of wire positions. Realistic values chosen for the errors are $eabs = 2\%$ of the peak number of counts, $erel = 0.01$, and $\delta x = 0.01$ cm. The result is shown in Fig. 2. It is evident from the figure that once the beam is sampled at more than 12 positions the error is minimized. Twelve

positions across 2 cm corresponds to 0.18 cm between sample positions, or just one rms beam width.

Next we scan through a range of errors on the wire position, for three different beam sizes, keeping $eabs = 2\%$ of the peak signal, $erel = 0.01$, and scaling the wire position spacing to be equivalent to 15 positions equally spaced across ± 1 cm for a 1.80 mm rms beam. The result is shown in Fig. 3. We see that there is a roughly linear relationship between the wire position error and the resultant error in the width measurement.

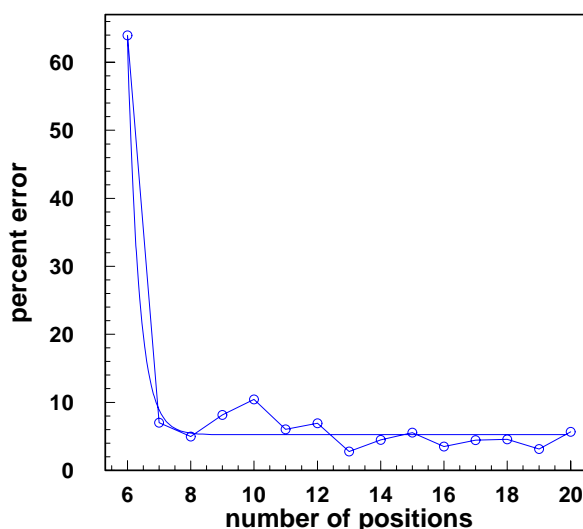


Fig. 2. Percent error in the width measurement vs. number of wire positions. The smooth solid line is a fit to the data points. The absolute error is about 2% of the peak signal, the relative error is 1% of the signal, and the wire position error is 0.01 cm.

Finally we scan through a range of absolute and relative signal errors for the 1.80 mm rms beam, while keeping the number of wire positions fixed to 15 and assuming no error in the wire positions. These results are shown in Fig. 4. We see that once the absolute error reaches about 5% of the peak signal, relative errors up to 15% do not contribute significantly.

3.1 Measurements of position and signal errors for the SNS linac actuators and electronics

Now that we have explored how a given set of actuator and electronics errors impacts the beam size measurement, we are in a position to determine the effects of the actual actuators and electronics designed for the SNS linac wire scanner system.

The noise floor on the SNS wire scanner electronics has been measured to be less than the least significant bit on the 12-bit digitizer, so it is essentially zero. The dominant noise source will be due to the accelerator environment. Assuming a reasonable quality cable plant, the noise should not exceed about 2% of the peak signal level. The electronics linearity is better than 0.1%, but to be conservative we choose $erel = 1\%$ for our simulations.

The positioning accuracy for the DTL and CCL actuators has been measured to be 0.18 mm in a prototype unit. We expect that design improvements will reduce the error in subsequent units to 0.1 mm.

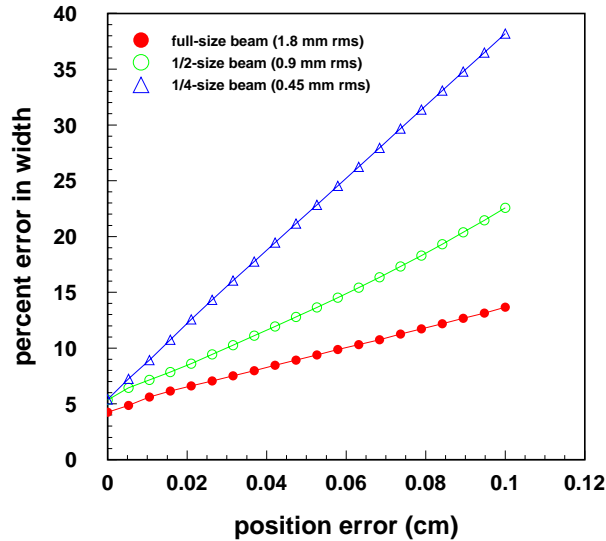


Fig. 3. Error in the beam width measurement as a function of wire position error, for three different beam sizes, assuming an absolute error equal to 2% of the peak signal, and a relative error of 1%. Full size beam = 1.8 mm rms, half size = 0.9 mm rms, quarter size = 0.45 mm rms.

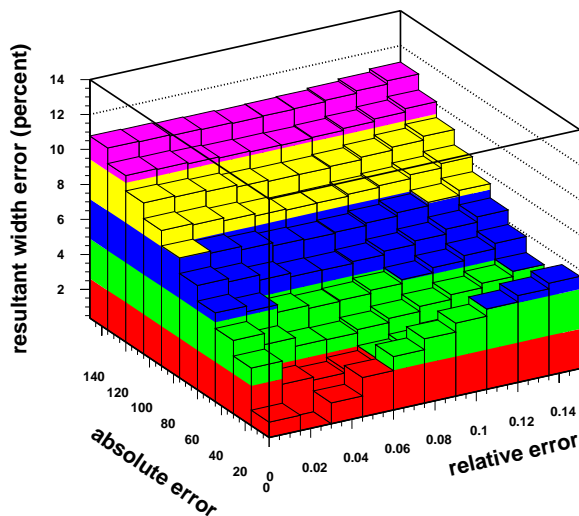


Fig. 4. Error in the beam size measurement as a function of absolute and relative error on the wire signal. The wire position error is assumed to be negligible here. An absolute error of 150 corresponds to 10% of the peak signal.

Model calculations show that in the DTL the minimum beam size will be 0.7 mm rms, and in the CCL it will be 0.5 mm rms. We now have all the parameters we need to simply look up the expected errors on the beam width measurements. From Fig. 3 we see the error in the DTL

width measurement will be about 8%. Similarly, for the CCL it will be about 9%.

Remember that these simulations do not include the effects of beam position and beam width jitter, which if severe enough could add additional error. Also, the work presented here assumes a Gaussian fit to the data. It is of course reasonable to use other functions as well. However, as long as the fitted function does a good job at describing the data, the results will be the same, since the wire position error enters the overall beam width error through the slope of the function at a given wire position, and the slope will barely change from one function to the next given the constraint that the function must describe the data.

4 CONCLUSIONS

We have modeled the wire signal creation process for H⁻ beams, and found that as the beam energy varies from 2.5 to 1000 MeV the peak signal level varies from about -0.32 mA to about +0.06 mA for a 0.2 cm rms, 26 mA, H⁻ beam. We have also modeled the effects of wire position errors and signal acquisition errors, and found that we can expect the SNS DTL and CCL wire scanners to be able to measure the beam sizes with accuracies of 8 to 9% in the absence of beam jitter.

5 REFERENCES

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