ANALYSIS OF DATA FROM THE LEDA WIRE SCANNER/HALO SCRAPER*

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Abstract

A new diagnostic has been designed and commissioned that measures the profile of the beam in the halo channel of the Low Energy Demonstration Accelerator at the Los Alamos National Laboratory. This paper describes the algorithms written to analyze the data from that diagnostic, a combined wire scanner and halo scraper. These algorithms determine the safe insertions limit of the scrapers, spatially differentiate the scraper signal, amalgamate the wire scanner data with the differentiated scraper data, determine when both the core and combined distributions rise above the noise floor, and compute the moments of the combined distribution. Results of applying the algorithms to data acquired during experiments matching the beam into the halo channel are presented.

1 INTRODUCTION

A new diagnostic[1] has been designed and commissioned[2] for examining halo formation[3, 4] in the Los Alamos National Laboratory's Low Energy Demonstration Accelerator (LEDA). Its goal is to quantify the transverse beam profile over a dynamic range of 10,000:1. This diagnostic has been installed at nine stations along the LEDA halo beamline. Stations are named for the quadrupole magnet that precedes it. The first scanner/scraper instrument is located at station #4, a few quadrupoles downstream of the exit of the radio frequency quadrupole. The next location is a group of four in the middle of the halo lattice at stations 20, 22, 24, and 26. Finally, there is a group at the end of the halo channel at stations 45, 47, 49, and 51. Each station consists of two orthogonal measurement axes, one for x and one for y. Each axis contains a slow moving 33-micron C wire and two Cu-backed graphite scrapers. The wire is used to measure the profile of the beam core; the scrapers probe the edges of the distribution.

A real time control system[5] synchronizes data acquisition to probe movement,[6] fits the x- and y-wire scanner distributions to Gaussians, computes the first four moments of these distributions, sets up and executes the scrape, permanently archives data, and writes files for use by the scraper data analysis routines. The scraper data analysis routines provide rapid feedback to the operators after data has been acquired. This analysis was carried out using the Interactive Data Language (IDL), and the routines were manually activated.

2 SCRAPER SCAN SETUP

A real-time IDL task sets up the limits of scraper insertion to keep the maximum scraper power density below 560 kW/cm^2. For 30-µs, 1-Hz operation at 6.7 MeV, this keeps the power density below the value to which the scraper has been successfully tested.[7]

Since they provide information necessary to determine the insertion limits, both x- and y-wire scans must be performed prior to a scrape. In order to construct a two-dimensional distribution from the wire scan data, it is assumed that the shape of the distribution in x is independent of y and that the y-shape is independent of x. Under these circumstances, the two-dimensional current density distribution, $F(x_i, y_j)$, is given by $F(x_i, y_j) = A\, f(x_i)\, g(y_j)$, where $f(x_i)$ and $g(y_j)$ are the measured x- and y-wire scanner distributions, and A is a normalization factor. By setting the integral of this distribution over x and y equal to the beam current, the normalization factor A can be determined. The safe scraper insertion limit in x can then be found by solving $J\_limit_x = A\, f(x_i)\, MAX[g(y_j)]$ for x_i, where $A\, f(x_i)\, MAX[g(y_j)]$ is the maximum current density at x_i, and J_limit_x is the power density limit expressed as current density. Similarly, the limit for y comes from $J\_limit_y = A\, g(y_j)\, MAX[f(x_i)]$. These x and y J_limit equations are each solved twice, once for each side of the distribution.

Upon completion of both wire scans, the control system computes and displays the four scraper limits together with the associated locations where the wire scanner signal rises above the background noise. This information allows the operator to select the starting points for the scrapes. The operator also sets the integer ratio, N, of the wire scanner step size to the scraper step size. The quality of the spatial derivative can be improved by choosing $N > 1$.

In order to join the wire scanner distribution to the scraper distributions, the two instruments need to visit the same spatial locations. To ensure that this is the case, a program adjusts the operator-selected starting point such that the scrape ends at a location visited by the wire scanner. An additional requirement is that the scraper insertion limit be several wire scanner points inboard of

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where the wire scanner signal rises above the noise. That is, there must be an overlapping region where both instruments have valid data. Once everything is set up, the operator can elect to perform an x-scrape, a y-scrape, or both.

3 ANALYSIS ROUTINES

It is important to know the locations where the wire scanner and scraper signals each rise above the background noise. An algorithm was developed using the average and standard deviation of all the points from the outboard edge to the point in question. The criterion used to determine where the signal exceeds the noise is $(signal_i - ave_{i-1})/stdev_{i-1} > 2$, where i is the index of the point under examination.

Since the wire passes completely through the beam and out the other side, both sides of the wire scanner distribution are examined for the signal > noise condition. Scrapers only probe the edges of the beam, so two scrapes are performed for each wire scan. The outboard end of each scrape is examined for signal > noise.

As the scraper marches inward, it intercepts an ever-increasing segment of the beam. It is therefore necessary to differentiate the scraper signal to determine the transverse distribution. As mentioned above, the operator can elect to take scraper data with N-times finer steps than used for the wire scan. This finer stepping allows the differentiation algorithm to smooth the data. The numerical derivative is computed as the difference between two N-point averages on either side of the point in question divided by the spatial separation between them. Tests with simulated random noise added to a Gaussian distribution showed that smoothing the derivative with N=4 increased the derivative's signal-to-noise ratio by a factor of ten relative to N=1. Larger values of N improve the signal-to-noise ratio even more, but at the cost of additional time to complete the scrapes.

Difficulties in implementing the differentiation algorithm are encountered at the ends of the data array. When there are less than N points between the point in question and the end of the array, the N-point-smoothing differentiation algorithm cannot be applied. Under these conditions, the number of points averaged is successively reduced. For the end points of the arrays, the derivative is computed using a forward finite difference technique. These modifications to the nominal algorithm result in a derivative that is noisy at the ends. While the derivative is computed for all points, in some of the algorithms, the end N points are ignored.

The first step in joining the scraper data to the wire scanner data is determining where the data sets overlap. The overlap region consists of wire scanner locations ranging from where the wire scanner signal-to-noise ratio is greater than 2 to the maximum insertion location of the scraper.

Once the region of overlap has been determined, the scraper data must be normalized to attach it to the wire scanner data. The scaling factor is the average of wire scanner to halo scraper signal ratios at two of the three most-inboard points in the overlap region (the most inboard point is excluded). Once scaled, the entire scraper data set is thinned by keeping only every N^{th} scraper point and attached at the connecting points. Measurements of wire to scraper distances were carried out with an uncertainty of 0.25 mm. This implies a positional attachment uncertainty of 0.25 mm.

At this point, the resulting three distributions have been combined into a single distribution with uniform step size. The first four moments of the combined distribution are computed. Values are reported for the mean, standard deviation, skew, and kurtosis.

The final routine archives the results to a file. The information in this file includes: the names of the parent files; the four moments of the combined distribution; the combined data set—signal array plus locations; the two scraper derivative sets—signal arrays plus locations; and the locations where the wire scanner and scraper signals rise above the noise (the measurable farthest extent).

4 RESULTS

The data to be shown were taken during an experiment to match the beam into the halo lattice. Currents on the four matching quadrupoles were sequentially increased by 5% and wire scans and scrapes taken at all locations. For the case at hand, the current in quadrupole #3 was 5% higher than nominal. Beam current was 75 mA, pulse length was 35 µs, and the repetition rate was 1 Hz. Due to lack of space, only the data taken in the y plane is shown.

The wire scan is shown in figure 1. Data were taken for locations from -9 mm to +9 mm in 73 0.25-mm steps. The ordinate is the difference in signal level (in counts) at two time points divided by the average number of counts from the AC toroid. The least significant bit corresponds to $\sim 3x10^{-4}$ (1 count divided by ~3000 counts corresponding to 75 mA).

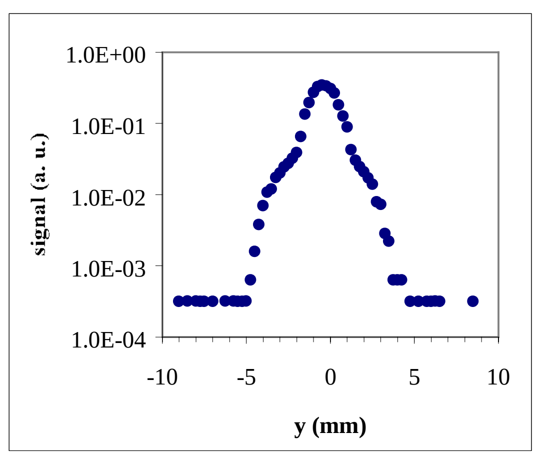

Figure 1. Y-axis wire scan, 0.25 mm step size.

For this scan, the maximum halo insertion points were computed to be -3.5 mm and 2.5 mm. The measurable farthest extents were -4.75 mm and 3.5 mm, providing 6 and 5 wire scanner points of overlap with the scraper. The first four moments of this distribution were: mean, -0.40 mm; standard deviation, 1.09 mm; skew, -0.21; kurtosis, 5.01.

Scraper data on the bottom of the beam were taken from -12 mm to -3.5 mm, in steps of 0.0833 mm (N = 3). The resulting signal is shown in figure 2. Also shown is the spatial derivative (x10) of the signal.

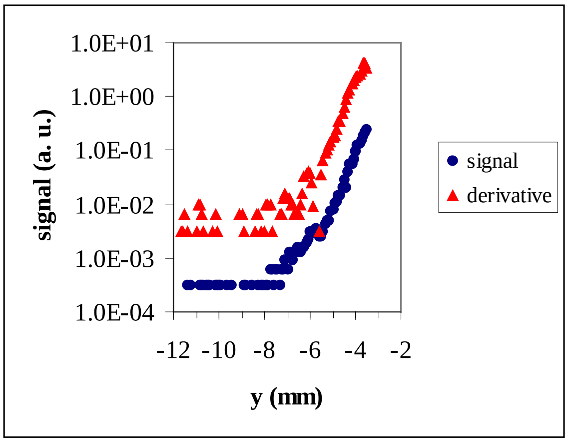

Figure 2. -Y scrape signal and derivative, 0.0833-mm step size. The derivative has been multiplied by ten.

Scraper data on the top of the beam were taken from 12 mm to 2.5 mm, in steps of 0.0833 mm (N = 3). The resulting signal and its derivative (x10) are shown in figure 3.

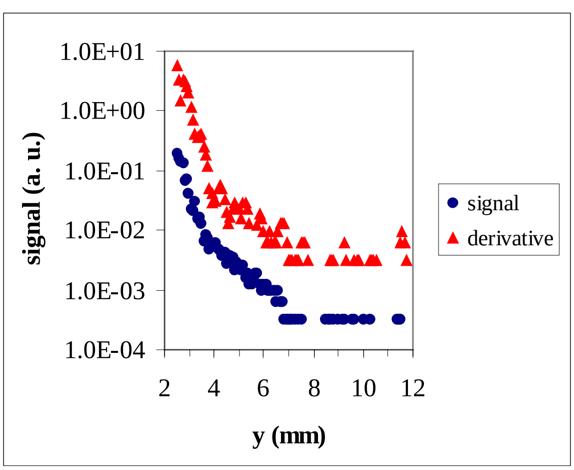

Figure 3. +Y scrape signal and derivative, 0.0833-mm step size. The derivative has been multiplied by ten.

In the process of attaching the scraper data to the wire scanner data, the -y scraper data was multiplied by 0.031 and the +y scraper data was multiplied by 0.009. The combined distribution is shown in figure 4.

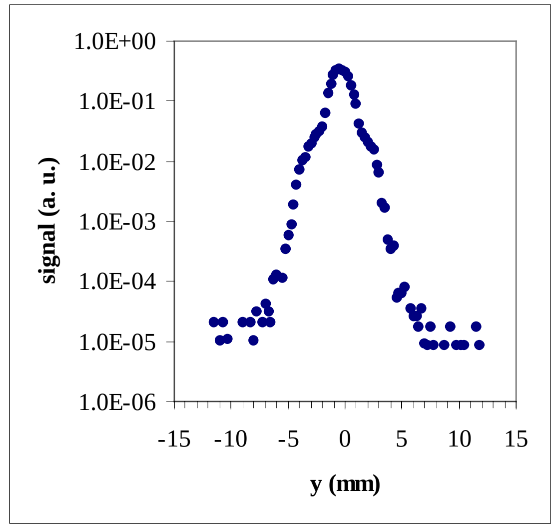

Figure 4. Combined distribution in y.

The moments of the combined distribution are: mean, -0.40 mm; standard deviation, 1.06 mm; skew, -0.20; kurtosis, 3.13. The addition of the scraper data has reduced the kurtosis by 40%, the dynamic range of the profile measurement has been extended from 1200 to 17,000, and the measurable furthest extent locations have been extended from 8.25 mm to 11.25 mm. Our dynamic range goal of 10^4 has been met; data sets with dynamic ranges of 10^5 are common.

5 REFERENCES

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