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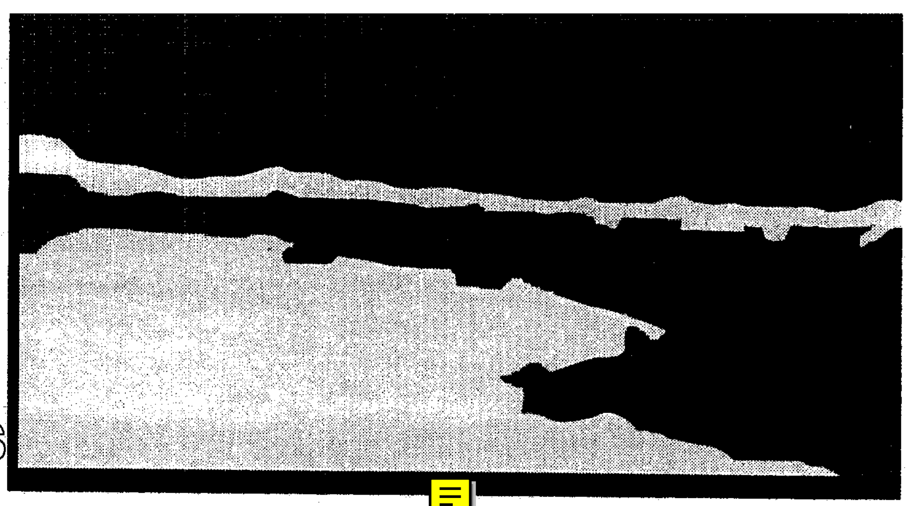

Los Alamos
NATIONAL LABORATORY

BEAM-PROFILE INSTRUMENTATION FOR BEAM-HALO MEASUREMENT: OVERALL DESCRIPTION, OPERATION, AND BEAM DATA*

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Abstract

The halo experiment presently being conducted at the Low Energy Demonstration Accelerator (LEDA) at Los Alamos National Laboratory (LANL) has specific instruments that acquire horizontally and vertically projected particle-density beam distributions out to greater than 10^5:1 dynamic range. We measure the core of the distributions using traditional wire scanners, and the tails of the distribution using water-cooled graphite scraping devices. The wire scanner and halo scrapers are mounted on the same moving frame whose location is controlled with stepper motors. A sequence within the Experimental Physics and Industrial Control System (EPICS) software communicates with a National Instrument LabVIEW virtual instrument to control the motion and location of the scanner/scraper assembly. Secondary electrons from the wire scanner 0.03-mm carbon wire and protons impinging on the scraper are both detected with a lossy-integrator electronic circuit. Algorithms implemented within EPICS and in Research Systems' Interactive Data Language (IDL) subroutines analyse and plot the acquired distributions. This paper describes this beam profile instrument, describes our experience with its operation, compares acquired profile data with simulations, and discusses various beam profile phenomenon specific to the halo experiment.

1 HALO INSTRUMENTATION

The LEDA facility contains a H^+ source and radio frequency quadrupole (RFQ) that generate and injects a 100-mA, 6.7-MeV beam into a 52-quadrupole magnet lattice (see fig. 1). Within this 11-m FODO lattice, there are nine wire scanner/halo scraper/wire scanner (WS/HS) stations, five pairs of steering magnets and beam position monitors, five loss monitors, three pulsed-beam current monitors, and two image-current monitors for monitoring beam energy. The WS/HS instrument purpose is to measure the beam's transverse projected distributions with sufficient detail to relate the acquired data of the generated beam halo to the distributions generated in various accelerator charged particle simulation codes. The first WS/HS station, located after the fourth quadrupole magnet, verifies the beam's transverse characteristics after the beam exits the RFQ. A cluster of four HS/WS located after magnets #20, #22, #24, and #26 provides phase space information after the beam has debunched but prior to a full formed beam halo. After magnets #45, #47, #49, and #51 resides the final four WS/HS stations. These four WS/HS acquire projected beam distributions under both matched and mismatched conditions. These conditions are generated by adjusting the fields in the first four lattice quadrupole magnets so that the RFQ output beam may be matched or mismatched in a known fashion to the rest of the lattice. Because the halo takes many lattice periods to fully develop, this final cluster of WS/HS are positioned within the lattice to be most sensitive to halo generation.

Figure 1. The 11-m, 52-magnet FODO lattice includes nine WS/HS stations that measure the beam's transverse projected distributions.

As the RFQ output beam is mismatched to the lattice, what is actually observed by the WS/HS is a variety of distortions to a properly matched gaussian-like distribution. These distortions appear as distribution tails or backgrounds added to beam's core distribution. It is the size, shape, and extent of these tails that predicts specific type of halo. However, not every lattice WS/HS observes the halo generated in phase space because the resultant distribution tails may be hidden from the projection's view due to the halo's orientation in phase space. This is why multiple WS/HS are used in clusters to observe these various distributions tails no matter what the phase space orientation is of either the beam core or its associated tail.

2 WIRE SCANNER/HALO SCRAPER

Each station consists of a horizontal and vertical actuator assembly (see fig. 2) that can move a 0.03-mm carbon monofilament and two graphite/copper scraper sub-assemblies. The carbon wire and scrapers are connected to the same movable frame. Attached to this movable frame is a linear actuator that provides the wire and scraper edges' relative position to within 0.2 μm, an additional linear potentiometer provides an absolute approximate position for LEDA's run permit systems. A stepper motor and ball lead screw drives the actuated wire and scrapers, and microswitches and motor brakes limit the wire and scraper movement.

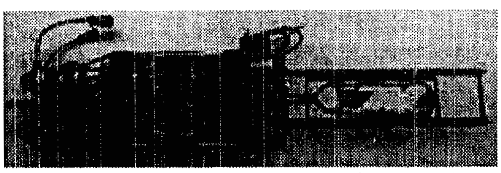

Figure 2. The WS/HS assembly contains a movable frame on which a 0.03-mm carbon wire resides between two water-cooled graphite scrapers.

The carbon wire, which senses the beam's core, is cooled by thermal radiation. If the beam macropulse is too long, the wire temperature continues above the 1800 K resulting in the onset of thermionic emission. Thermionic emission gives the distribution an inaccurate appearance of a larger distribution core current density. To eliminate these effects for the halo experiment, the maximum pulse length and repetition rate is limited to approximately 30 μs and 1 Hz, respectively.

The halo scrapers are composed of a 1.5-mm thick graphite plate brazed to a water-cooled 1.5-mm copper plate. Since 6.7-MeV protons average range in carbon is approximate 0.3 mm, the beam is completely stoped in graphite plate. The cooling via conduction lowers the average temperature of scraper sub-assembly and allows the scraper to be cooled more rapidly than the wire (see fig. 3). The lower average temperature and faster cooling allows the scraper to be driven in as far as 2 rms widths from the beam distribution peak without the peak temperature increasing above 1800 K.

The movement and positioning of each wire and scraper pair is controlled by a movement control system that contains a stepper motor, stepper motor controller, a linear encoder, and an electronic driver amplifier. The controller's digital PID loop controls the speed and accuracy at which the assembly is moved and placed.

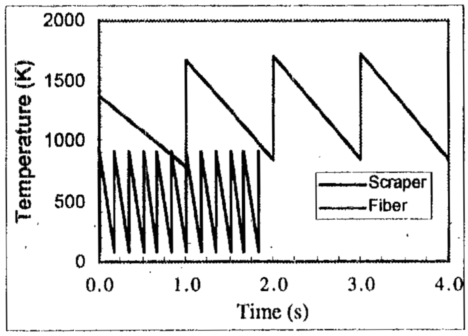

Figure 3: The temperature of the wire and scraper are shown to be below 1800 K under normal pulsed-beam conditions, of a 1-mm round beam with a 30-μs 100-mA beam pulse.

The target position, as defined by the WS/HS operator, is relayed from the EPICS control screen via a software process variable to a National Instruments LabVIEW Virtual Instrument (VI). Based on the EPICS command, the VI then instructs the controllers to move the wire and scraper to a target position. The VI also calibrates the relative position of the linear encoders based on the measured position of the limit switches, and provides some error feedback information. The total errors between the target wire position and the actual position attained are <+/-2% of a 1-mm width beam (see Fig. 4).

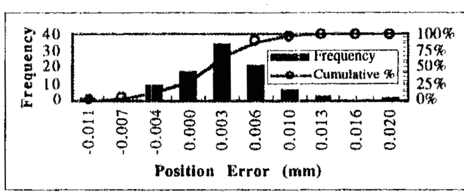

Figure 4. The above histogram above shows a typical distribution of wire/scraper movement errors of WS/HS #45 vertical axis.

The distribution core is sensed by carbon wire as the beam intercepts the wire. A small portion of the beam's energy is imparted to the wire causing secondary electron emission to occur. The secondary electrons leaving the wire are replaced by negative charge flowing from the electronics. This current flow for both axes is connected through a bias battery to an electronic lossy integrator circuit and followed by an amplification stage.

The integrator capacitance and amplifier gain are set to allow a very wide range of values of accumulated charge. The lossy integrator circuit reset time constant is 1 ms.

Data are acquired by digitising the accumulated charge through the lossy integrator at two different times within the beam pulse. The acquired charge difference acquired by subtracting the two values of charge within the macropulse provides a low noise method of relative beam charge acquisition. For the wire scanner, the bias is set to optimise secondary emission and limit the effects of positive ion collection by the wire. The scraper is biased slightly positive, sufficient to inhibit secondary emission and collect only 6.7-MeV proton charge. The wire and scraper accumulated charge signals are digitised using 12 bit digitisers. The analog noise floor has been measured to be 0.03 pC, a noise level slightly lower than the scraper digital LSB noise level of 0.15 pC using the highest gain settings within the detection electronics.

The front-end electronic circuitry, mounted on a daughter printed circuit board, is connected to a motherboard that has all of the necessary interface electronics to communicate to EPICS via a VXI controller module. A software sequence was written within EPICS to control and operate WS/HS instrumentation. The sequence instructs the VI to move the wire and scraper to a specific location, acquire a distribution data point from either the wire or scraper, normalise the acquired charge with a nearby toroidal current measurement, graph the normalised data, and write the distribution to a file. The sequence also instructs IDL to calculate the first through fourth moments, fit a gaussian distribution to the wire scanner data, and calculate the point at which the beam distribution disappears into the distribution background noise.

To plot the complete beam distribution for each axis, the wire scanner and two scraper data sets must be joined. To accomplish this joining, several analysis tasks are performed on the wire and scraper data including,

1) Scraper data are spatially differentiated,
2) Wire and scraper data are acquired with sufficient spatial overlap, and
3) Differentiated scraper data are normalised to the wire beam core data.

The scraper data need only be normalised in the relative charge axis since the distances between each wire and scraper edge are known within 0.25-mm. In addition, the first four moments and the point at which the beam distribution disappears into the noise are also calculated for the combined distribution data.

3 TYPICAL ACQUIRED DISTRIBUTIONS

Figure 5 shows a data from WS/HS #26 with some slight mismatch generated by increasing the field above nominal by 5% in the first matching quadrupole magnet. These typical WS/HS profiles show distributions with a dynamic range of > 10^5:1. The calculated rms widths are 1.10 and 1.13 mm for the horizontal and vertical distributions, respectively. The point at which the distributions rise out of the noise floor are 5.9 and –8.2 mm for the horizontal axis and 5.8 and –6.7 mm for the vertical axis. The WS/HS instrumentation is capable of providing distribution information to > 5X to 7X times typical rms widths of the beam.

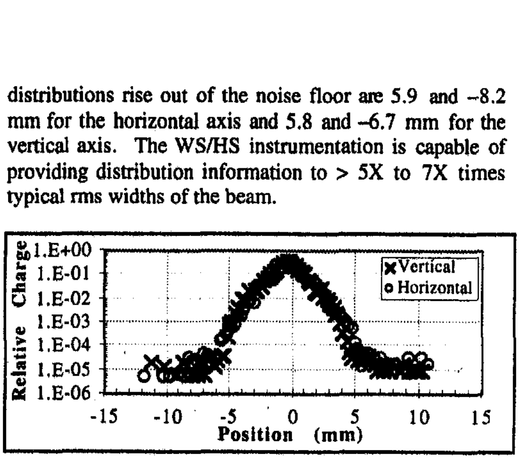

Figure 5. WS/HS distributions, such as #26 shown here, have a typical dynamic range of > 10^5:1.

4 WIRE/BEAM AND SCRAPER/BEAM PHYSICS

The choice of bias potential was determined by measuring the wire/scraper potential versus beam-related current. The resulting data displayed in fig. 6 show that the wire is optimally biased at -6 to -12 V and the scraper is optimally biased at +20 to +30 V.

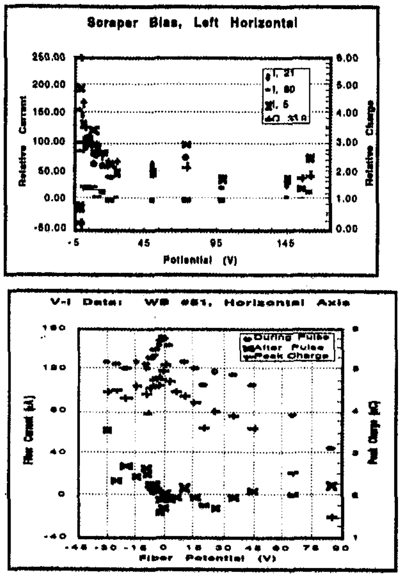

Figure 6. The above graph shows the scraper relative current as a function of the bias potential on the scraper.

The net wire current near the 0 V potential is approximately 15% higher than at either +6 V or –10V bias. One proposed cause of the elevated net wire current is the interception of electrons and ions from off-energy protons ionising residual background gas - both of these ionised species creating further secondary emission. As the wire is biased negatively, the intercepted electrons are rejected causing a reduction in secondary emission, and as the wire is biased positively, the intercepted ions are rejected causing a reduction in secondary emission. If the intercepted electron-ion pairs are the mechanism for the elevated net current, the wire should be biased to not include this additional 15% net current component. Also note that as the wire bias is positively increased from 0 V to > +100 V, the wire secondary electron emission is inhibited and the net wire current reduces to very near zero. As expected, it is clear that a large positive bias reduces the wire detection signal. Furthermore, it appears that the wire collects positive ions with < -25 V bias potentials well after the beam pulse. This additional limits how the amount of negative bias that is applied to the wire for proper secondary emission operation.

The scraper detection goal is to inhibit secondary emission and detect only 6.7-MeV protons. With 0 V applied to the scraper, the scraper net current is also elevated. With approximately +25 V bias applied to the scraper, the secondary emission is almost entirely inhibited. Furthermore, with this +25 V bias, no ions appear to be collected after beam pulse.

4 SUMMARY

A combination of a wire scanner and a halo scraper has been integrator into a single very wide dynamic range beam profile instrument. Nine of these profile instruments have been developed, installed, and operated at Los Alamos to measure the predicted beam halo generated by a magnetic lattice. These instruments are performing as expected and are present acquiring beam halo data.

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