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TITLE:

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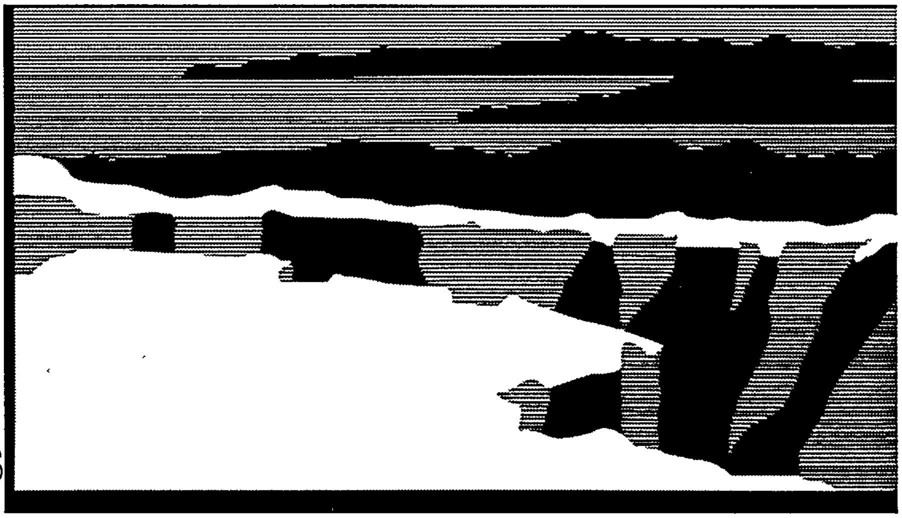

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Beam Diagnostics Instrumentation for a 6.7-MeV Proton Beam Halo Experiment*

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Abstract

A 52-magnet lattice is presently being installed in the Low Energy Demonstration Accel-erator (LEDA) facility between the radio frequency quadrupole (RFQ) and the simple LEDA high-energy beam transport (HEBT) [1,2]. The purpose of this FODO-lattice beam transport is to provide a beam line apparatus to measure the formation of beam halo and compare the measured data with halo simulations. To attain this measurement goal, several types of beam diagnostics instrumentation are being installed in the magnet lattice. The instrumentation suite includes nine beam profile measurement stations capable of detecting the beam distribution charge past 0.01% of the distribution peak. These profile measurement stations each use a slow wire scanner to detect the distribution core, a graphite/copper scraper that detects the "tails" of the distribution, and a separate prompt gamma loss measurement that detects that the "tail" particles are protons with energies greater than approximately 4-MeV. Included also in the instrumentation suite are five pairs of beam position monitors (BPM), five scintillator/photomultiplier tube loss monitors (BLM), three pulsed-current measurements, and a time-of-flight energy measurement. This paper describes each instrument, initial test data, and how they are expected to perform.

1 HALO EXPERIMENT LAYOUT

The primary purpose of a newly-installed 52-magnet FODO-lattice transport is to provide a vehicle to measure phase space halo. The quadrupole magnets are spaced every 21 cm so that beam measurement hardware may be interspersed between the magnets. Pictured in fig. 1 are most of the beam measurement hardware consisting of a wire scanner and halo scraper assembly (WS/HS), beam position monitors, a pulsed beam current transformer, a resistive wall current monitor (RWCM) for monitoring the central beam phase and energy, and loss monitors (not pictured).

The first four quadrupole magnets in the lattice are independently powered so that their gradients can be adjusted to match and mismatch the RFQ output beam to the lattice. Depending on how the magnets are adjusted, the development of specific types of halos is possible. These phase space halos manifest themselves as various shapes of "shoulders" on the projected beam distributions as measured by the WS/HS assemblies.

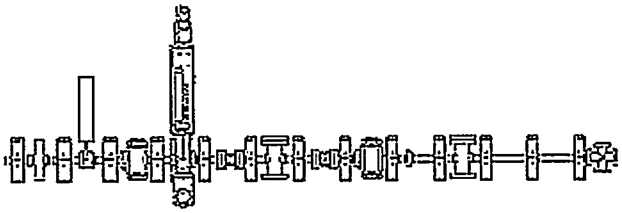

Figure 1. First section of the 52-magnet lattice contains the 13 quadrupole and 2 steering magnets, and the initial set of beam diagnostics measurements that will help measure the transverse beam halo.

Table 1 shows the locations of various beam diagnostic components and steering dipole magnets as defined by the space upstream of the numbered quadrupole magnet. The WS/HS assemblies measure projected beam distributions in both horizontal and vertical planes at 9 locations within the lattice. The first single location is used to verify the RFQ output beam's distribution. The two sets of 4 WS/HS provide beam matching and rms beam emittance information in the middle and end of the transport lattice. The mid-lattice set of 4 WS/HS assemblies measure the beam's match condition after the beam has sufficiently debunched to reduce any longitudinal space charge issues. The final set of 4 WS/HS assemblies provide sufficient mismatch information to detect two possible mismatch modes, the quadrupole and "breathing" modes [3].

The beam steering plan is to correct the beams position at the end of every set of BPM/steering magnet associated pairs separated by approximately 10 quadrupole magnets (see Table 1). Since the FODO-lattice period has a phase advance of approximately 80 degrees, each pair of BPMs can detect and each pair of steering magnets can correct the beam's position and angle.

Pulsed current measurements are monitored at the beginning, middle, and end of the transport lattice. Loss measurements are located over the steerers approximately 1 m from the beamline center. Finally, there is a set of

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RWCMs to allow for the measurement of the time of flight of the bunched beam so that central beam energy and phase may be measured.

Table 1. Halo lattice beamline component locations

Device	Locations (Quadrupole Magnet #)
WS/HS	5, 21, 23, 25, 27, 46, 48, 50, 52
BPM	6, 8, 17, 19, 28, 30, 38, 40, 49, 51
Steerers	4, 6, 15, 17, 26, 28, 36, 38, 47, 49
BLM	5, 16, 27, 37, 48
Toroid	2, 24, 44
RWCM	4, 9

2 BEAM PROFILES: WS/HS

The WS/HS mechanical beamline device, pictured in fig. 2, shows there are two types measurement devices that provide projected beam distribution information: a slow wire scanner and a pair of water-cooled graphite scrapers [4]. For each axis, there is a movable slow wire scanner that measures the beam's core distribution, i.e., inside +/- 3 rms widths. The outer edges of the beam distribution, i.e., outside 2.5 rms widths, are measured by the scrapers. Secondary electrons emitted from the 0.033-mm C monofilament detect the beam distribution or relative beam charge density versus transverse wire location. Since the 6.7-MeV protons range out in C in < 0.3 mm, the 1.5-mm thick graphite scrapers capture all of the beam and are cooled with a brazed copper plate [4]. These graphite scrapers are biased so that the proton beam charge is collected and emitted electrons inhibited.

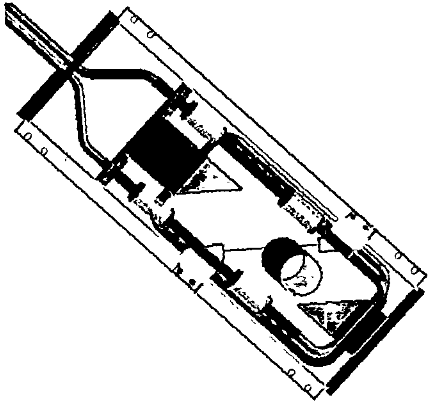

Figure 2. This picture shows the moving horizontal WS/HS assembly. The 2.8-cm beam pipe is shown for scale. A similar assembly oriented normal to this assembly provides vertical beam profiles.

Fig. 3 shows the result of what is expected from the combination of the wire scanner and scraper signals given a 1-mm rms width gaussian-distributed beam (i.e., expected match condition of the beam exiting the RFQ). There were four types of noise modeled: time-dependent beam current and position variations, wire placement error, and thermal signal-to-noise errors. The scraper data are normalized to the wire scanner data between 2.5 and 3 rms widths. Note that under these conditions we should be capable of measuring beam to approximately 5 rms widths.

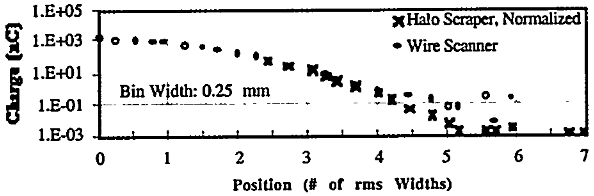

Figure 3. Simulation of beam distribution with four types of noise imposed on the signal. The binwidth in this particular simulation 0.1 mm.

The detection electronics for the scanner and scrapper for two beamline locations are contained in a single-wide VXI module. These electronics detect the negative charge leaving the electronic circuitry to replace electrons either leaving the wire or equalizing captured-proton scrapper charge. The detection is accomplished by integrating the charge using a lossy integrator op amp circuit. The resistor and capacitor in the amplifier feedback path were selected to optimize the amplifier's signal to noise and to be completely discharged within 0.1s. The signals are then digitized and passed to the EPICS control system [6].

Wire and scraper movement is accomplished by turning the attached lead screw assembly connected to a Compumotor OS22B-series stepper motor. The motor is control by a National Instruments PXI-7344 controller and the associated driver. The wire and scraper position is reported to the controller with a Dynamics Research Corporation optical linear encoder.

The EPICS control system uses portable channel access to pass process variables, such as a new wire location, to a National Instruments LabVIEW® virtual instrument running on a local computer. The VI then instructs the motor controller where to move the motor next and reports its new position once the controller has detected from the encoder that it has arrived.

3 PULSED BEAM CURRENT

The pulsed beam current measurement hardware is a high–permeable 122-mm ID X 156-mm OD X 30-mm length core with two sets of windings: a secondary and calibration winding (see Fig. 4). The secondary winding provides a +/- 4 V signal to an ADC for a 100-mA beam current. Fig. 4 also shows the steel cover that provides additional external-magnet-field shielding. The secondary winding signal is then fed to an ADC within a single-wide beam-current VXI module. This module has within it a pulsed current source that provides a calibrated method to verify the overall measurement accuracy. The toroids have been measured to have < 6%/ms droop and a < 1μs rise time which is equivalent to an approximate 0.009- to 620-kHz bandwidth.

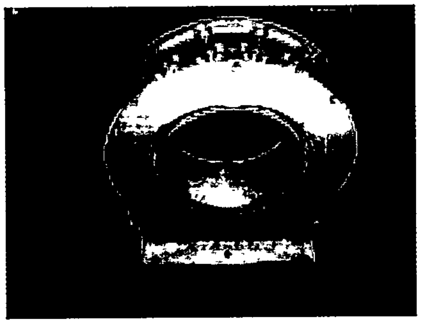

Figure 4. Bergoz ACCTs are installed with additional external magnetic-field shielding.

4 BEAM LOSS

For previous LEDA beam measurements, ionization chambers were used to measure the ionizing radiation resulting from beam impinging on beam line structures [7]. However, the amount of radiation was a factor of X10 lower than was initially expected resulting in a noisy measurement. To improve the loss monitor sensitivity, photomultiplier tubes (PMT) with a CsI scintillator have been ordered from Bicron. These devices will be mounted about 1 meter above the beam line between each pair of steering magnets.

5 BEAM POSITION

The BPMs are a standard 4-electrode micro-stripline design with an electrode aperture of 2.9 cm and a subtended angle of 45 degrees (see fig. 5). The mapped wire-based sensitivity was measured to be 2.170 +/- 0.005 dB/mm and with offsets no greater than +/- 0.5 dB.

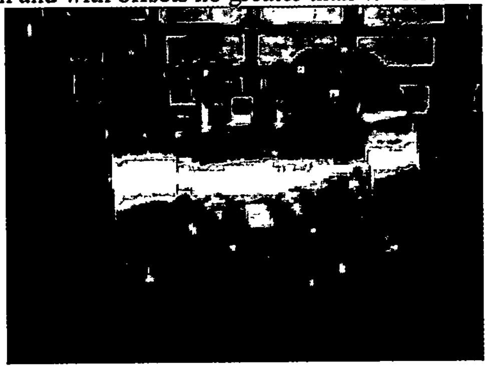

Figure 5. All of the BPMs have a sensitivity of 2.170 +/- 0.005 dB/mm and offsets < +/-0.5 dB.

The BPM electrode signals are fed to a VXI module that contains four independent AD8307 successive approximation amplifier channels. Each electrode's signal is detected, amplified, and digitized so that the signals from opposite electrodes may be subtracted, thereby creating a log ratio processor [8]. Fig. 6 shows a typical result of this subtraction. Within the processor, we have a calibrator so that signals may be fed either trough the BPM or through the processor to correct the errors shown in fig. 6 to < +/-0.05 dB [9].

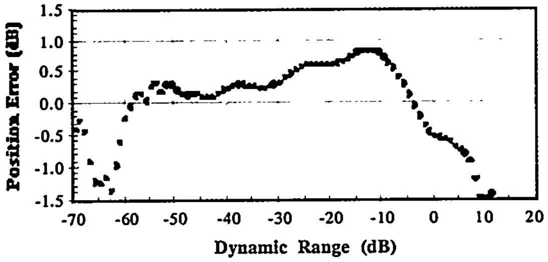

Figure 6. Position electronics uncorrected-error over the operational dynamic range of the circuitry.

5 CENTRAL BEAM ENERGY AND PHASE

The beam energy is measured using two newly installed RWCM. Their design was optimized for detecting the phase of the 350-MHz bunched beam. Twenty four, 1.2 kΩ resistors are soldered across a short ceramic vacuum break. A small core of ferromagnetic core in combination with the resistors provide a low frequency corner frequency of approximately 100 MHz. With a drift distance of approximately 1.05 m, 1-keV resoultion time-of-flight energy measurement will be made [10].

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