LA-UR-01- 3219

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EXPERIENCE WITH THE LOW ENERGY DEMONSTRATION ACCELERATOR (LEDA) HALO EXPERIMENT BEAM INSTRUMENTATION*

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Abstract

A 52 quadrupole-magnet FODO lattice has been assembled and operated at the Los Alamos National Laboratory. The purpose of this lattice is to provide a platform to measure the resulting beam halo as the first few magnets of the lattice produce various mismatch conditions. These data are then compared with particle simulations so that halo formation mechanisms may be better understood. The lattice is appended to the LEDA 6.7-MeV radio frequency quadrupole (RFQ) and is followed by a short high-energy beam transport (HEBT) that safely dumps the beam into a 670-kW beam stop. Beam diagnostic instruments are interspersed within the lattice and HEBT. The primary instruments for measuring the beam halo are nine interceptive devices that acquire the beam's horizontal and vertical projected particle density distributions out to greater than 10^5:1 dynamic range. These distributions are acquired using both traditional wire scanners and water-cooled graphite scraping devices. The lattice and HEBT instrumentation set also includes position, bunched-beam current, pulsed current, and beam loss measurements. This paper briefly describes and details the operation of each instrument, compares measured data from the different types of instruments, and refers to other detailed papers.

1 INTRODUCTIONS

The primary purpose of a 52-quadrupole-magnet FODO lattice is to provide a vehicle to measure phase-space halo. The quadrupole magnets are spaced every 21 cm so that beam measurement and other mechanical hardware may be interspersed between the magnets. Pictured in fig. 1 is the lattice that contains beam measurement hardware consisting of a wire scanner and halo-scraper assembly (WS/HS), beam-position monitors, a pulsed-beam-current transformer, and loss monitors. The beam position measurements also have the capability of reporting bunched beam current.

The initial-four quadrupole magnets in the lattice are independently powered so that their gradients are adjusted

development of specific types of halos has been documented. These phase space halos manifest themselves as various shapes or "shoulders" on the projected beam distributions as measured by the WS/HS assemblies.

Table 1 shows the locations of various beam diagnostic components and steering dipole magnets as defined by the space downstream 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 WS/HS located at quadrupole magnet #4 is used to verify the RFQ-output-beam distribution. The two sets of four WS/HS provide beam matching and rms beam emittance information in the middle and end of the transport lattice. The set of four WS/HS assemblies located between magnets 20 and 26 measure the beam's match condition after the beam has sufficiently debunched to reduce any longitudinal space charge issues. The set of four WS/HS assemblies located between magnets 45 and 51 provide sufficient mismatch information to detect two possible mismatch modes, the quadrupole and "breathing" modes.

Figure 1. Shown above are the initial 8 quadrupole magnets , 2 steering magnets, and the initial beam diagnostic instruments in the quadrupole-magnet lattice.

The beam-steering plan corrects the beams position at the end of every set of BPM/associated steering magnet

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 position and angle.

Pulsed current measurements are monitored at the beginning, middle, and end of the transport lattice. Bunched beam current measurements are acquired at each BPM location. Loss measurements are located over the steering-magnets approximately 1 or 2 m from the beam line center.

Table 1. Halo lattice beamline component locations

Device	Locations (Quadrupole Magnet #)
WS/HS	4, 20, 22, 24, 26, 45, 47, 49, 51
BPM	5, 7, 16, 18, 27, 29, 37, 39, 48, 50
Steerers	3, 5, 14, 16, 25, 27, 35, 37, 46, 48
BLM	4, 15, 26, 36, 47
Toroid	1, 23, 43

2 BEAM PROFILES

Throughout the halo lattice there are specific beam instruments that acquire horizontally and vertically projected particle-density 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 (see fig. 2) 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 subroutines analyze and plot the acquired distributions. This paper describes this beam profile instrument, describes our experience with its operation, compares acquired profile data with simulation, and refers to other detailed papers.

Figure 2. One of 2 WS/HS actuator assemblies per WS/HS station, these profile measurements detect the profile out to 10^5:1 in dynamic range.

3 BEAM LOSS

Beam loss is measured by detecting the gamma radiation resulting from the beam intercepting the beam pipe or other structures. A CsI scintillator attached to a 5-cm photomultiplier (PM) allows the detection of the interaction radiation over a dynamic range of $> 10^5$:1. The signal from high gain PM tube is fed to a transimpedance amplifier via a coaxial cable. The resultant bandwidth of 170-kHz allows for detection of 1-μs radioactive events.

Several experiments were performed to validate the performance of the loss monitors. The primary experiment was performed by intentionally allowing 1.6-mA beam current, as measured by the AC current transformers, to impinge on the beam pipe and measure the resulting signal from the upstream and downstream BLMs. This measurement showed that the BLMs were sufficiently sensitive to detect less than 1-μA of beam loss but subsequent drift measurements limits its use to approximately 1.6 μA.

4 PULSED & BUNCHED BEAM CURRENT

The pulsed beam current in the lattice is measured with a set of three AC Current Transformers manufactured for LEDA by Bergoz [1,7]. These transformers performed as specified with resolution and accuracy of < 0.1 and 0.5 mA.

The bunched beam current is the sum of the four electrode signals from a beam position monitor (BPM). These 350-MHz signals are summed after they have been process using a logarithmic amplifier/detector. To then acquire a magnitude proportional to the 350-MHz fundamental bunching current, the anti-log is taken of this digitized and summed signal. The result of this measurement and a simulation using LINAC is shown in fig. 3. Note that as the beam drifts through the halo
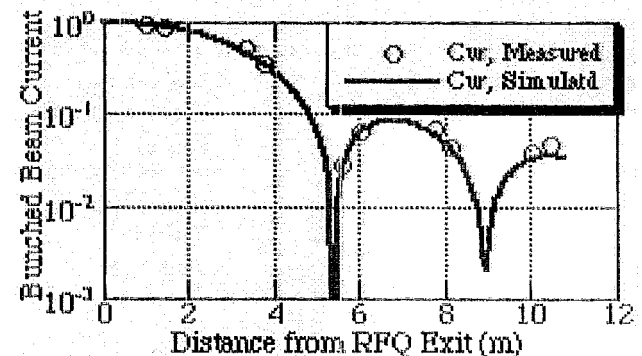

Figure 3. The relative bunched beam current is plotted here as a function of distance from the end of the RFQ. The reduction in bunched beam current is due to beam debunching and resulting in an overlap of itself twice within the halo lattice.

lattice, the 350-MHz fundamental component decreases in amplitude even though the pulsed beam current measured by the AC current transformers shows no change. This drop in bunched beam current is due to beam debunching as it drifts through the lattice. Furthermore, fig. 3 shows how neighboring bunches overlap one another at 2

locations within the lattice. Even though neighboring bunches overlap, there is sufficient 350-MHz current modulation to use devices such as BPMs to detect beam position, current, and possibly other beam parameters.

5 BEAM POSITION

The beam position measurement consists of a traditional micro-stripline type of beam position monitor (BPM), a cable plant, a 200-kHz log-ratio electronics processor, and an interface from LabVIEW to EPICS that provides the linearization and calibration algorithms. Fig. 4 shows the quality of the position and bunched beam current measurements presently installed in the 10 lattice-BPM locations. An in-situ calibration procedure corrects for non-linearity's and logarithmic non-conformities in the electronics processor. The outcome of a typical calibration is shown in fig. 4. Note that the relative position error throughout a 100:1 (40 dB) dynamic range in beam-current is < +/- 0.03 mm. Furthermore, a dynamic range of 5000:1 (76 dB) is easily obtained using a +/- 0.05-mm criterion.
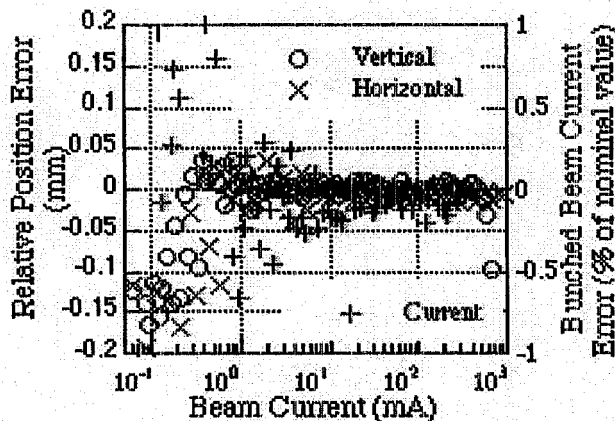

Figure 4. The relative position and current errors acquired by the in-situ calibration hardware are plotted as a function of beam current. These data were converted using a traditional micro-stripline BPM whose sensitivity to a 6.7-MeV proton beam is 2.32 dB/mm.

For the LEDA halo experiment, absolute beam position error is important to the extent that the beam must be centered within the 28-mm ID beam pipe aperture to within 1 mm. This is especially important since as the beam is mismatched, the maximum radial extent of the beam has been measured to be > 9 mm in the areas of the lattice where the beam is nearly round. If the beam is displaced from center too much, scraping occurs and the measured distribution tails are perturbed. Therefore, it was determined that the position measurement must be capable of centering the beam in the beam pipe to within 0.5 mm (i.e., approximately 1% of the beam pipe diameter). An error assessment was performed of all known absolute errors, such as mechanical displacement errors of the BPM, cable mismatch errors, errors shown in

fig. 4, etc. The resulting root of the sum of the squares of the known errors is approximately 0.25 mm [Check this Dean and Jim].

Since the beam position instrumentation also provides bunched beam current, the innate resolution of this measurement is also measured during the calibration procedure. The resolution of the bunched beam current instrumentation is < 0.75% of the measured nominal values throughout the range of 1 to 100 mA.

6 SUMMARY

During the past six months, we have gained experience measuring the beam halo using a instrumentation that includes WS/HS profile, loss, pulsed current, bunched beam current, and beam position measurements. The WS/HS measure the beam's profile with a 10^5: 1 dynamic range. The pulsed and bunched beam current measure these current parameters with a resolution < 0.1 mA. The position measurements have an accuracy and resolution of <1% and <0.02% of the beam pipe ID over a 76 dB dynamic range in beam current. These instruments continue to be invaluable in measuring the beam halo so that a clearer understand of the halo generation mechanisms may be obtained.

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