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**Author(s):** John D. Gilpatrick,  
Thomas R. Hodapp  
Kenneth F. Johnson  
Derwin G. Martinez  
Ricardo P. Martinez  
John F. Power  
Chris R. Rose  
Robert E. Shafer  
Robert B. Shurter  
Matthew Stettler

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# LEDA AND APT BEAM DIAGNOSTICS INSTRUMENTATION

J. D. Gilpatrick, T. R. Hodapp<sup>†</sup>, K. F. Johnson, D. G. Martinez<sup>†</sup>, R. P. Martinez<sup>†</sup>, J. F. Power, C. R. Rose, R. E. Shafer, R. B. Shurter, M. Stettler  
Los Alamos National Laboratory, Los Alamos, NM, 87505, USA

## Abstract

A 20-MeV 100-mA-cw proton-accelerator, Low Energy Demonstration Accelerator (LEDA), is presently being developed, fabricated, and tested at Los Alamos National Laboratory (LANL). The beam diagnostic instrumentation for LEDA and the final 1700-GeV Accelerator Production of Tritium (APT) are classified into two categories: operation and characterization instrumentation. The operational instrumentation does not intercept or minimally-intercepts the beam and are sufficiently prompt and robust to provide accurate information to the operators and commissioners during full-current cw beam operation. The characterization instrumentation, primarily utilized during commissioning project-phases, operates under more traditional 100-mA-peak and approximately 0.1-mA-average beam-current conditions. This paper will review some of the LEDA and APT operational beam diagnostic instrumentation.

## 1 INTRODUCTION

### 1.1 Accelerator Description

To provide a reliable supply of tritium, a proton linear accelerator will be built as a part of a tritium production plant to be located at the Department of Energy Savannah River Site[1,2]. The APT facility will accelerate 100-mA cw protons from 75 keV to 1700 MeV using both normal-conducting (NC) and superconducting (SC) accelerating structures. The high energy beam is further transported and expanded onto target/blanket assemblies in a 16-cm by 160-cm rectangular distribution[3].

LEDA, the facility that will verify operation of the initial 20-MeV portion of APT, consists of an 75-keV 100-mA cw injector, an 6.7-MeV radio-frequency quadrupole (RFQ), a portion of the coupled-cavity drift-tube linac (CCDTL), and a small high energy beam transport (HEBT) that transports the beam to a 2 MW beamstop[4]. LEDA will be assembled so that the accelerator components are tested in a series of staged experiments. Experiment 1 has already tested the injector, Experiment 2 will integrate the RFQ and injector and will verify the RFQ operation, and Experiment 3 will verify the CCDTL operation.

### 1.2 Beam Diagnostics Instrumentation Goal

The beam-diagnostic-measurement goal is to provide sufficient and necessary beam information to the accelerator commissioners and facility operators to operate the machine under normal and expected off-normal conditions[5]. The measurement requirements for much of the beam diagnostics instrumentation are given in Table 1. Characterization diagnostics more fully measure the six dimensions of beam phase space, but typically at the cost of intercepting the beam. These beam characterization measurements are most useful at key locations throughout the accelerator and at the end of each staged-commissioning-experiment.

Table 1: Beam diagnostics measurement requirements

Beam Parameter	Range	Accuracy	rms Precision	Bandwidth (kHz)
Current:				
cw	0.5-100 mA	0.5 mA	<0.3 mA	dc-0.5
Pulsed	0.5-100 mA	0.5 mA	<0.3 mA	<0.02-200
Bunched	0.5-100 mA	<5 mA	<0.3 mA	<0.02-200
Loss (Fast Protect)	10000:1	few mA	≈50 pA (≈ 1 μA)	<0.005 (40)
Position	± 0.8 radius	1% radius	<0.5% radius	200
Traj. Angle	<±20 mrad	<1 mrad	<30 μrad	200
Phase	±180°	±3°	0.1°	200
Energy	±20% nom. W	±0.2% nom. W	0.01% nom. W	200
Trns. Prof.	± 3 σ	250 μm, 5 μA	100 μm, 2 μA	0.01
Energy Spread	± 3 σ	<0.3% ΔW/W	<0.1% ΔW/W	< 0.0005
Phase Spread	5-40°	<5°	<1°	<0.0005
Trns. Halo	10 <sup>6</sup> - ≈30 pA	>100 pA	20 pA	<0.0005

The operational (permanent) diagnostics provide beam information using non-interceptive or minimally interceptive techniques. The permanent diagnostic's non-interceptive or minimally interceptive nature allow them to operate under a variety of cw and pulsed beam conditions.

Each of the beam diagnostic measurements will have an integral error-correction subsystem that corrects for

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most absolute instrumentation errors. These error corrections are either implemented with digital signal processing in the electronics processors or are added software algorithms in the EPICS computer control system[6].

## 2 TYPES OF MEASUREMENTS

### 2.1 Beam Current Measurement

LEDA and APT will use three types of current measurements: dc- or average-beam, pulsed-beam, and bunched-beam current measurement[7,8]. Average current measurements are most useful during normal facility operation. Pulsed or transient beam-current measurements provide transient-current information during startup, off-normal-event recover, and pulsed-beam commissioning. Average beam currents will be acquired with a dc-current transformer that consists of a multiple saturable-core beamline device and an electronics processor. Pulsed- or transient-beam-current measurements consist of a single, high-permeability core with one multi-turn winding that acts as the secondary winding of a transformer with the beam acting as the primary winding. Bunched-beam-current measurements are proportional to the peak bunched-beam current and sum the 350-MHz bunched-beam induced signals from the four-electrode beam position monitors (BPM).

### 2.2 Beam Loss Measurements

Beam-loss measurement systems have a twofold purpose: to act as an input to the fast protect system that protects beamline hardware in case a catastrophic equipment failure should cause the beam to impinge on a beamline component, and to sense for slightly off-normal accelerator conditions such as beam mismatches[7,9]. Beam loss will be measured by using an argon- or nitrogen-filled ionization chambers to sense the ionizing radiation associated with lost beam. With typical sensitivity to ionizing radiation of 50-70 nC/rad and transient response to radiation-generated events of ten's of ms, the beam loss monitors (BLM) can easily sense a large unexpected radiation transient or a continuing excessive beam loss.

### 2.3 Transverse Centroids (Position and Angle)

The beam-position measurements consist of four components: a beam-position monitor (BPM) and its associated cabling, an electronic processor, an on-line calibrator, and algorithms in the computer control system that convert the processor signals into beam positions[7,10,11,12,13,14]. The BPM, designed to measure both transverse planes, has four micro-stripline transmission lines terminated in their characteristic impedance. As the 350-MHz bunched beam passes by the BPM electrodes, the beam image currents induce a current on these electrodes. The electrode signals are then fed to the processing electronics via high-quality rf coaxial

cables. Typical BPM electrode 5-cm-lengths, 38°-subtended angles, and 1- to 10-cm radii, provide centered-beam signal powers of -3 to +12 dBm with 3.3- to 0.3-dB-per-mm probe sensitivities.

The electronics processor down converts the electrode signals to 2-MHz sinusoidal signals whose relative amplitudes are equal to the original probe 350-MHz Fourier component. The log ratio process on opposite-electrode 2-MHz signals is then performed using an analog logarithmic amplifier and a simple digital summing process. The processor's digital-output signal provides data to the software correction algorithms that compensates for the nonlinear BPM transfer function and the irregularities of the complete measurement system.

### 2.4 Longitudinal Centurions (Phase and Energy)

To properly set the CCDTL and CCL accelerating-cavity-fields' phases and amplitudes, the beam energy and phase must be measured at many locations throughout the accelerator[7,15]. The energy measurement is accomplished by performing a time of flight (TOF) measurement of the beam's relative velocity. This TOF technique uses signals from two cylindrically symmetric capacitive probes separated by a known drift distance. The TOF measurement system determines the time a particular bunch takes to travel this drift distance, and therefore the velocity, by measuring the phase difference between the 350-MHz probe signals. The energy is then calculated from the measured beam velocity.

The beam phase is the other required beam parameter necessary for proper cavity tuning. This measurement is performed by measuring the phase difference between the cavity accelerating field and the bunch. To provide an accurate measure of the beam phase, the phase-delay errors due to the energy-dependent drift times between the cavity and capacitive probes are subtracted from the actual measured phase. For both the phase and energy measurements, phase-measurement precisions of 0.1° at 350 MHz with the required overall bandwidths are typical.

### 2.5 Transverse Profiles

The primary goal for transverse profile measurements is to measure the cw full-current transverse profiles, the rms emittance and match parameters, and to verify that the beam is matched to its magnetic transport[7,16,17]. To acquire these rms match parameters, approximately 10 profile measurements will be placed within an approximate  $2\pi$  range of phase advance. For the bulk of the profile measurements, two measurement techniques will be used to measure the beam profiles.

For beam energies below 200 MeV, the beam energy that is deposited in the background residual gas near the beam region fluoresces. The fluorescent-light flux density is dependent on the local residual-gas partial pressure, the beam velocity, and the beam-current density. To acquire sufficiently precise profile information, the combined camera signal-to-noise (S:N) and light-to-

background ratios must be  $>90:1$  at the beam distribution peak. At beam energies  $>100$  MeV, these S:N ratios drop below 100:1 with gas pressures of 10-6 Torr, 100-mA cw-beam currents, and 2-mm rms widths. Also, since APT will be required to operate under pulse beam conditions, many of the cameras viewing beam profiles will require either a light intensifier or increased light-integration times.

For beam energies above 200 MeV, a flying-wire will acquire beam profiles. The expected precision of the profile measurement is  $\sim 10$  pC (or 2  $\mu$ A) of beam charge (current) by 100  $\mu$ m of relative wire position. For a wire made of SiC or C both having specific heats of approximately 1.2 joules per gram-K, the wire-temperature rise during a single sweep is about 320 K based on a 10-m/s wire velocity. For 1700-MeV protons, this temperature rise is also based on an energy-loss per unit length in these materials of 2 MeV-cm<sup>2</sup>/g and 1.8 MeV-cm<sup>2</sup>/g, respectively. The profile will either be measured by collecting the secondary electrons from the wire/beam interaction, measuring the moving-wire charge depletion (secondary electrons leaving the wire), or measuring the ionizing radiation produced by scattered protons interacting with the accelerator structures. The wire position will be measured by recording and integrating an attached tachometer signal.

To measure the expanded beams near either the final beamstop or target/blanket assemblies for LEDA or APT, expanded beam profile measurements are required. These expanded beam measurements use a multi-wire harp to acquire the horizontal, vertical, and two 45° projections. The wire composition may either be SiC, Ta or C. The 100- $\mu$ m diameter SiC and Ta wires will operate at about 1200 K and 1600 K, respectively. Two focal-plane-array IR cameras will view the hot-wire thermal image through front-surface cylindrical mirror optics. The optics path to the cameras, which will be outside the radiation area, will be a labyrinth to attenuate neutrons.

### 2.6 Longitudinal Profiles (Phase and Energy Spread)

Beam-momentum spread and space-charge forces cause the beam-bunch length to rapidly increase after leaving the linac[7,18]. Multiple bunch-length or phase-spread measurements close to and in the linac can provide useful information on the linac operation and the momentum spread of the beam. Specifically designed image-current probes with bandwidths  $>4$  GHz will be used to measure the Fourier-harmonic content of the microbunch-produced wall image currents. The phase spread or bunch length is acquired by measuring the ratio of the fundamental and higher harmonics of a beam-induced signal from these image-current probes. The linac-beam energy spread is acquired by measuring the beam's transverse profile in a

dispersive region of the beam transport, such as in the bends of the APT HEBT.

### 2.7 Beam Halo Measurements

As with beam loss, existence of beam halo will be another sensitive measure of beam mismatch. The halo measurement relies on intercepting a portion of the beam outside  $\pm$  two rms-widths of the beam transverse profile. The halo-monitor jaw or plate, constructed of graphite or tantalum, will intercept the beam for a short period of time. A nearby BLM integrates the induced gamma radiation, which is proportional to the intercepted beam. Downstream collimators will intercept and localize the scattered radiation from these scrapers and localize the resultant activation.

## 3 SUMMARY

This paper discussed the requirements and measurement techniques necessary to measure the APT and LEDA accelerator-beam parameters. The topics included were the operational beam diagnostic instruments to measure beam current, loss, position, angle, phase, energy, transverse and longitudinal profiles, and halo.

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