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LEDA & APT BEAM POSITION MEASUREMENT SYSTEM: DESIGN AND INITIAL TESTS[*]

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Abstract

Beam position measurements are being designed and fabricated for the Low Energy Demonstration Accelerator (LEDA), a 20-MeV, 100-mA-cw proton-accelerator, presently under construction at Los Alamos [1]. Similar position measurements will provide position information for a steering scheme within the Accelerator Production of Tritium (APT) linac magnetic lattice. The steering scheme, which centers the beam in the magnetic lattice, uses two position measurements and two translatable quadrupole magnets every 5.5-FODO-lattice periods. What makes these beam position measurements unique is how they will attain, maintain and verify the required accuracy. The position measurement systems consist of micro-stripline beam position monitors (BPMs) and RF coaxial cables, log-ratio processors, on-line error correction sub-systems, and a control system interface including associated algorithms and computer software. This paper discusses the mapping of the BPM probe response, the algorithm used to calculate low beam-velocity response, and the expected log-ratio processor performance.

1 INTRODUCTION

1.1 Beam Position Measurement Purpose

During the commissioning and operation of the LEDA radio frequency quadrupole (RFQ), beam position measurements serve two purposes. They provide sufficient beam position information for centering the 6.7-MeV beam both in the high energy beam transport (HEBT) magnetic lattice and on the high power beamstop, and they verify that the quadrupole magnetic field settings are properly set.

For APT, position measurements provide sufficient information for centering the beam in the magnetic lattice throughout the linac and HEBT. By placing BPM pairs within quadrupole magnet bores separated by ~90 degrees of phase advance, both beam position and trajectory angle are acquired. For example, early in the coupled cavity drift tube linac (CCDTL), where the phase advance per

FODO lattice period is 78 degrees, two BPMs are installed in two focusing quadrupole magnets separated by a defocusing quadrupole magnet.

1.2 APT Steering Schemes

The CCDTL BPM placement scheme repeats every 5.5-lattice periods, allowing operators to correct for various static random errors. This scheme was simulated using budgeted beam-position-measurement errors similar to those shown in Table 1 and multiple quadrupole magnet misalignments, field amplitude errors, and other errors. For a 25-mm radius BPM, the total budgeted position-measurement precision and accuracy is 0.06- and 0.21-mm, respectively. Typical accuracy errors include BPM alignment errors and precision errors include RF cable isolation and BPM vibration.

Table 1: Beam-position measurement-error budget table using a 25-mm radius BPM.

Measurement Components	Precision (mm)	Accuracy (mm)
BPM	0.01	0.12
RF Cable Plant	0.0003	0.02
On-line Calibrator	0.03	0.16
Log-Ratio Processor	0.04	0.04
TOTAL	0.05	0.21

APT beam steering is accomplished by translating a quadrupole magnets pair for each BPM pair with the last steerer residing in the same focusing quadrupole magnet as the first BPM [2]. The additional half FODO lattice in the steerer/BPM-pair placement period allows a single axis of the beam's central trajectory to be corrected every 11-lattice periods.

2 MEASUREMENT SYSTEM

2.1 System Description and BPM Design

The position measurement system consists of four components; the BPM and its associated set of RF cables, an electronics processor, on-line error correction circuitry,

and an Experimental & Physics Industrial Control System (EPICS) interface [3,4,5].

The BPMs are a four-electrode micro-stripline design with electrode characteristic impedances of 50-Ω. Each BPM has a physical feature that provides alignment verification with respect to the facility alignment references and ultimately with respect to the linac magnetic lattice. These alignment features also serve as a method to mate the BPM to its mapping fixture so that it's mapped electrical characteristics are directly related to the measured beam position. For the pictured LEDA HEBT BPM shown in Fig. 1, four optical-alignment-monument mounts are welded on the downstream vacuum flange. Those APT BPMs that are mounted within quadrupole magnets have additional constraints. For these BPMs, construction processes and materials are used to minimize the BPM's permeability and to ensure that the quadrupole magnetic fields are undistorted.

Figure 1: This LEDA 5-cm-aperture micro-stripline BPM has a 45 degree subtended angle and a 5-cm-length electrode.

2.2 Log-Ratio Electronics Processor

The electronics processor uses a log-ratio technique for analyzing the beam's position by demodulating and converting each BPM-electrode 350-MHz-signal current into a logarithmic signal voltage [6]. Each logarithmic lower-bandwidth analog voltage is digitized. The opposite electrode converted signals are then subtracted from each other to produce a stream of digital words that represent the detected log-ratio beam position.

Previously, demodulating logarithmic amplifiers were only available with limited input bandwidths. These limited bandwidth amplifiers forced the addition of a RF down converter to translate the BPM-electrode's fundamental RF signal to a frequency within these earlier amplifier's operational range. However, low-cost very-broad-bandwidth logarithmic amplifiers are now available and allow the exclusion of down converter circuitry in log-ratio processor designs. For example, the Analog Devices, Inc. AD8307 logarithmic amplifier has a 500-MHz bandwidth over a 92-dB dynamic range and can

operate at frequencies near 900-MHz with a reduced dynamic range.

As with previous versions, the logarithmic function is created by a series of amplifier stages that successively detect the RF signals and approximate the logarithm function in a piecewise linear fashion. Due to the detection technique, this type of logarithmic amplifier systematically deviates from the ideal logarithmic function. Fig. 2 shows how these deviations will effect the operation of the log-ratio processor. These data were acquired from a single AD8307 amplifier detecting a 350-MHz RF signal. The output signal mean and rms noise were acquired for each 1-dBm step of input signal power. The mean data were fitted to a logarithmic function and the residuals were plotted to show function-deviation information versus input beam current, where input beam current is derived from input signal power. Note that the logarithmic function deviation is approximately ±0.7-mm for a 50-mm aperture BPM over four decades of beam current. This deviation represents a worst case condition. In previous log-ratio processors, these amplifiers exhibited very similar logarithmic-function systematic errors. When used in pairs, the log-ratio detection method has a lower sysetmatic error behavior [5].
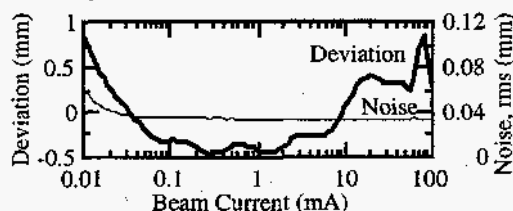

Figure 2: The above data show expected 350-MHz log-ratio position-detector performance using an AD8307 integrated circuit.

Fig. 2 also displays the rms noise characteristics of the AD8307 amplifiers. Because these logarithmic amplifiers contain many stages of detection and amplification, their noise figures are typically much larger than other beam position processing techniques. However, the AD8307 noise characteristics are sufficiently low to easily meet the APT and LEDA position measurement precision requirements. Note that these amplifiers are expected to provide beam position measurement precision of 0.04 mm within a 50-mm aperture BPM.

2.3 Error Correction and EPICS Interface

A unique feature of this particular measurement system is how the system's accuracy is maintained. During normal BPM operation, an RF relay connects a properly matched terminator to the downstream port of each BPM electrode. Additionally, this relay may also be switched to inject a 350-MHz signal from a stable and well-characterized 4-way RF splitter into each BPM electrode for measurement-system error correction. This error correction method will allow accelerator operators and commissioners, from within the accelerator control room, to verify and correct most measurement system errors. Early implementations of the log-ratio processor have

shown that systematic errors may be corrected to within a factor of X2 of the precision error using signal injection techniques [4,5].

Another unique feature is the method used to interface the log-ratio circuitry to EPICS. The current design calls for both the log-ratio processor and on-line correction module to be implemented as register-based VXI modules, and located in the same VXI crate. This module organization allows direct control and rapid automatic operation of both modules from the same control computer, typically referred to as an input/output controller (IOC). Both modules will implement full digital control and data acquisition via the VXI bus.

3 BPM CHARACTERIZATION

3.1 Mapping Characterization Process and Data

A mapping fixture was developed for LEDA and APT to accurately characterize the BPM beam-position response [7]. As a thin wire with an injected 350-MHz signal is accurately moved across a BPM aperture, the RF fields from the injected signal induce RF currents on the BPM electrodes. RF signal data from individual electrodes are acquired and the power ratios between opposing electrodes are calculated for each wire location. The resultant data maps are then fitted in a least squares sense to a 3rd-order 2-dimensional equation [8].

Fig. 3 shows a typical map of the 50-mm aperture BPM planned for use in the LEDA HEBT with its fitted 3rd-order surface fit. Typical mapped offsets and sensitivity terms are 0.07 mm and 1.36 mm/dB, respectively. The typical sensitivity terms are within a few percent of the theoretical values of 1.39 dB/mm based on a analytic circular-BPM model [6,9].

3.2 Low Beam-Velocity Correction

Because the relative beam velocities are low for the LEDA and APT CCDTL and coupled cavity linac (CCL) beams, the bunched beam fields deform such that the BPM offset, sensitivity, and 3rd-order terms will be slightly different from those acquired by the mapping fixture. A technique has been developed to correct these terms for low velocity beams and has been verified with beam experiments [9]. The technique consists of the following steps:
1. With $\beta=1$, adjust the electrode subtended angle and radius in the analytic model so that a new model-based map agrees with mapping fixture data.
2. Decrease β in the analytic model to agree with the expected beam velocity.
3. Produce new analytically-derived map.
4. Perform forward and inverse least-squares fits.
5. Change manufactured offsets in the initial mapped data by using the new low-β BPM sensitivity.

This procedure has been performed on 50-mm aperture LEDA BPMs and has shown sensitivities will increase to 1.76 dB/mm.
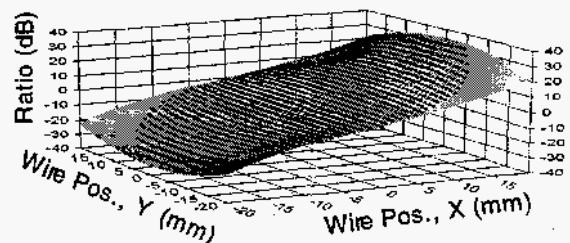

Figure 3: Position-sensitivity map of a BPM showing an opposing-electrode signal ratio for each wire location.

4 SUMMARY

This paper has discussed current LEDA and APT beam position measurement developments. These developments include the APT and LEDA beam steering scheme, changes to the log-ratio processor, the BPM characterization processes, and corrections to the BPM sensitivity due to low beam-energy effects.

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