# PROPOSED BEAM POSITION AND PHASE MEASUREMENTS FOR THE LANSCE LINAC*

J. D. Gilpatrick#, B. Blind, S. Kurennoy, R. McCrady, J. O'Hara, C. Pillai, J. Power, L. Rybarcyk
LANL, Los Alamos, NM, 87545, U.S.A.

*Abstract*

There is presently an ongoing effort to develop beam position and phase measurements for the Los Alamos Neutron Science Center (LANSCE) linac associated with an improvement project known as the LANSCE Refurbishment. This non-interceptive measurement's purpose is to provide both measurements of beam phase for determining RF-cavity phase and amplitude set points, and position for determining the 805-MHz linac input beam transverse position and trajectories. The measurement components consist of a four-electrode beam-position and phase monitor (BPPM), a cable plant that transports the 201.25-MHz signals, electronics capable of detecting phase and amplitude signals, and associated software that communicates with a mature LANSCE control system. This paper describes measurement requirements, proposed beam line device, initial concepts for the associated electronics, and some of the issues developing beam measurements for an operational facility.

## NEW LINAC BPPM REQUIRED

The LANSCE 805-MHz linac has a series of legacy beam-position monitors (BPMs) that contain four B-dot loops for beam-position measurements and an additional cylindrical-capacitive pickup, known as the "Delta-T loop." The Delta-T loops provide the 201.25-MHz bunched-beam signals to measure the beam's central phase with respect to a reference and determine the time of flight between accelerating cavities. This phase and time-of-flight information allows the LANSCE accelerator operators and operational scientists to set the accelerating modules' RF-fields phase and amplitude. Unfortunately, the B-dot position measurements do not reliably provide beam-position information.

Since there are no dependable non-interceptive beam-position measurements within this 48-module linac, the linac beam steering is corrected using beam-centroid information from slow wire scanners, and loss monitors. These measurement dependencies cause the linac tuning to be slow and eliminate auto-tuning possibilities. Therefore, new BPPM measurement systems are being developed for the 805-MHz linac.

## LANSCE BEAM "FLAVOURS"

Once extracted from their independent sources, the 750-keV $H^+$ and $H^-$ beams are combined in their low-energy transports by temporally multiplexing and injecting them into 16.7-MHz and 201.25-MHz bunching cavities. There they are partially bunched in preparation for their injection into the Drift Tube Linac (DTL), where the beams' 201.25-MHz time structures are maintained while they are being accelerated to 100 MeV. The $H^+$ beam typically has a 30-Hz Repetition Rate (RR) and a 0.625-ms long "macropulse" resulting in a Duty Factor (DF) of 1.875%. The $H^-$ beam has a more complicated time structure consisting of up to a 40-Hz RR and a 0.625-ms long "macropulse." This "macropulse" is further subdivided or chopped into ~1750 "minipulses" and consists of 300-ns-long beam pulses repeated with a RR of 2.8 MHz, the 72nd sub-harmonic of the 201.25-MHz bunching time structure. Ultimately, the "minipulse" length limits the measurement's ability to acquire valid beam position and phase information.

As both beams emerge from the DTL, they are magnetically separated. The $H^-$ beam's central phase delay is adjusted so that when the two beams are recombined prior to injection into the linac, each beam's central phase matches the proper 805-MHz linac RF bucket. The complicated transport beam line that accomplishes the adjustment of the $H^-$ beam's central phase with minimal disturbance to the beam's transverse characteristics is called the Transition Region (TR). The TR output beams are injected into the 805-MHz side coupled linac that accelerates these beams from 100- to 800-MeV. In the past, both beams were accelerated to 800-MeV but presently only the $H^-$ beam is injected into the linac and accelerated to 800-MeV. A spur beam line located near the beginning of the TR allows the $H^+$ beam to be transported to the Isotope Production Facility (IPF) beam line. Table 1 describes these conditions commonly called beam "flavours" or types of beams and timing structures that are transported through the linac and associated experimental areas, such as the Proton Storage Ring (PSR), the Proton Radiography (pRAD), or the Ultra Cold Neutron (UCN) areas.

The last row of Table 1 shows a particular beam "flavour" associated with the Weapons Neutron Research (WNR) experimental facility. Presently, each of the beam "flavours" is in its own individual 60-Hz half cycle or 8.3-ms period, except for those beams tuned for WNR. Unlike the other beam "flavours," this particular beam occupies the same "macropulse" period but in opposite 180-deg RF-phase buckets as the IPF beam. This $H^-$ beam has ~2.5X the charge in a single RF bucket and can be separated by multiples of ~1.8 microseconds, the 360th sub-harmonic of 201.25-MHz bunching time structure. Therefore, the BPPM signals will be a combination of the two species drifting through each BPPM bore, resulting in some additional measurement complications.

*Work supported by US Department of Energy.
#gilpatrick@lanl.gov

Table 1: Important LANSCE linac beam "flavours"

| Exp. Area | Beam Type | Minipulse | | Macropulse | | $I_{pk}$ | $I_{Avg}$ |
|---|---|---|---|---|---|---|---|
| | | DF (%) | RR (MHz) | DF (%) | RR (Hz) | (mA) | (μA) |
| IPF | H+ | N/A | N/A | 1.875 | 30 | 10 | 200 |
| MTS | H+ | N/A | N/A | 3.75 | 60 | 20 | 800 |
| UCN | H- | 17 | 5.4 | 1.875 | 30 | 10 | 60 |
| PSR | H- | 84 | 2.8 | 2.5 | <40 | 10 | 200 |
| pRAD | H- | 34 | 5.4 | 0.3 | 30 | 0.3 | 100 |
| WNR | H- | 0.008 | 5.4 | 6.25 | < 100 | ~0.7 | ~5 |

## MEASUREMENT REQUIREMENTS

Table 2 shows the BPPM measurement system's overall requirements, including such parameters as beam position, phase, and bunched beam current.

Table 2: Overall BPPM Measurement Requirements

| Parameter | Value |
|---|---|
| Position Repeatability (mm) | 0.1 |
| Position Accuracy (mm) | 1 |
| Beam Position Range (±mm) | 13 |
| Beam Position Response Time (μs) | 2 to 5 |
| Phase Repeatability (201.25-MHz-degrees) | 0.25 |
| Phase Accuracy (201.25-MHz-degrees) | N/A |
| Phase Range (201.25-MHz-degrees) | +/- 180 |
| Beam Phase Response Time (μs) | 50 to 100 |
| Current Repeatability (mA) | 0.05 |
| Current Accuracy (mA) | N/A |
| Current Range (mA) | 21 to 0.9 |
| Current Response Time (μs) | 2 to 5 |

There are two general goals for the placement of these BPPMs, namely to place a subset of BPPMs so that they provide both position and trajectory angle information, and to place BPPMs in the locations now populated by older and existing Delta-T loops, resulting in 19 locations within the linac.

Operational experience has shown that to minimize the beam losses in the linac, the $H^+$ or $H^-$ beam is injected into the 805-MHz linac such that established positions are achieved at a number of wire scanner locations. Once injected, the two beams are not steered throughout the rest of the linac. The proposed steering algorithm for placing the beam on the proper trajectory involves beam-position measurements before and after adjustment of upstream horizontal and vertical steerers. The resulting data are used to determine the relevant transfer-matrix elements between steerers and BPPMs, and subsequently, the proper settings of the steerers.

Through a set of simulations, locations in the linac were determined where BPPMs should be placed for the steering algorithm to work under a wide range of beam-optics conditions, such as for linac quadrupole doublets with settings of between 90% and 110% of their historic-average values and linacs with and without acceleration [1]. A single BPPM pair is not sufficient to assure that the beam is on the proper trajectory in all cases. Even for tunes where a particular BPPM pair is acceptable, configurations with three or four BPPMs out-perform a single BPPM pair prior to the 211-MeV beam stop.

Figure 1 shows the results of simulations with rms BPPM measurement errors of between 0.025 mm and 0.15 mm. For each BPPM configuration and rms BPPM error, 10,000 different sets of randomly generated measurement errors were used, and for each set the largest horizontal and vertical beam-centroid excursion after trajectory correction was determined. Then, rms values of the sets of maximum values were computed. Figure 1 shows plots of these horizontal and vertical rms values versus rms BPPM repeatability error, for the linac with acceleration and the historic-average settings of the quadrupoles. In simulating the steering algorithm, the two horizontal and two vertical steerers were adjusted to each cause beam-position changes within the linac of up to 2 mm. For a specific rms BPPM repeatability error, performance improves with larger steerer adjustments. However, in the eventual implementation of the steering algorithm beam losses must be avoided, which limits the acceptable changes in beam position.

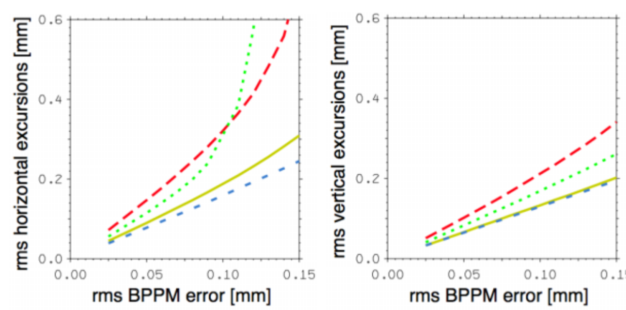


Figure 1. Rms values of the sets of horizontal (left) and vertical (right) maximum excursions as a function of rms BPPM repeatability error, for BPPMs downstream of RF tanks 6 and 7 (**long red dashes**); downstream of RF tanks 6 and 8 (**green dots**); down-stream of RF tanks 6, 7, and 8 (yellow); and downstream of RF tanks 7, 8, and 28, and upstream of RF tank 30 (**short blue dashes**).

## INSTRUMENTATION COMPONENTS

A different series of RF simulations was performed in order to establish the BPPM mechanical and electrical characteristics [2]. The BPPM measurement systems to be installed will process the beam's fundamental bunching frequency of 201.25 MHz. Since the design's intent is not to detect and measure much higher signal frequencies, the simulations showed that there were two primary designs of interest. One design showed the four electrodes terminated in their characteristic impedance and other design showed its four electrodes shorted to ground. Both of the designs studied operated equally well at the fundamental bunching frequency in the simulations and in the field. Ultimately, the choice between the two designs was based on reliability and complexity due to the fewest number of SMA coaxial feedthroughs used, resulting in the shorted-electrode design being chosen (see Table 3 for further mechanical design details).

Table 3. Primary Mechanical BPPM Design Details

| Mechanical Characteristics | Value |
|---|---|
| Electrode Characteristic Impedance (Ω) | 50 |
| Electrode Inner Radius (mm) | 22.16 |
| Electrode Length (mm) | 43 |
| Electrode Subtended Angle (degrees) | 60 |
| Body Inner Radius (mm) | 27.78 |
| Flange-to-Flange distance (mm) | 76.2 |
| Simulated Position Sensitivity (dB/mm) | 1.26 |
| Analytic Position Sensitivity Estimate (dB/mm) | 1.48 |

To simplify overall requirements, a single mechanical design will be used for the BPPMs throughout the 805-MHz linac. Given this single design, all BPPM electrodes will be as long as possible and will have 60-deg subtended angle. A strong electro-mechanical connection, such as a braze joint, between the feedthrough inner conductor and the electrode will be used. Alignment tooling on the BPPM body will provide a common interface between the BPPM's mapped characterization and its final non-adjustable beam line laser-tracker-measured location. The flanges and vacuum seals are those used throughout the LANSCE facility. Figure 2 shows a BPPM initial concept [3].

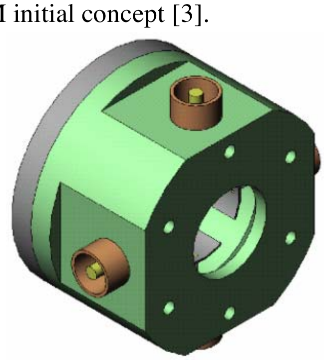

Figure 2. The picture above is a BPPM concept for use in the 805-MHz linac.

From previously discussed studies and other input, including a theoretical analysis of beam position monitors [4,5,6], BPPM signal parameters were estimated (see Table 4). Using these listed parameters, a simulation of In-phase and Quadrature-phase (I/Q) processor channel was performed [7]. This processor channel consists of a 201.25-MHz band pass filter, an amplifier, and a 14-bit Analog-to-Digital Converter (ADC). If the ADCs are clocked at a rate which "undersamples" the fundamental bunching period of the four filtered BPPM-electrode signals such that at least one I- and Q-sample is acquired during a single 60-nanosecond "minipulse", both beam magnitude and phase information may be reconstructed from the acquired samples.

The I/Q simulations showed the beam position measurements can reach their required repeatability by averaging 9 "minipulse" samples and the central beam phase measurements can reach their required repeatability by averaging 10 "minipulse" samples. Within the I/Q simulations, a 35-MHz clock was used to trigger the ADCs and the ADCs external trigger will be required to be synchronous with the linac's reference to within a 0.4-ps rms error.

Table 4. Estimated BPPM Port Signal Parameters

| Signal Parameter | 100-MeV | 800-MeV |
|---|---|---|
| Tuning Power $_{0.9\ mA,\ centered}$ (dBm) | -44 | -47 |
| Min Power $_{0.9\ mA\ \ offset}$ (dBm) | -56 | -59 |
| Max Power $_{21\ mA\ \ offset}$ (dBm) | -6 | -10 |
| S:N Ratio $_{0.9\ mA\ \ centered,\ @\ BPPM}$ (dB) | ~41 | ~38 |
| Position Repeatability $_{0.9\ mA\ \ centered}$ (mm) | ~0.07 | ~0.1 |
| Phase Repeatability $_{0.9\ mA,\ centered}$ (deg) | ~0.2 | ~0.3 |

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## SUMMARY

This paper has described some of the initial issues for developing beam position, phase, and bunched beam current measurements for the LANSCE 805-MHz linac. This report describes the linac operational requirements these BPPM measurements must satisfy. It has also described some of the logic for what locations the new BPPMs will be installed. Finally, this paper described the BPPM mechanical design and some initial simulations of a feasible electronic processor design.

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