Beam Position and Phase Monitors Characterized and Installed in the LANSCE CCL *


Abstract

The Los Alamos Neutron Science Center - Risk Mitigation (LANSCE-RM) project is in the process of replacing older Coupled-Cavity-Linac (CCL) Beam-Position Monitors (BPMs) with newer Beam and Phase Monitors (BPPMs) and their associated electronics and cable plants. In many locations, these older BPMs include a separate Delta-T loop for measuring the beam’s central phase and energy. Thirty-one BPPMs have been installed and many have monitored the charged particle beam. The installation of these newer BPPMs is the first step to installing complete BPPM measurement systems. Prior to the installation, a characterization of each BPPM took place. The characterization procedure includes a mechanical inspection, a vacuum testing, and associated electrical tests. The BPPM electrical tests for all four electrodes include contact resistance measurements, Time Domain Reflectometer (TDR) measurements, relative 201.25-MHz-beam position measurements, and finally a set of position-sensitive mapping measurements were performed which included associated fitting routines. This paper will show these data for a typical characterized BPPM.

Introduction

LANSCE-RM is presently replacing the older BPMs with newer BPPMs. The older BPMs are …

- A short small cavity with four, B-dot loops
- Or a short small cavity with four, B-dot loops and an additional cylindrical capacitive electrode
- All older BPMs’ signals are connected to a single-ended TNC-connector vacuum feedthrough
- Provide bipolar double signals for 201.25-MHz position and phase measurements.

Unfortunately, the position measurements provided by the four, B-dot loops are unreliable.

The newer BPPMs …

- Have a clear apertures whose diameter is the same as the beam pipe immediately upstream
- Design does not perturb the bunched beam image currents traveling along the beam pipe
- Use shorted-upstream electrode design that provides the bipolar doublet signal.
- Use single-ended SMA vacuum feed-through connectors by Shurter
- Alignment tools may be observed by a separate Laser Tracking system
- Physical guards protect the connector from external mechanical abuse
- 201.25-MHz signal from summed four electrodes provides a position-independent phase signal.

This signal used for the CCL beam-cavity phasing and acceleration measurement, locally known as the Delta-T procedure.

Simulated position sensitivity is based on a MAVIA simulations [1]

BPPM measurement requirements include the dynamic range and signal-to-noise-to requirements [2]

Additional are described by another paper at this workshop [3]

Electrode Contact Resistance Characterization

The received 120 feed-thru manufactured by CeramicTek did not test as expected [4]

- An Agilent 34410A multimeter 4-wire resistance measurement was performed on each BPPM-electrode feedthru received.
- Two-finger collets of the input sockets did not have a low contact resistance of <40 mΩ
- After visual inspection, and a contact resistance test
- Fingers did not appear to have a bend, i.e., the collet fingers exerted no lateral force on the mating SMA-connector pin
- To remedy this condition, the collet fingers were bent beyond the yield point using special tools
- Average contact resistance measured for the 112 feed-thrus (2 BPMs were left uncharged for comparison at a later date) was 23 mΩ

Electrode TDR Characterization

An analytic model for the position sensitivity has been available in the technical literature for some time [6,7,8].

- Model assumes a line charged-particle beam modulated at the accelerator’s fundamental-bunching frequency
- Bunch-beam surface or image charges travel along the four symmetrically spaced electrodes with known radius and length
- Position sensitivity may then be expressed as a solution to the Laplace equation for cylindrical boundary conditions.
- Ratio of right and left electrode signals (e.g., horizontal axis) for these bunched beam image currents [8]
- Ratio can also be approximated with a four- or ten-term, 2-D non-linear 3rd-order fitting equation [9]

This analytic model solution can be expressed as the sensitivity ratio, Rψ of the right and left electrode signals amplitudes from the bunches beam image current.

$$\frac{x(\tau)}{x(\tau)} = \frac{\beta_{y} - \beta_{y} \frac{\beta_{x}}{s_{x}^2}}{\beta_{y} - \beta_{y} \frac{\beta_{x}}{s_{x}^2}}$$

where $x_{x}$ is the BPPM electrode subtended angle, $\beta_{x}$ and $\beta_{y}$ are the polar coordinates of the beam position, and $x_{x}$ is the BPPM electrode radius. The functions $I_{x}$ and $I_{y}$ are the zero- and m²-order Bessel functions, respectively. The term “y” includes the effects of the beam velocity and is calculated to be

$$\gamma = \frac{c}{R_{\psi} \Delta \theta}$$

where $\gamma$ is the Lorentz factor, and (1-$\beta_{x}$)² for the horizontal axis, the four-axis forward fitting equation is

$$R_{\psi} = \frac{I_{x} + I_{y}}{I_{x} - I_{y}}$$

where $I_{x}$, $I_{y}$, $I_{x}$, $I_{y}$ are the coefficients of this fitting equation, x and y are the Cartesian coordinates of the mapping wire, $I_{x}$ is the fitted offset if relative power.

- Inverse fitting equation is also calculated
- Positional offsets varied from 0.65 m to 0.92 mm
- Sensitivities were typically 0.023 mV/mm or 0.12 dB/mm.
- Both 3rd order coefficients were similar

Table 2. Based on position mapping data, details of 38 manufactured BPMs:

<table>
<thead>
<tr>
<th>BPM Fit Coefficients</th>
<th>Avg</th>
<th>0.2σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset: Hor (dB)</td>
<td>1X10⁻⁴</td>
<td>0.28</td>
</tr>
<tr>
<td>Offset: Vert (dB)</td>
<td>8X10⁻⁴</td>
<td>0.23</td>
</tr>
<tr>
<td>Sensitivity: Hor (mm)</td>
<td>0.0045</td>
<td></td>
</tr>
<tr>
<td>Sensitivity: Vert (mm)</td>
<td>1.19</td>
<td>0.0048</td>
</tr>
<tr>
<td>Phase Offset: Hor (°)</td>
<td>1.5X10⁻²</td>
<td>3.5X10⁻³</td>
</tr>
<tr>
<td>Phase Offset: Vert (°)</td>
<td>5.0X10⁻³</td>
<td>3.5X10⁻³</td>
</tr>
<tr>
<td>10⁴ Order Cross Corr: Hor (°)</td>
<td>1.5X10⁻³</td>
<td>3.5X10⁻³</td>
</tr>
<tr>
<td>10⁴ Order Cross Corr: Vert (°)</td>
<td>5.0X10⁻³</td>
<td>3.5X10⁻³</td>
</tr>
</tbody>
</table>

Mapper analysis includes …

- Fitting axis data set with offset, sensitivity, and third-order terms using a 2-D nonlinear polynomial fitting equation
- Typical errors between the fit equation and the actual mapped-BPM data were
- ≤1% for mapper-wire locations inside 50% of the BPM’s radius
- ≤5% for mapper-wire locations between 75% and 50% of the BPM’s radius
- Due to each BPM’s manufacturing quality, the error bars were small enough such that the fitting errors did not include the second order terms.
- Offsets showed an ~0.25 dB variation

PHASE CHARACTERIZATION

Since these BPMs are used to measure the linac-cavities phase and amplitude set points, a phase characterization was also performed.

- Beam position monitors measure each electrode’s phase delay expected during both the injected “self test” and beam phase modes
- Test jigs transformation: from outer shield radius of an RF N-connector to BPPM 22.4-mm inter-bore radius
- 50Ω characteristic impedance
- BPPM-electrode signal power obtained using Sc measurement from an Agilent Technologies E5070B/NA
- Sc measurement: fundamental bunching frequency (201.25 MHz), and 1st, and 3rd harmonics
- All electrodes had a measured absolute phase delay spread of <1.8, 201.25-MHz-deg.
- All transmission-line-to-electrode attenuation for all electrodes was between -27 and -40 dB

Summary

Thirty-one of the characterized BPMs have been installed and many CCL BPMs are operational. By measuring the BPPM’s feedthru contact resistance, performing electrode TDR’s, mapping each of the BPM’s position sensitivities, offsets and 3rd-order coefficients, and measuring each BPM’s electrode phase delay, thirty-eight BPPM contact have characterized. After some initial minor difficulties, we corrected the BPM contact resistance such that all of the contact resistance and TDR measurements operated as expected. The BPMs’ position sensitivity is ± 1.9 dB/mm with offsets of ~0.25 dB. The absolute phase delays are spread of <1.8, 201.25-MHz-deg and within bench and beam line measurement tolerances.

References