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

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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 Position 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 phase 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 feedthru
- Provide bipolar doublet 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 aperture 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-thru connectors by CeramTek
- Alignment tooling may be observed by a separate Laser Tracking system
- Physical guard protects 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 MAFIA simulations [1]
- BPPM measurement requirements include the dynamic range and signal-to-noise requirements [2]
- Additional are described by another paper at this workshop [3]
- After an initial visual inspection, a vacuum test verified vacuum interfaces were operational.

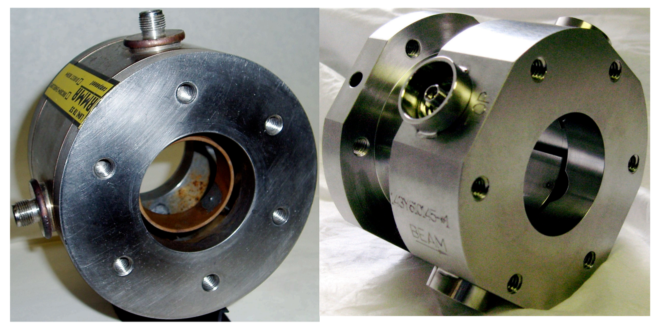

Figure 1. The older BPM (left) shows the inner capacitive Delta-T electrode and a newer BPPM (right) shows a typical inner electrode.

Table 1. Shorted-Upstream-Electrode BPPM Details

Mechanical Characteristics	Value
Electrode Characteristic Impedance (Ω)	50
Electrode Inner Radius (mm)	22.2
Electrode Length (mm)	50.3
Electrode Subtended Angle (degrees)	60
Body Inner Radius (mm)	22.2
Flange-to-Flange distance (mm)	76.2
Simulated Position Sensitivity (dB/mm)	1.26
Simple Calculated Position Sensitivity (dB/mm)	1.50

ELECTRODE CONTACT RESISTANCE CHARACTERIZATION

The received 120 feed-thrus manufactured by CeramTek did not test as expected [4].

- An Agilent 34410A milli-ohm 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 measurement
    - 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 BPPMs were left unchanged for comparison at a later date) was 23 mΩ
        - Minimum and maximum resistance of 15 mΩ and 33 mΩ

ELECTRODE TDR CHARACTERIZATION

A TDR was used to determine all electrode impedances.

- Each BPPM electrode was expected to be manufactured exactly the same.
    - Due to slight differences in manufacturing, electrode characteristic impedances vary
- TDR shows the four feed-thrus, four right angle connections, and four electrodes having similar approximate impedances.

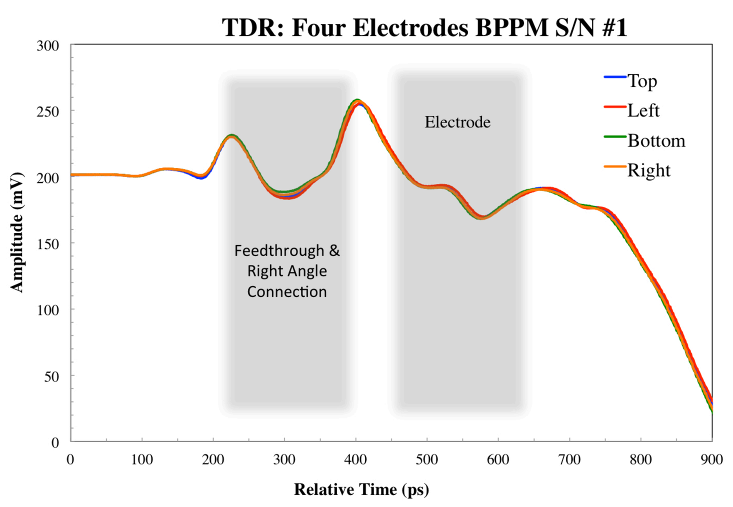

Figure 2. This graph shows the TDRs of all four BPPM feed-thrus, right-angle connections, and electrodes after each collet finger was bent.

BEAM POSITION CHARACTERIZATION

The BPPM's were characterized by acquiring their position offsets, sensitivities, and nonlinear terms using a single-wire mapping facility.

Mapper facility provides …..

- At each mapper antenna-wire location, the four signal powers acquired using a Boonton 4-channel Model 4300 RF power meter.
- A 201.25-MHz signal, from a HP 8640B signal generator, feeds the antenna wire.
- As the vertically-oriented antenna wire is moved to different BPPM locations, resulting signal power are digitized
- Each BPPM is centered with its associated flats and optical alignment monuments
    - Mapper associated laser BPPM-centering system allows alignment to within 0.025 mm
- The beam data includes….
    - Calibrated horizontal- and vertical-location coordinates of the antenna wire
    - Electrode signal power acquired by each of the four Boonton 51075 RF Power Sensor Heads
    - Header data
- The BPPMs are mapped to ~75% of their radius or to ~17 mm on a 1-mm grid.
- Mapper and LabVIEW software were rebuilt and is described in a paper at this beam instrumentation workshop [5]

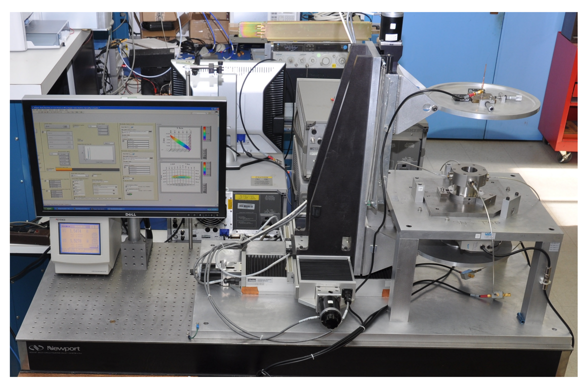

Figure 3. Mapper facility

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 beam's fundamental-bunching frequency
    - Bunched-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, R_x, of the right and left electrode signals amplitudes from the bunched beam image currents.

$$R_x[dB] = 20\log\left\{\frac{\dfrac{\theta_0 I_0\left(g\frac{r_0}{R}\right)}{I_0(g)} + \sum_{m=1}^{\infty}\dfrac{4\mathrm{I}_m\left(g\frac{r_0}{R}\right)}{mI_m(g)}\sin\left(\frac{m\theta_0}{2}\right)\cos(m\phi_0)}{\dfrac{\theta_0 I_0\left(g\frac{r_0}{R}\right)}{I_0(g)} + \sum_{m=1}^{\infty}\dfrac{4\mathrm{I}_m\left(g\frac{r_0}{R}\right)}{mI_m(g)}\sin\left(m\left(\pi+\frac{\theta_0}{2}\right)\right)\cos(m\phi_0)}\right\} \quad , [1]$$

where θ_0 is the BPPM electrode subtended angle, r_o and ϕ_0 are the polar coordinates of the beam position, and R is the BPPM electrode radius. The functions I_0 and I_m are the zeroth- and mth-order Bessel functions, respectively. The term "g" includes the effects of the beam velocity and is calculated to be

$$g = \frac{2\pi R}{\beta\gamma\lambda} \quad , [2]$$

where γ is the Lorentz factor, and $(1-\beta^2)^{-1/2}$.

For the horizontal axis, the four-term forward fitting equation is

$$R_x[dB] = x_0 + S_x x + S_{3Cross} xy^2 + S_3 x^3 \quad , [3]$$

where R_x, S_x, S_3, S_{3Cross} are the coefficients of this fitting equation, x and y are the Cartesian coordinates of the mapping wire, x_0 is the fitted offset rf relative power.

- Inverse fitting equation is also calculated
- Positional offsets varied from +0.65 to -0.92 mm
- Sensitivities were typically 0.822 mm/dB or 1.19 dB/mm.
- Both 3rd-order coefficients were similar

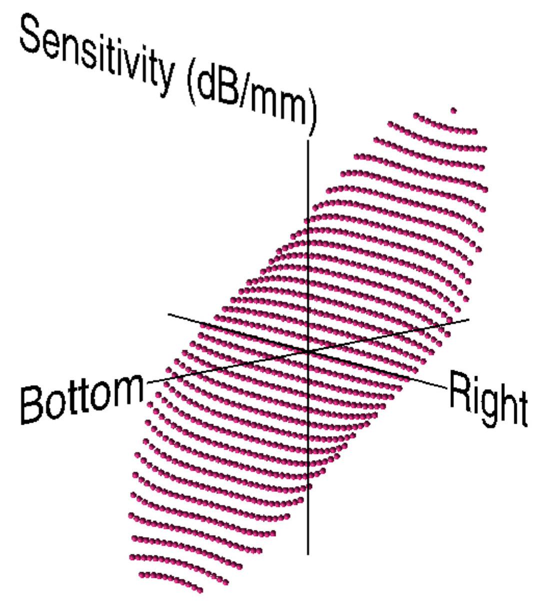

Figure 4. This graph shows the plot of BPPM vertical sensitivity as a function of relative power and beam location.

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

BPPM Fit Coefficients	Avg	Stdev
Offset, Hor. (dB)	-1.8×10^{-4}	0.28
Offset, Ver. (dB)	8.9×10^{-4}	0.23
Sensitivity, Hor. (dB/mm)	1.19	0.0047
Sensitivity, Ver. (dB/mm)	1.19	0.0048
3rd-Order Coef., Hor., (dB/mm^3)	-1.8×10^{-4}	5.0×10^{-6}
3rd-Order Cross Coef., Hor., (dB/mm^3)	3.5×10^{-4}	5.0×10^{-6}

Mapper analysis includes …..

- Fitting each 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-BPPM data were
    - <1% for mapper-wire locations inside 50% of the BPPM's radius
    - <4% for mapper-wire locations between 75% and 50% of the BPPM's radius
- Due to each BPPM's manufacturing quality, the error bars were small enough such that the fitting errors did not include the second order terms coefficients.
- Offsets showed an ~+/-0.25 dB variation

PHASE CHARACTERIZATION

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

- Bench measurements verify each electrode's phase delay expected during both the injected "self test" and beam phase modes
    - Test jig transformation: from outer shield radius of an RF N-connector to BPPM 22.2-mm inner-bore radius
    - 50-Ω characteristic impedance.
    - BPPM-electrode signal power obtained using S_{21} measurement from an Agilent Technologies E5070B NA
    - S_{21} 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 +/-0.4 dB

Figure 5. Components of the phase delay measurement test jig with a prototype BPPM

Summary

Thirty-one of the characterized BPPMs have been installed and many CCL BPPMs are operational. By measuring the BPPMs' feedthru contact resistance, performing electrode TDR's, mapping each of the BPPM's position sensitivities, offsets and 3rd-order coefficients, and measuring each BPPM's electrode phase delay, thirty-eight BPPMs have been characterized. After some initial minor difficulties, we corrected the BPPM contact resistance such that all of the contact resistance and TDR measurements operated as expected. The BPPM's position sensitivity is 1.19 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

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