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## BEAM POSITION AND PHASE MONITOR – WIRE MAPPING SYSTEM\*

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### *Abstract*

The Los Alamos Neutron Science Center (LANSCE) deploys many cylindrical beam position and phase monitors (BPPM) throughout the linac to measure the beam central position, phase and bunched-beam current. Each monitor is calibrated and qualified prior to installation to insure it meets LANSCE requirements. The BPPM wire mapping system is used to map the BPPM electrode offset, sensitivity and higher order coefficients. This system uses a three-axis motion table to position the wire antenna structure within the cavity, simulating the beam excitation of a BPPM at a fundamental frequency of 201.25 MHz. RF signal strength is measured and recorded on the four electrodes as the antenna position is updated. An effort is underway to extend the systems service to the LANSCE facility by replacing obsolete electronic hardware and taking advantage of software enhancements. This paper will describe the upgraded wire positioning system's new hardware and software capabilities including its revised antenna structure, motion control interface, RF measurement equipment and Labview software upgrades.

## INTRODUCTION

The main purpose of the wire mapping system at LANSCE is to characterize the amplitude response versus beam central position of BPPMs before they are installed in the beam line. The wire mapping system is able to simulate a beam using a thin wire and measure the signal response as the wire position is varied within the BPPM aperture.

### *Signal amplitude to beam position*

The BPPMs at LANSCE use a 2-dimesional polynomial to convert power ratio between electrodes in dB to beam central position. This formula is based on Gilpatrick's analysis in PSR-97-003 of LANSCE BPMs [1] and the use of 3<sup>rd</sup> order terms is explained in a paper by Power [2]. The polynomial form is:

$$x = c_1 R_x + c_2 R_x^3 + c_3 R_x R_y^2 - x_{offset} \quad (1)$$

where  $x$  is position in mm,  $R_x$  is power ratio in dB of horizontal electrodes and  $R_y$  is power ratio in dB of vertical electrodes.

To calibrate a BPPM for positional measurements the wire structure is excited with RF energy at 201.25MHz. The wire is then positioned throughout the probe aperture providing both positional data for the wire as well as

signal response from the electrodes. Polynomial coefficients are determined from the Levenberg-Marquardt (L-M) algorithm to fit the position and signal data. The resulting coefficients and offset are stored in a database for later use by BPPM electronics in the linac.

## HARDWARE UPGRADES

The wire positioning system used to characterize BPPMs at LANSCE was originally designed in the 1980's and has undergone several upgrades. The measurement equipment, motion controller and PC-based computer were obsolete making replacement parts difficult to procure thus necessitating a hardware upgrade to maintain and enhance the system's capabilities.

## *Replacing Hardware*

The wire positioning system hardware consists of four main areas: the motion control system, the measurement instrumentation, the computer with software and the antenna structure. The first three items were combined into a National Instruments PXI chassis. Figure 1 shows the system diagram after consolidation.

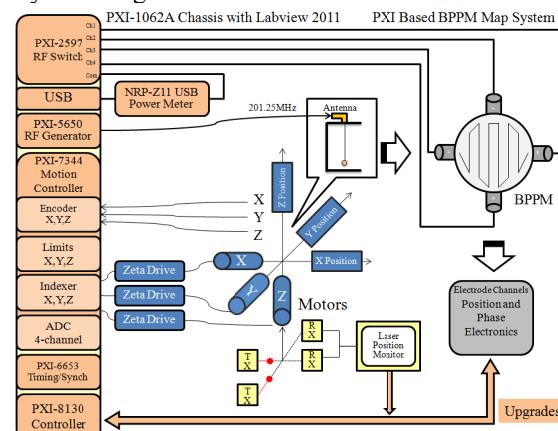


Figure 1: Block diagram of PXI based Mapping System

Instrumentation and Control

The NI PXI platform provides modular solutions for each of the obsolete equipment areas and supports a common communications interface for automated control.

The motion system was upgraded using the NI PXI-7344 motion controller which supports 4-axes of closed loop stepper motor control coupled with feedback from incremental encoders.

We used the NI UMI-7774 universal motion interface to adapt the motion controller to the existing motor drives, encoders and limit switches. This was not a standard interface so a custom cable set was created to provide the required connectivity between the motion table and controller.

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The motion control system is capable of positioning the wire in 0.002 mm steps with an overall positional accuracy of 0.015 mm for each axis.

The NI PXI-5650 signal generation card was selected to supply the RF signal to the wire. This generator operates from 500kHz to 1.3GHz at power levels up to +10dBm. A Mini-Circuits linear amplifier can boost the signal up to +30dBm if required.

A Rohde & Schwarz NRP-Z11 USB-connected power meter measures the four BPPM electrode signals multiplexed through a NI PXI-2597 6x1 terminated RF switch. The NRP-Z11 has 90dB of dynamic range and operates from 10MHz to 8GHz. Accuracy for the sensor is specified as 0.058dB.

The NI PXIE-8130 embedded computer is an AMD 2.3 GHz Turion based processor with a 40GB internal hard drive. The controller is configured with NI Labview 2011 running on the Windows operating system.

Figure 2 shows the equipment bay of the wire mapping system with all hardware installed. Figure 3 shows the test fixture, motion table, and display.

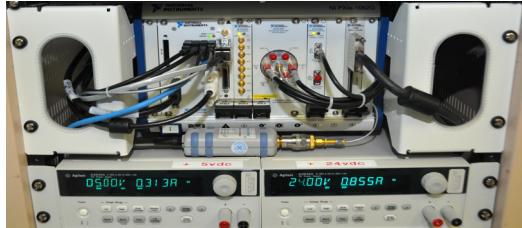


Figure 2: Equipment bay of BPPM Mapping System

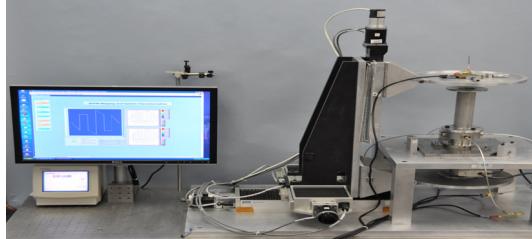


Figure 3: BPPM Wire Mapping System

## SOFTWARE UPGRADE

Labview 2011 was chosen as the software development platform since the majority of the upgrade equipment is manufactured by NI and project designers had prior knowledge of the tool. The legacy system was developed with Labview 5.1 which allowed portions of the original system code to be ported to the new system.

### Software Architecture

Software requirements:

1. Simple to use from an operator perspective
2. Retain the capability of the legacy system
3. Automate the map process and report generation
4. Ease of expanding capability in the future.

The software architecture was chosen based on some development talks with an NI Field Architect who suggested taking advantage of Labview's events, queue structures and functional global variables. These three

items met the requirements of retaining the legacy capability but also allowing for future expansion of the system. Figure 4 shows the architecture diagram for the upgraded system. This architecture is based on a queued state machine with producer and consumer loops (QSM-PC) [3].

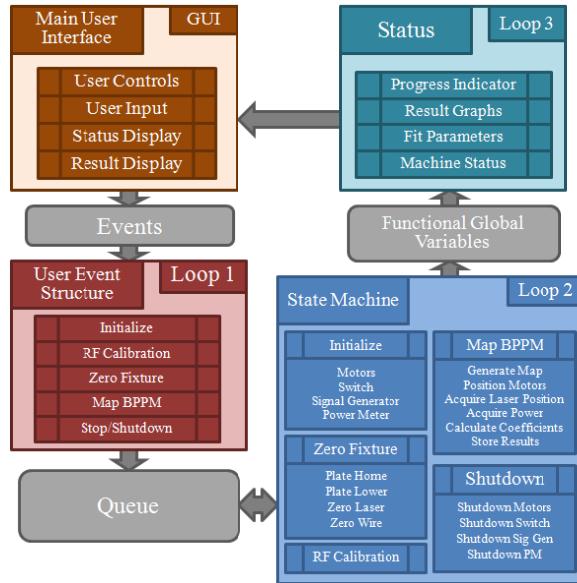


Figure 4: Software Architecture

### Events

The event structure waits for a button push event to occur on the front panel and then executes code pertaining to that event. Events allow the software to respond immediately to user input without requiring other processes to complete. This can be useful when the operator needs to make changes to the input settings once a map has started or if the wire is sent to a position beyond the boundaries of the aperture and needs to be halted. The event structure is a producer for the queue and adds new elements to the queue when events occur.

### Queue

The queue is a stack of instructions that is executed by the state machine. The state machine executes the queue instructions in a FIFO sequence and is designated the consumer loop since it removes elements from the queue. Once the state machine completes execution of an element it returns to a wait state until another element arrives at the queue.

This producer and consumer loop architecture allows the software to be easily modified for future functionality. A new process can be added by simply creating a new case in the state machine and defining the item in the queue.

### Functional Global Variables

Functional global variables (FGVs) are used to store data and provide data access to other portions of the software. They are referred to as global because they can be accessed from any Labview program or sub VI. FGVs can pass any type of data and are used in place of

standard local or global variables. They minimize race conditions since FGVs are not re-entrant and can only be accessed by a single process at a time.

The mapping system uses multiple FGVs to transfer data between the state machine and status loop. The status loop provides the feedback to the main UI indicating progress and updating displays in real time.

## WIRE STRUCTURE

The BPPM probe mapping system utilizes a unique design for inserting and tensioning the antenna wire [4]. The design concept is comprised of a 0.004" diameter, high-carbon steel, drawn music wire (such as ASTM A228) suspended vertically through the probe and tensioned by a ball attracted to a Samarium-Cobalt magnet of high coercivity with good  $BH_{max}$  to keep it very taught and straight with reliable force over time. The 3/16" dia. ball bearing was chosen for its high-precision diameter ( $\pm 0.0001"$ ) and sphericity (0.000025"), providing a high degree of repeatability when coupled with the "slip-fit" polyimide alignment guide.

The antenna is soldered into a 0.006" hole, 0.020" deep with an axially-aligned 0.010" bore from the opposite side. The small diameter hole depth limit was predicated on the length of the carbide drill available in that diameter. The larger drill had a greater aspect ratio, allowing it to meet the smaller hole. The ball bearings were annealed prior to drilling, although this step may be omitted with future balls. Other drilling and attachment techniques were researched, but electrical-discharge machining (EDM) and laser drilling, etc, were unsuitable due to the large aspect ratio of hole size and depth.

The small hole allows for keeping the wire from being skewed off-axis by asymmetry and preventing the wire from pulling out of the ball by shear forces and solder cold-flow under extreme tension.

A sapphire insulating guide bead, 0.0045" ID inserted into a conically shaped and radially pinned brass "plug" aligns the antenna top end.

## MAP RESULTS

Once the mapping system was upgraded and software development completed, a comparison was done of the new system versus the legacy system. BPPM S/N 38 [5] of the style installed in the coupled-cavity linac at LANSCE was used to compare the two systems.

The 3-dimensional plots of the horizontal and vertical power ratios are seen in figure 5.

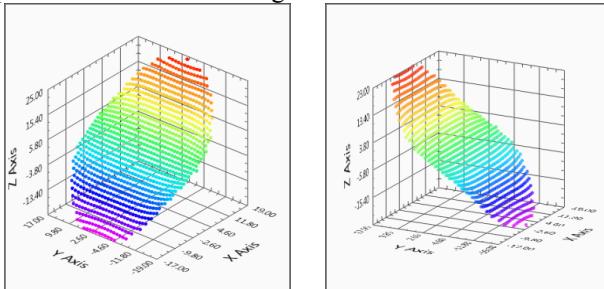


Figure 5: 3-dimensional mapping plots

Coefficient results from the L-M curve fitting are listed in Table 1 for the fits (equation 1) between the legacy system and the PXI based system. The difference between the 3<sup>rd</sup> order coefficients is very small as well as the sensitivity terms, indicating the new and legacy systems compare very closely. The largest difference is the delta offset value of 0.076 mm. Further experiments are needed to determine the source of this error. This error is small in comparison to the accuracy specification of 1.0mm for BPPM's.

Table 1: Coefficient comparison of PXI versus Legacy

| Fit                  | Term        | PXI       | Legacy    | Delta     |
|----------------------|-------------|-----------|-----------|-----------|
| Forward Fit L-R (dB) | offset      | 0.461     | 0.551     | 0.090     |
|                      | Sensitivity | 1.188     | 1.189     | 0.0010    |
|                      | Cubic       | 6.26E-04  | 6.29E-04  | 3.00E-06  |
|                      | Cross       | -7.21E-04 | -7.23E-04 | -2.00E-06 |
| Forward Fit T-B (dB) | offset      | -0.119    | -0.208    | -0.090    |
|                      | Sensitivity | 1.188     | 1.189     | 0.0002    |
|                      | Cubic       | 6.26E-04  | 6.30E-04  | 4.00E-06  |
|                      | Cross       | -7.11E-04 | -7.13E-04 | -2.00E-06 |
| Inverse Fit L-R (mm) | offset      | -0.370    | -0.441    | -0.071    |
|                      | Sensitivity | 0.825     | 0.824     | -0.0007   |
|                      | Cubic       | -1.81E-04 | -1.81E-04 | 0.00E+00  |
|                      | Cross       | 3.50E-04  | 3.50E-04  | 0.00E+00  |
| Inverse Fit T-B (mm) | offset      | 0.090     | 0.166     | 0.076     |
|                      | Sensitivity | 0.826     | 0.826     | -0.0003   |
|                      | Cubic       | -1.86E-04 | -1.87E-04 | -1.00E-06 |
|                      | Cross       | 3.43E-04  | 3.43E-04  | 0.00E+00  |

## CONCLUSION

We have successfully updated the wire mapping system at LANSCE to map and derive the positional transfer functions for up to 80% of a BPPM's radius with results matching the legacy system. It has been used to characterize BPPM electronics by providing beam position data for comparison to calculated position data. A future system enhancement will add the capability to characterize the phase response of BPPM electronics using a 5-channel phase coherent synthesizer.

## ACKNOWLEDGEMENT

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