OPERATION OF THE POSITION MEASUREMENTS FOR THE ISOTOPE PRODUCTION FACILITY

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Abstract
The Isotope Production Facility (IPF) will provide isotopes for medical purposes by using a 100-MeV H⁺ spur beam line from the Los Alamos Neutron Science Center (LANSCE) facility. Beam position measurements for IPF use a standard micro-stripline beam position monitor (BPM) with both an approximate 50-mm and 75-mm radius. The associated cable plant is unique in that it unambiguously provides a method of verifying the operation of the complete position measurement. The processing electronics module uses a log ratio technique with an error correcting software algorithm so that the overall position measurement is periodically calibrated over a dynamic range of > 85 dB with errors less than 0.15 dB. A National Instruments LabVIEW virtual instrument performs automatic periodic calibration and verification, and serves the data via the Experimental Physics and Industrial Control System (EPICS) channel access protocol. In order to report the data to the LANSCE facility operators and accelerator physicists, the served data are displayed and archived. This paper will describe the measurement system, commissioning and initial operating experiences.

IPF BEAM LINE
The LANSCE facility has constructed an IPF to provide radioisotopes for diagnosis and treatment of diseases [1]. This spur beam line starts at the 100-MeV transition region of the accelerator and transports H⁺ beam to a target area where samples may be irradiated and safely handled. The new beam line contains eight BPMs used to diagnose the beam’s position throughout the transport and verify the beam’s placement on the target/sample region during either a 5-kHz raster or static operation. Table 1 summarizes key operational requirements of the position measurements for IPF. A separate project called the Switchyard Kicker Upgrade (XDKI) also has successfully installed and operated similar beam position measurement within it but this paper will not discuss those position measurements.

BPM BEAMLINE COMPONENTS
A previous paper details the BPM’s mechanical construction and mapping [3]. Fig. 1 shows an installed XDKI BPM and its associated beam line components and Fig. 2 shows a block diagram of how the IPF and XDKI BPMs are configured. The IPF 50.4-mm-radius BPMs were characterized to have a 0.643-dB-per-mm sensitivity with typical offsets of < +/- 0.2 mm, such that their sensitivity is ~4% lower than the theoretical 0.670 dB per mm. The IPF 76.2-mm-radius BPMs were characterized to have a 0.424-dB-per-mm sensitivity with typical offsets of < +/- 0.3 mm such that their sensitivity is ~7% lower than the theoretical 0.458 dB per mm. Since the XDKI and IPF BPMs have feed-throughs at both the downstream and upstream end of each of the four electrodes, a unique method of measurement operation is performed to monitor the BPM’s condition during beam operation. As shown in Fig. 2, there is a completely unambiguous signal path for power measurements to and from the processor module through each BPM electrode.

Table 1: Overall IPF position measurement operational characteristics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IPF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. Macropulse Length (ms)</td>
<td>0.05</td>
</tr>
<tr>
<td>Min. Macropulse Pulse Beam Current (mA)</td>
<td>0.02</td>
</tr>
<tr>
<td>Bunching Frequency (MHz)</td>
<td>201.25</td>
</tr>
<tr>
<td>Base Bandwidth (MHz)</td>
<td>~4.5</td>
</tr>
<tr>
<td>Precision (% of pipe radius)</td>
<td>0.25</td>
</tr>
<tr>
<td>Accuracy (% of pipe radius)</td>
<td>~3</td>
</tr>
<tr>
<td>Beam Pipe Radius (mm)</td>
<td>50.4/76.2</td>
</tr>
<tr>
<td>Dynamic Range (dB)</td>
<td>&gt; 86</td>
</tr>
</tbody>
</table>

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Figure 1. This XDKI BPM (oriented vertically in figure) is shown with its associated verification hardware.

The 20-dB attenuators in each electrode signal path provide both additional RF divider leg isolation and 50-Ω termination for the BPM electrode downstream ports. The typical round-trip attenuation is 36 dB +/- 1 dB. With an injection signal power of ~25 dBm, the resulting verification power measurements are performed at ~61 dBm. Since the components in this loop are linear, a
single mid-dynamic-range power measurement for each
cable/electrode loop path is sufficient to determine the
health of each component within the loop. If a cable is
inadvertently crimped or a BPM electrode is injured to the
extent of losing its 50-Ω characteristic impedance, the
total loop attenuation will change. This attenuation
measurement is performed on an hourly basis between
beam pulses by a software process so that facility
operators always have a quantitative method of detecting
BPM and cable health.

LOG-RATIO ELECTRONIC PROCESSOR

The log-ratio electronics used in our VXI-crate-based
processor module incorporates a digital motherboard with
on-board digital signal processor (DSP) daughter cards, a
wide-bandwidth analog-front-end (AFE) board utilizing a
logarithmic amplifier in each of the four channels, and a
calibrator with an on-board 201.25-MHz oscillator. Fig. 3
shows a simplified schematic of the AFE and calibrator
daughter cards. Since all of the components in the
calibrator circuitry are solid-state devices, the multi-step
calibration process is accomplished within the 8.3-ms
period between beam pulses.

The present AFE circuitry measures very low-power
signals with a wide bandwidth. A Temex 201.25-MHz
band-pass filter was placed between the input transformer
for the Analog Devices AD8307 log amplifiers and a
GALI-52 Mini-Circuits pre-amplifier. These 4.5-MHz-
bandwidth filters also have short rise and fall times,
typically 76 ns and 132 ns respectively, providing
sufficient bandwidth to measure various chopped-beam
conditions in the XDK1 beam line.

Fig. 4 shows the result of a module’s two differenced
channels, resulting in the log-ratio process, prior to a 90-
dB software calibration using the circuitry shown in Fig.
3. The data labelled “Pre-Cal Error” are the residual
deterministic errors from a pure logarithmic function.
These errors are primarily due to the log-amp’s
logarithmic non-conformity and minor thermal variations
and are subtracted out during the calibration routine. The
Pre-Cal errors are shown for a centered-beam and an off-
centered-beam condition. The data are plotted as a
function of input signal power, in dBm, where a 1-mA
current will occur at approximately −55 dBm. Also
plotted in Fig. 4 are the random error data, the ultimate
limitation to the calibration process and measurement
precision. Although these displayed data show random
errors to be within <0.15 dB from approximately −12 to
−85 dBm, the hardware is capable of signal powers from
approximately 0 to −85 dBm. In terms of positional error
and beam current through the 50-mm IPF and XDK1
BPMs, this is equivalent to a <0.25-mm-rms error over an
approximation 0.1- to 20-mA current range.

POSITION MEASUREMENT SOFTWARE

A National Instruments LabVIEW virtual instrument
(VI) software process running on an input/output
controller (PCIoC) performs an hourly calibration and
verification procedure. This procedure uses the same
calibrator daughter-card signal-source shown in Fig. 3
that the verification measurement uses but in this case,
digitally-controlled step attenuators step through a 90-dB
range. Upon receiving a timing signal through each VXI
processor module, the VI acquires the digital information
from the four channels’ analog-to-digital converters
(ADCs) via the previously “armed” digital signal
processor (DSP) daughter cards [5]. These data are then
corRECTed by using a RAM look-up table (RAMLUT) that
contains the corrected data (in counts). These RAMLUTs
remove the systematic “Pre-Cal Errors” for each of the
four-processor channels. After the calibration has been completed on all four processor channels, opposing-electrode calibrated-signal powers are then digitally-subtracted to produce a calibrated log-ratio signal for a single axis. Since IPF is a pulsed beam facility, a separate timing signal between beam pulses initiates the calibration and verification sub-VI. This calibration process loads a RAMLUT while another previously loaded RAMLUT is used to provide calibrated position information. After the calibration RAMLUTs have been filled, loaded, and applied to incoming data, another sub-VI switches the appropriate GaAs RF switches in the AFE and Calibrator daughter cards so that the verification procedure checks the health of the cables and BPM electrodes as described earlier.

Finally, the VI serves the data via a portable channel access sub-VI written to interface with EPICS. This VI also allows the facility operators to initiate an “on-demand” calibration procedure and verification test, which must be accomplished with the beam off for accuracy reasons.

**OPERATIONAL EXPERIENCE**

Fig. 5 shows the systematic results of a horizontal automated calibration procedure. For each 1-dB step of injected 201-MHz current, an average value is calculated from 100-acquired data points. The resulting graph displays the systematic or deterministic errors plotted as a function of beam current. Note that as the calibration current reduces to an equivalent beam current of $< 0.03$ mA, the systematic errors diverge. However, for much of the dynamic range of the instrumentation, the systematic errors are very small, typically $< 0.1$ mm.

![Figure 5](image)

**SUMMARY**

This paper described a beam position instrumentation presently operating in the LANSCE IPF beam line. The measurement system uses 50-mm and 75-mm radius micro-stripline BPMs, an unambiguous verification process that monitors the measurement system’s beamline-hardware health, and an automatic calibration process that removes deterministic and thermal errors on a periodic basis without operator intervention. It has a dynamic range of > 85 dB as defined by errors that are $< 0.15$ dB (or $< 0.25$ mm). Even with this wide dynamic range, the instrumentation base bandwidth has been measured to be $> 2.5$ MHz.

**REFERENCES**


