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 measurements 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.

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Table 1: Overall IPF position measurement operational characteristics.

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

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.

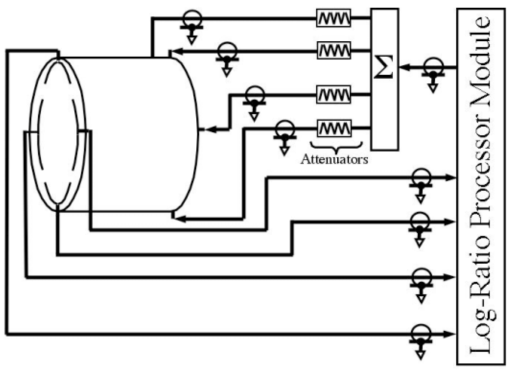

Figure 2. This simple block diagram shows the verification test hardware.

LOG-RATIO ELECTRONIC PROCESSOR

The log-ratio electronics used in this 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.

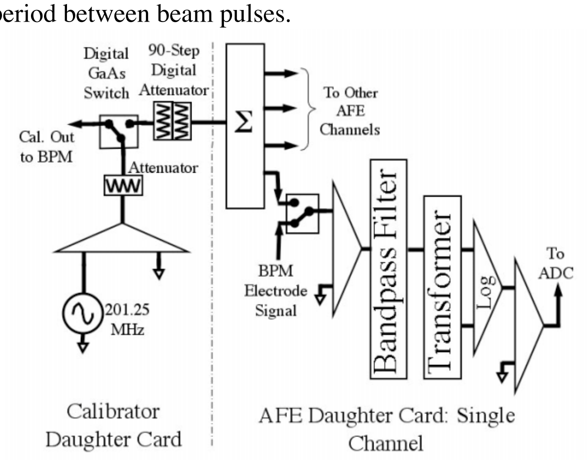

Figure 3. Simplified functional block diagram of the AFE and calibrator daughter cards.

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 XDKI 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 XDKI BPMs, this is equivalent to a <0.25-mm-rms error over an approximation 0.1- to 20-mA current range.

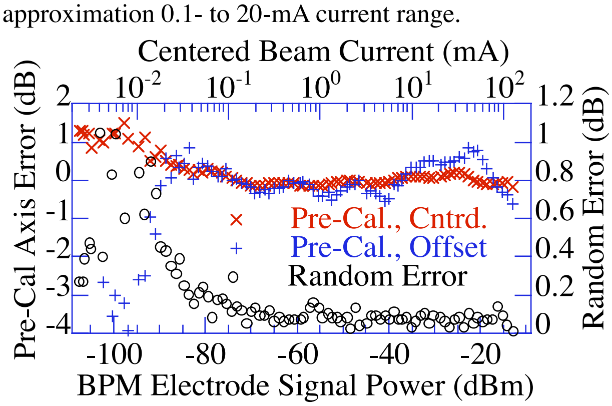

Figure 4. The above graph shows systematic and random errors prior to, and after a calibration is performed.

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.

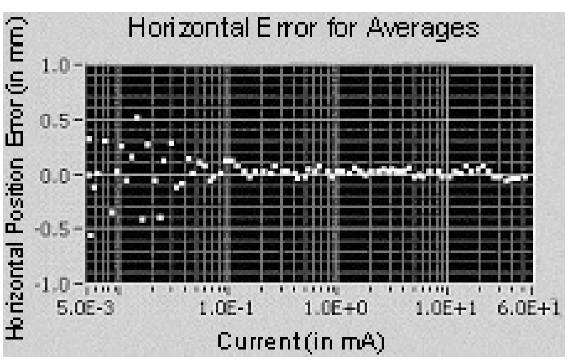

Figure 5. The resulting deterministic errors are displayed after each position measurement calibration.

Fig. 6 shows the random results of a horizontal automated calibration procedure. The same raw data are used as in Fig. 5, however, on this graph, the random errors (in this case, the standard deviations) are plotted as a function of equivalent beam current. Again, note that the random errors increase as the equivalent beam current drop below 0.03 mA. However, in this case, the random error is 3X to 4X larger than the deterministic error. As also shown for data displayed in Fig. 4, the equivalent-beam-current dynamic range displayed in Fig. 5 and 6 is less than the AFE amplifiers and associated calibration and verification procedure's actual dynamic range, typically measured to be between 0 and -85 dBm.

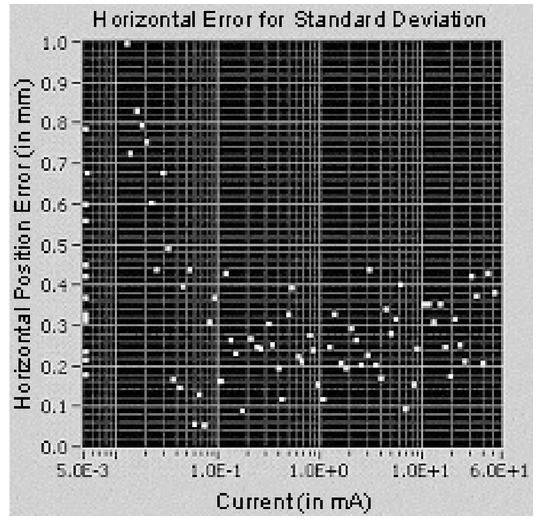

Figure 6. The resulting random errors are displayed after each position measurement calibration.

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 beam-line-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.

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