ABSTRACT

Instrumentation has been built to measure heavy ion and proton beam orbits over an intensity range of $2 \times 10^{10}$ to $1.5 \times 10^{13}$ particles per pulse. Twenty-two horizontal and 24 vertical pairs of electrostatic Pickup Electrodes (PUEs), each with a built-in test port, are interfaced with wideband, gain selectable front end electronics. The resulting real-time signals are linearly related (both in amplitude and temporal response) to the sum and difference of the charge induced on each electrode due to passing beam. PUE signals (or their sum and difference) are available at any detector location for use by other Booster systems e.g., the Tune Meter, Transverse Damper, Radial loop control, etc. Data acquisition electronics at each location integrate the processed front end signals over a selectable number of bunches, then digitize and transmit the integrated sum and difference to the host computer. Data normalization is done in the software, which also provides various orbit acquisition and display options to the user. This paper will describe the Booster Beam Position Monitor system, its performance objectives and the key design aspects used to meet these objectives. In addition, initial results will be presented.

1. SYSTEM COMPOSITION

The beam sensor used by the system is the split cylinder electrostatic type, chosen for its linear induced electrode signal vs. beam position. Each detector has been tested prior to its installation in the Booster, and has a verified linearity and resolution of greater than $\pm 0.1$ mm over the 60 mm circular measurement aperture [3]. The detector has a built-in test port consisting of a calibration ring concentric to the split cylinder assembly and centered along its length. Test signals from the BPM electronics to the calibration ring couple equally to both PUEs, simulating a transversely centered beam. These test signals are available at each electronics location in the Booster, and can be used to remotely verify operation of the electronics and all signal and data cable connections. Thermal Isolators are used at each of the four vacuum feedthrus on the detector to allow the signal cables to remain connected during bakeout at 300°C. The Isolators consist of stainless steel coaxial air lines with male N-type connectors on either end. Their 14 cm length is negligible as compared to the bandwidth of the electronics, and adds only 8 pF to the total capacitance load on each PUE.

The local processing electronics provides appropriate PUE signal scaling and frequency compensation, as well as real-time Sum/Difference processing [2]. Available at each BPM local electronics station is a secondary set of analog outputs which provides either buffered PUE signals or their sum and difference. These can be used for diagnostic purposes, or as real-time position information by other systems via analog fiberoptic link. In addition, the local electronics integrates the sum and difference signals over 1 to 255 bunches (up to 85 turns), then digitizes the resulting integrals to 13 bits. The local electronics can also generate test pulses to drive the calibration ring of the detector at any of five selectable frequencies (250 KHz - 4 MHz).

A Eurocard-style subrack at each BPM station houses the local processing electronics [1]. The body of the subrack is isolated from ground via analog and digital fiberoptic links, and is allowed to float at beampipe potential for purposes of increased noise immunity. Each of the 46 local subracks can accommodate a dual analog fiberoptic transmitter module, used to isolate the electronics from any external systems requiring real-time beam position information. (Several of these modules were used to remotely monitor beam position at key locations during initial Booster commissioning efforts, when the digital portion of the BPM system was not yet "on line".) Four user selectable gains are available for scaling the input signals to maximize the link SNR.

Timing for the BPM system is generated external to the ring by the BPM Sequencer [2]. Digital fiberoptic links enable a burst of low skew, precision timing pulses to be transmitted to each BPM station in the ring while maintaining a high degree of electrical isolation. The Sequencer divides the Booster into 48 equally spaced phases of the revolution frequency ($f_{rev}$), and uses a shift register technique whose output "follows the beam" around the ring. The transit time of all fiber-optic lines from the Sequencer to the Booster tunnel are matched using adjustable delays.

The Booster Low Level RF (LLRF) system provides the Sequencer with the RF frequency ($f_{RF}$) and $48 \times f_{rev}$, both phase

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locked to the beam using PLL and Direct Digital Synthesis (DDS) techniques [4] (Knowing both of these frequencies simultaneously makes operation of the Se-quencer independent of the harmonic number). The RF is gated into the data input of a 48 wide shift register, which is clocked by 48 x f_rev. Upon receiving a request from the BPM system computer interface, the gate opens and allows f_rev to be clocked through the SR. The gate is closed after counting an appropriate number of cycles (a set-point in the high level software), at which point the data input to the shift register is gated off.

The BPM Instrument Controller interfaces the host computer (Apollo system) with the Sequencer and the local processing electronics, and provides reports to the software of PUE sum and difference data from one or more samples during the Booster cycle. Communication between the local processing electronics and the instrument controller is effected via the fiberoptic version of the BNL DATACON standard. The optic input eliminates ground loops and allows the crate to float at beampipe potential. The instrument controller communicates with Apollo workstations via standard IEEE interface.

The "booster orbit" program is the high level applications software for the Beam Position Monitor, running on the Apollo computer system. Its primary function is to graphically represent the equilibrium orbit of the Booster ring at any time during the cycle. The program allows for the acquisition of data with varying parameters such as number of turns (over which to integrate), number of BPM Booster groups to acquire information from, acquisition times and gain settings. The program also allows for a variety of displays using saved, current or difference orbits with varying modes of averaging and plotting parameters. Statistical display options are also available.

In addition to orbit acquisition and display, the scope of the program extends to diagnostic testing of the hardware and display/update of static and dynamic BPM parameters (e.g. values of differential sensitivity, system offsets and operational status) used in the position calculations.

At the beginning of each Booster cycle (when there is no beam present), the program requests the instrument controller to poll all of the BPM stations in the ring. The Sum and Difference voltages returned by the instrument controller represent the total electrical output of the system, and are stored as baseline data for use in calculating the beam position at selected times during the cycle. Subtraction of the "zero beam" readings from subsequent sum and difference data (due to actual beam) enables the system to make position measurements at intensities below 10^-10 ppp.

2. RESULTS

Figure 1 is a typical bare injection orbit as displayed by the Booster BPM system. The area to the left of the plot is reserved for text describing the relevant system parameters for this orbit. "DATA" indicates whether the display is of the current orbit, a saved orbit or position information due to the calibration mode of the system. A time/date stamp is also included, along with the PPM user for this orbit. "GAIN" indicates the gain setting of the front end electronics, which can be set to x0.1, x1 or x10 as required.

Several systems "piggyback" the BPM system front end electronics to obtain real-time beam position information. The radial control loop and the tune meter both have parallel control

![Figure 1](image1.png)

Example of a raw orbit.

over the front end gain setting of specific BPM stations in the ring. The gains set by these systems have priority, since the BPM system is machine instrumentation, rather than a control component. "DIFFEREN GEIN SETTINGS" notifies the user if any of the other systems are using a front end gain setting other than that of the current orbit request.

Up to five groups of orbits may be displayed, each consisting of from one to five machine cycles (colors are used to differentiate between the various groups and cycles displayed). The user may select from among a variety of averaging options, with the current setting displayed under "AVERAGING MODE". In addition, several different read times may be requested within each cycle (displayed at the top right corner of the plot). During each read time, the PUE signals are integrated over a specified number of bunches (from 1 to 255), with the current setting displayed under "NUMBER OF BUNCHES".

The built-in test capabilities of the Booster BPM system can be used to provide a level of confidence for position measurements made at each BPM station in the ring. Since the local processing electronics resides in the tunnel [1], it is usually inconvenient to make repairs immediately upon diagnosis of a failed station. In such cases, the suspect BPM stations can be brought off line by tagging them as "bad". Stations currently tagged as bad are listed in the information section of the display, but are not plotted with the orbit. In addition, a tagged BPM will be excluded from any average orbit or harmonics calculations.

![Figure 2](image2.png)

Plot of SUMS data associated with Fig. 1.
Figure 2 is a plot of the integrated SUMS voltages associated with the orbit of Figure 1. The plot can be used to verify operation of the electronics at a particular station, or can be used to estimate local beam intensities around the ring [5].

Figure 3 is the orbit resulting from an extended bump centered at Quad location C6 near injection from the LINAC. The orbit is averaged over 50 bunches, at a front end gain of x1.

Figure 4 is an example of a difference orbit, averaged over 100 bunches. This particular orbit resulted from a bump whose maximum occurs at Quad location D6, near the internal beam dump. It should be noted that there is no position detector at D6, effectively limiting the resolution of the observed orbit in that locale. From the figure it can be seen that stations A2 and A8 (the location of the radial control loop electronics) have a different gain setting (x1) than that of the BPM system (x10). As such, they have been tagged as "bad" in order to remove them from the orbit display.

Figure 5 shows the orbit of an extraction bump centered at Quad F6. Note that F6 is the other "horizontal" quadrupole which lacks a position detector.

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4. REFERENCES


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