BEAM POSITION MONITORING SYSTEM FOR THE PIP-II INJECTOR TEST ACCELERATOR*

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Abstract

The Proton Improvement Plan II (PIP-II) injector test accelerator is an integrated systems test for the front-end of a proposed continuous-wave (CW) compatible, pulsed H^- superconducting RF linac. This linac is part of Fermilab's PIP-II upgrade. This injector test accelerator will help minimize the technical risk elements for PIP-II and validate the concept of the front-end. Major goals of the injector accelerator are to test a CW RFQ and H^- source, a bunch-by-bunch Medium-Energy Beam Transport (MEBT) beam chopper and stable beam acceleration through low-energy superconducting cavities. Operation and characterization of this injector places stringent demands on the types and performance of the accelerator beam diagnostics. A beam position monitor (BPM) system has been developed for this application and early commissioning measurements have been taken of beam transport through the beamline.

INTRODUCTION

A BPM system is required for providing transverse position, relative intensity, and relative phase measurements for the MEBT linac as shown in Figure 1. A 4-button BPM system is implemented to provide such measurements for beam parameters shown in Table 1.

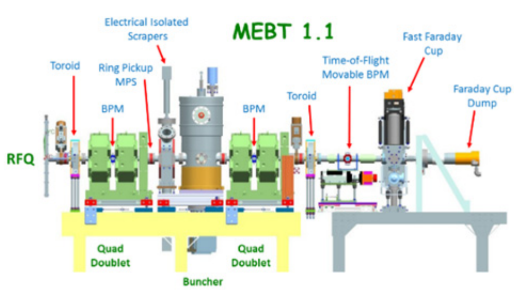

Figure 1: First Two BPMs in MEBT beamline.

Table 1: Typical Beam Parameters

Ion type	H^-
Beam Energy	2.1 MeV
Particles per bunch, nominal	$2x10^8$
Max rms beam size, x/y	4 / 4 mm
Max rms bunch length in MEBT	15º of 162.5 MHz
Maximum rms bunch length in SC cryo-modules	6º of RF frequency
Bunch/RF frequency in MEBT	162.5 MHz CW
β	0.067
rms bunch length (sigma)	120 psec

For position, the relative accuracy indicates the allowable deviation, at large averaging, of linearity between the reported and actual beam positions over ±5 mm range. The system should be able to subtract in software an absolute offset of BPM pickups and electronics up to 1mm.

For phase, the relative accuracy indicates the allowable deviation of linearity between the reported and actual beam phases, at large averaging, over ±5º.

DESIGN OVERVIEW

The BPM system block diagram is shown in Figure 2. Each BPM has 4 ports corresponding to each of the pick-ups. Figure 3 shows a picture of an individual uninstalled pick-up which is 20mm in diameter. The button pick-up is modified version of a design used by J. Crisp at FRIB [1]. Higher levels of assembly are shown in Figures 4 and 5. Superflex Heliax coaxial cable with SMA terminations is connected to each of the ports. This cable was selected due to its shielding performance, flexibility, durability and low signal attenuation. At about 100 to 200 feet in length, the RF cables are then connected to a rack which houses all the BPM electronics. Within the rack, the BPM signals connect to an in-house designed 4-channel analog signal conditioning transition module, whose picture is shown in Figure 6 and block diagram in Figure 7. One highlight of this module is that a bandpass filter is placed on a daughter card. This allows for a compact, yet flexible design where a filter change with different footprint would only require a new daughter card assembly. The current bandpass filter selects the fundamental frequency of the bunch train. Several analog bandpass filters, both commercial off the shelf (COTS) and custom designs were evaluated. The "SXBP-161R5+" Mini Circuits filter was selected for performance, package size, cost and the advantage of being COTS.

As a result, the output of each channel from this module is a 162.5MHz tone. Twenty transition modules are able to fit in a 5U high crate having a custom backplane. Therefore, one crate can support up to 20 BPMs.

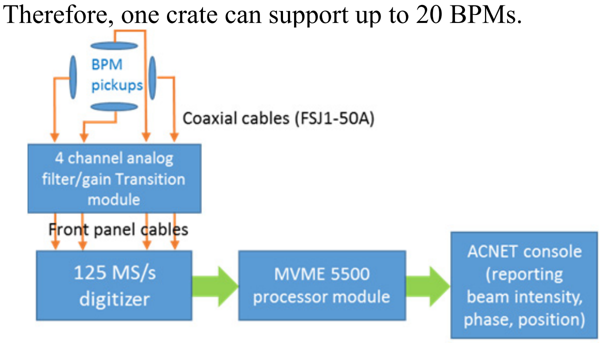

Figure 2: BPM system block diagram.

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Figure 3: Individual button pick-up.

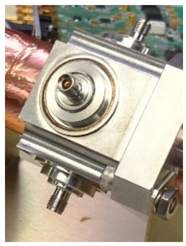

Figure 4: Button pick-up assembled in housing.

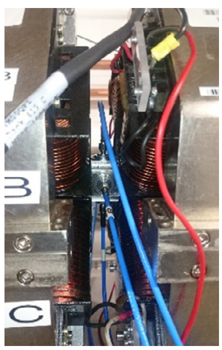

Figure 5: Button pick-up assembly installed in beamline.

Figure 6: Transition module with filter daughter board.

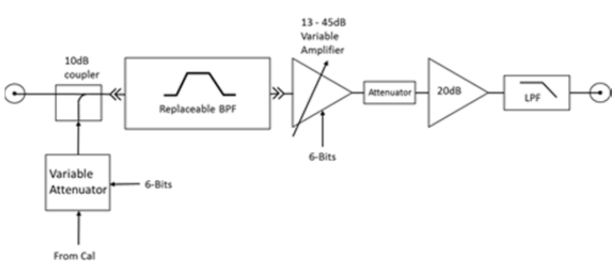

Figure 7: Block diagram of analog signal conditioning transition module.

The signals are then under-sampled by an in-house designed 8-channel digitizer board which can sample up to 125 MS/s with a 14-bit ADC. A block diagram illustrating the architecture of the digitizer module is shown in Figure 8. A VME crate supports up to 15 digitizer modules. Therefore, One VME crate can support up to 30 BPMs.

A few of the benefits of the in-house designed digitizer and transition modules are flexibility for hardware or firmware modifications, low-cost and an overall compact system where one rack can support many BPMs.

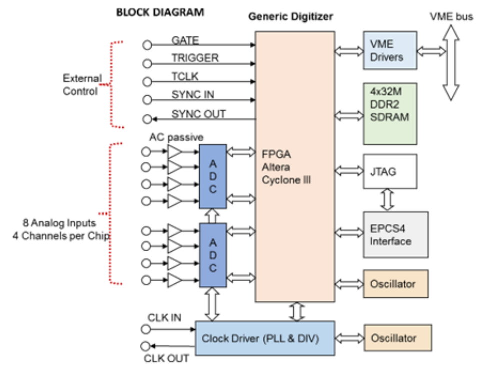

Figure 8: Digitizer module block diagram.

From the processed data, position, phase and intensity were calculated and made available to the ACNET interface. Phase will be relative to the RF signal that BPM electronics are locked to.

SIMULATION DETAILS

For preliminary analysis, a 3D model of the BPM was simulated using CST Particle Studio represented in Figure 9. A beam signal was create using an ideal Gaussian bunch train at 162.5MHz. Figures 10-11 illustrate the validation of expected signal out of the BPM port given the expected input excitation.

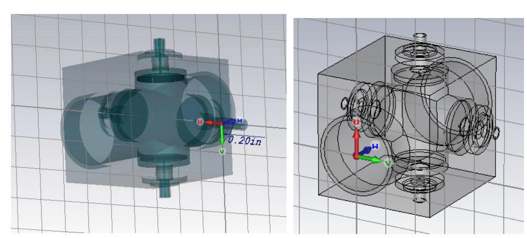

Figure 9: 3D Model of BPM assembled in housing.

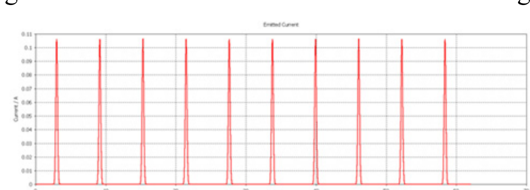

Figure 10: Excitation signal in CST.

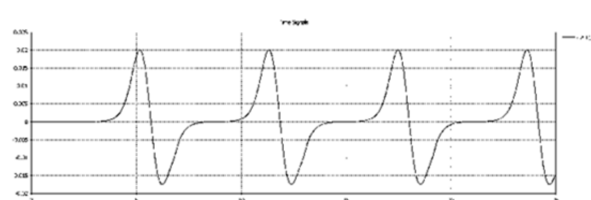

Figure 11: Signal from BPM electrode in CST.

POSITION CORRECTIONS

BPM Linearity Correction

A stretch wire scanning test was performed to map out the BPM pick up response versus position. In this test, a wire is stretched longitudinally across the beam pipe. The response of the BPM pick-ups was measured as the wire was swept vertically in the transverse direction. A 7^{th} order polynomial fit was applied to this data in order to correct for the loss in linearity as the beam moves away from the center of the beam pipe.

Low Beta Correction

Due to non-relativistic speed of the particles, we applied a correction factor which is a function of frequency and position from the center of the beam pipe. The correction based on R. Shafer's equations [2] is applied to the position calculations.

BEAM MEASUREMENTS

With a 5mA beam through the beamline, the response measured from the BPM pick-up after Superflex Heliax cable is shown in Figure 12. The measurement shows that the signal is on the order of hundreds of millivolts, depending on position. Figure 13 shows the 162.5MHz signal coming out of the transition module ready to be sent to the digitizer module.

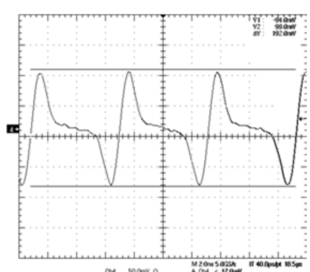

Figure 12: Measured BPM response at input to transition module.

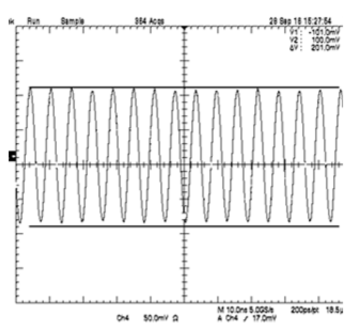

Figure 13: Measured BPM response at output of transition module (or input to digitizer module).

Measurements from the front end software is shown in Figure 14. This shows average phase, horizontal and vertical position and intensity. Figure 15 shows a measurement having around 60µm variation for x/y positions.

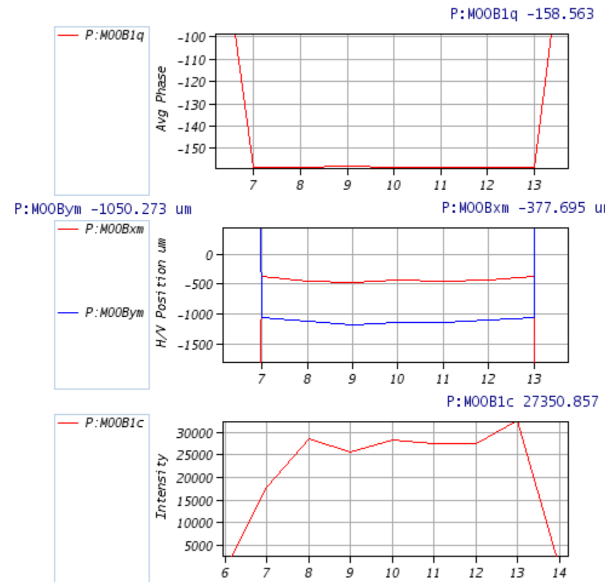

Figure 14: Phase, position and intensity measurements from BPM.

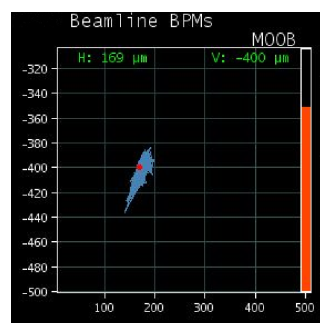

Figure 15: BPM position measurement variation.

CONCLUSION

In conclusion, the BPM system for the MEBT beamline has been demonstrated and provides the required phase, position and intensity measurements. Future plans include expanding the usage of this BPM in the beamline as well as upgrading the electronics to use a new in-house designed digitizer module capable of sampling up to 250MS/sec.

ACKNOWLEDGMENTS

Andrei Lunin, Bruce Hanna

REFERENCES

[1] J. Crisp *et al.*, "Beam Position and Phase Measurements of Micro-ampere Beams at the Michigan State University REA3 Facility", presented at NAPAC2013 Proc., Pasadena, CA, USA, 2013, p. 1187.

[2] R. Shafer. "Beam Position Monitor Sensitivity for Low-β Beams" in *Beam Instrumentation Workshop, Santa Fe, NM, 1993*, AIP Conference Proceedings 319, pp. 303-308.