CESR BEAM POSITION MONITOR SYSTEM UPGRADE FOR CESRTA AND CHESS OPERATIONS*

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Abstract

The beam position monitor (BPM) system at the Cornell Electron Storage Ring (CESR) has been upgraded for use in both CESR Test Accelerator (CesrTA) and Cornell High Energy Synchrotron Source (CHESS) operations. CesrTA operates with electron and positron bunch trains with as little as 4ns bunch spacing. CHESS operates with simultaneous counter-rotating electron and positron trains with 14ns bunch spacing. This paper describes the characteristics of the BPM hardware upgrade, performance figures of the electronics designed for this purpose, and the overall status of the upgrade effort. Examples of key measurement types and the analysis of data acquired from the new instruments are also presented.

INTRODUCTION

Since the conclusion of the CLEO-c high energy physics program in early 2008, CESR has been operated in two modes, one for CHESS operations and the other in support of the CesrTA research program for linear collider damping ring development [1]. An upgraded BPM system, which provides high resolution measurement capability, has been designed and deployed. In addition to standard position measurement capability, the system provides the capability to measure betatron phase by synchronous detection of a driven beam for optics diagnosis and correction.

SYSTEM REQUIREMENTS

The core operational requirements for the CESR BPM system include:

- Ability to operate with counter-rotating beams of electrons and positrons in a single vacuum chamber for CHESS operations;
- High-resolution measurement capability for low emittance optics correction and tuning;
- Turn-by-turn readout capability for multiple bunches to support beam dynamics studies;
- Capability for digitizing single species bunch trains with bunch spacing as small as 4ns and doing dual beam digitization for bunch trains with 14ns spacing.

The need for dual beam operation of the system places a unique constraint on the CESR BPM specifications. Since the relative arrival time of the bunches from the two beams varies widely from location to location around the ring, standard RF processing techniques to optimize resolution and minimize timing sensitivity cannot be applied to the full system. As a result, the CESR design utilizes peak sampling with a high bandwidth digitizer and incorporates hardware and software design features to optimize the system's timing performance. Table 1 summarizes the design specifications for the high-resolution measurements required for low emittance optics correction. Based on our design simulations for CesrTA, these specifications are sufficient to allow machine correction to the 5-10pm-rad vertical emittance regime in our baseline low emittance optics [1].

Table 1: BPM System Specifications for the CesrTA Low Emittance Tuning Program

Quantity	**Specification**
Front-End Bandwidth (for 4ns bunch trains)	500 MHz
Absolute Position Accuracy (long term)	100 μm
Single Shot Position Resolution	10 μm
Differential Position Accuracy	10 μm
Channel-to-channel Sampling Time Accuracy	10 ps
BPM Tilt Errors (after correction)	10 mrad

SYSTEM DESIGN

Fig. 1 shows a block diagram of the digital BPM readout modules developed for CESR. Each module incorporates four front end boards with dual parallel 16-bit digitizer chains based on the Analog Devices AD9461 operating to digitization rates of 125MHz. When operating with 4ns bunch trains, digitizing is interleaved between the two chains while, for 14ns dual species operation, each digitizer chain handles a single species. The front end boards have both a fixed gain amplifier optimized for precision measurements for bunches with $N_b{\sim}1\times10^{10}$ particles and a digital variable gain amplifier for measurements over a wide dynamic range. Timing configuration is carried out by a dedicated timing board integral to each module. This board takes a turn marker signal from the CESR master timing system and provides: overall digitization rate control, adjustment capability for channel-to-channel digitization times, and global adjustment capability for the module digitization time relative to the bunch arrival time at the detector. This fine degree of local timing adjustment is required in order to maintain the resolution and noise performance of each device. Communications, operational control, and onboard data processing for each device is provided

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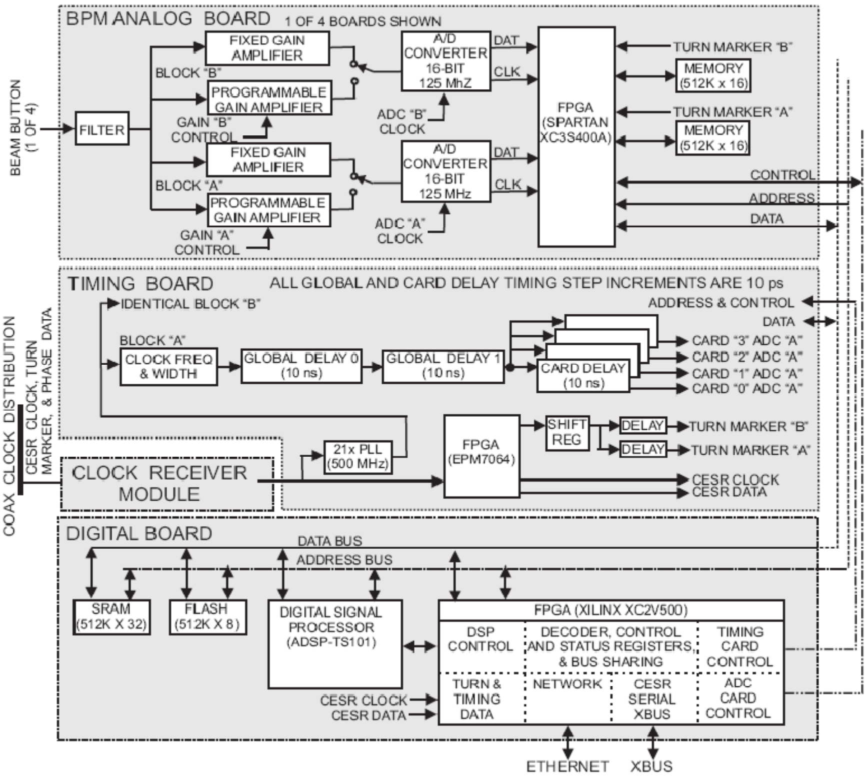

Figure 1: Block diagram showing the fundamental building blocks of a CESR BPM readout module. Each module includes a digital board with a TigerSharc DSP for control and onboard data processing. This board supports communications via a dedicated CESR field bus as well as ethernet. A timing board supports both the sophisticated onboard timing that is required for precision operation as well as flexible configuration for various bunch train structures. Each module has 4 separate front end boards to digitize the beam signals in parallel. These boards support operation with a fixed gain amplifier for precision measurements and a variable gain amplifier for wide dynamic range.

through a digital board and its TigerSharc digital signal processor (DSP). Communication is supported for both ethernet and a dedicated CESR field bus.

SYSTEM STATUS AND PERFORMANCE

New readout modules have been recently deployed around the entire CESR ring and are being actively used for low emittance tuning [3] and beam dynamics studies [4]. Fig. 2 shows vertical orbit differences between pairs of detectors in a diagnostic triplet mounted on a single vacuum chamber. The histograms include 256K turns of data (0.67s duration) taken simultaneously with each detector. The effective single device sigma is shown for each comparison and values are consistent with our target single-shot resolution. Because independent amplifiers are used for each button, their relative gains must be calibrated. A fast (~30s) beam-based technique utilizing the system's turn-by-turn readout capability has been developed to acquire the necessary calibrations [3]. In this method, the relationship between the button signals on the i^{th} turn is written as:

$$g_1B_1^i - g_2B_2^i - g_3B_3^i + g_4B_4^i = \frac{c}{I}\left(g_1B_1^i - g_2B_2^i + g_3B_3^i - g_4B_4^i\right)\times$$
$$\left(g_1B_1^i + g_2B_2^i - g_3B_3^i - g_4B_4^i\right),$$

where B^i_j is the button signal for the j^{th} button on the i^{th} turn, g_j is the effective gain for the j^{th} button's amplifier chain, c is a constant dependent on the beam pipe geometry, and I is the bunch current. With no loss of generality, we can set g_1=1 and calculate a chi-square based on the difference between the two sides of the above equation. We can then fit the turn-by-turn data to yield the relative gains of the 4 channels. Fig. 3 plots the two sides of the above equation for a set of such data before and after the fit is applied. The resulting fitted gains for the entire CESR BPM system (100 detectors ×

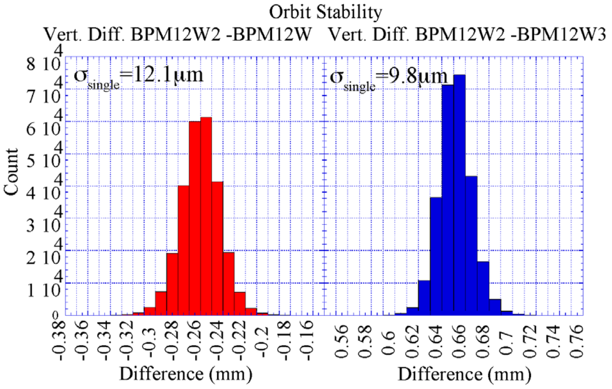

Figure 2: Position difference measurements between pairs of modules in a test triplet located on a single section of vacuum chamber.

4 buttons) is shown in Fig. 4. The observed distribution is consistent with BPM module component specifications.

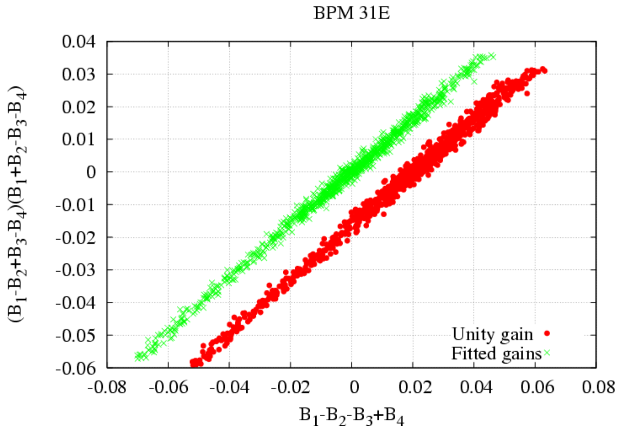

Figure 3: Response plot for 1024 samples of turn-by-turn data, before and after relative gain fitting.

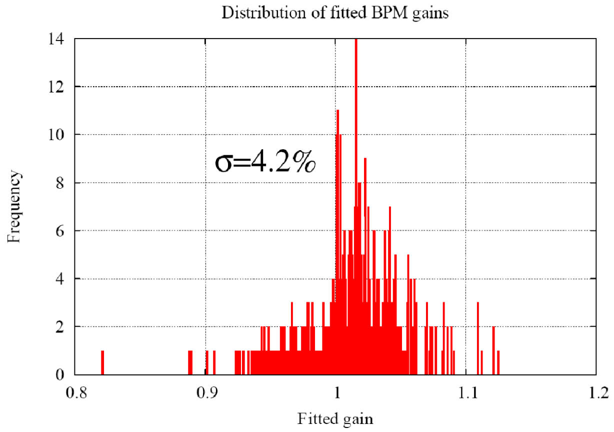

Figure 4: System-wide distribution of relative button gains. The width of the distribution is 4.2% which is consistent with BPM component specifications.

APPLICATION TO ELECTRON CLOUD STUDIES

One of the first applications of the multi-bunch readout capability of the modules has been to continue work on understanding the interaction of the electron cloud build-up around CESR with stored positron and electron beams [4]. Figures 6 and 7 show data acquired as part of bunch-by-bunch tune shift measurements. In one method, an entire train of bunches is excited vertically or horizontal with a single turn pinger and the tunes for all bunches are measured simultaneously using the multi-bunch BPM system. Fig. 5 shows the vertical trajectory for one bunch for such an excitation. The resulting bunch-by-bunch vertical tunes are shown in Fig. 6.

CONCLUSION

An upgraded BPM system is now in standard operation at CESR and is being actively utilized in the low emittance and electron cloud R&D program for CesrTA. While considerable development effort is still required, initial studies show promising performance that appears consistent with our operational and experimental needs.

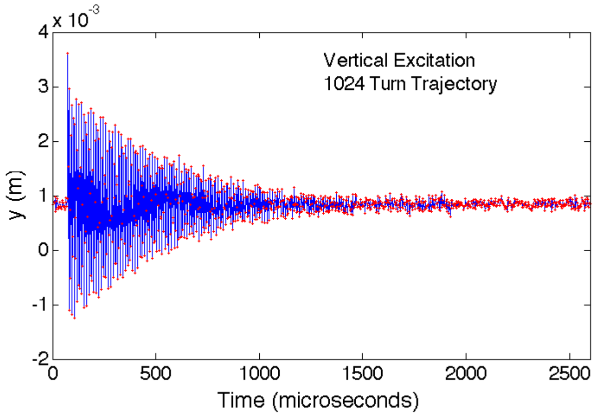

Figure 5: Turn-by-turn vertical trajectory showing excitation by a single turn vertical pinger. The signal shown is for bunch 1 in the train.

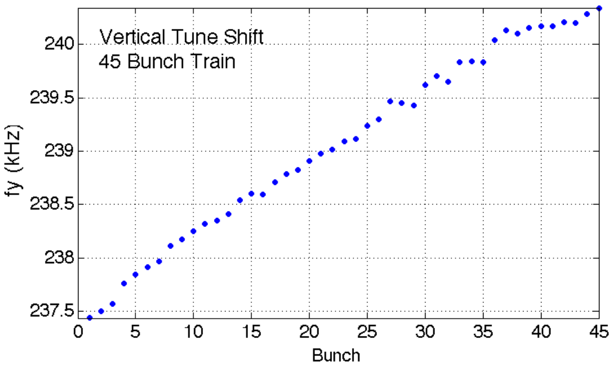

Figure 6: Bunch-by-bunch tunes obtained from turn-by-turn data after excitation by a single turn vertical pinger for a 45 bunch train of positrons at 0.75mA/bunch.

ACKNOWLEDGMENTS

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