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BPM PROCESSOR UPGRADES AT SPEAR3*

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Abstract

We are upgrading the BPM processors in the SPEAR3 accelerator complex as several of the existing systems have reached end of life. To reduce the resources required for maintenance we have evaluated and installed several commercial BPM processors from the SPARK series of Libera/Instrumentation Technologies. In SPEAR3 we evaluated the SPARK-ERXR turn-by-turn BPM processor as a replacement to the in-house developed/commercially built Echotek processors that are used for a range of accelerator physics studies. We show measurements of the orbit dynamics with another SPARK-ERXR in the booster synchrotron from beam injection up to ejection. We have further evaluated a Spark-EL in the transport lines to replace the in-house built uTCA-based single-pass BPM processors. In this paper we show measurements and discuss our experience with the Libera SPARK series of BPM processors and comment on the software integration.

INTRODUCTION

SPEAR3 is a 3 GeV, 500 mA, 3rd generation synchrotron light source, commissioned in 2004 [1]. It operates with beam current distributed in four bunch trains and a single isolated timing bunch for pump-probe experiments. Top-up occurs at 5-minute intervals. Each top-up event requires about 50 single-bunch charge pulses into targeted SPEAR3 buckets at a 10 Hz rate. The SPEAR3 storage ring contains 18 lattice cells each with 6 button-style Beam Position Monitors (BPMs). Three BPMs per cell are connected to Bergoz processors for fast orbit control and beam inter-lock purposes. Approximately 10 more BPMs are connected to the Echotek processors [2] to provide turn-by-turn orbit information at discrete locations. The Echotek processors were developed in-house and produced commercially when SPEAR3 was commissioned; they are used for accelerator physics programs and not for operations. The Echotek have reached their and of life and we have evaluated commercial alternatives for replacement. A Libera Brilliance+ was first tested in SPEAR3 in 2017 [3]. Since turn-by-turn studies for accelerator physics programs do not require the long-term stability capability of the Brilliance+, and additionally the fast orbit feedback is implemented in the Bergoz BPM system, a SPARK-ERXR processor [4] was purchased and installed for further testing.

The SPEAR3 injector was commissioned in 1990 [5], and includes the 120 MeV linac injector with a thermionic RF gun [6], the booster synchrotron [7] and the transport lines. The entire injector, including the transport lines, is equipped with stripline-style BPMs. The original booster synchrotron BPM electronics used a commercial multiplexer to switch between several BPM signals into an in-house built analog BPM processor electronics [8].

In the Linac-To-Booster (LTB) and Booster-To-SPEAR (BTS) transport lines 1990's-era Bergoz BPM processors have provided reliable shot-by-shot single-pass data at 10 Hz with limited resolution [8]. As an upgrade to the original transport line BPM processors, two smaller-diameter stripline BPMs connected to two SLAC-built uTCA-based BPM processors replaced the last two BPMs at the end of the BTS in 2015 (BTS BPMs 8 and 9). This systems has proven hard to maintain and we have evaluated the single-pass SPARK-EL processor as a replacement. The unit was tested in the BTS and LTB transport lines demonstrating comparable position resolution to the uTCA processors at the small-diameter striplines, as well as substantially improved resolution at the large-diameter striplines.

In this work we report on the operation of the SPARK series BPM processors across the SPEAR3 accelerator complex. The overall operational experience has been satisfactory and the software configuration provides a single, uniform working environment.

SPARK-ERXR IN SPEAR3

Figure 1 shows a direct comparison between the SPARK-ERXR (right) and Echotek (left) processors following a horizontal impulse to the beam. The impulse was generated using the SPEAR3 injection kickers with the data acquired on the same event using a synchronized 10 Hz trigger distribution system [9]. The beam current at the time was 1.9 mA in a single bunch and the motion fully damps after 10 ms, or about 12,000 turns.

Figure 2 shows a magnified view of the first 75 turns in the horizontal plane immediately following the impulse. Although the initial phase of the motion is different due to different BPM positions in the storage ring, both systems clearly resolve the turn-by-turn betatron motion with an amplitude difference proportional to square root of beta fuction values at the BPM sites. Using the numerical analysis of fundamental frequency algorithm [10] to evaluate the betatron tunes at $t = 4$ ms, the algorithm yields the expected values for the tunes for both processors.

Processor noise figures can be evaluated from data acquired after the damping event is complete, in this case from vertical data at points of zero dispersion. Note that phase oscillations are present in the horizontal plane and are difficult to remove for rms noise analysis. Figure 3 shows the verti-

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cal data 12 ms after the impulse excitation when the motion is fully damped. The rms position error for the SPARK is about 3 times less than the Echotek, or 8.1 µm rms compared to 24.4 µm rms, respectively. Table 1 contains a list of the measured machine parameters. An even larger discrepancy is anticipated at lower bunch charge. For further information concerning noise power spectra from the Brilliance+ processor tested on the same BPM see reference [3].

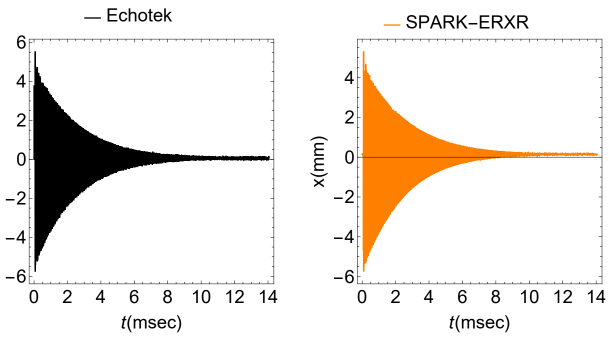

Figure 1: Damped horizontal beam excitation for the SPARK-ERXR (right) and the Echotek (left) processors.

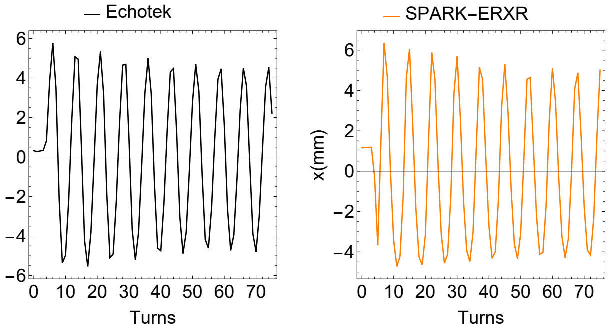

Figure 2: Detail of initial beam excitation following a horizontal kick for the SPARK-ERXR (right) and the Echotek (left).

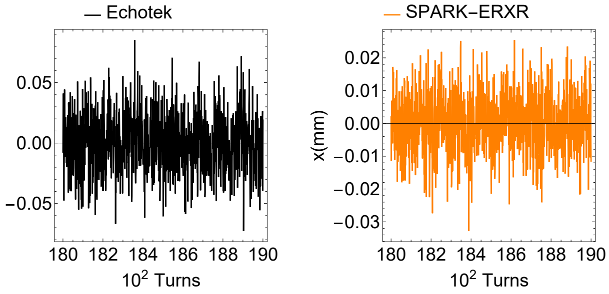

Figure 3: Vertical data in quiescent coasting beam for the SPARK-ERXR (right) and the Echotek (left).

SPARK-ERXR IN THE BOOSTER

The original booster BPM system switches several connected BPMs into one processor through a computer-controlled multiplexer chassis. Additionally, the original

Table 1: SPEAR3 parameter measurement comparison between the Echotek and the SPARK-ERXR.

	Echotek	SPARK-ERXR
I_{bunch}	1.9 mA	1.9 mA
$\beta_x/\beta_y/\eta_x$	3.0/12.5/0.055	2.66/14.85/0.04
K_x/K_y	194000/214000	194000/214000
Q_x/Q_y	0.1054/0.1776	0.1054/0.1776
Q_s	0.009	0.009
y_{rms}	24.4 µm	8.1 µm

coaxial cables were very lossy. The resulting measurement resolution was sub-optimal and at times intermittent due to the system reaching its end of life.

In order to quantify the SPARK-ERXR performance on the booster we replaced the original cables of four BPMs with low-loss LMR400 heliax cables. The signals from the striplines are connected to the SPARK through 290 MHz – 3 GHz band-pass filters. Internal filters then stretch the response which is sampled by PLL-controlled ADCs clocked at 109.8 MHz. The baseband signals were sampled 49 times each revolution; the revolution period is 466 ns. As reported in [3] the tests were successful demonstrating details of the beam capture dynamics as the linac bunches tumble in longitudinal phase space and radiation-damp into a single booster bucket.

In subsequent tests, the SPARK-ERXR modules were applied to BPM signals transmitted over the lossy coax cables, again with the band-pass pre-filtering at the front end. In this case typical peak voltages of the stripline pulse were reduced from 200 mV to 100 mV which was still sufficient to generate approximately 500 ADC counts in the SPARK. The processor again proved to accurately measure single-bunch beam position on a turn-by-turn basis with high resolution throughout the energy ramp.

Using a Matlab script we were able to acquire the progression of the single bunch orbit during a sequence of ramp cycles at top-up. As seen in Fig. 4, the horizontal orbit during the 37 ms energy ramp period is relatively constant across consecutive ramp cycles as viewed at a single stripline BPM. By recording the beam orbit throughout each top-up cycle it is now possible to monitor long-term performance of the booster and identify discrepancies from the optimal orbit when drifts occur.

SPARK-EL IN THE TRANSPORT LINES

We have evaluated the SPARK-EL processor as a replacement for the transport line BPMs. For these tests we compared the SPARK-EL side-by-side with the existing Bergoz and uTCA-based BPM processors for several of the LTB and BTS BPMs while varying the charge through the transport lines. Figures 5 and 6 show the results for the large-diameter LTB BPM 4 and BTS BPM 5. Compared to the Bergoz processors, the SPARK-EL shows more than a factor of 5 improvement in resolution. Figure 7 shows a comparison

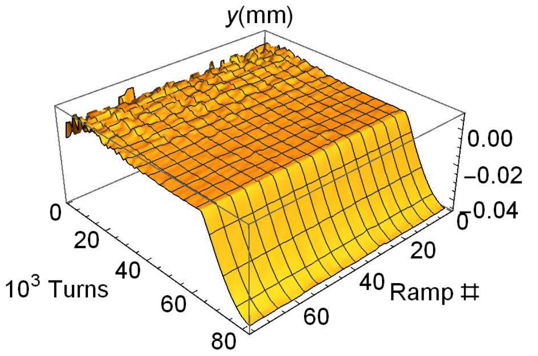

Figure 4: Vertical orbit energy ramp sequence during a single top-up cycle from the booster SPARK-ERXR.

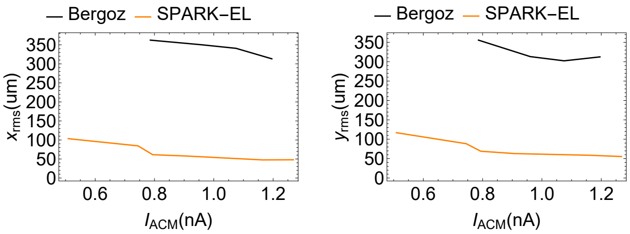

Figure 5: Comparison between the SPARK-EL and the Bergoz at LTB BPM 4.

between the SPARK-EL and the SLAC-built uTCA-based processors at a small-diameter BPM. In this case it is unclear whether the shot-to-shot variations in the SPARK-EL data are systematic or due to beam motion while the uTCA-based processor data shows a trend towards decreased resolution with decreasing bunch charge.

SOFTWARE INTERFACE

The SPARK modules were tested and evaluated in the Development Controls network and deployed in the Production Controls Network. The software integrates easily into the EPICS environment as the SPARK IOC's were built for the same EPICS base version R3.14.12 supported at SPEAR3. The cross-compiled target architecture running on OS Ubuntu 18.04 is unsupported at SLAC so we worked with the iTech to provide updated binaries.

SLAC also worked with iTech to add two additional SLAC production EPICS libraries to the `libera-ioc` source code and had the the IOC's cross-compiled for the Spark platform. One library is the `iocStats` module that supports standard features required by all SPEAR3 IOC's for housekeeping purposes. It also provides a watchdog for IOC heartbeats. This allows watchdog detection if BPM data is not acquired by the SPARK IOC. The other library was the EPICS `autosave` module which allows configuration save and restore across IOC reboots. At SPEAR3 the IOC data configuration is saved in centrally managed NFS space.

The EPICS databases were then modified to adhere to existing SPEAR3 naming conventions. Where possible the production EPICS software reuses the same PV names as the systems they replace for transparent software transitions. Future work involves upgrading the SPARK ioc to EPICS R3.15 and installing a virtual machine image that contains the complete environment for cross-compiling the source code at SLAC for the SPARK platform.

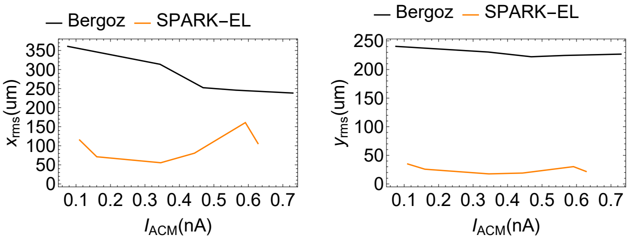

Figure 6: Comparison between the SPARK-EL and the Bergoz at BTS BPM 5.

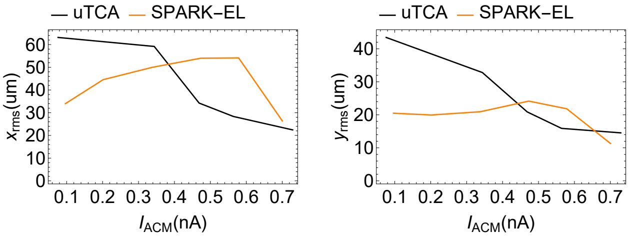

Figure 7: Comparison between the SPARK-EL and the uTCA at BTS BPM 9.

SUMMARY

In this paper we report on the evaluation of Libera SPARK BPM processors at SPEAR3, the booster synchrotron and transport lines. In SPEAR3, the SPARK-ERXR processor can seamlessly replace older processors with improved turn-by-turn measurement resolution. In the booster, the SPARK processors provide more accurate turn-by-turn time beam position measurements. In the transport lines, the SPARK-EL processors provide comparable resolution to the existing uTCA-based system. The full suite of SPARK processors is more easily managed in the EPICS environment and simplifies operations to a set of unified interfaces.

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