ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-WEPP017

CURRENT MONITOR AND BEAM POSITION MONITOR PERFORMANCE FOR HIGH CHARGE OPERATION OF THE ADVANCED PHOTON SOURCE PARTICLE ACCUMULATOR RING*

A. R. Brill†, J. R. Calvey, K. C. Harkay, R. T. Keane, N. Sereno, U. Wienands, K. P. Wootton, C. Yao
Argonne National Laboratory, Lemont, IL 60439, USA

Abstract

A design choice for the Advanced Photon Source Upgrade (APS-U) to inject into the storage ring using bunch swap out rather than off-axis accumulation means that the Advanced Photon Source (APS) injectors are required to accelerate much higher electron bunch charge than originally designed. In the present work, we outline upgrades to the current monitor and beam position monitor (bpm) diagnostics for the Particle Accumulator Ring (PAR) to accommodate bunch charges of 1-20 nC. Through experiments, we compare and characterize the system responses over the range of bunch charge.

INTRODUCTION

The APS injector consists of a linac, PAR, and booster synchrotron. The linac provides a series of 1-nC bunches at a 30-Hz repetition rate. The pulses are accumulated and damped in the PAR at the fundamental rf frequency. Approximately 230 ms before extraction, the single bunch is captured in a 12$^{\text{th}}$ harmonic rf system which further compresses the bunch. The APS injector was originally designed to provide a maximum bunch charge of 6 nC at a 2-Hz extraction rate.

The APS-U design requires on-axis injection to meet emittance performance goals. For APS-U, on-axis injection will be implemented using a swap-out scheme. In swap-out injection, the injectors are required to produce enough single-bunch charge to perform a complete bunch replacement. Swap-out places high demands on the injector bunch charge. For APS-U timing mode operations, the PAR will be required to provide 20 nC in a single bunch [1], which exceeds the original design parameters of the PAR by a factor of greater than three.

Operating at the default accumulation period of 0.5 s, the PAR is limited to providing approximately 10 nC per bunch. To provide up to 20 nC of charge, the injector cycle must be extended to at least 1 s allow sufficient time to accumulate and compress the required linac bunches [2].

CURRENT MONITOR PERFORMANCE

Several techniques have been used to measure the amount of charge in the PAR. The combination of high revolution rate and wide range of signal levels used in the PAR present unique challenges for measuring the stored beam charge. One option is to use the sum signal from the bpm electronics. Another option is to use the installed integrating current transformer (ICT). Each method has its own advantages and disadvantages.

Beam Position Monitor Sum

The simplest method of observing the PAR charge is to use the sum signal of one of sixteen 352-MHz stripline bpms to calculate the estimated charge present. By comparing the the readings of the linac-to-PAR (LTP) and PAR-to-booster (PTB) current transformers, the amount of charge in the PAR can be determined. By applying a calibration factor to the sum signal, a reasonable estimate of charge is calculated. There are some important limitations of this method. As the stored charge increases well beyond the initial design parameters, the sum signal from the bpm electronics begin to saturate, providing nonlinear results if the input signal is not sufficiently attenuated. The bpm sum signal also varies inversely with bunch length throughout the cycle, limiting the useful range of this measurement.

Integrating Current Transformer

An ICT produces an output signal that is very linear with charge but almost independent of the input bunch duration [3]. The original beam current monitor electronics were implemented with a gated integrator to measure the ICT pulse. However, due to the 9.78-MHz repetition rate and changes in bunch length and beam phase through the injection cycle, the gated integrator proved to provide unreliable readings. The gated integrator electronics were replaced with an FPGA-based data acquisition system around 2008 [4]. Using interleaved sampling, the FPGA processor digitizes the output waveform of the ICT to calculate the rms values in 10 user-defined time windows throughout the injection cycle. With these windows, injection efficiency can be observed in stages throughout the accumulation, damping, and harmonic capture portions of the PAR injection cycle.

A drawback of using an ICT in the PAR is that as the repetition rate of the input to an ICT increases, the baseline of the output waveform shifts. The baseline shift between a 1-MHz repetition rate and the PAR repetition rate is shown in Fig. 1. After subtracting the baseline offset, the shape of the waveform is almost identical. To evaluate the linearity of the ICT response through charge levels greater than 20 nC at the PAR repetition rate, the measured charge plotted in Fig. 2 is calculated using different methods, with baseline subtraction as the preferred method.

* Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
† abrill@anl.gov

ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-WEPP017

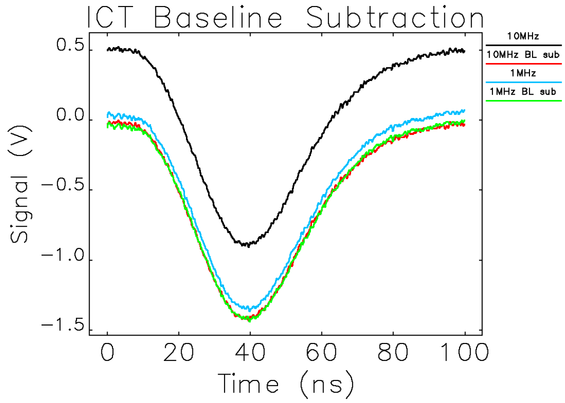

Figure 1: Measured ICT output waveform at 1 MHz and 10 MHz repetition rates. Subtraction of the baseline voltage shows that the waveform shape is nearly identical.

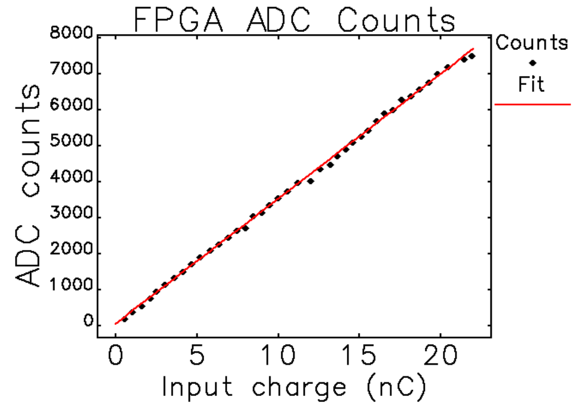

Figure 3: The relationship between input charge and ADC output counts for the FPGA-based data acquisition system. The ADC response is linear beyond 20 nC.

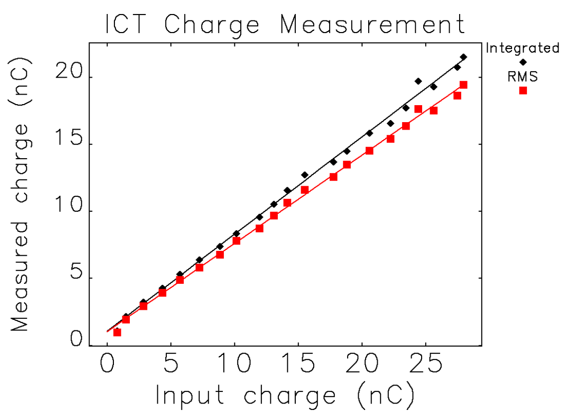

Figure 2: Measurement of charge by ICT at 10MHz input pulse rate. The measured output charge is evaluated using both baseline subtracted integration and rms.

Despite the baseline shift at the higher repetition rate, the rms value of the waveform is still proportional to the input pulse across the range of charge. The response of the FPGA data acquisition electronics to input charge at the PAR revolution frequency are shown in Fig. 3.

BEAM POSITION MONITOR PERFORMANCE

The PAR is presently still using the original bpm processing electronics which are over twenty five years old. They provide a single position reading per injection cycle with a resolution of approximately 100 µm [5]. In normal operations, the bpm readings are used in PAR slow orbit feedback to maintain a defined orbit in the PAR. The drive to achieve much higher charge through the injectors requires additional capabilities from the beam position monitor electronics.

To better understand the behavior of high-charge beam throughout the PAR cycle, we evaluated the Libera Spark ERXR beam position processor (Spark) from Instrumentation Technologies. To minimize disruption to existing systems, splitters were installed on the bpm outputs to provide equal signals to the original system and two Spark bpms. Since the stripline bpm pickups were designed to maximize signal to the original electronics for relatively low charge conditions, operation at significantly higher charges requires around 40 dB of attenuation to provide a safe signal level for the Spark signal inputs.

The biggest improvement offered by the Spark over the original PAR electronics is the ability to measure beam position at higher data rates throughout the injection cycle. The Spark has the ability to capture data at the ADC, turn-by-turn, Fast Acquisition (FA) and Slow Acquisition (SA) rates. The available data paths are summarized in Table 1. The ADC and turn-by-turn data buffers are available on demand with reference to an external trigger, while the FA and SA buffers stream independent of the trigger rate. With the relatively short duration of beam accumulation before extraction in the PAR, the streamed buffers are of limited value, since these streams are intended for a ring with constant stored beam.

Table 1: Libera Spark ERXR Data Paths

Data Stream	Sample Rate	Buffer Size	Time
ADC	108 MHz	4M	37.2 ms
Turn-by-turn	9.78 MHz	1M	102 ms
FA	10 kHz	stream	stream
SA	10 Hz	stream	stream

As with the current monitor, the unique operating cycle of the PAR presents challenges to the standard use of the Spark. Since beam is accumulated, compressed, and extracted in specific time windows each second, the PAR requires a hybrid of a single-shot measurement and stored beam measurement. We evaluated firmware designed for both storage ring and linac position measurement. To allow the flexibility to operate in both normal and high charge mode, it was determined that the stored beam firmware was

ISBN: 978-3-95450-204-2 ISSN: 2673-5350 doi:10.18429/JACoW-IBIC2019-WEPP017

preferred. To measure turn-by-turn position throughout the cycle, a network-controlled delay generator was used to align the turn-by-turn data buffer with the region of interest.

With attenuators installed to maintain ADC counts in a safe range, Fig. 4 shows that the Spark sum signal is also very linear.

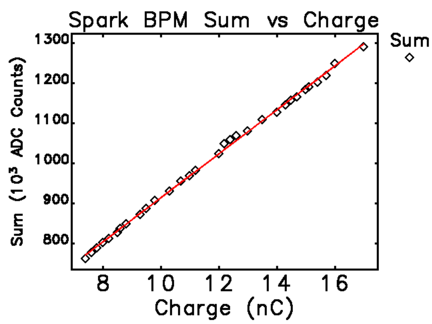

Figure 4: Sum signal vs. PAR charge with linear fit.

Prior to the installation of the Spark bpms, injection efficiency in the PAR dropped significantly starting at 14 pulses, limiting the ability to accumulate more than 16 nC per cycle. Using the turn-by-turn position information from the Sparks, large horizontal transients were observed corresponding to injection (See Fig. 5). Adjusting the PAR orbit bump at the septum and the injection kicker settings dramatically improved beam loss during injection.

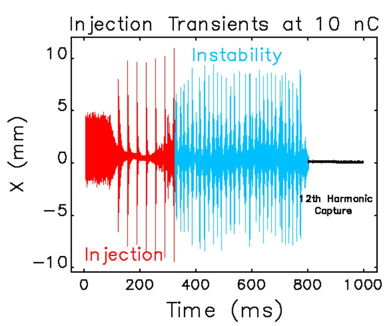

Figure 5: Horizontal injection transients observed while injecting 10 nC.

An additional challenge for the extraction of high charge is optimization of the 12$^{\text{th}}$ harmonic cavity detuning, which must be changed as a function of charge. If the 12$^{\text{th}}$ harmonic detuning is not ideal, instabilities occur. An example of mitigating instabilities with proper detuning is shown in Fig. 6.

The turn-by-turn position readbacks of the Spark bpms are a valuable tool during high charge studies in the PAR. Their use was an important factor in achieving the successful accumulation and extraction of 20 nC, achieving the APS-U requirement for charge provided by the PAR.

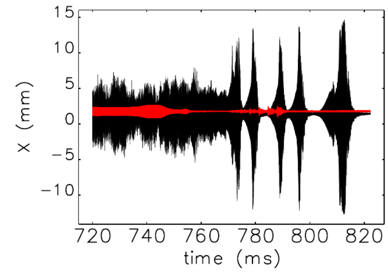

Figure 6: Comparison of Spark bpm data at 10 nC. The black curve shows insufficient detuning, the red curve shows improved stability with sufficient detuning. The 12$^{\text{th}}$ harmonic cavity turns on between 750 and 770 ms.

CONCLUSION

The APS-U design choice to use on-axis swap-out injection requires evaluating the capability of existing diagnostic systems to operate well beyond their original design parameters. Using a combination of bench tests and experiments in the PAR, we have verified that the existing ICT current monitor and FPGA data acquisition system have a linear response over the full range of charge. The existing beam position monitor electronics provide only a single position reading per cycle. Upgrading select cases of the original electronics to the Libera Spark ERXR, a modern beam position monitor processor with turn-by-turn processing capability, provided information critical to achieving the extraction of the target charge level from the PAR. Experiments with beam show that the Spark is a viable option for a comprehensive PAR bpm upgrade.

REFERENCES

[1] K. C. Harkay *et al.*, "High-Charge Injector for on-Axis Injection Into A High-Performance Storage Ring Light Source", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 3423–3426. doi:10.18429/JACoW-IPAC2019-THYYPLM3

[2] C. Yao *et al.*, "High Charge Development of the APS Injector for an MBA Upgrade", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 1828–1830. doi:10.18429/JACoW-IPAC2015-TUPJE079

[3] K. B. Unser, "Measuring Bunch Intensity, Beam Loss and Bunch Lifetime in LEP", in *Proc. 2nd European Particle Accelerator Conf. (EPAC'90)*, Nice, France, Jun. 1990, pp. 786–789.

[4] C. Yao and W. E. Norum, "Bunch Current and Phase Detection for the APS PAR", in *Proc. 23rd Particle Accelerator Conf. (PAC'09)*, Vancouver, Canada, May 2009, paper TH5RFP006, pp. 3447–3449.

[5] A. Lumpkin, *et al.*, "Initial Diagnostics Commissioning Results for the APS Injector Subsystem", in *AIP Conf. Proc.*, vol. 333, no. 1, pp. 191–187, 1995.