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BEAM POSITION MONITORING SYSTEM AND BEAM COMMISSIONING AT THE APS-U STORAGE RING*

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Abstract

The Advanced Photon Source Upgrade (APS-U) storage ring has recently finished installation and pre-beam testing and is being commissioned with beam. The APS-U storage ring has 560 Beam Position Monitor (BPM) pickups, each equipped with high-resolution electronics. This paper presents outcomes from pre-beam testing and earlier APS-U BPM system beam commissioning. We discuss features for advanced beam measurements, testing methods, and successful integration into the storage ring beam commissioning. The BPM system has demonstrated its crucial role in achieving the first beam and optimizing the APS-U storage ring's performance.

INTRODUCTION

APS-U is an ultimate low-emittance storage ring [1] that is being commissioned at Argonne National Laboratory. The machine has a designed horizontal emittance of 42 pm.rad, small dynamic aperture, and adapts swap-out injection. Advanced RF BPMs are equipped to measure beam trajectory and positions at various bandwidths to characterize the machine's performance.

There are 14 RF BPMs installed in a typical APSU sector, which gives a total of 560 BPMs in 40 sectors. Although the BPM feedthroughs share the same design, there are four different types of BPM pickups with different housing dimensions, namely P0 type, STD type, AP2 type, and BP5 type. The P0 and STD types have circular chambers of 22-mm diameter, and four buttons are symmetrically located at 45-deg angles. The AP2 and BP5 types have photon extraction slots and antechamber. Consequently, the button can only be located at 60-degree angles (relative to the horizontal plane). Within a sector, there is 1 AP2, 1 BP5, 2 P0, and 10 STD BPMs. The BPM pickup and feedthrough design can be found in [2].

Part of the Booster to Storage ring (BTS) transfer line has also been newly constructed, where new button-type BPMs are installed. There are 11 such BPMs installed in the new BTS, with the same feedthroughs as the storage ring (SR). The BTS section in the booster tunnel side remains the same, so the original stripline-type BPMs are still being used. All of the BTS BPMs are now using a new type of electronics.

Commercial electronics from I-Tech [3] have been selected for the APSU BPMs with added features. The BTS BPMs are equipped with Spark-EL single-pass electronics, which provide sufficient resolution at 1nC even with the 8mm button BPMs. 20dB attenuators are added for the old stripline BPMs to avoid saturation of the new sensitive electronics at high charge.

The storage ring button BPM signals feed Libera Brilliance Plus (LB+) electronics via coaxial cables. Each LB+ unit houses four BPM modules, one controller module, one timing module, and one Global Data Transmitter (GDX) module. The BPM modules condition the analog signals, digitize them, and process the data at various bandwidths and precision; the controller module manages the LB+ unit and houses EPICS IOC; the timing module communicates to the MRF timing system [4] so that the BPMs can be PLL locked to external machine clocks and triggered on different events. The GDX module streams fast turn-by-turn (TBT) data via fiber links. The streaming TBT data is used for other devices/applications, like the TBT data acquisition system (TBTDAQ), the beam position limit detection system (BPLD), and the fast orbit feedback system (FOFB).

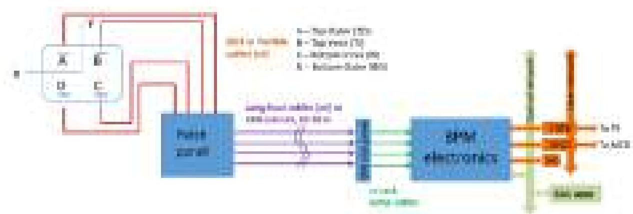

Figure 1: Block diagram of BPM wire connections.

In addition to the regular LB+ electronics, there are BPMs in the first three sectors after injection straight, equipped with fast RF switches and Spark ERXR electronics. The system allows precise single-bunch measurement during swap-out injection and similar measurements. Earlier beam test results of the prototype system can be found in [5]. There are 20 BPMs in the APSU ring equipped with such a system, and they have been preliminarily tested with the beam.

Figure 1 shows the block diagram of a typical BPM and its wiring connections.

INSTALLATION AND PRE-BEAM TESTING

Eight of the 14 BPMs in a sector were installed during girder assembly; the remaining six were installed in the tunnel. Once the BPM pickups were installed in place, the jump cables were connected to the patch panel on the girder. The pre-terminated long-haul cables were pulled and connected to the patch panels as the final step of the pre-beam test and checkout.

Upon delivery, the BPM pickup assemblies were tested using a 4-port VNA, a Hipot tester, and a TDR. The final

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installed BPMs in the tunnel (with jump cables) have been verified with the 4-port VNA. These measurements confirm the integrity of the BPM pickups, the jump cables, and the patch panels. Additionally, the electrical offsets have been derived from these measurements. More information can be found in [6].

The installed BPM long-haul cables, jump cables in the rack, and BPM electronics were tested using a signal generator and a 1 to 4-way switch. The continuous-wave signal was switched to A/B/C/D in sequence to verify the cable connections. The BPM electronics and gains (with cable losses) were parasitically measured. The measured BPM pickup offsets, BPM electronics offsets, and BPM-to-BPM gain calibration were applied during day-1 commissioning.

Figure 2 plots the statics of the BPM offsets. The top two subplots are the BPM pickup offsets measured with the 4-port VNA, while the bottom two show the BPM electronics offsets (with cables).

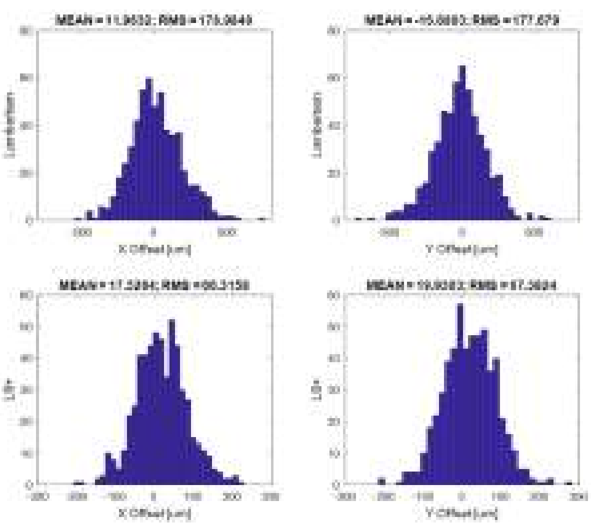

Figure 2: BPM offsets measured using the 4-port VNA (top), and electronics offsets measured using the signal generator and 1->4 switch (bottom).

One feature of the LB+ electronics is that each BPM has a synthetic data generator, which was widely used during pre-beam testing. At the time, there was no actual beam data, and the synthetic TBT data was used to test the communication to other systems (like TBTDAQ and BPLD) via fiber links. Up to 4096 turns of arbitrary waveform data can be programmed and streamed out on external triggers. This way, the TBTDAQ and BPLD functionalities, as well as synchronized data acquisition, were tested with the simulated TBT data.

BEAM COMMISSIONING RESULTS

APSU storage ring beam commissioning started in April 2024. All the new BPM pickups and electronics have seen beam so far and have been preliminarily commissioned.

Figure 3 shows the raw ADC SUM data while the beam was circulating in the ring for the first turn on April 13th. The horizontal axis is the 560 BPMs around the ring, starting at the injection point. The vertical axis is the ADC samples; note that there are 398 ADC samples per turn. The beam signal is represented with the bright strip starting at ADC sample #140. Beam survived the first turn as the strip moved to larger ADC samples following the BPM geographical locations. Some BPMs see the second-turn signals. The single bunch was injected into bucket #0.

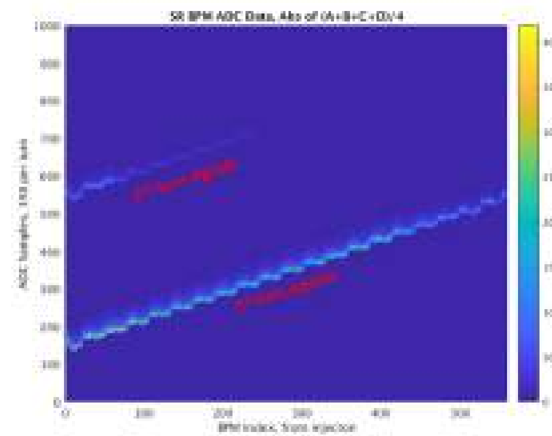

Figure 3: Raw ADC data of the first turn beam circulating in the ring.

Based on the arrival time of the 1st-turn beam, as seen in Fig. 3, the BPM signal processing timing was adjusted. This way, turn-to-turn signal processing is aligned between BPMs so they all report the data from the same turn. As the TBT data streams, they can be reliably captured by the TBTDAQ or BPLD system. Figure 4 is a plot of the BPM sum signal of individual turns. The beam arrived at turn #3 and survived for about 15 turns.

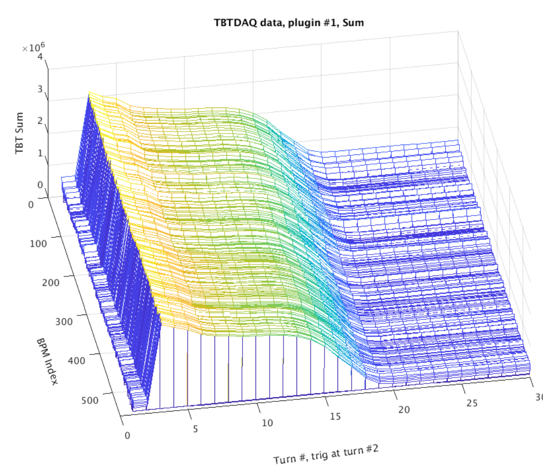

Figure 4: The beam circulates in the ring for ~15 turns. This plot shows the TBT sum signal from TBTDAQ.

Once the beam circulated in the ring, one crucial commissioning task was verifying shielding. Beam was purposely dumped at selected locations while radiation was measured. The BPM single pass data has been used to measure the first turn trajectory and the charge (proportional to BPM sum signals). An example is shown

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in Figure 5, where the injecting beam was dumped at the insertion device (ID) in S15. In the plot, s = 0m is the injection point, and negative s values represent BPMs in the BTS line. The ID is between BPM S15BP0 and S16AP0. There was ~1nC charge measured in the BTS, and ~38% of the charge was captured after the injection. The charge can be estimated benefiting from the calibrated BPM sum signals.

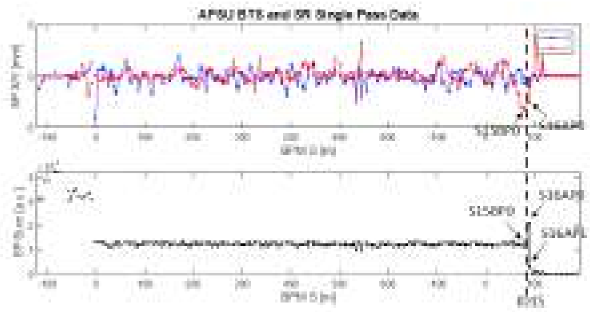

Figure 5: Single-pass trajectory and sum signal from BTS BPMs and the first sectors of the SR. The beam was dumped at ID15 for shielding verification.

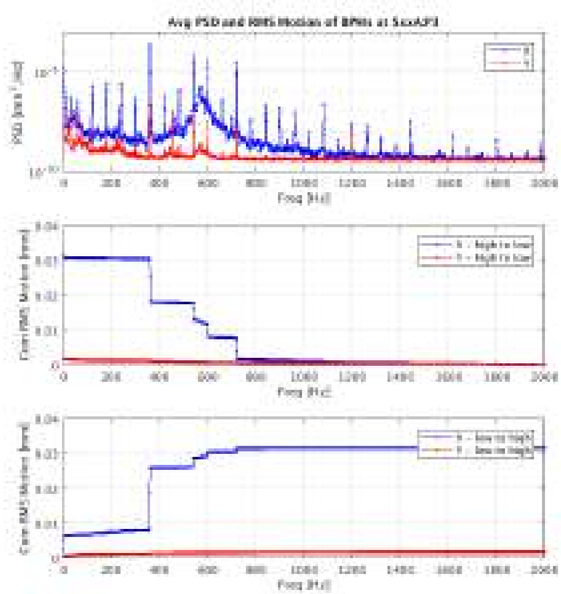

Figure 6: Averaged FA data spectra at dispersive BPMs AP3. The hump around 570Hz is due to synchrotron frequency, and the 60Hz and harmonics are seen.

As the electron beam is stored in the ring, multiple turns of TBT or long fast-acquisition (FA, averaged every 12 turns) data can be acquired to analyze the electronics resolution and beam stability. Figure 6 shows an example spectrum and cumulated RMS motion of dispersive BPMs AP3, averaged from 40 sectors around the ring. BPMs from low dispersion show a smaller amplitude of the synchrotron hump and 60Hz harmonics. About 1.2mA stored beam was in the ring, and the FA data had a measurement resolution of ~2 µm, calculated from the PSD noise floor. The noise floor is expected to be further reduced at higher currents and more stored bunches.

SUMMARY AND DISCUSSION

RF BPMs at the APSU storage ring and the BTS beamline have been fully installed, tested, and preliminarily commissioned with the beam. The system has been operating reliably and supports machine characterization.

The pre-beam testing and checkout have been effective and provide valuable data (like the electrical offsets and gain calibration) for earlier commissioning. Experience so far shows that these values are reliable.

Although not much discussed in this paper, the Spark ERXR and fast RF switches have been preliminary commissioned. With more bunches stored and the swap-out injection, the Spark ERXR can be more helpful in measuring the turn-to-turn trajectories of the injecting/extracting bunch. Features like the synthetic data generator have been widely used during pre-beam testing when actual beam data was not readily available. Other features, like the multiple gates, have yet to be thoroughly tested. We hope to report progress in the future.

ACKNOWLEDGMENTS

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