BPM STABILTIY STUDIES FOR THE APS MBA UPGRADE*

R. Lill, N. Sereno, B. Yang
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 USA

Abstract

The Advanced Photon Source (APS) is currently in the preliminary design phase for the multi-bend achromat (MBA) lattice upgrade. Beam stability is critical for the MBA and will require long term drift, defined as beam motion, over a seven-day timescale to be no more than 1 micron at the insertion device locations and beam angle change of no more than 0.25 micro-radian. Mechanical stability of beam position monitor (BPM) pickup electrodes mounted on insertion device vacuum chambers place a fundamental limitation on long-term beam stability for insertion device beamlines. We present the design and implementation of prototype mechanical motion system (MMS) instrumentation for quantifying this type of motion, specifically in the APS accelerator tunnel and experiment hall floor under normal operating conditions. The MMS presently provides critical position information on the vacuum chamber and BPM support systems. Initial results of the R&D prototype systems have demonstrated that the chamber movements far exceed the long-term drift tolerance specified for the APS Upgrade MBA storage ring.

INTRODUCTION

In order to achieve the MBA beam stability requirements, an extensive R&D program has been planned and is presently being implemented. The beam diagnostics required for the APS MBA are driven largely from a small electron beam size and the requirements for those systems are outlined in Table 1. The minimum beam size for the MBA lattice is expected to approach 4 microns at the insertion device (ID) source points. AC rms beam stability requirements are defined as 10% the minimum source size at the ID in the band 0.01-1000 Hz. The vertical plane stability requirement is the most ambitious, requiring a stability of 400 nm at the ID source point. In addition, long term drift, defined as motion over a seven-day timescale, can be no more than 1 micron.

Table 1: MBA Beam Stability Requirements

Plane	AC rms Motion (0.01-1000 Hz)	Long-term Drift (100s-7 days)
Horizontal	1.7 μm 0.25 μrad	1.0 μm 0.6 μrad
Vertical	0.4 μm 0.17 μrad	1.0 μm 0.5 μrad

* Work supported by U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

BEAM STABILITY R&D OVERVIEW

We have approached the MBA diagnostics R&D in two phases. The first phase, outlined in Figure 1, prototypes new, higher risk diagnostics and their interfaces. This R&D includes an MMS, BPM electronics, Grazing Incidence Insertion Device (GRID) X-Ray BPM [1], and new feedback processing electronics [2]. This phase is presently near completion and has provided the foundation for the next phase of R&D [3].

The MMS system shown on the lower section of Figure 1 will be discussed in greater detail in the paper. This diagnostic has been designed to monitor critical in-tunnel beam position monitoring devices. The mechanical motion generated from changes in chamber cooling water temperature, tunnel air temperature, beam current, and undulator gap position causes erroneous changes in beam position measurements, creating drift in the x-ray beam position. Research to quantify mechanical motion specifically for the APS accelerator tunnel has been ongoing for over five years [4,5].

The second phase of the R&D effort advances the design and integrates all systems required to qualify beam stability. The integrated beam stability testing will require 16 new rf BPMs and 8 new corrector power supplies and interfaces. The integrated beam stability effort will be required to operate transparent to normal APS operation and is planned to start in the late summer of 2016. This testing will greatly reduce risks and qualify many diagnostic systems and their related interfaces.

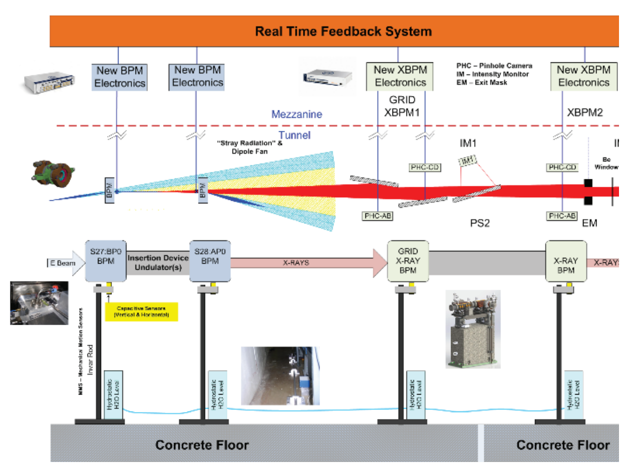

Figure 1: APS-U beam stability R&D.

ISBN 978-3-95450-177-9

MMS SYSTEM DESIGN

In order to achieve long-term beam stability goals, a mechanical motion system (MMS) has been developed. The need for this development started in early 2010 when periodic 15-minute duration beam motion was reported on many ID locations during user operations [4]. It was determined that the periodic beam position motion was correlated to the cooling water cycle for the aluminium vacuum chamber. Experiments conducted confirmed that thermal distortion of the vacuum chamber leads to movements of the BPMs up to 10 µm/˚C. This distortion was incompatible with the present operations of APS and with the new beam stability requirements for the planned MBA upgrade. Improvements to the aluminium water regulation system has greatly reduced these negative effects. Further studies of the ID BPM detectors have identified nonlinear mechanical movement of the BPM detectors that change with tunnel air temperature, and beam current. All sources of mechanical motion of critical in-tunnel beam position monitoring devices are presently being carefully evaluated and appropriately addressed.

The MMS instruments' critical ID and X-ray bpm locations with sensors are shown in the lower section of Figure 1. These diagnostics measure the mechanical movements of the detectors and the ground motion of the floor supporting the detectors. The ID and X-ray BPM detector locations are instrumented with commercial high-resolution non-contact capacitive detectors by Micro-Epsilon [6]. The capacitive detectors are mounted on super invar low expansion support systems. The Micro-Epsilon CapaNCDT 6200 is a multi-channel measuring system that is entirely modular and can support up to four synchronized channels with integrated Ethernet interface. A parallel plate capacitor is formed between the sensor and the BPM vacuum chamber. If a constant alternating current flows through the sensor capacitor, the amplitude of the alternating voltage on the sensor is proportional to the distance between the capacitor electrodes. Any change in the capacitance, due to a change in its area or spacing, is demodulated and presented as a dc signal. The range of measurement is 500 microns with a resolution of 10 nanometres. The capacitive detection electronics must be installed in the tunnel in a shielded enclosure.

Figure 1 illustrates the design Hydrostatic Level System (HLS) where the floor is measured at critical support locations. The fundamental principle of HLS is based on the communicating vessels principle. The baseline design uses Fermi Lab Budker design sensors [7]. Argonne has worked with Micro-Epsilon to combine their expertise in capacitive detection with the Budker HLS design concept and has developed and built prototypes presently being evaluated. The sensors have two main components: the water reservoir and the capacitive pick-up. The reactance of the capacitor changes in direct proportion to the water level. The electronics are similar to the capacitive detector described earlier.

Another capability that we added is the ability to precisely move the support system for the BPM detectors. The thermal expansion of the steel supports can be controlled using a 300-watt electric heater in an effort to regulate vertical height of the BPM. The MMS output is used in a feedback loop controlling the heater duty cycle holding the mechanical position of the BPM constant. The vertical drift of the BPM detector that typically moves 14 microns per degree Celsius can be regulated to less than 300 nanometre peak to peak. This test demonstrated the feasibility of regulating the steel support to compensate for many systematic effects altering the vertical position of the BPM.

PROTOTYPE TESTING

A rigorous test plan is presently being implemented for the MBA prototype diagnostics. The MBA R&D plan prototypes— the rf BPMs, GRID-XBPMs, MMS, and feedback system— will demonstrate compliance to the MBA requirements for beam stability. This testing has added new capacities to make precision mechanical movements of the bpm support system which enables cross calibration between beam diagnostic systems. Cross calibration tests can now be made using the local BPM and MMS. The BPM can be removed from being used in the orbit control feedback and then physically moved with the heater actuators vertically while stable beam is present. This presents a direct calibration of the BPM system with a known beam position movement. This data has been useful during the test and commissioning of the new bpm system installed.

To demonstrate the impact of mechanical motion for ID BPMs, we ran an experiment using the heater actuators where we moved each end of the ID supports. This was accomplished while the ID BPM on both sides of the 5-m ID chamber were being used in feedback to hold position constant to observe the movement on the GRID X-ray bpm 16-m further from the downstream end of the ID chamber. This experiment demonstrates the impact of bpm mechanical motion on beam stability during machine studies. First we moved the downstream bpm up by 5 µm (shown in Figure 2) at approximately 10 minutes shown on horizontal scale. This resulted in the X-ray beam moving approximately 20 µm as measured by the GRID (top plot). Next, the beam is deliberately steered by approximately 5 µm at the downstream bpm, thereby returning the X-ray bpm position back to the starting point as measured at the GRID at approximately 20 minutes. At approximately the 30 and 60-minute marks we repeat the experiment using the upstream BPM and steer the x-ray beam down by 15 µm at the XBPM with identical results. This experiment demonstrates the impact that a 5-micron thermally driven movement of the ID bpm can have on the x-ray beam 20 meter downstream. It also provides a cross-correlation calibration between the rf BPMs, MMS, and GRID BPMs used for this experiment.

In another example of how the mechanical motion system has improved the APS today, we discovered a step change of 60 microns vertically on the MMS when the undulator gap approaches the minimum gap. It turns out that the spring force of the limit switch plunger is strong enough to deflect the ID chamber and move the rf BPM. This problem has since been noted in other insertion device

ISBN 978-3-95450-177-9

locations. Based on this discovery, design changes are being made to minimize this adverse effect.

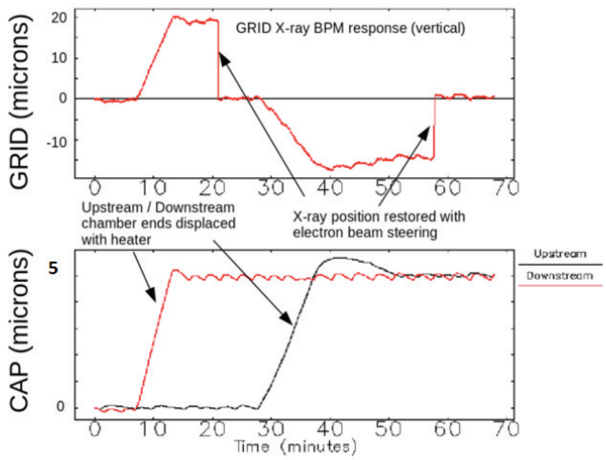

Figure 2: Impact of mechanical motion for ID BPMs.

The HLS, shown in Figure 1, measures the relative ground motion between the IDVC BPMs in the APS accelerator tunnel and the beamline x-ray BPM locations. Studies have been conducted to quantify this type of motion specifically for the APS accelerator tunnel. These studies are providing data under normal machine operating conditions necessary to develop a strategy for measurement and correction of this drift.

A common measure of diffusive ground motion over extended time periods is the so-called ATL law, whereby the mean square amount of ground motion taking place over a time period, T, between two points separated by a displacement, L, is proportional to their product, with proportionality constant, A [8]. Estimates of diffusive ground motion between the two IDVC BPMs separated by 5 meters can be expected to be up to 7 microns in a 5-day time period, using the constants provided in Ref. [7] for Fermi Laboratory Tevatron collider HLS. The ground motion at APS sector 27 ID typically measures about 1-micron peak to peak over a five-day period shown in figure 3.

The other ground motion observation shown in Figure 3 is an approximate 12-hour cycle. This 12-hour cycle can be correlated directly to tidal effects. The APS storage ring is also effected by tidal motion. The horizontal beam position is measured and the variation of the ring diameter is compensated by changing the rf frequency. The effective circumference change of the 1105-meter storage ring is 3 microns for the same five-day period shown in Figure 3.

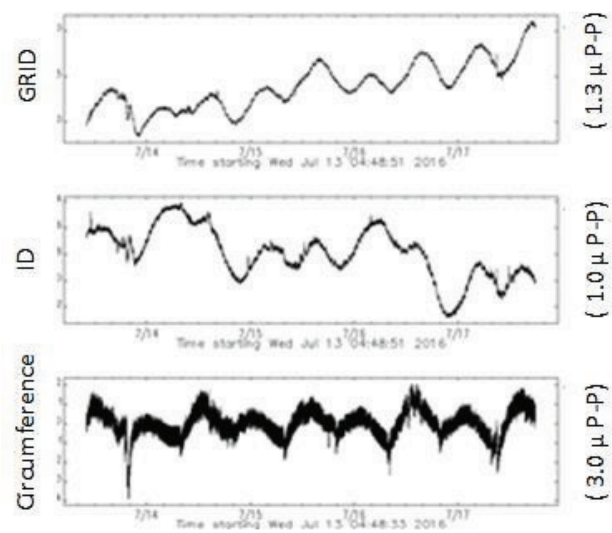

Figure 3: HSL and APS ring diameter change.

MBA SYSTEM DESIGN

The MBA upgrade will require instrumenting 35 ID BPMs and 35 X-ray BPMs for a total of 280 channels of capacitive detectors. These detectors will provide measurement information which will be used in a feed forward compensation loop to remove any residual mechanical motion for the bpm measurements. There will also be 140 hydrostatic detectors located at the ID and GRID BPM locations. These detectors will measure ground motion and be used to compensate for localized ground motion in each of the 35 locations.

The MMS has provided design insight on the vacuum chamber and beam position monitor support systems. The MBA design for the ID BPMs have recently been changed from a vacuum chamber mounted button to the bellows isolated BPM shown in Figure 4. The BPM will now be isolated from the negative effect of the chamber cooling water and additional vibrations when mounted directly to the vacuum chamber. The integration of the MMS system to the new bpm design is ongoing at this time.

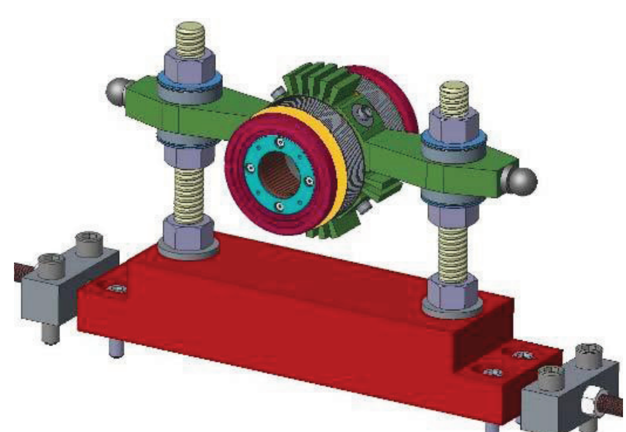

Figure 4: Bellows isolated BPM.

ISBN 978-3-95450-177-9

The supports for the ID bpm will also be changed from a steel support system to the concrete support system shown in Figure 5. This support system promises a greatly improved mechanical stability.

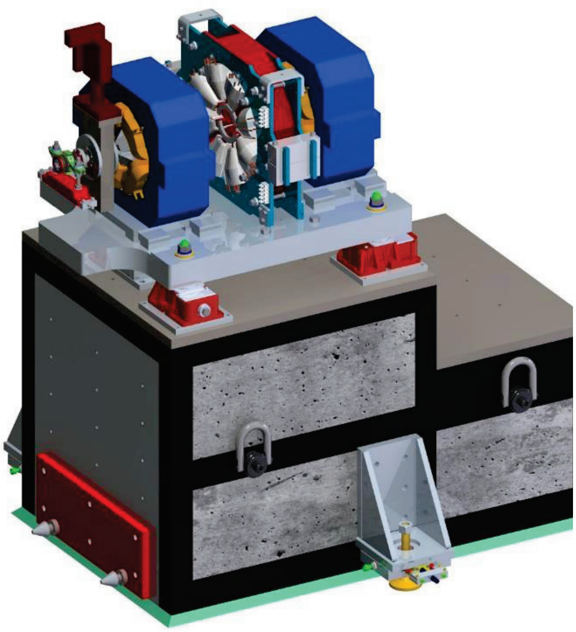

Figure 5: ID BPM concrete support system.

The MMS has also provided critical information on the accelerator cooling water and air handling systems' effects on beam stability. These systems have been proven to have significant impact on mechanical bpm detector stability. The MMS provides real time data to inform improvements of these systems and incremental improvements of the water and air handing regulation systems have been accomplished. These improvements presently benefit the current APS machine operations and also promise to ensure the MBA meets these very difficult beam stability requirements.

CONCLUSION

It is imperative that the MBA upgrade have world class beam stability performance. The MBA upgrade will instrument 35 ID BPM locations and 35 GRID X-ray BPM locations with high-resolution, non-contact capacitive detectors. The floors in these locations will be instrumented with a HLS system. The HLS will provide a reliable reference frame, which is not easily distorted, and MMS will link the position of the BPMs to the reference plane so their positions are known in real time. Only with the confidence of the physical locations of the diagnostics themselves will their position information be truly meaningful.

Having the access to study APS beam stability in the existing machine provides the great advantage of being able to prove and test designs for the new MBA machine. It also promises improvements to the existing machine.

ACKNOWLEDGMENTS

The authors would like to acknowledge the project support of Glenn Decker and John Carwardine. The authors would like to thank Steve Shoaf for his controls interface support, and thank Ron Blake, Randy Zabel, and Lester Erwin for all their help with building and testing the prototypes.

REFERENCES

[1] B. Yang *et al.*, "Design and Development for The Next Generation X-ray Beam Position Monitor System at the APS," *IPAC 2015*, Richmond, VA, USA (2015), paper MOPWI014.

[2] N. Sereno *et al.*, "Beam Stability R&D for the APS MBA Upgrade," *IPAC 2015*, Richmond, VA, USA (2015), paper MOPW011.

[3] N. Sereno *et al.*, "First Beam Tests of the APS MBA Upgrade Orbit Feedback Controller," presented at *IBIC 2016*, Barcelona, Spain (2016), paper MOPG06.

[4] R. Lill *et al.*, "Studies of APS Storage Ring Vacuum Chamber Thermal Mechanical Effects and their Impact on Beam Stability," in Proceedings of the *14th Beam Instrumentation Workshop*, Santa Fe, NM, USA (2010), paper TUPSM050.

[5] R.M. Lill *et al.*, "Design and Development of a Beam Stability Mechanical Motion System Diagnostic for the Aps MBA Upgrade," *IPAC 2015*, Richmond, VA, USA (2015), paper MOPWI010.

[6] Micro-Epsilon, micro-epsilon.com

[7] J. Volk *et al.*, "Hydrostatic Level Sensors as High Precision Ground Motion Instrumentation for Tevatron and Other Energy Frontier Accelerators," INST **7** (2012) P01004.

[8] V. Shiltsev, "Observations of Random Walk of the Ground in Space and Time," PRL **104**, 238501 (2010).

ISBN 978-3-95450-177-9