

DESIGN AND DEVELOPMENT OF A BEAM STABILITY MECHANICAL MOTION SYSTEM DIAGNOSTIC FOR THE APS MBA UPGRADE*

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Abstract

The Advanced Photon Source (APS) is currently in the conceptual design phase for the multi-bend achromat (MBA) lattice upgrade. In order to achieve long-term beam stability goals, a mechanical motion system (MMS) 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 causing drift in the x-ray beam position. The MMS has been prototyped and presently provides critical information on the vacuum chamber and beam position monitor (BPM) support systems. We report on the first results of the prototype system installed in the APS storage ring.

INTRODUCTION

In order to achieve the one micron long-term drift beam stability requirements seen in Table 1, all sources of mechanical motion of critical in-tunnel beam position monitoring devices must be carefully evaluated and appropriately addressed. Experiments conducted at the Advanced Photon Source (APS) clearly confirm that the thermal distortion of the vacuum chamber leads to movements of the BPMs up to $10 \mu\text{m}/^\circ\text{C}$, or a $0.5 \mu\text{m}$ peak-peak for a cooling water temperature change of 0.05°C peak-peak. This distortion is incompatible with the new beam stability requirements for the planned APS multi-bend achromat (MBA) upgrade. Research to quantify motion specifically for the APS accelerator tunnel and experiment hall floor has been ongoing for over five years [1].

The plan for the MBA upgrade is to use insertion device vacuum chambers (IDVCs) similar to what APS has installed today. Mechanical stability of BPM pickup electrodes mounted on these small-gap IDVCs potentially places a fundamental limitation on long-term x-ray beam stability for insertion device beamlines. The mechanical motion system (MMS) studies have opened a new window of understanding into how to measure and correct for these complex nonlinear mechanical movements with environmental changes. The MBA MMS design will monitor the position of the BPM in real time during user beam operations to compensate for the distortion of the insertion device vacuum chamber (IDVC).

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

MMS SYSTEM OVERVIEW

One of the most critical locations for electron beam stability is at the insertion device points. The existing APS IDVC is extruded aluminum, shown in Fig. 1, with integrated beam position monitor electrode housings machined out at each end. The wall thickness of the completed chamber at the beam orbit position is 1 mm. The design uses a rigid strongback that limits deflection of the chamber under vacuum despite the thin wall. The IDVC beam position monitors (BPMs) provide the critical steering data necessary to maintain beam stability through the insertion device. The BPM button electrodes mounted in the machined platforms have a 4-mm diameter. There are two button electrodes mounted on a single miniature vacuum flange [2].

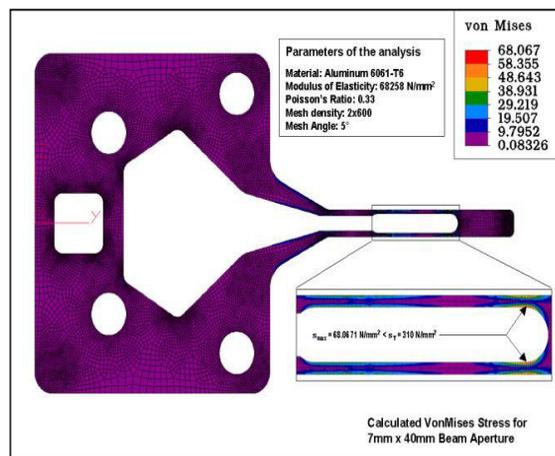


Figure 1: Existing storage ring IDVC cross section.

The rf and x-ray BPMs can be erroneously affected by changes in vacuum chamber cooling water temperature, tunnel air temperature, and beam current fluctuations. The block diagram shown in Fig. 2 illustrates the plan for instrumenting the MMS. Each ID location and grazing-incidence insertion device x-ray beam position monitor (GRID-XBPM) will be instrumented with capacitive detectors and hydrostatic detectors. The MMS is a real-time position monitoring system that measures the

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mechanical BPM detector position relative to the floor or to a reference surface defined by a hydrostatic level system (HLS).

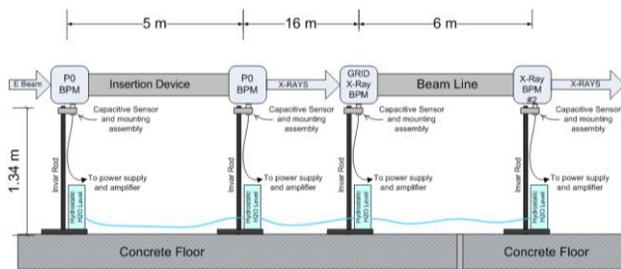


Figure 2: MMS block diagram.

DESIGN

The MBA upgrade will require instrumenting 35 IDVC BPM locations with high-resolution non-contact capacitive detectors mounted on extremely low expansion Super Invar rod. There are also 35 GRID-XBPM detectors that will be instrumented with similar capacitive detectors but have a larger range of measurement. Capacitive detection is a very sensitive technique for detecting small displacements. The two plate electrodes are represented by the sensor and the opposing measurement object. 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. Two conducting electrodes are formed by the vacuum chamber and detector separated by about 500 microns. Capacitance detection has the advantage of very high position resolution (10 nanometer), zero hysteresis, and zero power dissipation at the point of measurement. The Micro-Epsilon CapaNCdT 6200 is a multi-channel measuring system that is entirely modular [3]. The controller can support up to four synchronized channels with integrated Ethernet interface. The capacitive detection electronics must be installed in the tunnel in a shielded enclosure.

The HLS shown in Fig. 2 measures the relative ground motion between the IDVC BPMs in the APS accelerator tunnel and the beamline x-ray BPM locations. Studies to quantify this type of motion specifically for the APS accelerator tunnel and experiment hall floor are ongoing. These studies will provide the data under normal operating conditions necessary to develop a strategy for diffusive ground motion. 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 [4]. Estimates of diffusive ground motion between the two IDVC BPMs separated by 5 meters can be up to 6.7 microns in a one-week time period, using the constants provided in Ref. [4] for Fermi Laboratory Tevatron collider HLS.

The fundamental principle of HLS is that any fluid seeks its own level. The HLS is based on the communication vessels principle and the baseline design uses Fermi Lab Budker design sensors [5]. 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. Argonne has worked with Micro-Epsilon to combine their expertise in capacitive detection with the Budker HLS and have developed and built prototypes presently being evaluated.

PROTOTYPE TESTING

A rigorous test plan is presently being implemented for the MBA prototype diagnostics. The sector 27 R&D plan prototypes the rf BPMs, GRID-XBPMs, MMS, and feedback system and will demonstrate compliance to the MBA requirements for beam stability [6].

The data shown in Fig. 3 illustrates the APS operation mode of 324 singlet bunches where the beam decays to 80 mA before refilling to 100 mA. This non top-up mode typically reveals a beam position measurement systematic error of intensity dependence. It has always been believed that most of this error was due to intensity dependence of the BPM electronics, but Fig. 3 shows that the mechanical motion of the BPM detector is responsible for a large part of this error. Figure 3 also shows the correlation of the beam current with respect to the mechanical movement of the BPM detector and BPM readout.

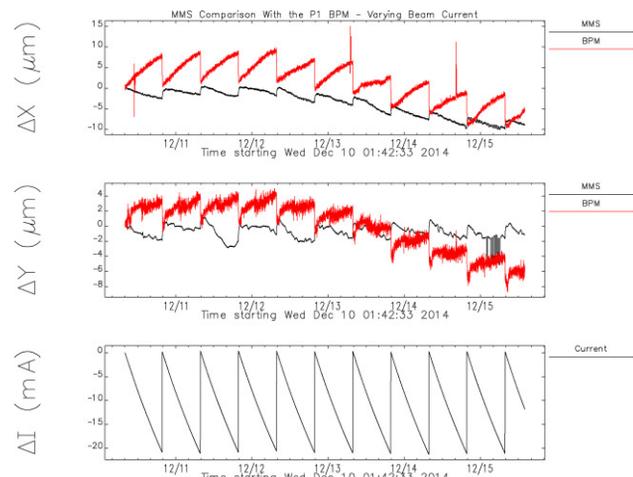


Figure 3: 324 bunch non top-up mode.

In another example of how the mechanical motion system may be used to improve the APS today, we observed that as the undulator gap is closed near the minimum gap, a step change of 60 microns can be seen vertically on the MMS when the limit switch plunger contacts the chamber. This problem has since been noted in other insertion device locations. Design changes are being considered to minimize this unwanted disturbance.

During the last shutdown period, a BPM vacuum chamber upstream support pedestal in the sector 27 test area was instrumented with a 300 watt electric heater in an

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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 8 microns per degree Fahrenheit is now regulated to less than 300 nanometer peak to peak as shown in Fig. 4. This test demonstrated the feasibility of regulating the steel support to compensate for many systematic effects altering the mechanical stability of the BPM. A second support pedestal will be instrumented during the next shutdown and studies are planned to continue.

The BPM support pedestal that has been instrumented with the electrical heated regulator has also been useful for cross calibration for the BPM electronics attached to that detector. For this test, we took the BPM monitored by the MMS out of the orbit control feedback and moved it vertically while stable beam was present, allowing a direct calibration of the BPM system shown in Fig. 5. The data shows a calibration error in the vertical plane that is presently being investigated.

CONCLUSIONS

A nonlinear, complex behavior has been observed in the BPM detectors that change with tunnel air temperature, IDVC cooling water temperature, and beam current. We present a conceptual design to monitor and correct for these environmental changes to achieve the 1 micron stability requirement for a week-long period.

Having access to study the as-built APS beam stability 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. This new diagnostic complements the existing BPMs and enables cross calibration between systems. Preliminary beam tests have produced encouraging results in validating the design for achieving the specified performance.

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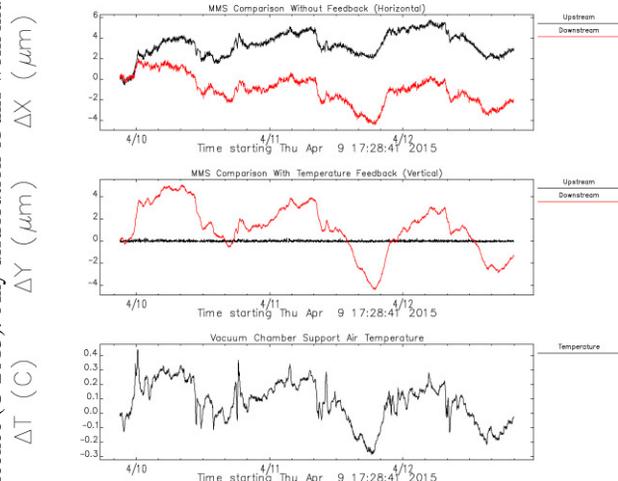


Figure 4: Thermally regulated support pedestal.

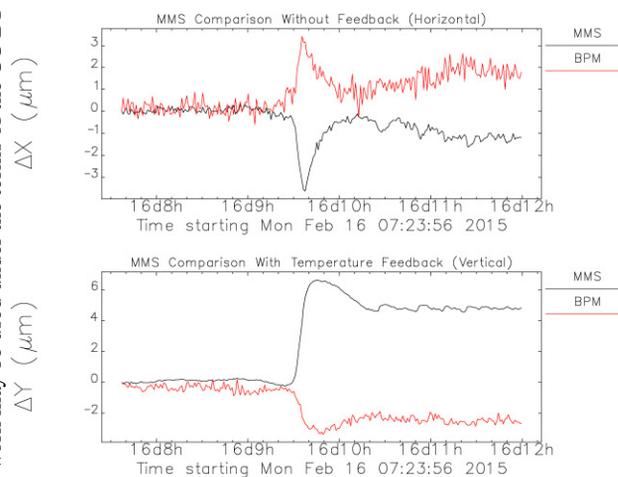


Figure 5: MMS and BPM cross calibration.