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BEAM STABILITY R&D FOR THE APS MBA UPGRADE*

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Abstract

Beam diagnostics required for the APS Multi-bend acromat (MBA) are driven by ambitious beam stability requirements. The major AC stability challenge is to correct rms beam motion to 10% the rms beam size at the insertion device source points from 0.01 to 1000 Hz. The vertical plane represents the biggest challenge for AC stability, which is required to be 400 nm rms for a 4-micron vertical beam size. In addition to AC stability, long-term drift over a period of seven days is required to be 1 micron or less. Major diagnostics R&D components include improved rf beam position processing using commercially available FPGA-based BPM processors, new X-ray beam position monitors based on hard X-ray fluorescence from copper and Compton scattering off diamond, mechanical motion sensing and remediation to detect and correct long-term vacuum chamber drift, a new feedback system featuring a tenfold increase in sampling rate, and a several-fold increase in the number of fast correctors and BPMs in the feedback algorithm. Feedback system development represents a major effort, and we are pursuing development of a novel algorithm that integrates orbit correction for both slow and fast correctors down to DC simultaneously. Finally, a new data acquisition system (DAQ) is being developed to simultaneously acquire streaming data from all diagnostics as well as the feedback processors for commissioning and fault diagnosis. Results of studies and the design effort are reported.

INTRODUCTION

The small emittance of the Multi-bend acromat (MBA) lattice translates into much smaller beam dimensions in the horizontal plane at the insertion device (ID) source points compared to the present APS lattice [1]. Since beam centroid motion of an appreciable fraction of the beam size results in increased effective emittance for users, AC beam stability requirements for the MBA upgrade are defined as 10% of the minimum expected beam size at the insertion device (ID) source points over the band 0.01 - 1000 Hz. Furthermore, long-term drift from 100 seconds to a period of seven days is defined as an estimate of diffusive ground motion over the long term. Table 1 summarizes these requirements. Beam stability R&D for the MBA upgrade focuses on developing diagnostics and controls systems to meet or exceed these requirements.

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Table 1: MBA Upgrade Beam Stability Requirements

Plane	AC rms Motion (0.01-1000 Hz)		Long-term Drift (100 s - 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

MBA DIAGNOSTICS INTEGRATION

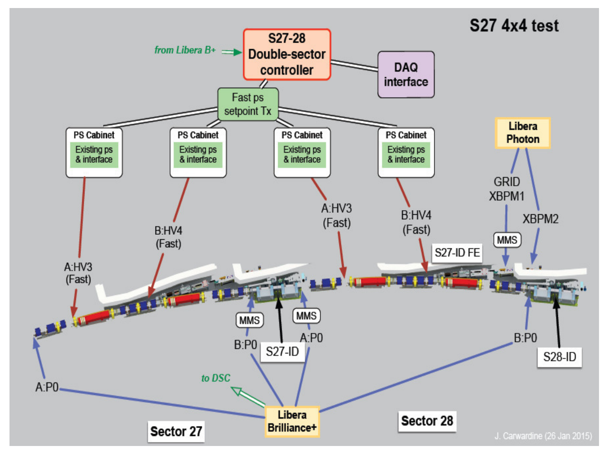

Figure 1: MBA diagnostics integrated R&D in APS storage ring sector 27. The P0 labels are ID BPMs and the HV labels are fast correctors.

Figure 1 shows the suite of diagnostics to be integrated and tested together as part of the MBA R&D plan. At the insertion device as well as the MBA arcs, we will use new commercial rf BPM electronics with a low noise floor. New high-power X-ray BPMs (called GRID for grazing-incidence insertion device) based on X-ray fluorescence off copper, and much less sensitive to background radiation coming from the ring multipoles, have been installed. A low power version of these X-ray BPMs based on Compton scattering off diamond is being developed for canted undulator beamlines. New hard X-ray intensity monitors will be installed to insure long-term reproduceability and relative flux calibration. A mechanical motion sensing system will be used to monitor position changes due to temperature, vibration, and ground motion at the ID rf BPMs as well as the X-ray BPMs. All these systems will be tied together using a distributed real-time orbit feedback system (RTFB) that will additionally take information from two pinhole cameras to correct coupling. The new RTFB system will include an increase of at least 15 in sampling rate (to 22 kHz) over the present system, increasing the closed-loop bandwidth to 1

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kHz. It will also be able to process information from all the rf and X-ray BPMs and control double the number of fast correctors compared to the present system. All these systems except the RTFB system are presently installed in sector 27 of the APS. New fast corrector power supplies and their interface will be installed for testing with feedback in sector 27. Over the next year we anticipate testing all these systems together with the new RTFB system prototype double sector controller (DSC) orbit-feedback processor as shown in Fig. 1.

RF AND X-RAY BPMS

RF BPMs provide the primary measurement of the electron beam trajectory through the ID straight sections and in the storage ring arcs. Each arc section will contain 12 BPMs in the arcs and two additional rf BPMs at the ends of the ID straight section. Canted sectors will require an additional BPM between insertion devices. Simulations indicate that the MBA rf BPM buttons will provide more than enough signal for processing using commercial "Libera Brilliance+" electronics from Instrumentation Technologies, Solkan, Slovenia. The Libera Brilliance-plus module shows excellent noise performance, approaching 2nm/$\sqrt{\text{Hz}}$, and excellent long-term stability of < 50 nm over a period of two days [2].

The new GRID-XBPM system will provide users with much better beam stability than the present legacy photoemission-based system [3]. The photoemission system suffers from systematic offsets due to soft radiation emitted by bending magnet fringe fields and multipoles. Compensation of these offsets requires an involved feedforward scheme, resulting in correction only at the level of a few μm pk-pk at best. In addition, the GRID-XBPMs have better than a factor of 30-50 signal to background compared to the photoemission BPMs, allowing them to be used at the largest gaps users prefer (30 mm). Two GRID-XBPM systems have been installed in 27-ID and 35-ID front ends and are presently undergoing testing. The Compton XBPM for canted undulator frontends is in active development. Mechanical motion sensing devices will be mounted on the GRID chambers to measure and correct for mechanical motion due to temperature drifts and ground motion.

MECHANICAL MOTION SENSING SYSTEM

The mechanical motion system (MMS) [4] consists of very sensitive non-contact capacitive detectors mounted on extremely low expansion Super Invar rods configured to detect slight motion of the ID vacuum chamber where the rf BPMs are located. Additional hydrostatic sensors detect floor tilt and complement the capacitive system. Experiments conducted on the sector 27 ID vacuum chamber show the BPMs moving on the order of 10 μm due to air and vacuum chamber water temperature variations.

REAL-TIME ORBIT FEEDBACK SYSTEM

The MBA RTFB system will be a major upgrade compared to the present 20-year old system [5,6]. The new system will feature modern digital processing and data communications hardware based on the micro-TCA platform. Given the several-orders-of-magnitude improvement in performance of modern digital processors and communications from the 1998-vintage hardware, the goal for the APS Upgrade RTFB is to increase the sampling rate at least 15 fold from ~1 kHz to 22.6 kHz while also increasing the number of correctors from 38 per plane to 160 per plane, and the number of BPMs from 160 to 560. Using four fast correctors per sector allows both position and angle to be corrected for fast AC motion at both 3-pole wiggler and ID source points.

Architecture

The system will use the present system's "double sector" architecture. In this architecture each feedback processor, known as a double-sector controller (DSC), processes BPM data from all BPMs around the ring and controls local slow and fast correctors in the two sectors. BPM data from around the ring is distributed via a fast fiber optic network connecting each double sector controller. Each micro-TCA double sector controller crate has inputs for all correctors and BPMs in the two local sectors and a fast fiber connection to communicate its BPM data around the ring. The candidate board we are evaluating for the prototype DSC is a CommAgility AMC-V7-2C6678 board that uses a combination FPGA and fast DSP for communication and processing. The FPGA will be used for communication of data from each DSC to shuttle BPM data around the ring as well as provide communication links to local correctors and BPMs. It also serves to send BPM and corrector data to and from the DSP. The DSP will contain the feedback algorithm and it is anticipated we will reuse some existing DSP code from the present system, saving some development time.

Unified Algorithm

Algorithm development for the MBA RTFB system is to unify both slow and fast corrector control in a single response matrix based algorithm. The present feedback system consists of two separate systems: a slow system called "datapool" that can use all BPMs and correctors, but is limited to a sampling rate of 10 Hz, and a fast system using a limited set of BPMs (160 per plane) and fast correctors (38 or one per sector) running at a sampling rate of 1.5 kHz. Datapool is able to correct many spatial modes slowly whereas the fast system corrects few spatial modes but corrects the main global spatial modes quickly. The two systems are kept from fighting each other using an orbit feedforward scheme where the change in orbit at the RTFB system's BPMs due to datapool is computed and applied via a set of orbit offset variables at each iteration of datapool. RTFB therefore does not react to the slow system's orbit change in the 1 Hz band where they overlap. This prevents

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the systems from fighting each other, but there is reduced orbit attenuation in the frequency band where they overlap.

We have investigated the feasibility of using both slow and fast corrector feedback systems correct down to DC in machine studies using an approach proposed by Carwardine [7] for formulating the inverse response matrices in such a way that the two systems would operate cooperatively; the RTFB would do the best job it can at correcting orbit motion all the way down to DC and datapool would further reduce the residual orbit errors at DC and low frequencies. We initially took an experimental approach to obtaining the correct response matrix for both systems, later deriving the same result from the full calculated response matrix for the ring. Experimentally we first configured RTFB to correct down to DC but otherwise use its full set of fast correctors and BPMs. We then experimentally measured the datapool response matrix with RTFB running and correcting down to DC. Intuitively, the response matrix so measured is what is left over or what RTFB cannot correct due to its limited access to the ring's spatial modes (due to its limited number of correctors).

The datapool response matrix measured or derived with RTFB correcting down to DC contains no time-varying terms and requires no synchronization or communication between RTFB and datapool. 'Coordination' between RTFB and datapool happens through the beam: when datapool makes a correction, RTFB sees an orbit error that it attempts to correct. When datapool remeasures the orbit on the next iteration, it observes the net effect of the orbit delta it applied on the previous step and the resulting reaction of the RTFB. Time-invariance of the datapool response matrix only holds true if the transient on RTFB has settled down before datapool remeasures the orbit for its next iteration, i.e., *RTFB must have a response time that is fast relative to the datapool sampling interval and also a high enough integral gain*.

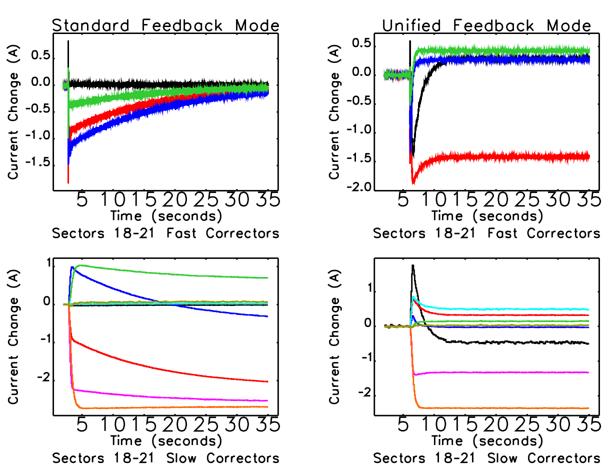

Figure 2: Vertical fast and slow corrector step response comparison between unified and standard feedback.

We configured and compared unified and standard feedback modes in machine studies. Figure 2 shows both vertical slow and fast corrector responses for both feedback modes to a step change in a fast corrector not used in feedback. This data was taken using a prototype data acquisition system (DAQ) that synchronously can capture BPM and corrector data from the RTFB reflective memory network at the full 1.5 kHz sampling rate. This DAQ system is planned to be extended to acquire timestamped data from not only the MBA feedback system but the other accelerator systems such as rf, power supplies, injector, etc. for machine and fault diagnosis. One can see the vertical fast and slow correctors for unified feedback settle out in 5 seconds compared with 30 seconds for the standard feedback mode case. The faster step response of unified mode is expected given that both RTFB and DP are correcting beam motion down to DC as fast as they can. This is compared to standard mode where only datapool has the ability to correct motion down to DC. Finally, four corrector bump local steering at the IDs was also demonstrated in unified mode.

CONCLUSIONS

APS has embarked on an ambitious diagnostics R&D program for the MBA upgrade to meet or exceed MBA requirements. It includes new rf and X-ray BPMs, a mechanical motion sensing system, and new pinhole camera imaging systems to measure emittance and correct coupling, all tied together with a new RTFB system with an order of magnitude bigger closed loop bandwidth and sampling rate. Other existing diagnostic systems such as transverse multibunch feedback (and possible longitudinal feedback) current monitors and streak camera will be upgraded and repurposed for the MBA machine. R&D of individual diagnostics has been ongoing in sector 27 of the APS ring with a full test of the prototype RTFB system DSC planned in the coming year.

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