

COMMISSIONING OF THE APS REAL-TIME ORBIT FEEDBACK SYSTEM

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CONF-970503--

Abstract

A unified global and local closed-orbit feedback system has been implemented at the Advanced Photon Source in order to stabilize both particle and photon beams. Beam stability requirements in the band up to 50Hz are $17\mu\text{m}$ in the horizontal plane and $4.4\mu\text{m}$ vertically. Orbit feedback algorithms are implemented digitally using multiple digital signal processors, with computing power distributed in 20 VME crates around the storage ring. Each crate communicates with all others via a fast reflective memory network. The system has access to 320 rf beam position monitors together with x-ray beam position monitors in both insertion device and bending magnet beamlines. Up to 317 corrector magnets are available to the system.

The global system reduces horizontal rms beam motion at the x-ray source points by more than a factor of two in the frequency band from 10mHz to 50Hz.

1 SYSTEM DESCRIPTION**1.1 Hardware Architecture**

The real-time orbit feedback system is implemented digitally using multiple digital signal processors (DSPs). A total of twenty VME crates are distributed around the circumference of the 40-sector APS storage ring to manage interfaces to beam position monitors (BPMs) and correctors, and to compute orbit corrections.

Figure 1 shows an overview of a typical crate. Each crate accesses locally available BPMs and correctors. A 68040 processor runs standard EPICS software, and one or more TMS320 DSPs perform orbit correction calculations at a 1kHz system sampling rate. Data from each crate is shared with all other crates via a synchronous reflective memory network running at 29MBytes/second.

A 21st VME crate serves as master and performs real-time analysis of data collected from the other crates.

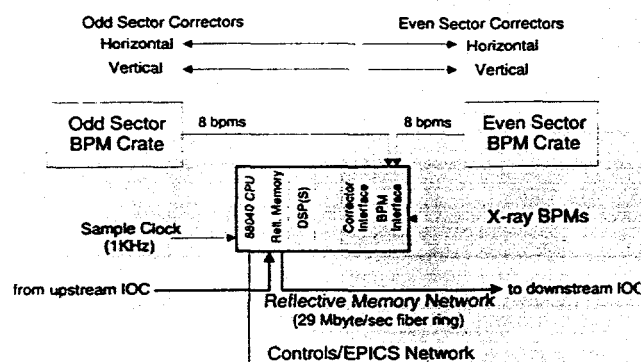


Figure 1: Architecture of a typical orbit feedback crate.

1.2 Software Architecture

The 68040 EPICS processor interfaces the DSP(s) to the control system and provides the means to monitor and control feedback algorithms running on the DSP. Data structures residing in dual-ported RAM on the DSP board are used to communicate commands and return status and data. The EPICS processor uses state programs to interface database variables with the shared data structures.

The reflective memories contain a shared data structure that is replicated at each node and is accessible to all processors in the feedback system. At each sample tick the DSP fetches BPM data from the BPM interfaces, computes the error in position, and writes the error values to assigned locations in the reflective-memory shared data structure. When all other DSPs have written their BPM errors, the DSP reads in the complete BPM error vector from the reflective memory and computes and writes new corrector values.

The master feedback crate provides global controls to the other 20 feedback crates by writing to specific locations in the reflective-memory shared data structure. In addition, it provides analysis tools such as 'dspscope' which functions like a digital scope, and 'ac voltmeter' which performs a sliding discrete Fourier transform in real time, both tools working on 40 channels of data.

1.3 RF Beam Position Monitors

The APS storage ring contains 360 rf BPMs, of which 320 are available to the real-time feedback system. In order to improve spatial resolution and minimize measurement error, it is preferable to use as many of the available BPMs as possible in the global correction algorithm. However computational resources are limited, and there is a trade-off between the number of BPMs in the algorithm and the overall sampling rate. The present configuration uses 160 BPMs and updates at 1kHz [1].

1.4 X-ray Beam Position Monitors

In addition to the rf BPMs, the APS is implementing x-ray BPMs on all the insertion device (ID) and bending magnet (BM) beamlines. These are intended to provide an absolute measure of the x-ray beam position for control of the x-ray source points.

1.5 Correctors

Each sector of the storage ring has a total of eight corrector magnets per plane. All of these could be made available to the orbit feedback system. One corrector magnet in each sector surrounds an Inconel vacuum chamber and has significantly higher effective bandwidth than the remain-

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ing correctors which surround a thick aluminum vacuum chamber. Only the high bandwidth correctors are presently used in the global correction algorithm (38 per plane).

Additional (low bandwidth) correctors will be used by the real-time feedback system for local steering of the insertion device and bending magnet x-ray source points.

1.6 Global Feedback Algorithm

As described elsewhere [2], singular value decomposition (SVD) is used to generate the required inverse response matrix. However, since we are using 160 BPMs and only 38 correctors, there may be no advantage to removing singular values from the matrix inverse calculation. Consequently, in this case, the SVD approach yields the same solution as the classical pseudo-inverse.

Use of a weighted pseudo-inverse is under consideration for local steering algorithms [1].

1.7 Regulator Design

The feedback loop regulator presently uses a digital implementation of simple analog elements; either an integrator or a bandpass filter are presently used. At the 1kHz sampling rate, the dynamics of the corrector magnets and of the inherent zero-order hold of the regulator each make comparable contributions to the open-loop dynamics. Consequently, a simple analog-equivalent regulator is sub-optimal and the closed-loop bandwidth is lower than could otherwise be achieved. In addition to redesigning the regulator, we are considering the implementation of a first-order hold in the corrector magnet power supply.

1.8 'DC' Mode of Operation

The real-time system can be configured to correct frequencies down to DC or to correct only dynamic orbit errors, leaving slow effects to an existing workstation-based system [3]. In 'DC' mode, integral feedback is used.

1.9 'Highpass' Mode of Operation

In this mode, the real-time system is used to supplement the existing workstation-based slow global feedback system which samples at 0.1Hz. Bandpass feedback is used in the real-time system to provide integral gain at higher frequencies but to roll off the gain at lower frequencies and decouple it from the workstation-based system. The highpass -3dB point is 20mHz.

The advantage to using the workstation-based system for slow effects is that it is better able to manage the effects of BPM systematic drift and random errors which appear at very low frequencies [3]. Techniques presently incorporated into this system (such as BPM 'despiking') will be incorporated into the real-time system at a later date.

The disadvantage of using both systems together is that the overall gain below 0.1Hz is less than could otherwise be achieved with the real-time system alone.

Beam-current dependence of the BPMs is also handled by a workstation-based system which varies the BPM offset calibrations as the current in the storage ring decays.

This system is compatible with the real-time system in both 'DC' and 'highpass' modes.

In order to minimize the turn-on transient of the highpass filter, the system is energized with a highpass -3dB point considerably higher than the operating value (giving a much faster transient decay time). The break point of the highpass filter is then ramped down with the loops closed.

2 GLOBAL FEEDBACK PERFORMANCE

The performance of the global system is viewed in terms of the net improvement in beam motion power spectral density (PSD) as measured at the ID x-ray source points, with data averaged over many source points.

Figure 2 shows the effect of the real-time feedback on the horizontal PSD, when operating in 'DC' mode with integral feedback. The -3dB point is approximately 25Hz, with an improvement of 20dB below 3Hz. The maximum improvement gives a measure of the uncorrectable beam motion. Since the system can only correct the first 38 modes of beam motion, the system noise floor is determined by a combination of BPM noise, drift, and real orbit motion in higher modes [1].

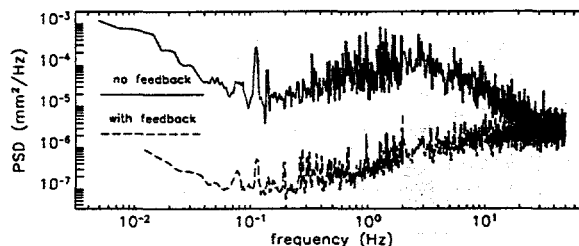


Figure 2: Horizontal power spectral density ('DC' mode).

The performance in 'highpass' mode in both horizontal and vertical planes is shown in Figure 3. Spikes at 0.1Hz are a consequence of the slow feedback system, but contribute little to the overall rms beam motion.

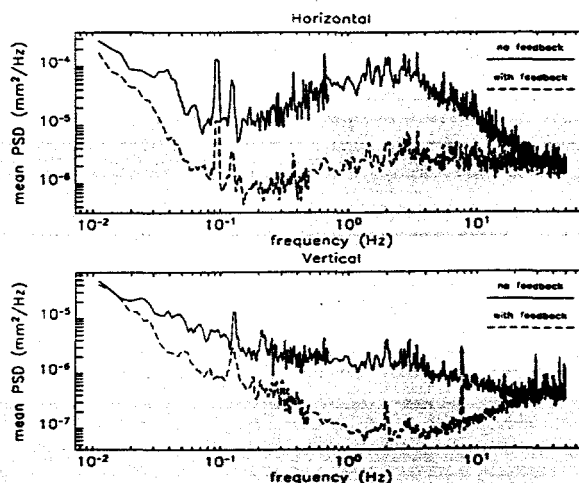


Figure 3: Power spectral density ('Highpass' mode).

The cumulative rms beam motion integrated from 10mHz is shown in Figure 4. In the band up to 50Hz, horizontal beam motion is reduced from typically 20μm to 10μm rms, and from 4μm to 3μm rms vertically.

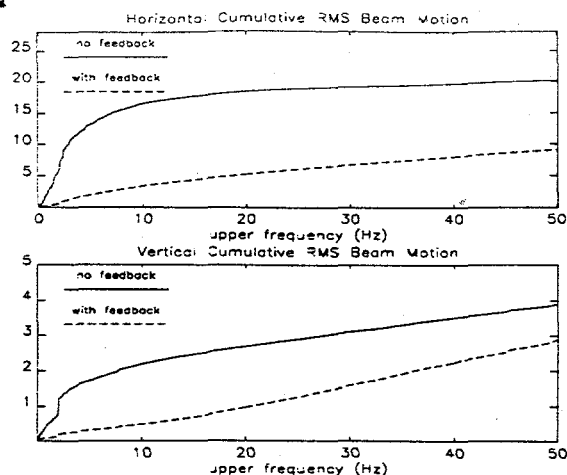


Figure 4: Cumulative rms beam motion above 10mHz ('Highpass' mode).

3 LOCAL FEEDBACK

Tests of local bump feedback using the low bandwidth correctors have revealed subtle differences in the frequency responses of the magnets used in the bumps. These differences are caused by eddy current effects in the various vacuum components surrounding each magnet. Closure of the local bump is very sensitive to these differences, and to achieve bump closure above a fraction of a hertz, the bump coefficients must be frequency dependent. So far, producing the right frequency dependence for the coefficients has proved extremely difficult.

Depending on the performance of the global (rms) algorithm, it is possible that local control may only be needed to make steering changes at the x-ray beamlines. Indeed, in order for continuous local feedback at the x-ray source points to be successful, long-term information from the x-ray BPMs must be more reliable than that provided by a large number of rf BPMs.

Since steering changes only require information from the local (rf or x-ray) BPMs for a short period of time, a low bandwidth local bump could be successfully implemented with good closure as originally planned. The bump would only be used during steering changes and disabled otherwise. An alternative is to implement a second global algorithm for the low bandwidth correctors, using rf BPMs from the entire ring and x-ray BPMs from the local beamlines. Since the system already takes care of reading BPMs from the entire ring, this is an attractive option.

4 DIAGNOSTIC CAPABILITIES

4.1 AC Lock-In Measurements

Various machine parameters (such as response matrices) can be measured by driving a global corrector at some frequency (e.g. 83.3Hz) and measuring only that frequency component in the BPM signals. This technique has the advantage that a low noise measurement can be made in a much shorter time than would be required with a comparable DC measurement. The real-time feedback system pro-

vides on-line capabilities to perform measurements using 38 correctors and 320 BPMs.

4.2 Lattice Null Measurements

The real-time feedback system offers some novel measurement opportunities. When running closed loop, the desired orbit is maintained automatically as machine conditions (such as quadrupole strength) are changed. Under these conditions, on-line measurement of quadrupole offsets or other machine parameters (such as beta function) could be considered even during user studies [4].

4.3 Identifying Sources of Beam Motion

The real-time feedback system plays a key role in identifying and localizing sources of orbit motion. The large number of BPMs available provides us with the ability to identify not only the existence of sources (from the orbit power spectrum), but also provides a means for identifying their location. By examining the relative power spectra of the drives to the 38 correctors, it is possible to identify and localize sources of orbit motion in real time to within a sector of the machine [1]. Further localization to the girder-level (1/200th of the machine) is considered achievable.

The technique of examining the corrector reference waveforms has already been used to correctly identify a glitching power supply. Figure 5 shows the feedback system's response to the glitch. Several time steps are overlaid by sector number, with the glitch appearing at only one time step. Using only BPM data, it was possible to correctly identify the corrector power supply which glitched.

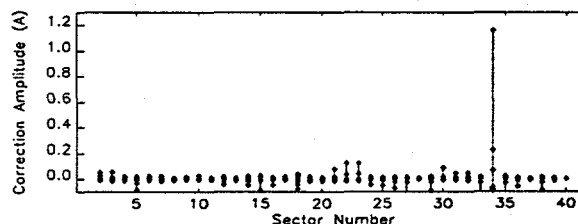


Figure 5: Glitching power supply identified on-line using BPM data alone.

5 ACKNOWLEDGEMENTS

We thank J. Galayda and L. Emery for their continuing support and insight into orbit correction.

This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

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