STATUS OF DIGITAL ORBIT FEEDBACK FOR SPEAR*

R. Hettel, J. Corbett, D. Keeley, I. Linscott, D. Mostowfi, J. Sebek and C. Wermelskirchen
Stanford Linear Accelerator Center / SSRL, Stanford, CA 94309

ABSTRACT

The present global orbit feedback system for SPEAR can adjust the electron beam position with a cycle time of 5 s. In addition, 50 Hz analog local servos stabilize the vertical photon beam position at monitors situated in the ten SSRL beamlines. The global and local systems will soon be merged into a single unified system operating from a dedicated DSP board. The goal is to acquire orbits, process the data, and correct beam position in a 1-2 ms interval to achieve a 30-50 Hz closed-loop bandwidth.

1 INTRODUCTION

With the introduction of a global orbit feedback system [1-5], photon beam stability at the ten synchrotron radiation beamlines on SPEAR has steadily improved over the past few years. The present global correction system employs 30 electron beam position monitors (BPMs) and 30 correctors per plane. Additionally, each beamline is equipped with a local analog 50 Hz closed-loop bandwidth steering system [6] that reduces vertical beam motion to the 10 mm rms level at a photon monitor. The combined global and local systems help to maintain photon beam position and angle at experimental stations.

In the past two years, the feedback system has benefitted from other programs to improve orbit stability and ring performance [7]. First a new lattice was implemented to eliminate strong quadrupoles from the colliding beam interaction regions [8] and to reduce the strength of another nearby quadrupole family by 80%. These changes decreased the diurnal orbit drift. High resolution BPMs [9] were installed, increasing the number of feedback BPMs from 20 to 30. Mechanical supports for these and other BPMs were upgraded to reduce transverse thermal motion. Resistive current shunts were then installed on each quadrupole [10] to determine beam centering (indicated when a shunt does not induce an orbit shift) and to measure offsets of nearby BPMs (some were a few millimeters). With improved, calibrated BPMs and a recent realignment of the storage ring and beamlines, we correct the orbit to <1 mm peak in the beamline arcs and the orbit feedback is more effective.

During a 24 hr beam delivery period, for example, horizontal and vertical stability at the BPMs is now

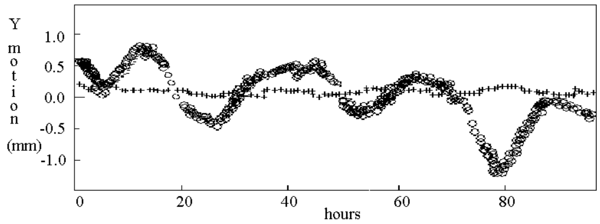

Figure 1 Vertical orbit motion at one BPM over 4 days with and without feedback. Step changes occur after each fill and energy ramp cycle.

80μm and 60μm rms, respectively. Fill-to-fill orbit reproducibility, after the 2.3-3 GeV energy ramp, is less than 100 mm rms (Fig. 1). These values represent a factor of 5 or more reduction in orbit motion, and a factor of 10 improvement in the fill-to-fill orbit reproducibility as compared to the situation with no feedback. Stability at the photon beam source points is now approximately 10% of the horizontal, and 20% of the vertical beam sizes given by the 130 nm-rad SPEAR emittance. Previous papers [1-6] address performance limitations caused by BPM noise, corrector-to-BPM response matrix errors, slow corrector frequency response, orbit sampling, and other factors.

In the next section, we review the orbit correction and feedback algorithms used at SPEAR. We then describe the feedback system architecture, including a DSP-based local/global system design for 50 mm rms orbit and 10 mm rms photon beam stability at position monitor sites. Finally, we discuss beam stabilizing limitations based on the BPM and corrector configuration and ways to improve feedback performance.

2 CONTROL ALGORITHM

The orbit control and feedback algorithm for SPEAR is based on multiplication of a BPM position error vector by the inverse corrector-to-BPM response matrix to derive corrector setpoint changes. The measured response matrix is inverted using singular value decomposition (SVD) [11,12] with the spectrum of singular values truncated at the low end depending on the required degree of control accuracy and BPM noise rejection [2]. The truncation process is analogous to a spatial low pass orbit filter. By simulation and by trial and error, we found that retaining about 50-70% of the

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eigenvectors provides good noise rejection, accurate orbit control, and tolerable corrector currents. SVD is also numerically stable, and provides a natural eigenbasis on which to decompose the orbit.

Typical orbit control applications include photon beam steering, orbit correction at specific BPMs, and configuration of local closed bumps. We often use the 'least norm' property of SVD to minimize corrector strengths [13]. In this application, we begin with a steered photon beam configuration, append the photon BPM error signals to the electron BPM signals, and form the corresponding 'unified' corrector response matrix for SVD inversion. With appropriate weights applied to the photon or electron BPMs, high corrector currents can be reduced. This technique is also used to steer the electron and photon beams each fill before launching feedback.

After initial steering, we activate the beamline servos and measure reference values for the orbit and servo drive currents. For slow feedback applications, we digitally subtract the action of the beamline servos from the measured orbit perturbation to decouple the fast servos from the slow global feedback system [3]. The drawback of this decoupling scheme is that due to the action of the servos, the electron beam is free to move at BPMs under the local servo bumps.

For the fast digital system, we plan to use a unified local/global inverse matrix approach [14]. Corrector currents obtained after matrix multiplication are digitally filtered to equalize frequency response, and a PID filter is applied to extend the bandwidth of the feedback system. Alternative digital processing techniques including state-space control are also being explored.

In order to optimize the speed of the feedback loop, we plan to make interlock checks for BPM readings and corrector set points at a slower rate on an adjacent microprocessor (see below). Where the servo decoupling scheme is needed, or if the ring buffer monitoring system is used, the feedback cycle time will be increased.

3 SYSTEM ARCHITECTURE

The phase I feedback algorithm outlined above operates on the main SPEAR VAXstation 4000/90. Here the electron and photon BPM readings are accessed directly from the SPEAR control database and the correctors are set through the database-driven system. Due to the relatively slow orbit acquisition system, the minimum feedback cycle time is limited to ~5 s.

The feedback software was designed in a modular form with a menu-based interface [3]. To manage data files, a configuration restore facility was added to read and write set-up parameters for BPMs and correctors, the digital filters, control algorithm, timing, and interlock limits. The menu environment also allows the operator to measure, save, and recall corrector-to-BPM response matrices, beamline bump response parameters, and orbit files Each time the feedback is started,. a log file is initiated that records the operating parameters, any subsequent fault messages, and cycle-by-cycle orbit and corrector values.

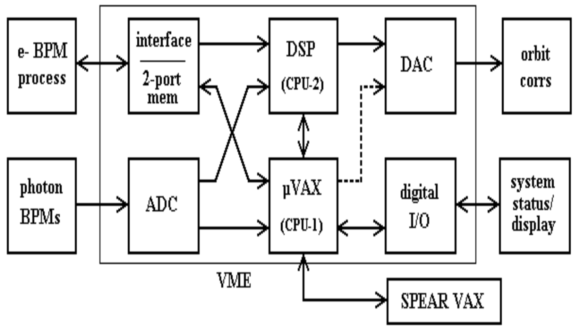

Figure 2 VME-based digital orbit feedback system

In the initial stage of phase II development, the orbit data and feedback processing functions are carried out in a remote VME crate (Fig. 2). A VME-based mVAX (CPU-1) handles exchange of BPM and photon monitor data and corrector set points with the SPEAR VAX. A second mVAX (CPU-2) is used to develop feedback software without interrupting CPU-1. The mVAXs were chosen to maintain software compatibility with phase I.

At this time, most of the software for the mVAX processors has been installed and tested. CPU-1 presently connects via ethernet to the original SPEAR BPM processor located in a CAMAC crate. The raw BPM signals are processed in CPU-1 at a rate of about 0.2 Hz and sent to the SPEAR VAX. The raw data is also mapped into global memory where it can be accessed by CPU-2 across the VME back plane.

When a new higher speed, higher resolution BPM processor comes on line [15-17], CPU-2 will acquire BPM button data over the VME backplane and perform linear position calculations each feedback cycle. CPU-1 will also acquire button data that has been averaged for longer periods in the processor for high resolution measurements. Polynomial fitting is used to remove BPM pincushion distortion. To alleviate possible bus contention, we anticipate either passing part of the BPM data to CPU-1 each feedback cycle or all of it during 'skipped' feedback cycles. Photon beamline signals and low-pass filtered corrector setpoints will also be relayed to the SPEAR VAX through CPU-1.

Communication of feedback parameters from the main SPEAR VAX to CPU-2 occurs via ethernet packets containing well-defined data structures and a command identifier in the header. For software compatibility, we use equivalent structure names and data formats in both the SPEAR VAX and CPU-2 feedback programs. The command identifier is interpreted at CPU-2 to either transfer data or execute code, and a reply is echoed back to the SPEAR VAX for verification.

Recently, we have tested the feedback system in CPU-2 at rates of up to 100 Hz on a 2-pole analog simulation circuit, and as a digital driver for the photon beamline servos. These tests were performed with VME 8-channel, 16-bit DACs (Pentland MPV955) and 32 channel, 16-bit ADCs (Pentland MPV915-21). Step, impulse, and frequency response functions have been recorded in ring buffers for system identification studies using MATLAB.

For DAC control in the feedback mode, CPU-2 will digitally sum the cumulative feedback corrector setpoints with the static SPEAR VAX setpoints each cycle. Low-pass filtered corrector setpoints will be transferred to CPU-1 for interlock checks and stored as bias setpoints in case the feedback is turned off. When the feedback is off, CPU-1 assumes control of the DACs and ADCs.

In the final phase II configuration, the CPU-2 mVAX will be replaced by a 32-bit floating point DSP (TI TMS320C40), and all communications with the SPEAR VAX, which include downloading of feedback parameters to the DSP, will be handled by CPU-1. The main DSP code will be downloaded from a PC. The BPM processor will write data to a dual ported memory arranged in two pages: while the DSP reads an orbit from one page, the processor writes a new orbit to the other page.

With an orbit update rate from the BPM processor of 1-2 ms, a closed-loop system bandwidth of 30-50 Hz will be achievable. The orbit update rate is limited by the 30-40 ms per button processing time needed to filter out the synchrotron oscillation signal, implying that a single processor can provide averaged orbit data for 8 BPMs in 1-2 ms. For 30 or more BPMs, the final feedback system will require at least four parallel processors.

4 CORRECTOR AND BPM SITES

The ability of the global feedback system to correct position and angle at the photon beamlines depends on the location of the correctors and BPMs relative to the orbit perturbation sources. Simulations have been made to analyze present system performance and to prioritize new BPM and corrector sites assuming orbit perturbations are caused by transverse quadrupole displacements [18].

With the present vertical corrector and BPM locations, most of which are at or near horizontally focusing QF magnets adjacent to ring straight sections, the global feedback can control position and angle very well at four of the ten beamlines. For these four insertion device (ID) beamlines, there are BPMs before and after the source point, no orbit perturbations between the BPMs, and the correctors are able to steer to both BPMs. BPMs will soon be added to the other two ID beamlines to produce the same configuration. In practice, BPM noise and mechanical vibrations lead to imperfect beam steering, but the local servos compensate for these imperfections.

Space limitations near the four bend magnet source points prohibit installing upstream and downstream BPMs without intervening quadrupole perturbations. For these beamlines, a BPM in the preceding straight section is followed by the first corrector of the servo bump (located on a perturbing quadrupole), and then the source point. In three of these cases, the preceding straight sections have two BPMs which permit the global system to correct position and angle of the beam entering the quadrupole. The local servo cancels the quadrupole perturbation so that the combined global and local systems correct beam position at the source point and at the photon monitor. The remaining beamline (BL 1) can be similarly controlled by adding another BPM and corrector.

In general, the vertically focusing QD quadrupoles can cause large vertical orbit perturbations, but they are also effective sites for vertical correctors and BPMs. For this reason, we plan to add several QD correctors and BPMs. Simulations show that these additions will improve the vertical stabilizing ability of the feedback system at the BL 1 source point, for example, by a factor of ~2.5.

5 ACKNOWLEDGMENTS

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