DIGITAL ORBIT FEEDBACK CONTROL FOR SPEAR[*]

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Abstract

A digital orbit feedback system is being developed for SPEAR to improve electron beam stability at photon beam sourcepoints. The first phase implementation of this system operates at 1 minute intervals and stabilizes the horizontal and vertical orbit position to 50 µm rms at beam position monitors. The vertical global system works in tandem with local 50 Hz analog photon beam steering systems to stabilize photon beam position and angle. We are now developing the second phase system which will execute a unified global/local, 30-50 Hz vertical orbit feedback algorithm digitally. In this paper, we discuss design and performance of orbit monitoring, signal processing, and orbit correction components for the digital feedback systems.

I. INTRODUCTION

The SPEAR storage ring presently operates as a second generation light source, having 10 dedicated beamlines with multiple branch lines, and having an emittance of 130 nm-rad at 3 GeV. Orbit instabilities, however, stem from ring components designed in the first generation, nearly 25 years ago, including magnets, supports, vacuum chambers, temperature controls, and power supplies. The dominant instability is a diurnal orbit drift having a peak-to-peak horizontal amplitude of about 1 mm and half as much in the vertical plane. The drift is caused primarily by vacuum chamber and magnet motion (particularly high beta quadrupoles near the colliding beam interaction regions) which is coupled to diurnal temperature and to beam current. In addition, the orbit can shift by a few hundred microns after a beam injection cycle when the 3 GeV ring is ramped down to 2.3 GeV and back. Motion of a few tens of microns can occur as the storage ring temperature stabilizes in the first hour after ramping. Smaller, higher frequency disturbances have electrical and mechanical sources [1].

Our goal is to stabilize the electron beam orbit at the photon beam sourcepoints to 10% of the transverse photon beam size and beam divergence, and to maintain constant flux (to a small fraction of a percent) through restrictive beamline apertures [2]. The most stringent orbit position stability requirements are 80 µm rms horizontally and 20-30 µm rms vertically at focused beamline source points.

For more than a decade SSRL has used local, 3-magnet bump steering systems to stabilize vertical beam motion at photon beam monitors to the 10 µm level [1]. These feedback systems use analog circuitry and have a 50 Hz bandwidth. They have only a limited stabilizing capacity, however, since they do not correct position and angle independently. Also, large bump currents are sometimes needed to correct disturbances that could be reduced more efficiently with global adjustments.

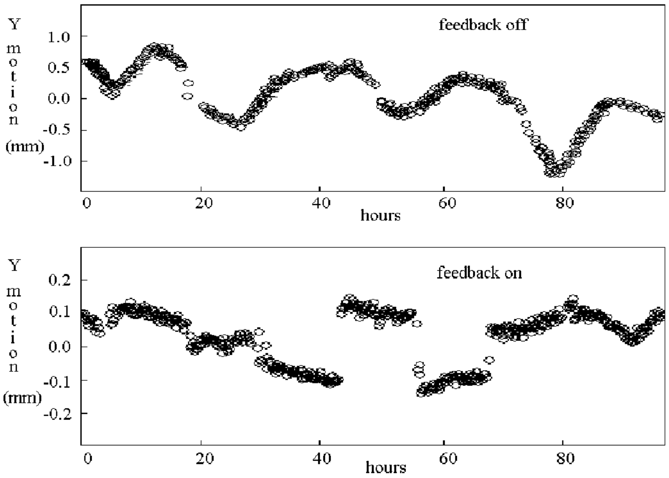

FIGURE 1. Vertical orbit motion at one BPM over 4 days with and without feedback. Step changes occur after each fill and energy ramp cycle. Note change in scale.

These local feedback limitations, together with a need for horizontal beam stabilization, have led us develop a global feedback system that uses the singular value decomposition (SVD) method to correct oribit 'eigenvectors' derived from the corrector-beam position monitor (BPM) response matrix [3,4]. The first phase system implementation executes an orbit correction every minute from the main SPEAR computer and has a closed-loop bandwidth of a few mHz. The local 50 Hz steering systems act in concert with the vertical global orbit feedback to stabilize photon beam position and angle. The global system holds the beam stable to better than 100 µm rms at the BPMs (Fig. 1).

We are now developing a unified global/local vertical feedback system that uses digital signal processing (DSP) in a VME environment to achieve 50 µm rms or better stability at electron BPMs, and 10 µm rms stability at photon BPMs. Our goal is to reduce the feedback processing cycle time to ~1 msec to achieve a closed-loop bandwidth of 30-50 Hz. We present simulations of fast feedback performance and discuss digital filter design in a companion paper [5]. In this paper, we consider the design, configuration, and performance

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requirements for digital system hardware and software components, focusing primarily on those for the unified vertical system.

II. SYSTEM DESIGN

The principle components of any orbit feedback system include its beam position monitoring, feedback signal processing, and orbit correction systems. We discuss these topics in the following sections.

A. Orbit Monitoring

The phase I feedback system presently uses a system of 20-25 BPMs to sample the electron orbit in SPEAR. All of these are situated in lattice straight sections, most near horizontally focusing QF quadrupoles Three new monitors [6] were installed within the last two years and several more are scheduled for installation over the next few years, including some near defocusing QD quadrupoles. The increased number of BPMs enhances our ability to detect the orbit and its perturbations, and to control orbit position at the photon beamline source points.

BPM button signals for this system pass through a CAMAC-based PIN diode multiplexer to a single wideband peak-detecting signal processor. The CAMAC μVAX crate controller computes beam position using the difference-over sum method, taking BPM response pincushion distortions into account. For orbit feedback operation, we average 10 orbits, each orbit the averaged result of 120 button readings, to obtain rms position noise on the order of 10 μm. The processor exhibits some beam intensity dependence, so the processing stability over the course of a beam fill is closer to a few tens of microns. An averaged orbit is transmitted over Ethernet to the main control computer database for display and feedback processing about every 5s.

To improve processing speed, signal resolution, and dynamic range for the phase II feedback system, we are building a narrowband heterodyne receiver tuned to the 717.1 MHz (2nd harmonic of the ring rf and 560th revolution harmonic) together with a new multiplexer having superior signal trsansmission and isolation properties at that frequency [7]. The 717.1 MHz signal is down-converted to the 5th harmonic of the revolution frequency (6.4 MHz) and sampled at 20.48 MHz (16th revolution harmonic) with a 12-bit ADC for one revolution period. The IF is mixed digitally to DC to produce two 16-bit words representing the I (in-phase) and Q (quadrature phase) components of this signal every revolution period. The I and Q signals for each button are then averaged over a programmable number of revolutions and stored in an on-board memory. We expect to be able to acquire a single orbit having 10 μm processing resolution from 25 BPMs with a single processor in ~5ms; acquisition speed may be increased using parallel processors. We are investigating the possibility of altering the programmable phase of the digital mixing frequency on a BPM-by-BPM basis so as to reduce the Q signals to near-zero. This would halve the amount of transmitted data and eliminate the quadrature sum button signal calculation.

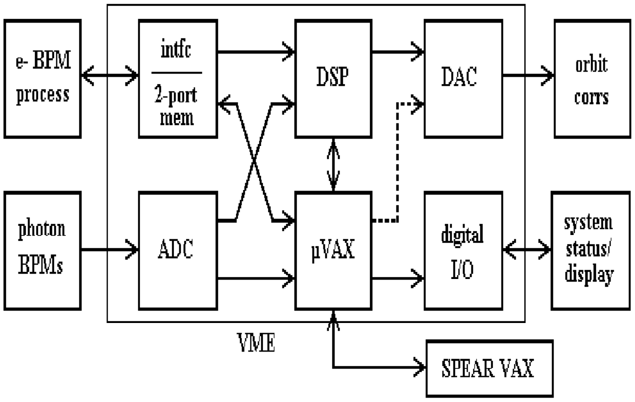

FIGURE 2. VME-based digital orbit feedback system.

B. Feedback Processing System

Phase I of the global feedback system uses the SPEAR control VAXstation 4000/90 to process orbit information and to update 30 corrector settings in each plane every minute. The control computer communicates with distributed CAMAC μVAX III crate controllers over Ethernet.

In each correction cycle, a reference orbit is subtracted from the acquired orbit to produce an error orbit which is in turn applied to the feedback algorithm. For the vertical plane, orbit changes at BPMs caused by the fast local steering bumps (responding to global corrections) are subtracted from the error orbit before global feedback processing. This ’bump subtraction’ decouples the global system from the local ones.

The phase II vertical system (Fig. 2) employs a unified electron and photon beam digital correction algorithm operating with a 30-50 Hz bandwidth so that analog steering servos can be eliminated. Beam will be stabilized at photon monitors by including those monitors in the response matrix. The control equations for the photon beam monitors are weighted more heavily than those for the electron BPMs so that, following the SVD matrix inversion, the photon monitor error signals can be more tightly constrained. The algorithm will be executed by a VME-based DSP module utilizing the Texas Instruments TMS320C40 DSP (a 32-bit floating-point processor having a 50 ns instruction cycle).

The phase II system will employ up to four parallel 717.1 MHz BPM processors to achieve a feedback cycle time of ~1 ms. Button I and Q data from 25 or more BPMs will be transferred over a ribbon cable to a custom VME interface module containing dual-port memory arranged in two pages. One page containing a complete orbit is transferred between the dual-port memory module and the DSP board over the VME bus while the other page is being loaded with new data by the BPM processor for the next feedback cycle. In each feedback cycle (of order 1 ms for vertical 50 Hz bandwidth), the DSP also acquires sum and difference signals from 10+ photon monitors with a 16-bit ADC. It then converts the integer orbit and photon monitor data to floating-point, calculates the quadrature sum of the I and Q values for each button, computes vertical positions (with a linear approximation for each BPM and photon monitor), and subtracts the reference position vector from the result. Next the DSP multiplies this error vector by the pseudo-inverse response matrix (~35x30) to generate correction values for 30 correctors and applies these values to a digital filter algorithm to produce corrector setpoints. These setpoints are converted to integers and sent to the 16-bit DACs. Position monitor signal levels and accumulated changes to corrector setpoints are monitored and the feedback loop is opened if those levels exceed programmed constraints. The whole acquisition and computation cycle takes less than 1 ms. Processing time is reduced if the Q data is reduced to zero by the BPM processor as mentioned above.

A VME μVAX crate controller must provide BPM button data, calculated x and y position values, and other feedback system parameters acquired within the VME crate to the SPEAR control VAX. This task, as well as special communications tasks for the DSP module, will be handled by the crate controller. The crate controller will normally access this data at 200-300 ms intervals from the dual-ported DSP and BPM processor interface memories. It will compute orbit position using a more accurate polynomial representation of the BPM pincushion response.

C. Orbit Correction

Trim windings on 26 solid iron-core quadrupole magnets in SPEAR are connected to produce most of the horizontal dipole orbit correctors for the vertical feedback system. Four additional "picture frame" magnets located near the colliding beam regions complete the vertical correction set. All correctors are powered by 2 kW bipolar linear supplies. For phase I feedback, 20 of these correctors receive setpoint inputs from both the control computer DAC system and from the local beamline steering systems by means of analog summing junctions. For phase II, the summing junctions will be implemented digitally in the VME feedback system. Orbit correction frequency response is dominated by eddy currents in the magnet core iron and in the aluminum ring vacuum chamber; lead-lag compensation in the feedback processor can extend the response to beyond 50 Hz [1,5]. Compensators are also needed to equalize the responses of the quadrupole and picture frame correctors.

Horizontal correctors are configured using trim windings on 26 of the solid core main bending magnets together with 4 picture frame magnets. Their response is limited to 2 Hz by core and chamber eddy currents.

III. PERFORMANCE AND IMPROVEMENTS

Phase I orbit feedback on SPEAR uses simple integral control to suppress the SPEAR diurnal orbit drift by a factor of ~5 in both planes over a 0.25 mHz bandwidth. Peak orbit excursions have been reduced to the 100 μm level over the diurnal cycle. Photon beam are vertically stabilized to 10 μm in a 50 Hz bandwidth at photon monitors by the local steering systems. In addition, we have augmented the vertical corrector-to-BPM response matrix to include the response at the photon monitors; we use an algorithm similar to that planned for the unified system at the top of each fill cycle to steer the photon beamlines with an optimized ’least norm’ global corrector pattern. This has reduced local corrector bump excursions for the analog beamline servos by a factor of 5 or more and has reduced overall corrector currents as well.

We believe the performance of the phase I feedback system is limited by several factors, including a lack of BPMs near some beamline source points and at QD sites, non-optimal BPM locations, temperature dependent BPM motion, BPM processing intensity dependence, and imperfect orbit correction patterns caused by magnet hysteresis and lattice nonlinearities (off-center beam position in sextupoles). Lattice nonlinearity and hysteresis can also corrupt measuremert of the response matrices and degrade system performance [3,5].

For the 30-50Hz Phase II feedback system, we will add new BPMs, the 717 MHz BPM processor, the VME-based DSP system, and more correctors. We are working to reduce the sources of orbit instabilities by installing more highly regulated main magnet power supplies, developing a new ring lattice to reduce the strengths of the interaction region quadrupoles [8], mechanically stabilizing magnets and BPMs, and realigning the ring. We are investigating temperature control for the SPEAR tunnel, and 3 GeV injection that would eliminate hysteresis due to energy ramping.

IV. ACKNOWLEDGEMENTS

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