Design and Characterization of the SSRL Orbit Feedback System*

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Abstract

Photon beam stability at SSRL is being improved by configuring a digital feedback system to reduce orbit motion at photon beam sourcepoints. The first implementation of the global feedback system operates with a milliHertz bandwidth to stabilize orbit position to 50 μm rms at position monitor sites. The vertical global system works in tandem with 50 Hz local photon beam steering systems to stabilize vertical photon beam position and angle. Design specifications and first phase realizations are presented for the orbit monitoring system, orbit correction algorithm, hardware components, and feedback processing system.

1. Introduction

The SPEAR 3 GeV storage ring serves a dedicated synchrotron light source SSRL beamlines. SPEAR has been transformed from a first generation to a second generation light source over the last decade by installing wiggler and undulator insertion devices and by reducing the beam emittance from the origiinal 500 nm-rad used for colliding beam operation to 130 nm-rad. The ring is mixture of old and new component designs spanning these two generations. In particular, it is plagued with orbit stability problems stemming from magnet and support, vacuum chamber, temperature control, power supply, and other component designs and implementations from the first generation.

The dominant uncorrected orbit instability has a peak-peak amplitude of about 1 mm horizontally (Fig. 1) and half as much vertically. It is caused primarily by vacuum chamber and magnet motion (particularly strong focusing quadrupoles near the colliding beam interaction regions) resulting from diurnal temperature change and in part by fill cycle beam decay. Position step changes, sometimes of a few hundred microns, are associated magnet field irreproducibility after the 2.3 GeV injection to 3 GeV energy ramp, while shifts of a few tens of microns occur as temperature stabilizes in the first hour after ramping. Smaller (tens of microns) higher frequency disturbances having mechanical and electrical sources [1].

We seek orbit stability at photon beam sourcepoints that is on the order of 10% of the sourcepoint photon beam transverse size and divergence to maintain flux constancy to a small fraction of a percent through restrictive beamline apertures. The most stringent positional stability requirements are 80 μm rms horizontally and 20-30 μm rms vertically to satisfy focused beam experiment needs; those for beam angle are 5 μrad vertically for undulator beamlines, and 50 μrad horizontally, needed to maintain constant flux in wiggler side stations.

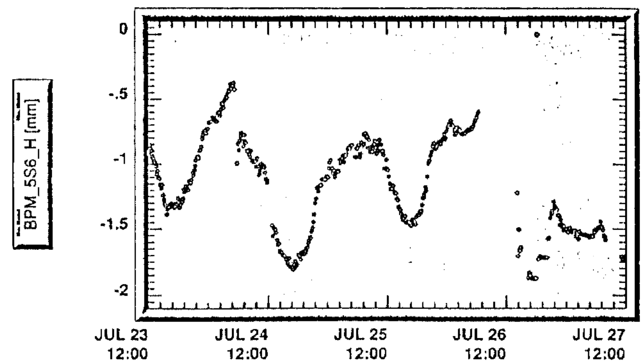

Figure 1. Uncorrected horizontal orbit motion over a four day period.

Local vertical steering feedback systems have been used for more than a decade at SSRL to stabilize beam position at single photon monitor locations in each beamline [1]. These systems have only a limited beam stabilizing capacity since they do not independently correct orbit position and angle. This limitation and a lack of horizontal beamline feedback systems have led us develop a global orbit feedback system for both planes using electron beam position monitors (BPMs). The vertical global system augments the local systems to help stabilize position and angle in that dimension. The goal for the first implementation of the global system is to stabilize the slow orbit drift (as measured by electron BPMs) to 50 μm vertically and 100 μm horizontally.

2. System Specifications and Design

Principle components of the global orbit feedback system (Fig. 2) include the orbit monitoring system, orbit correction system; and feedback processing system. Processing algorithms are implemented on the main SPEAR VAXstation 4000/90 host computer and interact with system hardware components and the local steering systems via a CAMAC interface and an ethernet communications link. Local μVAX III CAMAC controllers facilitate network communication and crate-based orbit monitoring and control.

2.1 Orbit Monitoring

The orbit monitoring system is presently comprised of 27 4-electrode capacitive pick-up assemblies placed around the ring which are connected to a single multiplexed rf processor

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in the SPEAR control room. Only 20 BPMs are presently reliable and are used for the feedback system. Most of them have an old design, with small button electrodes mounted in a large diameter cylindrical chamber that forms a step discontinutiy with adjacent rectangular chambers. A higher sensitivity rectangular BPM has been developed [2] and will be used to increase the number of usable BPMs to 30 or more.

BPM button signals pass through a CAMAC-based PIN diode multiplexing system to a single wideband peak-detecting rf signal processor. The processor output is sampled with a CAMAC transient digitizer. The processor is susceptible to wideband beam noise and has a limited dynamic range; it may also be sensitive to nonlinear field modes induced by chamber discontinuities or cavities near the BPM sites that can lead to current dependent processing offsets. We are presently building an improved processing system that uses a narrowband heterodyne receiver tuned to the 717.1 MHz second harmonic of the ring rf [3] and expect that it will be less susceptible to these problems .

The local controller can average any programmed number of button readings; it computes beam position using the difference-over sum method, taking into account BPM pincushion distortion. For feedback operation, we average 10 orbits, each orbit the result of 120 averaged button readings, to obtain rms position noise on the order of 10 μm. The averaged orbit is transmitted to main control computer database every 2.5 secs where it can be accessed by any number of application programs, including those for operational orbit display and for the feedback system.

2.2 Orbit Correction

Two orbit-correcting algorithms have been pursued in developing the global feedback system [4]: one based on decomposition of the orbit into Fourier harmonic components [5], and the other based on a decomposition into eigenvectors of the corrector-to-BPM response matrix as determined by the singular value decomposition (SVD) method. Common to both algorithms is representing the orbit at BPM sites as a limited sum of dominant orthogonal basis vectors (harmonics or eigenvectors) and correcting this "filtered" orbit using a measured 30-corrector to 20-BPM response matrix. Harmonic correction uses model-based or measured betatron parameters; the SVD algorithm produces orthonormal orbit basis vectors directly from the response matrix and bypasses the ring model.

Harmonic analysis of the SPEAR orbit shows that at least three harmonics in each plane (h=6,7,8) need to be corrected for effective stabilization; we can correct up to ten, limited by the number of usable BPMs. The minimum number of effective correction eigenvectors is 5 or 6; we can correct up to 20 based on the given number of BPMs. Both methods are limited by the limited number of BPMs, BPM readout and corrector errors, and by a nonlinear ring lattice; these problems lead to errors in measuring the response matrix, detecting the orbit, and applying the desired correction pattern. The number of corrected harmonics or eigenvectors must be reduced from the maximum to minimize vulnerability to these errors [4].

The digital feedback system makes a discrete orbit

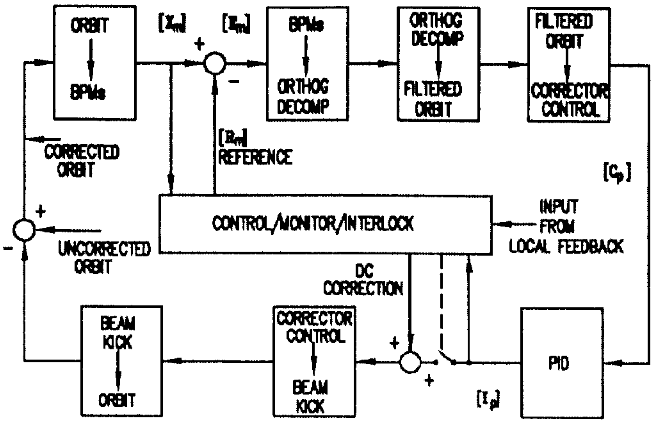

Figure 2. Global orbit feedback system.

correction every minute. The local vertical feedback systems respond to these corrections within a few tens of milliseconds, altering beam position at electron BPMs that are within the local corrective orbit bumps. To reduce interaction between the slow global system and the fast local systems, changes caused by the local systems are subtracted from the BPM readings used to compute the global correction.

2.3 Feedback Process and Control

The basic feedback system algorithm is: 1) sample time-averaged orbit vector $[X_m(n)]$, m = 1-20, at discrete time n; 2) subtract $[X_m(n)]$ from the desired reference orbit $[R_m]$ (which for the vertical system includes orbit changes at specific BPMs caused by the local feedback systems) to produce error orbit $[E_m(n)]$; 3) apply $[E_m(n)]$ to the harmonic or SVD orbit correction algorithm to generate corrector control values $[C_p(n)]$, p = 1-30, based on filtered orbit reconstruction; 4) apply $[C_p(n)]$ to a proportional-integral (PI) filter to produce actual corrector current setpoints $[I_p(n)]$; and 5) wait and repeat at discrete time n+1. The reference orbit is acquired using the BPM system just before launching the feedback algorithm. For the first phase, just integral control and a 1-minute sample period is used, aimed at suppressing the main diurnal orbit drift. The closed-loop bandwidth is 0.25 mHz, corresponding to a step response time constant of about 7 minutes.

In addition to the feedback algorithms, several other control and monitor routines have been installed. These include operator interface, loop mode and gain control, harmonic or eigenvector selection, cycle-by-cycle orbit, corrector update, and other system parameter logging, and interlock programs.

3. Performance and Improvement Plans

The global orbit feedback system was first operated in harmonic correction mode during dedicated SPEAR accelerator study periods. When the system was configured to correct less than 10 harmonics, we found that the applied orbit corrections were contributing significant energy to uncorrected harmonics. When correcting all 10 harmonics that were discernible with

20 BPMs (equivalent to trying to pin the beam in every BPM), orbit position at BPM sites was stabilized to the 40 μm level, but very large corrector strengths were needed to suppress detected low order harmonics (h=1,2). Evidence from beamline monitors and readings at BPMs not in the correction set suggested that orbit distortion between feedback BPMs was much larger than 40 μm. Subsequent simulations demonstrated that a combination of BPM readback noise and aliasing from harmonics higher than h=10 on the non-uniform BPM sampling grid could contribute to this problem [4]. We hypothesized that orbit detection problems together with errors in applied corrections could cause harmonic channel cross-coupling and "pumping" of uncorrected harmonics. We later discovered that horizontal correctors using main bending magnet cores had a large hysteresis error that may have abetted this problem; we have since reduced this error by cycling the correctors a few times over their operating range prior to using them for feedback.

Before resolving the complications encountered with harmonic feedback, we proceeded to test SVD eigenvector feedback. At first we attempted to correct all 20 eigenmodes given by the 20 BPMs (again equivalent to trying to pin the beam at BPMs) with the result that the orbit was stabilized to the 40 μm rms level BPMs, but again large corrector strengths were needed. The phenomenon was attributed to the correction algorithm trying to compensate for an apparent horizontal DC orbit shift (as if the ring diameter were changing) detected by the BPMs using the 20th, lowest order, eigenvector (most prone to measurement error), which had a DC component. This DC shift was not seen in the vertical plane. We achieved an equivalent stability level with a factor of ten less corrector strength, but with an accumulated apparent DC offset of 50-80 μm, by reducing the number of correction eigenvectors to between 12 and 17; we have been able to reduce the number of horizontal correctors from 30 to 22 with little impact.

When the local vertical feedback systems are turned on during global feedback operation, the global vertical system can develop a localized orbit bump of a few hundred micron in the vicinity of two of the nine beamlines over a period of tens of update cycles. This effect happens consistently at the top of a beam fill, when current and ring temperature are changing the fastest; it does not always happen later in the fill when conditions are more stable. Once developed, this bump is stable to the 40 μm rms as read by the BPMs. We can explain this phenomenon by assuming that the global BPM located within the local beamline bumps has a current-dependent readout that feeds a global-local interaction; we have yet to prove this is actually happening..

If we measure BPM-detected orbit stability after the aforementioned localized vertical bumps and the horizontal DC shift develop we find that we have have achieved or exceeded our goal to stabilize orbit at BPMs to the 50 μm rms with the first phase SVD global feedback system (Fig. 3). However there is sufficient evidence from photon beamline monitors that the orbit between BPMs may be a factor of two less stable. The system does not suppress fill-to-fill orbit shifts because, in the present mode of operation, the reference orbit is whatever the acquired orbit happens to be just before launching the feedback algorithm; we are considering but have not yet tried using a fixed orbit for the reference.

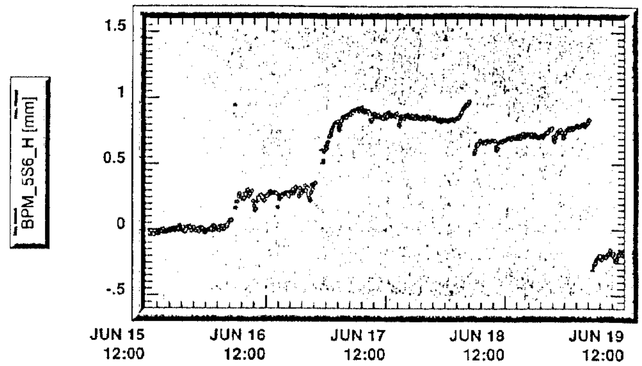

Figure 3. Orbit motion over four days with feedback on. A new reference orbit is used for each beam fill.

We are presently investigating possible causes of limited performance. We have already determined that some BPMs move horizontally by 40 μm pk-pk over a 24 hour period and now plan to mechanically stabilize all BPMs. We also observe fictitious current-dependent orbit shifts related to BPM pick-up or processing imperfections which we hope to reduce with the new processing system. We plan to add more linear correctors to reduce correction imperfections. Efforts continue to reduce orbit instability at its source by improving power supply and magnet support stability; a new ring lattice has been developed that reduces the strength of the interaction region quadrupoles by a factor of 10 [6]. We have concluded that the feedback system is serving as an excellent diagnostic tool for uncovering SPEAR instrumentation, control, and performance deficiencies.

Future goals for the orbit feedback system are to stabilize the beam to 25 μm rms at beamline sourcepoints and at experimental stations over a 1 Hz bandwidth horizontally and a 50 Hz bandwidth vertically using a DSP-based unified global-local system.

4. ACKNOWLEDGMENTS

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