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Abstract

Feedback systems have been commissioned for the PEP-II B factory to control orbit drifts from thermal and other transients, and to optimize the transverse overlap of the stored beams at the interaction point. BPM-based feedback loops correct the orbit at several points around both the low- and the high-energy ring. The beams are kept centered in collision by an optimization feedback that "dithers" the transverse position of one of the beams at the interaction point to maximize the readout of a radiative-Bhabha luminosity monitor. Luminosity-optimization dithering is also used to stabilize the relative vertical angle of the two beams, and to keep the positron beam aimed at the luminosity monitor. The current implementation acts on the beams at a rate of up to 2 Hz, and can compensate for changes within 10 seconds or less. This paper outlines the implementation of the feedback loops, and highlights the main improvements inspired by the first year of physics running at PEP-II.

1 INTRODUCTION

PEP-II is an asymmetric, high-luminosity e$^+$ - e$^-$ collider operating at the Y(4S) resonance [1]. 9 Gev electrons circulating in the High Energy Ring (HER), collide with 3.1 GeV positrons stored in the Low Energy Ring (LER). The nominal bunch collision rate is 238 MHz.

Operational experience in PEP-II has identified the need for stabilization of the average beam trajectories in response to slow drifts. This has been achieved using feedback loops that react in a few seconds to a few minutes, matching the time scale of fluctuations induced, for instance, by beam-current-dependent thermal drifts or by day-night variations in the temperature of magnet supports. As these systems use actuators and monitors already incorporated in the control system, they can be expanded and refined as needed, without requiring new, dedicated hardware. The system described here is complementary to, and completely distinct from, the dedicated bunch-by-bunch loops that control fast longitudinal & transverse multibunch instabilities in each of the rings [2,3].

Table 1 lists the slow loops currently implemented or planned. Most use multi-corrector, closed orbit bumps as actuators. Ring-specific orbit stabilization, whether global (HERO, LERO) or local (HSEX, HTFB, HCOL, HSYN and their LER equivalent), relies on beam position monitors (BPMs). At the interaction point (IP), even more precise stabilization is needed. Here, optimization feedback loops move, one at a time, their respective control knobs around the current settings, and interpolate to maximize the instantaneous luminosity measured at each step by a fast counter.

Name	Location/Purpose	Sensor	Actuators	Interacts with
HERO	Global x, y orbit drifts (HER final doublet)	8 BPMs	1 XCOR, 1 YCOR	All HER loops except HFTB,HSYN,HCOL
LERO	Global x, y orbit drifts (LER final doublet)	8 BPMs	1 XCOR, 1 YCOR	LSEX, HLERYANG
IPXY	e$^-$ x & y IP position (e$^+$ - e$^-$ transverse overlap)	LMon	2 closed bumps, 4 XCOR, 4 YCOR	HERO
HER_YANG	e$^-$ IP y-angle (e$^+$ - e$^-$ y-z overlap)	LMon	Closed bump, 4 XCOR, 4 YCOR	HERO
HLERYANG	Common e$^+$ - e$^-$ IP y-angle (γ's aiming -> Lum Mon)	LMon	2 closed bumps, 4 XCOR, 4 YCOR	IPXY
LER_XANG	e$^+$ IP x-angle (γ's aiming -> Lum Mon)	LMon	Closed bump, 4 XCOR, 4 YCOR	IPXY
HSEX, LSEX	Orbit in Arc sextupoles	4 BPMs	4 closed bumps/ring, 3 YCOR ea.	HERO (resp. LERO)
HTFB, LTFB	Offset @ multibunch transverse-feedback sensor	4 BPMs	Closed bumps, 4 XCOR, 4 YCOR per ring	(LTFB: LCOL)
HSYN	Synch. light monitor	4 BPMs	Closed bumps, 4 XCOR, 4 YCOR	
LCOL	βtron collimators	4 BPMs	Closed bumps, 7 XCOR, 9 YCOR	LTFB
HCOL	βtron & energy collim.	4 BPMs	Closed bumps, 8 XCOR, 12 YCOR	

Table 1: PEP-II feedback loop summary (LMon is the luminosity monitor; XCOR and YCOR are horizontal and vertical correctors).

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2 ARCHITECTURAL ISSUES

The systems discussed in this paper were built upon the capabilities of the SLC control system [4]. There, correctors and BPMs were accessed via remote microcomputers, and a generalized feedback system was used to stabilize the beam. As most of the slow control devices and monitors in the PEP-II rings are accessible through microcomputers which are part of the same architecture, the existing feedback system could be adapted for PEP-II with accommodations for new device types and algorithms.

PEP-II actuators controlled by the feedback system include both small and large power supplies, which are accessed through a Bitbus network and smart power supply controllers; these power supplies usually respond within about 0.5 second. Feedback sensors are most often BPMs. These measure the transverse position of a representative longitudinal slice of the bunch train, internally averaged over 1024 ring turns by the BPM processor to provide a noise-free input to the feedback system. For some applications, a radiative-Bhabha photon counter provides a signal proportional to the instantaneous luminosity, which is made available to the control system through a sampling ADC and digitized 8 times per second. Because of the very high counting rate of the physics process used (>1 γ per bunch crossing at design specific luminosity), signal fluctuations are inherently very small, and the luminosity optimization system can respond to changes within a few seconds.

The feedback control algorithm is based on the state-space formalism of digital control theory [5]. Matrices are designed offline, with the goal of providing optimal control and minimal RMS noise response. The typical design produces a feedback response with a time constant of six feedback iterations: an orbit control loop running at 2 Hz, for instance, should be able to correct 2/3 of a step change within about 3 seconds. For most of the orbit loops in PEP-II however, users have chosen to slow down the feedback response to avoid orbit jumps with potential deleterious impact on backgrounds or luminosity.

The system is database-driven, so that additional feedback loops can be added without requiring new software, as long as the required functionalities are already supported. Several new capabilities have been implemented for PEP-II. First, generalized bump-knob support was added, to control linear combinations of correctors in a local closed orbit bump. Next, the need arose to have multiple feedback loops actively control a set of common correctors at the same time. At the IP in particular, several LER & HER correctors are invoked by at least two of the following loops:

- global orbit feedback in both rings
- horizontal & vertical IP position of the e^- beam
- vertical IP angle of the e^- beam
- common vertical IP angle of the e^- and e^+ beams
- horizontal IP angle of the e^+ beam

Because of rapid, beam-current-induced thermal drifts during injection, it proved necessary to provide the first two types of control simultaneously. But to keep the feedback database easily maintainable, it was desirable to have separate feedback loops in some cases. The solution was a low-level device arbitrator, which implements the changes requested by multiple feedback loops. An essential ingredient here is that the different loops control truly orthogonal parameters.

3 ORBIT CONTROL

The most significant global orbit drifts were found, in each ring separately, to originate from one of the corresponding final-quadrupole doublets. These orbit distortions are compensated by one loop per ring, which, based on BPM measurements in the nearby arcs, controls one horizontal and one vertical steering corrector in each ring. Figure 1 shows the response of the HER orbit feedback loop to a step change in the beam. This loop runs at about 2 Hz, but its user-controlled gain has been set to 15% only, so at present the loop takes about 30 seconds to converge.

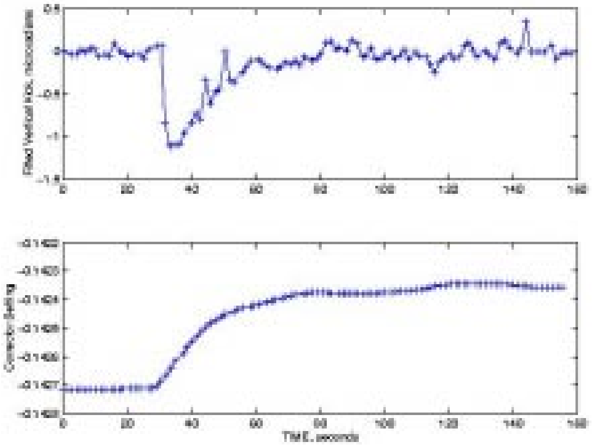

Figure 1: Step response of HER orbit feedback loop. Fitted angle and corrector setting are shown as a function of time.

Other feedback loops, that rely on one or more BPM readings and control closed orbit bumps, stabilize the transverse beam position at sensitive locations without, in principle, affecting the orbit in the rest of the ring. Such are, for instance, the two locations in each ring, on either side of the detector straight, where maintaining the beam vertically centered in the arc sextupoles is crucial to achieving a good local x-y coupling correction. Local stabilization is also provided at the location of the fast transverse-feedback pickups. Additional controls are planned to stabilize the transverse beam position near fixed collimator jaws, and to keep it centered within the optical acceptance of the synchrotron light monitor.

In some cases, the choice of the BPMs and steering correctors affecting neighboring or overlapping loops requires care, in order to avoid cross-talk between the actuators of one loop and the sensors of the other. For instance, for the global-orbit (H/LERO) and sextupole (H/LSEX) loops, the BPMs of the former were chosen to bracket the actuators of the latter.

4 OPTIMIZATION

The use of beam-beam deflections to maintain the beams in head-on collision, though very successful at the SLC, proved impractical at PEP-II because of the excessive requirements it implies for the resolution and long-term stability of the BPM system. Adjusting instead the positions and angles of the beams at the IP, with the luminosity as a criterion, proved a more effective approach.

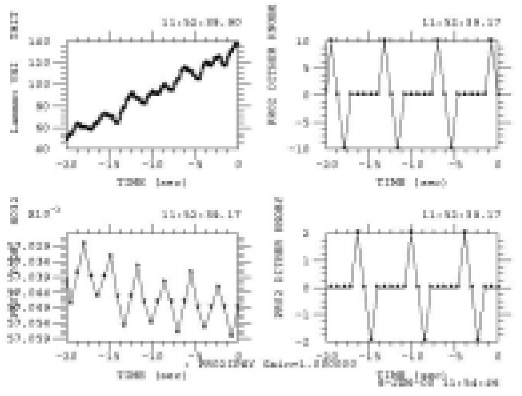

Figure 2: Collision feedback dithering to keep the beams in collision during a fill.

The generalized luminosity-optimization feedback capability used in the SLC to control higher-order aberrations in the final focus [6, 7], was adapted to optimize transverse beam-beam overlap at the PEP-II IP. In a "dithering" feedback system, a linear combination of devices is moved through three settings: the current value, and settings closely above and below it. For each "dither setting”, after an optional settling time, the software averages the luminosity over a predetermined number of measurement cycles. Finally, a parabolic fit to the three (average) luminosity readings determines the new optimal actuator setting.

In PEP-II, the IPXY loop alternates between dithering the horizontal and the vertical e^- position to keep the beams centered on each other; a complete dither cycle (both planes) currently requires six seconds. The operation of this loop is illustrated in Fig. 2. The luminosity is shown in the upper left, increasing steadily with beam current, but also going up and down with the dithering. On the right side of the figure the dithering knobs are displayed. These are linear combinations of devices which control the horizontal and vertical beam positions; while one knob is going through a dither cycle the other one is held steady. In the lower left, a selected single corrector is shown, moving through different patterns for the two dithering knobs, and moving to new settings to keep the beams in collision.

Stabilization of IP angles also relies on the optimization system. e^+e^- overlap in the y-z plane is controlled by the e^- vertical angle, while the radiative-Bhabha photons are kept centered onto the luminosity monitor by two LER angle loops. Because they tend to move the positrons slightly out of collision, the LER angle loops are configured to run at the same time as the collision loop, but on a much slower time scale ("nested dithering"). Each time a LER angle is modified, the IPXY loop is given time to restore head-on collisions, and this is built into a long "settling" time for the LER angle loops. These optimizations are currently configured to take 72 seconds for a single iteration.

5 CONCLUSION

Slow-feedback stabilization has proven an essential ingredient to achieve high integrated luminosity in the B-factory. The number of loops in the PEP-II rings and at the IP, as well their complexity, has been steadily expanding as performance requirements are becoming more stringent. In the future, a more global orbit feedback is being considered, as well as the stabilization of ring tunes and a global luminosity optimization using optical-correction magnets.

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