SLAC-PUB-7837
June 1998

Commissioning the Beam Diagnostics for the PEP-II B Factory

A. S. Fisher *et al.*

Presented at 3rd European Workshop on Beam Diagnostics and Instrumentation
for Particle Accelerators (DIPAC 97), 10/12/98—10/14/98, Frascati, Italy

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

Work supported by Department of Energy contract DE–AC03–76SF00515.

Commissioning the Beam Diagnostics for the PEP-II B Factory

A.S. Fisher, D. Alzofon, B. Collins, A. Gioumousis, T. Himel, R. Iverson, R. Johnson, A. Kulikov, R. Larsen, D. McCormick, J. Seeman, S. Smith, R. Stege, H.U. Wienands
Stanford Linear Accelerator Center
M. Chin, J. Hinkson, M. Zisman
Lawrence Berkeley National Laboratory

Abstract. PEP-II is a 2.2-km-circumference collider with a 2.1-A, 3.1-GeV positron ring (the Low-Energy Ring) 1 m above a 1-A, 9-GeV electron ring (the High-Energy Ring); both rings are designed for a maximum current of 3 A. We describe the beam diagnostics and present measurements from HER commissioning. The beam profile is measured using near-UV synchrotron light extracted by grazing-incidence mirrors that must withstand up to 200 W/cm. Normally 1658 of the 3492 buckets will be filled, and the charge must be equal within 2%. To measure the charge in each bucket, the sum signal from a set of 4 pickup buttons is digitized and averaged over 256 samples per bucket in every 60-Hz interval. The sum is then normalized to the ring current, measured by a DC current transformer. The 300 beam-position monitors per ring are multiplexed to share 171 processor modules, which use DSPs for recording positions over 1024 turns and for calibration. For both diagnostics and machine protection, 100 photomultipliers with fused-silica Cherenkov radiators measure beam losses and can trigger a beam abort in case of high loss. For the ring tunes, signals from a set of 4 pickup buttons are combined into horizontal, vertical, and sum signals. Two signals are selected and downconverted into the range of a 10-MHz, 2-channel, programmable, DSP-based spectrum analyzer, connected over ethernet to the control room.

1 INTRODUCTION

The PEP-II *B* Factory [1], an electron-positron collider under construction [2] at the Stanford Linear Accelerator Center in collaboration with the Lawrence Berkeley and Lawrence Livermore National Laboratories, involves two rings at different energies; both rings require large currents for high luminosity (see Table 1). The HER, which reuses the PEP-I magnets (with a new, low-impedance, vacuum chamber), was completed first and began commissioning in May 1997. The LER will start in the spring of 1998, and the BaBar detector will be installed in 1999. At this time (October 1997), the HER has stored up to 300 mA, filling up to 1700 buckets; the current should continue to increase toward the 1-A design value with progress in commissioning the transverse, longitudinal, and RF feedback loops. Here we discuss the commissioning of the HER diagnostics; their design has been presented in [3].

Parameter	HER	LER
Circumference [m]	2199.318	
Revolution time [μs]	7.336	
RF frequency [MHz]	476	
Harmonic number	3492	
Number of full buckets	1658	
Bunch separation [ns]	4.20	
Nominal current [A]	0.99	2.16
Maximum current [A]	3	3
Nominal energy [GeV]	9.01	3.10
Maximum energy [GeV]	12 (at 1 A)	3.5
Bend radius in arc dipoles [m]	165	13.75
Critical energy in dipoles [keV]	9.80	4.83

Table 1. PEP-II Parameters.

2 SYNCHROTRON-LIGHT MONITOR

Synchrotron radiation (SR) in the visible and near ultraviolet (600–200 nm) is used to measure the beam profile. HER light is measured at the location shown in Fig. 1, with provision for the LER at the same point. Design considerations included high SR power on the first mirror, low-impedance vacuum chambers with limited access to the beam, and a narrow tunnel.

HER arcs are almost entirely occupied by dipoles, with a quadrupole, corrector and sextupole taking up much of the rest of each half cell. The intense SR fan strikes the water-cooled outer wall of the chamber. The first mirror M1 (Fig. 2), mounted in the vacuum chamber on the arc's outer wall, reflects the light horizontally across the chamber to the downstream inner corner. The arrangement shadows both the mirror's upstream edge and the leading edge of the chamber at the downstream end from receiving power at normal incidence. The beam is incident on each mirror at 4˚ to grazing, giving a maximum power along the SR stripe of 200 W/cm.

A mirror cannot be cooled sufficiently at this power to obtain adequate flatness for good imaging. Instead, note that the SR fan at the critical energy is 15 times narrower than the visible fan we image. When the electrons travel on axis, a narrow slot along the mirror's mid-plane passes the x-ray fan, while visible light reflects from the surfaces above and below. Because of grazing incidence, the x rays never reach the bottom of the slot, but travel past the mirror to dump their heat into a thermally separate absorber (Fig. 2). When the electrons are off center, we demand only that the mirror not exceed its yield strength while the orbit is corrected and the mirror cools [4].

After M1, two 45˚ mirrors and a fused-silica window bring the light to imaging optics in a nitrogen-filled enclosure on an optical table below the HER dipole, in order to get good resolution from a short, stable optical path. The

Diagnostics and Instrumentation for Particle Accelerators
Frascati. Italv. 12–14 October 1997

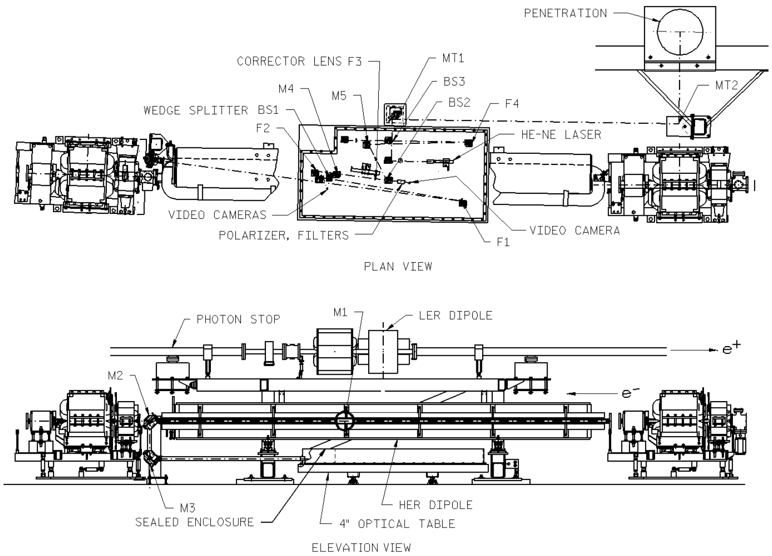

Figure 1. HER and LER beamlines in mid-arc, showing path of the HER synchrotron light and the optical table under the HER dipole.

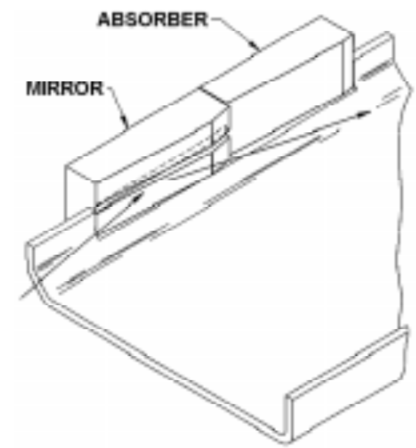

Figure 2. The slotted first mirror M1 and the x-ray absorber, both mounted in the wall of the HER chamber.

beam is split, with half used for this local imaging and half planned for a path through a 10-m penetration to an optics room at ground level, for equipment like a streak camera and fast-gated camera.

This system, installed for our September run, soon produced beam images, although adjustments of the optics continue. The light level is controlled using the electronic shutter of the CCD; no color filter is yet in use. At high currents, the monitor displays strong beam oscillations. Bunch-by-bunch transverse [5] and longitudinal [6] feedback decrease the motion and the spot size.

Issues from these first weeks include finding a second, distorted image above the main one (even at low current), perhaps due to mechanical stress on M1, and not reaching best focus within the adjustment range, again suggesting a mounting problem with the mirror. The mirror will be inspected in November, after the run.

3 BEAM-POSITION MONITORS

Each BPM [7] uses four 15-mm-diameter pickup buttons, arranged near ±45˚ to the horizontal at each quadrupole, with ≈300 sets per ring. Except near the interaction and injection points, only one plane is measured—*x* only at QFs, *y* at QDs. Next to the quad, the four button signals are filtered at $2f_{RF}$ (952 MHz) and combined into two (up/down or left/right).

The processors, CAMAC modules multiplexed between HER and LER, use I&Q (in-phase and quadrature) detectors, digitizers, and digital signal processors (DSPs) to record 1024 turns (either consecutive or every N^{th}) from any 40-ns bucket group, for display, averaging or a fast Fourier transform (FFT). The single-turn resolution is <1 mm for 5×10^8 $e^\pm$, <100 µm for 10^{10}, and, for a 1024-turn average, <10 µm for 10^{10}. We are presently limited by a calibration problem that makes it appear as if the beam had a 300-µm peak-to-peak oscillation at 21 Hz.

4 TUNE MONITOR

The tune is monitored with a spectrum analyzer processing signals from dedicated BPM-type pickup buttons. The button signals are first combined with 180˚ hybrids to form a sum signal and horizontal and vertical difference signals. Two of these combinations are selected, then attenuated or amplified to cover a broad dynamic range, from one bunch of 5×10^8 e^+ or e^- in the ring to 1658 bunches of 8×10^{10}, 4.2 ns apart. Up to this point, broadband components keep the pulses narrow, so that a 2-ns-rise-time GaAs switch can select the signal from a specific bunch, bunch group, or the entire ring. Other gates let us measure the tunes while turning off feedback for a specific bunch.

The front-end circuit next mixes the signals at $2f_{RF}$, to bring the signals into the frequency range of the two-channel spectrum analyzer (HP 89410A), which uses DSPs and FFTs to compute spectra from 0 to 10 MHz. The analyzer incorporates both GPIB and an ethernet interface providing control from an X-terminal, using a graphical image of the front panel. Its processor runs both built-in functions (like peak finding) and user programs on command from the PEP control system. We are now testing software to follow tune peaks during measurements of resonances or *xy* coupling.

The analyzer includes a tracking generator to excite the beam with a swept sine or broadband noise. Instead of using a separate system, the drive signal is summed with the input to the power amplifiers for transverse and longitudinal feedback. We may later program the beam-excitation level to measure the tune peak with the minimum drive. The drive can be switched on or off separately for each plane, and also passes through a 2-ns gate, to allow excitation of any bunch. To study multibunch instabilities, for example, we plan to drive one bunch while measuring the response of the following bunches. When the LER is complete, we can excite bunches in one ring and measure the corresponding bunches in the other.

5 CURRENT MONITORS

The current in the HER (and soon the LER) is measured by a DC current transformer (DCCT) [8] with a 5-μA resolution over a 1-s integration time and a full-scale value of 5 A. (For comparison, a 1-A current with a 3-hour lifetime drops by 93 μA/s, and injecting 5×10^8 $e^\pm$ adds 11 μA.) Our DCCT housing places it outside the vacuum envelope, provides an electrical gap directing DC wall currents around the transformer core, and capacitively bypasses the gap for higher frequencies to provide a low impedance to the beam. A scanning integrating voltmeter (Keithley 2002) reads the output from both rings.

Two neighboring systems [9] are being commissioned to measure the charge in each RF bucket (the bunch-current monitor, BCM), and control the fill (the bunch-injection controller, BIC). Normally, 1658 buckets, 4.2 ns apart (two RF periods), will be filled equally within ±2%, up to 8×10^{10} $e^\pm$ for a 3-A beam.

The BCM (one per ring) updates measurements at 60-Hz, the maximum fill rate, with a design accuracy of ±0.5%. The accuracy must increase to 0.05% in 1 s to find the lifetimes of individual bunches, for quick adjustments of a lossy bunch. In each ring we sum and filter the signals from a set of four BPM-type buttons, then mix the signals at $3f_{RF}$. An 8-bit ADC in a VXI crate digitizes the signal at f_{RF}. The data stream is downsampled and divided among 12 logic arrays, to sample all buckets once in 8 turns, and the data is summed over 256 measurements in each 60-Hz interval. The sums are written into a table in a reflected (dual-port) memory. The VXI processor maintains a second table with sums over 1-s intervals. Commands are passed to it through this memory as well.

The BIC, in an adjacent VME crate, reads the memory of both rings and, over GPIB, also reads their DCCT voltages and the exact measurement times. It normalizes the individual bunch currents and calculates lifetimes. Using an EPICS interface to the control system, it communicates results and receives commands. The bunch-injection controller plans the injection sequence for a third system, the master pattern generator, which times the injector linac to fill the appropriate buckets in the rings.

6 BEAM-LOSS MONITORS

A network of 100 beam-loss monitors (BLMs) detects losses around the rings, at selected quadrupoles and septa (and, in the future, at collimators). The output is used for machine tuning, for loss histories, and for the rapid detection of high losses requiring a beam abort. We have chosen a Cherenkov detector, using a small (16 mm diameter), fast (2-ns-wide pulses) photomultiplier, with a 10-mm-long, fused-silica, cylindrical Cherenkov radiator on the fused-silica PMT window. The assembly is enclosed in 1 cm of lead to reduce synchrotron-radiation background, but remains small enough to be moved for commissioning and troubleshooting. Using the ring magnets as shielding, the BLMs can have preferential sensitivity to HER or LER. All are now placed around the HER.

Ten-channel CAMAC modules in crates around the rings process each BLM signal through parallel paths that together provide a wide dynamic range. For low losses, the PMT pulses pass through a discriminator and are counted over 1-s or 8-ms intervals. Higher loses are better handled by integrating the signal with a 10-μs (≈1 turn) RC filter. The peak output in each 8 ms is digitized and available when requested by the control system; in addition, a peak exceeding a programmable threshold can trigger a kicker to abort one or both rings. The BLM processor then records the triggering channel, and all BLMs around the rings freeze their most recent readings. For 100 μs after injection into a ring, the BLM network is inhibited from aborting the stored beam, since faulty injection is a more likely source of a large loss. To measure this injection loss, the output of the peak detector is digitized at the end of this inhibit interval.

[1] *PEP-II: An Asymmetric* B *Factory*, Conceptual Design Report, LBL-PUB-5379, SLAC-418, CALT-68-1869, UCRL-ID-114055, UC-IIRPA-93-01, June 1993.

[2] U.S. Dept. of Energy contracts DE-AC03-76SF00515 (SLAC), DE-AC03-76SF00098 (LBNL), and W-7405-Eng-48 (LLNL).

[3] A.S. Fisher, D. Alzofon, D. Arnett, E. Bong, E. Daly, A. Gioumousis, A. Kulikov, N. Kurita, J Langton, E. Reuter, J.T. Seeman, H.U. Wienands, and D. Wright, M. Chin, J. Hinkson, D. Hunt, and K. Kennedy, “Diagnostics Development for the PEP-II *B* Factory,” *Proc. 7th Beam Instrumentation Workshop*, Argonne, IL, May 1996, Conf. Proc. 390 (Amer. Inst. of Physics, Woodbury, NY, 1997).

[4] E.F. Daly, A.S. Fisher, N.R. Kurita, J Langton, “Mechanical Design of the HER Synchrotron-Light-Monitor Primary Mirror,” *Proc. IEEE Particle Accelerator Conf.*, Vancouver, BC, May 1997 (IEEE, Piscataway, NJ), in press.

[5] Barry, W., Byrd, J., Corlett, J., Fahmie, M., Johnson, J., Lambertson, G., Nyman, M., Fox, J., and Teytelman, D., “Design of the PEP-II Transverse Coupled-Bunch Feedback System,” *Proc. IEEE Particle Accelerator Conf.*, Dallas, TX, May 1995 (IEEE, Piscataway, NJ).

[6] D. Teytelman et al, “Diagnostic Use of Digital Beam Feedback Systems,” in these Proceedings.

[7] S.R. Smith, G.R. Aiello, L.J. Hendrickson, R.G. Johnson, M.R. Mills, J.J. Olsen, “Beam Position Monitor System for PEP-II”; R. Johnson, S. Smith, N. Kurita, K. Kishiyama, J. Hinkson, “Calibration of the Beam-Position-Monitor System for the SLAC PEP-II *B* Factory,” *Proc. IEEE Particle Accelerator Conf.*, Vancouver, BC, May 1997 (IEEE, Piscataway, NJ), in press.

[8] Parametric Current Transformer, Bergoz Precision Beam Instrumentation, Crozet, France.

[9] M.J. Chin, J.A. Hinkson, “PEP-II Bunch-by-Bunch Current Monitor,” *Proc. IEEE Particle Accelerator Conf.*, Vancouver, BC, May 1997 (IEEE, Piscataway, NJ), in press.