DESIGN AND INITIAL COMMISSIONING OF BEAM DIAGNOSTICS FOR THE PEP-II *B* FACTORY

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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 are designed for 3 A maximum. We describe the beam diagnostics for HER commissioning, starting in May 1997. LER commissioning will follow in 1998. The beam size and pulse duration are measured using near-UV synchrotron light extracted by grazing-incidence mirrors that must withstand 200 W/cm. To measure the charge in every bucket at 60 Hz with an accuracy of •0.5%, the sum signal from a set of 4 pickup buttons is digitized and averaged over 256 samples per bucket. The sum is 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 diagnostics and machine protection, 100 photomultiplier-based Cherenkov detectors measure beam losses and abort the beam in case of high loss.

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). Because the HER reuses the PEP-I magnets (although with a new, low-impedance, vacuum chamber), its commissioning is beginning at the time of this conference (May 1997), while the LER, with similar diagnostics, will start in early 1998. The BaBar detector will be installed in 1999.

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) will be used to measure the beam's transverse profile and, with a streak camera, in the longitudinal direction. Both rings will be measured at the location shown in Fig. 1. The design must cope with high SR power on the first mirror, low-impedance vacuum chambers, 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 (see Fig. 1). The intense SR fan strikes the water-cooled outer wall of the chamber. The mirror (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 shades 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.

The HER mirror cannot be cooled sufficiently at this power to obtain adequate flatness for good imaging. Instead, we make use of the fact 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 the visible beam 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, as discussed in [3].

After this first mirror, 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 beam is split, with half used for this local imaging and half sent upwards through a 10-m

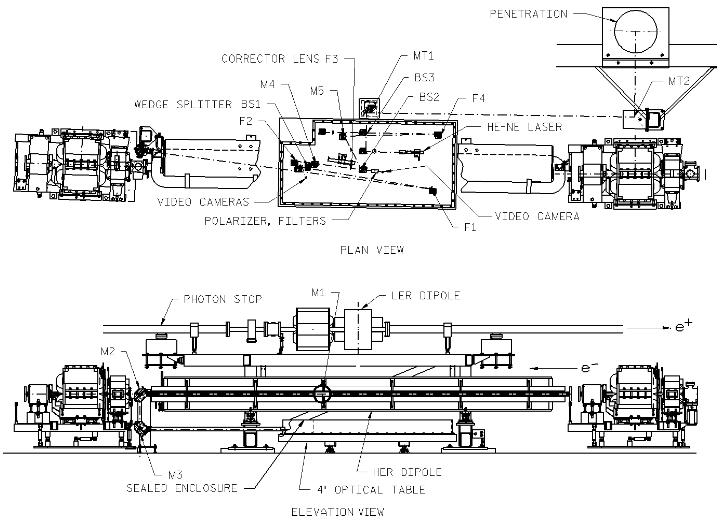

Figure 1. HER and LER beamlines in mid-arc, showing path of the HER synchrotron light and the optical table under the HER dipole.

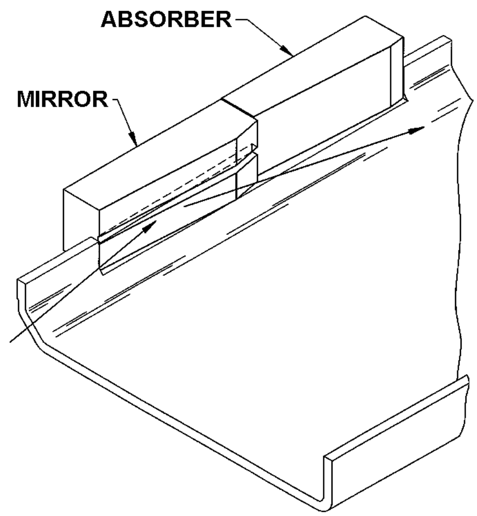

Figure 2. The slotted first mirror and the x-ray absorber, both mounted in the wall

penetration to an optics room at ground level, to keep equipment like the streak camera away from radiation.

In the LER, the SR diverging from the beam at each dipole enters an antechamber; 2/3 of these photons strike a water-cooled photon stop 6 m beyond the bend (Figs. 1 and 3), while the remainder hit the next photon stop downstream. We pass light from the closer dipole (to avoid clipping in the narrow antechamber of the intervening magnets) through a 15-mm-wide vertical slice in the photon stop. The light then strikes a slotted mirror similar to that of the HER but inclined at 9° to grazing. The maximum SR power density is 110 W/cm—half that of the HER. The light is deflected horizontally away from the positron orbit, since the slit in the photon stop shades the leading edge of the mirror. Two mirrors then send the beam down to the common optical table under the HER dipole.

3 BEAM-POSITION MONITORS

Beam position measurements use four 15-mm-diameter pickup buttons, arranged near ±45° to horizontal at each quadrupole, for a total of ≈300 sets per ring. Most

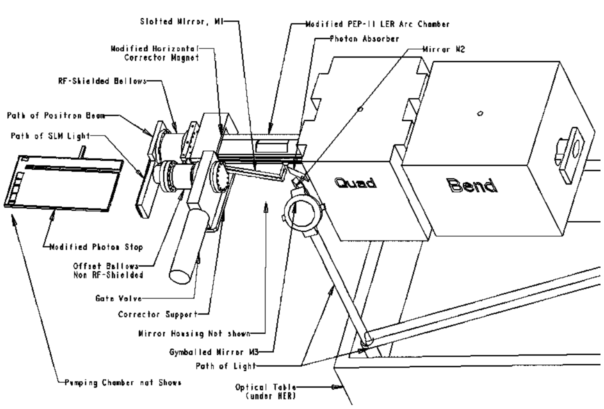

Figure 3. The LER synchrotron-light monitor, showing the modified photon stop and the slotted first mirror.

measurements are single plane (*x* only at QFs, *y* at QDs), except near the interaction and injection points, with pairs of buttons summed next to the quad. The CAMAC processor modules, multiplexed between HER and LER, use I&Q (in-phase and quadrature) detectors and digital signal processor (DSP) chips that record 1024 turns and can provide single-turn or averaged positions, with resolutions (measured in the lab) of 100 µm and 1 µm respectively. A detailed description and preliminary commissioning data are presented in other papers at this conference [4].

4 TUNE MONITOR

The tune of each ring will be monitored with a spectrum analyzer processing the signal from dedicated BPM-type pickup buttons. The analyzer includes a tracking generator to excite the beam with a swept sine or broadband noise. Instead of using separate excitation structures, the drive signal can be summed with the input to the power amplifiers for transverse [5] and longitudinal [6] feedback.

The button signals are combined with 180° hybrids to form a sum signal, and horizontal and vertical difference signals. Two of these are switched into two channels, then attenuated or amplified to cover a broad dynamic range, from one bunch of 5×10^{8} electrons or positrons to 1658 bunches of 8×10^{10}, 4.2 ns apart. Broadband components are used up to this point to keep the pulses narrow, so that a 2-ns GaAs switch can gate the signal for measurements of specific bunches or pass the signal from the entire ring. The gate also allows us to measure the tune while turning off feedback for a specific bunch.

The two-channel spectrum analyzer uses DSPs and a fast Fourier transform (FFT) to compute spectra from 0 to 10 MHz. To bring the signals into range, the front end includes mixers at $2f_{RF}$ (952 MHz). The analyzer incorporates both GPIB and an ethernet interface for control by an X terminal, using a functional image of the front panel. It has peak tracking to automatically follow the tune and runs user programs, allowing control, for example, of the beam-excitation signal to measure the peak with the minimum drive.

Other systems will be available to follow the beam's response. Each ring has a second dedicated set of buttons reserved for special measurements, such as high-frequency spectra to examine bunch dynamics. Also, the DSP on each BPM processor card can record signals from 1024 turns and calculate an FFT. Using all the BPMs, we can follow oscillations of a bunch around 1024 turns.

5 CURRENT MONITORS

The current in each ring is measured by a commercial [7] DC current transformer (DCCT) 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 second system (detailed at this conference [8]) measures the charge in each of the 3492 RF buckets. In a normal fill (see Table 1), 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. With 0.5% accuracy, the bunch-current monitor must update measurements of each ring at 60-Hz to control the fill. To find the lifetimes of individual bunches, we need an accuracy of 0.05% in 1 s, allowing 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} (476 MHz). The data stream is downsampled and divided among 12 logic arrays, to sample all buckets every 8 turns, and the data is averaged over 256 measurements in each 60-Hz interval. The averages are written into a table in a reflected (dual-port) memory. The VXI processor maintains a second table with sums over 1-s intervals.

Another VXI-based system, the bunch-injection controller, reads this memory and the DCCT. It normalizes the individual bunch currents, performs lifetime calculations, and communicates with the control system. The bunch-injection controller determines the injection sequence for a third system, the master pattern generator, which controls the timing of the injector linac to fill the appropriate buckets in the rings.

6 BEAM-LOSS MONITORS

A network of 100 beam-loss monitors (BLMs) detects beam losses at collimators, septa, and selected quadrupoles around the rings. The output will be 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 over the fused-silica PMT window. The assembly is enclosed in 1 cm of lead to reduce synchrotron background, but still remains small enough to be moved around for commissioning and troubleshooting. Using the ring magnets as shielding, the BLMs can have preferential sensitivity to HER or LER. All are now being placed around the HER and have detected losses from the first injection.

Ten-channel CAMAC modules in crates around the rings process each BLM signal through two paths that together provide a wide dynamic range. For low losses, PMT pulses are sent through a discriminator and counted over 1-s or 8-ms intervals. At higher loss rates, the signal goes through a 10-μs *RC* filter; this integrated signal is used twice. First, it passes through a peak detector and is digitized every 8 ms for output to the control system. Second, if the 10-μs signal exceeds a programmable threshold, then one or both rings may be aborted. The processor records the channel that triggered the abort, 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 high loss rates. To measure injection loss, the output of the peak detector is digitized at the end of this inhibit interval.

REFERENCES

[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] E.F. Daly, A.S. Fisher, N.R. Kurita, J Langton, "Mechanical Design of the HER Synchrotron-Light-Monitor Primary Mirror," in these Proceedings.

[4] 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," in these Proceedings.

[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," in *Proc. IEEE Particle Accelerator Conf.*, Dallas, TX, May 1995 (IEEE, Piscataway, NJ) in press.

[6] Oxoby, G., et al, "Bunch-by-Bunch Longitudinal Feedback System for PEP-II," in *Proc. European Particle Accelerator Conf.*, London, 27 June–1 July 1994 (World Scientific, Singapore, 1994) pp. 1616–1618; Teytelman, D., et al, "Feedback Control and Beam-Diagnostic Algorithms for a Multi-Processor DSP System," in these Proceedings.

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

[8] M.J. Chin, J.A. Hinkson, "PEP-II Bunch-by-Bunch Current Monitor," in these Proceedings.