SLAC–PUB–6181
June 1993
(A)

Progress on PEP-II Injection R&D*

E. Bloom, F. Bulos, T. Fieguth, G. Godfrey, G. Loew, R. Miller
Stanford Linear Accelerator Center
Stanford, CA 94309 USA

I. ABSTRACT AND INTRODUCTION

The R&D program described in this paper focuses on an improvement of the SLAC linac designed to extract and study a 9 GeV electron beam under stringent control of energy, energy spread, emittance, optical parameters, and timing.

The extraction system begins with an on-axis pulsed magnet, followed by a magnetic lattice and diagnostic equipment required for the measurement and optimization of the above beam qualities. Design, construction, and installation of this system is the first step in the development of the overall PEP-II $e^{\pm}$ injection system.

This system is required to fill 1658 bunches of 9 GeV electrons (0.99A stored) and 3.1 GeV positrons (2.14A stored) in two separate rings in a total of about 6 minutes from zero ring current (i.e., full-fill mode, 0 to 100%) or in about 3 minutes from 80% ring current (i.e., topping-off mode, 80 to 100%).

This unprecedented rate of filling can be met[1] by a judicious use of the SLC linac, damping rings, and positron source.

II. ROLE OF R&D PROGRAM IN OVERALL PEP-II INJECTION

The overall goals of the PEP-II Injection System are summarized in Table 1. These differ from those given in earlier papers[2,3] in that the current of the electron ring (HER) was recently lowered from 1.48 to 0.99A, and that SLC operation showed that the transverse beam emittance can be decreased by going to flat beams ($\varepsilon_y \sim \varepsilon_x/8$). These two factors both ease the injection process.

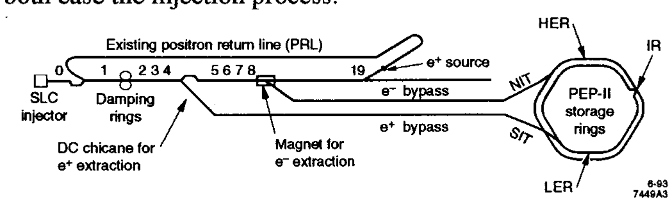

Fig. 1. Schematic of the B Factory $e^{\pm}$ injection system, based on use of the SLC linac with bypass lines.

Figure 1 shows a diagram of the entire injection system using the SLC. Alternate linac pulses accelerate the electrons for HER on one 60 Hz time slot, and the positrons for LER together with the electrons which make the positrons on the next 60 Hz time slot. The electrons are stored in the North Damping Ring (NDR) for 1/120th of a second, the positrons are stored in the South Damping Ring (SDR) for 1/60th of a second. The first eight sectors of the linac are pulsed at 120 Hz, the remaining sectors up to the $e^{\pm}$ source are pulsed at 60 Hz. The extraction of the positrons takes place by means of the DC chicane in Sector 4. The extraction of the electrons takes place in Sector 8 by means of the slow pulsed bending magnet and lattice described in this paper.

The correct injection timing of the bunches, which in PEP-II are spaced 4.2 ns apart, is obtained by adjusting the timing of the damping-ring extraction kickers and the phase of the DR rf (714 MHz) during the damping interval. The linac rf frequency (2856 MHz) and the PEP-II rf frequency (476 MHz) are harmonically related and locked together.

TABLE 1: Selected PEP-II Injection Parameters.

Beam energy	
High-energy ring (HER)	9 [range:8-10] [GeV]
Low-energy ring (LER)	3.1 [range: 2.8-4] [GeV]
Beam Current	
High-energy ring (HER)	0.99/4518 [$A/10^{10}e^-$]
Low-energy ring (LER)	2.14/9799 [$A/10^{10}e^+$]
Particles per bunch	
High-energy ring (HER)	2.7 [$10^{10}e^-$]
Low-energy ring (LER)	5.9 [$10^{10}e^+$]
Linac repetition rate	60/120 [Hz]
Linac current range during filling	0.1-3 [10^{10} $e^{\pm}$/pulse][a]
Invariant linac emittance	
ε_x	4×10^{-5} [m · rad]
ε_y	0.5×10^{-5} [m · rad]
Normal filling time	
Topping-off (80-100%)	3 [min.]
Full fill (0-100%)	6 [min.]
Revolution period	7.336 [μs]
Harmonic number	3492
Number of bunches[b]	1746-5%=1658
Vertical damping time	
HER	38 [ms]
LER, with wigglers	40 [ms]
LER, without wigglers	68 [ms]
Nominal beam emittance	
HER, horizontal/vertical	48/1.9 [nm · rad][c]
LER, horizontal/vertical	64/2.5 [nm · rad][c]

[a] Assuming 75% filling efficiency. The SLC routinely delivers 2.8×10^{10} $e^{\pm}$ per linac pulse at the detector.
[b] For filling, the rings are divided into nine equal zones. A 5% gap leaves one zone partially unfilled.
[c] Unnormalized, or geometrical, values.

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

Presented at the Particle Accelerator Conference (PAC 93), Washington D.D., May 17–20, 1993

III. EXTRACTION SYSTEM AND LATTICE

The geometry and optical lattice of the extraction system design[4] are influenced by the desire to accomplish extraction without significantly perturbing the optics of the linac. This will be conducive to the operation of interlaced beams and to switching operating modes between SLC, beams for fixed target experiments, and the PEP-II studies.

The extraction lattice has a phase advance of 90° per cell. Extraction dipoles are placed in pairs having equal but opposing bends, and are separated by four cells or 360° in phase advance. The extracted beam is thus made to be parallel to, but offset from, the linac beam, and the induced dispersion is suppressed overall.

Figure 2 shows the optical functions of the beam line and Fig. 3 is a schematic of its components. Four regions are indicated. The first, Region I, where the beam is dispersed, will be used for measurements pertaining to the beam energy. Also in this region, capability is provided to correct errors in the dispersion without modifying the overall monoenergetic parameters (i. e., beta and alpha functions).

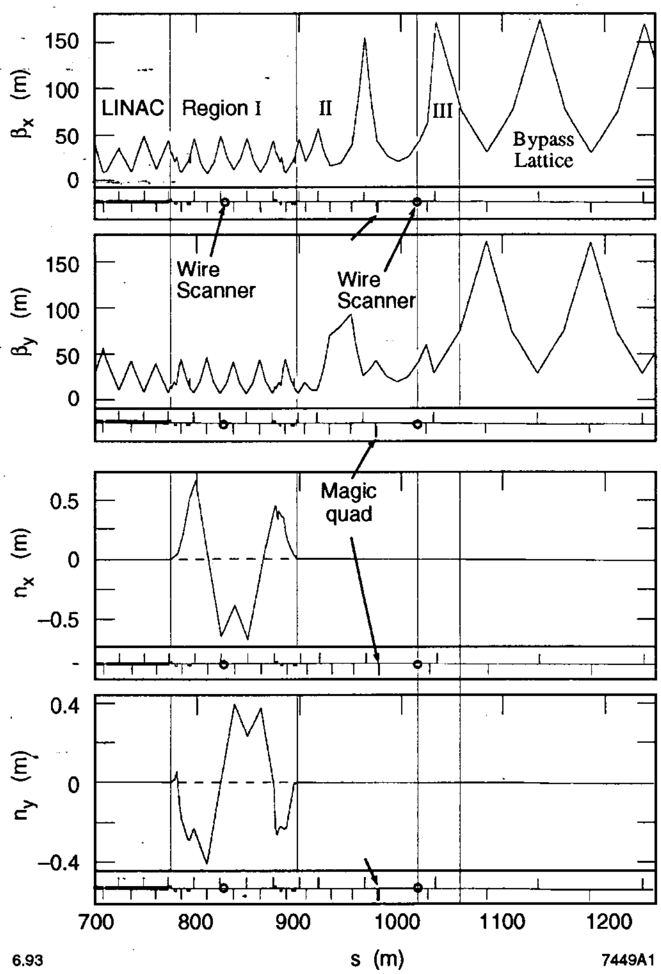

Fig. 2. Machine function for the PEP-II, 9 GeV electron beam extraction system.

Region II provides the facility to correct the errors in these latter parameters, but again in an orthogonal manner, that is, without changing the dispersion. This region is equipped with a wire scanner and a single "magic" quadrupole[5] (see below) for the purpose of measuring beta, alpha and the emittance of the beam in each plane. Region III is a matching section which matches the linac lattice to the Bypass lattice.

Finally, the first two cells of the Bypass lattice are represented in the last region, which can be continued by repeating this lattice until the end of the linac housing is reached, and the beam line is connected to the existing north PEP transport line going to the ring housing. The Bypass lattice also has a phase advance of 90° per cell with the cell length designed so that there is one cell per linac sector. This short section of Bypass line is terminated by a beam dump and can be extended at a later time.

IV. EXTRACTION LINE BEAM-POSITION MONITORS

Every quadrupole in the extraction system, and in the subsequent transport lines, will be equipped with a beam-position monitor (BPM) capable of measuring beam position in the x- and y-plane, but only one coordinate will be measured from each instrument. A measurement of the orbit—at 90° intervals in phase advance—throughout the dispersive and non-dispersive regions will allow separation of betatron oscillations from energy dependent effects. These latter changes in position due to energy will be monitored by a feedback system to hold the energy constant.

Because of their importance to the beam parameter measurements and their relatively large number and cost, the BPMs must be engineered very carefully. In the linac housing, wherever possible, two cables (for x or y) will be run from each new BPM to a nearby existing linac BPM to which they will be coupled with ~10 dB loss couplers. This multiplexing, which is already being used for the existing Positron Return Line in the linac housing, will save greatly on the cost.

The position resolution of the extraction and transport line BPMs is determined by the need to steer the beam through apertures and to match it to the acceptance[6] in position, angle and energy of PEP-II. If the BPM resolution is better than the beam σ_x and σ_y everywhere in the extraction and transport line, then the beam position will be known well enough with respect to their apertures. The minimum β_x or β_y of the β–function maxima (where the BPMs will be used) is ~40 meters. For a beam emittance of 2.5×10^{-9} m · rad, this minimum size corresponds to a σ of 0.3 mm. The closest (in mm) object to the injected beam is a PEP-II septum at 3.5 mm (~10 σ_y). The PEP-II energy acceptance is ±.5%. This corresponds to ±2 mm position resolution in x in the dispersive region (η_x ~ 0.4 meters) at the beginning of the extraction line where the beam energy will be stabilized by the feedback loop. An easily attainable resolution of 100 µm for all BPM position measurements will be comfortably less than these minimum σs. This specification of a 100 µm resolution

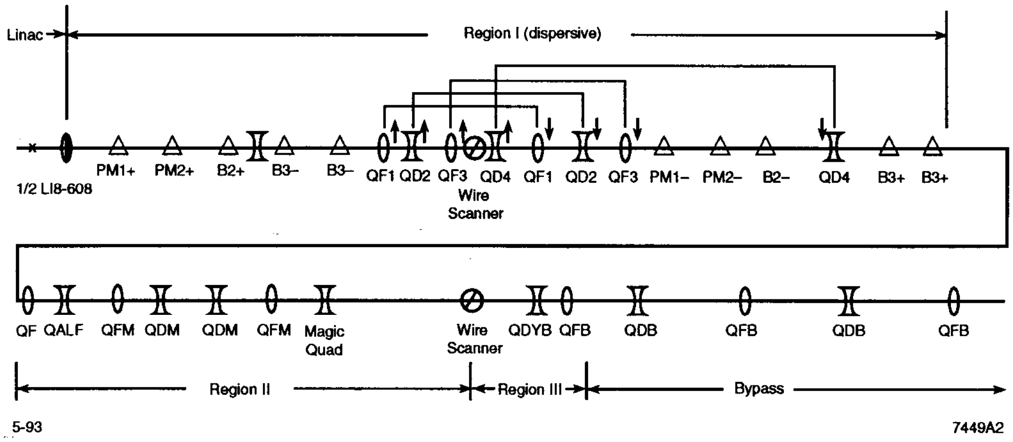

Fig. 3. Schematic of optical components for electron extractor system.

will apply for a pulse of 1×10^9 electrons, a value representing the smallest quantum of charge that is planned to be injected.

V. MEASUREMENT AND ADJUSTMENT OF BEAM PARAMETERS

As mentioned above, the parameters of the extracted electron beam will be measured and adjusted in the first two regions shown in Figs. 2 and 3.

In Region I, where the dispersion is maximum, it contributes as much as 15 times the monochromatic beam size ($\sqrt{\beta\varepsilon}$). A wire scanner, located at a point of almost maximum and equal dispersion in both x and y, will be used to measure the energy distribution. The expected scanner accuracy is ~50 μm and the beam size from dispersion is ~2500 μm. Thus ΔE will be measured to ±2%, and ΔE/E to about ±0.01%, assuming an incoming beam spectrum of ±.5%.

As shown in Fig. 3, in Region I there are four pairs of quadrupoles (180° per cell apart in each pair) which are used to correct for errors in the dispersion. By changing the strength of these quadrupoles in each pair equally but in opposite direction, it is possible to eliminate the anomalous residual dispersion at all points in the dispersion-free Region II downstream. This scheme has the virtue of leaving β–functions unchanged in the downstream region, eliminating the need for retuning.

In Region II a second wire scanner and a single quadrupole are used to measure the emittance and Twiss parameters of the beam. This quadrupole is called magic because, unlike the behavior normally associated with quadrupoles, it does not change the shape of the beam which for equal (unequal) emittance in both planes will always be round (flat). Thus, at its nominal setting the beam is round (flat) and a minimum in size; it will stay round (flat) but become larger for any change of the quadrupole strength in either direction. This allows measurement of the size of the beam about its minimum in both planes simultaneously with reasonable changes in quadrupole strength.

The quadrupoles in the dispersion-free Region II will be independently controlled to provide the capability of correcting the Twiss parameters, and matching the proper conditions for launch into the Bypass lattice.

The addition of instrumentation for measurement of beam charge and timing will complete the instrumentation. The controls will be provided by utilizing the existing SLC control system and its application programs.

VI. CONCLUSION

The proposed electron extraction system will be capable of measuring all beam parameters important to the development of an injection system for the PEP-II asymmetric collider. Modifications to the linac and its operations will be quite modest.

REFERENCES

[1] E. Bloom et al., "A Critical Examination of the PEP-II Injection System and Alternative Proposals." SLAC–PEP–II–AP–NOTE–1–92, Sept. 1992.

[2] LBL–PUB–5303, SLAC-372, CALT–68–1715, UCRL–ID–106426, UC–IIRPA–91–01 (1991).

[3] E. Bloom et al., "The Proposed Injection System for an Asymmetric B Factory in the PEP Tunnel." *Proc. of IEEE Particle Accelerator Conference*, San Francisco, CA, Vol. 2, p. 982, (1991), SLAC–PUB–5771 (1991).

[4] T. Fieguth et al., "Injection System for the PEP-II Asymmetric B Factory at SLAC," *Proc. of Third European Particle Accelerator Conference*, Berlin, Germany, Vol. 2, p.1443 (1992), SLAC–PUB–5771 (1992).

[5] T. Fieguth, "Comments on Optics for Electron Extraction," PEP-II Technical Note No.12, May 1993.

[6] F. Bulos et al., "Optimizing the Injection Straight of PEP-II Asymmetric B Factory at SLAC," contributed to the *International Conference on B Factories,* Stanford, CA, April 1992, SLAC–PUB–5800 (1992).