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Injection System for the PEP II Asymmetric B Factory at SLAC*

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Abstract

The asymmetric energy B Factory proposed as an upgrade of PEP at Stanford Linear Accelerator Center will require a highly reliable and efficient injection system. The conceptual design[1] has shown the feasibility of extracting 9 GeV electrons and 3.1 GeV positrons from the existing linac and injecting equal charges into 1658 buckets in each of the two rings of the collider. An injection study group has continued the development and study of this proposal and has generated workable designs for many related systems and subsystems.

1. INTRODUCTION

A key feature in the design of a B Factory is the need for a powerful injector. Fortunately, at SLAC a powerful source of low emittance high energy positrons and electrons already exists. The SLC linac, including its damping rings and positron source, is ideal for this purpose. Approximately two-thirds of the linac will be used with a few modifications and simplifications. The goal is to top off both rings about once per hour, completing the cycle for both rings in about 3 minutes (see Table 1). Practical designs exist for nearly all the positron transport system, including extraction, optical matching, bypass line and interface matching to the SIT beamline (see Fig. 1). Magnet and vacuum design is underway and a practical injection optics for the rings including septum magnets and vacuum chambers is well advanced. The system of collimators for protecting the detector from particles lost during injection is understood and being specified.

As illustrated in Fig. 1, positrons will be extracted from the linac near the beginning of Sector 4 and electrons near the beginning of Sector 8. After extraction, each beam will traverse the length (>2 km) of a respective bypass line connecting at the downstream end to the existing NIT or SIT line, to be transported to the injection point of its proper ring.

Table 1. Selected B Factory 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)	1.48/6777	[A/10^{10} e^-]
Low-energy ring (LER)	2.14/9799	[A/10^{10} e^+]
Particles per bunch		
High-energy ring (HER)	4.1	[10^{10} e^-]
Low-energy ring (LER)	5.9	[10^{10} e^+]
Linac repetition rate	60 or 120	[pps]
Linac current	0.4–2	[10^{10} $e^\pm$ / pulse][a]
Invariant linac emittance	5×10^{-5}	[m·rad]
Normal filling time		
Topping-off (80–100%)	3	[min]
Filling time (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	37	[ms]
Nominal beam emittance		
HER, horizontal/vertical	48/1.9	[nm·rad][c]
LER, horizontal/vertical	96/3.8	[nm·rad][c]

[a] Assuming 50% filling efficiency. The SLC routinely delivers 2.5×10^{10} $e^\pm$ per linac pulse.

[b] For filling the rings are divided into nine equal zones. A 5% gap leaves one zone partially unfilled.

[c] Unnormalized, or geometrical, values.

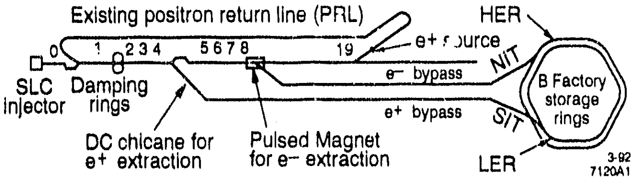

Fig. 1. Schematic of the B Factory $e^\pm$ injection system, using the SLC linac and added bypass lines.

The operation of the linac for filling the B Factory has been simplified vis-à-vis SLC operation. On one 60-pps time slot a positron bunch and an electron bunch are extracted from their respective damping rings. Both bunches are accelerated in Sectors 2 and 3. The 3.1 GeV positrons are extracted in Sector 4 and transported to the LER while the electrons continue to be accelerated to 30 GeV and are used to generate a new positron bunch at Sector 19. These low energy (200 MeV) positrons are returned to Sector 1 via the Positron Return Line (PRL), accelerated to 1.2 GeV and stored in the damping ring for about 16 ms when the sequence starts again.

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Interlaced with this sequence at 60 Hz is the generation, damping and acceleration of the 9 GeV electron beam for the HER. Only one electron bunch is in the damping ring at a time, which considerably eases extraction compared with present SLC operation. A slow (milliseconds) pulsed magnet at Sector 8 is used to extract the electrons for HER. Sectors 9 through 19 run at 60 pps and Sectors 1 through 8 run at 120 pps.

2. EXTRACTION AND TRANSPORT TO NIT AND SIT

Figure 2 shows the beta functions for the positron extraction, bypass lines and its connection to the existing SIT.

The designs of both extraction regions provide a match to the linac lattice, remove dispersion from extraction dipoles, provide monitoring and feedback control of the extracted beam energy and an optical match to the bypass lines. This is accomplished with the minimum of disturbance to the present linac structures and would permit early installation of some injection hardware with the possibility of early beam tests.

Desired control of the extraction optics is served by the simple expedient of using an optical continuation of the linac lattice and adjusting the phase advance per cell to be exactly 90° in both planes (the phase advance in the linac is nominally 76.5°). The extraction dipoles are placed in pairs (two dipoles of opposite polarity) at points separated by an optical transfer matrix equal to the identity, thus controlling dispersion. Two pairs are required in each region to obtain the desired geometry and clear existing linac components.

The positrons at Sector 4 are extracted using a chicane of DC magnets. The electrons undergo a local bump in the chicane and return to the linac. At Sector 8 the electron extraction is initiated by two pulsed magnets each bending 0.25°. These magnets exist and were used for extracting PEP beams.

The energy resolution in the dispersive regions is approximately 1×10^{-3}, matching the specification for the feedback system. Following the dispersive region is a dispersion-free region which will be used for beam diagnostics and for operational tuning to match into the bypass line. Next is a short matching section, where four quadrupoles are used to match the beta functions to those of the bypass line optics.

The bypass lines are FODO arrays with exactly one cell per linac sector (L_{cell} = 101.6 m) and a phase advance per cell of 76.5°. With these determined, $\beta_{\max}$ = 169 m and $\beta_{\min}$ = 40 m, as shown in Fig. 2. The focal length is 41 meters, which requires only about 0.25 T of integrated gradient at 3.1 GeV.

These low-strength quadrupoles are suspended from the ceiling of the linac housing. At each quadrupole there is a beam position monitor (BPM) measuring either the horizontal or vertical position and one steering dipole steering the beam in that same plane. Thus, each corrector is located at a maximum of beta with a phase advance between like correctors equal to that for one cell (76.5°).

The apertures of the bypass quadrupoles will be 1-in but the intervening vacuum chambers will be fabricated from 4-in.-diameter seamless stainless steel tubing to provide the pumping conductance.

Matching to NIT and SIT

The existing NIT and SIT transport lines which now bring electrons and positrons to PEP are more than adequate for the B Factory. To take advantage of this, a point near the beginning of each was chosen where all of the 14 optical and geometrical parameters could be matched thus requiring no modification downstream. This has been accomplished.

3. INJECTION INTO HER AND LER

Injection into both rings will occur in the vertical plane. The most important reason for this choice is that it most effectively reduces the parasitic beam-beam forces (beams passing but not at IP) which can cause beam blow up[2].

The injection scheme illustrated in Fig. 3 employs two identical fast pulsed kickers (~1.5 μs) which generate a fast closed bump, four DC dipoles for a slow closed bump, and two other magnets, a Lambertson septum and a current sheet septum magnet, for bringing the injected beam near the bumped stored beam. Injection occurs at the center of a split quadrupole where the stored beam is at a waist with a β_y of

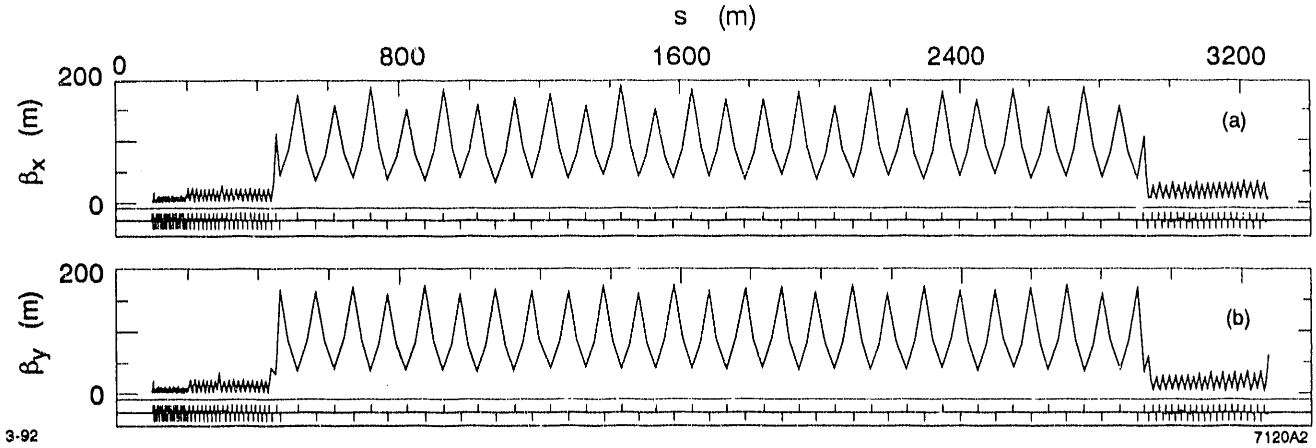

Fig. 2. Optics for the positron extraction, bypass line, connection to SIT and SIT (dispersion not shown).

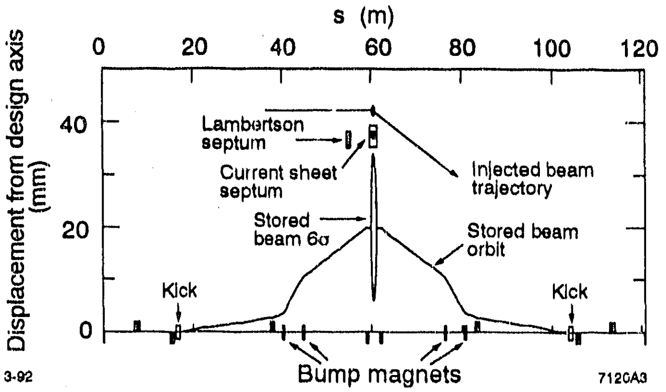

Fig. 3. Stored beam orbit during injection into HER. Applies also to LER with a change of scale.

215 m. Our studies have shown that this maximizes the acceptance for the injected beam. Most of the other injection optical components are placed with mirror symmetry about this injection point. The fast kickers are symmetrically placed and separated by a π phase advance. Thus the orbit of the closed bump is maximum at the injection point and, since the kickers are identical, the bump is closed for all bunches included in the envelope of the pulse. The DC magnets are turned off for coasting beams allowing a larger Beam Stay Clear (BSC). This design meets the established design criteria for the worst case *fully coupled vertical emittance* which are:

- The BSC for the coasting beam must be $\geq 12\sigma + 5$ mm.
- The BSC for the DC bump only must be $\geq 10\sigma$
- The BSC for the combined bumps must be $\geq 6\sigma$

Chromatic Correction

Electron-positron storage ring colliders with low-beta insertions have chromatic aberrations that are dominated by the chromatic effects of the insertion quadrupoles. In correcting these aberrations, particular importance is given to correcting the linear variation of the beta functions with momentum at the interaction point (this also helps in the correction of the quadratic component of the tune variation with momentum). At the same time, to obtain good injection efficiency with a wide enough momentum acceptance the functions[3]

$$B = W\cos(\phi) = \frac{d\beta / \beta}{d\delta}$$

$$A = W\sin(\phi) = \frac{d\alpha}{d\delta} - \alpha\frac{d\beta / \beta}{d\delta}$$

should also be made small at the point of injection, otherwise the phase space ellipses (representing an acceptance within the Beam Stay Clear of the machine) for different momenta will not overlap sufficiently to accept off-momentum injected particles.

Figure 4 shows the phase space (in the vertical plane) at the injection point for the High Energy Ring. Correction of the W function was accomplished by using the HARMON module in the computer program MAD. Chromatic correction of the collision insertion is done in the two adjacent arcs, the A and B functions then oscillate with small amplitude throughout the remainder of the ring and are insensitive to small changes such as a change of ring tune. The magnitude of the oscillation is small since it is due solely to the smooth chromaticity and smooth correction in the remainder of the ring.

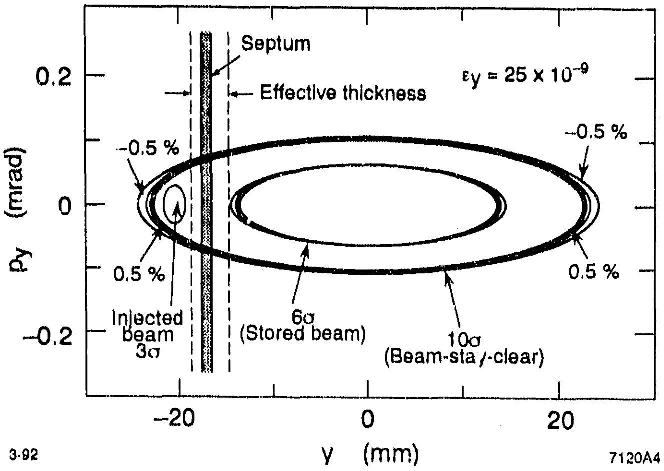

Fig. 4. Phase space diagram of injection acceptance for HER after chromatic correction.

4. GRADED APERTURE COLLIMATION

In order to protect the detector during injection and stored beam operation, the rings will be provided with a series of collimators between the point of injection and the IR. Their purpose will be to intercept particles with too large an energy deviation or with too large an amplitude betatron oscillation. Table 2 lists the apertures of the injection septa, collimator sets and the IR. Collimators 1 and 2 have the smallest apertures in the rings, and the aperture increases (is graded) in collimator 3 and the IR as the detector is approached. Collimator 3 is intended to catch any spray from 1 and 2. Collimator 1 is placed where the horizontal dispersion is high, and provides a dp/p=±0.9% momentum window for injection and a safe dump for the stored beam in case of RF or other failures. Collimator 2 is placed where the dispersion is zero and bounds the horizontal (and vertical) 10 sigma phase space ellipse with a hexagon such that all points on a >11.6 sigma ellipses hit the collimator.

Table 2 Collimator properties.

	Aperture	Horizontal Col		Vertical Col.	
		No.	Ph. adv.	No.	Ph. adv.
Inject	$12\sigma + 5$ mm	—	—	–	—
Col.1	10σ	2	90°	–	—
Col. 2	10σ	3	60°	3	60°
Col. 3	12σ	3	60°	3	60°
IR	$15\sigma +$ [illegible] mm	—	—	–	—

5. REFERENCES

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

[2] Yong Ho Chin, LBL-31434, ESG Note-158, ABC-51(1992)

[3] B. W. Montague, Linear Optics for Improved Chromaticity Correction. LEP Note 165, CERN, 1979.

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