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THE PEP INJECTION SYSTEM*

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Summary

A system to transport 10-to-15-GeV electron and positron beams from the Stanford Linear Accelerator and to inject them into the PEP storage ring under a wide variety of lattice configurations has been designed. Optically, the transport line consists of three 360° phase-shift sections of FODO lattice, with bending magnets interspersed in such a way as to provide achromaticity, convenience in energy and emittance definition, and independent tuning of the various optical parameters for matching into the ring. The last 360° of phase shift has 88 milliradians of bend in a vertical plane and deposits the beam at the injection septum via a Lambertson magnet. Injection is accomplished by launching the beam with several centimeters of radial betatron amplitude in a fast bump provided by a triad of pulsed kicker magnets. Radiation damping reduces the collective amplitude quickly enough to allow injection at a high repetition rate.

PEP Injection Specifications

The calculated nominal momentum acceptance of the ring is $\pm$ 0.5 percent $\frac{\Delta p}{p}$ at all energies. The emmittance of the SLAC positron beam is expected to be of the order of 0.3π mm mr at 10 GeV, decreasing as $1/E$. The emittance of the electron beam is typically an order of magnitude less than this. Both are well within the acceptance of the ring.

Based on the above specifications, the proposed injection system has been designed to transmit a momentum pass band of up to $\pm$ 0.8 percent $\frac{\Delta p}{p}$ with a momentum resolution of at least $\pm$ 0.3 percent. With these specifications on the momentum pass band, the monoenergetic emittance of the SLAC linac is easily transmitted and poses no particular problem. The magnet apertures are thus dominated by the momentum passband and resolution requirements.

Description of the Beam Transport System

Because of cost considerations and the relatively modest momentum resolution demanded of the system, a simple periodic FODO array of identical quadrupoles with interspersed bending magnets has been selected as the basis for the design of the beam transport system. The spacing, ℓ, between quadrupoles and the total angle of the bend, combined with the required momentum pass band, uniquely determine the horizontal magnet apertures. The transmitted monoenergetic emittance of the beam determines the vertical aperture requirements. The tentative apertures selected are $\pm$ 25 mm for the "good" field region of the quadrupoles and a total effective bending magnet gap of 25 mm.

For the periodic FODO quadrupole array, the phase shift per unit cell distance of 2ℓ is chosen to be 90°. Thus it follows that the monoenergetic matrix transformation between any two positions, separated by a distance of 4ℓ is -I (minus unity). Because of this, each 360° segment of the system will be achromatic if for every $\Delta\alpha$ of bend angle inserted at position s there is an equal $\Delta\alpha$ of bend inserted at position $(s + 4\ell)$.

The proposed design is illustrated in Fig. 1. The total system consists of three 360° achromatic segments, the first two bending in the "horizontal" plane and the last in the vertical plane. The plane of the "horizontal" segments is rolled 6.04° about the initial SLAC beam axis to match the lower elevation of the ring. The distribution of bending magnets has been selected for practical reasons consistent with the above rule for achromaticity. The bending magnets in the first two segments are distributed as shown because of two dominant considerations; first there are "missing" magnets to simplify transporting the beam through existing SLAC concrete walls, and second, the first and second achromatic segments are placed in mirror symmetry so as to provide five quadrupoles (Q6 through Q10) in the achromatic region between the two segments to adjust the monoenergetic beam phase ellipses to match the various PEP injection configurations. In addition, two appropriate quadrupoles in the second 360° segment, separated by a -I transformation, are varied in the opposing sense so as to vary η' at the injection point without disturbing the monoenergetic phase space configurations.

The last 360° achromatic segment bends the beam vertically a total of 88 milliradians and deposits it at the ring injection position via a Lambertson septum magnet.

The Injection Process

The injection process whereby the electron or positron beam from the linear accelerator is trapped in the PEP storage ring has two steps as illustrated in Fig. 2 and 3: (1) a launch into a large-amplitude betatron oscillation about a stable orbit in the ring, followed by (2) a slow damping of that oscillation down to a small-amplitude, equilibrium distribution.

The entering beam is deflected horizontally by a pulsed "kicker" magnet (Kicker Magnet 3) onto an orbit in which it can safely circulate within the vacuum chamber with a radial collective betatron oscillation of 2 or 3 cm amplitude, depending on the lattice configuration in use. In order to compensate the effect of this kicker magnet on the local beam already stored in the ring, it is made part of a triad of pulsed magnets (Kickers 1, 2, and 3) whose function is to distort, or "bump", the local closed orbit at the time of injection as illustrated in Fig. 2. The amplitude of the bump required is the sum of the width of the injected beam (including dispersion effects) plus the septum width and a small allowance for clearance; the sum typically running 1 to 2 cm. In this system the septum separating the external path of the entering beam from the internal orbits is the thin conductor which terminates the field of Kicker Magnet 2. The beam enters the ring vacuum through a foil window that is on the <u>inner</u> radius of the ring in order to protect it from the intense synchrotron radiation. In the vertical plane, the beam is centered and phase-space matched.

While the beam circulates, the synchrotron radiation process continuously damps the beam dimensions and also the energy spread toward an equilibrium

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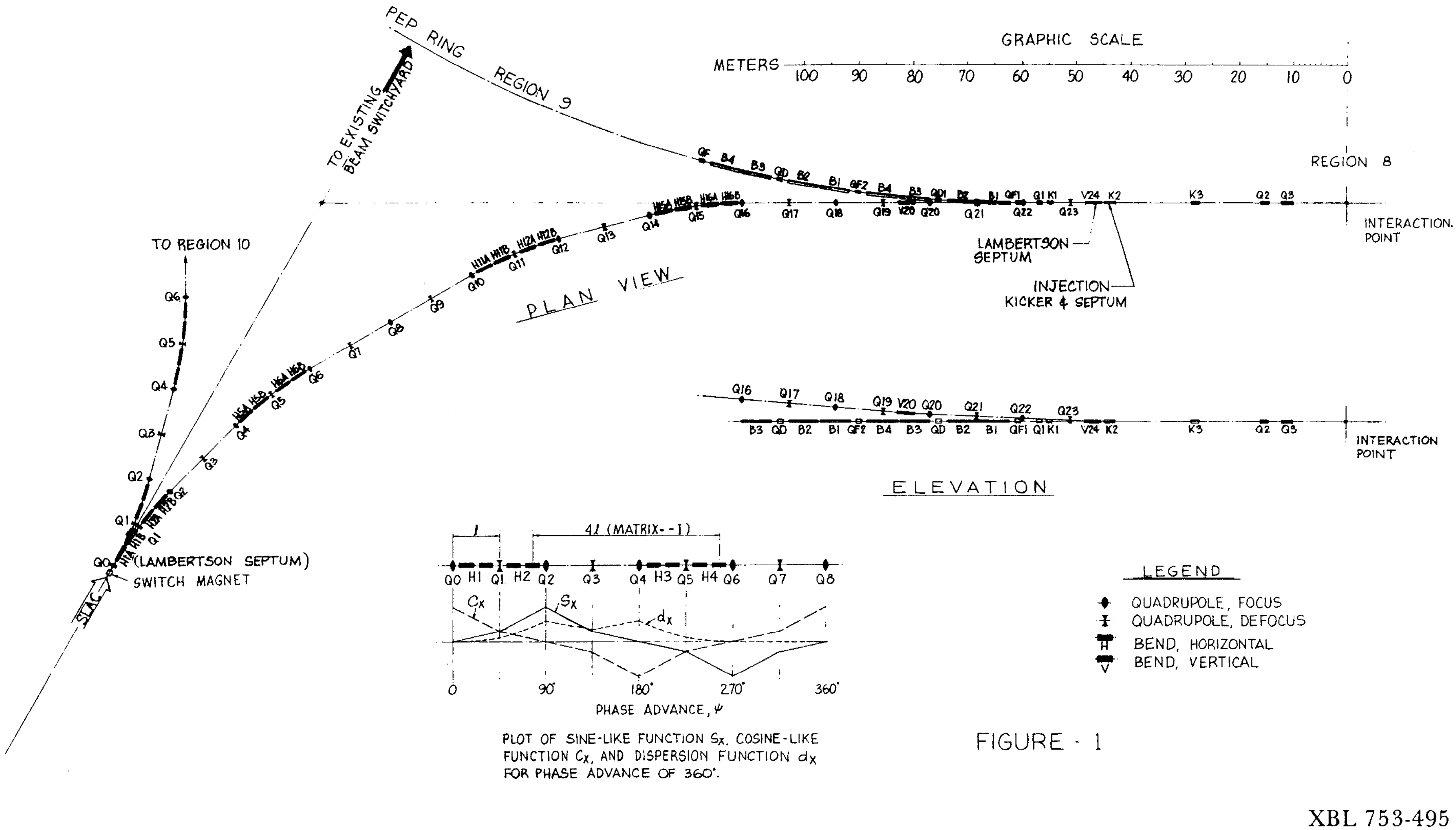

FIG. 1 The Beam Transport System for Injection into PEP.

distribution determined by quantum fluctuations. This radiation process allows each injected pulse of particles eventually to be deposited in a volume of phase space already occupied by previously stored bunches and thus avoids the limitation of constant phase-space density (Liouville's Theorem) common in proton machines. Also, it is a "forgiving" process in the sense that deliberate or accidental variations in the injection procedure do not affect the final equilibrium beam distribution.

In order to minimize the loading time, the radiation damping time constants should be comparable to or shorter than the feeding interval from the SLAC linac, which is 8.33 milliseconds, if the three bunches in the PEP ring are fed in consecutive, rotating order. The radiation damping time constants vary as E^{-3}; the time constant for transverse betatron oscillations is about 8 ms at 15 GeV, 28 ms at 10 GeV, and 225 ms at 5 GeV in the PEP ring. Because of this rapid variation of the damping time with beam energy, and since some tens of thousands of pulses from the linac typically will be needed to fill the PEP ring, the injection energy will be limited probably to energies of 10 GeV or higher. Precise timing and energy definition are required for successful injection. Each injected pulse of 10^8 positrons (or 10^9 electrons) is about 1.05 nanoseconds in length (consisting of four S-band pulses) and has ± 0.5% energy spread. These dimensions just fit within a typical RF bucket in the PEP ring. Furthermore, each injected pulse must be placed in a specific RF bucket, one of three in use (out of a total of 2,592 in the ring).

Acknowledgement

The injection process discussed here is essentially that described by G. E. Fischer (unpublished PEP Note 84, March 1974) and presently used for the SPEAR ring.

Frank Rothacker is responsible for making all of the computer runs used in the design studies to date.

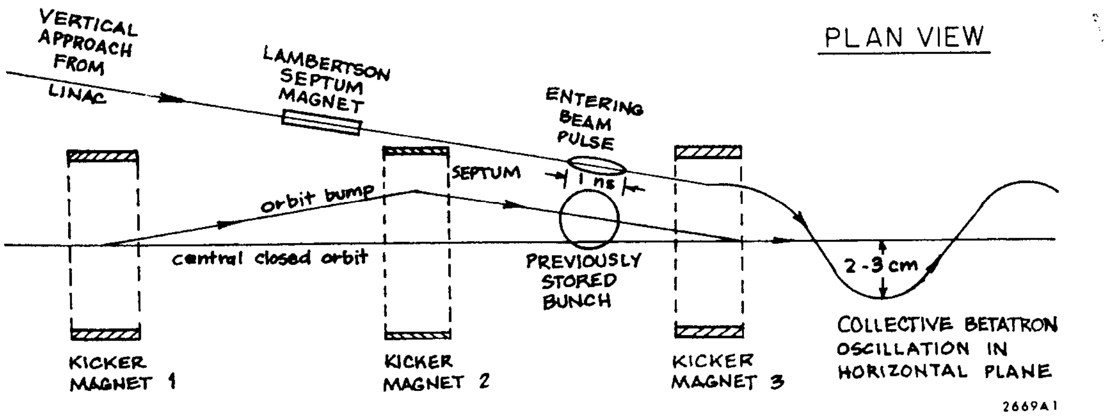

FIG. 2 INJECTION SYSTEM SCHEMATIC

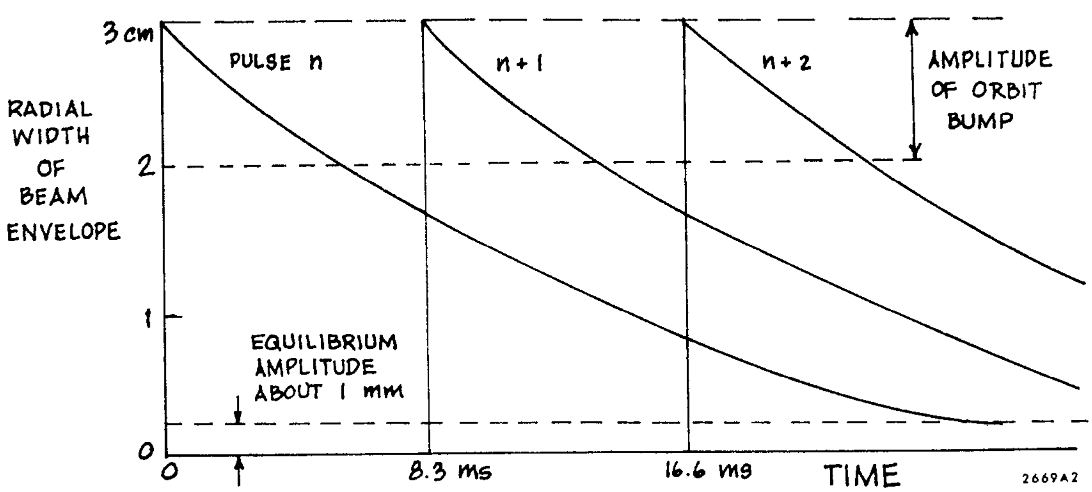

FIG. 3 RADIATION DAMPING OF BEAM ENVELOPE AFTER INJECTION OF SEVERAL BEAM PULSES.