

Design of Beam Transfer Line and Injection System of Pohang Light Source*

In Soo Ko and M. Yoon
Pohang Accelerator Laboratory/POSTECH
Pohang, Korea 790-600

Abstract

The 2 GeV electron (or positron) beam provided by full energy linac is injected into the storage ring after passing about 100 m long beam transfer line. Since the linac is located outside and 6 m below the ring, the injecting beam is approached to the ring in the vertical plane by Lambertson magnet. Prior to the injection, the orbit of stored beam is deflected toward the septum by using four bump magnets. The injection rate is 10 Hz.

I. Introduction

The injection system of 2 GeV Pohang Light Source (PLS) is a full energy linear accelerator. This 150 meter-long linac is placed at the underground tunnel located 6 meters below the ground level in order to achieve enough shielding at the klystron gallery. The storage ring (SR) is placed on the ground level. The electron beam path is located 1.4 meter above the floor for both linac and storage ring, so the vertical distance of beam paths remains 6 meters. Major change after conceptual design report [1] published January 1990 is that the injection of storage ring is taken place in vertical plane by Lambertson magnet instead of horizontal plane. This vertical injection scheme saves about 45 meters of beam transfer line from previous design. It is also very important that the design and the manufacturing of thin and thick septa and their vacuum chambers are avoided.

The normalized emittance for the electron beam of the linac is $0.015 \pi \text{ MeV}/c \text{ cm rad}$. It corresponds the emittance at 2 GeV is $7.5 \times 10^{-8} \pi \text{ m rad}$. The energy spread of the electron beam is $\pm 0.6\%$ at FWHM. The above values are, in fact, measured at BEPC and found to be well in agreement with the calculation.

II. Beam Transfer Line

The beam transfer line (BTL) provides a dispersion-free, focused beam that is matched to the displaced storage ring

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acceptance. The BTL consists of three major sections: vertical section, horizontal section, and linac-side section. The horizontal section is bent by 20 degree from the direction of linac. The electron beam goes to the beam dump straightforwardly when the linac is commissioning or testing. Two 10 degree bending magnets and one quadrupole between them are used to form an achromatic section so there is no horizontal dispersion beyond this section. There are 6 quadrupole pairs in the dispersion free space.

The vertical section is made of three vertical bending magnet and a Lambertson magnet, so all the bending is taken place in the vertical plane. The bending angle of these magnets is 8 degrees. The two vertical magnets are formed an achromatic section like the horizontal section with one quadrupole. Another achromatic section is by the Lambertson magnet and nearest vertical bending magnet. In the latter case, two quadrupoles are used instead of one. There are four quadrupoles placed in the dispersion-free space in the vertical section. These quadrupoles are used to match beta and alpha functions at the injection point.

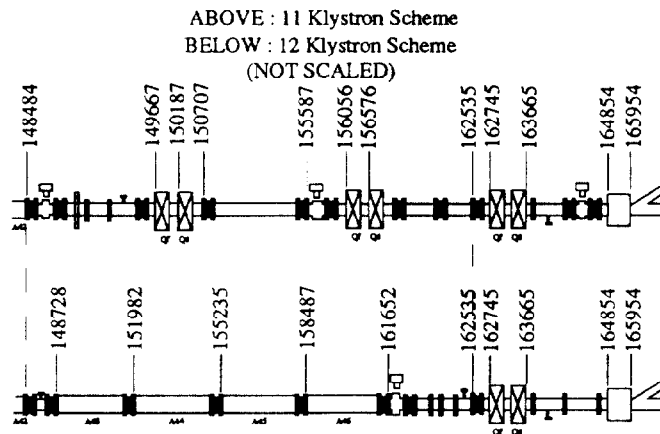


Figure 1. Linac-side BTL. The elements between lines can be replaced for future upgrade.

The linac-side section is shown in Figure 1. Most of this drift section is actually the reserved space for future upgrade of the linac. The distance between the end of

42nd accelerating column and the 3rd quadrupole pair is about 14 meters. Four accelerating column will be located in this space when the future upgrade is necessary. This layout provides minimum effort and material loss in case of future upgrade.

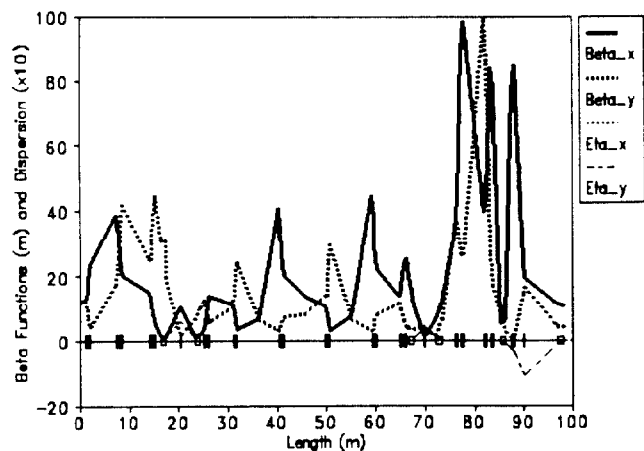


Figure 2. Beta functions and dispersions for BTL lattice.

The lattice functions and the beam envelopes are shown in Figures 2 and 3. Maximum beta function and dispersion are roughly 100 m and 1 m, respectively. The beam envelope is within 8 mm for the electron. Since the positron injection is one of future options, the positron beam is also considered. In this case, the emittance of positron is assumed to be $7.5 \times 10^{-7} \pi$ m rad and the maximum beam envelope is about 8 mm.

Table 1. PLS Beam Transfer Line Magnets

Type	Length (m)	Bending Angle	Strength	Units
Bend (H)	1.1	10°	1.0582 T	2
Bend (V)	1.1	8°	0.8465 T	3
Lambertson Septum	1.17	8°	0.8 T	1
Quad	0.4		13 T/m	26

The information of BTL magnet is summarized in Table 1. Maximum quadrupole strength is 13 T/m. BTL vacuum chamber will be made by simple stainless tube. Its outer diameter is 50 mm and, thus, the pole gap of the bending magnet and the aperture of quadrupole are 54 mm.

III. Injection into Storage Ring

A. Bumped Orbit

The length of the injection straight is 6.8 meters. Along this straight, we place four bump magnets and one Lambertson magnet, a typical arrangement for the off-axis, vertical injection scheme. The electron beam passing the last vertical bending magnet is in parallel in horizontal direction with the storage ring bump orbit and it is injected with 8 degrees vertically. The Lambertson magnet then bends this beam by -8 degrees vertically to make it on the same level with the bumped orbit. The schematic diagram of this vertical injection scheme is shown in Figure 4. Here we take the bumped orbit to be 21 mm. This particular value was chosen by considering the injection system hardware arrangement (i.e. space requirement) as well as the good field region requirement for the bump magnets and the storage ring quadrupole magnet.

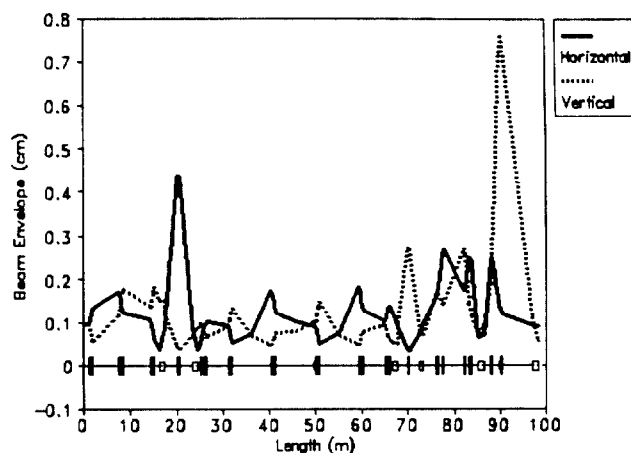


Figure 3. Beam envelopes for BTL. The momentum spread is assumed to be 0.6%.

The clearance between the center of the bumped orbit to the storage ring vacuum chamber is taken to be 4 mm at the position of the Lambertson magnet. Therefore, the physical aperture at this point is 25 mm from the center of the stored beam. This location of the chamber wall seems to be reasonable considering the reduction in dynamic aperture due to various errors in the ring.

The coherent betatron oscillation amplitude, the distance between the center of the bumped orbit to the edge of the injected orbit, was chosen to be 15 mm. This means that the horizontal good field region of the bump magnet should be ± 36 mm because the good field region of the bump magnet has to include the injected beam from the beam transfer line. In the vertical direction, the good field region of the bump magnet is taken to be ± 9 mm.

Unlike thin or thick septum, the septum wall of the Lambertson magnet is located in the air, so the vacuum chamber thickness of both BTL and SR must be included for

the effective septum thickness. The effective thickness is 4 mm including gaps between chambers and the Lambertson magnets. Figure 5 shows this thickness and other dimensions at the injection point.

The horizontal phase space acceptance of the storage ring is given by

$$A_x = \frac{(x_b + 4\sigma_o)^2}{\beta_{x_o}},$$

where x_b is the bumped orbit ($=21\text{mm}$) and σ_o is the *rms* value of the horizontal beam size at the injection point which is 0.387 mm. β_{x_o} is the horizontal beta function at the injection point (≈ 10 m). Substituting these values yields $A_x = 50$ mm mrad which is sufficient to accept the injected beam. In the vertical direction, the acceptance is $A_y = 40$ mm mrad.

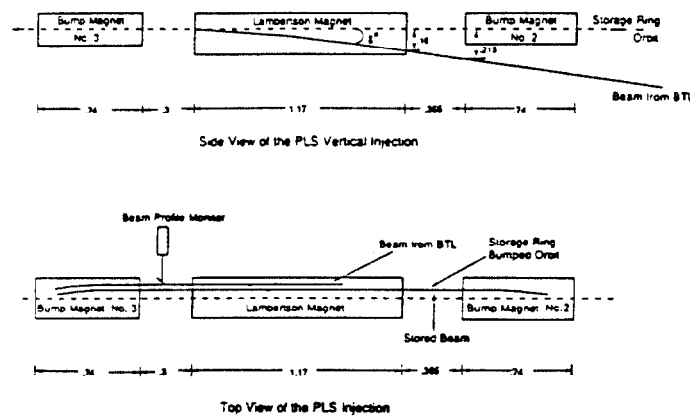


Figure 4. Schematic diagram of vertical injection.

B. Injection Hardware

The required magnitude of the kick for 4 bump magnets is obtained from

$$x_b = L \times \tan \left(\frac{B_b l_b}{B\rho} \right),$$

where L is the distance between the centers of the first two bump magnets. B_b and l_b are the magnetic field and the length of the bump magnet, respectively. $B\rho$ is the usual magnetic rigidity in Tesla-meter which is 6.67 for a 2 GeV electron. By taking 0.74 m for the effective length of the bump magnet and 1.26 m for L , the required magnetic field for a bump magnet to produce 21 mm bumped orbit is found to be 1.5 kG at 2 GeV. The kick angle of the bump magnet is then 16.64 mrad.

The bump magnet is operated with 10 Hz repetition rate. Therefore, the pulse to pulse separation is 100 msec which is about 6 damping times of the storage ring. The excitation of the bump magnet has a 4 μsec half-sine waveform so the rise and fall time are respectively 2 μsec . Thus,

the injected beam will restore the original stored orbit in less than three orbital turns (the revolution time of the storage ring beam is 0.94 μsec).

For bump magnet power supply, the required peak current is 4,775 A when the gap height of the bump magnet is 40 mm and the required peak voltage per each magnet is 8.33 kV.

The Lambertson magnet is 1.17-m long and the maximum field is 8 kG. Since the bending angle of the Lambertson magnet is 8 degrees, the distance between the stored beam orbit and the injecting beam path is 16 cm at the entrance of the Lambertson magnet and 21.5 cm at the nearest bump magnet. Thus the bottom of this bump magnet must clear the BTL vacuum chamber. In the drift space located at the downstream, the injected beam profile can be measured by using a destructive profile monitor. The enclosure for the placement of this monitor will be kept at low vacuum. The BTL vacuum and the storage ring vacuum will be separated by thin foils at this low vacuum enclosure.

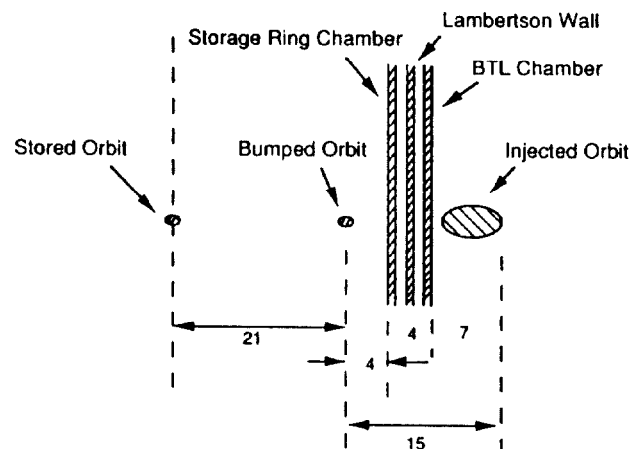


Figure 5. Schematic diagram of cross section at the injection point.

Four photon stoppers are allocated in order to prevent the photon beam from hitting the ceramic vacuum chamber walls of the bump magnet. A number of smooth transition pieces are also placed between various vacuum chambers in order to reduce the RF impedance seen by a beam. Two pneumatic gate valves are placed at each side of the straight section to separate the remaining storage ring section from injection region.

IV. References

1. Conceptual Design Report of Pohang Light Source, January 1990, POSTECH.