Injection Dynamics of the Pohang Light Source Storage Ring

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Abstract

The injection system of the Pohang Light Source (PLS) storage ring employs four kicker magnets and one Lambertson magnet, all located in one of the straight section. The incoming elctron beam from the beam transfer line is horizontally parallel with the storage ring bumped orbit and it is injected with 8 degrees vertically. The Lambertson magnet then bends this beam by -8 degrees vertically in order to make it on the same level as the bumped orbit. In this paper, we describe the injection system layout of the PLS storage ring and the results for the injection dynamics investigation.

1. INTRODUCTION

The injection system for the PLS storage ring includes a 2 GeV full energy electron linear accelerator located at the underground tunnel. The length of this linac is about 150-m and it produces a 2-ns long electron pulse with a 10 Hz repetition rate. The frequency of the RF system of the linac is 2,856 MHz. The electron gun produces 80 kV, 2A electron pulse. This pulse then passes through a standing-wave prebuncher and a traveling-wave buncher, all modulated with the same 2,856 MHz frequency. The combination of these elements together with the first accelerating column compresses the RF phase of the electrons to ± 5 degrees. The normalized emittance for the electron beam is 0.015 MeV/c cm radian which translates into the unnormalized emittance of 0.075 mm mrad at 2 GeV.

Between the linac and the storage ring, the beam is transported along the beam transfer line (hereafter BTL) which brings the beam from the underground linac tunnel up to the storage ring beamline. The storage ring beamline is located 1.4-m above the ground. The storage ring injection system then captures the incoming injected beam from the BTL and the injected beam undergoes the coherent betatron oscillation until the beam damps. The horizontal damping time of the PLS storage ring is 16 ms.

In this report, we describe the injection system of the PLS 2 GeV storage ring. Layout of the injection system and major parameters of the injection components are presented in detail. Aperture requirement of the storage ring for the injection is also discussed. Results of the beam dynamics simulation are then presented.

2. STORAGE RING INJECTION SYSTEM

The length of the injection straight allocated for our storage ring lattice is 6.8 m. Along this injection straight, we place four bump magnets and one Lambertson magnet. The Lambertson magnet could have been replaced by a combination of thick and thin septum magnets. This has an advantage of reducing the coherent betatron oscillation amplitude for the injected beam because of the smaller effective thickness of the thin septum magnet than that of the Lambertson magnet. However, in this case, the space requirement becomes more stringent for placing all the injection magnets in one straight section.

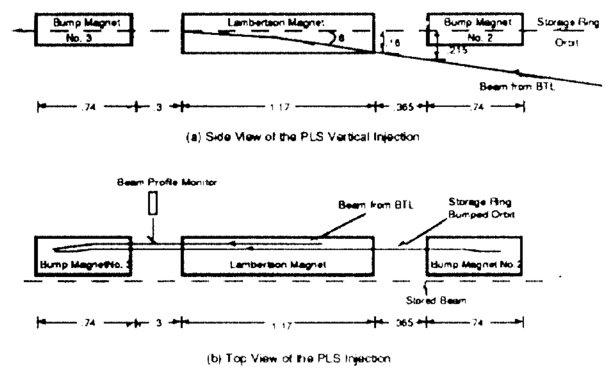

Fig. 1 Layout of the PLS injection system

The incoming electron beam from the BTL is horizontally parallel with the storage ring bumped 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 as the bumped orbit. The schematic diagram of this vertical injection scheme is shown in Fig.1. 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 magnet and the storage ring quadrupole magnet.

2.1 Bump magnet and bumped orbit

In order to make a bumped orbit, four kicker magnets are placed in the straight section. Among these four magnets, the first two magnets are used to displace the stored orbit close to the septum and the remaining two magnets then restore the bumped orbit to the original stored orbit. The required magnitude of the kick for these bump magnets is obtained from

$$x_b = L \times \tan(\frac{B_b l_b}{B\rho}) \quad , \tag{1}$$

where L is the distance between the centers of the first two bump magnets. B_b and l_b are respectively the magnetic field and the length of the bump magnet. 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 ($=B_b l_b/B\rho$) is then 16.64 mrad.

The distance between the center of the bumped orbit to the storage ring vacuum chamber at the position of the Lambertson magnet is taken to be 4 mm (the horizontal *rms* beam size of the storage ring at the injection point is 0.348 mm). Therefore, the physical aperture at this position is set at 25 mm from the center of the stored orbit. The maximum β_x of the nominal PLS lattice is 13.5 m and occurs at Q2. The good field radius of the quadrupole magnet was designed to be 30 mm. Hence,

$$25mm \times \sqrt{\frac{\beta_{x_{max}}}{\beta_i}} = 25mm \times \sqrt{\frac{13.5}{10}} \approx 30mm \quad . \quad (2)$$

This means that the horizontal aperture of the injection vacuum chamber is quite consistent with the good field region of the storage ring quadrupole. In addition, 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 (=21 mm + 15 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 because the maximum vertical chamber gap is about 20 mm and the maximum β_y of the storage ring is 20 m;

$$20mm \times \sqrt{\frac{\beta_{y_i}}{\beta_{y_{max}}}} = 20mm \times \sqrt{\frac{4}{20}} \approx 9mm \quad . \quad (3)$$

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

$$A_x = \frac{x_w^2}{\beta_{x_0}} \quad , \quad (4)$$

where x_w is the horizontal half size of the injection vacuum chamber. β_{x_0} is the β_x at the injection point ($\approx$ 10 m). Substituting these values yields A_x=62.5 mm mrad. On the other hand, the minimum acceptance for an ideal injection scheme is related with the sum of half of the stored (that is, damped) beam size, the effective thickness of the septum (which includes the storage ring and BTL vacuum chamber) and the full size of the injected beam from the BTL:

$$(A_x)_{min} = \frac{(2\sigma_0 + (x_s)_{eff} + 6\sigma_i)^2}{\beta_{x_0}} \quad . \quad (5)$$

This yields $(A_x)_{min}$=22.5 mm mrad, which is substantially smaller than the actual storage ring acceptance, A_x. Therefore, we have a substantial safety margin considering the errors and operational inefficiencies of the storage ring. In the vertical direction, the acceptance is A_y=25 mm 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 bump magnet has a 4 μs half-sine wave so that the rise and fall time are respectively 2 μs. Thus, the injected beam will restore to the original stored orbit in less than three orbital turns (the revolution time of the storage ring beam is 0.94 μsec).

In Fig.2 is described the horizontal phase space diagram of the PLS injection system at the center of the Lambertson magnet.

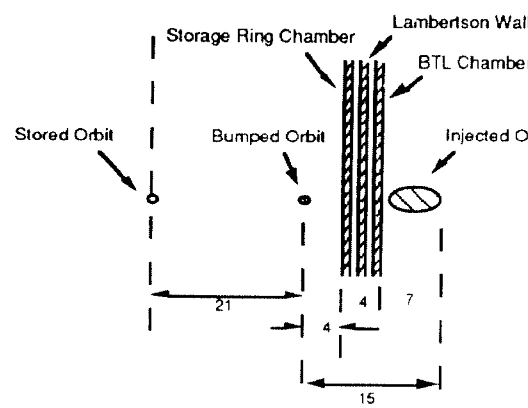

Fig. 2 Horizontal diagram at the PLS injection point

In case the bump magnet produces smaller bumped orbit than the design value, 21 mm, we have a provision of using four corrector magnets, two downstream and two upstream of the injection area, to make additional offset at the injection point. Location of these correctors are shown in Fig. 3. In this figure, K1 and K2 are the upstream bump magnets, with kick angles $\pm\theta_3$, and H/V denotes the corrector magnet for both horizontal and vertical orbit correction with a horizontal kick of θ_2. θ_1 is the kick angle of the dipole trim winding. Q_i denotes quadrupole magnets and BM is the main dipole magnet. The required strengths to generate for example 6 mm offset were estimated to be θ_1=2.3 mrad and θ_2=−0.17 mrad, respectively.

In order to measure the bumped orbit, a provision is made to insert a Sabersky finger at the known horizontal position. It will be located at the space between the second bump magnet and the Lambertson magnet, possibly at the photon stop. By detecting the beam interruption on the Sabersky finger and the current of the bump magnet, the distance of the bumped orbit can be deduced by interpolation.

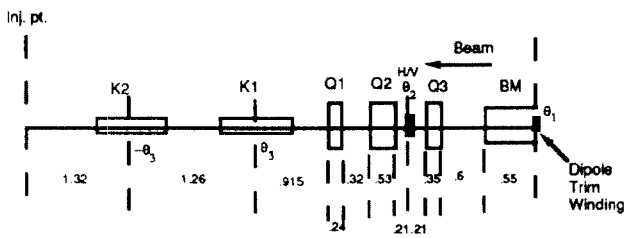

Fig. 3 Layout around the injection region

2.2 Lambertson magnet

The injected beam from the BTL is in parallel with the bumped orbit horizontally and it is bent by the Lambertson septum magnet. In the present design, the Lambertson magnet is 1.17-m long and the maximum field was chosen to be 8 kG. The bending angle is therefore 8°. Increasing the field beyond 8 kG, and therefore the possibility of reducing the length, is being explored at present.

In the drift space between the Lambertson magnet and the bump magnet 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.

2.3 Injection dynamics

The injected beam from the BTL oscillates coherently with respect to the stored orbit until its oscillation amplitude gets stabilized by means of radiation damping and quantum fluctuation. The purpose of the injection dynamics study is to make sure that the injected beam does not hit any physical obstacles before it damps. The computer program DIMAD was utilized for this study. This program has a capability of including the time variation of the kicker magnet as well as the tracking simulation. First, we assumed that the injected beam from the BTL and the storage ring bumped orbit are perfectly matched. The emittance of the injected beam is determined by that of the linac beam if we neglected the emittance decrease due to the slits placed in the BTL. For a 2 GeV electron, the emittance is 0.075 mm mrad. This value is in fact not an *rms* value but the value at FWHM. However, in this study we assumed that it is an *rms* value. Further, the energy spread of the injected beam was assumed to be ±0.6%. This value is small enough to be fit into the storage ring RF bucket (ie. ≈ 2 %). We have a plan to put the momentum defining slit in the BTL where η_x is not zero.

Our investigation revealed that for the ideal lattice (ie. without magnetic errors) all injected particles are stable. In the presence of errors and without COD correction, however, the injection is very unstable. It shows strong dependence on the distribution of the magnet errors. In some case, the efficiency is over 90 % and in other case, the efficiency is near zero. The reason behind this drastic variation is probably the strong dependence on seed numbers of the dynamic aperture with COD errors. The simulation result strongly indicates the need of COD correction for injection.

With COD correction, the result is very encouraging; COD errors at the injection point are below 1 mm, even though the correction method was not fully optimized. In order to find the minimum required bumped orbit for the injection, we decreased the bump magnet kick strength step by step. Until 10 mrad kick, the efficiency is over 80 %. Between 8 to 9 mrad kick range, the efficiency drops abruptly. This range corresponds to the initial amplitude of 22 mm which is close to the dynamic aperture range with multipole errors.

It will be more realistic if we assume that the orbit correction is not perfect. We have therefore deliberlately made the residual COD after correction become about 2 mm rms. With all the seed numbers we tried, the injection efficiency is over 90 % between 15 mrad to 16.64 mrad kick. As the bumped orbit decreases, however, the situation gets worse. For example, Table I summarizes the result for 13 mrad kick.

Table I Injection efficiency with monitor error and COD correction

seed number	efficiency(%)
482	100
89	40
45234	95
987156	94
6	42

bump magnet kick: 13 mrad

The unnormalized injected beam emittance we took in this study was 0.075 mm·mrad. Doubling the emittance did not make a big difference.

3. SUMMARY AND DISCUSSION

We presented the PLS injection system characteristics so far. The bumped orbit is 21 mm away from the storage ring axis. The physical aperture at the injection point is set at 25 mm which is consistent with the good field region requirement of the storage ring quadrupole magnet. The coherent betatron oscillation amplitude is 15 mm leading to the good field region requirement of the bump magnet to be 36 mm. The storage ring acceptance is large enough to accomodate the emittance of the incoming electrons from the linac. The characteristic feature of our injection system is that it is a vertical injection using Lambertson septum magnet. The injection dynamics simulation verifies the validity of our design of the injection system.