INJECTION SCHEME FOR TPS STORAGE RING

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Abstract

A 3~3.3 GeV synchrotron light source with full energy injection is proposed to be built at NSRRC and named Taiwan Photon Source (TPS) [1]. The design of injection scheme for TPS is presented. The space allocation of injection components, the bumper design and the particle dynamics of injected and stored beam will be discussed. Particle tracking for the first few turns after injection is performed to check the validity of the scheme and the working point of the design. The aperture required by the injection scheme is calculated and compared with the aperture required by the momentum acceptance.

INTRODUCTION

The lattice design of TPS is a 24-cell DBA structure with a circumference of 518.4 m. The natural horizontal emittance is less than 2 nm-rad (dispersive, named TPS24P18K1) and 6 nm-rad (non-dispersive, named TPS24P18L1). The injector may be a booster in the same tunnel as the storage ring, or a separate booster. Top-off operation is considered for routine operation.

The injection scheme of TPS will adopt the combination of one septum magnet and four kickers. The incoming beam will be injected into the storage ring horizontally to increase the accumulation of the stored beam current. An off-axis injection is designed. The whole injection system will be placed in the same long straight section as shown in Fig. 1. This design is similar to the injection scheme of the TLS. The merits of this scheme are simple kicker design with same strength for all kickers, simple to manipulate the bumper height and elimination of the nonlinear effects of quadrupole and sextupole due to the bumper amplitude. The disadvantage of this scheme is that it requires a rather long straight section to accommodate the kickers and the injection septum. A straight section of at least 10.6 m long is reserved for the injection elements of the TPS.

INJECTION SCHEME

The considerations and assumptions used for the injection design are as follows:

- 5 mm is allowed for the thickness of injection septum including alignment error.
- Maximum emittance of the booster ring is 150 nm-rad.
- Storage ring emittance is assumed to be 4 times the theoretical minimum emittance 1.92 nm-rad, and another factor of 4 for error tolerances.
- Injected beam size $\pm 3\sigma_{xi}$ is allowed, corresponding to 99.6 % of the incoming beam.
- $\pm 4\sigma_{x0}$ is allowed for the stored beam.
- Storage ring is assumed to accept particles with up to ±2% energy deviation.
- A small deflection angle of septum is preferred. However one should avoid the equipment conflict in storage ring and beam transfer line.
- Horizontal aperture of the kicker vacuum chamber should be wide enough to avoid scraping the injected beam.

The lattice parameters of the storage ring at injection points are β_{x0} = 12.928 m, β_{y0} = 9.794 m, α_{x0} = 0.0, α_{y0} = 0.0, D_{x0} = 0.0 m. The optimum horizontal beta function of the transfer line at the injection point can be derived by solving the following equation [2]:

$$\beta_{xi}^{2} + \frac{n\sigma_{x0} + T}{2\sqrt{\varepsilon_{xi}}}\beta_{xi}^{3/2} = \frac{\beta_{x0}^{2}}{2} \tag{1}$$

where β_{xi} is the beta function of the injected beam at the end of the septum, ε_{xi} is the horizontal emittance of the injected beam, β_{xo} is the horizontal beta function of the stored beam at the injection point, nσ_{x0} is the horizontal size of the stored beam at the injection point, T = 5 mm is the effective septum width including alignment error. A factor of two is applied to the beta function of injected beam for the possible nonlinearities. The beam parameters used for the calculation of aperture at injection point are summarized in Table 1.

Table 1: Beam parameters for the calculation of aperture at injection.

Beam Parameter	Storage Ring	Transfer Line
Emittance (3 GeV) (nm-rad)	1.912*4*4= 30.6	150
Horizontal beta value at injection point (m)	12.928	3.723
Horizontal dispersion at injection point (m)	0.0	0.0
Energy spread	9.5321E-04	6.53E-04
Horizontal beam size (mm)	0.629	1.057

The off-axis amplitude A of injected beam at injection point is A = 4*σ_{x0} +T+3*σ_{xi}*2 = 13.857 mm. The maximum horizontal beta function of the storage ring is 24.168 m. The aperture at this maximum beta point without scraping the injected beam is $13.857 \times \sqrt{\frac{24.168}{12.918}} = 18.946$ mm. Assuming a 9 mm orbit

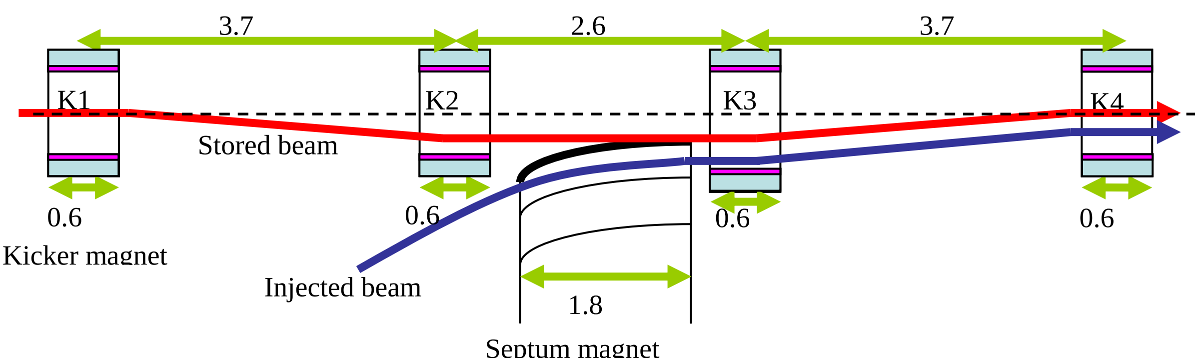

Figure 1: Schematic layout of the TPS injection system, in units of m.

distortion and 3 mm contingency at the beginning of operation, the required aperture at the location of maximum horizontal beta function is 30.946 mm. The aperture acceptance required for the injection in the whole ring is:

$$\mathrm{APX\_INJ} = \left(A_{x,\max}^{2} \times \frac{\beta_{x0}}{\beta_{x,\max}} + (D_x\delta)^2\right)^{1/2} \qquad (2)$$

The result is shown in Fig. 2. The aperture required at injection point is 22.63 mm. It means that the maximum horizontal bump at the injection point is 20.11 mm. Figure 3 shows the horizontal phase space at the injection point. The parameters of septum and kicker to fulfill the requirement are listed in Table 2. The length of the kicker is 0.6 m. The distance between the first and second kicker is 3.7 m. The maximum kicker deflection angle is 5.435 mrad in order to reach the bumper height of 20.11 mm. The length of the septum is 1.8 m and its deflection angle is 174.5 mrad.

With this design the duration of the injection bumper is three turns. The stored beam will experience bumper amplitude of 10.055 mm, 20.11mm and 10.055 mm at injection point at every successive turn. The injected beam is 30.8 mm away from the storage ring reference orbit at injection. After injected into the storage ring, the injected beam executed betatron oscillation with amplitude of 13.86 mm around the stored beam. The oscillation will be damped due to synchrotron radiation. The horizontal phase space tracking of injected beam and stored beam for the first few turns during injection is shown in figure 4. The injected beam is well captured in this design.

Table 2: Parameters of TPS storage ring kicker and septum magnet.

	Septum	Kicker
Magnetic length (m)	1.8	0.60
Maximum field (T)	0.97	0.0906
Deflection (mrad)	174.5	5.435
Magnet current waveform(half-sine)		5.184 µs

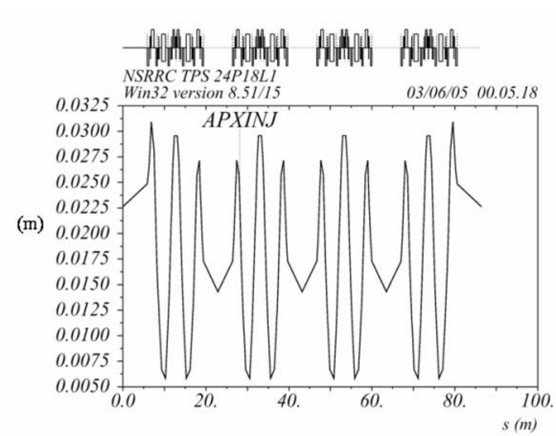

Figure 2: The aperture acceptance required at injection in the horizontal plane of TPS storage ring.

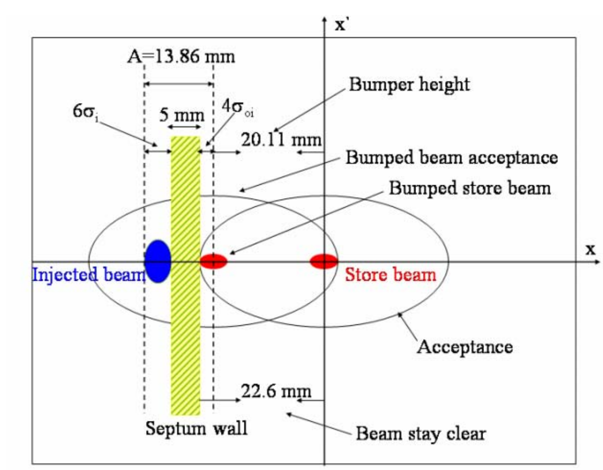

Figure 3: Horizontal phase space at the injection point.

INJECTION APERTURE

The determination of physical aperture has to include both the injection allowance and the consideration of beam lifetime. In order to have long enough beam lifetime, the transverse aperture of the electron bunch should be able to tolerate ±4% momentum deviation (δ=± 0.04).

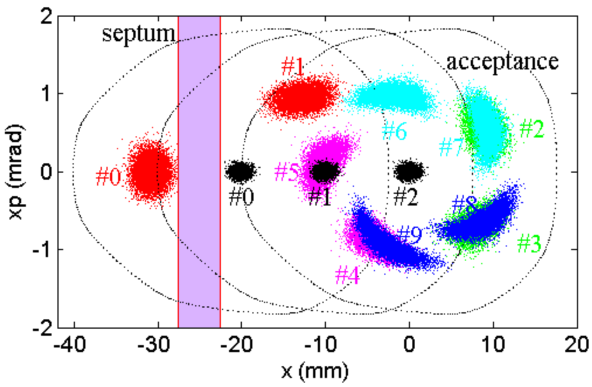

Figure 4: Horizontal phase space tracking of injected beam for the first few turns.

The transverse aperture determined by the momentum acceptance δ is calculated as followings: A particle at location *i* scattered to lose a relative energy δ will in the linear case induce betatron oscillation in both planes. The amplitudes of the oscillation in horizontal and vertical planes are

$$A_{x,i} = H_{x,i}\delta^2 + \kappa H_{y,i}\delta^2 \qquad (3)$$

$$A_{y,i} = H_{y,i}\delta^2 + \kappa H_{x,i}\delta^2 \qquad (4)$$

$$H_{z,i} = \gamma_z D_z^2 + 2\alpha_z D_z D_z' + \beta_z D_z', \quad z = x, y \qquad (5)$$

where κ is the coupling coefficient, α, β, γ are twiss functions and *D*, *D'* the dispersion function and its derivative. The particle will reach maximum amplitude at another position *k* in the horizontal plane of

$$x_k = \sqrt{A_{x,i}\beta_{x,k}} + D_{x,k}\delta = (\sqrt{H_{x,i}\beta_{x,k}} + D_{x,k})\delta \qquad (6)$$

For a fix δ the maximum amplitude occurs at maximum $H_{x,i}$. Maximum $H_{x,i}$ is 0.008 in this case.

Figures 5 and 6 show the simulation results of the required horizontal and vertical aperture with ±4% momentum deviation calculated by Eq. (6) with maximum $H_{x,i}$, respectively. Comparing with Fig. 2 and Fig. 5 one finds the required horizontal aperture to tolerate with ±4% momentum deviation is larger than the horizontal aperture due to the requirement of injection allowance. The calculations of the required transverse aperture acceptance with ±4% momentum deviation is based on the lattice 24P18L1 with zero-dispersion in the long straight section. The same simulation can be applied to the case of the distributed dispersion lattice 24P18K1. The required horizontal aperture to tolerate with ±4% momentum deviation is shown in Fig. 7. Comparing with Fig. 2 and Fig. 7 one finds the required horizontal aperture to tolerate with ±4% momentum deviation is smaller than the horizontal aperture due to the injection considerations. Therefore the minimum physical aperture required is determined by the transverse aperture of the lattice 24P18L1 to tolerate with ±4% momentum deviation plus contingency and closed orbit allowance. The horizontal half vacuum chamber size is 35 mm for TPS design.

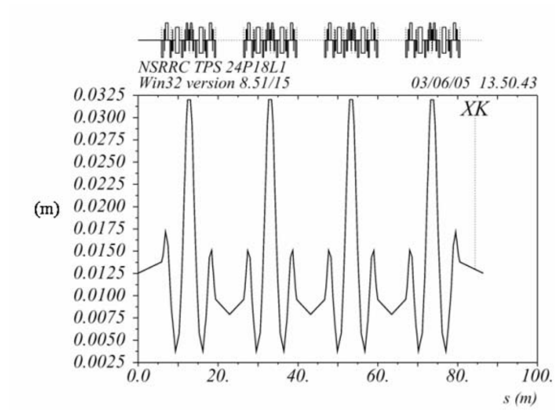

Figure 5: Horizontal required aperture acceptance of the TPS storage ring of ±4% momentum deviation, lattice 24P18L1.

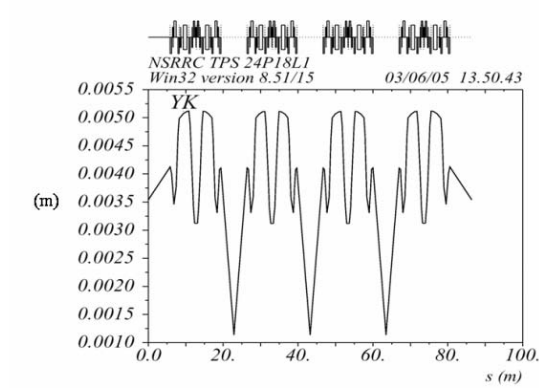

Figure 6: Vertical required aperture acceptance of the TPS storage ring of ±4% momentum deviation, lattice 24P18L1.

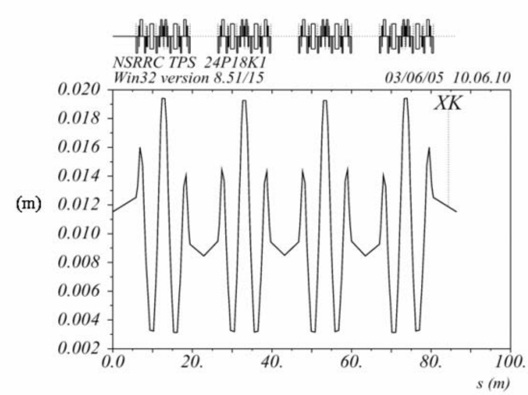

Figure 7: Horizontal required aperture acceptance of the TPS storage ring of ±4% momentum deviation, lattice 24P18K1.

REFERENCES

[1] C.C. Kuo, et al., "Design of Taiwan Future Synchrotron Light Source", these proceedings.
[2] S. Tazzari, "Aperture for injection", ESRP-TRM-4/83.