DESIGN CONSIDERATIONS OF THE TPS LINAC-TO-BOOSTER TRANSFER LINE

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Abstract

Design considerations of the linac to booster (LTB) transfer line for Taiwan Photon Source (TPS) project is described in this report. Electron beam from the linac with 150 MeV, 50 π-mm-mrad normalized emittance and 0.5% energy spread will be transferred to a booster synchrotron of 496.8m. This LTB transfer line is designed with the flexible tuning capability and the diagnostics are included. Matching of transverse beam parameters from linac to booster is deliberated. The on-axis injection scheme with repetition rate around 2 or 3 Hz and efficiency with beta-mismatch for top-up operation is also studied.

DESIGN PHILOSOPHY

The LTB transfer line [1] guides the beam from the 150 MeV linac [2] to the booster ring for acceleration to 3 GeV. Due to the concentric booster and storage ring to share the same tunnel, the linac location and two beam dumps required to be installed, a schematic layout of the LTB is shown in figure 1. It is designed to measure the beam parameters of the linac exit with quadrupoles before upstream of the first bending magnet B1 [3]. There is a horizontal energy pair of slits (HS) located at a high dispersion (η_x) and low beta (β_x) area to accurately deliver the beam energy. Inside linac tunnel, two beam dumps are requested installed, one straight ahead of the linac and the other for beam diagnostic purposes. These two bending magnets, B1 and B2, after the linac should be interlocked with the linac trigger to allow beam to pass into the storage ring tunnel when it is safe. After the B2, several quadrupoles are used for injection matching and optics adjustment.

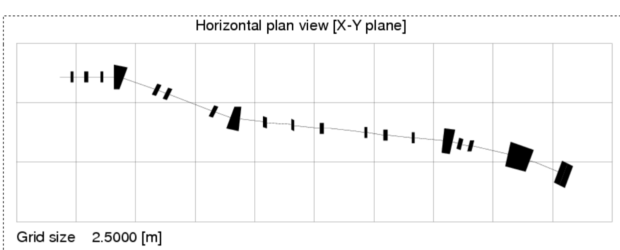

Figure 1: Layout of LTB transfer line.

LATTICE DESIGN

The design philosophy introduced in the above includes 1) transportation and beam parameters measurement 2) optics matching and injection 3) energy control 4) radiation safety and 5) tuning flexibility for different launching Twiss parameters of linac 6) fit the geometric restriction bound by the concentric booster and storage ring, the location of pre-injector and space for beam dumps. All the considerations have been included in the LTB lattice design.

The optics matching of the booster injection asks for the injected bunch beam to be into the booster survival region of the horizontal and vertical phase spaces. The dispersion functions are well matched in design and betatron functions are less constrained within the reference betatron functions of booster, such that the overall betatron functions of the LTB can be limited within 35 meter. Figure 2 shows the optical functions of the LTB transfer line with the initial Twiss functions $\beta_x=\beta_y=7$m and $\alpha_x=\alpha_y=0$ at the exit of linac. The corresponding 3σ beam envelopes of the betatron beam size and the energy spread are shown in figure 3. The components used in the LTB lattice are listed sequentially in the Table 1.

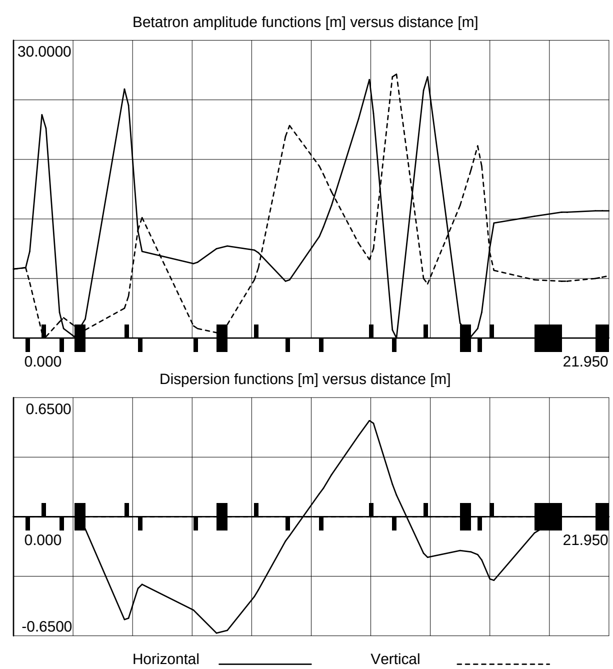

Figure 2: For the initial Twiss functions $\beta_x=\beta_y=7$m and $\alpha_x=\alpha_y=0$ at the exit of linac, the designed optical functions, upper includes the β_x (solid line) and the β_y (dash line) and lower is the horizontal dispersion, of LTB transfer line are shown.

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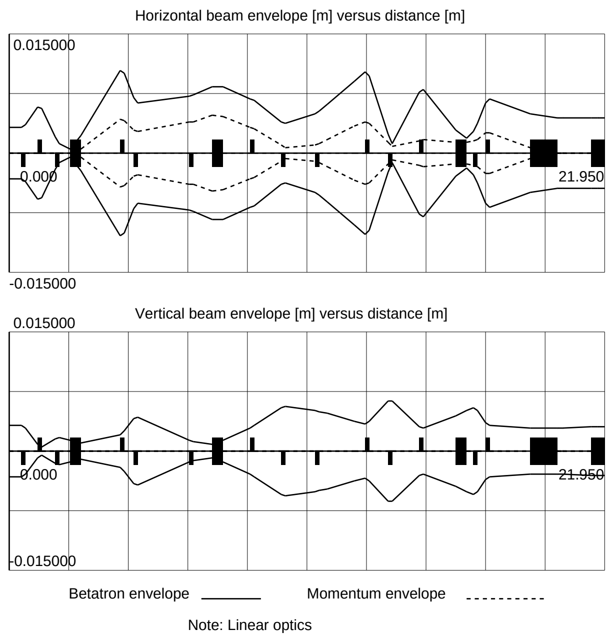

Figure 3: The 3σ horizontal (upper) and vertical (lower) beam envelopes of the LTB transfer line are presented. The dash line in the horizontal shows the component included in the horizontal beam size and come from the dispersion times the 3σ energy spread.

Table 1: LTB magnet parameters

Label	Magnet	L(m)	Strength
Q1A	QUAD	0.15	K1 = -10.1 (m^{-1})
Q1B	QUAD	0.15	K1 = 14.6 (m^{-1})
Q1C	QUAD	0.15	K1 = -17.8 (m^{-1})
B1	SBEND	0.40	ANGLE = 20°
Q2A	QUAD	0.15	K1 = 9.4 (m^{-1})
Q2B	QUAD	0.15	K1 = -9.4 (m^{-1})
Q2C	QUAD	0.15	K1 = -1.7 (m^{-1})
B2	SBEND	0.4	ANGLE = -14°
Q3A	QUAD	0.15	K1 = 1.9 (m^{-1})
Q3B	QUAD	0.15	K1 = -3.2 (m^{-1})
Q3C	QUAD	0.15	K1 = -1.3 (m^{-1})
Q4A	QUAD	0.15	K1 = 9.1 (m^{-1})
Q4B	QUAD	0.15	K1 = -7.1 (m^{-1})
Q4C	QUAD	0.15	K1 = 10.0 (m^{-1})
B3	SBEND	0.40	ANGLE = 6°
Q5A	QUAD	0.15	K1 = -7.7 (m^{-1})
Q5B	QUAD	0.15	K1 = 10.0 (m^{-1})
Si	(Septum)	1.00	ANGLE = 10°
Ki	Kicker	0.50	ANGLE = 1.15°

Table 2: Different launching parameters at the linac exit are used for flexibility study of the LTB transfer line.

Initial Set	βx (m)	αx	βy (m)	αy
#70	7	0	7	0
#50	5	0	5	0
#a0	10	0	10	0
#7n	7	-1.5	7	-1.5

Different launching parameters at the exit of linac listed in Table 2 have been used to test the flexibility of optics adjustment. The obtained maximum betatron functions can be limited within about 35 m and the beam sizes are about 15 mm in horizontal and with 10 mm in vertical. For the estimation of the beam stay clear (BSC) and the chamber requirement, the tolerance study of the possible trajectories with errors and steered by some correctors is described in the bellows.

Construction and alignment errors, field errors and non-ideal launching conditions at the linac exit, as listed in Table 3, contribute to various trajectories. 100 different random values of these errors have been used to calculate possible trajectories as shown in figure 4. With correctors distributed along the LTB transfer line, the trajectories can be corrected within ±2.5 mm shown as the figure 5. With the normalized emittance given by the pre-injector ε_n=50 (π-mm-mrad), the aperture requirements are ±20 mm in horizontal and ±15 mm in vertical.

Table 3: Error set for orbit distortion calculation.

Error sources	Magnitude (truncated at nσ)
Bending field error (absolute)	2 Gauss (1)
Bending field error (relative)	0.1% (1)
Bending displacement error (x, y and s)	0.2 mm (2)
Bending roll error (around all 3 axes)	0.4 mrad (2)
Quadrupole field error (relative)	0.5% (1)
Quadrupole displacement error (x and y)	0.2 mm (2)
Quadrupole roll error (around all 3 axes)	0.4 mrad (2)
Septum field error	0.05% (1)
Septum displacement error (x, y and s)	0.2 mm (2)
Septum roll error (around all 3 axes)	0.4 mrad (2)
Launch condition (x, px and y, py)	1 mm, 0.5 mrad (1), (1)
Launch condition (dp/p)	0.5% (1)

INJECTION SCHEME

An on-axis injection scheme with a septum and kicker magnet is used to inject the beam into the booster ring (see Figure 6). The relationship of beam parameters between septum and kicker and the strength of the kicker can be calculated from booster optical functions.

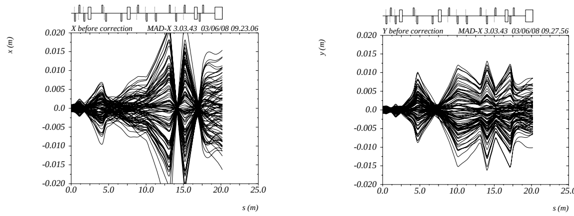

Figure 4: The possible trajectories in horizontal (left) and vertical (right) calculated with errors (100 random seeds).

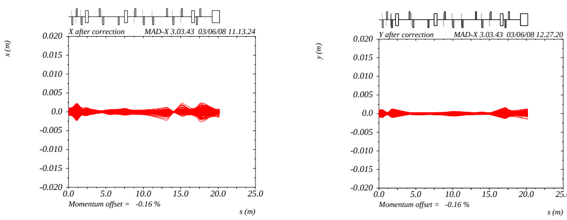

Figure 5: The steered trajectories in horizontal (left) and vertical (right) are within about ±2.5.

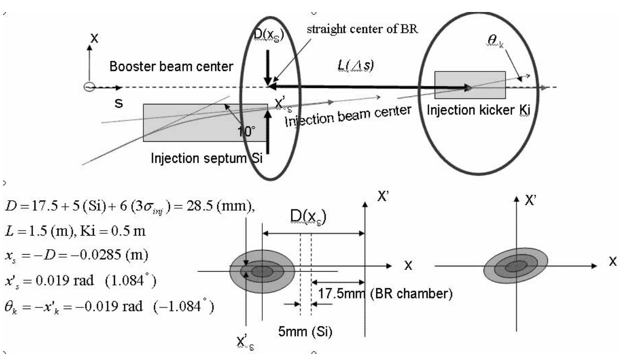

Figure 6: Upper shows the on-axis injection scheme of booster ring. Lower shows the beam horizontal phase-space progresses from the exit of the injection septum (left) to the end of the injection kicker (as shown on the right) in booster ring. The beam shape's evaluation is given by the transformation of the betatron functions through the σ-matrix.

Define the vector $\vec{z}_k^T \equiv (x, x')_k = (x(s_k), x'(s_k))$ and the vector of the injection beam can be transferred by the transfer matrix from the exit of septum to the kicker centre $\vec{z}_k = M_{s,k} \cdot \vec{z}_s$. Then add up the $\vec{z}_k$ and the kicker's angle, the on-axis injection condition requires

$$\begin{pmatrix} 0 \\ 0 \end{pmatrix} = \begin{pmatrix} x \\ x' \end{pmatrix}_k + \begin{pmatrix} 0 \\ \theta_k \end{pmatrix}$$

We have the following results

$$x_s = -\frac{\beta_s \sin\Delta\psi_{sk} \cdot x'_s}{(\alpha_s \sin\Delta\psi_{sk} + \cos\Delta\psi_{sk})}$$

or

$$x'_s = -(\alpha_s + \cot\Delta\psi_{sk}) \cdot x_s / \beta_s$$

and the required kicker angle is

$$\theta_k = -x'_k = x_s \Big/ \left(\sqrt{\beta_s \beta_k}\, \sin\Delta\psi_{sk}\right),$$

where the phase advance $\Delta\psi_{ij} = \psi_j - \psi_i = \int_{s_i}^{s_j} ds/\beta(s)$.

The horizontal Twiss parameters of the booster ring at the injection point are α_s=0 and β_s=14.049 m. The betatron function at the injection kicker is β_k=14.049 m and the phase advance between these two locations is $\Delta\Psi_{sk}$=0.106814×(2π). At the exit of septum the injection beam is displaced from the ideal booster orbit toward the booster centre by a distance of D=(17.5+5+6)=0.0285 m. The distance from the septum exit to the kicker centre is L=1.5 m and the length of kicker Ki is 0.5 m, i.e. $x_s = -D$. Such that we have

$$x'_s = -(\alpha_s + \cot\Delta\psi_{sk}) \cdot x_s / \beta_s = 0.01892 \text{ (rad)}$$

$$\theta_k = -x'_k = x_s \Big/ \left(\sqrt{\beta_s \beta_k}\, \sin\Delta\psi_{sk}\right) = -0.01892 \text{ (rad)}$$

Parameters of these pulse magnets, fast kicker Ki and injection septum Si, are listed in Table 4.

Table 4: Parameters of the pulse magnets Ki and Si used for the on-axis injection scheme of the booster.

Component	Angle (mrad/degree)	Length (m)
Kicker (Ki)	-18.92 / -1.08408°	0.5
Septum (Si)	174.533 / 10°	1.0

DISCUSSIONS

Due to the building structure of TPS concentric booster and storage ring, the LTB transfer line is designed not only for the transportation of the injection beam from linac to booster. The design considerations include the beam dumps for safety requirement, parameters measurement for linac acceptance test, energy control, optical matching for injection and tuning flexibility for different operation modes.

The components, structure, optics and trajectory due to errors and trajectory steering of the LTB lattice have been presented. The on-axis booster injection scheme is also given. Furthermore detailed study and optimization are in progress.

REFERENCES

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[3] Daniel Oliver Sütterlin, Diploma thesis, ETHZ-IPP internal report 2001-06, September 2001.