

DESIGN OF A NEW BOOSTER TO STORAGE RING TRANSFER LINE FOR NONLINEAR INJECTION KICKER IN TAIWAN PHOTON SOURCE

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Abstract

The nonlinear kicker injection scheme is a potential option for the future Taiwan Photon Source. Compared to the current four-bump injection scheme, which occupies the entire 12-meter-long straight section, the nonlinear kicker requires only a few tens of centimeters in length. A new booster-to-storage-ring transfer line has been designed to create additional space for installing more insertion devices for users. This article discusses the geometrical constraints imposed by the existing storage ring and the requirements of the injection scheme. In addition, trajectory correction and emittance measurements of the injected beam in the transfer line, as well as the injection efficiency of the nonlinear kicker, are also addressed.

INTRODUCTION

The nonlinear kicker (also known as nonlinear injection kicker, NIK, or a multipole injection kicker, MIK) [1-7] has been studied and adopted in recent years, following the introduction of pulsed quadrupole and sextupole injection schemes [8, 9]. These schemes offer advantages such as transparent injection and space-saving designs. To the author's knowledge, most NIK designs are based on the BESSY-II configuration [1], which uses a ceramic chamber with eight cables (a single cable with multiple turning points) positioned at the vertices of two squares. The prototype of NIK, designed and manufactured by the vacuum and magnet groups at NSRRC for Taiwan Photon Source (TPS) is shown in Fig. 1.

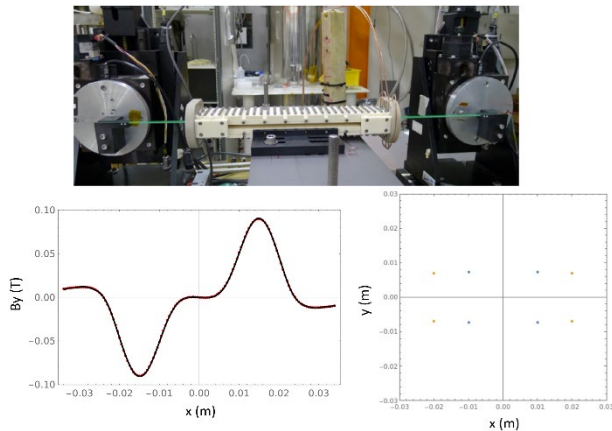


Figure 1: Prototype of the NIK in TPS. Bottom: Field profile of the NIK. Red dots: calculated by Biot-Savart law of infinite long cables. Blue curve: polynomial fitted result.

In the future, the current bump-based injection scheme, which employs four kickers occupying the entire 12-meter injection section, could be replaced by a single compact NIK. Given that an NIK is approximately 34 cm long, this

would allow the installation of an additional insertion device between the new injection point and the NIK, providing an extra experimental hutch for users. This article outlines a plan for a 7-meter sub-straight section between the injection point and the end of the injection section, which would allocate nearly 5 meters of space for an insertion device. The remaining approximately 2-meter section would accommodate essential components, including the NIK, its corresponding corrector, a pumping port, and a screen monitor. To achieve this 7-meter sub-straight section, the injection point must be shifted 1.8 meters upstream (see Fig. 2 and Fig. 3), necessitating a redesign of the booster-to-storage-ring transfer line (BTS).

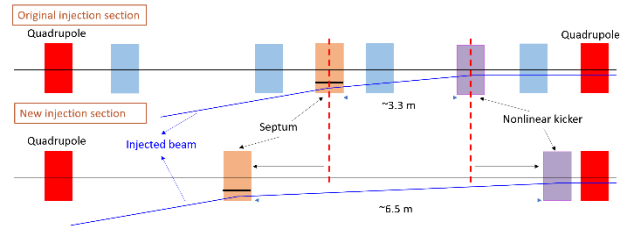


Figure 2: Comparison of the original and new injection section in TPS.

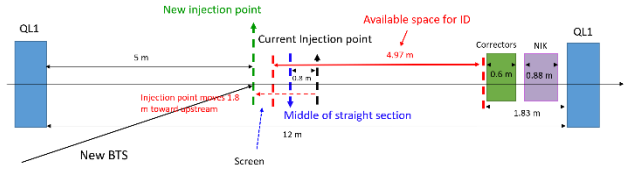


Figure 3: New injection section in TPS.

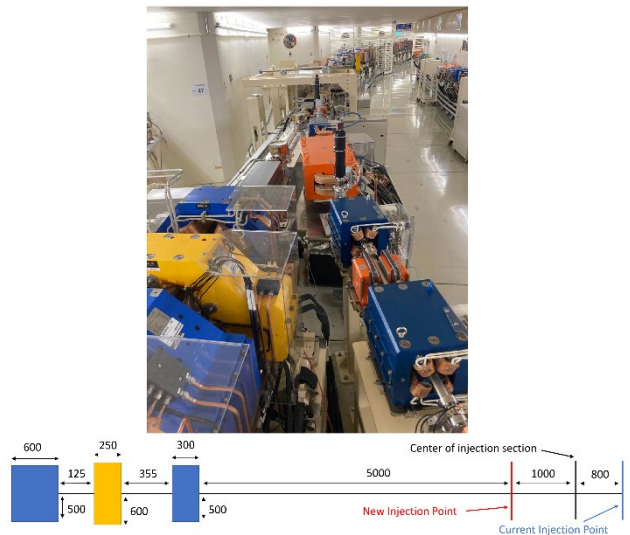


Figure 4: Top: Storage ring (left) and current BTS (right) in the tunnel of TPS. Bottom: Schematic of the injection section and upstream magnets, with dimensions in millimeters.

The requirements that must be satisfied for this redesign are listed below.

1. Geometrical constrain (existing booster ring and storage ring).
2. Equipment conflict avoidance (with elements in the storage ring).
3. Sufficient drift space for personnel to pass through
4. Tunability for the matching conditions at the injection point.
5. Limitation of betatron functions, especially in the injection septum magnets in which the cross section is 13 mm (V) x 20 mm (H) [10].

For the second requirement, as shown in the bottom-left of Fig. 4, the upstream region of the injection section of TPS contains quadrupole (blue) and sextupole (yellow).

NEW BTS DESIGN

Layout

The schematic of the final design of the new BTS for the TPS is presented in Fig. 5.

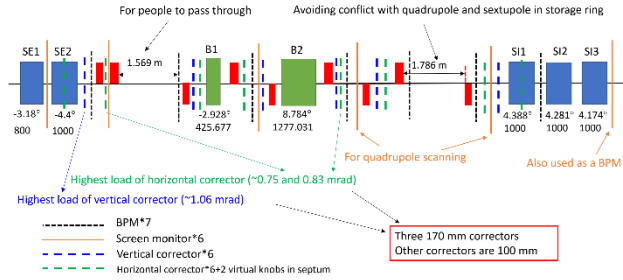


Figure 5: Schematics of the new BTS.

The final matching results are presented in Fig. 6, with the corresponding injected beam size. The beam sizes are calculated based on the emittance measured during commissioning in ϵ_x and ϵ_y are 14 and 6.8 nm-rad respectively [11].

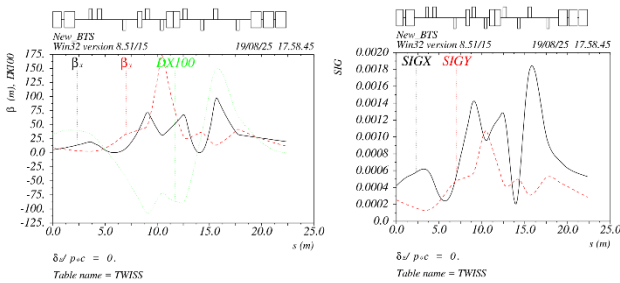


Figure 6: Left: Lattice functions in the new BTS. The green curve (DX100) represents the horizontal dispersion function scaled by a factor of 100. Right: Injected beam size in the redesigned BTS (SIGX: horizontal, SIGY: vertical). long current carrying cables. Blue curve: polynomial fitted result.

The engineering drawings, provided by Huang, Din-Goa, are based on a survey file generated by MADX [12] and are presented below. A comparison between the original and redesigned BTS is depicted in top of Fig. 7 in which

the absolute coordinates of the injection points are given, confirming that the injection point in the redesigned BTS is shifted approximately 1.8 m upstream from its original position. A zoomed-in view of the region near the upstream quadrupole and sextupole magnets is provided in bottom of Fig. 7 to verify that no physical conflicts exist between the storage ring and the new BTS. The redesigned BTS appears to remain compatible with the support structure of the original BTS.

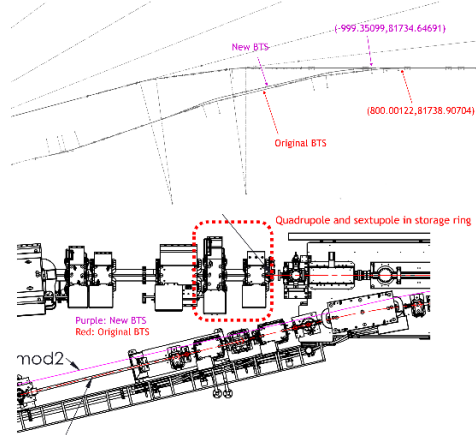


Figure 7: Top: Geometry of original BTS and the new BTS. Bottom: Zoomed-in view of engineering drawing near the upstream quadrupole and sextupole magnets.

Injection Efficiency

Considering the misalignment of magnets in the storage ring, the injection efficiency for various initial conditions: transverse offsets (x, y) and angles (x', y') at the injection point is evaluated through numerical simulations (2000 particles, 500 turns, excluding bunch-to-bunch transverse fluctuations) done by AT [13], as shown in Fig. 8. The lattice parameters for the new BTS and the original BTS are listed as "Optimized parameters of new BTS" and "Matched parameters of original BTS," respectively, in Table 1.

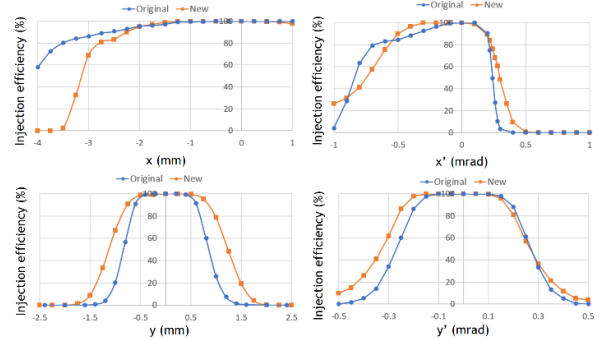


Figure 8: Injection efficiency with different transverse initial conditions at the injection point.

Table 1: Lattice Parameters of the Original and New BTS at the Injection Point

	β_x (m)	α_x	β_y (m)	α_y
Original parameters	2.503	0.00	6.156	-0.73
Optimized parameters of new BTS	20.00	1.3.00	12.00	2.20
Optimized parameters of original BTS	4.000	1.250	10.00	-0.25
Matched parameters of original BTS	4.112	1.078	10.012	-0.156

For the original BTS, injection efficiency is optimized based on numerical simulations, with the optimal result corresponding to the "Optimized parameters of new BTS." However, due to limitations in the focusing strength of the quadrupoles in the current BTS, the matching cannot fully achieve the optimized parameters, resulting in the "Matched parameters of original BTS." Note that in each sub-figure of Fig. 8, when one variable (x , y , x' , or y') is varied, the other variables are set to zero.

Two types of estimations for bunch-to-bunch transverse fluctuations are presented in this report. The first is the trajectory correction method, in which the distribution of trajectories after applying trajectory correction (to compensate for misalignment errors of elements in the BTS) is taken as the fluctuation. The second is the BPM data-based method, which is described below. For the currently operational BTS, bunch-to-bunch fluctuations are estimated using data from BPMs and screen monitors (see Fig. 9). At present, one screen monitor is functional. In addition, five BPMs (BPM1–BPM5) are operational in the BTS. For the New BTS, since no measurement data is available, only the trajectory correction method is provided.

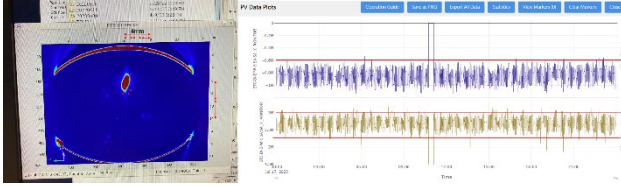


Figure 9: Left: Image of the injected beam on the fourth screen monitor in the BTS. Right: Archived data from BPM5 on July 17, 2025, in units of nm.

The overall injection efficiency is defined as the previously defined injection efficiency, but now taking into account bunch-to-bunch fluctuations. Note that the effects of the bunch train where each bunch experiences a different kick strength due to the varying arrival time within the half-sine pulse are not considered here. The results of overall injection efficiency are presented in Table 2.

Table 2: Overall Injection Efficiency of Original and New BTSs

	Trajectory correction	BPM data-based
Original BTS (Original design)	86.2	98.1
Original BTS (New design)	86.3	98.3
New BTS	72.4	

Perturbation on the Stored Beam

When the NIK is activated, it perturbs the motion of the stored beam, despite the ideal design in which the magnetic field from symmetrically placed current-carrying cables cancels at the kicker's center, where the stored beam passes through. Several factors contribute to this perturbation

1. Dipole term at the center
2. Quadrupole term at the center
3. Quadrupole term combined with COD

The measured field integral distributions of the prototype NIK in the TPS are presented in Fig. 10, with measurements conducted in 2024 (Fig. 10 a, b) and 2025 (Fig. 10, c, d). In the previous measurement of 2025, the residual

horizontal field integral is excessively high (-40.48 G-cm) on the horizontal axis. To mitigate this, a vertical offset of approximately $0.2 \mu\text{m}$ is applied to the kicker, reducing the field integral to -1.68 G-cm, as shown in subfigure (d). Table 3 summarizes the vertical stored beam sizes at SSS and LSS for different coupling ratios (κ), the ratio of centroid oscillation amplitude to beam size ($\Delta y/\sigma_y$) for the 2024/2025 field integrals, and the corresponding field integral limits ($\int B_x ds$) for transparent injection.

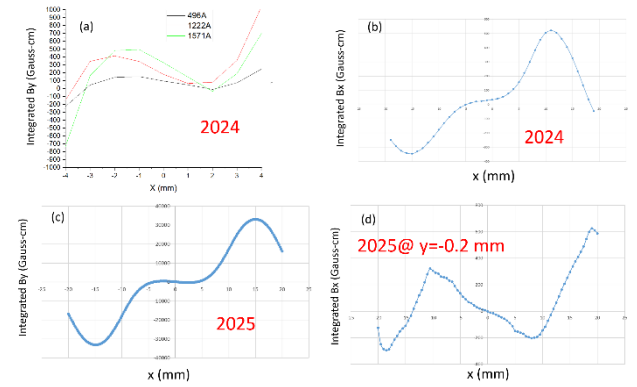


Figure 10: Measured field distributions on the horizontal axis ($y=0$ mm) of the prototype nonlinear kicker in TPS. (a) Vertical field integral in 2024, (b) horizontal field integral in 2024, (c) Vertical field integral in 2025, (d) horizontal field integral in 2025 with a vertical offset ($y=-0.2$ mm).

Table 3: Summary of Stored Beam Parameters and Injection Transparency Requirements

	$\kappa = 0.01$	$\kappa = 0.005$	$\kappa = 0.001$
$\sigma_{y,SSS}$ (μm)	5.26	3.73	1.67
$\sigma_{y,LSS}$ (μm)	9.81	6.95	3.12
$\Delta y_{SSS}/\sigma_{y,SSS}$ (2024)	2.46	3.47	7.74
$\Delta y_{SSS}/\sigma_{y,SSS}$ (2025)	0.13	0.18	0.40
$\int B_x ds$ (G-cm) for $\Delta y/\sigma_y=10\%$	1.33	0.96	0.43
$\int B_x ds$ (G-cm) for $\Delta y/\sigma_y=5\%$	0.67	0.48	0.21
$\int B_x ds$ (G-cm) for $\Delta y/\sigma_y=3\%$	0.40	0.29	0.13

SUMMARY AND OUTLOOK

A new BTS transfer line has been designed for the NIK injection scheme at TPS, following the relocation of the injection point 1.8 meters upstream to create approximately 5 meters of space for additional insertion devices. To achieve this, the design meticulously accounts for geometrical constraints between the existing booster and storage rings, avoids physical conflicts with storage ring components such as quadrupoles and sextupoles, and ensures necessary drift space for personnel access. Using MAD-X and AT for lattice development and numerical simulations, the research evaluates injection efficiency under various initial conditions and examines the NIK's perturbation on the stored beam.

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