REVISION OF BOOSTER TO STORAGE RING TRANSPORT LINE DESIGN AND INJECTION SCHEME FOR TOP-UP OPERATION AT NSRRC

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Abstract

In order to help the operation of constant current, the optics of booster to storage ring transport line (BTS) design is reinvestigated[1]. The initial Twiss parameters are derived by measurement. The optics of the transport line is readjusted according to the measured initial beam parameters. The design of pulse width of the injection kicker is also changed from 1.2 μs to 2.0 μs. The injection scheme is reviewed and the effects of the kicker error on both injected and stored beam are investigated and shown in this report.

DETERMINE THE INITIAL BEAM PARAMETERS OF BTS WITH MEASUREMENT

The initial beam parameters of booster to storage ring transport line (BTS) are measured. We use the method of σ matrix to measure the initial Twiss parameters and emittance. The Courant-Snyder invariant defined by

$$\varepsilon = \gamma(s)u(s)^2 + 2\alpha(s)u(s)u'(s) + \beta(s)u'(s)^2 = \frac{1}{\beta(s)}\{u(s)^2 + [\alpha(s)u(s) + \beta(s)u'(s)]^2\},$$

where α, β, γ are Courant-Snyder variables also called Twiss parameters, ε is the emittance of the ring, u represents the transverse coordinate x or y. The σ matrix of a beam distribution is defined as[2]

$$\sigma(s) = \begin{pmatrix} \sigma_{11}(s) & \sigma_{12}(s) \\ \sigma_{21}(s) & \sigma_{22}(s) \end{pmatrix} = \varepsilon \begin{pmatrix} \beta(s) & -\alpha(s) \\ -\alpha(s) & \gamma(s) \end{pmatrix} \quad \sigma^{-1} = \frac{1}{\varepsilon}\begin{pmatrix} \gamma & \alpha \\ \alpha & \beta \end{pmatrix}$$

$$\sigma_{22}u(s)^2 - 2\sigma_{12}u(s)u'(s) + \sigma_{11}u'(s)^2 = \varepsilon^2$$

$$u^T\sigma^{-1}u = 1 \quad \Rightarrow \quad u_2^T\sigma_2^{-1}u_2 = u_1^T\sigma_1^{-1}u_1$$

$$u_2 = M(s_2, s_1)\, u_1 = \begin{pmatrix} c(s) & c(s) \\ c'(s) & s'(s) \end{pmatrix} u_1$$

$$\sigma_2 = M(s_2,s_1)\sigma_1 M^T(s_2,s_1),$$

where $M(s_2,s_1)$ is the transform matrix from S_1 to S_2., The transform matrix of quadrupole magnet with thin length approximation is $M_Q = \begin{pmatrix} 1 & 0 \\ -k\ell & 1 \end{pmatrix}$, where k is the quadrupole strength in unit m^{-2}, ℓ is the quadrupole length. By properly adjusting the quadrupole strength and measure the beam size (i.e. σ_{11}) at the screen D distance down stream the quadrupole. The variation of the measured beam size (σ_{11}) will show quadratic dependency on the quadrupole strength k. The component of the sigma matrix at the quadrupole can be derived by fitting quadratic curve according to the following formula:

$$\begin{aligned} \sigma_{11,s} &= c^2\sigma_{11,Q} + 2cs\sigma_{12,Q} + s^2\sigma_{22,Q} \\ \sigma_{12,s} &= cc'\sigma_{11,Q} + (cs' + c's)\sigma_{12,Q} + ss'\sigma_{22,Q}, \\ \sigma_{22,s} &= c'^2\sigma_{11,Q} + 2c's'\sigma_{12,Q} + s'^2\sigma_{22,Q} \end{aligned}$$

where

$$c = 1 - Dk\ell, \quad s = D, \quad c' = -k\ell, \quad s' = 1$$

$$\sigma_{11,s} = D^2\ell^2\sigma_{11,Q}k^2 - 2(D\ell\sigma_{11,Q} + D^2\ell\sigma_{12,Q})k + (\sigma_{11,Q} + 2D\sigma_{12,Q} + D^2\sigma_{22,Q})$$

We choose to adjust the first defocusing quadrupole, Q1, to derive the vertical beam parameters and the focussing, Q2, to derive the horizontal beam parameters. The measured beam size at screen 2, SCN2, and fitting results are shown in Figure 1 and Figure 2 respectively. The position of Q1, Q2 and screen are indicated in Figure 4.

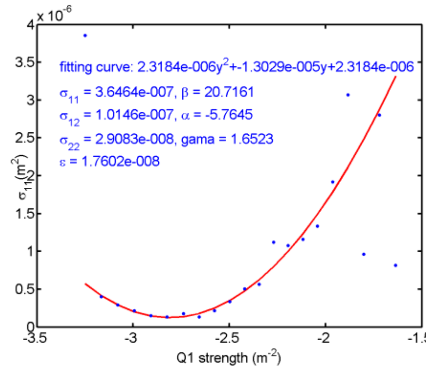

Figure 1: Measurement of vertical beam size versus the strength of defocusing quadrupole Q1. The vertical beam parameters α_y =-5.7465, β_y = 20.7161, γ_y = 1.6523, and vertical emittance ε_y=-1.7602e-8 m.rad at Q1 are deduced.

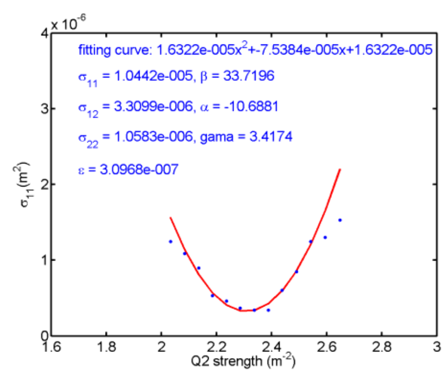

Figure 2: Measurement of horizontal beam size versus the strength of focusing quadrupole Q2. The horizontal beam parameters α_y =-10.6881, β_y = 33.7196, γ_y = 3.4174 and horizontal emittance ε_y=3.0968e-8 m.rad at Q2 are deduced.

We can also measure the dispersion function at the screens by adjusting the extraction beam energy from booster. We change the extraction time from the booster to adjust the extraction beam energy. The beam position will shift on the screen if the screen is located at the non

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dispersion free region due to the energy offset. The shift δx is according to $\delta x = \eta \delta p/p$ where η is the dispersion function and $\delta p/p$ is the percentage of energy difference. By measuring the dispersion function at two screens, we can derived the derivative of the dispersion function at the first screen. We choose to measure the beam position shift versus the delay time of booster extraction trigger system at screen 1 and screen 2. The position of the screen is indicated in Figure 4. One of the measured results is shown in Figure 3. The derived dispersion function at screen 1 is -0.48662 m and is -0.33084 m at screen 2. Therefore the value of derivative of the dispersion function at screen 1 is -0.1460.

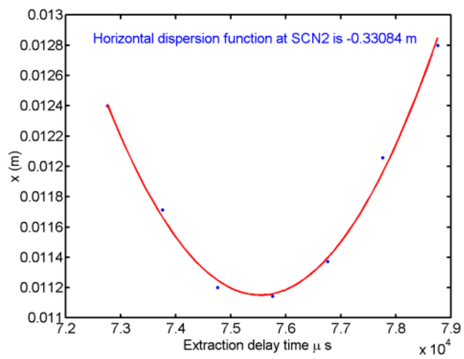

Figure 3: Beam position shift versus the delay time of booster extraction trigger system at screen 2. The derived dispersion function at screen 2 is -0.33084 m.

With these measurement data we can derived the initial Twiss parameter at the beginning of the BTS transport line. The initial condition at the extraction septum end is summarized in Table 1. The lattice function with the old designed magnet settings with the initial Twiss parameters of Table 1 are shown in Figure 4(green line). We need to readjust the magnet settings of the transport line to bring back the transport line lattice design. The Twiss functions of new BTS magnet settings with these initial values are shown in Figure 4(blue line).

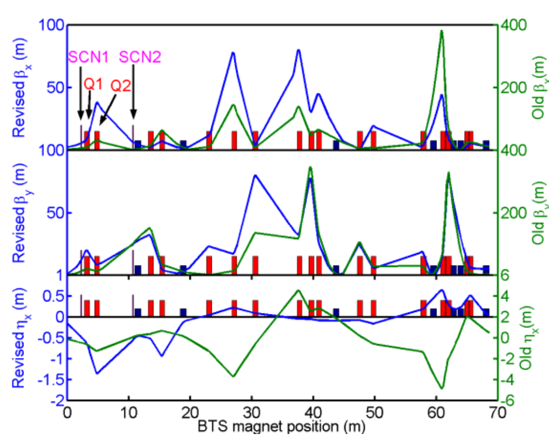

Figure 4 Revised BTS lattice function. The blue lines are revised lattice function. The green lines are old magnet setting with the initial Twiss parameters of Table 1. The blue blocks and red blocks represent the position of dipole and quadrupole respectively. The screens and quadrupoles we use in the measurement are indicated.

Table 1: Measured initial Twiss parameters of BTS transport line at the end of booster extraction septum

	α	β	D	D'	ε(m.rad)
x	-0.201	2.260	-0.152	-0.146	3.10e-7
y	-0.561	0.796	0.0	0.0	1.76e-8

EFFECTS OF KICKER ERROR DURING INJECTION

In order to reduce the kicker pulse jitter and amplitude stability, the kicker half sine pulse width is lengthened form 1.2 μs to 2.0 μs. The revolution time of the TLS is 0.4 μs. The effects of kicker error during injection are analyzed. The new kicker parameters are as followings: Maximum kicker strength is 11.65mrad, kicker length is 40 cm and kicker pulse (half sine) is 2.0 μs. The schematic arrangement of the four kickers and the bumper height changes during the injection is shown in Figure 5. The magnitude of the magnet field of the four kickers is the same, with K1 and K4 the same direction and K2 and K3 the opposite to K1. One of the measured kicker wave form from the current transformer on the current loop of the kicker magnet is shown in Figure 6. The converting curve from the CT reading to the integrated kicker magnetic field is provided by our magnet measurement group[3].

The analyses of the kicker errors include the effects of ±2 ns, ±4 ns time jitter and ±0.1%, ±0.5%, ±1% amplitude stability. We consider the analyses only in the horizontal plane since the beam is injected from the horizontal plane. A Gaussian beam distribution of ten thousand particles of the horizontal phase space of the injected beam is generated according to the Twiss function at the end of the BTS as shown in Figure 4. A stored Gaussian beam in horizontal phase space is also generated. A five turn particle phase space tracking during the injection kicker firing is performed. The horizontal phase space evolution of the beam in five turns during the kicker fire without kicker errors is shown in Figure 7. The single injected beam capture efficiency and the stored beam survival percentage are calculated after the tracking. Since we use multibunch injection, the bunch train from the booster is not single beam. The maximum bunch train from booster is 120 bunches. We take this into consideration in our errors analyses. In Figure 8 we show the injected beam capture efficiency versus different bunch index in the booster under the influence of kicker time jitter and amplitude stability. The booster bunch index is from 1 to 120. The on top injection occurred at bunch index of 60. In Figure 9 we show the stored beam survival percentage versus bunch index of the stored beam which is from 1 to maximum of 200 under the same errors. The errors we use to simulate are the worst case combination i.e. the errors of the four kickers add up in the direction to make the total error the biggest.

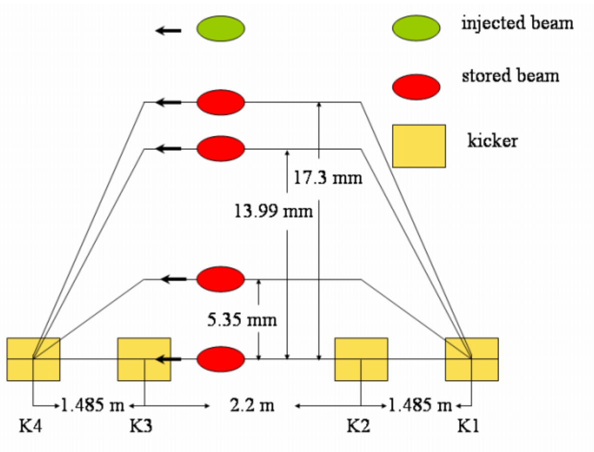

Figure 5: Schematic layout of the injection section and the bumper height evolution during injection.

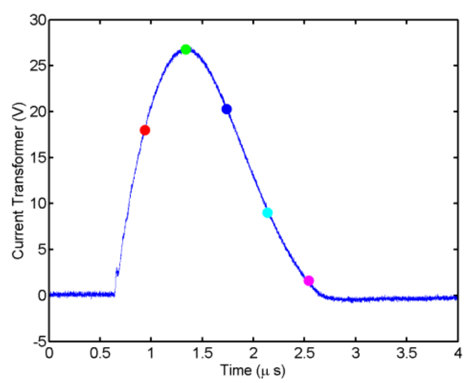

Figure 6: One of the measured kicker wave form from the current transformer on the current loop of the kicker magnet is shown. The colour labels mark on the curve with a converting factor[3] represent a corresponding kicker field strength the stored beam experienced during the on top injection. This can be crossed reference to Figure 7.

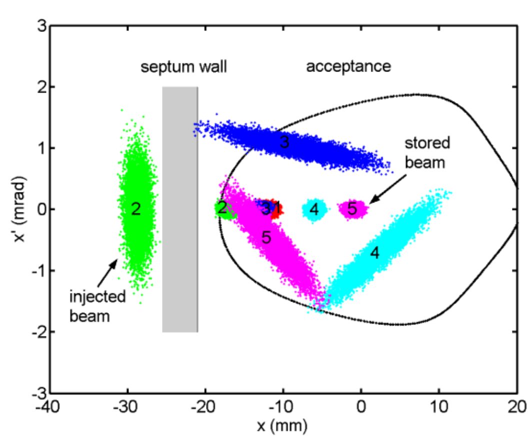

Figure 7: Horizontal phase spaces tracking of on top injection at the injection point, the five turns during the kicker fire without kicker errors are shown. Different colour represents different turn of the tracking.

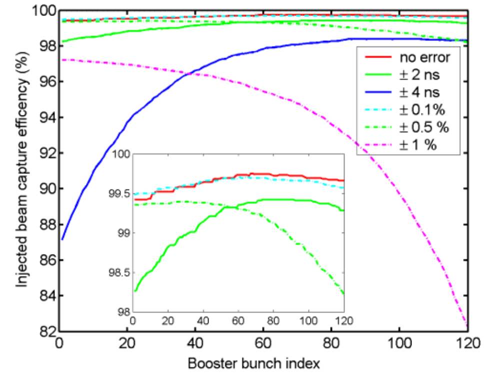

Figure 8 Injected beam capture efficiency.

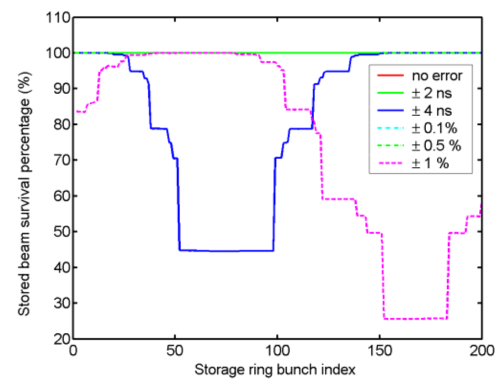

Figure 9: Stored beam survival percentages. There are no stored beam lose of kicker pulse time jitter 2 ns and the amplitude stability smaller than 0.5%.

DISCUSSION

The measurement of the initial condition of BTS helps to revise the BTS magnet setting. This also explains why the BTS magnet setting of daily operation is different from the design value planed at fourteen years ago[1].

In the study of the injection kicker error we find for efficient injected beam capture and no stored beam loss the kicker pulse time jitter should less than 2 ns and the amplitude stability smaller than 0.5%. If the error is small the length of bunch train from booster does not affect the injection efficiency much. For large error, shorter booster bunch train and proper extraction time will help to minimize the effect of the error as shown in Figure 8. The injection efficiency at on top injection without error surprisingly does not reach 100%. One reason is the measured horizontal emittance from booster is 3.10e-7 m.rad as shown in Table 1, which is two times larger than the design value of 1.59e-7 m.rad.

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[3] Tai-Ching Fan, et al., "Magnetic Field Measurement on a Refined Kicker”, this proceedings.

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