INJECTION SIMULATIONS FOR NSLS-II STORAGE RING*

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Abstract

The NSLS-II storage ring [1] will operate in the top-off mode in order to achieve the stability required for full utilization of ultra-small emittance. The injection process is expected to have near 100% efficiency in order to reduce radiation levels. This task is complicated by strong nonlinearities produced by the sextupoles and insertion devices. The simulations described below are perfomed to establish requirements for the injection system including emittance of the injected beam and its stability.

INTRODUCTION

The NSLS-II storage ring lattice will have 30 double-bend achromatic cells. The equilibrium emittance for bare lattice is expected to be around 2 nm and the damping wigglers will reduce emittance down to 0.5 nm [2]. The lattice is designed to have dynamic aperture at least 15 mm for realistic accelerator.

Thirty skew quadrupoles will be used to correct the linear coupling. They will also generate a vertical dispersion wave in order to provide acceptable beam lifetime by increasing vertical beam size to the diffraction limited level [3].

Tight tolerances on the alignment errors and multipole field quality are adopted to achieve ultimate performance. Alignment tolerances for the major components are shown in Table 1.

Table 1. Alignment tolerances for NSLS-II storage ring.

Element	Position	Roll
Girder	0.1 mm	0.5 mrad
Quadrupole on girder	0.03 mm	0.2 mrad
Sextupole on girder	0.03 mm	0.2 mrad
Dipole	0.1 mm	0.5 mrad

INJECTION STRAIGHT GEOMETRY

The injection straight geometry is described in [4]. The closed injection bump for the stored beam is created by four fast kickers located in the 8 meter injection straight. The injection point is in the center of the straight. The kickers generate half-sine pulse with duration of about two revolution periods. The peak amplitude of injection bump is 15 mm. Non-interleaved placement of injection hardware simplifies the design and minimizes the influence on the stored beam.

The wall thickness of pulsed septum is chosen to be 3 mm. Taking into the account mechanical tolerances and sizes of the injected and stored beams one can expect 6 to 9 mm separation between the centers of incoming and circulating beams. The beam optics of the transport line is matched for optimal injection. The optimization of β-functions is done that injected beam occupies minimal phase space in the storage ring.

INJECTION SIMULATIONS WITH TRACY-II

The simulations were performed in frame of the Tracy-II package for the lattice shown in the conceptual design report [1]. The tracking was done with and without synchrotron motion and/or damping.

The simulations were done using the following steps:

- The realistic models (machine files) of the storage ring were prepared using tolerances for alignment errors (including rolls of magnetic elements) and multipole components of the magnetic field. The rectangular apertures for each element were loaded into the model as well. Vertical aperture at the locations of insertion devices was 5 mm (full gap).
- The closed orbit was corrected with 30 microns r.m.s. deviation from the magnetic centers of the quadrupoles adjacent to beam position monitors.
- The tunes and coupling were corrected and 20 mm vertical dispersion wave was created.
- The particles with desired distribution in the phase space were generated.
- The generated particles were tracked for predetermined number of turns. If the particle transverse position at any point exceeded the corresponding aperture size then this particle was considered lost and tracking was stopped.

The nominal parameters of the injected beam are shown in Table 2.

Table 2. Nominal parameters of injected beam.

Parameter	Value
Horizontal emittance	34 nm
Vertical emittance	3.4 nm
Energy spread	0.1%
Bunch length	50 ps

Stay Clear Aperture

Beam envelope for the injected beam with nominal parameters was used to find the stay clear aperture of the storage ring. The injected particles were tracked for 500 turns. The vertical amplitude of betatron motion in the short straight sections is well below half gap of insertion devices, the amplitude of horizontal motion reached 16 mm in the long straights.

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Aiming stability of the beam

In order to determine requirements on the aiming stability of the injected beam we have done tracking of 200 particles with the nominal distribution for 500 turns. No synchrotron motion and damping was assumed. The dependence of capture efficiency on the displacement and aiming angle of the incoming beam is shown in Figures from 1 to 4.

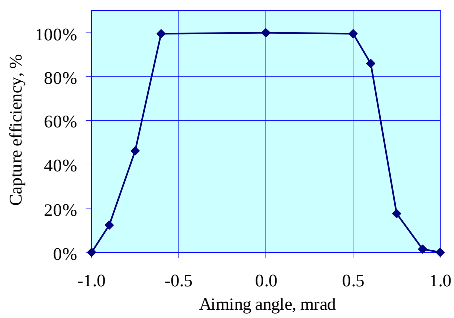

Fig. 1. Dependence of capture efficiency on the horizontal aiming angle of the injected beam.

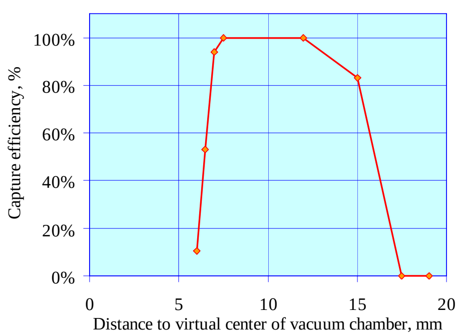

Fig. 2. Dependence of the capture efficiency on the distance between centers of the injected and stored beam. The particle with smaller separation are lost on the wall of the septum which is 6.4 mm away from the circulating beam.

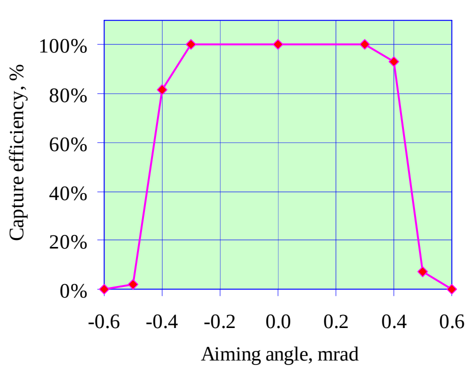

Fig. 3. Dependence of capture efficiency on the vertical aiming angle of the injected beam.

The horizontal displacement is actually distance between centers of the beams. The nominal distance between centers of the beams was 9 mm.

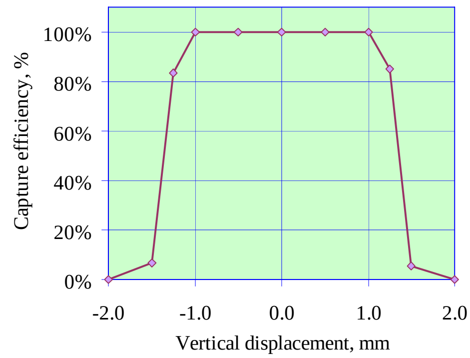

Fig. 4. Dependence of capture efficiency on the vertical position of the injected beam.

Energy and time mismatch

Influence of the longitudinal parameters was done by tracking for 10000 turns (two damping times) of 200 particles. The energy offsets and times of arrival were varied. The results of simulations are shown in Figures 5 and 6.

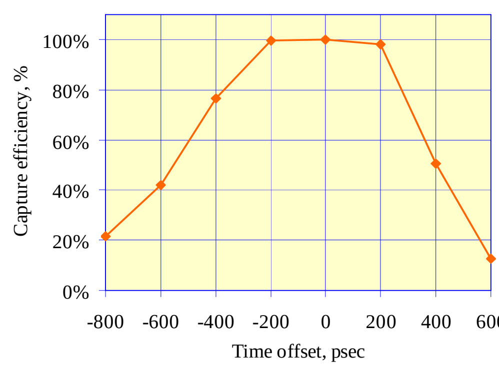

Fig. 5. Dependence of capture efficiency on the relative delay of the injected beam with respect to the stored beam.

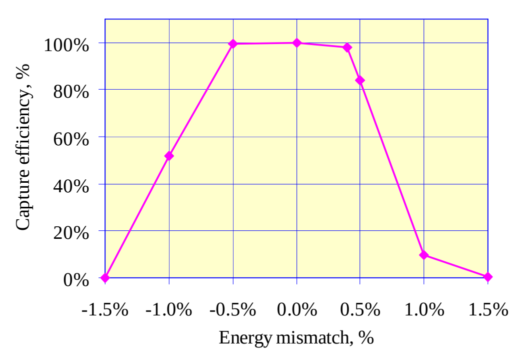

Fig. 6. Dependence of capture efficiency on the energy mismatch of the injected beam.

Tolerances for injection system stability

The requirements for stability of injected beam, which are based on the abovementioned results of the particle tracking, are shown in Table 3.

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Table 3. Tolerances for r.m.s. deviations of injected beam from the nominal values.

Parameter	Value
Horizontal position	1 mm
Horizontal angle	0.2 mrad
Vertical position	0.25 mm
Vertical angle	0.08 mrad
Energy mismatch	0.17%
Bunch delay	85 ps

To verify the acceptability of such parameters we have done tracking of 500 particle for 10000 turns for 25 seeds of alignment and field errors. The observed capture efficiency is 97.7±1.6%.

TRACKING WITH ELEGANT

For comparison we performed injection simulations using the ELEGANT code [5] with the similar ring model and beam parameters as for the tracking with TRACY (however yet excluding rolls in the lattice elements and coupling correction).

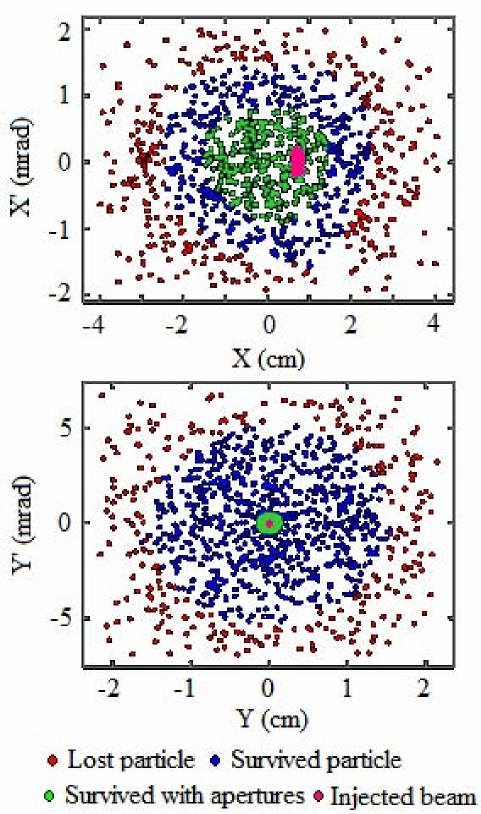

Fig. 7. Storage ring acceptance available for injection

In order to access a value of the phase space area available for injection we track particles with initial parameters shown in Fig. 7. Blue points correspond to the particles survived for 500 turns, when the red ones are lost due to the ring dynamic aperture. Physical apertures limit the ring acceptance to the area filled by the green particles. The phase space occupied by the injected beam with realistic parameters is shown pink. This plot exhibits sufficient margin for the injected beam in both horizontal and vertical planes.

We also performed tolerance studies in the same fashion as with TRACY. During tracking we detuned centroid of the injected beam in every dimension from the nominal position until injection rate deviated from 100%. Computed ranges of the lossless injection are listed in the Table 4.

Table 4. Range of beam parameters for a lossless injection

Parameter	Range of 100% injection efficiency
Horizontal position	-10..10 mm
Horizontal angle	-3..2 mrad
Vertical position	-1.1..1.3 mm
Vertical angle	-0.4..0.3 mrad
Energy offset	-1.7..1.1%

CONCLUSION

We have done systematic study of the capture efficiency of the injected beam into the NSLS-II storage ring with realistic parameters. The simulations confirmed feasibility of lossless injection with compact booster.

Based on the tracking the requirements for the injection system were established.

The work on the injection tracking will continue to accommodate the changes in the baseline lattice and to account for nonlinearities introduced by the insertion devices. Future studies of the injection process with ELEGANT will focus on including coupling correction and models of insertion devices, calculating loss patterns and simulation of realistic injection errors.

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