TOP-UP SAFETY SIMULATIONS FOR THE TPS STORAGE RING

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Abstract

TPS is a 3 GeV third generation light source[1] and planed to operate in the top-up mode scheme. During the top-up injection, the photon shutter of beamline are always open. To ensure the radiation safety of beamline experiments, we studied the possible particle leakage to ID and neighboring bending beamlines. The effects of magnets errors and beam chamber misalignments are investigated.

INTRODUCTION

The storage ring consists of 24 straight sections separated by 24 arc sections. Each section contains a number of bending magnets, quadrupoles, sextupoles and corrector magnets. The photon beams from the IDs and bending magnets are extracted along photon beamlines. A schematic layout of one unit section containing two bending magnets and one ID straight is shown in Fig. 1 below.

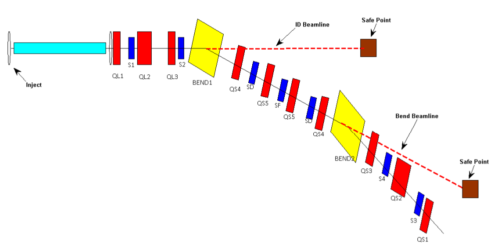


Figure 1:The locations of main accelerator components is shown in the layout of one unit section.

A photon beamline can be considered safe to operate in the top-up mode if any one of the following statements can be demonstrated to be true[2]:

- It is not possible for a bunch of electrons travelling *forward* from an ID straight or a bending magnet to pass beyond a pre-determined 'safe point' in the beamline.
- It is not possible for a bunch of electrons travelling *backward* from the beamline safe point to pass beyond the ID straight or a bending magnet.
- The trajectories of electrons travelling forwards from an ID straight or a bending magnet do not overlap with those of electrons travelling backwards from the safe point in the beamline at any intermediate location.

The above statements were used as the basis in our tracking studies.

The possible phase space of particles from ID was determined by the geometry of ID chamber with all possible errors. Figure 2 shows the ID geometry and the corresponding phase space. The phase space for particles from beamline was determined according to the beamline geometry with a looser condition for conservative estimation. Figure 3 shows the beamline geometry and the corresponding phase space. Since the coordinate system in storage ring and beamline are different, we need to perform a coordinate transformation.

In the tracking studies, the intersecting location was selected at BEND1 entrance. The phase space tracking provided us the information of possible particle leakage. During the tracking, we performed a beam chamber limitation check on each lattice component. For the neighboring bending beamline, the backward tracking ~~is~~ was performed by including the lattice from the safety point of bending beamline to the intersecting location. We used Accelerator Toolbox (AT) [3] with MATLAB as the analysis platform.

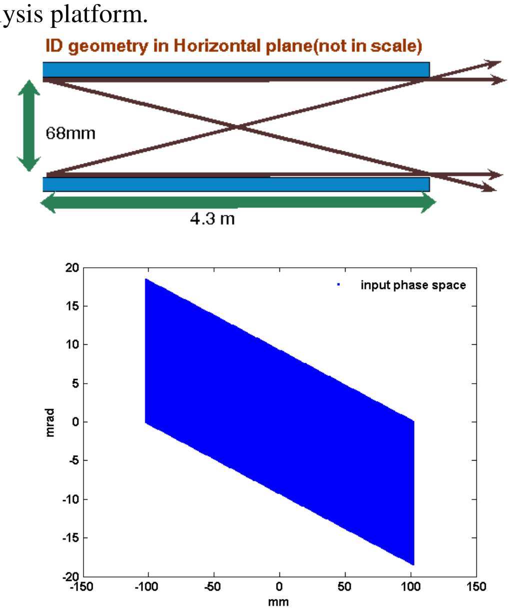
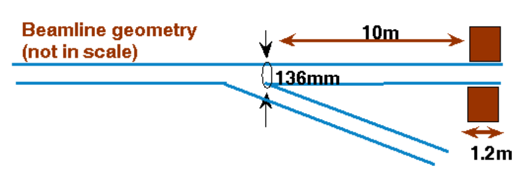


Figure 2: The input distribution used for forward tracking. The top figure indicates the possible motion of particle going through insertion device. The lower figure is the phase space for ID straight section.



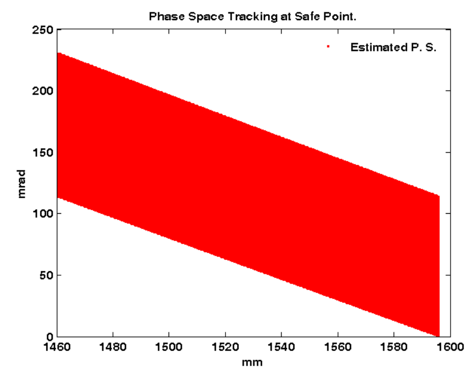


Figure 3: The input distribution used for backward tracking. The top figure shows the beamline geometry. The lower figure is the phase space for beamline section .

MAGNET MODELING AND ERROR SCENARIO

The real magnetic fields are no longer well described by a series of multipoles. It has been necessary to use the 2D field profiles for large amplitudes and the FEA code[2] to accurately describe the magnetic fields. The MATLAB-based tracking code AT and the new pass method in the FEA code were used for tracking through the bending magnets, quadrupoles and sextupoles. Each of them was thoroughly tested to ensure that the path of the tracked particle at small amplitude closely followed that predicted by the original pass methods in AT. The path of tracked particle with expected field roll-off at large amplitudes was obtained using the FEA code. Results of particle tracking through a quadrupole and a sextupole using both new and old pass methods are shown in Fig. 4 below.

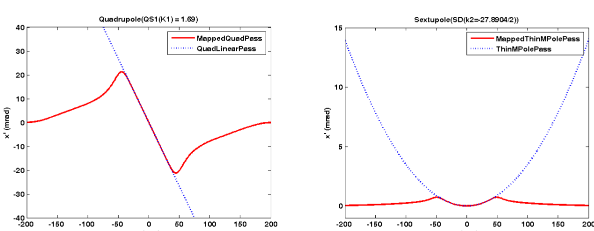


Figure 4: Results of particle tracking through a quadrupole (left) and a sextupole (right) using both new and old pass methods.

To investigate effects due to magnet errors, we varied the quadrupole and sextupole fields randomly from zero (OFF) to 1.5 times larger than the nominal value by the asymmetry Gaussian distribution and truncated it at 0 and 1.5 respectively. The range of corrector magnets were randomly varied from -1.2 mrad to 1.2 mrad by one sigma truncated Gaussian distribution. The error scenario been considered was beam energy error up to +20% for an energy mismatch between the injected and stored beam. We investigated 200 pseudo-machines to ensure enough coverage of possible error scenarios. The error scenario used in tracking particles is shown in Table 1 below.

Table 1: The Error Scenarios for Tracking Particles

Error Source	Range for simulation
Q ($\Delta K1/K1$)	-100% to +50%
S ($\Delta K2/K2$)	-100% to +50%
COR (θ)	±1.2mrad
E($\Delta p/p$)	0% to 20%

RESULTS FOR ID BEAMLINES

The tracking result for ID beamline is shown in Fig. 5. The top plot shows the ID beamline section used in the tracking studies. The lower left plot shows the initial phase space coordinates for the forward tracked beam. The lower right plot shows the initial coordinates for the backward tracked beam, and the lower middle plot compares the final two distributions. In this example the two distributions does not overlap, indicating a safe combination of magnet strengths used in the tracking study.

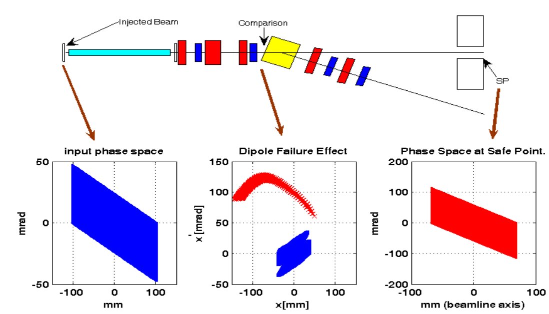


Figure 5: The top plot shows the ID beamline section in the storage ring. The lower left plot shows the initial phase space coordinates for the forwards track beam(blue), the lower right plot shows the initial coordinates for the back tracked beam(red), and the lower middle plot compares the final two distributions.

Results of varying the beam energy up to +20% is shown in Fig. 6. As shown in Fig. 6 there is a large degree of separation between the particle distributions tracked from the ID straight section and beamline at the entrance of the first dipole over this range of energies. The phase space evolutions are brought closer together with increasing injected beam energy.

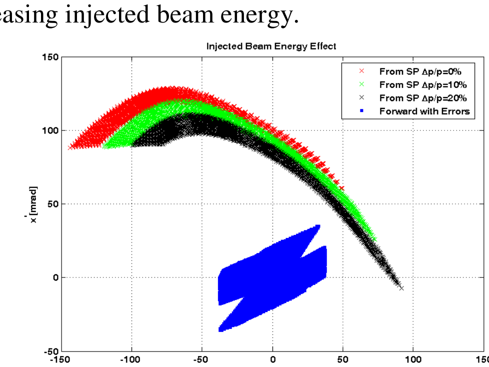


Figure 6: Phase space boundaries at the BEND1 entrance. Different errors of particle energy were assumed from 0%

to +20%. Boundaries tracked forward from the ID straight section are dot mark (blue) and backwards from the beamline are cross mark (red, green and black).

The magnet that has the strongest effect on the particle trajectories is the bending magnet. If the bending magnet BEND1 is switched off, the electrons travelling forward from the ID straight section will follow a straight line and pass straight down the ID beamline. This scenario is depicted in Fig 7. The phase space boundaries from the ID straight section and beamline begin to overlap when the strength of downstream bending magnet has fallen to 40% of the nominal value. This situation is not a case for concern, since simulations for energy acceptance have shown it is not possible to store beam with energy errors outside the range from +4% and -6%[4]. Besides the stored beam interlock would inhibit the injection before a dangerous situation was reached.

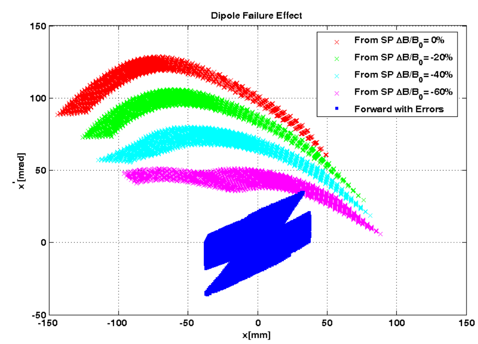


Fig 7: Phase space boundaries tracked to the BEND1 entrance for varying degrees of bending magnet failure.

RESULTS FOR BENDING BEAMLINES

The tracking result for bending beamline is shown in Fig. 8. The top plot shows the bending beamline section used for the tracking studies. The lower left plot shows the initial phase space coordinates for the forward tracked beam. The lower right plot shows the initial coordinates for the backward tracked beam, and the lower middle plot compares the final two distributions. In this example the two distributions do not overlap, indicating a safe combination of magnet strengths was used.

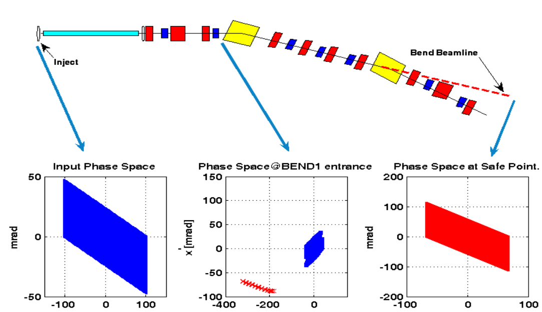


Figure 8: The top plot shows the bending beamline section of the storage ring. The lower left plot shows the initial phase space coordinates for the forward tracked beam. The lower right plot shows the initial coordinates for the backward tracked beam, and the lower middle plot compares the final two distributions.

As shown in Fig. 9 the phase space boundaries from the ID straight section and bending beamline begin to overlap once the strength of bending magnet BEND2 has fallen to 40% of its nominal value. It is similar to the results in the ID beamline study.

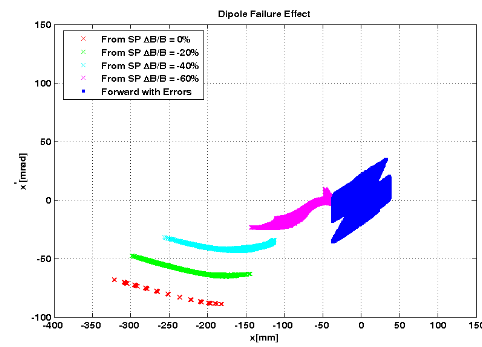


Figure 9: The phase space boundaries from the ID straight section and bending beamline begin to overlap once the strength of bending magnet BEND2 has fallen to 40% of its nominal value.

SUMMARY

The safety issues of TPS top-up injection were investigated with various error scenarios. These analyses were performed with TPS parameters and some conservative assumption. We conclude that the TPS top-up injection is safe when all magnets behave in normal condition. When errors occurred in the magnets, only the bending magnet error could possibly induce the particle leakage to the beamline. The interlock system for bending magnets is necessary to ensure a safe top-up operation for the beamline experiments.

ACKNOLEDGEMENT

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