Conceptual design of Hefei Advanced Light Source (HALS) injection system*

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Abstract The Hefei Advanced Light Source(HALS) is a super low emittance storage ring and has a very short beam life time. In order to run the ring stablely, top-up injection will be necessary. The injection system will greatly affect the quality of beam. This article first gives a physics design of the injecting system. Then the injecting system is tracked under different errors. The responses of storage beam and injecting beam are given in the article.

Key words injected beam, stored beam, tracking, elegant, kicker

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1 Introduction

The Hefei advance light source (HALS) is a super low emittance storage ring. It will be one of the most advanced VUV and soft X-ray light sources in the world, with higher brilliance, better coherence, more insertion devices than these of the current Hefei Light Source (HLS). HALS's circumference is 392 m long. It has 18 super periods. Each super period is a FBA lattice. 18 long straight sections in the ring can be used to install undulators, wigglers, injection system, RF system and so on. Except the sections used for injection and damping wiggler, there are more than 12 long straight sections for 6 m long insertion devices.

Table 1 gives the main parameters of HALS. More detailed descriptions can be found in our other publications[1—3]. HALS's emittance will be less than 0.2 nm·rad after the damping wiggles are installed. The emittance is so small that the ring has a very poor beam life time. Its beam life time is less than 1 hour. In order to run the ring stabl, top-up injection will be necessary. To minimize the disruption of the operations, the design of injection system will be very important. It also should be capable of filling the beam from empty to full charge in a reasonable time.

Table 1. Main parameters of HALS.

parameters	values
circumference	392 m
energy	1.5 GeV
lattice structure	FBA
super-period number	18
straight section length	7.6 m
emittance of bare lattice	0.27 nm·rad
emittance with damping Wigglers	<0.20 nm·rad
transverse tunes	29.32,10.28
natural chromaticities	−55,−51
momentum compaction factor	0.00047
energy spread	0.00022
harmonic number	648

2 Physics design of HALS injection system

To maintain high quality of the HALS ring, the injection system should obey the following demand. First, the ring runs in top-up operation mode. In this mode, we require that the injection efficiency to reach 100%. No electrons should be lost in the injection process because of the problem of radiation

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protection. This also give a requirement to the beam from booster or LINAC. Second, the disturbance of injection to the stored beam must be small. The synchrotron users should not see the injection process and their experiments can go on without interruption. And in order to reduce the dependence on the lattice, the HALS injection system will be placed in one straight section. So the bump from kickers can be compensated perfectly.

The whole HALS injection system is located in a 7.6 m long straight section. It includes four kickers with separated power supplies. The four kickers are distributed symmetrically in the section. Each kicker is 0.3 m long. The space between kicker 1 and kicker 2 and also kicker 3 and kicker 4 is 1.3 m and the space of 3.2 m between kicker 2 and kicker 3 is used to place septum magnets. Septum is split into two parts for the convenience of installation. Table 2 give out the parameters of kickers and septums.

Table 2. The parameters of the injecting system

element	l/m	angle/mrad	B/T	rising time/μs
K1	0.3	6.25	0.1043	1.15
K2	0.3	-6.25	0.1043	1.15
K3	0.3	-6.25	0.1043	1.15
K4	0.3	6.25	0.1043	1.15
SEP1	0.918	55	0.30	60
SEP2	0.918	55	0.30	60

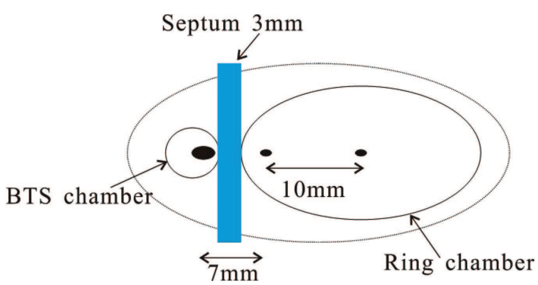

Fig. 1. The receiving space of injecting system.

The magnetic field waveform of kickers is a 2.3 μs sinusoidal waveform. The rising time and falling time each are 1.15 μs. The pulse length is about 1.76 times longer than the revolution time. So the injection beam will not see the kicker's magnetic field again. The kickers are set to produce a max bump height of 10 mm in a single turn. The max kick angle is about 6.25 mrad. The height of septum is 13 mm and the thickness of septum is 3 mm. The beam from booster is 17 mm high. Fig. 1 shows the receiving space of the HALS injecting system and show the positions of kicked and unkicked stored beams, as well as the position of the injected beam at the injection point. To increase the injection efficiency, the stored beam should be bumped as high as possible, so that at the injection point, the injected beam and the stored beam can be as close as possible, but at the same time, the space between the septum and beams should be large enough to prevent electrons from any scraping.

3 Tracking of HALS injection system

In order to check the performance of the design of the HALS injection system, Elegant[4] was used to track injection process. Elegant is a particle tracking code from APS. Elegant stands for "ELEctron Generation ANd Tracking", which is a 6D accelerator program generating particle distributions and tracking them.

3.1 Tracking of injected beam

By tracking the injected beam, we can determine the minimum acceptance required by the injection process, we simulated the electron distribution in x, x' phase space after the injection. The quality of the injected beam may play an important role in the efficiency of transport and injection which in turn, affects the radiation environment in the machine. We have begun to study the injection efficiency by tracking particles through the existing HALS lattice for a few turns. Description of the injection parameters is as the previous section. Fig. 2 illustrates the results of the tracking in the horizontal phase space where the injected beam's emittances are 1 nm·rad, 5 nm·rad, 20 nm·rad and 50 nm·rad separately. Each beam was tracked 5 turns. At the injection point, the injected beam's emittance affected the injection efficiency always. By simulation, an emittance smaller than 20 nm·rad of the injected matched beam can fulfill HALS's demand on the injection efficiency.

Errors can affect the performance of injection system. There are two kinds of injection errors mainly. One is the errors from injected beam, for example, the mismatching of the injected beam. This kind of error influences the injection efficiency, but does not affect the stored beam. Our attention was mainly paid to the errors from the elements of injection system. Errors from the other elements of ring influence the injection efficiency also. We will discuss them in other papers.

Errors from the elements of injection system include errors of peak field of kickers, the installation errors, the alignment errors and time errors of kickers, and also the residual field of septum. These errors will affect not only the motion of injected beam but also the motion of stored beam. So user's experiment

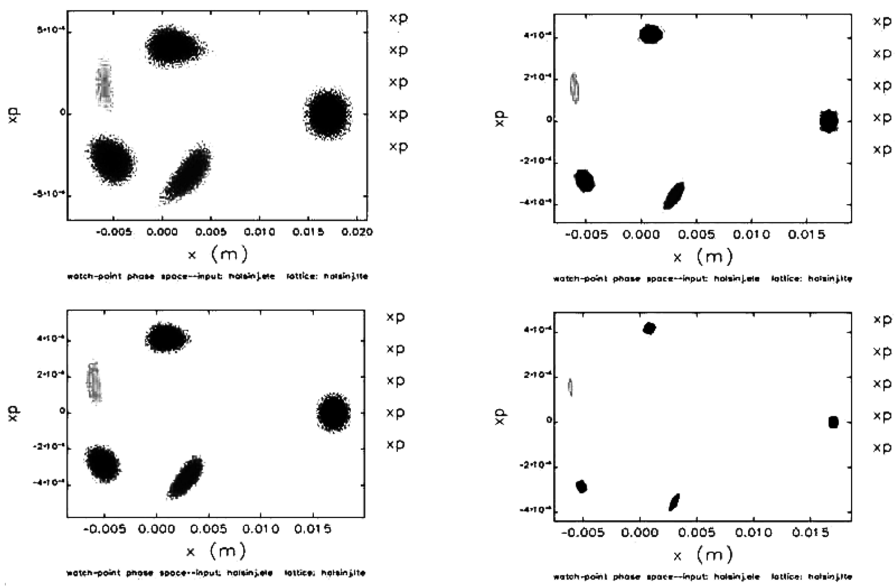

Fig. 2. Particle tracking for the injected beams. Left up: 50 nm·rad, left down: 20 nm·rad, right up: 5 nm·rad, right down: 1 nm·rad.

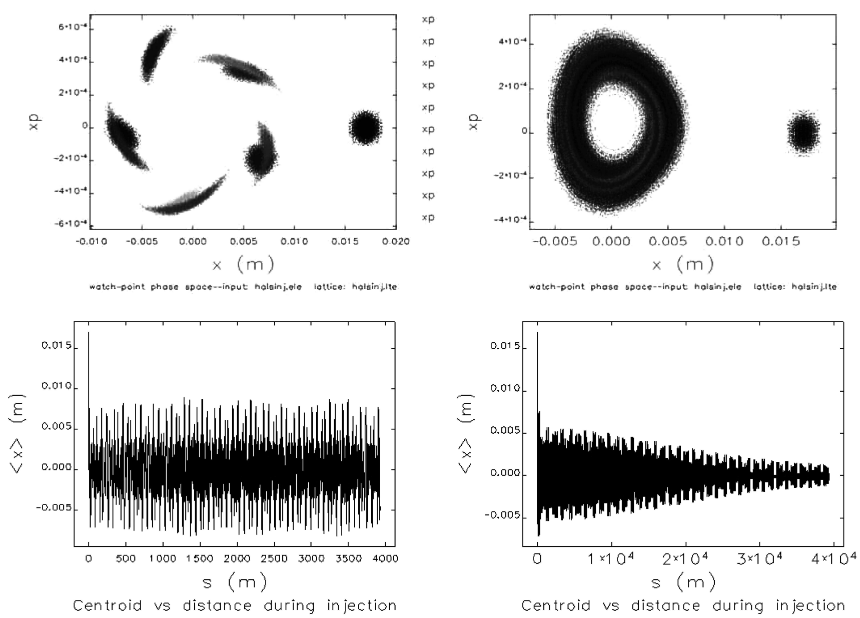

Fig. 3. Particle tracking for the injected beams. Left: 5 turns tracking, right: 50 turns, up: phase space, down: central trajectory.

is possible to be interrupted by injection with large errors.

Errors are considered as follows in the tracking. For kickers, the rms peak field error is set to 0.5%, the rms time error is set to 0.5 ns, and the rms rotation error is set to 0.5 mrad. To the four kickers, there is no correlation for the different kicker's errors because of the separating power supplies. We also assume a residual field of septum causes a 0.1 mrad angle kick at the height of 10 mm.

Figure 3 illustrates the results of the tracking where errors of the injection system are considered and the beam's emittance is 20 nm·rad. The figure shows the injected beam 5 turns and 50 turns of motion in the phase space under different errors(up two sub-figures). Two sub-figures at the bottom show the central trajectory of the injected beam in the ring. Comparing Fig. 2 and Fig. 3, errors distort the injected beam's distribution in the phase space and increase the residual oscillation of the central trajectory. The magnitude of oscillation is increased from 5 mm to 7 mm. This would reduce the efficiency of injection.

3.2 Tracking of the stored beam

The disturbance of the injection system to the stored beam in the ring must be considered also in the tracking. For the ideal injection, different stored beam bunches would undergo different kicker fields. The above half of bunches would see kicker field two times. The perfect bump would exist only in the injection straight section. There was not affection to the electric trajectory in the other part of the ring.

Figure 4 shows tracking result of stored beam in and after the injection when errors were added. Error setting was as same as the case of the injected beam. The left two are the phase space and central trajectory of bunches undergoing bump once. The right two are the phase space and central trajectory of bunches undergoing bump twice. After errors were added, perfect bump disappeared. A residual oscillation of 2 mm would disturb the motion of stored beam. It would require a damping time of about 0.06 s to be damped by synchrotron radiation.

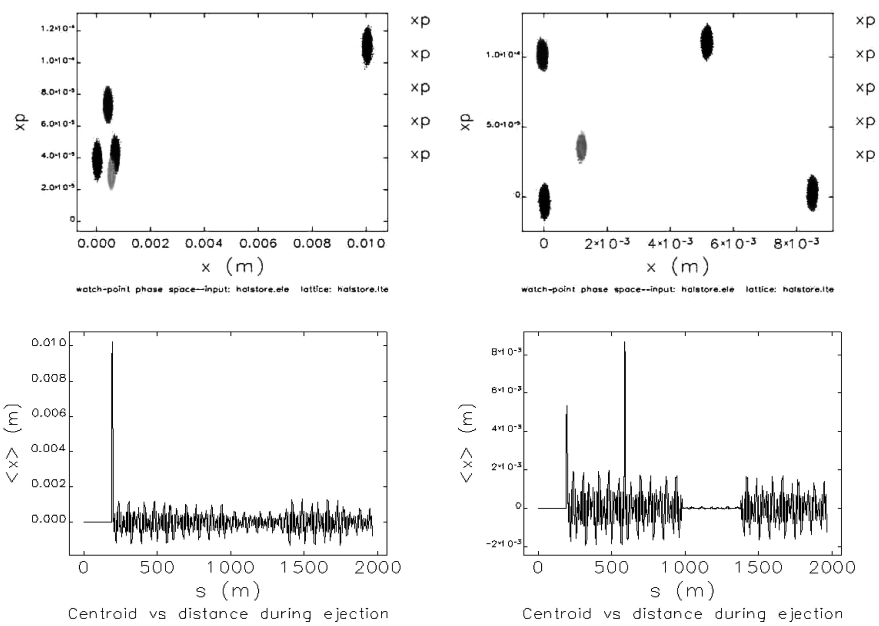

Fig. 4. The tracking results of stored beam in and after injection with errors,the left and the right are the phase space (up) and the central trajectory (down) of different stored bunches.

4 Summary and concluding remarks

Simulation shows that the matched beams emittance smaller than 20 nm·rad can reach a 100% injected efficiency. But the disturbance to the stored beams is large still. In order to reduce the residual oscillation of stored beam, we need to decrease the bump height in the future work. The time structure of kickers will be studied also in future. The unmatched injection, the errors of other system of ring, the lattice errors and disturbed close orbits are also our future works.

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