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OFF-ENERGY OFF-AXIS INJECTION WITH PULSED MULTIPOLE MAGNET INTO THE HALS STORAGE RING*

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Abstract

As a future Diffraction-Limited Storage Ring (DLSR) at NSRL, the Hefei Advanced Light Source (HALS) has been proposed and has a great progress in the lattice optimization. The nonlinear dynamics is well designed and shows good performance, which makes it easier for beam injection and gives us more choices to design a more suitable injection scheme. In this paper, a new off-energy off-axis pulsed multipole injection scheme is proposed. The off-energy beam is off-axis injected into the acceptance of the storage ring with one or several pulsed multipole kickers and meanwhile the stored beam is almost unaffected during the injection. The injection acceptance of the storage ring is analyzed and the injection scheme is preliminary designed. A series of tracking simulations are carried out and the results are presented.

INTRODUCTION

Hefei Advanced Light Source (HALS) [1] which is proposed by NSRL is a new VUV and soft X-ray diffraction-limited storage ring-based light source. In order to achieve world-class performance, the lattice of the storage ring is continuously designed and optimized with many newly developed design concepts in recent years, such as locally symmetric MBA [2] and interleaved dispersion bumps MBA [3]. Recently a well-designed 30×7BA lattice was determined as the base-line lattice version for the HALS storage ring [4]. This lattice achieved a very low natural emittance of 24.7 pm·rad at an electron beam energy of 2.4 GeV with longitudinal gradient bends and anti-bends employed. The main designed parameters of the HALS storage ring are shown in Table 1.

Table 1: Main Parameters of the HALS Storage Ring

Parameters	Values
Beam energy [GeV]	2.4
Circumference [m]	672
Number of cells	30
Natural emittance [pm·rad]	24.7
Momentum compaction factor	5.0×10^{-5}
Natural chromaticities	-96.5/-110.3
Transverse tunes	71.296/23.296

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In order to achieve such small natural emittance, many high gradient quadrupoles and strong chromaticity correction sextupoles are employed in the lattice design, which may seriously restrict the physical and dynamic aperture of the storage ring. Consequently, the conventional off-axis injection schemes that require sufficient physical and dynamic aperture are proved impossible to realize the beam injection for DLSR. To overcome the expected difficulties and limitations of DLSR, new on-axis injections have therefore been proposed and developed in recent years, such as swap-out injection scheme [5] and longitudinal injection scheme [6].

With the swap-out injection scheme, the stored bunches are completely swapped with the injection bunches, either bunch by bunch or with bunch trains, when beam current decreases below a top-up injection threshold. The required dynamic aperture is smallest in this scheme which can simply overcome the dynamic aperture limitation of DLSR. The technical requirement of the short pulsed kicker is not challenging when the swapping-out is performed bunch-train by bunch-train. But an accumulator ring is needed to prepare the injection beam which will significantly increase the complexity of the injection system and the construction costs.

The longitudinal injection scheme is another on-axis injection scheme where the off-energy injection beam can be transversely on-axis injected onto the corresponding off-energy closed orbit between two stored bunches by a pulsed dipole kicker. This injection scheme requires a small dynamic aperture whereas the momentum aperture should be large enough to realize the accumulation of the injected beam. In addition, to make sure the injection is fully transparent to the stored beam, the dipole kicker must be shorter than the bunch spacing, less than 10 ns even for the 100 MHz RF cavity, which is a major challenge for the technology of the pulsed dipole kicker.

Thanks to the well-designed lattice of the HALS storage ring, the dynamic aperture is more than 300 beam size and the momentum aperture is about 6% at the long straight section. Furthermore, off-momentum dynamic apertures are also rather good. Consequently, a new off-energy off-axis pulsed multipole injection scheme that do not require complex injection systems and very difficult kicker technology is designed for the HALS storage ring.

OFF-ENERGY OFF-AXIS INJECTION

Multipole kicker injection (MKI) scheme is an off-axis injection scheme very suitable for top-up injection. The injection beam is directly off-axis injected into the acceptance of the storage ring with a single multipole kicker,

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which is almost transparent to circulating bunches, but has a force on injection beam with some transverse position offset. This offset, which we call injection amplitude, can be expressed by

$$A_{inj} = \delta\eta + B \,, \tag{1}$$

where B denotes the initial amplitude of the beta oscillation which is limited by the dynamic aperture of the storage ring. $\delta\eta$ is the off-energy closed orbit that is determined by the energy deviation of the injected beam and the dispersion at the position of the kicker.

If the injection beam is on-energy ($\delta = 0$), the injection amplitude is only rely on the dynamic aperture. The traditional MKI therefore requires a large dynamic aperture. If the injection beam is placed onto the off-energy closed orbit with shifted beam energy ($\delta \neq 0, B = 0$), which has been proposed [7], the injection amplitude only depends on the dispersion at the position of the kicker and the momentum aperture which limits the energy deviation. In fact, it is difficult to introduce a large dispersion function into the low-emittance MBA lattices of DLSR. Considering the good nonlinear dynamic performance of the HALS lattice design, large momentum aperture and big enough off-energy dynamic aperture, we tried a new MKI scheme where the off-energy injection beam is inserted into the off-energy dynamic acceptance with a reasonable offset from the off-energy closed orbit ($\delta \neq 0, B \neq 0$). The schematic layout of injection devices for this new injection scheme is shown in Fig. 1.

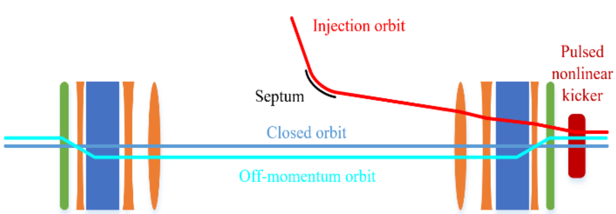

Figure 1: Schematic layout of injection devices for the off-energy off-axis multipole kicker injection.

The needed injection system is as simple as the traditional MKI scheme. And this injection method can increase the injection amplitude as much as possible which may reduce the technical requirements for the pulsed multipole kicker.

ACCEPTANCE ANALYSIS

The injection process is mainly to inject the beam into the acceptance of the storage ring. So it is very important to figure out the acceptance at the injection point before designing the detailed injection scheme. In order to increase the injection amplitude as much as possible, the main pulsed multipole kicker (K0) is placed at the position with large dispersion and enough installation space. The extra multipole kicker (K1) is added at the long straight section to match the phase space and improve the freedom of injection commissioning. Figure 2 shows the detailed layout of the injection devices with the linear optics of the HALS storage ring.

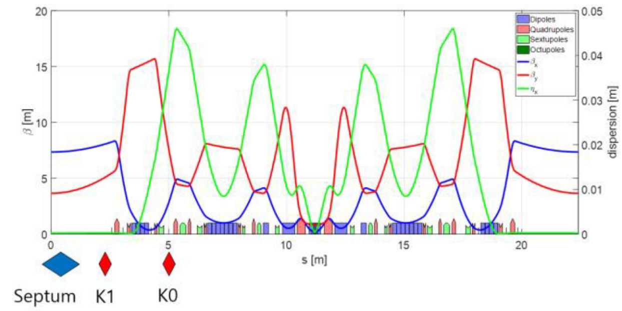

Figure 2: Detailed layout of the injection devices.

The energy deviation is set to -5% within the limit of the momentum aperture and the acceptance at the position of K0 is much larger than the energy deviation of 5%. The comparison result is presented in Fig. 3.

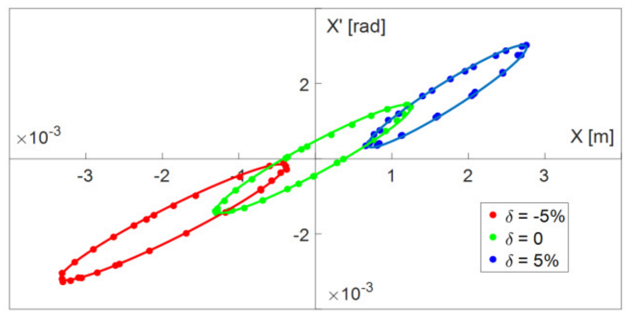

Figure 3: Comparison of the acceptance with different energy deviations.

Considering that the acceptance may shrink in real storage ring with the tolerance effect, the acceptance for injection is conservatively estimated. The largest injection amplitude at K0 is kept at 3 mm.

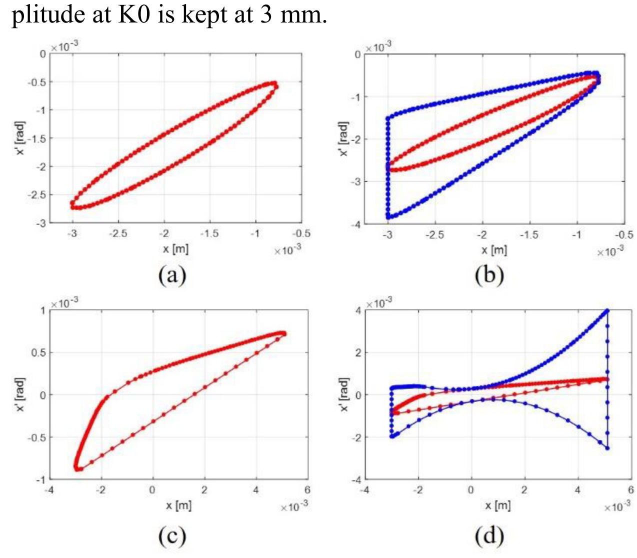

Figure 4: The progress of acceptance analysis.

The final acceptance for injection is shown in Fig. 4 (a). Including the kick of the pulsed multipole kicker, the acceptance can be enlarged as shown in Fig. 4 (b), where a standard pulsed sextupole is applied here to K0 and K1 with the magnet field B ≈ 300 Gs at the offset positon of 3

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mm which can provide here 1 mrad kick angle. After reverse tracking from K0 to K1, the acceptance can be obtained at the positon of K1, which is indicated in Fig. 4 (c). In a similar way, the acceptance with the kick of K1 included can also be worked out, just as shown in Fig. 4 (d).

After such a series of analysis, the acceptance for injection at the injection point can be determined and the solution for the injection scheme can be optimized. Figure 5 gives a solution for this injection scheme.

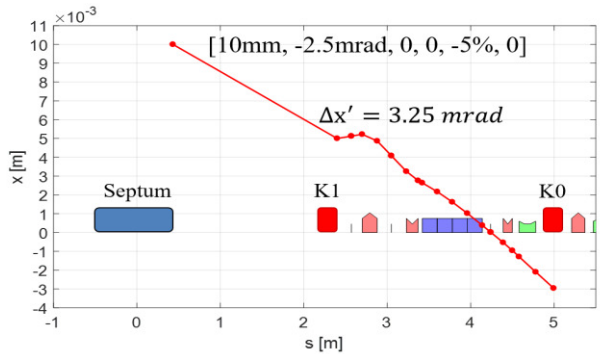

Figure 5: A solution for the off-energy off-axis multipole kicker injection scheme.

SIMULATION

The injection and accumulation are simulated with the parameters shown in Fig. 6. The parameters of the injection bunch for simulation are listed in Table 2.

Table 2: Main Parameters of the Injection Bunch

Parameters	Values
Energy deviation	-5%
Emittance [pm·rad]	500
Energy spread	5.0×10^{-4}
Bunch length [mm]	5
Number of particles	1000

The accumulation progress in this injection scheme involves betatron oscillation and longitudinal oscillation. Both of the simulation results are shown in Fig. 6 and Fig. 7. The results show that the injection efficiency of this injection scheme reaches 100% without considering bunch errors and the tolerance influence of the storage ring.

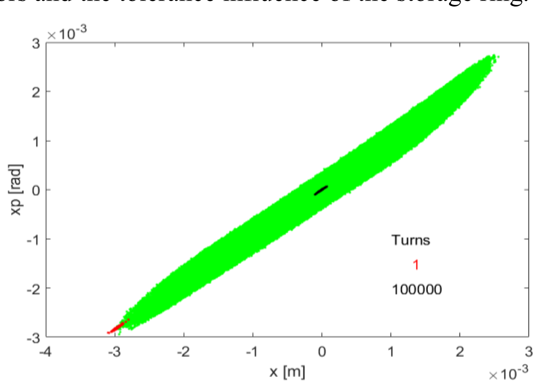

Figure 6: Simulation result of the betatron oscillation.

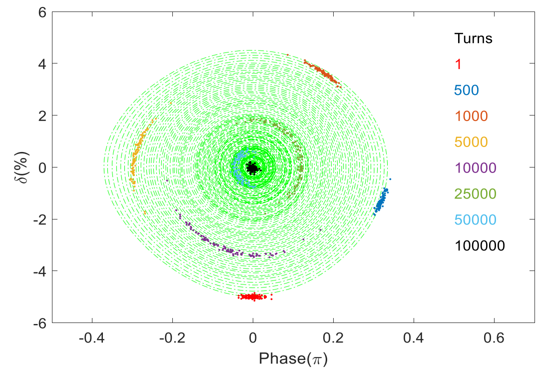

Figure 7: Simulation result of the longitudinal oscillation.

SUMMARY AND OUTLOOK

Without complicated injection system and high technical requirement of kicker, the off-energy off-axis multipole kicker injection scheme has potential to be applied for beam injection of DLSR, especially for the HALS storage ring which has large momentum aperture and off-energy dynamic apertures. In this paper, we present an application of this injection scheme to the base-line lattice of the HALS storage ring. The detailed injection scheme was designed through the acceptance analysis, and the injection and accumulation results showed good with numerical simulations. Further studies of this injection scheme, including the impact of the injection on the stored beam, error analysis and so on, are ongoing.

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