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# BEAM INJECTION WITH A PULSED NONLINEAR MAGNET INTO THE HALF STORAGE RING *

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*Abstract*

The nonlinear optics of the HALF storage ring are well optimized to make it possible to inject the beam with the traditional off-axis injection method. The pulsed multipole injection scheme, which is quasi-transparent to circulating bunches and compatible with top-up injection, is adopted for the HALF storage ring. In this paper, the injection scheme is studied with an innovatively designed pulsed nonlinear magnet. The layout and parameters of the injection system are designed based on the acceptance analysis. The injection process is simulated with particle tracking is presented in this paper.

## INTRODUCTION

Hefei Advanced Light Facility (HALF) [1] is proposed to be a new VUV and soft X-ray diffraction-limited storage ring-based light source. In order to achieve world-class performance, a series of the key physical and technical issues are studied during a pre-research project for several years. Especially for the lattice design of the storage ring, many newly design concepts have been developed to realize the several-tens picometer transverse electron beam emittance and large enough dynamic aperture, such as locally symmetric MBA [2]and interleaved dispersion bumps MBA [3]. The different beam injection methods are studied simultaneously for these lattice design, such as longitudinal injection scheme and off-energy off-axis MKI injection scheme [4].

Recently a well-designed 20×6BA lattice is determined as the base-line lattice version for HALF. This lattice can achieve a natural emittance of 85 pm·rad at electron beam energy of 2.2 GeV with longitudinal gradient bends and anti-bends employed [5]. The main designed parameters of the HALF storage ring are listed in Table 1. This lattice is a hybrid MBA lattice, which has been adopted in many DLSR design. And each cell in this lattice has a long straight section and a middle straight, which can install more beam lines and stations for users. The magnet layout and the linear optical functions are shown in Fig. 1. Extra sextupoles and octupoles are employed in this lattice for the sake of increasing the dynamic aperture. More than 15 mm 4D dynamic aperture is obtained with this lattice. Considering the magnet misalignment and field errors, the values of which are listed in Table 2, the 6D dynamic apertures are calculated with 100 sets of errors. The result is present in Fig. 2.

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Table 1: Main Parameters of the HALF Storage Ring

| Parameter | Value |
|---|---|
| Beam energy [GeV] | 2.2 |
| Circumference [m] | 480 |
| Number of cells | 20 |
| Natural emittance [pm·rad] | 85 |
| Transverse tunes | 48.24/17.24 |
| Momentum compaction factor | $6.3\times10^{-5}$ |
| Energy lose in one turn [keV] | 217.56 |
| Damping time [ms] | 21.97/32.38/21.22 |

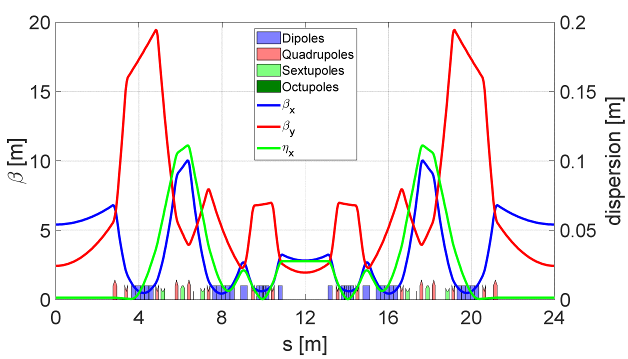


Figure 1: Magnet layout and linear optical functions.

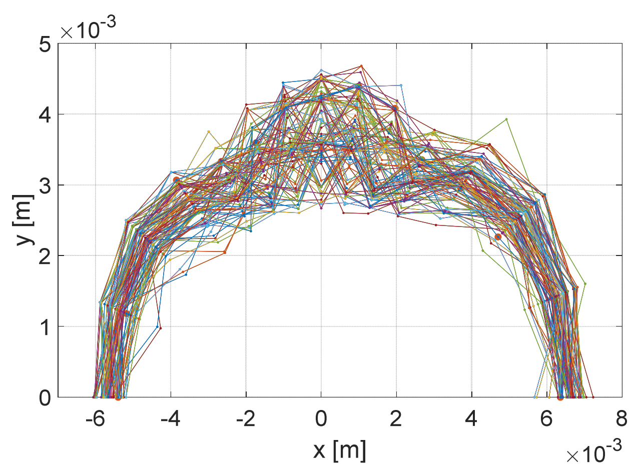


Figure 2: Dynamic apertures with 100 sets of errors.

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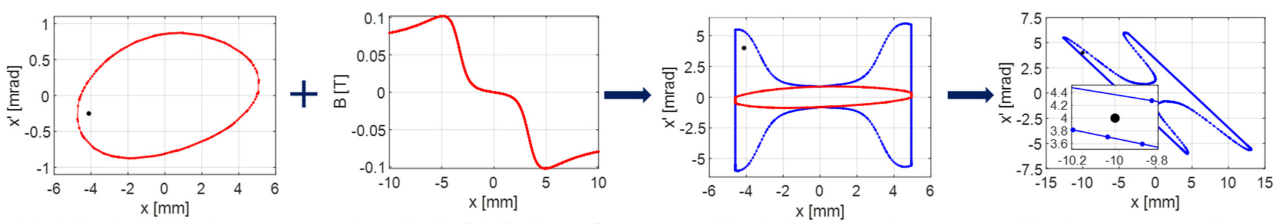
Table 2: Magnet Misalignment and Field Errors

| | Dipole | Quadrupole | Sextupole | Octupole | Girder |
|---|---|---|---|---|---|
| Transverse shift X/Y (µm) | 200 | 30 | 30 | 30 | 50 |
| Longitudinal shift Z (µm) | 150 | 150 | 150 | 150 | 200 |
| Tilt about X/Y (mrad) | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| Tilt about Z (mrad) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Nominal field | 1e-3 | 1e-3 | 1e-3 | 1e-3 | \ |
| Multipole field (r = 8 mm) | 5e-4 | 5e-4 | 5e-3 | 5e-3 | \ |




**(a):** Injection acceptance at the place of NLK. **(b):** Field distribution of the nonlinear kicker. **(c):** Equivalent acceptance with the effect of the kicker. **(d):** Acceptance at the place of septum by tracking.

Figure 3: The progress of acceptance analysis.

According to the calculation results, the 6D dynamic aperture with errors is more than 5 mm., which make it possible to adopt the off-axis injection for the beam injection. Considering that the pulsed multipole injection (MKI) scheme is quasi-transparent to circulating bunches and more compatible with top-up injection [6]. An injection scheme with an innovatively designed pulsed nonlinear magnet is preferentially studied for the HALF storage ring.

## INJECTION SCHEME DESIGN

The main goal of the injection scheme design is to obtain a set of parameters of the injection system, which can inject the beam from the transport line into the acceptance of the storage ring. The injection system of the MKI injection scheme simply includes a septum and a multipole kicker. The strengths and positions of these magnets should be optimized to make sure the injection beam surviving in the storage ring and robust to the errors. An acceptance analysis method is used to design the MKI injection scheme for the HALF storage ring [7]. The analysis progress is shown in Fig. 3.

The final acceptance of the storage ring is shown in Fig. 3 (a). 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 the nonlinear kicker (NLK) is kept at 5 mm. Including the kick of the NLK, the designed field distribution of which is shown in Fig. 3 (b), an equivalent acceptance can be calculated as shown in Fig. 3 (c), where an innovatively designed pulsed nonlinear magnet [8] is applied here with the magnet field B ≈ 900 Gs at the offset positon of 4 mm which can provide 4.25 mrad kick angle. After reverse tracking from the NLK to, the acceptance can be obtained at the positon of the exit of the septum, which is indicated in Fig. 3 (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 4 gives a solution for this injection scheme.

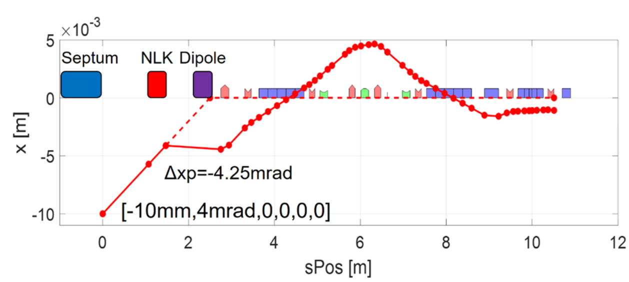



Figure 4: An injection solution for the HALF storage ring.

An extra on-axis injection system with a single dipole is designed specifically for the commissioning of the storage ring. In order to reduce the adjustments of the MKI injection system, an integrated design for the two injection system is completed, just as shown in Fig. 4. In this design, the parameters including the strengths and positions of these three magnets don't need to change when switching the two injection modes, which is very convenient for commissioning.

## SIMULATION

The beam damping and accumulation progress are simulated with the parameters of the injection bunch, which

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are listed in Table 3. The results of the simulation are shown in Fig. 5 and Fig. 6. 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.

Table 3: Main Parameters of the Injection Bunch

| Parameter | Value |
|---|---|
| Emittance [pm·rad] | 500 |
| Energy spread | $5.0\times10^{-4}$ |
| Bunch length [mm] | 5 |
| Number of particles | 1000 |

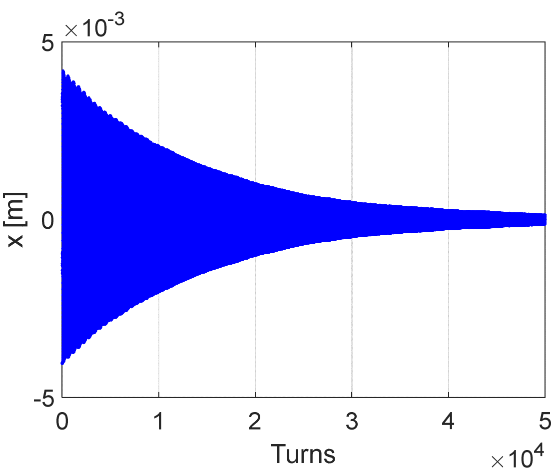


Figure 5: Simulation result of the damping progress.

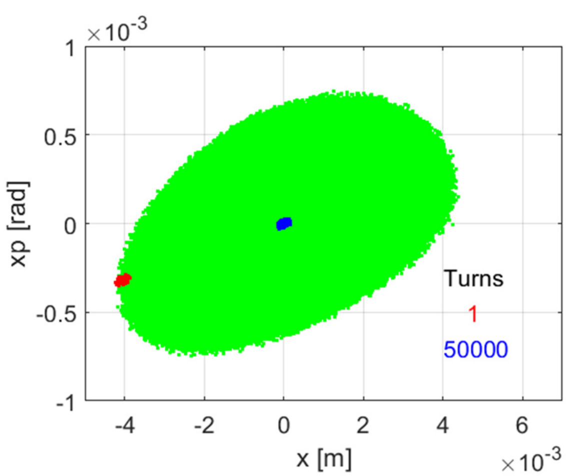


Figure 6: Simulation result of the betatron oscillation.

## SUMMARY AND OUTLOOK

A combined injection system has been designed for the HALF storage ring, including a MKI injection system for normal operation and an on-axis injection with a single dipole for commissioning. The acceptance analysis method is used for the scheme design, which can help to choose the best parameters of the injection system. The simulation of the beam damping and accumulation progress has been finished, which present a high injection efficiency of this injection design. Further studies of this injection scheme, including the impact of the injection on the stored beam, error analysis and etc. are ongoing.

## REFERENCES

[1] Lin Wang *et al.*, "Hefei Advanced Light Source: A Future Soft X-ray Diffraction-limited Storage Ring at NSRL", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 4598-4600. doi:10.18429/JACoW-IPAC2018-THPMK120

[2] Zhenghe Bai *et al.*, "Design Study for the First Version of the HALS Lattice", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 2713-2715. doi:10.18429/JACoW-IPAC2017-WEPAB060

[3] Zhenghe Bai *et al.*, "Super-period Multi-bend Achromat Lattice with Interleaved Dispersion Bumps for the HALS Storage Ring" in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18),* Vancouver, Canada, Apr.-May 2018, pp. 3597-3599. doi:10.18429/JACoW-IPAC2018-THPAK147

[4] Gangwen Liu *et al.*, "Off-energy Off-axis Injection with Pulsed Multipole Magnet into the HALS Storage Ring", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19),* Melbourne, Australia, May 2019, pp. 187-189. doi:10.18429/JACoW-IPAC2019-MOPGW044

[5] Zhenghe Bai *et al.*, "A Modified Hybrid 6BA lattice for the HALF storage ring", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2019, paper MOPAB112, this conference.

[6] Hiroyuki Takaki, Norio Nakamura, *et al.*, "Beam injection with a pulsed sextupole magnet in an electron storage ring", *Phys. Rev. ST Accel. Beams*, vol. 13, p. 020705, Feb. 2010. doi:10.1103/physrevstab.13.020705

[7] Peining Wang, Gangwen Liu, *et al.*, "Acceptance Analysis Method for the Scheme Design of Multipole Kicker Injection", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2019, paper WEPAB125, this conference.

[8] L. Shang, F. L. Shang, *et al.*, "Status of the R&D for HALS Injection System", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19),* Melbourne, Australia, May 2019, pp. 2335-2337. doi:10.18429/JACoW-IPAC2019-WEPMP015