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COMMISSIONING SIMULATION FOR THE HALF STORAGE RING*

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Abstract

Hefei advanced light facility (HALF) is a fourth-generation light source under construction. Its storage ring is a diffraction-limited one with an energy of 2.2 GeV and an extremely low emittance of less than 100 pm · rad. The real storage ring is different from the ideal lattice due to various kinds of errors. Those errors come from many sources, like misalignment of components, imperfect magnetic fields, RF cavity, etc. Due to the strong nonlinear nature and small dynamic aperture of the HALF storage ring, those errors significantly increase the difficulty of its commissioning. To figure out the practical performance of the lattice with those errors, a start-to-end commission simulation is performed in this study, which also helps to generate effective commissioning process for the HALF storage ring.

INTRODUCTION

In general, the actual storage ring deviates from the ideal lattice due to various errors. In a fourth generation light source, a low emittance is achieved by adopting quadrupoles with much stronger strengths than those currently in use, which leads to large negative chromaticities. To correct those chromaticities, it is necessary to utilize sextupoles with strong strengths. Consequently, misalignment of quadrupoles could lead to large kicks and coupling to the storage ring. And so do the errors in the sextupoles. Those effects would seriously influence the ring dynamics and degrade its performance. To evaluate the practical performance of the lattice with errors and figure out effective corrections, a start-to-end simulated commissioning is essential. Accelerator toolbox (AT)[1] and Commissioning Stimulation (SC) [2][3] toolkit is used in the paper.

The subsequent sections of this paper are organized as follows. Firstly, the layout of the HALF storage ring and the main parameters are introduced. Secondly, errors and related parameters are given. Thirdly, the correction chain is shown. Finally conclusion is presented.

LAYOUT OF LATTICE

The layout of HALF lattice is illustrated in Fig. 1. The unit cell is composed of 6 bends, 4 reverse bends, 16 quadrupoles, 8 sextupoles and 2 octupoles. The main parameters are shown in Table 1. The configuration of correctors and BPMs is depicted in Fig. 2. Each cell contains 12 horizontal correctors, 12 vertical correctors, and 12 BPMs. A circular aperture with a radius of 13 mm is applied to all elements.

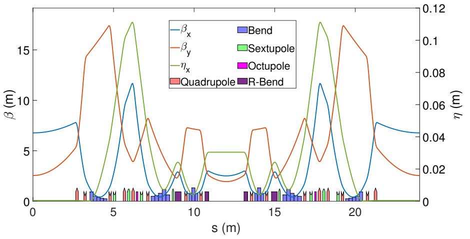

Figure 1: Lattice of the HALF storage ring in one cell.

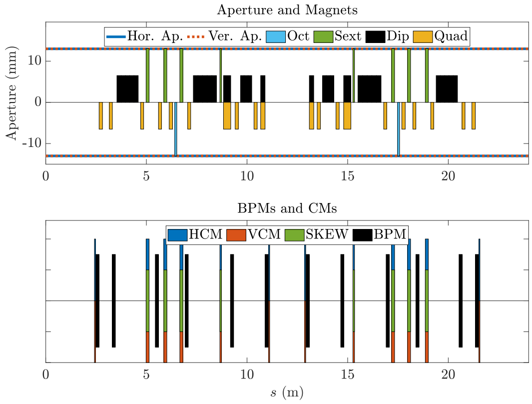

Figure 2: The configuration of correctors and BPMs in one unit cell.

Table 1: Main Parameters of the HALF Storage Ring

Parameter	**Unit**	**Value**
Energy	GeV	2.2
Circumference	m	479.86
RF frequency	MHz	499.8
Harmonic number	-	800
Natural emittance	pm · rad	85.8
Transverse tunes	-	48.19/17.19
Natural Chromaticities	-	-81.6/-56.6
Corrected Chromaticities	-	+3/+3
Momentum compaction factor	-	9.4×10^{-5}
Damping time	ms	28.5/38.8/23.7
Natural energy spread	-	0.61×10^{-3}

ERRORS SETUP

In this study, we incorporate various types of errors into the lattice. The random errors are generated based on a 2σ-truncated Gaussian distribution, where σ represents the root mean square (RMS) of the errors.

The misalignment errors of the main magnets are detailed in Table 2. Here, dx, dy, and dz denote shift errors in the horizontal, vertical, and longitudinal plane respectively, while

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rx, ry, and rz represent rotation errors in the same respective plane. The field errors of the bends and quadrupoles is 5×10^{-4}, and the field errors of the sextupoles and octupoles is 1×10^{-3}. The errors of RF cavity are presented in Table 3. The limitation of strength in the correctors is 1 mrad, and the calibration error is 5 %. The shift and rotation errors of the BPMs are 300 µm and 300 µrad respectively. The BPM noise level is 30 µm and the calibration error is 3 %. The parameters and errors of the injected beam are shown in Tables 4 and 5.

Table 2: Misalignment Errors of the Elements

Elem	dx/dy(µm)	dz(µm)	rx/ry(µrad)	rz(µrad)
Bends	200	150	100	100
Quads	30	150	100	100
Sexts	30	150	100	100
Octs	30	150	100	100
Girders	100	150	100	100

Table 3: RF Cavity Errors

Parameters	Values	Units
Voltage offset	1	%
Frequency offset	1×10^3	Hz
Time lag offset	90	Deg

Table 4: Parameters of the Injected Beam

Parameters	Values	Units
ϵ_x/ϵ_y	500/500	pm · rad
σ_x	58.18	µm
$\sigma_{x'}$	8.59	µrad
σ_y	35.70	µm
$\sigma_{y'}$	14.01	µrad
σ_δ	0.05	%
σ_ϕ	10	ps

Table 5: Errors of the Injected Beam

Parameters	Systematic	Jitter	Units
Δx	100	10	µm
$\Delta x'$	100	10	µrad
Δy	100	1	µm
$\Delta y'$	100	1	µrad
$\Delta E/E$	0.5×10^{-3}	1×10^{-4}	-
$\Delta\phi$	0	0.1	Deg

CORRECTION CHAIN

In a fourth-generation light source, the closed orbit may be absent before any correction. The existence of closed orbit is examined by scaling the global error factor as depicted in Fig. 3. It can be seen that the closed orbit is all existing when the factor is less than 20%. When the factor increases to 100%, the proportion of cases with a closed orbit almost disappears.

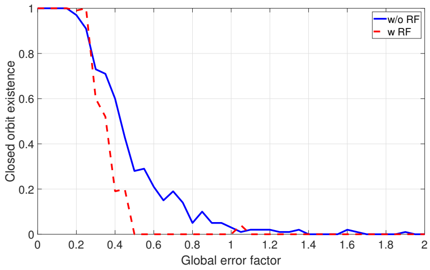


Figure 3: The closed orbit existence before any correction.

Initial and Multi-turn Transmission

Initially, it is necessary to obtain a closed orbit from the trajectory of the injected particles. After the initial correction, the orbit becomes closed and particles can traverse numerous turns (see Fig. 4). Multi-turn trajectory and static injection error corrections must be executed for the accumulation of multi-turn beams. Following these corrections, particles can be stored in an increased number of turns.

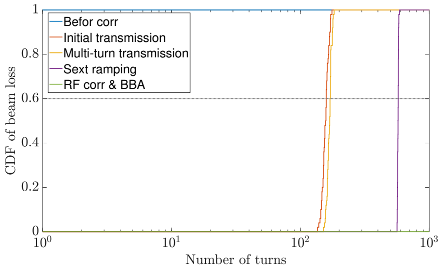


Figure 4: Beam transmission at various steps of the correction chain.

Sextupole Ramping and RF Correction

For a real machine with large negative chromaticities, the beam transmission would be limited. Here we gradually ramp up sextupoles to correct chromaticities. In Fig. 4, particles can travel more than 500 turns after ramping up all sextupoles. RF correction includes phase correction (see Fig. 5) and frequency correction (see Fig. 6). Using turn by turn BPM reading, RF correction can be performed [4][5]. After RF correction, particles could survive more than 1000 turns as shown in Fig. 4.

Beam-based Alignment and Optics Correction

The beam would receive a kick when it travels away from the center of quadrupoles due to magnetic field feed-down effect. A golden orbit should traverse all centers of the quadrupoles. This golden orbit can be determined using the beam-based alignment (BBA) technique. The closed orbit is then adjusted to this reference orbit. The linear optics can be

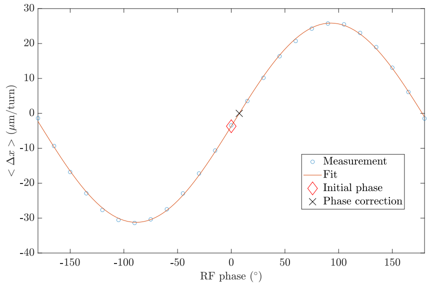


Figure 5: RF phase correction.

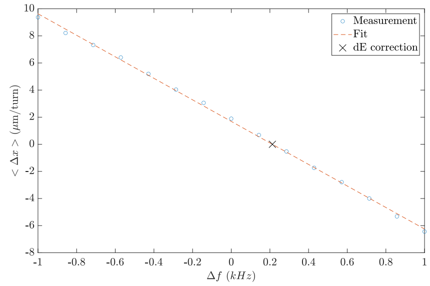
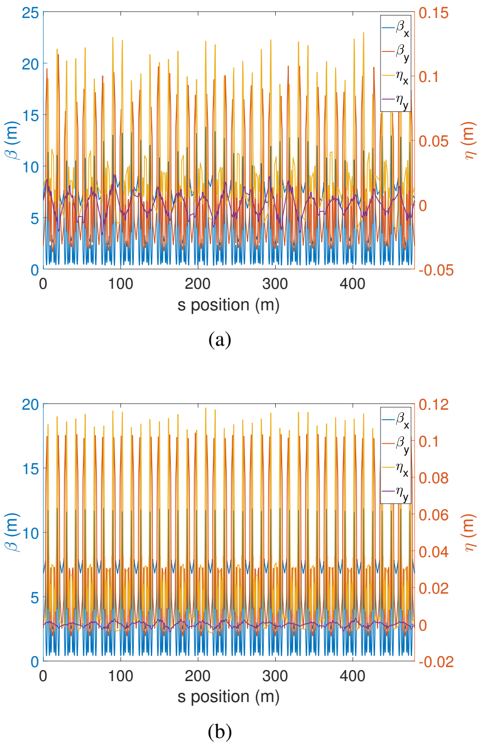


Figure 6: RF frequency correction.

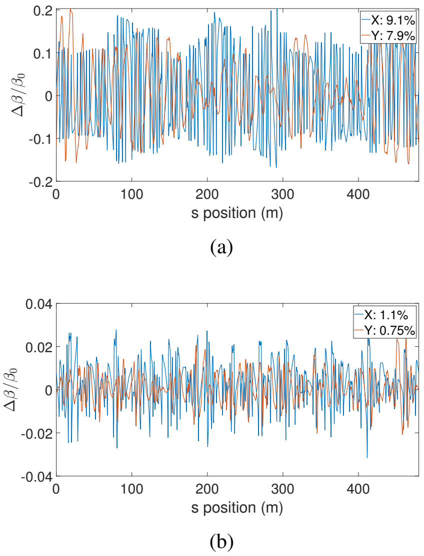
restored through the correction based on the LOCO (Linear Optics from Closed Orbit) algorithm [6]. The results of this optics correction are shown in Figs.7 and 8. Following LOCO correction, the optical functions approach the ideal values.



(a)

(b)

Figure 7: Linear optics of the HALF storage ring before and after correction. (a) Before correction. (b) After correction.



(a)

(b)

Figure 8: Beta beating of the HALF storage ring before and after correction. (a) Before correction. (b) After correction.

CONCLUSION

In the paper, a start-to-end commission simulation for the HALF storage ring is performed. After a serious of correction procedures, the beam is able to be stored in excess of 1000 turns, and the optics functions of the lattice with errors are reasonably closed to their ideal values. In the next research, we are going to perform this start-to-end commission simulation with a large number of random seeds to analyze the statistical outcomes.

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