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NONLINEAR OPTIMIZATION FOR THE HLS-II STORAGE RING*

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Abstract

Hefei Light Source (HLS) is a small and compact synchrotron light source with an electron beam energy of 800 MeV and a circumference of 66.13 m. The storage ring lattice adopts the Double-Bend Achromat (DBA) structure with 4 super periods. Considering the future upgrade of the injection system by using a nonlinear kicker (NLK), we optimize the dynamic performance of the storage ring. The optimization mainly aims at increase the dynamic aperture and beam lifetime, which helps improve the injection efficiency for the new injection scheme. While keeping the current layout of the lattice, the linear optics is also modified in order to improve its nonlinear performance. In this paper, we present our work on the optimization of the HLS-II storage ring.

INTRODUCTION

Hefei Light Source was a second generation synchrotron light source. After the massive upgrade project (HLS-II) in 2014, the lattice of the storage ring changed from the TBA type to the DBA type while remaining the same circumference and increasing the number of straight sections to 8. Two of the straight sections are used for installing the RF cavities and for beam injection. The others are used for insertion devices (IDs). The main parameters of HLS-II are listed in Table 1. Due to the limited good field region of one insertion device, the lattice is modified into two super periods which is similar to the Double DBA (DDBA) structure. This modification helps decrease the horizontal beta function in the long straight section. The optics functions for one super period of the HLS-II storage ring is shown in Fig. 1.

The nonlinear performance of the storage ring, including the dynamic aperture and momentum aperture determines the beam lifetime and affects beam injection. A previous work on replacing the current local bump injection system by using a nonlinear kicker (NLK) in HLS-II storage ring is reported in Ref. [1]. The efficiency of the NLK injection scheme is limited by the dynamic aperture and momentum aperture of the ring. To further improve the injection efficiency, we optimize the nonlinear dynamics of the HLS-II storage ring.

The remaining sections are arranged as follows. Firstly, the optimization strategy is described. Then the results of the nonlinear optimization are presented and compared with the current ring lattice. Finally, a brief summary is given.

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Table 1: Main Parameters of the HLS-II Storage Ring

Parameters	HLS-II
Beam energy (MeV)	800
Circumference (m)	66.13
Harmonic number	45
RF frequency (MHz)	204
Beam emittance (nm · rad)	38
No. of straight sections	8
Transverse tunes [H, V]	(4.44, 2.36)
Damping time (ms)	19.9/21.1/10.8
Momentum compaction factor	1.58×10^{-2}

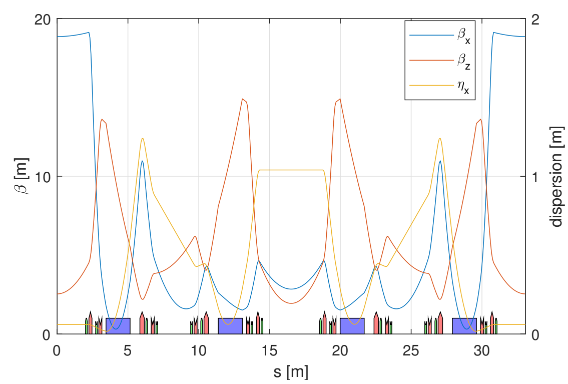

Figure 1: The optics functions for one super period of HLS-II storage ring. The lattice is a DDBA-like one in order to decrease the horizontal beta function in the long straight section.

OPTIMIZATION STRATEGY

One super period in the HLS-II storage ring contains 4 dipoles, 16 quadrupoles and 16 sextupoles. The sextupoles are powered by four families of power supplies. Since there is no dispersion-free section in the ring, all sextupoles can affect the chromaticities. Due to the fixed positions of all magnets, the optimization only changes the strengths of the quadrupoles and sextupoles. A good choice for the linear optics is a necessary starting point for a successful optimization of the nonlinear dynamic [2]. The current local bump injection needs the horizontal fractional tune to be near 0.5, which is 0.44. The new injection scheme offers an opportunity to move the working point to a new region to avoid resonance lines. All quadrupoles are used to match a new lattice and the transverse tunes are finally set to $(\nu_x, \nu_y) = (4.26, 2.22)$. With all sextupoles, the chromaticities are determined as $(\xi_x, \xi_y) = (1, 1)$.

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The generic algorithm of multi-objective particle swarm optimization (MOPSO) [3] is adopted for the nonlinear optimization of the storage ring. The optimization objectives include the dynamic aperture and Touschek beam lifetime. The Accelerator Toolbox (AT) is used in this work.

OPTIMIZATION RESULTS

Dynamic Aperture

DA is usually defined as the maximum stable area in transverse plane at the injection point. Particles with initial condition within this area will survive after a certain number of turns of tracking [4]. DA is also related to the ring acceptance which determines the injection efficiency. A large dynamic aperture is beneficial to the injection of the storage ring.

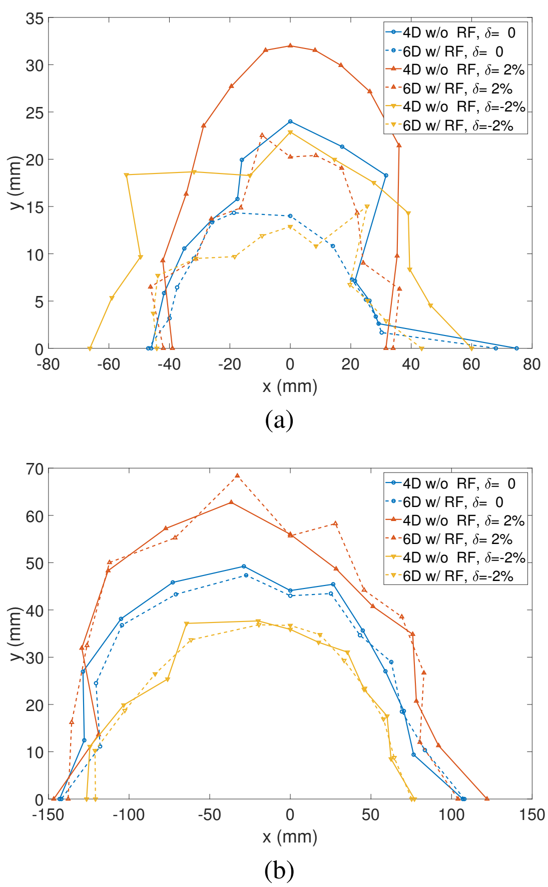

Figure 2: On-momentum and off-momentum dynamical apertures of the HLS-II storage ring. (a) Before optimization. (b) After optimization.

Figure 2 shows the results of the 4D and 6D momentum dependent dynamic apertures before and after optimization. The results shows that the aperture is improved after optimization.

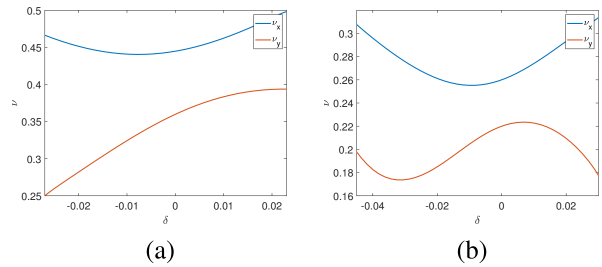

Figure 3: Horizontal and vertical tune shifts with momentum deviation. (a) Before optimization with tunes of (4.44, 2.36). (b) After optimization with tunes of (4.26, 2.22). After optimization, the 4D momentum acceptance obtained from the tune shift calculation is larger than the ring linear energy acceptance.

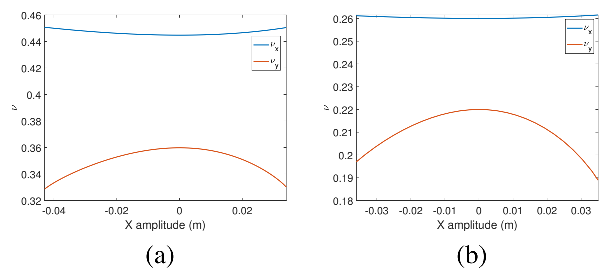

Figure 4: Horizontal and vertical tune shifts with horizontal amplitude. (a) Before optimization with tunes of (4.44, 2.36). (b) After optimization with tunes of (4.26, 2.22).

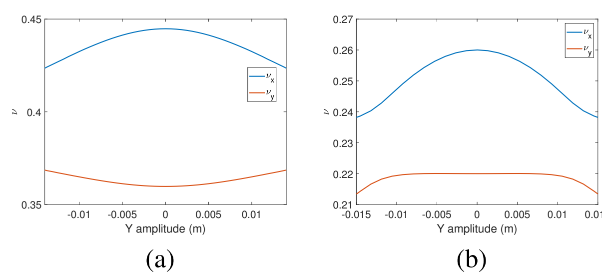

Figure 5: Horizontal and vertical tune shifts with vertical amplitude. (a) Before optimization with tunes of (4.44, 2.36). (b) After optimization with tunes of (4.26, 2.22).

Tune Shifts

A control of the tune shifts to avoid destructive resonance-crossing is critical in DA and MA optimization. The tune shifts with momentum deviation, horizontal amplitude and vertical amplitude are shown in Figs. 3, 4 and 5 respectively.

Momentum Aperture and Touschek Lifetime

The operation of a storage ring requires large local momentum apertures (LMA) for long Touschek lifetime. The comparison of 6D local momentum apertures before and after optimization are plotted in Fig. 6.

The 6D momentum aperture in one super period after optimization is shown in Fig. 6. The overall lifetime in the

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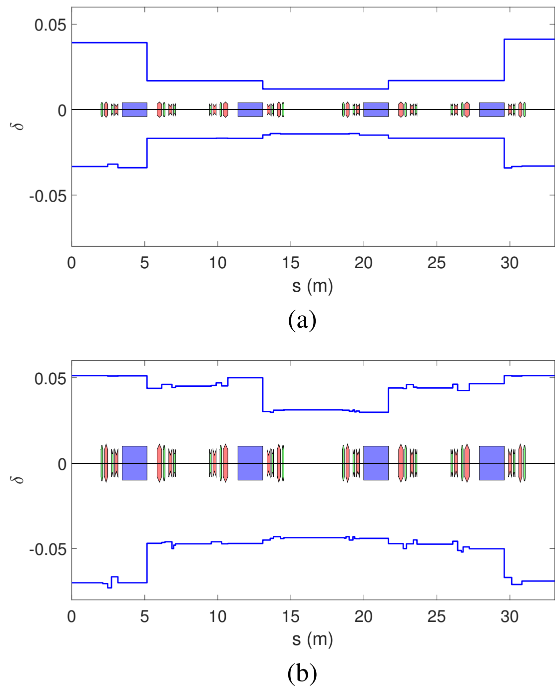

Figure 6: 6D Momentum aperture in one super-periods of the HLS-II storage ring. (a) Before optimization. (b) After optimization.

storage ring is based on a combination of different scattering processes such as quantum scattering, Touschek scattering, elastic and inelastic gas scattering [5]. The dominant scattering process is the Touschek lifetime which scales with the momentum aperture. Touschek lifetime can be calculated using the flat beam equation proposed by Brück and its modification from Piwinski [6]. Considering 2% of the transverse motion coupling and 400 mA of the beam current, the Touschek lifetime using Piwinski formula with 6D local momentum aperture is evaluated as 19.8 hours after optimization while the lifetime before optimization is 4.5 hours.

Comparison

After optimization, some parameters are changed. The optics functions of the new lattice are shown in Fig. 7. The parameters after optimization are shown in Table 2.

Table 2: Parameters After Optimization of the HLS-II Storage Ring

Parameters	**After Optimization**
Transverse tunes [H, V]	(4.26, 2.22)
Corrected chromaticity [H, V]	(1, 1)
Natural emittance (nm · rad)	33
Momentum compaction factor	2.08×10^{-2}

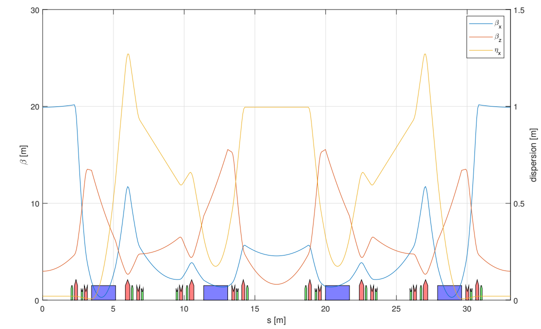

Figure 7: The optics functions for one super period of the HLS-II storage ring after optimization.

SUMMARY

Nonlinear optimization of the HLS-II storage ring is performed with the aim to increase its dynamic aperture and Touschek lifetime. The optimization is carried out based on the layout of the current lattice without changing the positions of the storage ring. The results shows that the nonlinear performance of the storage ring is greatly improved. This modified lattice offers an alternative choice for the future upgrade of the injection system using a nonlinear kicker for the HLS-II storage ring.

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